CASE 3455: Application of BENSON-MONTIN-GREER for division of an oil pool into 2 pools and special rules.

CASE NO. 3455

Application,
Transcripts,
Small Exhibits
ETC.

SAM G. DUNN, M.D., F.A.C.S. O. L. STALCUP, JR., M. D.

FROM THE SURGICAL SECTION
OF
SAM G. DUNN, M.D., F.A.C.S.
WEST TEXAS CLINIC
LUBBOCK, TEXAS

May 23,1966

BEFORE THE
OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
Exhibit No. 2
Case No. 3455

Mr. Al Greer
Benson, Montin & Greer
Petroleum Center Building
Farmington, New Mexico

Dear Mr. Greer:

In answer to your inquiry relative to running an electric log on the Puerto Chiquito Unit No. 20 will say that I have had so much unshirted hell on that least that I am pretty well disgusted with the whole deal. As a last resort I am sending a reverse rig up there to see if we can bypass the tools that we lost in the hole which could not be fished out. As for getting the Gravey Unit outside of the Puerto Chiquito Pool will say that in a way I believe you may be right about the wells being too close together. Before the unit was formed I had already drilled the No. 2 Gravey and there is definitely a connection between the No. 1 and No. 2 because when I am pumping one of them the other one goes down which shows they are both dipping in to the same pool of oil. We plan to go up on top of the hill to the orthodox location for the next well, if I drill another one, that would meet the requirements of the Puerto Chiquito Unit as I am afraid if I drill where I have already spent a lot of money making a location, and was prevented from drilling by the Unit Rules, that I might be going in to the same pool again. Everyone tells me that you know more about the oil in place in that area than anyone else and I value your opinion very highly relative to this. If it is necessary to run a log on this deal then I will probably go in with you before we finally abandon it. The USGS has required so many sacks of cement placed at so many different levels that it is going to be quite expensive to plug and abandon. Since I have already spent over $20,000 on that hole I am somewhat averse to spending any more than I have to as you can readily see.

As you no doubt know I bought the Boulder Unit from Mobil in the Jicarilla Indian Reservation and I plan to work some of the wells over to see if we can raise their production somewhat. It seems however that the production in the whole area is like a quarter horse in that they will run like hell for a quarter of a mile then fold up in the stretch which of course is a lot different from our San Andres production in this area.

SAM G. DUNN, M.D., F.A.C.S.

O. L. STALCUP, JR., M. D.

FROM THE SURGICAL SECTION
OF
SAM G. DUNN, M.D., F.A.C.S.
WEST TEXAS CLINIC
LUBBOCK, TEXAS

You can rest assured that I will keep you posted concerning future developments and I appreciate your offer and interest very much. With kindest personal regards I am,

Sincerely,

Sam G. Dunn, M.D.

SGD/jf

SSION

dearnley-meier reporting service, inc.
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1120 SIMMS BLDG. • P. O. BOX 1092 • PHONE 243-6691 • ALBUQUERQUE, NEW MEXICO

BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
September 14, 1966

REGULAR HEARING

IN THE MATTER OF:

Application of Benson-Montin-Greer Drilling Corporation for division of an oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico.

Case No. 3455

BEFORE: Honorable Jack M. Campbell
Mr. A. L. "Pete" Porter
Mr. Guyton B. Hays

TRANSCRIPT OF HEARING

dearnley-meier
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MR. PORTER: We'll call at this time Case No. 3455. Is Mr. Cooley for the applicant present? I believe he had a motion.

MR. COOLEY: William J. Cooley, appearing for the applicant Benson-Montin-Greer Drilling Corporation. I am the victim of Frontier's unspoken slogan, "If you have time, go by air." I notice that the Commission has in its docket advertised this case with at least the indication that it will be continued to the November regular hearing.

I feel for the purposes of this record that I should, on behalf of the applicant, make a formal motion to that effect at this time. Further, that the temporary rules governing this pool which were instituted some three years ago be continued in force not only until that hearing but until such time as an order can develop out of the hearing.

As grounds for this motion, I would respectfully show the Commission that Benson-Montin-Greer has diligently, over the past three years, sought to develop more information about this large area of oil and gas reserves in the State of New Mexico than probably any other pool in the entire State. That is, to develop information prior to complete development and abandonment of a field.

It has been our purpose throughout these efforts to find out beforehand, before it's too late, how this oil pool of

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quite peculiar producing characteristics can best be produced and how the most oil can be recovered from this pool. B and G is presently drilling two wells on the northwest flank of the Puerto Chiquito, which we feel will provide in addition to the wealth of information that we already have, some very conclusive data that will be of considerable value to this Commission in making its determination of this case.

We anticipate that these wells will have been completed by the November hearing; and this information will have been collated and ready for presentation to this body, and we, therefore, respectfully request that this motion be granted.

MR. PORTER: You request that it be continued to the regular hearing in November?

MR. COOLEY: Yes, Mr. Commissioner?

MR. PORTER: Are there any objections to the counsel's motion, which also requests that the existing order be continued in effect until further order of this Commission? If not, the motion will be granted, Mr. Cooley. The case will be continued and an interim order will be entered continuing the present rules in effect until further order is issued.

STATE OF NEW MEXICO)
) ss
COUNTY OF BERNALILLO)

I, ADA DEARNLEY, Notary Public in and for the County of Bernalillo, State of New Mexico, do hereby certify that the foregoing and attached Transcript of Hearing before the New Mexico Oil Conservation Commission was reported by me; and that the same is a true and correct record of the said proceedings, to the best of my knowledge, skill and ability.

Witness my Hand and Seal this 10th day of October, 1966.

Ada Dearnley
NOTARY PUBLIC

My Commission Expires:

June 19, 1967.

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EFFECT OF WELL DENSITY
ON INCOME TO PRINCIPAL ROYALTY OWNERS
(UNITED STATES, STATE OF NEW MEXICO,
COUNTY OF RIO ARRIBA)

WEST PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

THE FOLLOWING FIGURES ARE FOR EACH 16 SQUARE MILE PRODUCTIVE "TRACT" OF THE RESERVOIR WITH SURFACE DIMENSIONS OF 4 MILES ALONG THE STRIKE AND 4 MILES DOWN DIP, AND WITH 1,500 BARRELS PER ACRE OF OIL IN PLACE

WELL DENSITY ACRES/ WELL	ULTIMATE RECOVERY		ROYALTY INCOME TO		
	%	(Thousands of Barrels)	UNITED STATES (Thousands of Dollars)	STATE OF NEW MEXICO (Thousands of Dollars)	COUNTY OF RIO ARRIBA (Thousands of Dollars)
40	6	920	201	252	25
80	7	1,070	234	294	30
160	14	2,150	470	590	59
320	41	6,900	1,510	1,840	190
640 & greater	65	10,000	2,185	2,744	276

BEFORE EXAMINER NUTTER
OIL CONSERVATION COMMISSION
EXHIBIT NO. 3
CASE NO. 3455 (Reopened)

NOTE: Royalty income figures are based on:

$0.2185 per barrel to United States
$0.2744 per barrel to State of New Mexico
$0.0274 per barrel to County of Rio Arriba

(See Page 2)

REVENUE ACCRUING TO THE UNITED STATES,
THE STATE OF NEW MEXICO AND RIO ARRIBA COUNTY
FOR EACH TEN MILLION BARRELS OF OIL PRODUCED FROM
WEST PUERTO CHIQUITO (FEDERAL LANDS)

CURRENT WELLHEAD VALUE $2.80 FOR 39° API

SOURCE	AMOUNT ACCRUING TO UNITED STATES	NEW MEXICO	COUNTY OF RIO ARRIBA
12.5% ROYALTY	$2,185,000	$1,315,000	
2.55% NEW MEXICO SALES TAX ON WELLHEAD SALES		624,750	
2.5% SEVERANCE TAX		612,500	
4% NEW MEXICO SALES TAX ON PIPELINE TRANSPORTATION CHARGE OF 25¢/BARREL		100,000	
AD VALOREM TAX		91,900	275,700
T O T A L	$2,185,000	$2,744,150	$275,700
$/BARREL	0.2185	0.274415	$0.02757

NOTE: (1) AD VALOREM TAX RATE ESTIMATED TO BE AVERAGE .030

(2) CONSERVATION TAX EXCLUDED FROM ABOVE FIGURES

EXHIBIT 4

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 3455
Order No. R-2565-B
NOMENCLATURE

APPLICATION OF BENSON-MONTIN-GREER
DRILLING CORPORATION FOR DIVISION OF
AN OIL POOL INTO TWO POOLS AND FOR
SPECIAL RULES FOR EACH, RIO ARRIBA
COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on November 16, 1966, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission."

NOW, on this 28th day of November, 1966, the Commission, a quorum being present, having considered the testimony presented and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That by Order No. R-2565, dated September 9, 1963, as amended by Order No. R-2565-A, dated September 9, 1963, and Order No. R-2855, dated December 29, 1964, temporary Special Rules and Regulations were promulgated for the Puerto Chiquito-Gallup Oil Pool, Rio Arriba County, New Mexico.

(3) That by Order No. R-3118, dated September 21, 1966, said temporary Special Rules and Regulations were continued in full force and effect until further order of the Commission.

(4) That by Order No. R-2580, dated October 30, 1963, the

Puerto Chiquito-Gallup Oil Pool was redesignated the Puerto Chiquito-Mancos Oil Pool.

(5) That the applicant, Benson-Montin-Greer Drilling Corporation, seeks the abolishment of the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool), Rio Arriba County, New Mexico, the creation of the East Puerto Chiquito-Mancos Oil Pool, and the creation of the West Puerto Chiquito-Mancos Oil Pool, with vertical limits of each to be the Mancos formation and horizontal limits as follows:

EAST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM

Sections 2 through 5: All
Sections 8 through 10: All
Sections 15 through 17: All
Sections 20 through 22: All
Sections 27 through 29: All
Sections 32 and 33: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM

Sections 3 through 10: All
Sections 14 through 18: All
Sections 20 through 23: All
Sections 26 through 29: All
Sections 32 through 35: All

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM

Sections 3 through 10: All
Sections 15 through 22: All
Sections 27 through 30: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM

Section 1: E/2
Section 12: E/2
Section 13: E/2
Section 24: E/2
Section 25: E/2

WEST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM

Sections 6 and 7: All

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM (CONTINUED)
Sections 18 and 19: All
Sections 30 and 31: All

TOWNSHIP 25 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Section 19: All
Sections 30 and 31: All

TOWNSHIP 26 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: W/2
Sections 2 through 11: All
Section 12: W/2
Section 13: W/2
Sections 14 through 23: All
Section 24: W/2
Section 25: W/2
Sections 26 through 30: All

(6) That the applicant proposes that the East Puerto Chiquito-Mancos Oil Pool be governed by all the previous rules, regulations, and orders of the Commission presently applicable to the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool).

(7) That the applicant also seeks the promulgation of temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool, including a provision for 320-acre spacing units.

(8) That the applicant further seeks the establishment of an administrative procedure whereby the operators in the West Puerto Chiquito-Mancos Oil Pool would be permitted to conduct interference tests and to transfer allowables among producing wells on the same lease or, if in a unitized area, to wells in the same participating area in order to facilitate the gathering of information pertaining to reservoir characteristics.

(9) That the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool) encompasses more than one separate common source of supply and should therefore be abolished.

(10) That each of the proposed pools encompasses a separate common source of supply.

(11) That the East Puerto Chiquito-Mancos Oil Pool and the West Puerto Chiquito-Mancos Oil Pool should be created with horizontal limits as proposed by the applicant and vertical limits comprising the Niobrara member of the Mancos shale.

(12) That the East Puerto Chiquito-Mancos Oil Pool should be governed by all the previous rules, regulations, and orders presently applicable to the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool).

(13) That in order to prevent the economic loss caused by the drilling of unnecessary wells, to avoid the augmentation of risk arising from the drilling of an excessive number of wells, to prevent reduced recovery which might result from the drilling of too few wells, and to otherwise prevent waste and protect correlative rights, temporary Special Rules and Regulations providing for 320-acre spacing units should be promulgated for the West Puerto Chiquito-Mancos Oil Pool.

(14) That the temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool should provide for limited well locations in order to assure orderly development of the pool and protect correlative rights.

(15) That the said temporary Special Rules and Regulations should be established for a three-year period in order to allow the operators in the West Puerto-Chiquito Mancos Oil Pool to gather reservoir information to establish the area that can be efficiently and economically drained and developed by one well.

(16) That an administrative procedure should be established whereby the operators in the West Puerto Chiquito-Mancos Oil Pool would be permitted to conduct interference tests and to transfer allowables among producing wells on the same lease or, if in a unitized area, to wells in the same participating area, during the temporary three-year period in order to facilitate the gathering of information pertaining to reservoir characteristics.

(17) That this case should be reopened in November, 1969, at which time the operators in the West Puerto Chiquito-Mancos Oil Pool should appear and show cause why the said pool should not be developed on 40-acre spacing units.

IT IS THEREFORE ORDERED:

(1) That the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool) is hereby abolished.

(2) That a new pool in Rio Arriba County, New Mexico, classified as an oil pool for Mancos production, is hereby created and designated the East Puerto Chiquito-Mancos Oil Pool, with vertical limits comprising the Niobrara member of the Mancos shale, and with horizontal limits as follows:

EAST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 2 through 5: All
Sections 8 through 10: All
Sections 15 through 17: All
Sections 20 through 22: All
Sections 27 through 29: All
Sections 32 and 33: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10: All
Sections 14 through 18: All
Sections 20 through 23: All
Sections 26 through 29: All
Sections 32 through 35: All

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10: All
Sections 15 through 22: All
Sections 27 through 30: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: E/2
Section 12: E/2
Section 13: E/2
Section 24: E/2
Section 25: E/2

(3) That a new pool in Rio Arriba County, New Mexico, classified as an oil pool for Mancos production, is hereby created and designated the West Puerto Chiquito-Mancos Oil Pool, with vertical

limits comprising the Niobrara member of the Mancos shale, and with horizontal limits as follows:

WEST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 6 and 7: All
Sections 18 and 19: All
Sections 30 and 31: All

TOWNSHIP 25 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Section 19: All
Sections 30 and 31: All

TOWNSHIP 26 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: W/2
Sections 2 through 11: All
Section 12: W/2
Section 13: W/2
Sections 14 through 23: All
Section 24: W/2
Section 25: W/2
Sections 26 through 30: All

(4) That the East Puerto Chiquito-Mancos Oil Pool shall be governed by all the previous rules, regulations, and orders presently applicable to the Puerto Chiquito-Gallup Oil Pool (re-designated the Puerto Chiquito-Mancos Oil Pool).

(5) That temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool are hereby promulgated as follows:

SPECIAL RULES AND REGULATIONS
FOR THE
WEST PUERTO CHIQUITO-MANCOS OIL POOL

RULE 1. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be spaced, drilled, operated, and

EXHIBIT 4

BEFORE EXAMINER NUTTER
OIL CONSERVATION COMMISSION
EXHIBIT NO. 4
CASE NO. 3455

produced in accordance with the Special Rules and Regulations hereinafter set forth.

RULE 2. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located on a standard spacing unit consisting of approximately 320 acres which shall comprise any two contiguous quarter sections of a single governmental section, being a legal subdivision (half section) of the United States Public Lands Survey. For purposes of these rules, a spacing unit consisting of between 316 and 324 contiguous surface acres shall be considered a standard unit. No non-standard spacing units shall be authorized except after notice & hearing.

RULE 3. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located within 165 feet of the center of one of the governmental quarter-quarter sections in the spacing unit.

RULE 4. The Secretary-Director of the Commission may grant an exception to the requirements of Rule 3 without notice and hearing when an application has been filed for an unorthodox location necessitated by topographical conditions or the recompletion of a well previously drilled to another horizon. All operators offsetting the proposed unorthodox location shall be notified of the application by registered or certified mail, and the application shall state that such notice has been furnished. The Secretary-Director may approve the application upon receipt of written waivers from all offset operators or if no offset operator has entered an objection to the unorthodox location within 20 days after the Secretary-Director has received the application.

RULE 5. A standard proration unit in the West Puerto Chiquito-Mancos Oil Pool (316 through 324 acres) shall be assigned a 320-acre proportional factor of 8.00 for allowable purposes. Any non-standard proration unit containing less than 316 acres or more than 324 acres shall be assigned a proportional factor in the same ratio to 8.00 as the acreage in the unit bears to 320.

IT IS FURTHER ORDERED:

(1) That any well presently drilling to or completed in the Niobrara member of the Mancos shale within the West Puerto Chiquito-Mancos Oil Pool that will not comply with the well location requirements of Rule 3 is hereby granted an exception to the requirements of said rule. The operator shall notify the Aztec District Office

of the Commission in writing of the name and location of the well on or before December 15, 1966.

(2) That any operator desiring to dedicate 320 acres to a well presently drilling to or completed in the West Puerto Chiquito-Mancos Oil Pool shall file a new Form C-102 with the Commission on or before December 15, 1966.

(3) That the Secretary-Director of the Commission is hereby authorized to approve interference tests and the transfer of allowables to wells on the same lease or, if in a unitized area, to wells in the same participating area, provided however, that no transfer well shall be permitted to receive, in addition to its own allowable, more than one top unit allowable for the West Puerto Chiquito-Mancos Oil Pool; that the Secretary-Director of the Commission is hereby authorized to permit the accumulation of allowables for wells shut in for interference tests and to permit the transfer of back allowables from shut-in wells, provided however, that the period of time authorized to produce back allowable shall not exceed six months following completion of the interference tests.

To obtain administrative approval for interference tests and the transfer of allowable, the operator shall submit in triplicate a request for such authority describing in detail the proposed method of conducting such tests and transferring the allowable. The application shall be accompanied by a plat showing thereon all Mancos wells within a radius of two miles of the proposed shut-in well(s) and the transfer well(s). The plat shall also identify each lease or participating area as to ownership or operating rights. The application shall include evidence that all offset operators to the shut-in well(s) and the transfer well(s) have been furnished a complete copy of the application. It shall also be accompanied by Form C-116 for each shut-in well, showing the results of a pre-shut-in test to determine the amount of allowable to be transferred. The transferred allowable shall not exceed the volume of oil produced during the last 24 hours of a 72-hour period during which the well shall be produced at a constant rate. The Commission and offset operators to both the shut-in well(s) and the transfer well(s) may witness such tests if they so desire and shall be notified of the tests at least 48 hours prior to the commencement thereof.

The Secretary-Director of the Commission may grant approval of the interference tests and trasnfer of allowable upon receipt

of waivers from all offset operators or upon expiration of a 20-day waiting period, provided no offset operator has objected to the proposed test and transfer.

(4) That notwithstanding any of the provisions of Rule 104(a) of the Commission Rules and Regulations, the temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool shall not be applicable outside the limits of said pool as hereinabove defined or as hereafter extended.

(5) That this case shall be reopened in November, 1969, at which time the operators in the West Puerto Chiquito-Mancos Oil Pool may appear and show cause why the said pool should not be developed on 40-acre spacing units.

(6) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

JACK M. CAMPBELL, Chairman

GUYTON B. HAYS, Member

A. L. PORTER, Jr., Member & secretary

S E A L

esr/

Val R. Reese, C.P.G.

Oil / Gas / Mining

Geological Consultant
900 Bank of New Mexico Building
Albuquerque, New Mexico 87101

Office: Phone 243-0665
Home: Phone 255-9749

July 9, 1970

Mr. I. R. Trujillo, Chief
Administrative Services
New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Dear Mr. Trujillo:

I am returning to you herewith the following material which was loaned to me by your office:

1. December 1969 report by Albert R. Greer on Oil Recoveries under Gravity Drainage Depletion and Pressure Maintenance.

2. November 16, 1969, Exhibits in Case No. 3455, Benson-Montin-Greer Drilling Corp. (data relative to economics).

3. November 16, 1969, Exhibits in Case No. 3455, Benson-Montin-Greer Drilling Corp. (multiple exhibits).

I very much appreciate the courtesy which has been shown me by you and your office staff.

Sincerely,

VAL R. REESE

VRR:mb

MICHIGAN WISCONSIN PIPE LINE COMPANY

P. O. BOX 2267 DENVER, COLORADO 80201
TELEPHONE (303) 893-5517

July 31, 1974

Ms. Ida Rodriguez
Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico 87501

Dear Ms. Ida Rodriguez:

Please find enclosed exhibits from the Benson-Montin-Greer Drilling Corporation verses New Mexico Oil Conservation Commission which I borrowed a few weeks ago and am now returning.

Your assistance in this matter was most appreciated.

Sincerely,

Dave Muirhead

DM:mad

Enclosures: Four Manuals

OIL CONSERVATION COMMISSION

STATE OF NEW MEXICO
P. O. BOX 2088 - SANTA FE
87501

GOVERNOR
DAVID F. CARGO
CHAIRMAN

LAND COMMISSIONER
ALEX J. ARMIJO
MEMBER

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

January 6, 1970

Mr. Jack Cooley
Burr & Cooley
Attorneys at Law
152 Petroleum Center Building
Farmington, New Mexico 87401

Re: Case No. 3455
Order No. R-2565-C
Applicant:
Benson-Montin-Greer

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Very truly yours,

A. L. PORTER, Jr.
Secretary-Director

ALP/ir

Copy of order also sent to:

Hobbs OCC x
Artesia OCC
Aztec OCC x

Other

Docket No. 30-69

DOCKET: EXAMINER HEARING - WEDNESDAY - NOVEMBER 5, 1969

9 A.M. - OIL CONSERVATION COMMISSION CONFERENCE ROOM, STATE LAND OFFICE BUILDING - SANTA FE, NEW MEXICO

The following cases will be heard before Elvis A. Utz, Examiner, or Daniel S. Nutter, Alternate Examiner:

CASE 4243: Application of Mobil Oil Corporation for downhole commingling, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to commingle production from the Vacuum-Upper Pennsylvanian Pool and the Vacuum-Middle Pennsylvanian Pool in the wellbore of its Bridges State Well No. 121 located in Unit L of Section 13, Township 17 South, Range 34 East, Lea County, New Mexico.

CASE 4244: Application of Gulf Oil Corporation for an amendment to Order No. R-1084, Lea County, New Mexico. Applicant, in the above-styled cause, seeks the amendment of Order No. R-1084 to permit the simultaneous dedication of the 480-acre non-standard gas proration unit established by said order to its H. T. Mattern (NCT-E) Wells No. 10 and 11 located, respectively, 660 feet from the South line and 1980 feet from the West line of Section 1 and 1980 feet from the East line and 660 feet from the North line of Section 12, both in Township 22 South, Range 36 East, Eumont Gas Pool, Lea County, New Mexico. Applicant further seeks authority to produce the allowable assigned to said unit from either of the aforesaid wells in any proportion.

CASE 3889: In the matter of Case No. 3889 being reopened pursuant to the provisions of Order No. R-3585, which order established 160-acre spacing units and 160-acre proportional factors of 4.77 for the Middle Allison-Pennsylvanian Pool, Lea and Roosevelt Counties, New Mexico, for a period of one year. All interested parties may appear and show cause why said pool should not be developed on less than 160-acre spacing and why the 160-acre proportional factor of 4.77 should or should not be retained.

CASE 4245: Application of Texas Pacific Oil Company, Inc., for several non-standard gas proration units, Lea County, New Mexico. Applicant, in the above-styled cause, seeks the dedication and rededication of certain acreage and the establishment of the following non-standard gas proration units in Townships 22 and 23 South, Range 36 East, Jalmat Gas Pool, Lea County, New Mexico:

A 160-acre unit comprising the W/2 SE/4 and the E/2 SW/4 of Section 8, Township 22 South, Range 36 East, to be dedicated to the State "A" a/c-2 Well No. 56 located in Unit J of said Section 8;

A 200-acre unit comprising the NW/4 and the NW/4 SW/4 of Section 11, Township 22 South, Range 36 East, to be dedicated to the State "A" a/c-2 Well No. 42 located in Unit E of said Section 11;

A 280-acre unit comprising the SE/4, S/2 SW/4, and the NE/4 SW/4 of Section 11, Township 22 South, Range 36 East, to be dedicated to the State"A" a/c-2 Well No. 36 located in Unit M of said Section 11;

A 200-acre unit comprising the N/2 NE/4, the SE/4 NE/4, and the NE/4 NW/4 of Section 15 and the SE/4 SW/4 of Section 10, Township 23 South, Range 36 East, to be dedicated to the State "A" a/c-1 Well No. 31 located in Unit H of said Section 15;

A 160-acre unit comprising the S/2 NW/4, SW/4 NE/4 and the NW/4 NW/4 of Section 15, Township 23 South, Range 36 East, to be dedicated to the State "A" a/c-1 Well No.33 located in Unit F of said Section 15;

A 240-acre unit comprising the SW/4 of Section 3 and the N/2 NW/4 of Section 10, Township 23 South, Range 36 East, to be dedicated to the State "A" a/c-1 Well No. 35 located in Unit L of said Section 3;

A 160-acre unit comprising the S/2 NW/4 and N/2 SW/4 of Section 10, Township 23 South, Range 36 East, to be dedicated to the State "A" a/c-1 Well No. 37 located in Unit F of said Section 10.

CASE 4246: Application of Humble Oil & Refining Company for salt water disposal, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water into the San Andres formation in the perforated interval from 3860 feet to 4020 feet in its New Mexico "S" State Well No. 26 located in Unit L of Section 2, Township 22 South, Range 37 East, South Eunice-San Andres Pool, Lea County, New Mexico.

CASE 3928: (Reopened)

In the matter of Case No. 3928 being reopened pursuant to the provisions of Order No. R-3586, which order established 80-acre spacing units for the East Shoe Bar-Devonian, Lea County, New Mexico, for a period of one year. All interested parties may appear and show cause why said pool should not be developed on 40-acre spacing units.

CASE 4247: Application of J. J. Travis for a unit agreement, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks approval of the North Shugart Queen Unit Area comprising 520 acres, more or less, of federal lands in Sections 20, 21, and 28, Township 18 South, Range 31 East, Shugart (Yates-Seven Rivers-Queen-Grayburg) Pool, Eddy County, New Mexico.

CASE 4248: Application of J. J. Travis for a waterflood project, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project in his North Shugart Queen Unit Area by the injection of water into the Queen formation through nine wells at orthodox and unorthodox locations in Sections 20 and 21, Township 18 South, Range 31 East, Shugart (Yates-Seven Rivers-Queen-Grayburg) Pool, Eddy County, New Mexico. Applicant further seeks a procedure whereby additional injection wells at orthodox and unorthdox locations may be approved administratively.

CASE 4249: Application of Tenneco Oil Company for amendment of Order No. R-3822 and off-lease storage, San Juan County, New Mexico. Applicant, in the above-styled cause, seeks amendment of Order No. R-3822, which order pooled all mineral interests in the Basin-Dakota Gas Pool underlying the N/2 of Section 11, Township 29 North, Range 13 West, San Juan County, New Mexico, to form a 320-acre gas proration unit dedicated to a well to be drilled at an unorthodox location 2250 feet from the North line and 600 feet from the East line of said Section 11. Applicant now seeks amendment of said order to permit the drilling of said well at a point 2390 feet from the North line and 275 feet from the East line of said Section 11. Applicant further seeks authority to transport, prior to measurement, to another lease for storage the liquid hydrocarbons produced by the subject well.

CASE 3455: (Reopened):

In the matter of Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320-acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, for a period of three years. All interested parties may appear and show cause why said pool should not be developed on 40-acre spacing units.

CASE 4250: Application of McCrary & Franklin for waterflood project, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project by the injection of water into the Grayburg and Lovington sands through their Shipley Well No. 2 located in Unit K of Section 3, Township 17 South, Range 29 East, Square Lake Pool, Eddy County, New Mexico.

CASE 4251: Application of Kersey & Company for a waterflood project, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project by the injection of water into the Queen formation through its Welch Well No. 2 located in Unit G of Section 4 and its Welch Well No. 4 located in Unit C of Section 4, both in Township 19 South, Range 31 East, Shugart Pool, Eddy County, New Mexico.

CASE 4220: (Continued from the October 8, 1969, Examiner Hearing)

In the matter of the hearing called by the Oil Conservation Commission on its own motion to permit E. P. Campbell, and all other interested parties to appear and show cause why the E. P. Campbell Christmas Well No. 1 located in Unit C of Section 6, Township 23 South, Range 36 East, Jalmat Pool, Lea County, New Mexico, should not be plugged and abandoned in accordance with a Commission-approved plugging program.

Case 3455

BURR & COOLEY
ATTORNEYS AND COUNSELORS AT LAW
SUITE 152 PETROLEUM CENTER BUILDING
FARMINGTON, NEW MEXICO
87401

August 16, 1966

JOEL B. BURR, JR.
WM. J. COOLEY

TELEPHONE 325-1702
AREA CODE 505

'66 AUG 17 AM 7 59

NEW MEXICO OIL CONSERVATION COMMISSION
Post Office Box 2088
Santa Fe, New Mexico

Gentlemen:

We would appreciate it if you would set the enclosed Application of Benson-Montin-Greer Drilling Corp. down for hearing before the full Commission at its regular hearing date for the month of September, 1966.

Thank you.

Very truly yours,

BURR & COOLEY

By William J. Cooley

WJC:kp
Encs.

DOCKET MAILED
Date 10-24-69

DOCKET MAILED
Date 9-1-66

'63 AUG 17 AM 7 59

BEFORE THE OIL CONSERVATION COMMISSION

STATE OF NEW MEXICO

IN THE MATTER OF:)

THE APPLICATION OF BENSON-MONTIN-GREER DRILLING CORP. FOR AN ORDER:)

DIVIDING THE PUERTO CHIQUITO-MANCOS OIL POOL INTO THE EAST PUERTO CHIQUITO-MANCOS OIL POOL AND THE WEST PUERTO CHIQUITO-MANCOS OIL POOL, and,)

ESTABLISHING PERMANENT 160 ACRE DRILLING, SPACING AND PRORATION UNITS IN THE EAST PUERTO CHIQUITO-MANCOS OIL POOL, and,)

ESTABLISHING TEMPORARY 320 ACRE DRILLING, SPACING AND PRORATION UNITS IN THE WEST PUERTO CHIQUITO-MANCOS OIL POOL.)

Case 3455

A P P L I C A T I O N

Comes now the applicant, BENSON-MONTIN-GREER DRILLING CORP., and would respectfully show the Commission as follows:

1. That heretofore on September 9, 1963 the Commission entered Order No. R-2565, as amended by Nunc Pro Tunc Order No. R2565-A. extending the horizontal limits of the Puerto Chiquito-Mancos Oil Pool and providing for temporary 160 acre oil well spacing in said Pool for a period of three years.

2. That drilling and production experience since the entry of Order No. R-2565 indicates that there are two separate common sources of supply within the boundaries of the Puerto Chiquito-

Mancos Oil Pool, and that based upon this information the Commission should divide the present pool into two separate pools as follows:

EAST PUERTO CHIQUITO-MANCOS OIL POOL

Vertical Limits

Mancos formation

Horizontal Limits

Township 25 North, Range 1 East, N.M.P.M.

Sections 2 through 5, inclusive : All

Sections 8 through 10, inclusive : All

Sections 15 through 17, inclusive: All

Sections 20 through 22, inclusive: All

Sections 27 through 29, inclusive: All

Sections 32 and 33 : All

Township 26 North, Range 1 East, N.M.P.M.

Sections 3 through 10, inclusive : All

Sections 14 through 18, inclusive: All

Sections 20 through 23, inclusive: All

Sections 26 through 29, inclusive: All

Sections 32 through 35, inclusive: All

Township 27 North, Range 1 East, N.M.P.M.

Sections 3 through 10, inclusive	:	All
Sections 15 through 22, inclusive	:	All
Sections 27 through 30, inclusive	:	All

Township 27 North, Range 1 West, N.M.P.M.

Section 1	:	East Half (E½)
Section 12	:	East Half (E½)
Section 13	:	East Half (E½)
Section 24	:	East Half (E½)
Section 25	:	East Half (E½)

WEST PUERTO CHIQUITO-MANCOS OIL POOL

Vertical Limits

Mancos formation

Horizontal Limits

Township 25 North, Range 1 East, N.M.P.M.

Section 6	:	All
Section 7	:	All
Section 18	:	All
Section 19	:	All
Section 30	:	All
Section 31	:	All

Township 25 North, Range 1 West, N.M.P.M.

Sections 1 through 36, inclusive	:	All

Township 26 North, Range 1 East, N.M.P.M.

Section 19	:	All
Section 30	:	All
Section 31	:	All

Township 26 North, Range 1 West, N.M.P.M.

Sections 1 through 36, inclusive	:	All

Township 27 North, Range 1 West, N.M.P.M.

Section 1	:	West Half (W½)
Sections 2 through 11, inclusive	:	All
Section 12	:	West Half (W½)
Section 13	:	West Half (W½)
Sections 14 through 23, inclusive	:	All
Section 24	:	West Half (W½)
Section 25	:	West Half (W½)
Sections 26 through 30, inclusive	:	All

3. That production experience and the interference tests conducted by applicant since the entry of Order No. R-2565 conclusively prove that one well will efficiently and economically drain an area of 160 acres or more in the proposed East Puerto Chiquito-Mancos Oil Pool, and the Commission should, therefore, establish permanent 160 acre oil well drilling, spacing and proration units in said Pool.

4. That production experience and the interference tests conducted by applicant since the entry of Order No. R-2565 indicate that one well will efficiently and economically drain in excess of 320 acres in the proposed West Puerto Chiquito-Mancos Oil Pool and that the Commission should, therefore, establish

temporary 320 acre oil well drilling, spacing and proration units in said Pool for a period of three (3) years from and after the date of the entry of the Commission's order in this case.

5. That a standard proration unit in the proposed East Puerto Chiquito-Mancos Oil Pool should be assigned a 160 acre proportional factor of 4.00 for allowable purposes.

6. That a standard proration unit in the proposed West Puerto Chiquito-Mancos Oil Pool should be assigned a 320 acre proportional factor of 8.00 for allowable purposes.

7. That the Commission should administratively authorize performance of additional interference tests in the proposed West Puerto Chiquito-Mancos Oil Pool in order to better establish the area which one well will efficiently and economically drain in this Pool, and in connection therewith, the operator conducting such interference tests should be administratively authorized to transfer allowables among wells on the same lease during the period of said interference tests and for a reasonable period after the conclusion of the same in order to reduce loss of production to a minimum.

8. That the granting of the relief requested in this application will prevent economic loss caused by the drilling of unnecessary wells, and will avoid the augmentation of risk arising from the drilling of an excessive number of wells.

9. That the granting of the relief requested in this application will prevent waste and protect the correlative rights of

all owner, royalty owner and other interested parties in the area involved.

WHEREFORE, applicant respectfully requests that this case be set down for hearing before the full Commission at its regular hearing date scheduled for the month of September, 1966, and that upon reviewing the evidence there presented, enter its order granting the relief hereinabove requested.

BURR & COOLEY
Attorneys for Applicant

By William J. Cooley
William J. Cooley
152 Petroleum Center Building
Farmington, New Mexico

GOVERNOR
JACK M. CAMPBELL
CHAIRMAN

State of New Mexico
Oil Conservation Commission

LAND COMMISSIONER
GUYTON B. HAYS
MEMBER

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

P. O. BOX 2088
SANTA FE

November 28, 1966

Mr. George Verity
Brown, Verity & Brown
Attorneys at Law
2220 First National Building
Oklahoma City, Oklahoma

Re: Case No. 3455
Order No. R-2565-B
Applicant:

BENSON-MONTIN-GREER

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Very truly yours,

A. L. Porter, Jr.

A. L. PORTER, Jr.
Secretary-Director

ir/

Carbon copy of order also sent to:

Hobbs OCC x
Artesia OCC
Aztec OCC x

OTHER Messrs. Wm. J. Cooley, Albert R. Greer, J. K. Moore, Tom Bolack, Jack London, Virgil L. Stoabs, William V. Montin, Richard Bramblett, Montin-Harbert Pipeline Construction, General American Oil Company and F. H. Carpenter

Docket No. 29-66

DOCKET: REGULAR HEARING - WEDNESDAY - NOVEMBER 16, 1966

OIL CONSERVATION COMMISSION - 9 A.M. - MORGAN HALL, STATE LAND OFFICE BUILDING, SANTA FE, NEW MEXICO

ALLOWABLE: (1) Consideration of the oil allowable for December, 1966;

(2) Consideration of the allowable production of gas for December, 1966, from thirteen prorated pools in Lea, Eddy and Roosevelt Counties, New Mexico, and also presentation of purchaser's nominations for said pools for the six-month period beginning January 1, 1967; Consideration of the allowable production of gas from nine prorated pools in San Juan, Rio Arriba and Sandoval Counties, New Mexico, for December, 1966.

CASE 3455: (Continued from the September 14, 1966 Regular Hearing) Application of Benson-Montin-Greer Drilling Corporation for division of an oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico. Applicant, in the above-styled cause, seeks the division of the Puerto Chiquito-Gallup Oil Pool into two separate pools, being the East Puerto Chiquito-Mancos Oil Pool and the West Puerto Chiquito-Mancos Oil Pool. Applicant further proposes that the present temporary 160-acre proration units for the Puerto Chiquito-Gallup Oil Pool be made permanent for the proposed East Puerto Chiquito-Mancos Oil Pool and that temporary pool rules for the proposed West Puerto Chiquito-Mancos Oil Pool be adopted, said rules to provide for 320-acre proration units in said pool for a period of three years. Applicant seeks an administrative procedure whereby interference tests could be conducted in the proposed West Puerto Chiquito-Mancos Oil Pool, including a provision for allowable transfer among wells.

CASE 3491: Southeastern New Mexico nomenclature case calling for an order for the creation and extension of certain pools in Lea, Eddy and Roosevelt Counties, New Mexico.

a) Create a new pool in Lea County, New Mexico, classified as an oil pool for San Andres production and designated as the East Brunson-San Andres Pool. The discovery well is Texaco, Inc., A. H. Blinebry NCT-1 No. 10, located in Unit D of Section 20, Township 22 South, Range 38 East, NMPM. Said pool described as:

TOWNSHIP 22 SOUTH, RANGE 38 EAST, NMPM
SECTION 20: NW/4

b) Create a new pool in Eddy County, New Mexico, classified as an oil pool for Delaware production and designated as the Scanlon-Delaware Pool. The discovery well is Harvey E. Yates, Stebbins Deep Federal No. 1, located in Unit H of Section 30, Township 20 South, Range 29 East, NMPM. Said pool described as:

TOWNSHIP 20 SOUTH, RANGE 29 EAST, NMPM
SECTION 30: SE/4 NE/4

c) Extend the vertical limits of the Morton-Lower Wolfcamp Pool in Lea County, New Mexico, to include the entire Wolfcamp formation and redesignate said pool as Morton-Wolfcamp Pool.

d) Extend the Flying "M"-San Andres Pool to include therein:

TOWNSHIP 9 SOUTH, RANGE 33 EAST, NMPM
SECTION 29: NW/4

e) Extend the Grama Ridge-Morrow Gas Pool to include therein:

TOWNSHIP 22 SOUTH, RANGE 34 EAST, NMPM
SECTION 10: All

f) Extend the Middle Lane-Permo Pennsylvanian Pool to include therein:

TOWNSHIP 10 SOUTH, RANGE 33 EAST, NMPM
SECTION 3: SE/4
SECTION 10: NE/4
SECTION 15: NE/4

g) Extend the Lazy J-Pennsylvanian Pool to include therein:

TOWNSHIP 13 SOUTH, RANGE 33 EAST, NMPM
SECTION 36: SW/4

h) Extend the Lovington-Paddock Pool to include therein:

TOWNSHIP 16 SOUTH, RANGE 37 EAST, NMPM
SECTION 30: NW/4

i) Extend the Lusk-Strawn Pool to include therein:

TOWNSHIP 19 SOUTH, RANGE 31 EAST, NMPM
SECTION 28: SE/4

j) Extend the West Mesa-Upper Queen Gas Pool to include therein:

TOWNSHIP 16 SOUTH, RANGE 31 EAST, NMPM
SECTION 12: W/2

k) Extend the Milnesand-San Andres Pool to include therein:

TOWNSHIP 8 SOUTH, RANGE 35 EAST, NMPM
SECTION 28: NW/4

l) Extend the North Osudo-Morrow Gas Pool to include therein:

TOWNSHIP 20 SOUTH, RANGE 36 EAST, NMPM
SECTION 19: S/2
SECTION 30: E/2

m) Extend the Ranger Lake-Pennsylvanian Pool to include therein:

TOWNSHIP 12 SOUTH, RANGE 34 EAST, NMPM
SECTION 14: SW/4

n) Extend the Shoe Bar-Pennsylvanian Pool to include therein:

TOWNSHIP 16 SOUTH, RANGE 35 EAST, NMPM
SECTION 26: NE/4

OVER

ir/

Docket No. 28-66

DOCKET: EXAMINER HEARING - WEDNESDAY - NOVEMBER 16, 1966

8 A.M. - OIL CONSERVATION COMMISSION CONFERENCE ROOM,
STATE LAND OFFICE BUILDING - SANTA FE, NEW MEXICO

- - -

The following cases will be heard before Daniel S. Nutter, Examiner, or Elvis A. Utz, Alternate Examiner:

CASE 3485: Application of Phillips Petroleum Company for a waterflood project, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project by the injection of water into the Grayburg-San Andres formation through three injection wells located in Sections 8 and 9, Township 17 South, Range 33 East, Maljamar Pool, Lea County, New Mexico.

CASE 3486: Application of Shenandoah Oil Corporation for a waterflood project, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project by the injection of water into the Grayburg-San Andres formation through four injection wells located in Sections 7, 8, and 16, Township 17 South, Range 33 East, Maljamar Pool, Lea County, New Mexico.

ir/

November 8, 1966

New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Re: CASE NO. 3455

Gentlemen:

This is to advise you that I, Noel Reynolds, as a lease owner and as an oil and gas operator within the boundaries of the Puerto Chiquito Mancos Oil Pool wish to support the application of Benson-Montin-Greer Drilling Corp. in the above referred to case.

Please include my name on the record as a supporter for the applicant.

Very truly yours,

'66 Nov 21 AM 9 1

Noel Reynolds

BENSON-MONTIN-GREER DRILLING CORP.

GENERAL OFFICE:
1390 FIRST NATIONAL BLDG.
OKLAHOMA CITY, OKLAHOMA 73102
PHONE 235-0546

221 PETROLEUM CENTER BUILDING
FARMINGTON, NEW MEXICO 87401
PHONE 325-8874

August 17, 1966

New Mexico Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico

'66 AUG 18 PM 1 38

Re: APPLICATION OF BENSON-MONTIN-GREER DRILLING CORP. FOR SPACING ORDER IN THE PUERTO CHIQUITO MANCOS OIL POOL

Case 3455

Gentlemen:

Forwarded herewith is a list of parties who may be interested in the above referenced application. We have sent copies of the application to each of these parties, and would appreciate your sending them copies of all dockets and other notices in connection with this hearing. We have omitted Intex Oil Company from this mailing list, inasmuch as Intex has agreed to sell to Benson-Montin-Greer Drilling Corp. its operating rights in all of its interests in oil and gas leases in this area, and we presume this sale will be concluded prior to the hearing.

In view of the fact that we are currently drilling two additional wells in Township 27 North, Range 1 West, which we consider wells critical to the subject of the hearing, it is our plan to request the Commission, when the matter comes before it at its September regular hearing, to continue the hearing until November, and to maintain the present temporary order in force until such time as the Commission hands down an opinion on the current application. We have advised each of the parties on the enclosed list of our intentions in this regard.

Yours very truly,

BENSON-MONTIN-GREER DRILLING CORP.

BY: Albert R. Greer
Albert R. Greer
Vice-President

DOCKET MAILED
Date 11-4-66

DOCKET MAILED
Date 9-1-66

ARG:nej

BENSON-MONTIN-GREER DRILLING CORP.

GENERAL OFFICE:
1390 FIRST NATIONAL BLDG.
OKLAHOMA CITY, OKLAHOMA 73102
PHONE 235-0546

221 PETROLEUM CENTER BUILDING
FARMINGTON, NEW MEXICO 87401
PHONE 325-8874

August 17, 1966

Case 3455

To: OWNERS OF OIL AND GAS INTERESTS
PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

'66 AUG 18 PM 1 30

This is to advise you that Benson-Montin-Greer Drilling Corp. is making application to the New Mexico Oil Conservation Commission regarding spacing of wells in the Puerto Chiquito Mancos oil pool. For your information we are enclosing copy of our application. It is our understanding that this application will be docketed on the Commission's September regular hearing.

It is our intention, in order to allow time to develop information from wells currently drilling, to request the Commission at this September regular hearing to continue the case until its November hearing, and maintain the present temporary order in force until the Commission hands down a decision on the present application.

We presume the Commission will grant our request to continue this matter until November, unless there be serious objection from other interested parties. Accordingly we request that if any interested party objects to continuing this matter until November, we be advised as soon as possible.

BENSON-MONTIN-GREER DRILLING CORP.

BY: Albert R. Greer
Albert R. Greer
Vice-President

MAILING LIST ATTACHED

ARG:nej

Case 3455

'66 Aug 18 PM 1 39

OWNERS OF OIL AND GAS INTERESTS
PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

JOHN R. ANDERSON, BOX 149, FARMINGTON, NEW MEXICO

ATLAS CORPORATION, NATIONAL BANK OF TULSA BUILDING, TULSA, OKLAHOMA

M. A. BARTON, BOX 2154, SANTA FE, NEW MEXICO

R. L. BAYLESS, BOX 1541, FARMINGTON, NEW MEXICO

BENSON-MONTIN-GREER DRILLING CORP., 221 PETROLEUM CENTER BUILDING, FARMINGTON, NEW MEXICO

TOM BOLACK, 1010 NORTH DUSTIN, FARMINGTON, NEW MEXICO

BURK ROYALTY COMPANY, 800 OIL & GAS BUILDING, WICHITA FALLS, TEXAS

F. H. CARPENTER, BOX 608, SOUR LAKE, TEXAS

CHEVRON OIL COMPANY, BOX 1660, MIDLAND, TEXAS

CLEARY PETROLEUM, INC., 310 KERMAC BUILDING, OKLAHOMA CITY, OKLAHOMA

CORAL OIL & GAS COMPANY, 2127 SAN MATEO NE, ALBUQUERQUE, NEW MEXICO

DR. SAM G. DUNN, 1312 MAIN STREET, LUBBOCK, TEXAS

J. V. FRITTS, ROSWELL, NEW MEXICO

GENERAL AMERICAN OIL COMPANY OF TEXAS, MEADOWS BUILDING, DALLAS, TEXAS

ALBERT R. GREER, 221 PETROLEUM CENTER BUILDING, FARMINGTON, NEW MEXICO

H & S DRILLING COMPANY, TRI STATE INSURANCE BUILDING, TULSA, OKLAHOMA

HUMBLE OIL & REFINING COMPANY, BOX 801, TULSA, OKLAHOMA

MOBIL OIL CORP., BOX 1652, CASPER, WYOMING

MOUNTAIN STATES NATURAL GAS CORP., BOX 1362, TULSA, OKLAHOMA

HAROLD O'CONNOR, 300 CARLISLE SE, ALBUQUERQUE, NEW MEXICO

PAN AMERICAN PETROLEUM CORP., SECURITY LIFE BUILDING, DENVER, COLORADO

NOEL REYNOLDS, 305 KORBER BUILDING, ALBUQUERQUE, NEW MEXICO

ROYAL DEVELOPMENT COMPANY, BOX 1299, ALBUQUERQUE, NEW MEXICO

SKELLY OIL COMPANY, BOX 4115, STATION A, ALBUQUERQUE, NEW MEXICO

JOE E. SMITH, 8285 WHITE ROAD, BEAUMONT, TEXAS

ROBERT D. SNOW, TRI STATE INSURANCE BUILDING, TULSA, OKLAHOMA

SUNRAY DX OIL COMPANY, BOX 1416, ROSWELL, NEW MEXICO

TEXOTA OIL COMPANY, 110 - 16th STREET, DENVER, COLORADO

ENCO

HUMBLE OIL & REFINING COMPANY

DENVER, COLORADO 80201

DENVER DISTRICT

POST OFFICE BOX 120

November 8, 1966

New Mexico Oil Conservation Commission
Morgan Hall
State Land Office Building
Santa Fe, New Mexico

Gentlemen:

This letter refers to case number 3455, the application of Benson-Montin-Greer Drilling Corporation for division of an oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico, continued for hearing on November 16, 1966. The applicant has proposed that the present temporary 160 acre proration units be made permanent for the proposed East Puerto Chiquito-Mancos oil pool and that temporary pool rules for the proposed West Puerto Chiquito-Mancos oil pool be adopted to provide for 320 acre proration units in that pool for a period of three years.

This company is a owner of a small leasehold interest and a substantial overriding royalty interest in the lands affected by the subject application. We acknowledge receipt of a copy of the application as filed with the Commission which copy was furnished to us by the applicant.

Would you please be advised that Humble Oil & Refining Company has no objection to the orders and rules sought by the applicant, Benson-Montin-Greer Drilling Corporation, in the subject application as filed with you.

Very truly yours,

HUMBLE OIL & REFINING COMPANY

By COPY ORIGINAL SIGNED J. ROY DORROUGH
District Superintendent

JRD(WSL)jf
cc: Mr. Virgil L. Stoabs
Benson-Montin-Greer Drilling Corp.
221 Petroleum Center Building
Farmington, New Mexico

GOVERNOR
JACK M. CAMPBELL
CHAIRMAN

State of New Mexico
Oil Conservation Commission

LAND COMMISSIONER
GUYTON B. HAYS
MEMBER

P. O. BOX 2088
SANTA FE

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

September 21, 1966

Mr. William J. Cooley
Burr & Cooley
Attorneys at Law
152 Petroleum Center Building
Farmington, New Mexico

Re: Case No. 3455
Order No. R-3118
Applicant:

Benson-Montin-Greer Drlg. Co.

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Very truly yours,

A. L. Porter, Jr.

A. L. PORTER, Jr.
Secretary-Director

ir/

Carbon copy of order also sent to:

Hobbs OCC x
Artesia OCC
Aztec OCC x
OTHER

DOCKET MAILED
Date 11-4-66

CLASS OF SERVICE
This is a fast message unless its deferred character is indicated by the proper symbol.

WESTERN UNION TELEGRAM

W. P. MARSHALL
CHAIRMAN OF THE BOARD

W. W. McFALL
PRESIDENT

1986 NOV 14 PM 4 08

SYMBOLS
DL = Day Letter
NL = Night Letter
LT = International Letter Telegram

The filing time shown in the date line on domestic telegrams is LOCAL TIME at point of origin. Time of receipt is LOCAL TIME at point of destination

LA47 KB349

K CHA121 PD=CASPER WYO 14 321P MST=
BENSON- MONTIN - GREER DRILLING CORP=
221 PETR CENTER BLDG FARMINGTON NMEX=

:PLEASE BE ADVISED THAT MOBIL OIL CORP HAS NO OBJECTION TO THE APPLICATION OF BENSON -MONTIN- GREER DRILLING COPR FOR WELL SPACING IN FIELD RULES PUERTO CHIQUITO POOL RIO ARRIBA COUNTY NEW MEXICO ORIGINAL COPY OF THIS TELEGRAM TO NEW MEXICO OIL CONSERVATION COMMISSION COPY
BENSON - MONTIN- GREER DRILLING=
J M MCLAUGHLIN DIVN PRODUCING MGR.

WU1201 (R2-65) THE COMPANY WILL APPRECIATE SUGGESTIONS FROM ITS PATRONS CONCERNING ITS SERVICE

CLASS OF SERVICE
This is a fast message unless its deferred character is indicated by the proper symbol.

WESTERN UNION
TELEGRAM

W. P. MARSHALL, PRESIDENT

1201 (4-60)

SYMBOLS
DL = Day Letter
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LA081 KB346

K CMA150 PD=CASPER WYO 14 321P MST=
NEW MEXICO OIL CONSERVATION COMM=
BOX 871 SANTA FE NMEX=

1966 NOV 14 PM 4 05

Case 3455

'66 NOV 14 PM 4 08

PLEASE BE ADVISED THAT MOBIL OIL CORP HAS NO OBJECT TO THE APPLICATION OF BENSON = MONTI = GREER DRILLING COPR FOR WELL SPACING IN FIELD RULES PUERTO CHIQUITO POOL RIO ARRIBA COUNTY NEW MEXICO ORIGINAL COPY OF THIS TELEGRAM TO NEW MEXICO OIL CONSERVATION COMMISSION COPY BENSON = MONTIN= GREER DRILLING=

: J M MCLAUGHLIN DIVN PRODUCING MGR.

THE COMPANY WILL APPRECIATE SUGGESTIONS FROM ITS PATRONS CONCERNING ITS SERVICE

November 8, 1966

New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Re: CASE NO. 3455

Gentlemen:

This is to advise you that I, Noel Reynolds, as a lease owner and as an oil and gas operator within the boundaries of the Puerto Chiquito Mancos Oil Pool wish to support the application of Benson-Montin-Greer Drilling Corp. in the above referred to case.

Please include my name on the record as a supporter for the applicant.

Very truly yours,

Noel Reynolds

Noel Reynolds

'65 Nov 15 AM

November 10, 1966

New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Re: CASE NO. 3455

Gentlemen:

I wish to support the application of Benson-Montin-Greer Drilling Corp in their case #3455 to be heard in Santa Fe on November 16, 1966.

I own both leases and overriding royalty in the proposed West Puerto Chiquito Mancos Oil Pool.

'65 Nov 15 AM 8 04

Sincerely yours,

Charles B. Gonsales

Charles B. Gonsales

ENCO

HUMBLE OIL & REFINING COMPANY

DENVER, COLORADO 80201

DENVER DISTRICT

POST OFFICE BOX 120

November 8, 1966

New Mexico Oil Conservation Commission
Morgan Hall
State Land Office Building
Santa Fe, New Mexico

Gentlemen:

This letter refers to case number 3455, the application of Benson-Montin-Greer Drilling Corporation for division of an oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico, continued for hearing on November 16, 1966. The applicant has proposed that the present temporary 160 acre proration units be made permanent for the proposed East Puerto Chiquito-Mancos oil pool and that temporary pool rules for the proposed West Puerto Chiquito-Mancos oil pool be adopted to provide for 320 acre proration units in that pool for a period of three years.

This company is a owner of a small leasehold interest and a substantial overriding royalty interest in the lands affected by the subject application. We acknowledge receipt of a copy of the application as filed with the Commission which copy was furnished to us by the applicant.

Would you please be advised that Humble Oil & Refining Company has no objection to the orders and rules sought by the applicant, Benson-Montin-Greer Drilling Corporation, in the subject application as filed with you.

Very truly yours,

HUMBLE OIL & REFINING COMPANY

By _____
District Superintendent

JRD(WSL)jf
cc: Mr. Virgil L. Stoabs
Benson-Montin-Greer Drilling Corp.
221 Petroleum Center Building
Farmington, New Mexico

The Masi Company
P. O. BOX 705
SANTA FE, NEW MEXICO
87501

November 7, 1966

SUBJECT: CASE NO. 3455:
Application of Benson-Montin-Greer Drilling Corporation for division of the Puerto Chiquito-Gallup Oil Pool into two separate pools and for special rules for each, Rio Arriba County, New Mexico.

Oil Conservation Commission
State of New Mexico
State Land Office Building
Santa Fe, New Mexico 87501

Gentlemen:

After having read and studied the conditions apparent in the area referred to by Benson-Montin-Greer Drilling Corporation plus the fact that I own producing overriding royalty interests and Federal oil and gas leases covering several hundred acres of land within the area described, it is my contention the program proposed and the spacing suggested by Benson-Montin-Greer Drilling Corporation, is to the benefit of the State of New Mexico and the parties of interest in the area.

As my interest can profit only by the most efficient and economical development of this area, I respectfully request that the application presented by Benson-Montin-Greer Drilling Corporation be acted upon in favor of the applicant.

Very truly yours,

THE MASI COMPANY
By: R M Barton
R. M. Barton

FORM 1397 1-66

PAN AMERICAN PETROLEUM CORPORATION

SECURITY LIFE BUILDING
DENVER, COLORADO 80202

PRODUCING DEPARTMENT
H. T. HUNTER
DIVISION PRODUCTION
MANAGER

DISTRICT SUPERINTENDENTS
W. M. JONES
A. E. PIPER
T. M. CURTIS
JOINT INTEREST
SUPERINTENDENT
S. B. RICHARDS

November 9, 1966

File: AMR-1965-986.51

Re: Puerto Chiquito Pool Hearing
Case No. 3455
November 16, 1966

Mr. A. L. Porter, Jr.
New Mexico Oil Conservation Commission
P. O. Box 871
Santa Fe, New Mexico

Dear Mr. Porter:

Please be advised that Pan American, as a Working Interest Owner and Royalty Owner in acreage within the boundaries of the Puerto Chiquito Oil Pool, supports the application of Benson-Montin-Greer Drilling Corporation for an order dividing the Puerto Chiquito Pool into the East and West Oil Pools, establishing 160-acre drilling, spacing and proration units in the East Pool and 320-acre drilling, spacing and proration units in the West Pool. This application is to be heard on Wednesday, November 16, 1966, Case No. 3455.

Pan American hereby requests the approval of this application by the Commission.

Yours very truly,

S B Richards G

cc: Mr. Albert R. Greer
Benson-Montin-Greer
Drilling Corp.

ROSWELL PETROLEUM BUILDING
505 622-7330

67 RIVERSIDE
505 622-6923

ERNEST A. HANSON
OIL OPERATOR
P. O. BOX 1515
ROSWELL, NEW MEXICO
88201

November 10, 1966

Mr. A. L. Porter
Secretary Directal
New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico

Re: Case No. 3455
November 10, 1966
Benson, Montain & Greer
Drilling Company Applicant

Dear Mr. Porter:

We agree with the findings of the Operator and wish to support the application as presented.

Yours very truly,

ERNEST A. HANSON

EAH/lp

CC: Benson, Montain & Greer

ATLAS MINERALS
DIVISION OF ATLAS CORPORATION
OIL AND GAS DIVISION
707 NATIONAL BANK OF TULSA BUILDING
TULSA, OKLAHOMA 74103

TELEPHONE (918) LUTHER 2-7274

November 8, 1966

Oil Conservation Commission
State of New Mexico
State Land Office Building
Santa Fe, New Mexico 87501

Re: Case No. 3455 - Application of Benson-Montin-Greer Drilling Corp. for division of the Puerto Chiquito-Gallup Oil Pool into two separate pools and for special rules for each, Rio Arriba County, New Mexico.

Gentlemen:

Atlas Corporation is the owner of oil and gas, minerals and leasehold interests in the area covered by the subject application and supports the application presented by Benson-Montin-Greer Drilling Corporation.

Very truly yours,

ATLAS MINERALS
Division of Atlas Corporation

By F. T. Anderson
F. T. ANDERSON
Vice President

FTA:hh
cc-Mr. Virgil Stoabs
c/o Benson-Montin-Greer
Drilling Corp.
221 Petroleum Center Building
Farmington, New Mexico 87401

SKELLY OIL COMPANY

TULSA, OKLAHOMA 74102

PRODUCTION DEPARTMENT
C. L. BLACKSHER, VICE PRESIDENT
W. P. WHITMORE, MGR. PRODUCTION
W. D. CARSON, MGR TECHNICAL SERVICES
ROBERT G. HILTZ, MGR. JOINT OPERATIONS
GEORGE W. SELINGER, MGR. CONSERVATION

November 8, 1966

Case 3455

Re: Case No. 3455

Mr. A. L. Porter, Jr., Secretary-Director
Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Dear Mr. Porter:

On Wednesday, November 16, the Commission will hear a continued case from September 14, on the application of Benson-Montin-Greer Drilling Corporation regarding the Puerto Chiquito-Mancos Oil Pool.

As an interested party in these proceedings, we wish to go on record as favoring the application of Benson-Montin-Greer Drilling Corporation for the division of the Puerto Chiquito-Gallup Oil Pool into two separate pools; that the East Puerto Chiquito-Mancos Oil Pool have 160-acre proration units as permanent rules, and that the West Puerto Chiquito-Mancos Oil Pool have established 320-acre proration units either on a temporary or permanent basis.

We understand applicant seeks administrative procedure regarding interference tests, allowable transfer, and such other operating rules as may be necessary, to which we concur.

Respectfully submitted,

George W. Selinger

GWS:br

cc-Mr. A. R. Greer
Benson-Montin-Greer Drilling Corp.
221 Petroleum Center Building
Farmington, New Mexico 87401

B. A. Kimbell, President
J. C. Bulmer, Secy.-Treas.

Burk Royalty Co.

800 Oil & Gas Building
Wichita Falls, Texas 76301

Tom Darling, V. P. Eng.
Bill Duncan, V. P. Prod.

November 4, 1966

Re: Temporary 320 Acre Spacing
Case No. 3455

New Mexico Oil Conservation Commission
P. O. Box 871
Santa Fe, New Mexico

Gentlemen:

The Burk Royalty Co. concurs with the Benson-Montin-Greer Drilling Corp.'s application for temporary 320 acre spacing in the West Puerto Chaquito Moncos Oil Pool in Rio Arriba County, New Mexico.

Yours very truly,

BURK ROYALTY CO.

Tom Darling

TD:sc

READING & BATES PRODUCTION CO.

11TH FLOOR, PHILTOWER BUILDING
TULSA, OKLAHOMA 74103

PHONE
AREA CODE 918
LU 3-8525

November 1, 1966

New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico

Gentlemen:

Re: Conservation Commission Hearing -
November 16, 1966 - Case # 3455

As owners of a working interest in certain lands in T25N, R1W, Rio Arriba County, which lands comprise a portion of the area in which 320 acre spacing is proposed for the Mancos shale fractured reservoir, please be advised that Goff Oil Company (now owned by Reading & Bates Production Company) supports the granting of a temporary 320 acre spacing order and will not oppose same at the scheduled hearing November 16, 1966.

Yours very truly,

READING & BATES
PRODUCTION CO.

I. J. Pierce, President

IJP:np

cc: Mr. Virgil Stoabas
Benson-Montin Greer
221 Petroleum Centre Building
Farmington, New Mexico

'66 Nov 3 PM 1 17

NEW MEXICO OIL CONSERVATION COMMISSION
Post Office Box 2088
Santa Fe, New Mexico

Re: Case No. 3455

Gentlemen:

Del-Lea, Inc. is the owner of certain leases in the proposed West Puerto Chiquito-Mancos Oil Pool, and we wish to go on record in the above referenced case as supporting the application of Benson-Montin-Greer Drilling Corp. for the establishment of temporary 320 acre spacing in that Pool.

Very truly yours,

DEL-LEA, INC.

By J. Lon Hudgens
President

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

CASE No. 2881
Order No. R-2565-A

IN THE MATTER OF THE APPLICATION OF BENSON-MONTIN-GREER DRILLING CORPORATION FOR 160-ACRE SPACING, RIO ARRIBA COUNTY, NEW MEXICO.

NUNC PRO TUNC ORDER

BY THE COMMISSION:

It appearing to the Commission that due to clerical error and inadvertence, Order No. R-2565, dated September 9, 1963, does not correctly state the intended order of the Commission,

IT IS THEREFORE ORDERED:

(1) That the following-described non-standard units are hereby stricken from Order No. R-2565:

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM

Section 5:	E/2 NW/4	80.00 acres
Section 5:	W/2 NW/4	80.00 acres

(2) That the following-described non-standard units are hereby interlineated in lieu of the above-described non-standard units:

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM

Section 5:	N/2 NW/4	80 acres
Section 5:	S/2 NW/4	80 acres

(3) That this order shall be effective nunc pro tunc as of September 9, 1963.

DONE at Santa Fe, New Mexico, on this 8th day of July, 1964.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

JACK M. CAMPBELL, Chairman

E. S. WALKER, Member

S E A L

esr/

A. L. PORTER, Jr., Member & Secretary

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE NO. 2881
Order No. R-2565
NOMENCLATURE

APPLICATION OF BENSON-MONTIN-GREER
DRILLING CORPORATION FOR 160-ACRE
SPACING, RIO ARRIBA COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 o'clock a.m. on August 14, 1963, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission."

NOW, on this 9th day of September, 1963, the Commission, a quorum being present, having considered the testimony presented and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, Benson-Montin-Greer Drilling Corporation, seeks the promulgation of special rules and regulations establishing 160-acre spacing units for oil wells completed in the vicinity of the Puerto Chiquito-Gallup Oil Pool for a temporary period of three years.

(3) That the applicant also seeks authority to conduct interference tests in the subject area and to transfer allowables among producing wells on the same lease while such tests are being conducted.

(4) That the horizontal limits of the Puerto Chiquito-Gallup Oil Pool should be extended in order to include therein all wells producing from the same common source of supply.

(5) That in order to prevent the economic loss caused by the drilling of unnecessary wells, to avoid the augmentation of risk arising from the drilling of an excessive number of wells, to prevent reduced recovery which might result from the drilling of too few wells, and to otherwise prevent waste and protect correlative rights, temporary special rules and regulations providing for 160-acre spacing units should be promulgated for the Puerto Chiquito-Gallup Oil Pool.

(6) That the temporary special rules and regulations should provide for limited well locations in order to assure orderly development of the pool and protect correlative rights.

(7) That the temporary special rules and regulations should be established for a three-year period in order to allow the operators in the subject pool to gather reservoir information to establish the area that can be efficiently and economically drained and developed by one well.

(8) That an administrative procedure should be established whereby the operators in the Puerto Chiquito-Gallup Oil Pool would be permitted to conduct interference tests and to transfer allowables among producing wells on the same lease during the temporary three-year period in order to facilitate the gathering of information pertaining to reservoir characteristics.

(9) That this case should be reopened in September, 1966, at which time the operators in the subject pool should appear and show cause why the Puerto Chiquito-Gallup Oil Pool should not be developed on 40-acre spacing units.

IT IS THEREFORE ORDERED:

(1) That the horizontal limits of the Puerto Chiquito-Gallup Oil Pool are hereby redefined to include the following-described area:

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 2 through 10 inclusive: All
Sections 15 through 22 inclusive: All
Sections 27 through 33 inclusive: All

TOWNSHIP 25 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36 inclusive: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10 inclusive: All
Sections 14 through 23 inclusive: All
Sections 26 through 35 inclusive: All

TOWNSHIP 26 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36 inclusive: All

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10 inclusive: All
Sections 15 through 22 inclusive: All
Sections 27 through 30 inclusive: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 30 inclusive: All

(2) That Special Rules and Regulations for the Puerto Chiquito-Gallup Oil Pool are hereby promulgated as follows:

SPECIAL RULES AND REGULATIONS
FOR THE
PUERTO CHIQUITO-GALLUP OIL POOL

RULE 1. Each well completed or recompleted in the Puerto Chiquito-Gallup Oil Pool shall be spaced, drilled, operated, and produced in accordance with the Special Rules and Regulations hereinafter set forth.

RULE 2. Each well completed or recompleted in the Puerto Chiquito-Gallup Oil Pool shall be located on a standard 160-acre unit comprising a single governmental quarter section.

RULE 3. Each well completed or recompleted in the Puerto Chiquito-Gallup Oil Pool shall be located within 165 feet of the center of a governmental quarter-quarter section.

RULE 4. The Secretary-Director may grant an exception to the requirements of Rule 3 without notice and hearing when an application has been filed for an unorthodox location necessitated by topographical conditions or the recompletion of a well previously drilled to another horizon. All operators offsetting the proposed unorthodox location shall be notified of the application by registered or certified mail, and the application shall state that such notice has been furnished. The secretary-Director may approve the application upon receipt of written waivers from all offset operators or if no offset operator has entered an objection

to the unorthodox location within 20 days after the Secretary-Director has received the application.

RULE 5. A standard unit in the Puerto Chiquito-Gallup Oil Pool (158 through 162 acres) shall be assigned a 160-acre proportional factor of 4.00 for allowable purposes. Any unit comprising less than 158 acres or more than 162 acres shall be assigned a proportional factor in the same ratio to 4.00 as the acreage in the unit bears to 160.

IT IS FURTHER ORDERED:

(1) That any well presently drilling to or completed in the Gallup formation within the Puerto Chiquito-Gallup Oil Pool that will not comply with the well location requirements of Rule 3 is hereby granted an exception to the requirements of said rule. The operator shall notify the Aztec District Office of the Commission in writing of the name and location of the well on or before October 1, 1963.

(2) That any operator desiring to dedicate 160 acres to a well presently drilling to or completed in the Puerto Chiquito-Gallup Oil Pool shall file a new Form C-128 with the Commission on or before October 1, 1963.

(3) That the following-described non-standard units comprising less than 160 acres are hereby approved:

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM

Section 5:	E/2 NE/4	80.00 acres
Section 5:	W/2 NE/4	80.00 acres
Section 5:	E/2 NW/4	80.00 acres
Section 5:	W/2 NW/4	80.00 acres
Section 9:	E/2 NW/4	80.00 acres
Section 9:	W/2 NW/4	80.00 acres
Section 15:	SE/4 SW/4	40.00 acres
Section 15:	N/2 SW/4 and SW/4 SW/4	120.00 acres
Section 16:	E/2 NE/4	80.00 acres
Section 16:	W/2 NE/4	80.00 acres
Section 21:	E/2 SE/4	80.00 acres
Section 21:	W/2 SE/4	80.00 acres
Section 22:	W/2 NW/4	80.00 acres
Section 22:	E/2 NW/4	80.00 acres

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM

Section 28:	N/2 NW/4	80.00 acres
Section 28:	SW/4 NW/4 and Lot 4	64.21 acres
Section 28:	SE/4 NW/4 and Lot 3	64.01 acres
Section 29:	N/2 NE/4	80.00 acres
Section 29:	N/2 NW/4	80.00 acres
Section 29:	SW/4 NW/4 and Lot 4	64.30 acres
Section 29:	SE/4 NW/4 and Lot 3	64.30 acres
Section 29:	SW/4 NE/4 and Lot 2	64.30 acres
Section 29:	SE/4 NE/4 and Lot 1	64.30 acres

PROVIDED HOWEVER, That none of the aforesaid non-standard units shall become effective until the operator thereof has filed with the Commission Form C-128 outlining thereon the acreage dedicated to the well.

(4) That the Secretary-Director of the Commission is hereby authorized to approve interference tests and the transfer of allowables to wells on the same lease or, if in a unitized area, to wells in the same participating area, provided however, that any such authorization shall be limited to a period of six months, but may be renewed. No transfer well shall be permitted to receive, in addition to its own allowable, more than 50 per cent of one top unit allowable for the Puerto Chiquito-Gallup Oil Pool.

To obtain administrative approval for interference tests and the transfer of allowable, the operator shall submit in triplicate a request for such authority describing in detail the proposed method of conducting such tests and transferring the allowable. The application shall be accompanied by a plat showing thereon all Gallup wells within a radius of two miles of the proposed shut-in well(s) and the transfer well(s). The plat shall also identify each lease or participating area as to ownership or operating rights. The application shall include evidence that all offset operators to the shut-in well(s) and the transfer well(s) have been furnished a complete copy of the application. It shall also be accompanied by Form C-116 for each shut-in well, showing the results of a pre-shut-in test to determine the amount of allowable to be transferred. The transferred allowable shall not exceed the volume of oil produced during the last 24 hours of a 72-hour period during which the well shall be produced at a constant rate. The Commission and offset operators to both the shut-in well(s) and the transfer well(s) may witness such tests if they so desire

and shall be notified of the tests at least 48 hours prior to the commencement thereof.

The Secretary-Director of the Commission may grant approval of the interference tests and transfer of allowable upon receipt of waivers from all offset operators or upon expiration of a 20-day waiting period, provided no offset operator has objected to the proposed test and transfer.

(5) That notwithstanding any of the provisions of Rule 104(a) of the Commission Rules and Regulations, the Special Rules and Regulations for the Puerto Chiquito-Gallup Oil Pool shall not be applicable outside the limits of said pool as hereinabove defined or as hereafter extended.

(6) That this case shall be reopened in September, 1966, at which time the operators in the subject pool may appear and show cause why the Puerto Chiquito-Gallup Oil Pool should not be developed on 40-acre proration units.

(7) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

JACK M. CAMPBELL, Chairman

E. S. WALKER, Member

A. L. PORTER, Jr., Member & Secretary

S E A L

ir/

Docket No. 34-69

DOCKET: EXAMINER HEARING - WEDNESDAY - DECEMBER 17, 1969

9:30 A. M. - OIL CONSERVATION COMMISSION CONFERENCE ROOM,
STATE LAND OFFICE BUILDING - SANTA FE, NEW MEXICO

The following cases will be heard before Daniel S. Nutter, Examiner, or Elvis A. Utz, Alternate Examiner:

CASE 4276: Application of Humble Oil & Refining Company for a special gas-oil ratio limitation, Lea County, New Mexico. Applicant, in the above-styled cause, seeks an exception to Rule 506 of the Commission Rules and Regulations to provide for a limiting gas-oil ratio of 6,000 cubic feet of gas per barrel of oil in the Oil Center-Blinebry Pool, Lea County, New Mexico.

CASE 4277: Application of Pan American Petroleum Corporation for two unorthodox gas well locations, Rio Arriba County, New Mexico. Applicant, in the above-styled cause, seeks approval of two unorthodox gas well locations in Township 26 North, Range 4 West, Blanco-Mesaverde Gas Pool, Rio Arriba County, New Mexico, as follows:

Jicarilla Apache 102 Well No. 15 located 790 feet from the South line and 1190 feet from the East line of Section 9;

Jicarilla Apache 102 Well No. 16 located 1070 feet from the South line and 1450 feet from the East line of Section 10.

CASE 3455: (Reopened) Continued from the November 5, 1969 Examiner Hearing

In the matter of Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320-acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, for a period of three years. All interested parties may appear and show cause why said pool should not be developed on 40-acre spacing units.

CASE 4257: (Continued from the November 19, 1969 Regular Hearing)

Application of Sohio Petroleum Company for salt water disposal, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water into the San Andres formation in the open-hole interval from 4920 feet to 4995 feet in its Phillips Lea SWD Well No. 4 located in Unit M of Section 31, Township 17 South, Range 34 East, Vacuum Grayburg-San Andres Pool, Lea County, New Mexico.

CASE 4263: (Continued from the November 25, 1969 Examiner Hearing

Application of Wynn & Brooks for an unorthodox gas well location, San Juan County, New Mexico. Applicant, in the above-styled cause, seeks approval for the unorthodox location of its Federal "E" Well No. 3, to be located 590 feet from the South line and 1590 feet from the West line of Section 13, Township 27 North, Range 8 West, Blanco-Mesaverde and Basin-Dakota Pools, San Juan County, New Mexico.

CASE 4264: (Continued from the November 25, 1969, Examiner Hearing)

Application of Wynn & Brooks for an unorthodox gas well location, San Juan County, New Mexico. Applicant, in the above-styled cause, seeks approval for the unorthodox location of its Federal "J" Well No. 1, to be located 2390 feet from the South line and 2410 feet from the East line of Section 11, Township 27 North, Range 8 West, Blanco-Mesaverde and Basin-Dakota Pools, San Juan County, New Mexico.

CASE 4278: Application of Anne Burnett Windfohr, dba Windfohr Oil Company, for an exception to Order No. R-3221, as amended, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks an exception to Order No. R-3221, as amended, which order prohibits the disposal of water produced in conjunction with the production of oil on the surface of the ground in Lea, Eddy, Chaves, and Roosevelt Counties, New Mexico. Said exception would be for applicant's Gissler B Wells Nos. 11 and 12, located, respectively, in Units J and I of Section 23, Township 17 South, Range 30 East, Jackson-Abo Pool, Eddy County, New Mexico. Applicant seeks authority to dispose of salt water produced by said wells in unlined surface pits in the vicinity of said wells.

CASE 4279: Application of Anne Burnett Windfohr, dba Windfohr Oil Company, for an exception to Order No. R-3221, as amended, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks an exception to Order No. R-3221, as amended, which order prohibits the disposal of water produced in conjunction with the production of oil on the surface of the ground in Lea, Eddy, Chaves, and Roosevelt Counties, New Mexico. Said exception would be for applicant's Gissler B Well No. 4 located in Unit B of Section 8, Township 17 South, Range 30 East, Grayburg-Jackson Pool, Eddy County, New Mexico. Applicant seeks authority to dispose of salt water produced by said well in an unlined surface pit in the vicinity of said well.

CASE 4279: Application of J. M. Huber Corporation for salt water disposal, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water into the Lower Wolfcamp formation in the perforated interval from 10,358 feet to 10,419 feet in its Stoltz State Well No. 1 located in Unit M of Section 6, Township 15 South, Range 35 East, Morton-Wolfcamp Pool, Lea County, New Mexico.

CASE 4281: Application of Continental Oil Company for a dual completion Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval for the dual completion (conventional) of its SEMU Well No. 21 located in Unit O of Section 19, Township 20 South, Range 38 East, Lea County, New Mexico, in such a manner as to produce oil from an undesignated Blinebry oil pool and gas from an undesignated Drinkard gas pool through parallel strings of tubing.

CASE 4282: Application of Continental Oil Company for a waterflood project, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project in the East E-K Unit Area by the injection of water into the upper Queen formation through two wells located in Units N and P of Section 22, Township 18 South, Range 34 East, East E-K Queen Pool, Lea County, New Mexico.

CASE 4283: Application of Continental Oil Company for a unit agreement, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the East E-K Unit Area comprising 400 acres, more or less, of state lands described as the NW/4, E/2 SW/4 and SE/4 of Section 22, Township 18 South, Range 34 East, East E-K Queen Pool, Lea County, New Mexico.

CASE 4284: Application of Continental Oil Company for salt water disposal, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water in its Springs SWD Wells Nos. 1 and 2, located in Unit F of Section 3 and Unit A of Section 4 respectively, Township 21 South, Range 25 East, Springs-Upper Pennsylvanian Gas Pool, Eddy County, New Mexico. Disposal into Well No. 1 would be into the Bone Spring, Wolfcamp and Upper Pennsylvanian formations in the openhole interval from 2700 feet to 8350 feet. Disposal into Well No. 2 would be into the Upper Pennsylvanian formation in the perforated interval from 8300 feet to 8410 feet.

Docket No. 34-69

CASE 4265: (Readvertised):

Application of Union Oil Company of California for salt water disposal, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water into the Yates, San Andres and other formations in the open-hole interval from approximately 4450 feet to 6067 feet in its Midway State Well No. 3 located in Unit J, Section 12, Township 17 South, Range 36 East, Lovington Field, Lea County, New Mexico.

CASE 4285: Application of Southwestern Natural Gas Inc., for an unorthodox gas well location, Lea County, New Mexico. Applicant, in the above-styled cause, seeks an exception to the special rules and regulations governing the North Osudo-Morrow Gas Pool to permit the drilling of a well at an unorthodox gas well location 1980 feet from the South line and 660 feet from the East line of Section 19, Township 20 South, Range 36 East, Lea County, New Mexico.

OCT 29 1969

BURR & COOLEY
ATTORNEYS AND COUNSELORS AT LAW
SUITE 152 PETROLEUM CENTER BUILDING
FARMINGTON, NEW MEXICO
87401

JOEL B. BURR, JR.
WM. J. COOLEY

TELEPHONE 325-1702
AREA CODE 505

October 28, 1969

NEW MEXICO OIL CONSERVATION
P. O. Box 2088
Santa Fe, New Mexico

Attention: Mr. D. S. Nutter

Re: Case No. 3455; Order No. R2565-B

Gentlemen:

Please accept this letter as an application on behalf of our client, Benson-Montin-Greer Drilling Corporation, for a continuance of at least 30 days of the hearing scheduled on November 5, 1969, in the above-referred matter.

Our client is still in the process of assembling and interpreting all available information bearing upon the subject case, and will require the additional time above requested in order to complete this task.

Very truly yours,

BURR & COOLEY

By William J. Cooley
William J. Cooley

WJC:jjh

cc: Mr. Al Greer
BENSON-MONTIN-GREER DRILLING CORP.
221 Petroleum Center Building
Farmington, New Mexico 87401

DOCKET MAILED
Date 12-5-69

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 3455
Order No. R-3118

APPLICATION OF BENSON-MONTIN-GREER
DRILLING CORPORATION FOR THE DIVISION
OF THE PUERTO CHIQUITO-GALLUP OIL POOL
INTO TWO POOLS AND FOR SPECIAL RULES
FOR EACH, RIO ARRIBA COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on September 14, 1966, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission."

NOW, on this 21st day of September, 1966, the Commission, a quorum being present, having considered the testimony presented and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That by Order No. R-2565, dated September 9, 1963, as amended by Order No. R-2565-A, September 9, 1963, and Order No. R-2855, dated December 9, 1964, temporary Special Rules and Regulations were promulgated for the Puerto Chiquito-Gallup Oil Pool, Rio Arriba County, New Mexico.

(3) That Order No. R-2565, dated September 9, 1963, as amended by Order No. R-2565-A, September 9, 1963, and Order No. R-2855, dated December 9, 1964, provided Case 2881 was to be reopened in September, 1966, to allow the operators in the subject pool to appear and show cause why the Puerto Chiquito-Gallup Oil Pool should not be developed on 40-acre proration units.

(4) That the applicant now seeks the division of the Puerto-Chiquito Gallup Oil Pool into two pools and for special rules for each.

(5) That no additional evidence was presented at this hearing.

(6) That the applicant, Benson-Montin-Greer Drilling Corporation, requested the continuance of this case to November 16, 1966, to allow the applicant time to gather additional information concerning the reservoir characteristics of the pool from two wells now being drilled in the pool.

(7) That the applicant also requested that the Special Rules and Regulations be continued in effect until further order of the Commission.

(8) That no objection was made to the continuance of this case to November 16, 1966.

(9) That no objection was made to the request that the Special Rules and Regulations be continued in effect until further order of the Commission.

(10) That this case should be continued to November 16, 1966, and that the temporary Special Rules and Regulations for the Puerto Chiquito-Gallup Oil Pool should be continued in effect until further order of the Commission.

IT IS THEREFORE ORDERED:

(1) That the temporary Special Rules and Regulations for the Puerto Chiquito-Gallup Oil Pool, promulgated by Order No. R-2565 and as amended by Order No. R-2565-A and Order No. R-2855, are hereby continued in full force and effect until further order of the Commission.

(2) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

Jack M Campbell

JACK M. CAMPBELL, Chairman

Guyton B. Hays

GUYTON B. HAYS, Member

A. L. Porter, Jr.

A. L. PORTER, Jr., Member & Secretary

ocr/

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 3455
Order No. R-2565-C

APPLICATION OF BENSON-MONTIN-GREER
DRILLING CORPORATION FOR DIVISION OF
AN OIL POOL INTO TWO POOLS AND FOR
SPECIAL RULES FOR EACH, RIO ARRIBA
COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9:30 a.m. on December 17, 1969, at Santa Fe, New Mexico, before Examiner Daniel S. Nutter.

NOW, on this 6th day of January, 1970, the Commission, a quorum being present, having considered the testimony, the record, and the recommendations of the Examiner, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That by Order No. R-2565-B, dated November 28, 1966, temporary Special Rules and Regulations were promulgated for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, establishing 320-acre spacing units for a period of three years.

(3) That pursuant to the provisions of Order No. R-2565-B, this case was reopened to allow the operators in the subject pool to appear and show cause why the West Puerto Chiquito-Mancos Oil Pool should not be developed on 40-acre spacing units.

(4) That the evidence establishes that one well in the West Puerto Chiquito-Mancos Oil Pool can efficiently and economically drain and develop 320 acres.

(5) That the evidence establishes that waste may occur if more than one well is drilled to the subject pool on a 320-acre spacing or proration unit.

(6) That Rules 2, 3, and 5 of the Special Rules and Regulations promulgated by Order No. R-2565-B should be amended to read in their entirety as follows:

RULE 2. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located on a standard spacing or proration unit consisting of approximately 320 acres which shall comprise any two contiguous quarter sections of a single governmental section, being a legal subdivision (half section) of the United States Public Land Surveys. For purposes of these rules, a spacing or proration unit consisting of between 316 and 324 contiguous surface acres shall be considered a standard spacing or proration unit. No non-standard spacing or proration unit shall be authorized except after notice and hearing.

RULE 3. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located within 165 feet of the center of one of the governmental quarter-quarter sections in the spacing or proration unit; provided, however, that nothing contained herein shall be construed as permitting the drilling of more than one well on a spacing or proration unit.

RULE 5. A standard spacing or proration unit in the West Puerto Chiquito-Mancos Oil Pool (316 through 324 acres) shall be assigned a 320-acre proportional factor of 8.00 for allowable purposes. Any non-standard spacing or proration unit containing less than 316 acres or more than 324 acres shall be assigned a proportional factor in the same ratio to 8.00 as the acreage in the unit bears to 320.

(7) That in order to prevent the economic loss caused by the drilling of unnecessary wells, to avoid the augmentation of risk arising from the drilling of an excessive number of wells, to prevent reduced recovery which might result from the drilling of too few wells, and to otherwise prevent waste and protect

correlative rights, the Special Rules and Regulations promulgated by Order No. R-2565-B as amended by this order should be continued in full force and effect until further order of the Commission.

IT IS THEREFORE ORDERED:

(1) That Rules 2, 3, and 5 of the Special Rules and Regulations governing the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, promulgated by Order No. R-2565-B, are hereby amended to read in their entirety as follows:

RULE 2. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located on a standard spacing or proration unit consisting of approximately 320 acres which shall comprise any two contiguous quarter sections of a single governmental section, being a legal subdivision (half section) of the United States Public Land Surveys. For purposes of these rules, a spacing or proration unit consisting of between 316 and 324 contiguous surface acres shall be considered a standard spacing or proration unit. No non-standard spacing or proration unit shall be authorized except after notice and hearing.

RULE 3. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located within 165 feet of the center of one of the governmental quarter-quarter sections in the spacing or proration unit; provided, however, that nothing contained herein shall be construed as permitting the drilling of more than one well on a spacing or proration unit.

RULE 5. A standard spacing or proration unit in the West Puerto Chiquito-Mancos Oil Pool (316 through 324 acres) shall be assigned a 320-acre proportional factor of 8.00 for allowable purposes. Any non-standard spacing or proration unit containing less than 316 acres or more than 324 acres shall be assigned a proportional factor in the same ratio to 8.00 as the acreage in the unit bears to 320.

(2) That the Special Rules and Regulations governing the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, promulgated by Order No. R-2565-B as amended by this order are hereby continued in full force and effect until further order of the Commission.

(3) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

DAVID F. CARGO, Chairman

ALEX J. ARMIJO, Member

A. L. PORTER, Jr., Member & Secretary

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BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE No. 3455
Order No. R-2565-B
NOMENCLATURE

APPLICATION OF BENSON-MONTIN-GREER
DRILLING CORPORATION FOR DIVISION OF
AN OIL POOL INTO TWO POOLS AND FOR
SPECIAL RULES FOR EACH, RIO ARRIBA
COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on November 16, 1966, at Santa Fe, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission."

NOW, on this 28th day of November, 1966, the Commission, a quorum being present, having considered the testimony presented and the exhibits received at said hearing, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That by Order No. R-2565, dated September 9, 1963, as amended by Order No. R-2565-A, dated September 9, 1963, and Order No. R-2855, dated December 29, 1964, temporary Special Rules and Regulations were promulgated for the Puerto Chiquito-Gallup Oil Pool, Rio Arriba County, New Mexico.

(3) That by Order No. R-3118, dated September 21, 1966, said temporary Special Rules and Regulations were continued in full force and effect until further order of the Commission.

(4) That by Order No. R-2580, dated October 30, 1963, the

Puerto Chiquito-Gallup Oil Pool was redesignated the Puerto Chiquito-Mancos Oil Pool.

(5) That the applicant, Benson-Montin-Greer Drilling Corporation, seeks the abolishment of the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool), Rio Arriba County, New Mexico, the creation of the East Puerto Chiquito-Mancos Oil Pool, and the creation of the West Puerto Chiquito-Mancos Oil Pool, with vertical limits of each to be the Mancos formation and horizontal limits as follows:

EAST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 2 through 5: All
Sections 8 through 10: All
Sections 15 through 17: All
Sections 20 through 22: All
Sections 27 through 29: All
Sections 32 and 33: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10: All
Sections 14 through 18: All
Sections 20 through 23: All
Sections 26 through 29: All
Sections 32 through 35: All

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM
Sections 3 through 10: All
Sections 15 through 22: All
Sections 27 through 30: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: E/2
Section 12: E/2
Section 13: E/2
Section 24: E/2
Section 25: E/2

WEST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 6 and 7: All

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM (CONTINUED)
Sections 18 and 19: All
Sections 30 and 31: All

TOWNSHIP 25 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Section 19: All
Sections 30 and 31: All

TOWNSHIP 26 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: W/2
Sections 2 through 11: All
Section 12: W/2
Section 13: W/2
Sections 14 through 23: All
Section 24: W/2
Section 25: W/2
Sections 26 through 30: All

(6) That the applicant proposes that the East Puerto Chiquito-Mancos Oil Pool be governed by all the previous rules, regulations, and orders of the Commission presently applicable to the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool).

(7) That the applicant also seeks the promulgation of temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool, including a provision for 320-acre spacing units.

(8) That the applicant further seeks the establishment of an administrative procedure whereby the operators in the West Puerto Chiquito-Mancos Oil Pool would be permitted to conduct interference tests and to transfer allowables among producing wells on the same lease or, if in a unitized area, to wells in the same participating area in order to facilitate the gathering of information pertaining to reservoir characteristics.

(9) That the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool) encompasses more than one separate common source of supply and should therefore be abolished.

(10) That each of the proposed pools encompasses a separate common source of supply.

(11) That the East Puerto Chiquito-Mancos Oil Pool and the West Puerto Chiquito-Mancos Oil Pool should be created with horizontal limits as proposed by the applicant and vertical limits comprising the Niobrara member of the Mancos shale.

(12) That the East Puerto Chiquito-Mancos Oil Pool should be governed by all the previous rules, regulations, and orders presently applicable to the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool).

(13) That in order to prevent the economic loss caused by the drilling of unnecessary wells, to avoid the augmentation of risk arising from the drilling of an excessive number of wells, to prevent reduced recovery which might result from the drilling of too few wells, and to otherwise prevent waste and protect correlative rights, temporary Special Rules and Regulations providing for 320-acre spacing units should be promulgated for the West Puerto Chiquito-Mancos Oil Pool.

(14) That the temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool should provide for limited well locations in order to assure orderly development of the pool and protect correlative rights.

(15) That the said temporary Special Rules and Regulations should be established for a three-year period in order to allow the operators in the West Puerto-Chiquito Mancos Oil Pool to gather reservoir information to establish the area that can be efficiently and economically drained and developed by one well.

(16) That an administrative procedure should be established whereby the operators in the West Puerto Chiquito-Mancos Oil Pool would be permitted to conduct interference tests and to transfer allowables among producing wells on the same lease or, if in a unitized area, to wells in the same participating area, during the temporary three-year period in order to facilitate the gathering of information pertaining to reservoir characteristics.

(17) That this case should be reopened in November, 1969, at which time the operators in the West Puerto Chiquito-Mancos Oil Pool should appear and show cause why the said pool should not be developed on 40-acre spacing units.

IT IS THEREFORE ORDERED:

(1) That the Puerto Chiquito-Gallup Oil Pool (redesignated the Puerto Chiquito-Mancos Oil Pool) is hereby abolished.

(2) That a new pool in Rio Arriba County, New Mexico, classified as an oil pool for Mancos production, is hereby created and designated the East Puerto Chiquito-Mancos Oil Pool, with vertical limits comprising the Niobrara member of the Mancos shale, and with horizontal limits as follows:

EAST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM

Sections 2 through 5: All
Sections 8 through 10: All
Sections 15 through 17: All
Sections 20 through 22: All
Sections 27 through 29: All
Sections 32 and 33: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM

Sections 3 through 10: All
Sections 14 through 18: All
Sections 20 through 23: All
Sections 26 through 29: All
Sections 32 through 35: All

TOWNSHIP 27 NORTH, RANGE 1 EAST, NMPM

Sections 3 through 10: All
Sections 15 through 22: All
Sections 27 through 30: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM

Section 1: E/2
Section 12: E/2
Section 13: E/2
Section 24: E/2
Section 25: E/2

(3) That a new pool in Rio Arriba County, New Mexico, classified as an oil pool for Mancos production, is hereby created and designated the West Puerto Chiquito-Mancos Oil Pool, with vertical

limits comprising the Niobrara member of the Mancos shale, and with horizontal limits as follows:

WEST PUERTO CHIQUITO-MANCOS OIL POOL

RIO ARRIBA COUNTY, NEW MEXICO

TOWNSHIP 25 NORTH, RANGE 1 EAST, NMPM
Sections 6 and 7: All
Sections 18 and 19: All
Sections 30 and 31: All

TOWNSHIP 25 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 26 NORTH, RANGE 1 EAST, NMPM
Section 19: All
Sections 30 and 31: All

TOWNSHIP 26 NORTH, RANGE 1 WEST, NMPM
Sections 1 through 36: All

TOWNSHIP 27 NORTH, RANGE 1 WEST, NMPM
Section 1: W/2
Sections 2 through 11: All
Section 12: W/2
Section 13: W/2
Sections 14 through 23: All
Section 24: W/2
Section 25: W/2
Sections 26 through 30: All

(4) That the East Puerto Chiquito-Mancos Oil Pool shall be governed by all the previous rules, regulations, and orders presently applicable to the Puerto Chiquito-Gallup Oil Pool (re-designated the Puerto Chiquito-Mancos Oil Pool).

(5) That temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool are hereby promulgated as follows:

SPECIAL RULES AND REGULATIONS
FOR THE
WEST PUERTO CHIQUITO-MANCOS OIL POOL

RULE 1. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be spaced, drilled, operated, and

produced in accordance with the Special Rules and Regulations hereinafter set forth.

RULE 2. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located on a standard unit consisting of approximately 320 acres which shall comprise any two contiguous quarter sections of a single governmental section, being a legal subdivision (half section) of the United States Public Lands Survey. For purposes of these rules, a unit consisting of between 316 and 324 contiguous surface acres shall be considered a standard unit.

RULE 3. Each well completed or recompleted in the West Puerto Chiquito-Mancos Oil Pool shall be located within 165 feet of the center of a governmental quarter-quarter section.

RULE 4. The Secretary-Director of the Commission may grant an exception to the requirements of Rule 3 without notice and hearing when an application has been filed for an unorthodox location necessitated by topographical conditions or the recompletion of a well previously drilled to another horizon. All operators offsetting the proposed unorthodox location shall be notified of the application by registered or certified mail, and the application shall state that such notice has been furnished. The Secretary-Director may approve the application upon receipt of written waivers from all offset operators or if no offset operator has entered an objection to the unorthodox location within 20 days after the Secretary-Director has received the application.

RULE 5. A standard unit in the West Puerto Chiquito-Mancos Oil Pool (316 through 324 acres) shall be assigned a 320-acre proportional factor of 8.00 for allowable purposes. Any unit containing less than 316 acres or more than 324 acres shall be assigned a proportional factor in the same ratio to 8.00 as the acreage in the unit bears to 320.

IT IS FURTHER ORDERED:

(1) That any well presently drilling to or completed in the Niobrara member of the Mancos shale within the West Puerto Chiquito-Mancos Oil Pool that will not comply with the well location requirements of Rule 3 is hereby granted an exception to the requirements of said rule. The operator shall notify the Aztec District Office

of the Commission in writing of the name and location of the well on or before December 15, 1966.

(2) That any operator desiring to dedicate 320 acres to a well presently drilling to or completed in the West Puerto Chiquito-Mancos Oil Pool shall file a new Form C-102 with the Commission on or before December 15, 1966.

(3) That the Secretary-Director of the Commission is hereby authorized to approve interference tests and the transfer of allowables to wells on the same lease or, if in a unitized area, to wells in the same participating area, provided however, that no transfer well shall be permitted to receive, in addition to its own allowable, more than one top unit allowable for the West Puerto Chiquito-Mancos Oil Pool; that the Secretary-Director of the Commission is hereby authorized to permit the accumulation of allowables for wells shut in for interference tests and to permit the transfer of back allowables from shut-in wells, provided however, that the period of time authorized to produce back allowable shall not exceed six months following completion of the interference tests.

To obtain administrative approval for interference tests and the transfer of allowable, the operator shall submit in triplicate a request for such authority describing in detail the proposed method of conducting such tests and transferring the allowable. The application shall be accompanied by a plat showing thereon all Mancos wells within a radius of two miles of the proposed shut-in well(s) and the transfer well(s). The plat shall also identify each lease or participating area as to ownership or operating rights. The application shall include evidence that all offset operators to the shut-in well(s) and the transfer well(s) have been furnished a complete copy of the application. It shall also be accompanied by Form C-116 for each shut-in well, showing the results of a pre-shut-in test to determine the amount of allowable to be transferred. The transferred allowable shall not exceed the volume of oil produced during the last 24 hours of a 72-hour period during which the well shall be produced at a constant rate. The Commission and offset operators to both the shut-in well(s) and the transfer well(s) may witness such tests if they so desire and shall be notified of the tests at least 48 hours prior to the commencement thereof.

The Secretary-Director of the Commission may grant approval of the interference tests and trasnfer of allowable upon receipt

of waivers from all offset operators or upon expiration of a 20-day waiting period, provided no offset operator has objected to the proposed test and transfer.

(4) That notwithstanding any of the provisions of Rule 104(a) of the Commission Rules and Regulations, the temporary Special Rules and Regulations for the West Puerto Chiquito-Mancos Oil Pool shall not be applicable outside the limits of said pool as hereinabove defined or as hereafter extended.

(5) That this case shall be reopened in November, 1969, at which time the operators in the West Puerto Chiquito-Mancos Oil Pool may appear and show cause why the said pool should not be developed on 40-acre spacing units.

(6) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

Jack M. Campbell

JACK M. CAMPBELL, Chairman

Guyton B. Hays

GUYTON B. HAYS, Member

A. L. Porter, Jr.

A. L. PORTER, Jr., Member & Secretary

ear/

BENSON-MONTIN-GREER DRILLING CORP.

EXHIBITS IN CASE NO. 3455

before the

NEW MEXICO OIL CONSERVATION COMMISSION

December 17, 1969

I N D E X

SECTION A — PLAT OF WEST PUERTO CHIQUITO POOL

SECTION B — SCHEDULES OF BOTTOM HOLE PRESSURE DATA:

1. CAÑADA OJITOS UNIT A-23 OBSERVATION WELL
2. CAÑADA OJITOS UNIT E-10 INITIAL PRESSURE: COMPARISON WITH OBSERVATION WELL
3. CAÑADA OJITOS UNIT A-22 INITIAL PRESSURE: COMPARISON WITH OBSERVATION WELL

SECTION C — CAÑADA OJITOS UNIT L-27 INITIAL PRESSURE DATA:

1. GRAPH SHOWING RATE OF FLUID LEVEL DECLINE FOLLOWING SANDFRAC TREATMENT
2. GRAPH SHOWING ACTUAL FLUID LEVELS FOLLOWING SANDFRAC TREATMENT

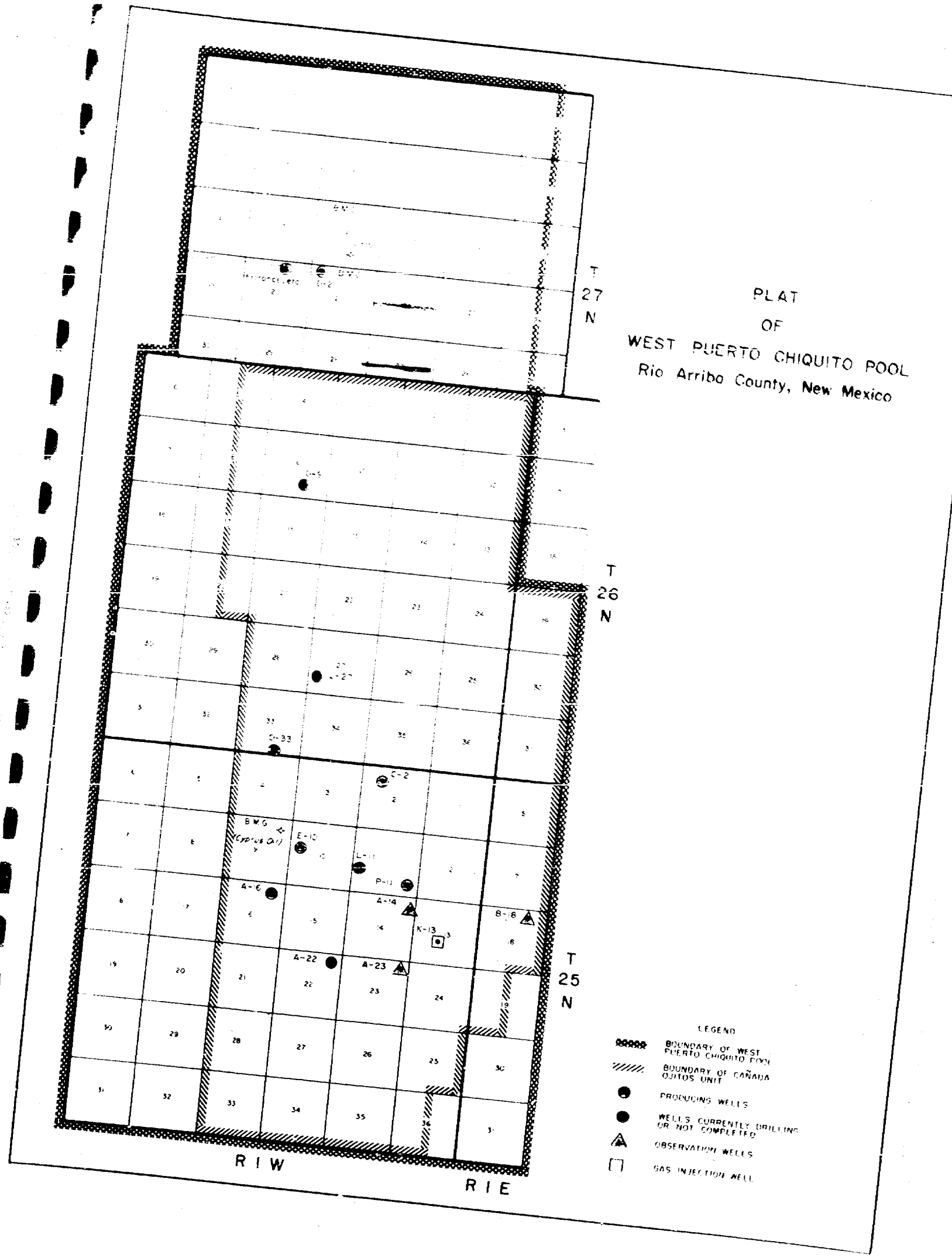
SECTION D — PRODUCTION DATA FOR YEARS 1967, 1968, 1969 FOR CANADA OJITOS UNIT:

1. GRAPH FOR 1967
2. GRAPH FOR 1968
3. GRAPH FOR 1969

SECTION E — GAS-OIL RATIO HISTORY OF CAÑADA OJITOS UNIT L-11:

1. SCHEDULE OF GAS-OIL RATIO DATA
2. GRAPH OF GAS-OIL RATIO DATA

PLAT
OF
WEST PUERTO CHIQUITO POOL
Rio Arriba County, New Mexico



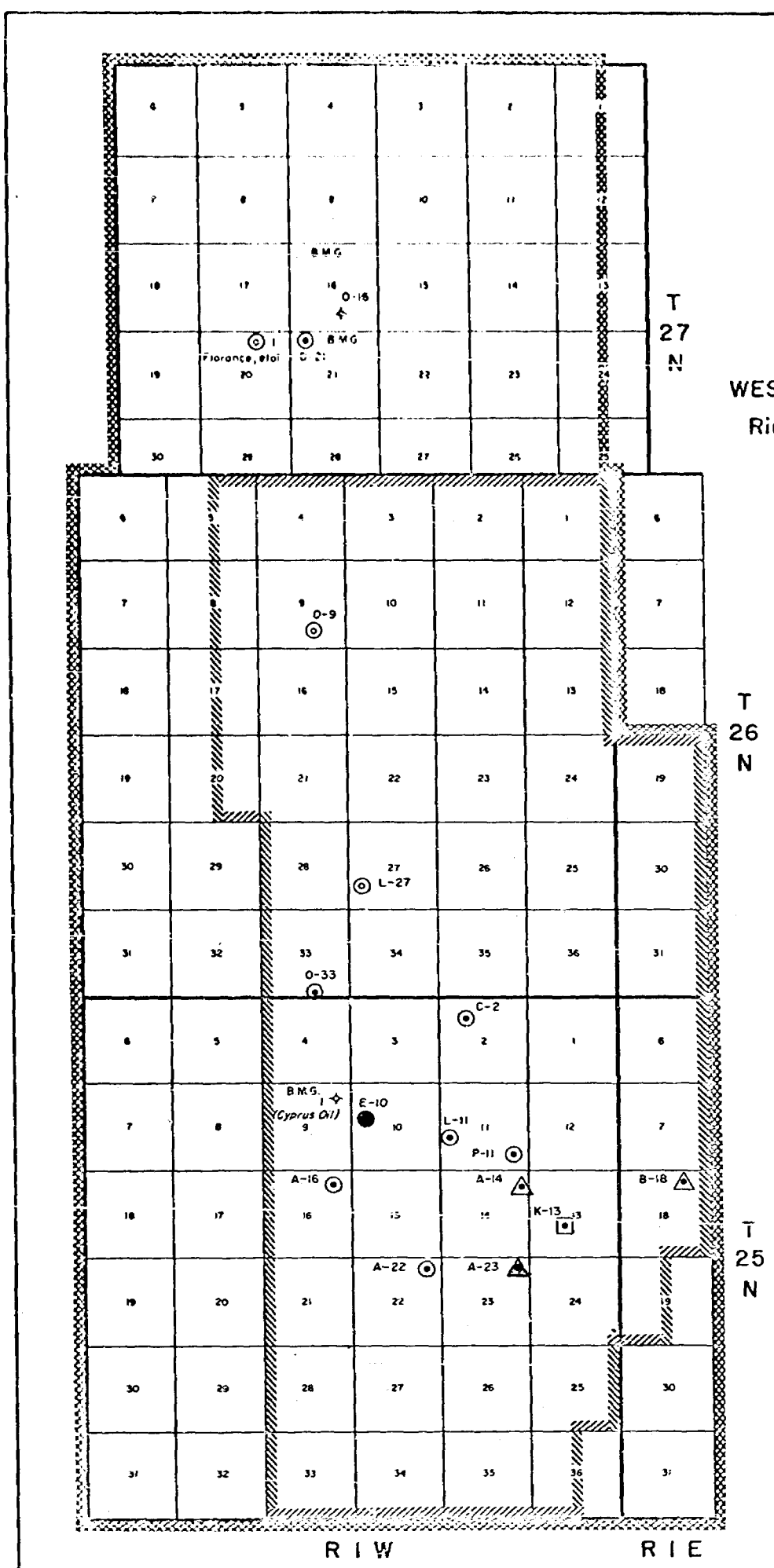
CANADA OJITOS UNIT A-23

BOTTOM HOLE PRESSURE SUMMARY

1967 - 1968 - 1969

SURVEY DATE	PRESSURE (PSIG) AT 6300' RKB FOR PRESSURE GAUGE INDICATED			PRESSURE ADJUSTED TO DATUM OF + 1195'	FLUID LEVEL (FEET FROM SURFACE)	6300' FLUID LEVEL	AVERAGE DENSITY OF OIL COLUMN #/in^2/ft.
	AMERADA #42	AMERADA #43	AVERAGE				
3-28-67	1484.4	1482.8	1483.6	1379.6	1895	4405	.3368
3-20-68	1434.0	1435.5	1434.8	1330.8	2058	4242	.3382
3-27-69	1446.0	1445.1	1445.6	1341.6	1992	4308	.3356
6-18-69	1434.6	1434.3	1434.4	1330.4	2009	4291	.3343
10- 9-69	1429.5	1426.6	1428.0	1324.0	2031	4269	.3345
11- 4-69	1426.9	1428.5	1427.7	1323.7	2017	4283	.3333
12- 1-69	N.G.	1423.7	1423.7	1319.7	2003½	4296	.3314

PLAT
OF
WEST PUERTO CHIQUITO POOL
Rio Arriba County, New Mexico



LEGEND

- BOUNDARY OF WEST PUERTO CHIQUITO POOL
- BOUNDARY OF CAÑADA OJITOS UNIT
- PRODUCING WELLS
- WELLS CURRENTLY DRILLING OR NOT COMPLETED
- OBSERVATION WELLS
- GAS INJECTION WELL

CAÑADA OJITOS UNIT E-10

COMPARISON OF INITIAL BOTTOM HOLE PRESSURE
WITH THAT OF A-23 OBSERVATION WELL

NOTE (1) E-10 treated with sandfrac 7-19-67

Rate of fluid level drop had slowed to ± 2'/day by 8-9-67, when BHP taken

Pressure measured at 6900' 1609 psig

Elevation 7341 RKB
- 6900

+ 441 datum of pressure

Pressure adjusted to datum of + 1195
(1195 - 441)(.312) = - 235# = 1374#

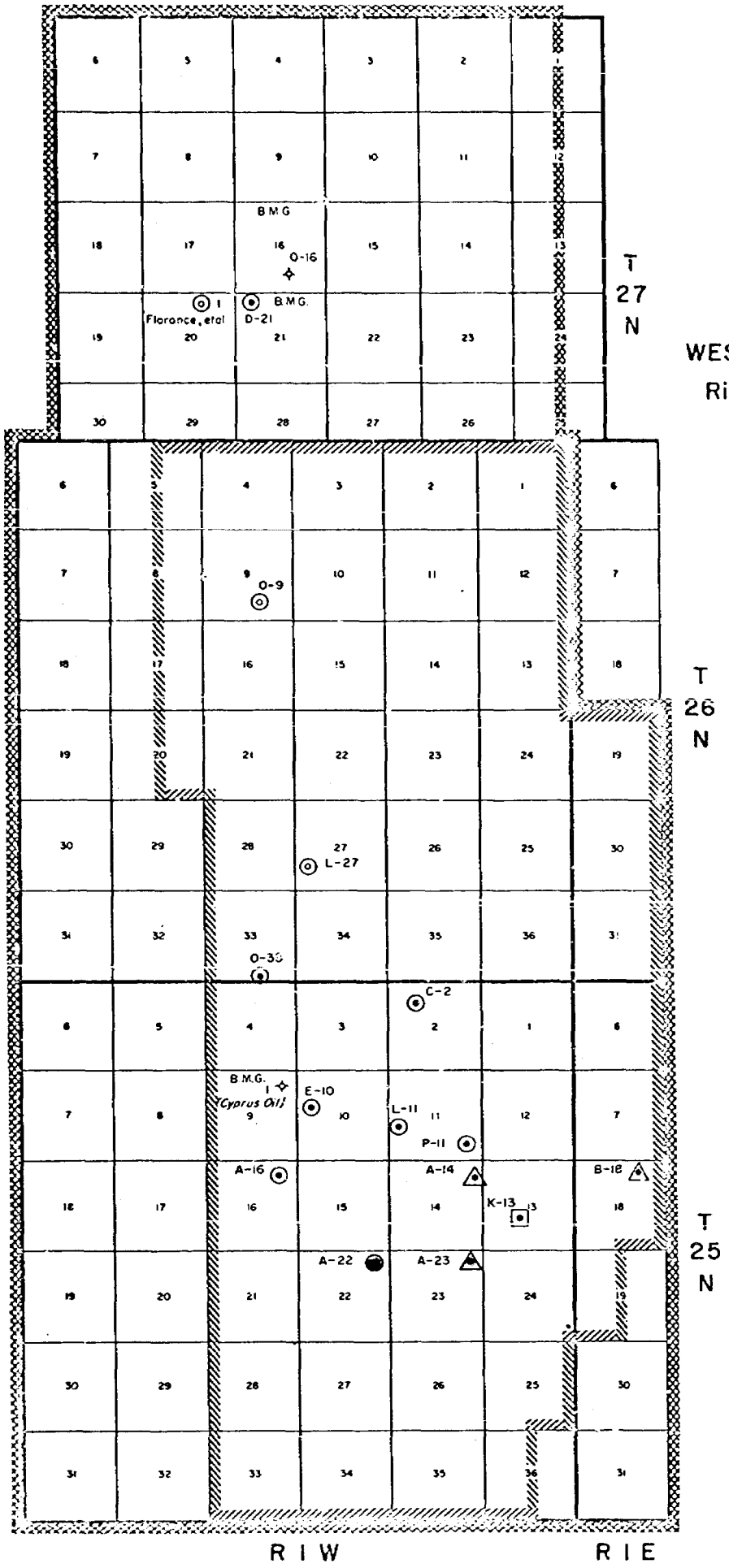
OBSERVATION WELL DATUM PRESSURE
on 3-28-67 1379.6

Estimated datum pressure on
8-9-67 15# less than on 3-28-67 = 1365#

NOTE (2) Reservoir virgin pressure at + 1195 datum 1620#

NOTE (3) Distance between A-23 and E-10
approximately 13,000' (2½ miles)

PLAT
OF
WEST PUERTO CHIQUITO POOL
Rio Arriba County, New Mexico



LEGEND

- BOUNDARY OF WEST PUERTO CHIQUITO POOL
- BOUNDARY OF CAÑADA OJITOS UNIT
- PRODUCING WELLS
- WELLS CURRENTLY DRILLING OR NOT COMPLETED
- OBSERVATION WELLS
- GAS INJECTION WELL

CAÑADA OJITOS UNIT A-22

COMPARISON OF INITIAL BOTTOM HOLE PRESSURE
WITH THAT OF A-23 OBSERVATION WELL

NOTE (1) A-22 treated with sandfrac 9-20-68 and by 10-1-68 fluid level decline had stopped.

NOTE (2) Gas injection started 8-9-68 and by 10-15-68 fluid level in A-23 observation well was approximately 100' higher because of interference effect than if there had been no gas injection.

I. PRESSURE IN A-22 10-15-68 1486.6# at 6750'

Elevation of A-22 7355 RKB
- 6750
+ 605

Pressure adjusted to datum of + 1195'
(1195 - 605)(.312) = - 184 = 1302.6 psig ✓

II. PRESSURE IN A-23 OBSERVATION WELL ON 10-15-68:

Measured pressure 3-20-68 1328# at + 1195

Fluid level 3-20-68 2058½
Fluid level 10-15-68 2055½

Pressure on 10-15-68 + 1328# + 1# = 1329 psig ✓

III. Calculated difference in interference effect of gas injection on A-23 and A-22:

100' - 19' = 81' 81' = ± 27#

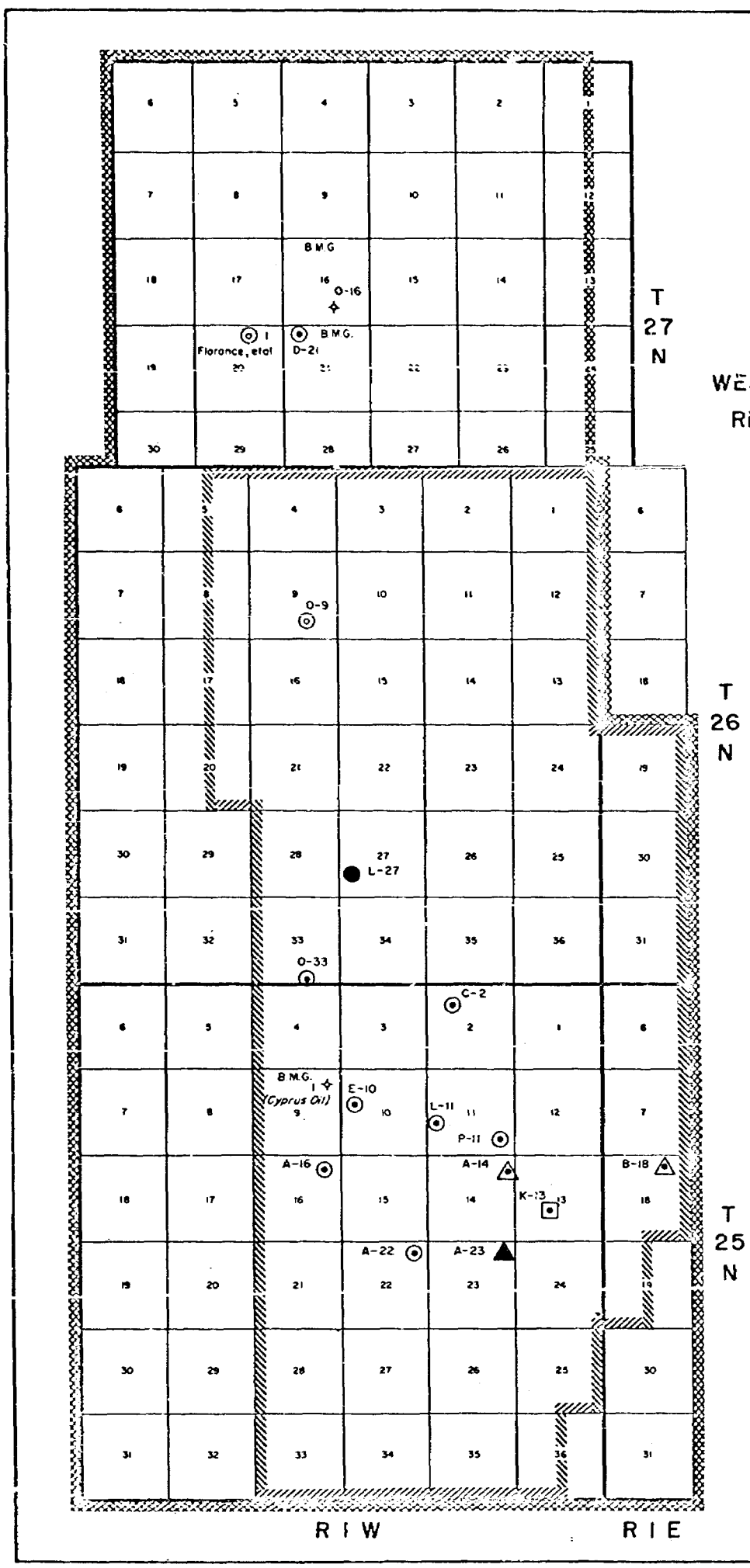
IV. Estimated comparative pressure in A-23 observation well:

1329# - 27# = 1302 psig

NOTE (3) Reservoir virgin pressure at + 1195 datum 1620#

NOTE (4) Distance between A-23 and A-22 approximately 1 mile

PLAT
OF
WEST PUERTO CHIQUITO POOL
Rio Arriba County, New Mexico



LEGEND

- BOUNDARY OF WEST PUERTO CHIQUITO POOL
- BOUNDARY OF CAÑADA OJITOS UNIT
- PRODUCING WELLS
- WELLS CURRENTLY DRILLING OR NOT COMPLETED
- OBSERVATION WELLS
- GAS INJECTION WELL

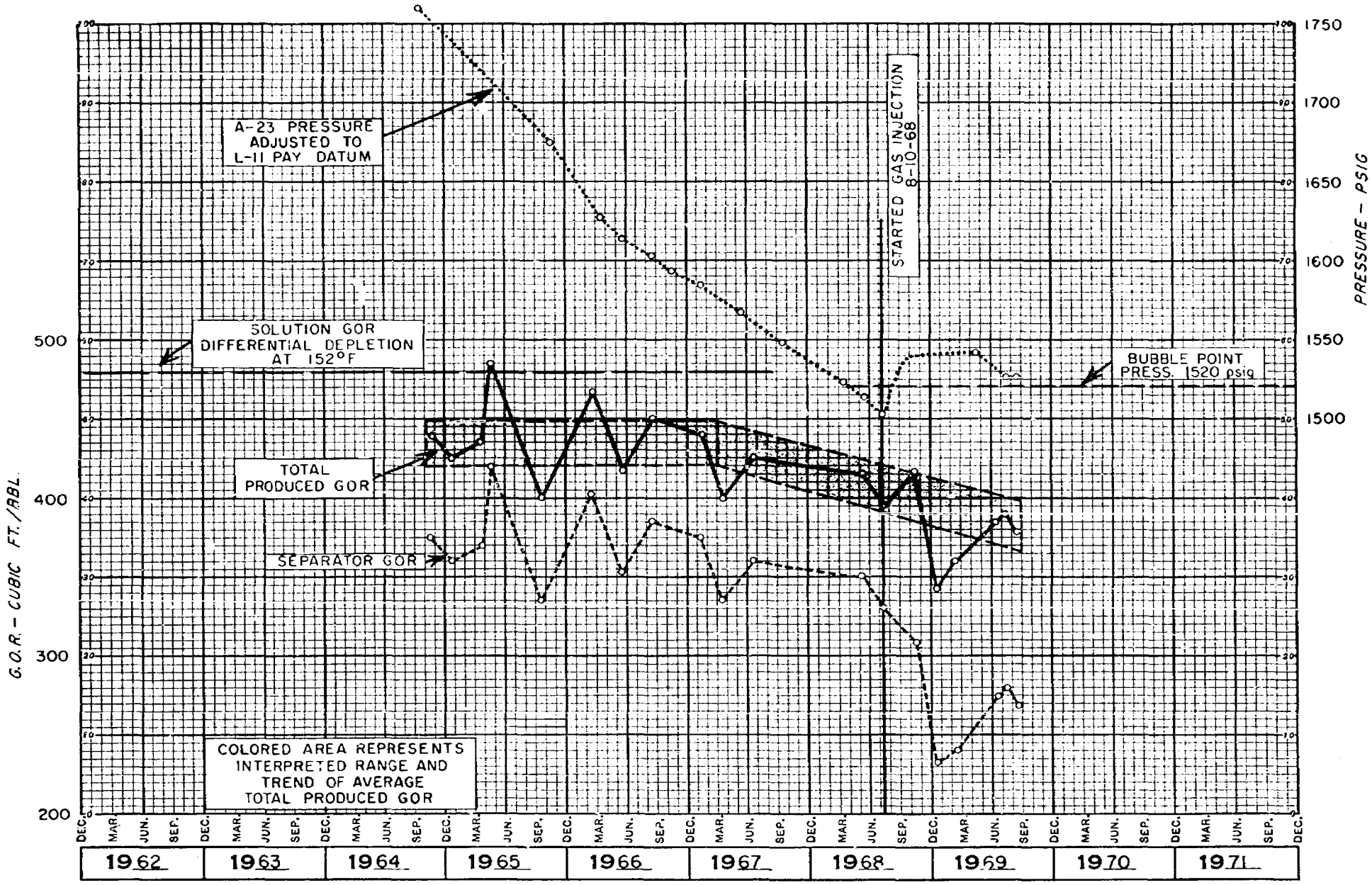
CANADA OJITOS UNIT WELL L-11

SUMMARY OF GAS-OIL RATIO HISTORY

DATE	Type Measuring Equipment	OWT Volume Std. Tables for Gas Gravity of 0.6 MCF/ DAY	Volume adjusted to 0.7 gravity MCF/ DAY	Est. flowing temperature °F	Volume adjustment for temperature MCF/ DAY	Gas used for Heater Engine MCF/ DAY	Gas used for Engine MCF/ DAY	Total Separator volume MCF/ DAY	Oil Production Rate BOPD	Separator GOR CF/ BBL.	Separator Pressure psig	Gas in solution at separator pressure CF/ BBL.	TOTAL GOR CF/ BBL.	REMARKS
11-7/8-64	DWT	161	149	40	152	14	15	181	485	374	40	65	439	
1-13-65	"	150	139	20	144	14	15	173	480	360	"	"	425	
3-13/23-65	"	185	171	30	176	14	15	205	555	370	"	"	435	Avg. of 4 days
4-7/8-65	"	248	239	60	239	14	15	268	555	420	"		485	
10- 4-65	"	171	158	50	160	14	15	159	475	335	"	"	400	
3-20-66	"	178	165	20	172	14	15	201	500	402	"	"	467	
6-17-66	"	155	143	50	145	0	15	160	455	352	"	"	417	Approx. mo. avg.
9-1/10-66	"	160	148	45	150	"	15	175	455	385	"	"	450	"
2-25/28-67	"	136	126	25	130	"	15	145	385	375	"	"	440	
4-18-67	"	156	144	60	144	"	15	159	475	335	"	"	400	Approx. mo. avg.
7-28-67	"	131	121	70	120	"	15	135	375	360	"	"	425	"
6-15-68	"	125	116	60	116	"	15	131	375	350	"	"	415	"

DATE	Type Measuring Equipment	O/E Volume Std. Tables for Gas Gravity of 0.6 MCF/ DAY	Volume adjusted to 0.7 gravity MCF/ DAY	Est. flowing temperature °F	Volume adjustment for temperature MCF/ DAY	Gas used for Heater MCF/ DAY	Gas used for Engine MCF/ DAY	Total Separator Volume MCF/ DAY	Oil Production Rate BOPD	Separator GOR CF/ BBL.	Separator Pressure psig	Gas in solution at separator pressure CF/ BBL.	TOTAL GOR CF/ BBL.	REMARKS
8- 1-68	DWT	119	110	70	109	0	15	124	375	330	40	65	395	
11- 9-68	"	72	67	40	68	"	15	83	270	308	125	110	418	
1-18-69	"	64	59	20	61	"	15	76	328	232	"	110	342	
3-18-69	"	72	67	30	69	"	15	84	349	240	"	110	360	
7-1/8-69	DM	105	97	70	96	"	15	111	390	275	"	110	385	
8-1/5-69	DM	49	45	70	44	"	15	59	210	280	"	110	390	
9-20/25-69	DM	77	71	50	72	"	15	87	325	268	"	110	378	

CAÑADA OJITOS UNIT # L-11
GAS-OIL RATIO HISTORY



OIL RECOVERIES UNDER GRAVITY DRAINAGE DEPLETION AND PRESSURE MAINTENANCE AS DEPENDENT ON PHYSICAL RESERVOIR CHARACTERISTICS AND AS AFFECTED BY WELL SPACING

FRACTURED SHALE RESERVOIRS

NIOBRARA MEMBER OF THE MANCOS SHALE FORMATION

WEST PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

ALBERT R. GREER

DECEMBER, 1969

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PART A - SCHEMATIC COMPARISON OF "CHANNELLING POTENTIAL"

PART B - INJECTION WELL DIFFERENTIAL PRESSURES

REFERENCES

INTRODUCTION

In accordance with the applicant's request in Case No. 3455, November 16, 1966, before the New Mexico Oil Conservation Commission, a three-year temporary spacing order of 320 acres was granted for the West Puerto Chiquito Mancos Pool, Rio Arriba County, New Mexico. In this Case, the witness for the applicant, Benson-Montin-Greer Drilling Corp., stated that a significant increase in ultimate recovery in West Puerto Chiquito might occur if advantage could be taken of the potentially high efficiency of the gravity drainage depletion mechanism, particularly if the reservoir would respond to pressure maintenance by gas injection. Gravity drainage depletion is, of course, a rate sensitive mechanism, and for the general magnitude of the physical properties involved it was apparent that the reservoir's gravity drainage ability could easily be exceeded if a large number of wells were drilled and produced at rates which would return the drilling costs in a reasonable time. Accordingly the witness further stated that a greater ultimate recovery could be anticipated with a spacing density of less than one well to 160 acres than for 160-acre or closer spacing. The purpose of the study presented here is to provide the foundation and evidence regarding potentially greater oil recoveries through wide spacing and operation of the gravity drainage mechanism, along with a discussion of the role of pressure maintenance in the depletion process of this fractured shale reservoir.

GENERAL CONSIDERATIONS

As described in another study (Reference No. 1) determination of oil in place in a fractured shale reservoir cannot be accomplished by the ordinary methods of coring and logging. Under certain conditions, oil in place can be calculated from results of a properly conducted interference test. This has been done for West Puerto Chiquito, and the results recorded at the second spacing hearing (Case No. 3455, November 1966) before the Oil Conservation Commission. To arrive at the amount of oil which may ultimately be produced one must know, of course, in addition to the amount of oil in place, the share of this oil in place that is producible. For a fractured shale reservoir this recovery factor, in itself, is just as difficult to determine as oil in place, and consequently compounds the problem of estimating recoverable oil from a fractured shale reservoir. This study is concerned only with recovery factors, particularly the difference in recoveries as dependent upon the method of exploitation, rather than with determination of oil in place. It is believed that the relative recovery factors determined herein will apply even though the true value of oil in place may be different than that here assumed.

A general range of per acre recoveries was earlier made by analogy with other fields. At the time of the first (1963) spacing hearing, approximate recoveries of 500 barrels per acre were estimated for West Puerto Chiquito by analogy with the Verde Gallup Pool recoveries on the west side of the San Juan Basin, some ninety miles away. By the time of the 1966 hearing a closer pool, Boulder Mancos, only ten or fifteen miles from West Puerto Chiquito, was

essentially depleted and provided a means of more direct comparison. The average recovery in Boulder was approximately 60,000 barrels per well on 80-acre spacing, or approximately 700 barrels per acre. Since this recovery fell well within the previously determined 500 to 1,000 barrels per acre recovery for the Verde Gallup Pool, one might merely rationalize that this simply confirmed the general range of 500 to 1,000 barrels per acre recovery that could be anticipated for the fractured shale reservoirs in the Mancos Formation in the San Juan Basin, and accordingly would be applicable to West Puerto Chiquito.

Analysis of the facts, however, gave rise to concern about recoveries in West Puerto Chiquito, should this pool be produced in the same "uncontrolled" manner as were the older and other non-unitized pools in the San Juan Basin. (The term "uncontrolled" as used in this paper means that wells are produced under competitive methods under the rules of the New Mexico Oil Conservation Commission, whereby high gas-oil ratio wells are merely limited in total reservoir space voided, rather than being shut in, and that no regard is given to maintaining field production rates at the reservoir gravity drainage ability).

The cause for concern about recoveries in West Puerto Chiquito, arising from a review of the Boulder Mancos history, stemmed from a comparison of two of the characteristics of the two fields. One characteristic, transmissibility, appeared to be substantially higher in Boulder than in West Puerto Chiquito. This was evidenced not only by tests reported by Standard of Texas, as measured in some of its wells, but by the fact that some of the wells in Boulder were completed natural for high capacities, one

well even flowing in excess of 4,000 barrels per day, whereas in West Puerto Chiquito all of the wells have required sand fracture treatments in order to produce at commercial rates. A rather high capacity fracture system has been measured in West Puerto Chiquito, but it does not appear to be as high as was the fracture system in Boulder. Not only that, but it appeared possible that in West Puerto Chiquito a substantial part of the reservoir would prove to be made up of rather tight "blocks", and although it is presumed the same occurred in Boulder, it also seemed probable that in West Puerto Chiquito a higher percent of the reservoir was occupied by these tight blocks than in Boulder.

The other physical characteristic was the difference in the oil formation volume factors. These were approximately 1.10 for Boulder and 1.30 for West Puerto Chiquito. This meant a shrinkage of approximately three times as great (30 percent compared to 10 percent) for West Puerto Chiquito as compared with Boulder. Accordingly, for solution gas drive depletion, a substantially lower recovery would be anticipated for West Puerto Chiquito than for Boulder. The shrinkage factor is, of course, partially offset by lower viscosity of the West Puerto Chiquito oil. It is probable, however, that the adverse effects of the high shrinkage factor in West Puerto Chiquito would far outweigh the benefits of lower viscosity under solution gas drive depletion.

Therefore, by analogy with the closest and most comparable field, Boulder, we must conclude not that recoveries in West Puerto Chiquito by solution gas drive can be expected to be 500 to 1,000 barrels per acre, but rather that the recovery must be somewhat less than Boulder's 700 barrels per acre. Depending

upon the relative permeability characteristics of the two reservoirs, along with the unfavorable shrinkage of West Puerto Chiquito, the recovery at West Puerto Chiquito might by analogy be estimated to be considerably less than 500 barrels per acre if production from both pools were from solution gas drive only.

Further study indicates that the situation could be even more serious than this. Because of the high transmissibility of Boulder, part of its recovery must have resulted from gravity drainage, despite the fact that the field was produced in an uncontrolled fashion. It is entirely possible that a very substantial part of the Boulder production was a result of gravity drainage rather than solution gas drive, simply because of its high transmissibility and possibly high percent of the reservoir being occupied by a high capacity fracture system. Here again the relatively high shrinkage factor at West Puerto Chiquito would result in a comparatively rapid decrease in permeability to oil as pressure depletes, and all other factors being the same, West Puerto Chiquito's gravity drainage recovery could be expected to be considerably less than was Boulder's. Under such circumstances, considering both solution gas drive and gravity drainage, recoveries in West Puerto Chiquito could be seriously less than was Boulder's, with recoveries possibly as low as 200 to 300 barrels per acre, if West Puerto Chiquito were to be produced in the same fashion as Boulder.

Fortunately from the standpoint of those economically interested parties (including royalty owners) the commercial part of the West Puerto Chiquito reservoir lies wholly within a unitized area, and it is accordingly possible to exploit the reservoir in

the most efficient manner practicable. It is necessary only to determine what method of exploitation is the most efficient, and if it can be economically accomplished.

To determine this most efficient method of exploitation an attempt was made to better understand the producing mechanisms of the various Niobrara reservoirs in the San Juan Basin and reasons for differences in recoveries. The study was extended to the Gallegos Gallup Pool, where a greater degree of similarity with Boulder and West Puerto Chiquito was found than was anticipated at the outset. Although in Gallegos Gallup the Niobrara exhibited a sand development of sorts, core analyses of some twenty wells showed porosity characteristics more like those of shale than of sand. Three of the four zones showed average porosities of 5 percent or less, with total liquid saturations of 84 percent to 91 percent. This leaves a net effective porosity of .5 percent or less of the bulk volume of the reservoir, and is quite similar to analyses of the Niobrara where it is pure shale. Reported material balance calculations for Gallegos Gallup show that initial oil in place approximated 3,000 barrels per acre. Ultimate primary recovery in Gallegos Gallup approximated 150 barrels per acre, or about 5 percent of the oil in place. Gallegos Gallup exhibited an early high permeability to gas which, when taken with its dissolved gas and shrinkage factors as high as West Puerto Chiquito, was responsible for the low solution gas drive recovery of its primary production phase.

This high Kg/Ko relation is not uncommon for fractured reservoirs. Some have been reported (Reference No. 2) in the technical literature to have early high permeabilities to gas.

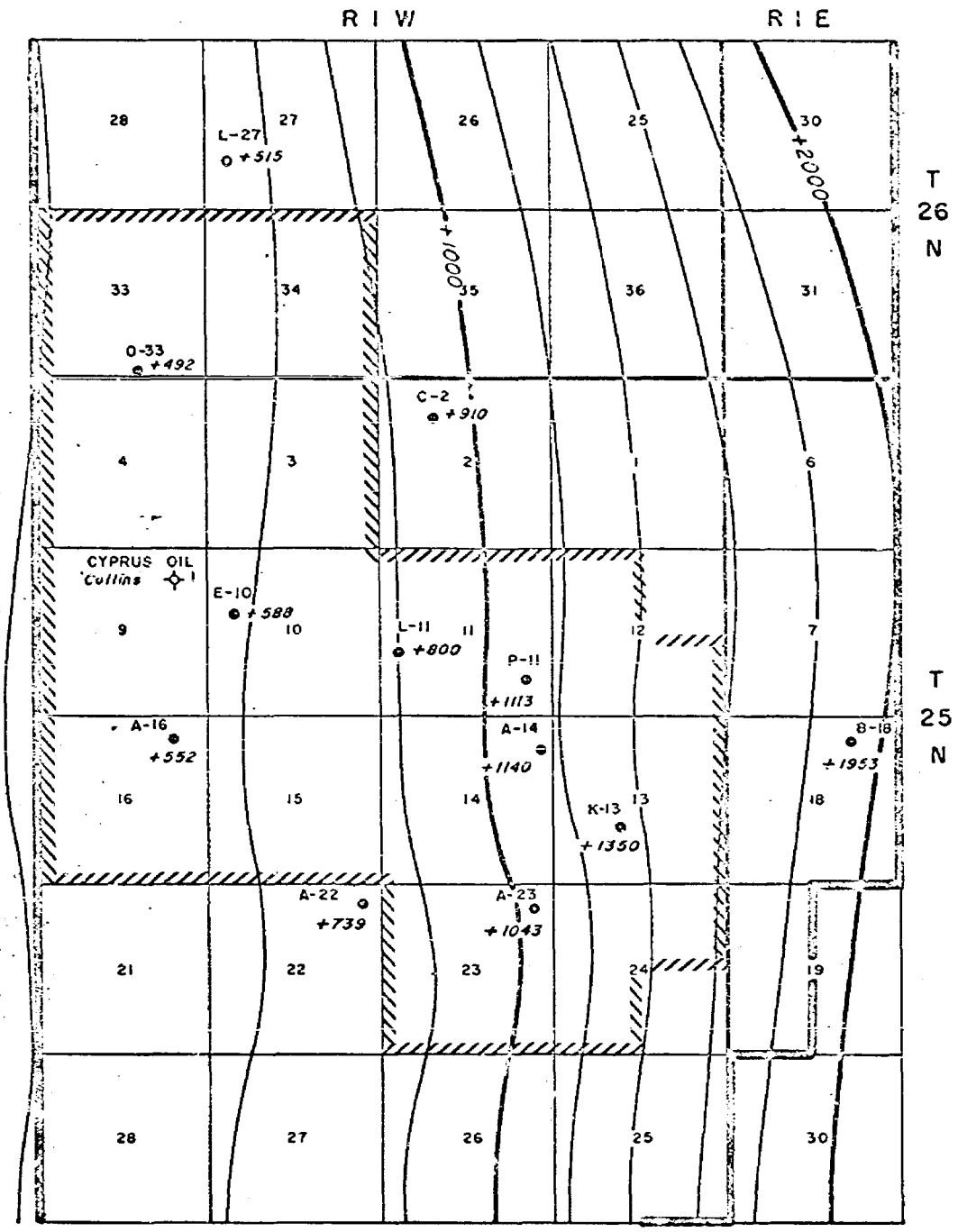
Other fractured reservoirs have apparently had "good" Kg/Ko relationships; however, in such instances it is entirely possible that the net result as calculated from field performance was primarily caused by beneficial effects of gravity drainage rather than a low ratio of the relative permeability characteristic in itself.

Considering all aspects of depletion mechanisms and the remarks above, as one studies the recoveries and physical reservoir characteristics of the various Niobrara Pools in the San Juan Basin the set of conditions which most probably would cause the various recoveries experienced are:

1. A high relative permeability to gas, which when combined with a high shrinkage factor (as for Gallegos Gallup and West Puerto Chiquito) will yield low solution-gas drive recoveries.

2. In comparison of one reservoir with others, there is a varying "mix" of transmissibilities of tight blocks and high capacity fracture systems.

Under such conditions it is to be expected that a wide range of recoveries will result from these fractured reservoirs, even though they may contain, in virgin conditions, an equal pore space, and otherwise appear quite similar. Although the reservoir rock properties are not good for solution-gas drive, they are good for gravity drainage when combined with steep formation dips. Good gravity drainage performance is possible for reservoirs with a high percent of reservoir oil in the high capacity fracture system, steep dips, low shrinkage and low viscosity. A variation of the order of ten to one is possible when comparing the recovery from a steeply dipping reservoir, whose production rate is restricted to the reservoir's gravity drainage ability, to a similar but horizontal reservoir produced strictly by solution gas drive. At least a two to



PLAT OF PART
OF
CAÑADA OJITOS UNIT

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

one variation is to be expected in a steeply dipping reservoir resulting from depletion under different production methods (controlled production with pressure maintenance versus uncontrolled production methods) and a variation of five to one under such conditions is possible.

PART I - SUMMARY OF DEVELOPMENT AND SPACING ORDERS

Most of the development and production in West Puerto Chiquito has been in and near the participating area of the Cañada Ojitos Unit. This study is confined to this area. On the page facing is a structural contour map of the main area of interest. It is a portion of the Cañada Ojitos Unit within the West Puerto Chiquito Pool. The map is contoured on top of an electric log marker, which for the purpose of this paper has been designated Zone A. An electric log section showing this marker is given in Appendix III, Figure III-1.

First production was obtained in this area with the drilling of the K-13 in Section 13, Township 25 North, Range 1 West, in 1962. This well had an initial natural producing ability of approximately 15 barrels per day. First commercial production was obtained from the A-14 in Section 14, also drilled in 1962, with first production in December of 1962. Productions graphs for these wells, along with subsequently drilled wells, are shown at the end of this text.

The first spacing hearing was in the fall of 1963, at which time temporary 160-acre spacing was established. Pursuant to regulations established in the order following the 1963 hearing, extensive interference tests were conducted during the years 1965 and 1966. These tests indicated wells would be capable of draining exceptionally large areas. Accordingly in November of 1966 a temporary spacing of 320 acres per well was requested, and witness for the applicant stated that under wider spacing than 160 acres per well a greater ultimate recovery would result. Also, if the

request for 320-acre spacing were granted, the applicant proposed to institute pressure maintenance by gas injection as an aid to the increased recovery by wider spacing. The application for a 320-acre temporary spacing order was approved by the Commission, to be effective until November, 1969.

Following the Commission's order for 320-acre spacing, plans were made to commence pressure maintenance by gas injection in the subject area. It was planned to inject gas up-dip and produce oil down-dip. To provide adequate down-dip producing ability, two high capacity recovery wells were drilled in the down-dip area near (within one mile of) the initial producing wells, one in 1967 and one in 1968. A gas gathering system from the producing wells was completed and arrangements made for purchase and transmission of make-up gas, along with installation of compression facilities. These arrangements were completed in the summer of 1968 and gas injection was commenced in August of 1968.

At the present time, after a little more than a year of operation, it appears that the reservoir is properly responding to gas injection, and accordingly an increased ultimate recovery as a result of wide spacing and pressure maintenance is anticipated. A third down-dip recovery well is currently (fall of 1969) being drilled some three miles north of the main producing area. Depending upon results of completion of this well, gas injection will probably be extended to the north part of the Cañada Ojitos Unit.

PART II - DESCRIPTION OF RESERVOIR CHARACTERISTICS AND DRAINAGE ABILITY OF WELLS

GENERAL

The subject reservoir rock is a fractured shale. Production is from the Niobrara Member of the Mancos Shale Formation, with wells presently completed in the interval designated Zone C as shown on the electric log section, Appendix III, Figure III-1.

The producing interval is believed to be from 20 to 50 feet thick. As discussed in more detail later in this Part II and in Appendix II, the reservoir comprises fracture blocks of relatively low transmissibility (.01 to 1 darcy feet) and a high capacity fracture system with transmissibilities of perhaps as high as 500 darcy feet. Total overall reservoir transmissibility approximates 2 to 10 darcy feet. Oil in place approximates 1,500 stock tank barrels per acre. Oil characteristics of gas in solution, formation volume factors and gas deviation factors are shown respectively in Figures 1, 2 and 3 following Part IV. These graphs also show characteristics for oil produced from the East Puerto Chiquito and Boulder Pools. Oil viscosity variation with pressure is shown on Figure 4.

SECTION 1 - TRANSMISSIBILITY

Transmissibilities have been measured from data of individual wells and from this information transmissibilities of the "tight" blocks have been determined. Transmissibility data for

larger sections of the reservoir have been determined as a result of concurrent pressure data from two or more wells, including two interference tests. These data give information as to overall reservoir transmissibility, or at least the transmissibilities for large segments of the reservoir.

Details of individual well transmissibilities are described in Appendix I, Part A.

Details of reservoir transmissibilities determined from interference tests and concurrent pressure data from more than one well are described in Appendix I, Part B.

SECTION 2 - MEASUREMENT OF SIZE OF FRACTURE BLOCKS

As indicated earlier, the reservoir comprises individual fracture "blocks" joined by a high capacity fracture system. It is believed the greater part of the bulk volume of the reservoir is formed by these fracture blocks, and that the high capacity connecting fracture system forms a relatively small part of the bulk volume of the reservoir. Accordingly, one may expect on the drilling of a well to penetrate not the fracture system but rather one of the fracture blocks. This is apparently what has happened in West Puerto Chiquito. Only occasionally does a well encounter natural production, and these natural production rates have never been high enough to indicate direct communication with the high capacity fracture system. It is only after sand-fracture treatments that wells capable of producing at high rates have been developed.

In some instances it is possible, from the transmissibility data of individual wells such as those given in Appendix I, Part A, to calculate approximately the size of these small fracture

blocks. The primary method used is that shown in Part VII (Page 37) of Reference 1. Another method, along with its derivation and the details of all the calculations made of sizes of fracture blocks, is given in Appendix II.

These calculations show the tight blocks to contain oil volumes of the order of 10,000 to 50,000 barrels (stock tank oil) each, and individual surface areas are estimated to be of the order of 30 to 70 acres. The test shown in Appendix I, Figure I-5, apparently covers a much greater area and is believed to be not one uniform block but rather a sort of sub-system of the entire reservoir, the average transmissibility of which approximates 1 darcy feet.

SECTION 3 - OIL IN PLACE PER ACRE AND RELATION OF TRANSMISSIBILITY TO PORE SPACE

Two interference tests have been conducted whereby a direct calculation of oil in place per acre has been made. The first was in 1965, and reported at the November, 1966, spacing hearing. The other was the interference test resulting from the commencement of gas injection. Both of these tests are discussed above and in Appendix I with respect to transmissibility. With regard to oil in place per acre and for the two tests respectively, the following additional comments are made:

1. 1965 Interference Test: For a transmissibility of 6.2 darcy feet as assumed at the 1966 hearing and as discussed in Appendix I, the range of values for oil in place as determined from this test is 1,000 to 2,500 barrels per acre. This variation results primarily from the unknown compressibility of the formation

and its effect in the calculation. Another variation could occur if the true average transmissibility of the formation at the time of the test was different from 6.2 darcy feet, as the oil in place per acre will vary directly with this transmissibility. At this time it seems doubtful that true value of the average reservoir transmissibility could be significantly different from this. Accordingly at this time and from this test the same conclusion is reached as expressed at the 1966 spacing hearing, which is that the figures of 1,000 and 2,500 probably represent extremes and the actual average is estimated to be 1,500 to 2,000 barrels per acre. It is believed this test is representative of a large part of the reservoir - an area of the order of 5,000 to 10,000 acres.

2. 1968 Interference Test: As discussed in Appendix I, in which the details of this test are related, because of the low diffusivity constant and the distances involved it is not possible to determine transmissibility from a direct plot of pressures versus log time for the interference well data. It was necessary to assume values of oil in place and transmissibility, and by trial and error determine the values which best fitted the data. Even so, it is believed that this test and resulting calculations have yielded a value of oil in place with an accuracy comparable to, if not greater than, that of the 1965 test. With respect to accuracy, one significant feature of the 1968 test is that with lower compressibility of the oil, the indefinite value of the formation compressibility is much less important. For the 1965 test the variation of this unknown quantity could result in a variation of oil in place of the order of two to one. For the 1968 test the same variation in formation compressibility could cause an error of only 4 or 5 percent.

Because of the low diffusivity constant and proximity of the injection well to the up-dip field boundary, the area of this test is much smaller than that of the 1965 test. It is believed this test represents an area of 2,000 to 3,000 acres.

This test indicates a pore volume of 1,600 stock tank barrels per acre and a transmissibility of 1.8 darcy feet. At the time of the 1968 interference test some of this pore space, of course, was occupied by free gas which had been liberated from the oil. Total pore space, however, in terms of stock tank barrels per acre calculates to be about 1,600. As stated in Appendix I, this is for a part of the reservoir in which the initial transmissibility is estimated to have been from 2.3 to 3.6 darcy feet.

A range of values for oil in place was not calculated for this second interference test. It is believed, however, that the figure of 1,600 barrels per acre would be within 20 percent of the true value.

This compares with the range of estimates of 1,500 to 2,000 barrels per acre reported at the 1966 spacing hearing.

Under the circumstances, and in view of the wide variation of transmissibilities throughout the reservoir, it is remarkable that these two interference tests show such close agreement for value of oil in place per acre. At the time the first interference test was run, it was assumed that it would show only the general magnitude of value of oil in place, i.e., whether it is 200 barrels per acre, 2,000 barrels per acre or 20,000 barrels per acre. Instead, it now appears that this type interference test is an excellent tool with which to estimate rather consistently, and perhaps accurately, value of oil in place per acre.

In order to analyze reservoir performance and to aid in planning a pressure maintenance program for this reservoir, particularly with reference to attempting to recover the maximum practicable amount of oil from the tight blocks, an effort was made to determine the per acre oil in place in these tight blocks and in the high capacity fracture system. In addition, in order to properly analyze pressure maintenance performance once it was commenced, it was necessary to know approximately the percent of oil in place in the high capacity fracture system and in the tight blocks. Accordingly a study was undertaken directed toward this end. The results of this study are recorded in Appendix III.

This appendix shows that from a completely theoretical relation of permeability to pore space for fracture systems, it is possible, for the pay thicknesses of the wells in West Puerto Chiquito, to calculate transmissibilities and pore space values of fracture systems which agree rather closely with those which apparently exist in the fractured shale reservoirs which have been reviewed in connection with this study.

For some of the comparisons made in Appendix III, a value of 6.5 darcy feet and 1,500 barrels per acre of stock tank oil in place were used. Only slight variations in the conclusions reached would result if the true value of oil in place per acre were to vary from the figures used by 20 or 25 percent, which is the range of error now believed to be the maximum variation of true conditions from those calculated by interference tests.

Two significant conclusions can be drawn from a study of Appendix III. These are: (1) for low transmissibilities, of the order of .02 to .03 darcy feet, stock tank barrels per acre of oil

in place are estimated to be of the order of 300 to 400 (between the Y and Z relations of Appendix III, Figure III-5); and (2) a relatively high percent of the total oil in place occurs in the high capacity fracture system, despite the fact that this high capacity fracture system probably constitutes only a small percent of the bulk volume of the reservoir. For example, from Figure III-10 of Appendix III, for only 1 percent of the bulk volume of the reservoir being occupied by the high capacity fracture system, oil in place in this high capacity system will be from 14 to 18 percent of total reservoir oil if the average reservoir transmissibility is 5 to 10 darcy feet. If the high capacity fracture system occupies as much as 10 percent of the bulk volume of the reservoir, then half of the oil in place will be in the high capacity fracture system. For the purposes of analyzing reservoir behavior and forecasting pressure maintenance operations for West Puerto Chiquito, it is accordingly concluded that it is reasonable at this time to assume approximately half of the oil in place occurs in the high capacity fracture system and half in the tight blocks.

SECTION 4 - SOLUTION-GAS DRIVE DRAINAGE ABILITY

Wells in West Puerto Chiquito have demonstrated amazing abilities to drain large areas. The capacity to do this was forecast from the interference test taken in 1965. By 1968, at the start of gas injection operations, the facts were almost unbelievable. For example, at the start of gas injection in August, 1968, one well, the L-11, had produced 470,000 barrels of oil, and was producing at the rate of about 300 barrels per day. The well was capable of producing at higher rates, but its production had been restricted in

order to commence gas injection operations with the minimum possibility of gas channelling. This 470,000 barrels of oil is equivalent to the ultimate production from eight average wells in the Boulder Pool, which in itself is evidence of exceptional drainage. The striking aspect, however, is that after having produced this amount of oil, the reservoir at the datum of this well had suffered a depletion from initial oil in place of only 1.5 percent.

Determination of the depletion of the reservoir at this well's datum results from a rather simple and accurate calculation. Muskat (Reference No. 3) has shown the relation of pressure to depletion for solution gas drive reservoirs if the physical facts of the reservoir are known. In this instance, in which no free gas has been produced, the analysis depends only on the character of the oil as determined from a bottom hole sample analysis. This information is available, and the relation of pressure to percent of oil produced is given in Appendix IV. Pressure in the reservoir was accurately known as a result of data from the observation well, the A-23, which has been in a continual observation status since it was completed.

Accordingly this figure of 1.5 percent can be relied on as being quite accurate for indicating at that time the maximum depletion of the reservoir at this well's datum. This figure cannot, of course, be used to forecast ultimate recovery from the well, but it does clearly show the reservoir's amazing capacity to permit oil migration and to point up the fact that recovery for any given area, structural datum, or reservoir as a whole, will be essentially independent of the number of wells drilled.

This exceptional drainage ability of wells in the West Puerto Chiquito Pool undoubtedly results from the high transmissibility of the high capacity fracture system. It is apparent that this system not only forms a reservoir of excellent drainage qualities, but also forms a system for efficient (to the extent possible under solution gas drive) drainage of the low capacity fracture blocks. Each of the fracture blocks of 30 to 100 acres whose area has been measured (as discussed in Part I) is unquestionably surrounded completely by the high capacity fracture system. Under such circumstances, the large surface area of each block which is exposed to the fracture system will cause the oil within the block to be drained much more effectively than can be accomplished by the drilling of a well inside the block. In fact, it is possible to recover oil into the high capacity fracture system from a block whose transmissibility is too low to allow a well completed in it to produce at commercial rates. It is perfectly clear that wells with good connection to the high capacity fracture system can more efficiently recover (through the high capacity fracture system) the oil from another well's low capacity fracture "block" in which it is completed, than can the well itself. This statement will hold true even though the "recovery" wells are two or three miles away from the subject well whose tract is being drained. Details of analysis showing, for one of these tight blocks, the drainage ability of a well drilled in it as compared to the surrounding fracture system's ability are discussed and examples given in Appendix V.

PART III - GRAVITY DRAINAGE

Gravity drainage has undoubtedly been a contributing factor in the depletion mechanism of many oilfields. Its exact effect, however, is difficult to analyze from field performance. Because of the competitive nature of the exploitation of most oilfields, it is ordinarily impossible to deliberately utilize the gravity drainage depletion mechanism, and its role in oil recovery is usually happenstance in overall field production.

Insofar as analyzing gravity drainage effects for a field such as West Puerto Chiquito is concerned, there is very little in the technical literature of practical value. It has been necessary to develop the useful equations from more fundamental relationships. Since the formulae used have not been reported in the literature, their derivations are shown herein.

For the subject reservoir, no knowledge is available as to effects of capillary forces, and these capillary effects are disregarded throughout the calculations of this paper. The amount of error in the calculations caused by this omission is not known. It is believed, however, that the general results and conclusions reached would not be materially changed from those given herein, had it been possible to include these capillary effects in the calculations.

Gravity drainage equations are usually designed to yield the gravity drainage rate in terms of barrels per day per surface area of exposed gas-oil contact. This relation requires a knowledge of the permeability of the formation as well as the surface area of the gas-oil contact. In the instance of West Puerto Chiquito,

neither permeability nor pay thickness (from which resulting surface area can be determined) is available. Accordingly gravity drainage was studied to ascertain if the information required about it could be determined from other data. Reasonly accurate information has been developed for values of transmissibility and pore space, and the study was particularly directed toward solution of gravity drainage aspects from these data only.

The results of this study showed that to evaluate gravity drainage behavior it is not necessary to know permeability and surface area of the gas-oil contact. As can be seen from the analysis that follows, all of the essential relations can be determined from a knowledge of transmissibility and pore space.

Insofar as West Puerto Chiquito is concerned, the most important facts to be determined are:

1. The gravity drainage rate in terms of barrels per day per unit of distance along the strike of the producing formation, and

2. Rate of movement (horizontally and vertically) of the gas-oil contact "plane".

That these essential facts can be calculated from a knowledge only of transmissibility and pore volume is illustrated by comparison of simplified flow systems such as those given in Appendix VI, Part A.

The gravity drainage rates shown herein are for assumed positions of horizontal gas-oil contact plane. Any such assumed horizontal plane will intersect the producing formation parallel to its strike. Accordingly, in this study of West Puerto Chiquito, the gravity drainage rate is expressed in terms of barrels per day per

linear mile along the strike of the formation.

This gravity drainage rate is given by the relation:

$$Q = 2{,}580 \frac{h\ K\ d \sin \theta}{\mu\ B} \qquad (1)$$

where Q = gravity drainage rate, barrels per day per linear mile of gas-oil contact along the strike

K = permeability to oil, darcys

d = difference in specific gravities of oil and water (air = 1.0)

μ = oil viscosity, cp

B = FVF of oil

θ = angle of dip of formation

Derivation of this equation is given in Appendix VI, Part B.

For the values of oil viscosity and oil and gas density, Equation 1 has been used to calculate, for various transmissibilities, the rate of gravity drainage which can be expected in West Puerto Chiquito for that part of the reservoir in which the dip is 400 feet per mile. This relation of transmissibility to gravity drainage rate in terms of barrels per day per linear mile is shown at the end of Part IV on the graph, Figure No. 5.

As stated by Muskat, if no free gas is present and only an oil phase exists, the gas gravity term can be dropped from the equations, resulting in a higher rate of gravity drainage. For Figure No. 5, rates are shown both with and without a gas phase present. For a gas phase present, a pressure of 1,500 psia has been used to calculate gas density.

Formulae for calculating horizontal and vertical rates of movement of the gas-oil contact "plane" are derived in Appendix VI, Part C. Use of these relations is discussed in the appendix, along with graphs to facilitate calculations and comparison of data observed in West Puerto Chiquito.

From the gravity drainage properties discussed above, along with oil characteristics and relative permeability of the formation, it is possible to calculate gravity drainage recovery under various conditions and to compare this recovery with solution-gas drive recovery. Comparisons have been made assuming a reservoir of uniform transmissibility and a constant dip. For the examples calculated, permeability relationships that were used are shown on Figure 6. The resulting relative permeability relation, Kg/Ko, is shown on Figure 7.

It is not known what the true relative permeability characteristics of this fractured shale formation are, but for purposes of comparison of depletion under various methods it is not necessary to know the exact relationships. The differences in recovery will be somewhat the same for one type of depletion compared to another for any given relative permeability characteristic. We are, of course, interested in making an accurate estimate of ultimate recovery. More important, however, is the <u>difference</u> in recovery of one type of depletion mechanism as opposed to the other, and for this purpose it is not necessary to know exactly the relative permeability characteristics of the formation.

Figure 8 shows the production history of a reservoir with relative permeability characteristics of Figure 6 and West Puerto Chiquito oil, for strictly solution-gas drive recovery,

assuming no additional help from gravity drainage. Figure 9 shows the production history for the same reservoir for strictly gravity drainage depletion, assuming that the dip of the formation is 400 feet per mile and that the production rate is constantly being adjusted downward so as not to exceed the gravity drainage rate at the gas-oil contact. In this calculation it is assumed that oil is produced only from down-dip wells, and that upon reaching a free gas saturation of 1 percent all gas commences to migrate up-dip to form a secondary gas cap, and that the gas saturation increases upward to the gas-oil contact, at which point it is 8 percent. The gravity drainage rate for the reservoir, then, is determined by the viscosity of the oil at the gas-oil contact and the relative permeability to oil at the gas-oil contact for a free gas saturation of 8 percent. The time required to produce the oil under gravity drainage depletion as outlined is shown on Figure No. 10.

Under actual producing conditions one would expect the recovery to be somewhere between the two amounts shown on Figures 8 and 9, and ordinarily this will be the case. This is not always so, however, as field recovery could be somewhat less than the normal solution-gas drive recovery shown if the field is produced under competitive methods and the up-dip wells have adequate capacity to produce high volumes of gas. This is because, in view of the high permeability to gas and its tendency to migrate up-dip, if the up-dip wells are produced under standard rules of the Oil Conservation Commission the up-dip wells can produce gas at a higher rate than the strict solution-gas drive calculations would indicate. Accordingly the pressure may drop faster and the oil viscosity increase more rapidly and ultimate recovery be less than that

indicated on Figure No. 8. This will, of course, be partly offset by the incidental gravity drainage benefits of the down-dip wells, but whether one will balance the other will depend upon the physical reservoir characteristics and well capacities existing for the particular reservoir. The situation is, of course, aggravated by increased numbers of wells.

For the example reservoir produced under conditions in which both the gravity drainage and solution-gas drive mechanisms are operating, the ultimate recovery essentially for any section of the reservoir (section of the reservoir as used here is one linear mile along the strike and four miles down the dip) will be a function of the rate at which oil is produced from that section of the reservoir (assuming no interference from other sections). Accordingly recovery can be plotted against production rate in terms of barrels per day for the linear mile of reservoir section along the strike. This production rate will of course decline as the field nears depletion. For practical purposes, however, this initial production rate is adequate to define the conditions.

Calculations for the example reservoir have been made of ultimate recovery versus production rate in terms of barrels per day per linear mile of strike. This is compared with resulting per well production rates for various assumed spacings. The results are summarized on the graph, Figure No. 11. The shaded area represents, for the per mile production rate shown, the individual well producing rates (and resulting well spacings) which are too low to permit drilling costs to be returned in a reasonable time. This figure shows clearly the detriment to ultimate recovery which would result from development of the pool on well spacings usually

considered "normal" when compared to optimum spacings to achieve gravity drainage benefits.

Concerning the adequate number of wells required to deplete a section of the reservoir, it is of interest to review the effect of increased numbers of wells on the gravity drainage recovery alone. In this connection (and assuming sufficient wells are drilled in the lowermost row of wells on the down-dip side of the reservoir) it is impossible through the drilling of additional wells (even an infinite number of additional wells) to increase the gravity drainage recovery.

For any given part of a reservoir there will be only one gravity drainage rate available, and it can be produced by one row of wells on the down-dip side of the reservoir. If intervening rows of wells are drilled and produced at additional rates, these new wells will succeed only in increasing the total production from the reservoir; and having exceeded the reservoir gravity drainage rate, the production will take on the characteristics of the less efficient solution-gas drive.

Not only will the up-dip rows of wells fail to increase the gravity drainage recovery of the reservoir, but they will serve to decrease the reservoir's ultimate recovery to the extent the gravity rate is exceeded and the less efficient solution-gas drive becomes operative.

Moreover, the up-dip rows of wells cannot expect to share even a part of the gravity drainage recovery. They are committed only to solution-gas drive recoveries. This statement can best be understood by visualizing an intermediate row of wells along the strike and assuming this row of wells has a drainage area which

extends halfway up-dip to the next row of wells and halfway down-dip to the next lower row of wells. All other conditions being the same, one can presume that at any given time in the history of the reservoir, the pressure at the up-dip boundary of the drainage area of the subject row of wells will be less than the pressure at the down-dip boundary of the same drainage area. As a result, at any time, and at all times, the oil viscosity on the up-dip boundary will be more than the viscosity on the down-dip boundary and free gas saturation will be greater at the up-dip boundary than at the down-dip boundary, causing the permeability to oil to be less at the up-dip boundary than at the down-dip boundary. Accordingly, as far as gravity drainage is concerned, at any time there will be more oil moving away from the drainage area of an intermediate row of wells than is moving in to it.

From this reasoning it is obvious that if the lowermost row of wells produces at the reservoir's gravity drainage rate, or higher, this row of wells is the only one that can benefit substantially from gravity drainage. All the others will have minimum benefit from this source. Their recoveries must be nearly all from the solution-gas drive mechanism. Any attempt to capture the gravity drainage potential by drilling of additional up-dip wells can result only in a reversal of pressure gradients and an increased solution-gas drive recovery of oil in the up-dip area. It is, of course, possible, by the drilling of additional up-dip wells, to deny the down-dip wells part of the gravity drainage recovery, but in so doing the up-dip area will be produced at so high a rate that there will be virtually no gravity drainage recovery from it. The end result, then, of drilling additional up-dip wells

is to reduce overall reservoir gravity drainage and consequently, ultimate recovery.

Conversely, the drilling of additional down-dip wells cannot increase the reservoir's gravity drainage rate, and minimum benefit can be expected from the drilling of more down-dip wells than are required to produce the reservoir's gravity drainage potential. Some benefit can, of course, result from such additional wells if, by reducing the per well producing rates, their presence causes the wells' pressure "drawdown" differentials to be lowered to points that prevent serious channelling that otherwise would occur. The subject of optimum number of down-dip wells is discussed in Appendix VI, Part D.

PART IV - PRESSURE MAINTENANCE IN FRACTURED RESERVOIRS

SECTION 1 - INCREASED RECOVERY BY DEPLETION AT HIGH PRESSURE

In depletion of a reservoir by gravity drainage or by waterflooding, greater recoveries can be expected (from those parts of the reservoir in which gravity drainage or waterflooding is the responsible recovery mechanism) by operating the project at higher pressures. Optimum pressure is the bubble point. No increased recovery can be expected by operating at pressures higher than the bubble point, although it may be desirable for other reasons (i.e., production by flowing, or gas lift, as opposed to pumping).

This increased recovery at higher pressure, for all other things being the same, is caused primarily by the benefits of no shrinkage of the oil (FVF remains high) and the lower viscosity of the oil.

The combined effects of these properties, along with the other influencing factors, are shown later herein with numerical examples. It is interesting, however, to examine at this time the effect of shrinkage alone in comparing recovery at high versus low pressure. As it affects different reservoirs, of course, the higher the shrinkage factor the greater will be the benefit of depletion at high pressure. For West Puerto Chiquito, with its shrinkage of approximately 30 percent, the benefit of depletion at high pressure is significant.

The fractional recovery of oil from a reservoir in

depletion from one pressure to another can be expressed as the difference in oil in place at the first pressure and that remaining in place at the second pressure (Reference 3):

$$\text{Fractional Recovery} = \left(\frac{So}{B}\right)_1 - \left(\frac{So}{B}\right)_2 \qquad (2)$$

where So = Oil saturation, fraction of pore space

B = FVF

and subscripts 1 and 2 refer to Conditions 1 and 2.

With this relation we can compare recoveries at various pressures. One comparison is made (Figure 12) assuming the low pressure recovery is for 50 pounds and the high pressure recovery is for 1,500 pounds.

The variations in recovery are for various final oil saturations, but the saturation is assumed to be the same for the specific high and low pressure depletion. No information is available for determining exactly final oil saturation, so Figure 12 is prepared for a wide range, and it can be seen that increased recoveries by operation at high pressure for any given final oil saturation are significant.

SECTION 2 - "SWEEP" EFFICIENCIES OF GAS AND WATER AND CHANNELLING TENDENCIES

In view of the extremely great differences in transmissibilities throughout the reservoir, as mentioned earlier and as discussed particularly in Appendix III, it is believed that the type of "flood" project in which either water or gas is used to "sweep" the oil from the formation would have very little chance of success in a fractured shale reservoir. Even in reservoirs of

relatively uniform permeabilities, experience has shown that once gas breaks through there is a rapid increase in gas-oil ratios, and the gas is merely "cycled" with very little sweep effect and very little additional recovery resulting from the gas injection. This is particularly true of a reservoir at or near depletion, in which the free gas saturation is relatively high at the commencement of injection. Water, on the other hand, having a viscosity more nearly the same as oil, has a much greater sweep efficiency, and can be expected in most instances to have a far greater benefit with substantially greater ultimate recoveries than with gas. Once free gas saturation has resulted in a high capacity fracture in a fractured shale reservoir, one can be assured that gas will channel, and channel at extremely high rates, much higher in fact than has been experienced in other reservoirs.

Because of the situation as described above, most operators are fearful of attempting gas injection in a fractured shale reservoir, although some have tried waterflooding. Reports available on waterflood projects are quite discouraging, and the writer knows of no other gas injection projects attempted in fractured shale reservoirs.

Despite the reluctance of operators to attempt gas injection in fractured shale, and the fact that in waterflood projects the water has channelled seriously, and that usually one expects gas to channel even worse than water, there are certain theoretical aspects of pressure maintenance by gas injection in a fractured reservoir which indicate that if the project is properly carried on there is no reason why it should not be successful, and every reason to believe a substantial increase in ultimate recovery will result.

It is considered axiomatic that excessive channelling would result in a fractured shale reservoir if gas injection were not commenced until the reservoir was partially depleted and gas saturations were high. In other words, secondary recovery by gas injection is considered completely hopeless. The discussion here is confined entirely to pressure maintenance commenced early in the life of the reservoir when gas saturations are low.

Upon investigation we find that the very quality (low viscosity) of gas which causes it to channel at high rates once the reservoir, or part of it, reaches "critical" gas saturation, is a quality which will operate in the first instance to avoid channelling. When compared with water it is strikingly superior. It is of interest to examine the circumstances which cause channelling and to compare gas and water from a standpoint of their "channelling potential", when used as an injecting fluid for pressure maintenance. A pressure maintenance project cannot, of course, be successful if serious channelling occurs. To prevent serious channelling one must, of course, understand how and why it can occur, and operate the pressure maintenance project in line with measures which will prevent its occurrence.

It is helpful in this analysis to place numerical values on this characteristic and for the purpose of this study the term "channelling potential" is coined and defined as follows:

(a) For an injection well it is the differential pressure (in pounds per square inch) required to inject its fluid divided by the difference in density (in pounds per square inch per foot of depth) of the injecting fluid and the reservoir oil.

(b) For a producing well it is the differential (drawdown) pressure (in pounds per square inch) divided by the density of the reservoir oil (in pounds per square inch per foot of depth).

The result in each instance is in terms of vertical feet. It is assumed that the gas will be injected on the up-dip side of a reservoir, and the channelling potential is therefore measured down-dip from the injection well. It is assumed that water would be injected on the down-dip side of a reservoir, and consequently the channelling potential for a water injection well will be measured vertically up-dip from it.

If there is one injection well and one producing well, the channelling potential will be the sum of the individual channelling potentials.

If, for example, there are two wells in the reservoir, one an injection well up-dip and the other a producing well down-dip, and the vertical separation of the two wells is 1,000 feet, then at commencement of gas injection there can be absolutely no channelling from the injection well to the producing well if the sum of the channelling potentials of the two wells is less than 1,000 feet.

If there are more than one injection well (located at the same datum) and more than one producing well (producing wells at one datum) the maximum channelling potential will be the sum of the channelling potentials for the injection well with the greatest channelling potential and the producing well with the greatest channelling potential.

For multiple well systems, where the wells are completed at different structural datums, it becomes necessary (as to each well) to reduce the channelling potential to a structural datum. This is accomplished by adding (or subtracting as the case may be) the channelling potential of a well to its structural datum. Comparison then of the datums of the channelling potentials so calculated will reveal if channelling could occur.

In actual practice, of course, if there is any communication at all throughout the reservoir other than in the channel, then injection pressure will tend to equalize the reservoir pressure with the pressure in the channel, so that the actual channelling tendency will be far less than the "potential". The channelling potential, calculated as described above, determines the absolute maximum value. One can be assured that it will be somewhat less than this, depending upon the equalization of pressure throughout the reservoir.

The differential pressure to use in calculating channelling potential is not necessarily the difference in the well's operating pressure at the pay zone and the reservoir static pressure at that datum. If there is a substantial distance between the injection well and the producing well (by "substantial" is meant a relatively large part of the reservoir will exist outside the separate local fracture blocks in which the injection and producing wells are completed) the differential pressure to be used in determining channelling potential is the pressure drawdown from static in the high capacity fracture system at the point nearest the well where the high capacity fracture system and the well's low capacity fracture "block" join.

As the gas-oil contact moves down-dip it forms the datum from which the injection well's channelling potential is to be subtracted in arriving at the datum of the injection well's channelling potential. In this instance the injection well's differential pressure to be used in calculating channelling potential is the differential pressure above static caused by the injection well at the gas-oil contact.

As indicated above, for multiple well systems the channelling potential is not cumulative. Channelling cannot occur if vertical separation exists between the highest datum of the producing well's channelling potential and the lowest datum of the injection well's channelling potential (for pressure maintenance by gas injection).

Actually, of course, additional wells can serve to reduce the channelling potential if the total injection and withdrawal rates are maintained the same (by distributing the fluid requirements and lowering the per well rates). The numbers of injection and producing wells required to avoid channelling will depend, of course, upon the particular physical reservoir characteristics, and no general statement can be made as to number of wells required to reduce the channelling potential to a practicable level. Dip of the formation obviously is important here. Where producing rates are held at or near the gravity drainage rate, ordinarily the producing wells' differential (drawdown) pressures will be quite low, and relatively few wells are required to keep the channelling potential within reasonable limits if a dip of several hundred feet per mile exists in the vicinity of the recovery wells.

If reservoir production rates are maintained within the gravity drainage rate, then the gas-oil contact will drop within the reservoir much as the oil level in an open tank. No free gas will evolve, and there will be a continuous solid column of oil from the gas-oil contact to the producing wells. Accordingly, under these conditions the channelling potential for the gas injection and oil producing wells can be simply and accurately described by comparison with pipes in an open tank. Such a comparison is discussed in Appendix VII, Part A.

Once the conclusion is reached that it is impractical to attempt to sweep oil through a fractured reservoir, either with water or gas, but that an effort will be made to achieve the potentially greater recoveries by operating the reservoir at high pressures (as discussed in Section 1 above) then two choices of pressure maintenance operation remain to be considered: (1) gravity drainage down-dip under gas, and (2) "gravity drainage" up-dip over water. There is probably very little difference in overall efficiency of displacement of oil by these two methods, if in each instance production rates are maintained at or below the respective "gravity drainage" rates. There is, however, a striking difference in the practical aspects of the two operations, particularly with regard to the number of injection wells required.

It is here that we find the low viscosity of the gas to be extremely beneficial. Although other factors are also involved (as more particularly described in Appendix VII, Part B) one may estimate approximately the ratio of injection pressure differentials of a water injection well to a gas injection well from the ratios of their viscosities, which for the reservoir

temperatures of West Puerto Chiquito is in the range of 25 to 30. Accordingly for the same reservoir space displaced, operating differential pressures for a gas injection well can be expected to be about 1/25th that of a water injection well.

A comparison of overall channelling tendency requires, in addition to the pressure differential as discussed above, a consideration of density differences of the injecting fluid and reservoir oil. The difference in density of oil and gas is nearly twice as great as the difference in density of oil and water. Since the channelling potential as defined earlier for an injection well results from its pressure differential divided by the difference in density of the two fluids, we find that the channelling potential for the same injection pressure differential is twice as great for a water injection well as for a gas injection well. When we combine this factor with the producing differential relation described above, we find that a gas injection well can maintain reservoir pressure with about 1/50th of the injection pressure differential required by a water injection well. Expressed in another manner, it will take 50 water injection wells to inject the same volume of reservoir space as one gas injection well and maintain the channelling potential of the water injection project to the same point as the channelling potential of the gas injection project.

So, although in most pressure maintenance projects water is selected over gas because of its sweep efficiency and less channelling tendency, we find for our purposes in this fractured shale reservoir that gas is far superior from a standpoint of avoidance of channelling in the first instance. Also, under the

gravity drainage concept of depletion, we are not interested in sweep efficiency of the displacing fluid as such. All we expect from the injecting fluid is to maintain pressure. The rest of the depletion mechanism takes place naturally. With the above considerations in mind, for the pressure maintenance project in the Cañada Ojitos Unit in West Puerto Chiquito gas was selected as the injecting fluid.

SECTION 3 - OIL RECOVERY FROM THE LOW CAPACITY FRACTURE BLOCKS

A study of pressure maintenance for this fractured shale reservoir is not complete without consideration being given to the possibilities of gravity drainage depletion under pressure maintenance of the low capacity fracture blocks.

Under normal solution-gas drive depletion, as discussed in Part III, some gravity drainage benefits can be expected from the high capacity fracture system. It is doubtful, however, that under such conditions there will be significant gravity drainage oil recovery from the tight blocks. Pressures can be expected to be equalized all around the individual fracture blocks, and the density of the oil in the high capacity fracture system surrounding the blocks will be approximately the same as the density of the oil within the tight blocks. Consequently there will be no pressure differential between a tight block and its adjoining fracture system due to density differences within and outside the fracture block. Moreover, any gravity drainage of oil out of the down-dip side of a tight block will more than likely be offset at least partially by gravity drainage into the block on its up-dip side.

Under pressure maintenance, however, an interesting possibility exists whereby a substantial amount of gravity drainage may be anticipated from the tight blocks. In the first stages of pressure maintenance, since there will be no expansion of oil due to declining pressures (pressures will be maintained constant at any one point in the reservoir) oil will drain down-dip in the high capacity fracture system and leave above it a gas cap or channels of gas surrounding the up-dip fracture blocks. Just as described above for solution-gas drive depletion, at times when a fracture block is surrounded by oil, any gravity drainage out of the down-dip side of the fracture block will probably be offset by gravity drainage into the block on the up-dip side. Once, however, the block is entirely surrounded by gas, there will be no gravity drainage into the up-dip side of the block, and the oil which gravitates out of the down-dip side will likely find its way into the high capacity channels and continue its down-dip path to producing wells.

It is possible to calculate approximately the time required to deplete one of these fracture blocks by gravity drainage from its transmissibility and length of its down-dip dimension, if the dip of the formation is known. This is discussed in detail in Appendix VI, Part C. The rate of down-dip movement of the gas-oil contact plane as dependent on transmissibility is shown on the graph, Figure 13, in terms of feet per day. From this velocity and knowledge of the length of the down-dip dimension of a tight block, one can determine the time required to deplete it by gravity drainage.

From this figure it can be seen, for example, that for

a low capacity fracture block with a transmissibility of only .03 darcy feet, a horizontal movement of oil under gravity drainage would be .20 feet per day. This means for a fracture block with a down-dip dimension of 1,500 feet, its contained oil could be depleted by gravity drainage in about 20 years. This is not an untenably long period of time to deplete a reservoir if the producing wells can be maintained at reasonably high rates of production.

With regard to rates of production available from these tight blocks, it is interesting to note that a fractured reservoir offers far greater potential for gravity drainage of "tight" areas than a reservoir with "uniform" properties. The reason is that the gravity drainage rates from individual fracture blocks can be cumulative. As distinct from the rows of wells which were discussed in Part III, gravity drainage production from fracture blocks surrounded by gas will be additive, such that the production rate available for the down-dip wells can be expected to be the sum of the rates from the individual fracture blocks exposed. As can be seen from Figure 5, if the average transmissibility of the tight blocks is .1 darcy feet, their average gravity drainage rates would be 15 barrels per day per linear mile. If there are three fracture blocks per mile and three miles of fracture blocks exposed down-dip, the sum would be 135 barrels per day in gravity drainage from these tight blocks. If there is to be supported the operating cost of only one producing well per linear mile in the down-dip recovery area, it is apparent that the project can be economically continued until the blocks are substantially depleted by gravity drainage.

In view of the above remarks, it is to be anticipated that the fall of the gas-oil interface in the high capacity fracture system will initially be at a rather high rate, but that as it drops down-dip and exposes additional fracture blocks, the gravity drainage volumes will be increased by the amounts available from the exposed fracture blocks, so that the rate of fall of this interface should continually decrease (for the same reservoir withdrawal rate). In West Puerto Chiquito the operator of the Cañada Ojitos Unit proposes to make periodic determinations of the rate of fall of the gas-oil contact to determine if this in fact does occur. The rate of the fall of the gas-oil interface in the high capacity fracture system will be determined by adjusting injection volumes and production rates so that steady state conditions obtain, and then determining the rate of fall of the gas-oil interface by the increase in pressure in the gas cap. (It is apparent that if the oil zone pressures remain constant as oil is produced and the gas-oil interface drops down-dip, the pressure in the gas cap will necessarily increase). The rate of increase of pressure in the gas cap will afford a measurement on the rate of fall of the gas-oil interface. For any given pressure increase, the vertical fall of the gas-oil interface can be determined by dividing this pressure rise, in pounds per square inch, by the difference in density of the gas and the oil in terms of pounds per square inch per foot.

The volumes of injected gas required to maintain the reservoir pressure constant in the oil zone for given rates of production for West Puerto Chiquito are shown on the graph at the end of this Part IV, Figure 14. That the injected gas volumes are displacing almost exactly the reservoir space voided by the oil is

evident from the stabilization of pressure in the oil zone, as shown by operating pressures of the wells, and the pressure in the observation well, the A-23.

SECTION 4 - NOTE REGARDING RELATIVE PERMEABILITY EFFECTS

Consideration of relative permeability effects under pressure maintenance requires first a general consideration of relative permeability as we know it, without regard to pressure maintenance. Here, of course, with the paucity of information available as to relative permeability characteristics of fractured formations, there are many unanswered questions, and to solve our problems it is necessary to make assumptions based on judgment of such facts as are available.

One of the puzzles, of course, is the true relationship of permeability tc oil at different liquid saturations. It would appear from the high ratios of relative permeabilities at high liquid saturation, as indicated by laboratory tests, that there must be practically no permeability to oil at liquid saturations as high as 85 to 90 percent. There is some question, however, that the horizontal permeability to oil would be the same as the vertical permeability to oil. One can visualize a rather wide fracture with oil draining by gravity down each side and an opening in the middle through which gas would flow without "sweeping" the oil along horizontally, even though oil is draining vertically down-dip. Accordingly, if one assumes the relative permeability ratio shown on Figure IV-2 and the permeability to oil shown on Figure V-1, the resulting permeability to gas has the odd relationship shown on Figure 6. For the reason just mentioned, the relations of Figure 6

cannot be entirely discounted, as this may very well present the different situations where horizontal permeability to oil may be different from vertical permeability to oil, and where drainage is an important contributing factor to the producing mechanism. It would perhaps appear more reasonable to show the relative permeability to oil to decline more rapidly than is shown on Figure 6. However, for the purposes of this paper, particularly with regard to the matter of Appendix V, it was believed desirable to show calculations which include a favorable relative permeability to oil.

With such a relative permeability to oil as shown on Figure 6, one might assume that higher gravity drainage recoveries might exist following an initial depletion cycle under solution-gas drive than is shown on Figure 11, under the assumption that once the gas has been evolved, dissipated and produced, the remaining oil would simply drain down-dip by gravity. Whether such a cycle can happen, of course, depends primarily on shrinkage factor of the oil, as for instance in Boulder with its low shrinkage such a process probably did occur to a certain extent. In West Puerto Chiquito, with its higher shrinkage factor, however, this is less likely.

Also, as pointed out in Appendix IV, actual gravity drainage benefits cannot be realized as long as the bulk volume of the oil in the reservoir is "expanding" as a result of gas breaking out of solution. Until these gas bubbles have worked their way to the top of the structure or to the gas cap, true benefits from gravity drainage cannot be realized. Any oil which tends to move down-dip at the gas-oil contact (top of the structure) is very

effectively moved back up-dip by the expanding gas bubbles. This situation, of course, has no particular influence in a reservoir in which the bubbles can rapidly migrate vertically up-dip and where a relatively large volume of oil per acre exists. In West Puerto Chiquito, where the bubbles have actual horizontal distances to move of three to four miles up a relatively gentle slope, this does become a significant factor. It is particularly important when involved, as it is in West Puerto Chiquito, with a relatively small volume of oil in place per acre. Under these conditions, and under relatively close spacing (less than 320 acres per well) and normal production rates, the depletion process will evidently follow the solution gas drive mechanism almost completely until such time as extremely high permeability to gas exists and the gas can move at high rates to the gas cap. Unfortunately at this time the pressure and permeability to oil will be low, and the viscosity high, before gravity drainage can even begin.

In view of the effects of these factors, the per well productivities, as shown on Figure V-2, can be extremely low, and only those wells with exceptionally good connection with the high capacity fracture system can produce at commercial rates at the time the gravity drainage mechanism begins to work. It is therefore unlikely that in West Puerto Chiquito significant gravity drainage recoveries can be anticipated following an initial production cycle of solution-gas drive.

As indicated earlier, because of the complexity of the situation it is difficult, from analysis of production behavior of depleted fields, to exactly identify these gravity drainage and relative permeability effects. At this time only general comparisons

can be made. For example, it is believed that the recoveries in Boulder were approximately 15 to 30 percent of the oil in place. Boulder was developed on 80-acre spacing, and it might appear at first that with reference to Figure No. 11 this range of recovery is not consistent with recoveries suggested on this Figure 11 for 80-acre spacing. It must be recognized, however, that in Boulder the shrinkage factor was only about 10 percent, reducing (by comparison with West Puerto Chiquito) this detrimental effect to ultimate recovery discussed above. Possibly more important, however, is the relation of the Boulder Pool's surface area to the dip of the formation. This pool is approximately three miles in length, along the strike, with only one mile of width, down the dip. All other factors being equal, with only one mile down-dip at Boulder, whereas there are four miles at West Puerto Chiquito, a well density of four to one could be used at Boulder (wells produced at equal rates) when compared to West Puerto Chiquito to give the same relative production rate in terms of barrels per day per linear mile along the strike, and accordingly have the same impact on gravity drainage recoveries. Further in this regard, with Boulder's initial viscosity of 3 cp, FVF of 1.10, formation dip of approximately 1,000 feet per mile and assumed transmissibility of 10 darcy feet, its initial gravity drainage rate would be estimated at (Equation 1, Page 21 herein) approximately 1,000 barrels per day per linear mile. Boulder's highest production rate was about 1,500 barrels per day, or 500 barrels per day per mile along the strike. Accordingly, a high gravity drainage recovery should have been realized at Boulder, and a recovery of 30% of the oil in place (considering the "uncontrolled" manner by

which Boulder was produced) is quite consistent with the principles of calculation underlying Figure 11.

From these remarks it can be seen that the resolution of true relative permeability characteristics is difficult to make from a simple analysis of field performance, and field data can only be interpreted generally. One particular interpretation, however, should be noted with respect to the apparent range of the ratio of relative permeabilities of fractured formations (as shown on Figure IV-2). The early high permeability to gas, which indicates a "poor" Kg/Ko relation as far as solution-gas drive depletion is concerned, is a "good" characteristic for gravity drainage, and gravity drainage under pressure maintenance. High permeability to gas at low gas saturations does not necessarily mean that gas will "channel" immediately under pressure maintenance, rather the gravitational forces will tend to establish a more uniform gas-oil contact "plane" than if the gas had a lower relative permeability for the same gas saturation. This statement is best understood by visualizing permeability to gas to have an infinite value. If this were the case, immediately upon breaking out of solution (under producing conditions of reducing pressure) gas would by gravitational segregation instantly move to the gas cap, if the gravity drainage rate was not exceeded by the producing wells. Also, gas entering the reservoir from a gas injection well would likewise instantly rise to the gas cap. On the other hand, if under gas injection, where this high Kg/Ko relation exists, the oil producing rate exceeds the gravity drainage ability of the reservoir, gas "break-through" would be anticipated earlier than for a reservoir with a lower Kg/Ko relation. Such break-through times and recoveries can be calculated (Reference 9). Such calculations

reveal that it is impossible to hasten the gravity drainage process, for if the gravity drainage rate of production is exceeded, lower ultimate recoveries will result under pressure maintenance, the same (although for different reasons) as gravity drainage without pressure maintenance, where the production rate exceeds the reservoir's gravity drainage ability and the solution-gas drive mechanism becomes operative.

The end result of such analyses is simply that production rates under pressure maintenance should be restricted to approximately the gravity drainage ability of the reservoir.

SECTION 5 - SUMMARY

Benefits from pressure maintenance by gas injection in most reservoirs ordinarily is expected to include only slight benefit in additional ultimate recovery. The main benefit is probably faster rate of recovery. In the instance of West Puerto Chiquito, however, because of its unusual nature, a substantial increase in ultimate recovery is anticipated from use of pressure maintenance, as compared to producing the pool without it. The primary reason, of course, is that pressure maintenance will insure that the gravity drainage depletion mechanism actually has an opportunity to be effective. In this connection the following remarks are offered:

1. As to the volume of the oil in the high capacity fracture system, now thought to be perhaps half of the oil in the reservoir, there will be no "free gas phase" affecting the gravity drainage rate, and accordingly under pressure maintenance the slightly higher gravity drainage rate, as shown on Figure No. 5,

for the condition of no free gas present, will obtain.

2. By maintaining the pressure, the viscosity will always stay low, and the gravity drainage rate will not decrease with stage of depletion of the reservoir. Also, the oil saturation will stay high and the relative permeability to oil will stay high. These things taken into account, it should be possible to deplete the reservoir in one-third to one-half the time which would otherwise be required and at the same time enjoy the high gravity drainage recoveries.

3. The gravity drainage process will commence as soon as steady state conditions are reached under the gas injection project, avoiding the hazard of gas expansion and the time required for the gas bubbles to migrate to the gas-oil contact, as discussed in Section 4 of this Part IV. This phenomenon is believed to be extremely detrimental to potential gravity drainage recoveries, and its hazard is completely eliminated under pressure maintenance.

4. A higher recovery of oil from the tight blocks is anticipated under gravity drainage and pressure maintenance, as discussed in Section 3 preceding.

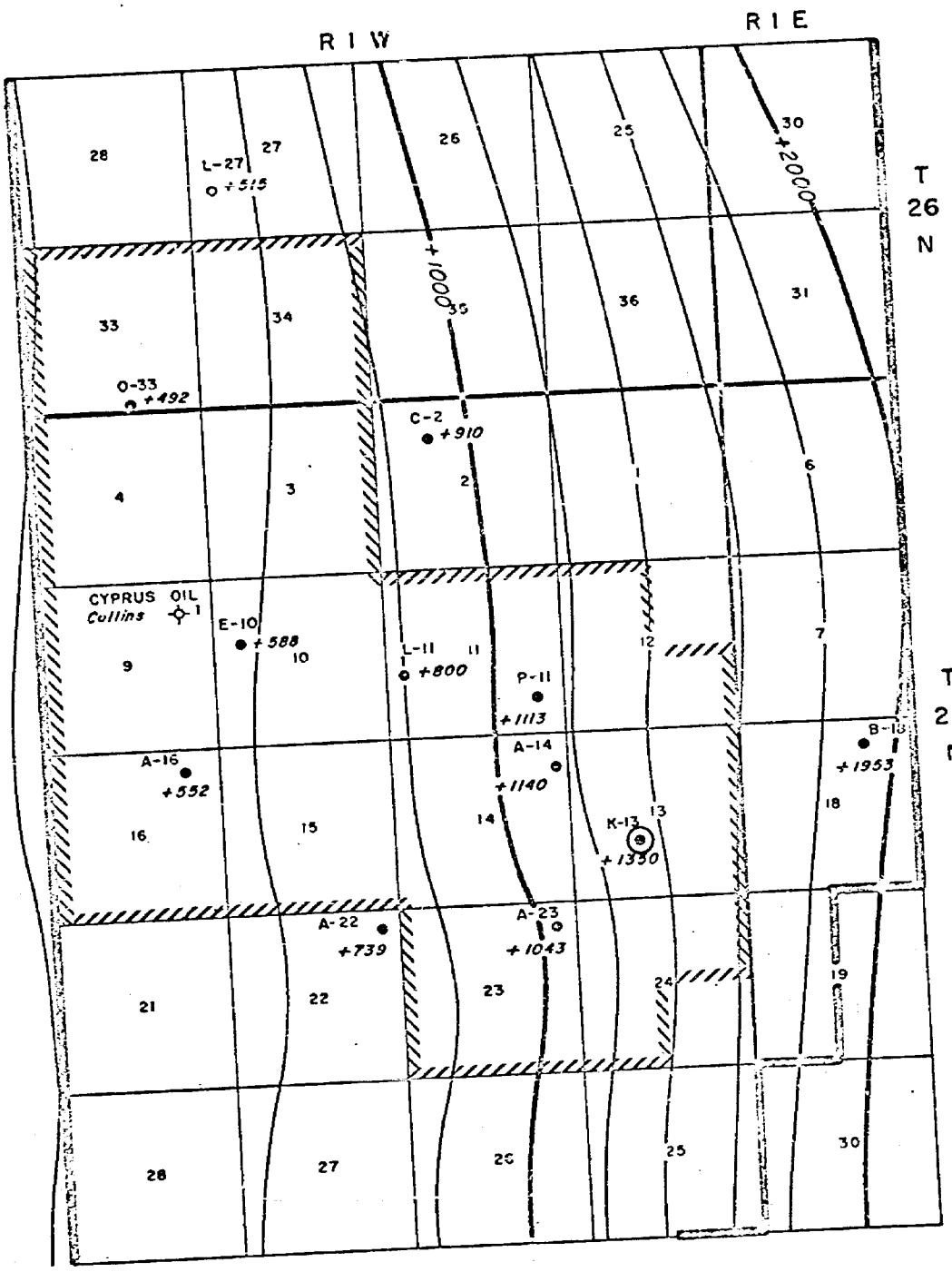
5. Although little benefit in ultimate recovery is ordinarily anticipated under pressure maintenance as compared to gravity drainage without pressure maintenance, this is because, among other things, one usually anticipates the final liquid saturation under gravity drainage to be quite low. If it is, then of course there is little difference in ultimate recovery with or without pressure maintenance. If, however, the final liquid saturation is as much as 50 or 60 percent of the total pore space,

then very substantial increases in ultimate recovery will result, as discussed earlier and shown on Figure No. 12. Not knowing the value of this final liquid saturation, it is only prudent to use pressure maintenance to "be safe" in recovering the maximum possible amount of oil, as long as its cost is not prohibitive.

6. If the down-dip wells do not have high capacity communication with the main fracture system, wells will reach economic limits while there is still a substantial amount of oil which might otherwise be recovered. The additional pressure of the pressure maintenance project will insure this final amount of oil will be recovered.

The pressure maintenance project is visualized as comprising three phases. The first phase is drainage of the high capacity system. This will be at times when the pressure in the oil zone (below the gas-oil interface in the high capacity fracture system) is maintained constant and the pressure in the gas cap is continually increasing. The second phase will be essentially a gas cycling phase, at which time the same volume of gas which is produced is returned to the reservoir, and thence cycled. During this period of time the reservoir pressure will decline slightly by the amount of oil withdrawn which is not replaced by gas. The third phase will be a period of rapidly declining pressures, during which gas will not be returned to the reservoir, or if returned, will be returned in quantities less than produced. During this time part, if not all, of the gas will be marketed and the producing mechanism for the down-dip areas will be a combination of gravity drainage and solution-gas drive. The extent to which gravity drainage or solution-gas drive will dominate in the recovery of oil from the down-dip areas will of course depend strictly on the

economics of the situation and the degree to which producing rates can practicably be restricted. At that time, however, some 80 to 90 percent of the ultimate recovery will have been realized through the efficient gravity drainage mechanism, and even though the rest of the reservoir were to be depleted by strictly solution-gas drive, the overall recovery would be highly efficient as compared to either solution-gas drive alone or gravity drainage depletion without pressure maintenance.



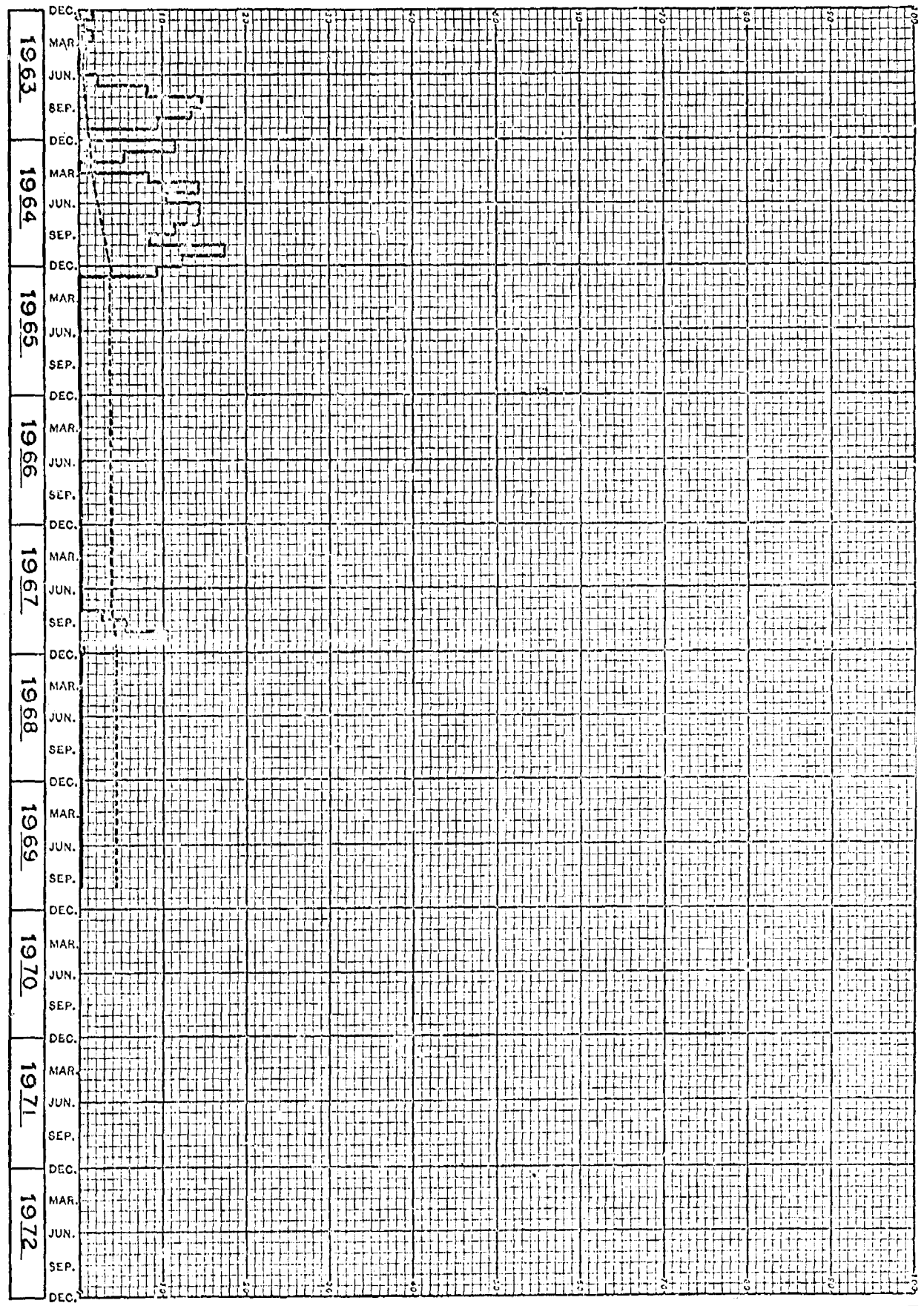
PLAT OF PART
OF
CAÑADA OJITOS UNIT

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C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

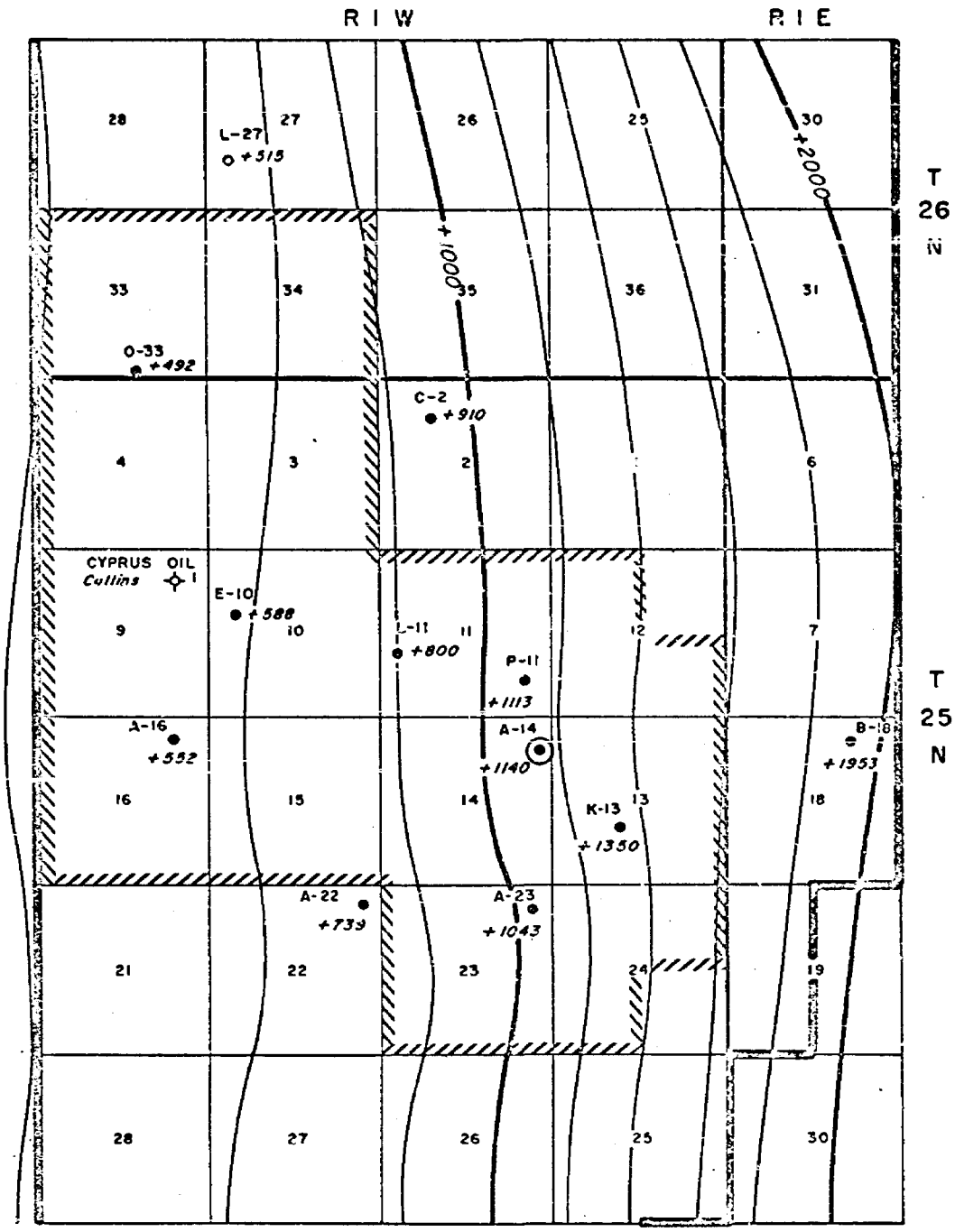
PRODUCTION RATE–THOUSANDS OF BARRELS PER MONTH



CUMULATIVE PRODUCTION–HUNDREDS OF THOUSANDS OF BARRELS

CAÑADA OJITOS UNIT – # K-13

PRODUCTION RECORD



PLAT OF PART
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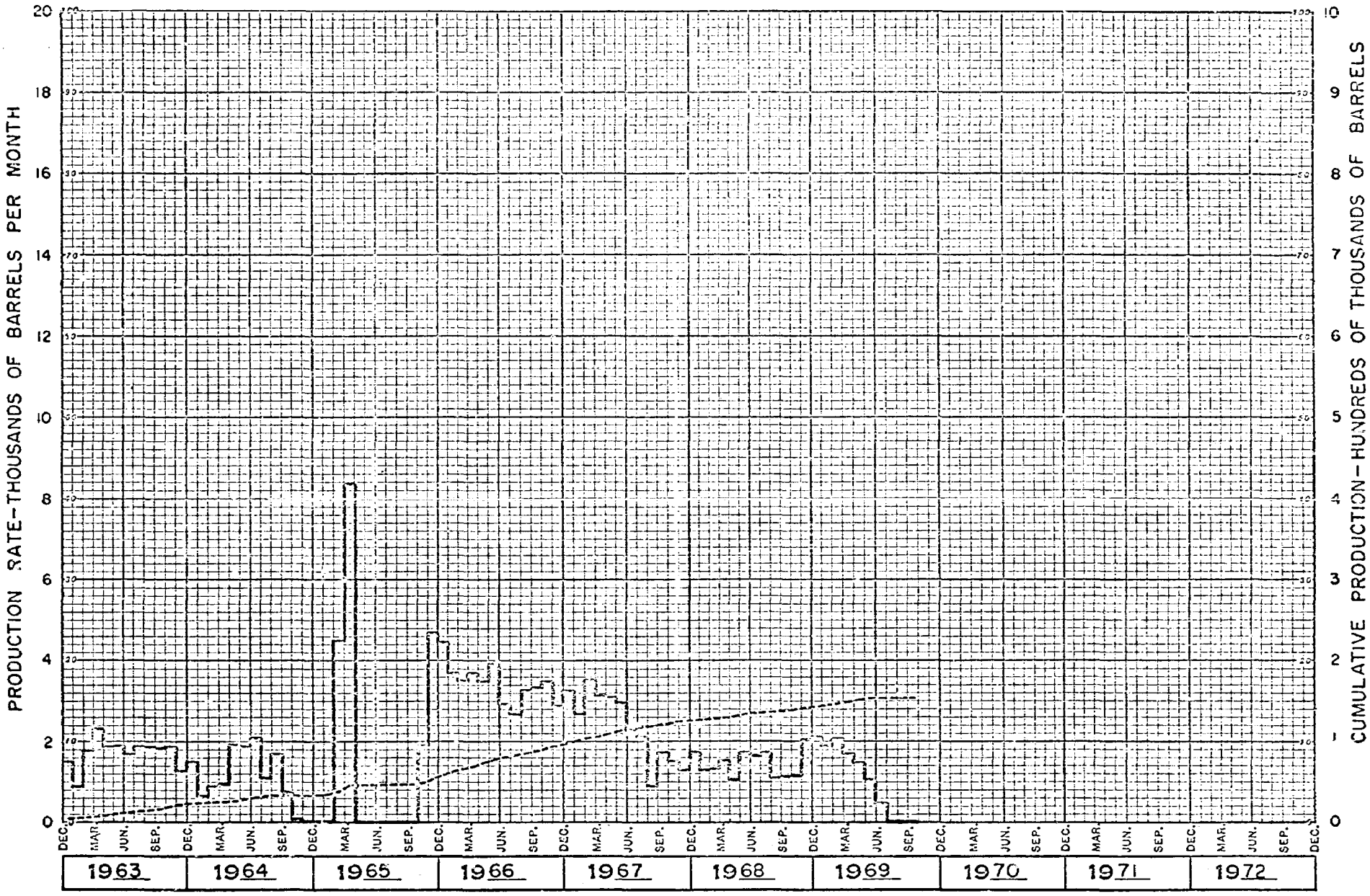
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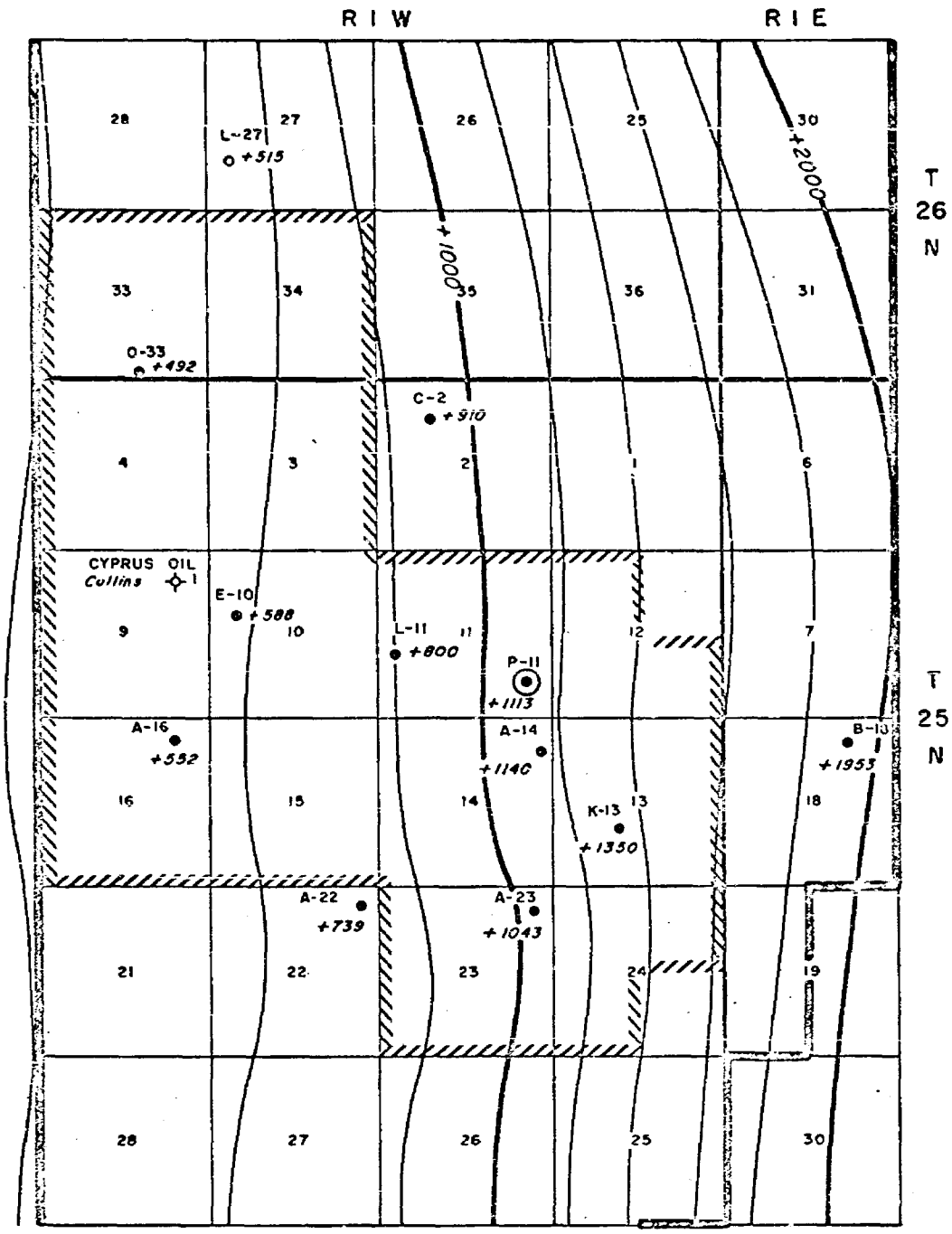
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-14

PRODUCTION RECORD





PLAT OF PART
OF
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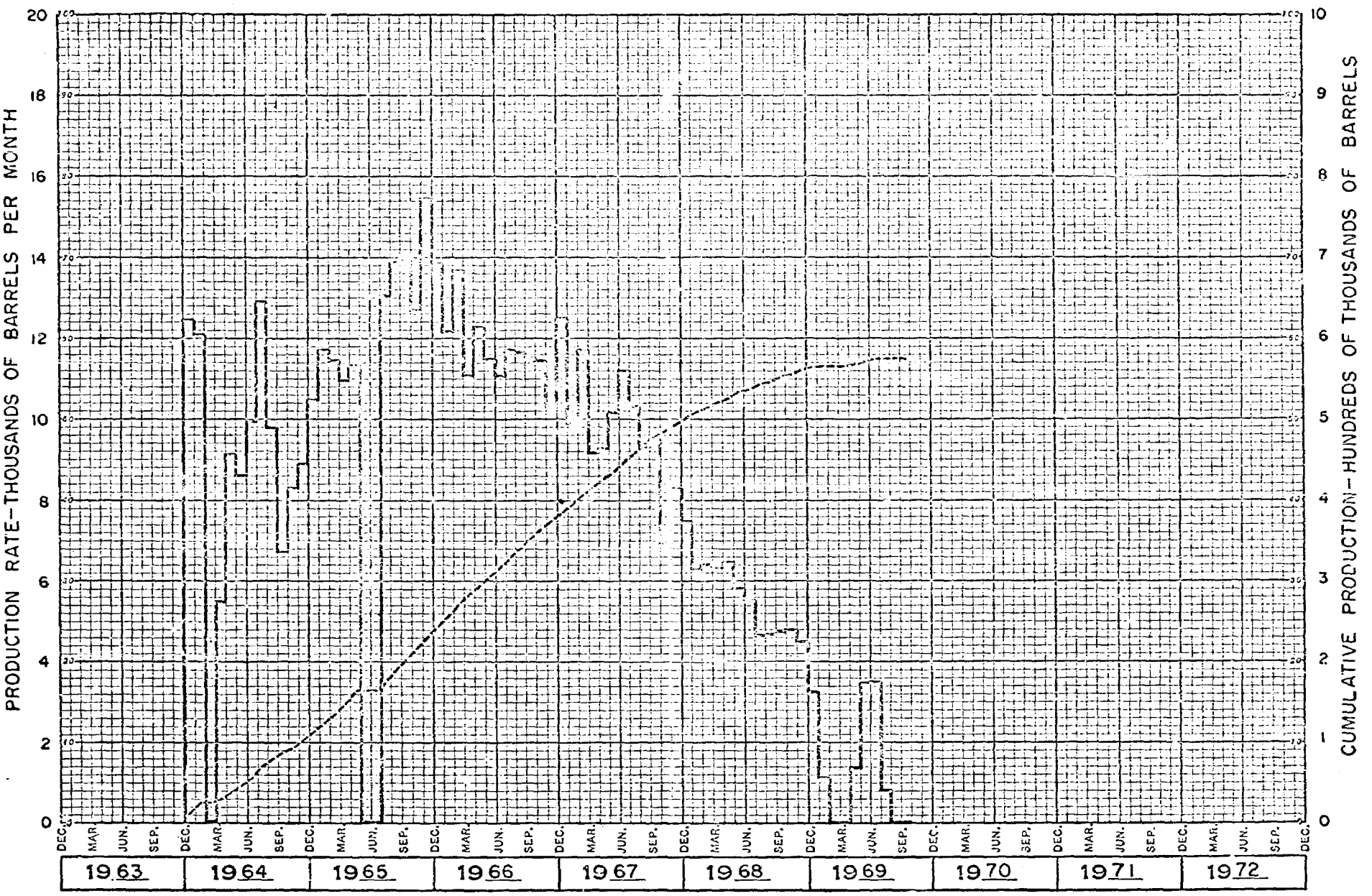
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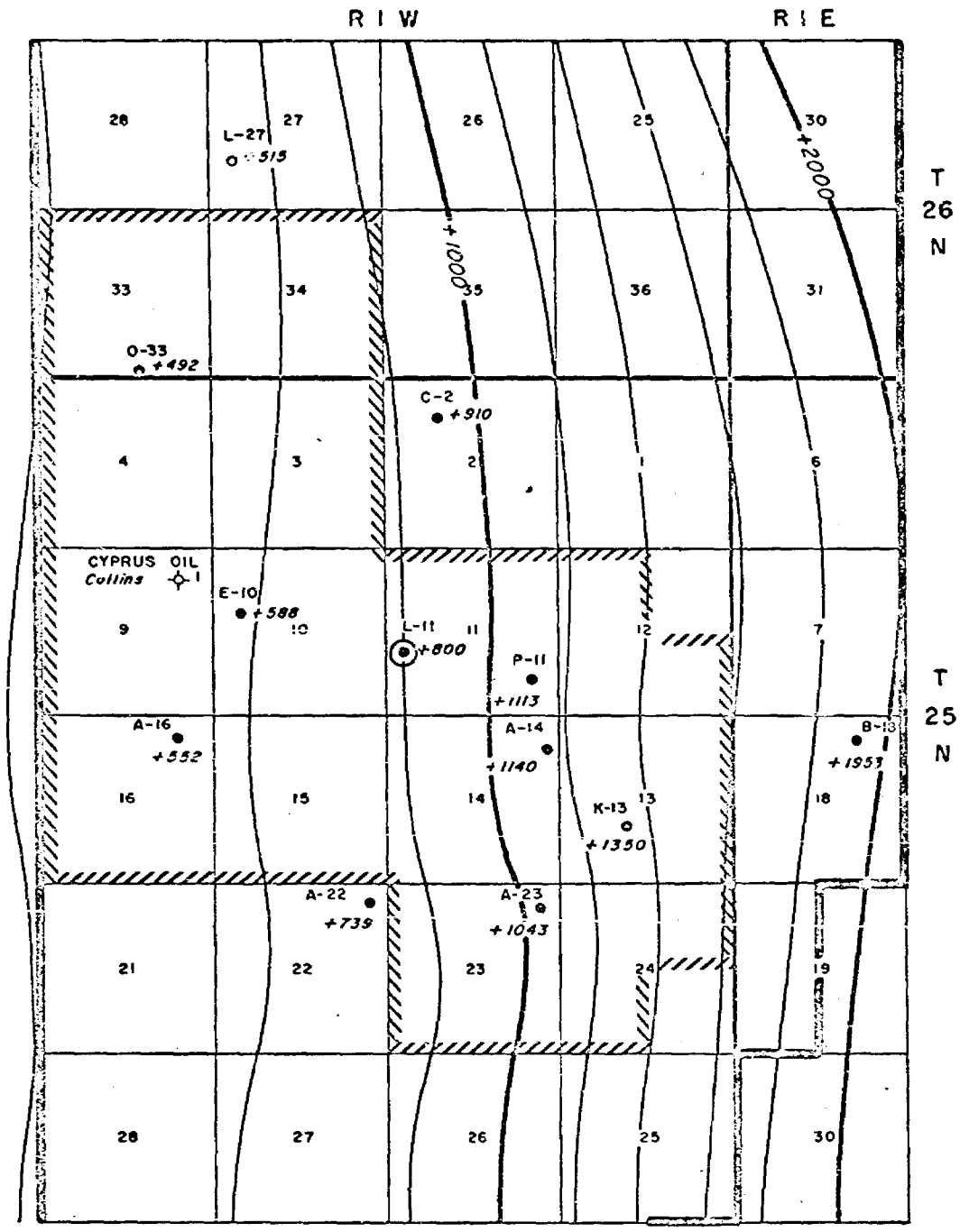
//// BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT — # P-11

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

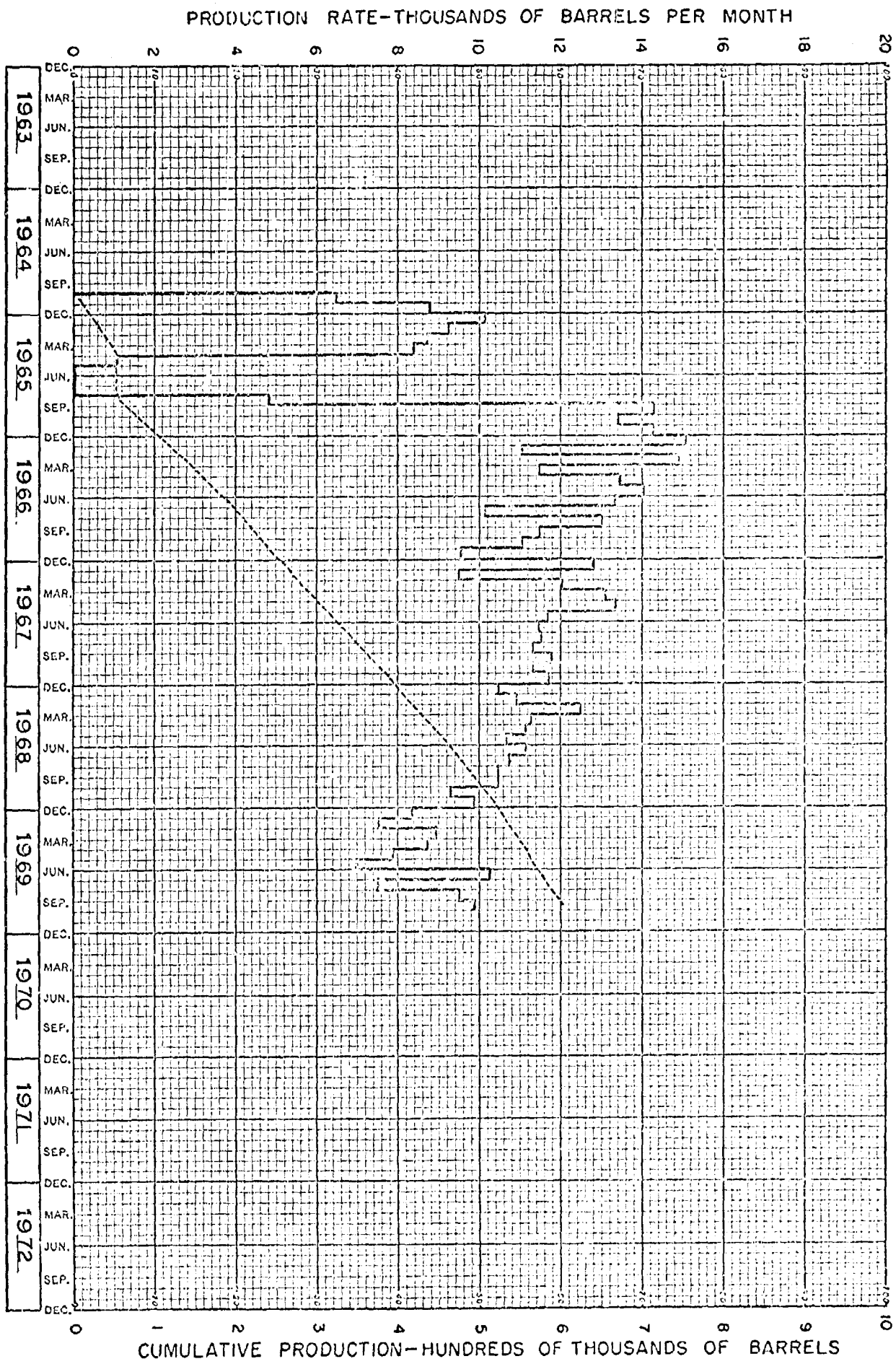
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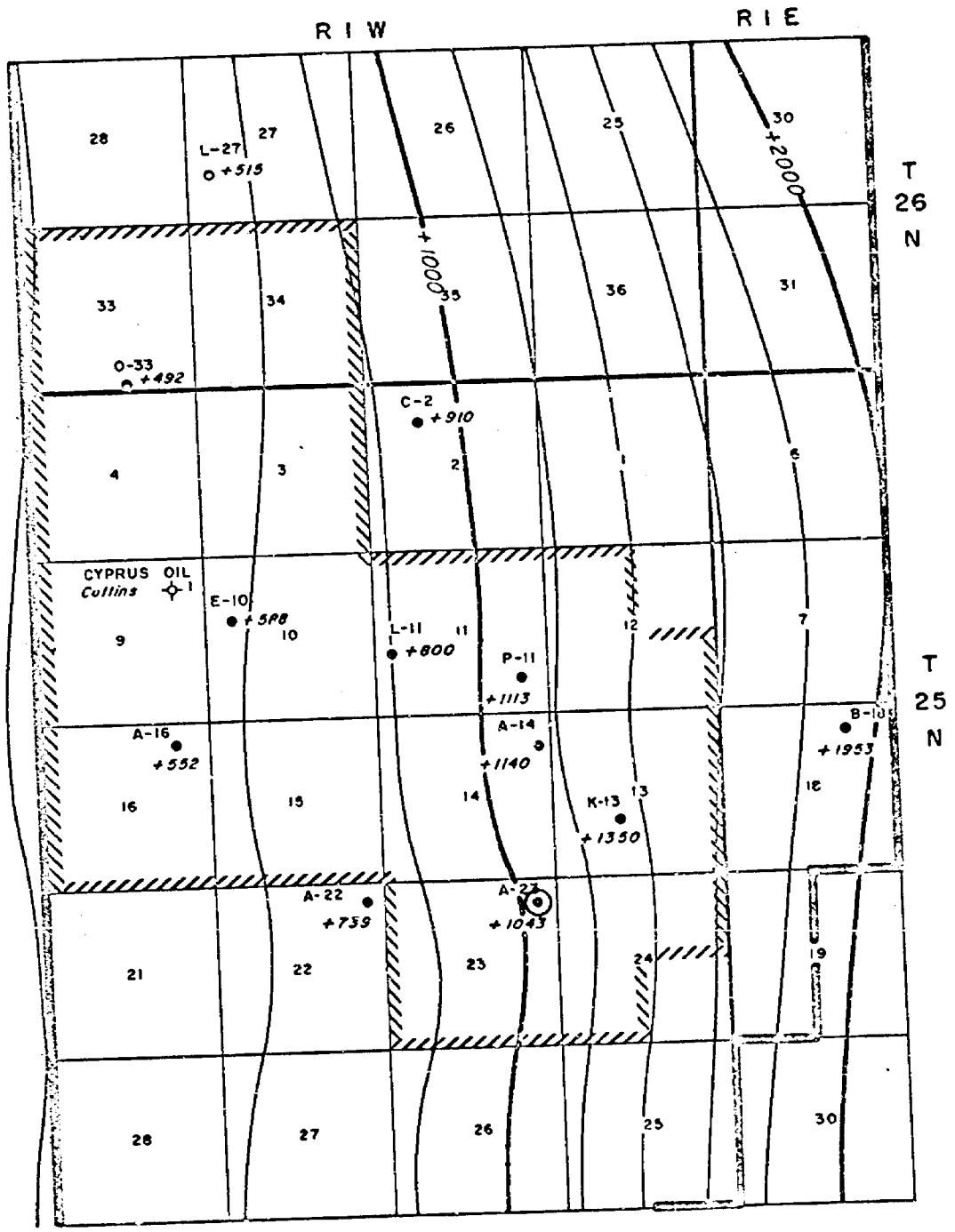
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT - # L-11

PRODUCTION RECORD





PLAT OF PART
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CAÑADA OJITOS UNIT

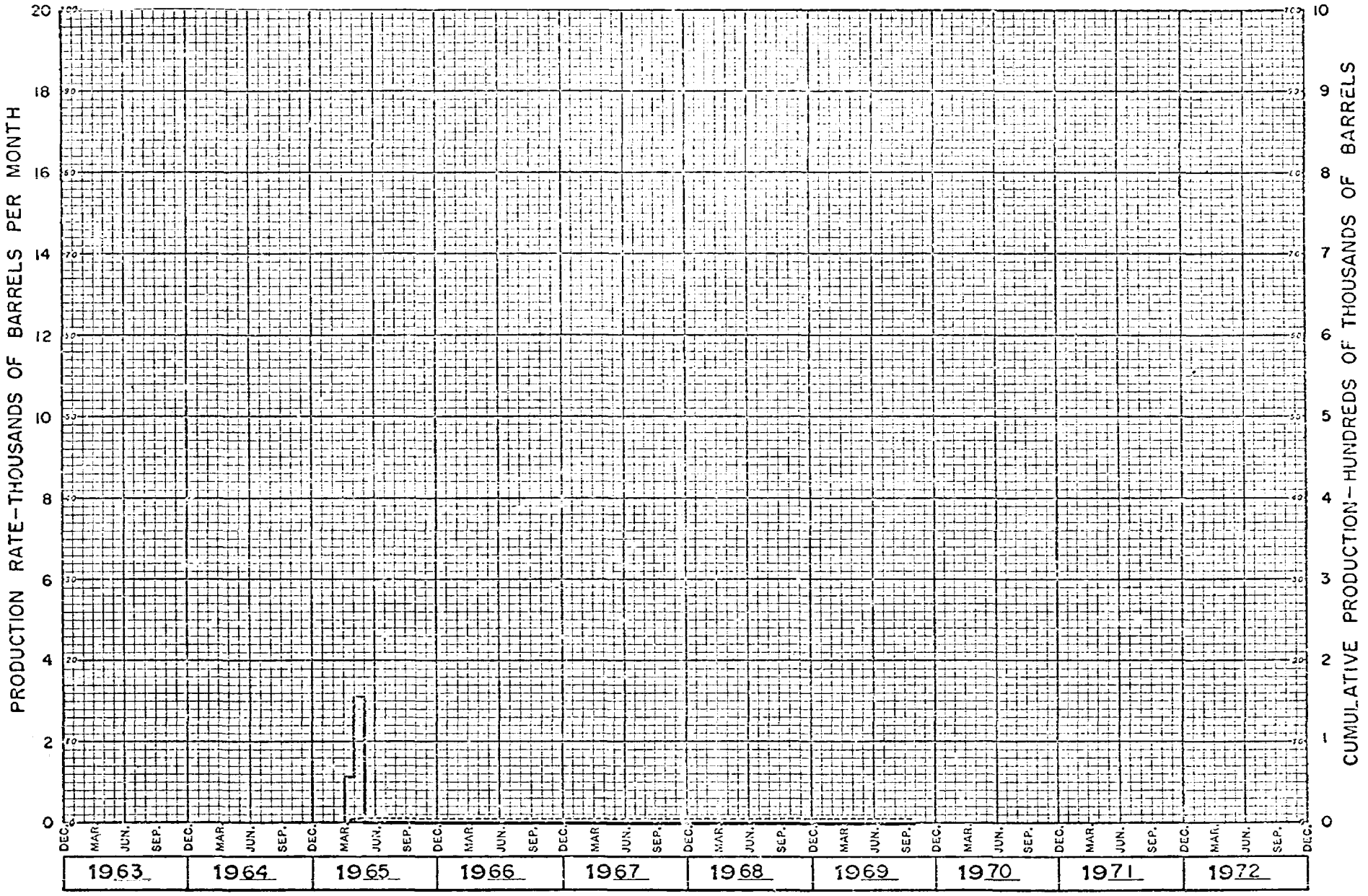
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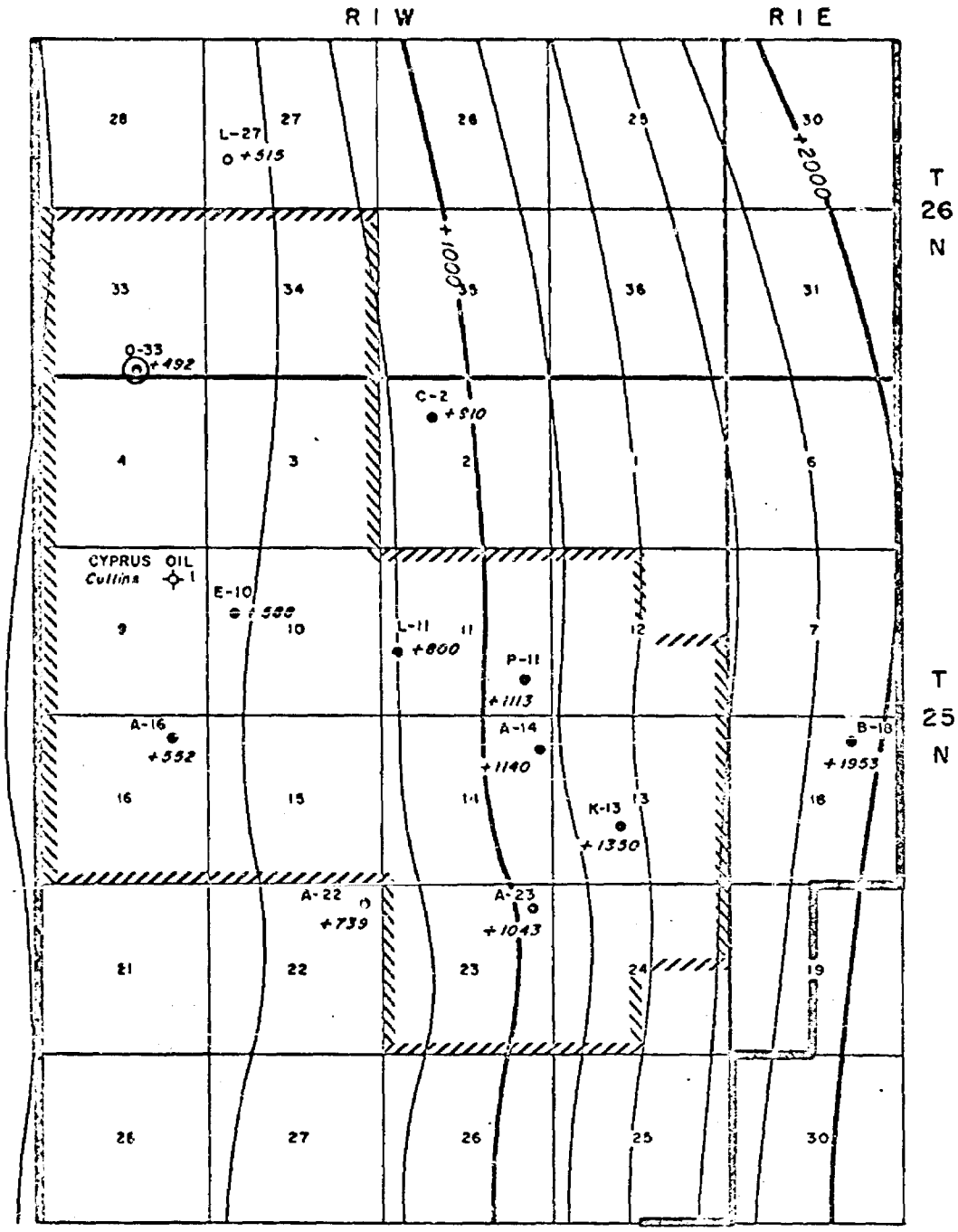
//// BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-23

PRODUCTION RECORD





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OF
CAÑADA OJITOS UNIT

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C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

PRODUCTION RATE–THOUSANDS OF BARRELS PER MONTH

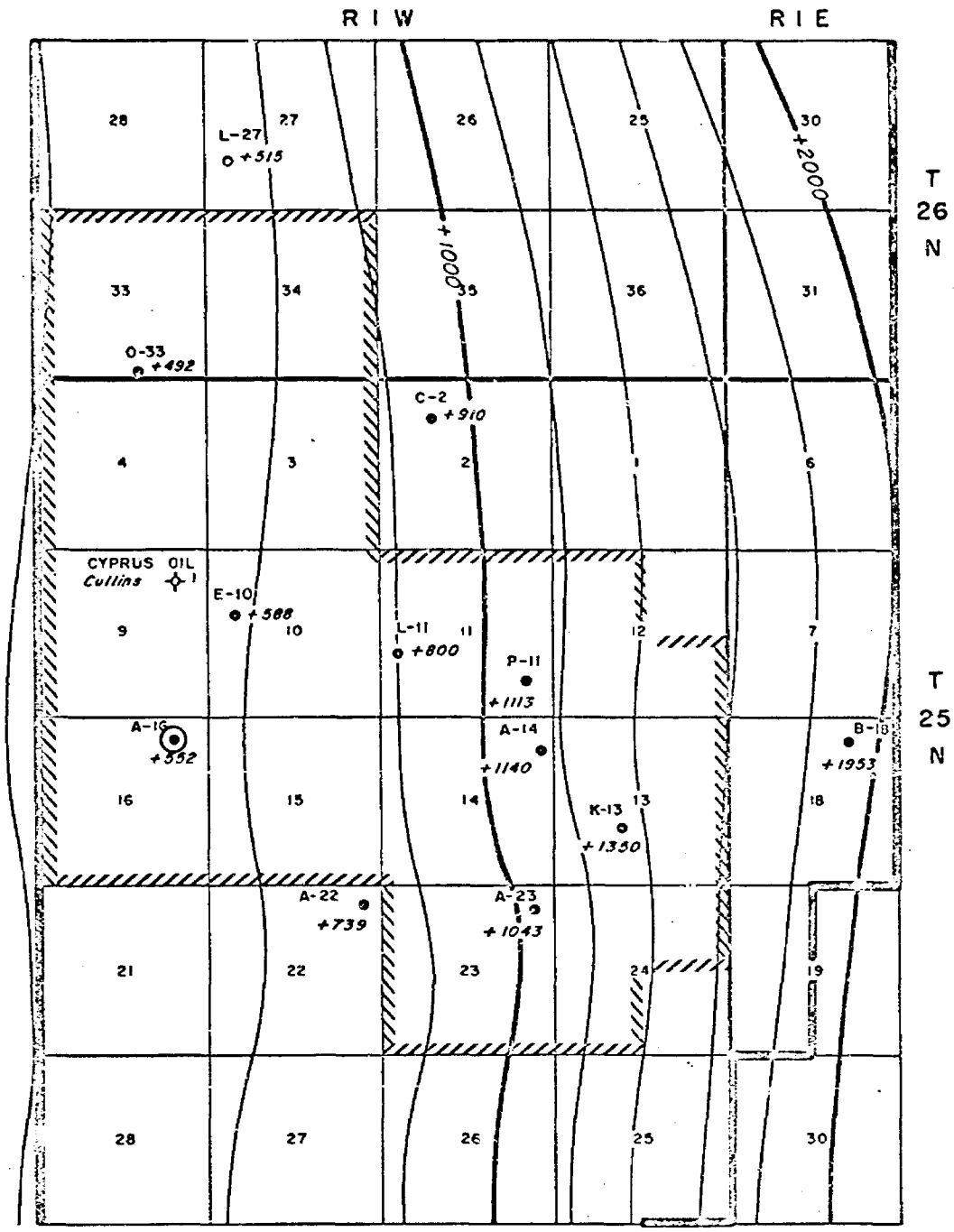
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1970 DEC. MAR. JUN. SEP.
1971 DEC. MAR. JUN. SEP.
1972 DEC.

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CUMULATIVE PRODUCTION–HUNDREDS OF THOUSANDS OF BARRELS

CAÑADA OJITOS UNIT – # 0-33
PRODUCTION RECORD



PLAT OF PART
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CAÑADA OJITOS UNIT

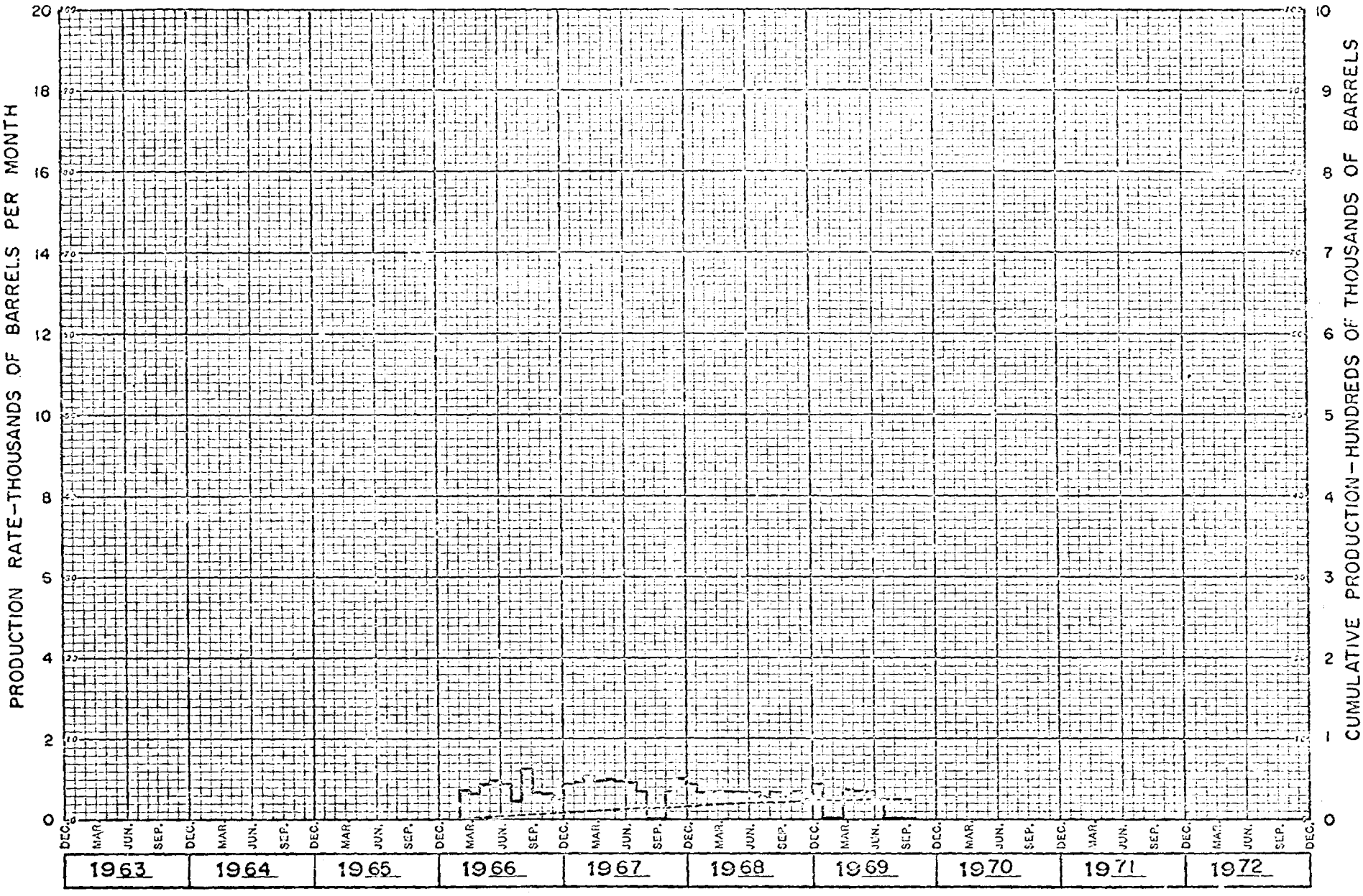
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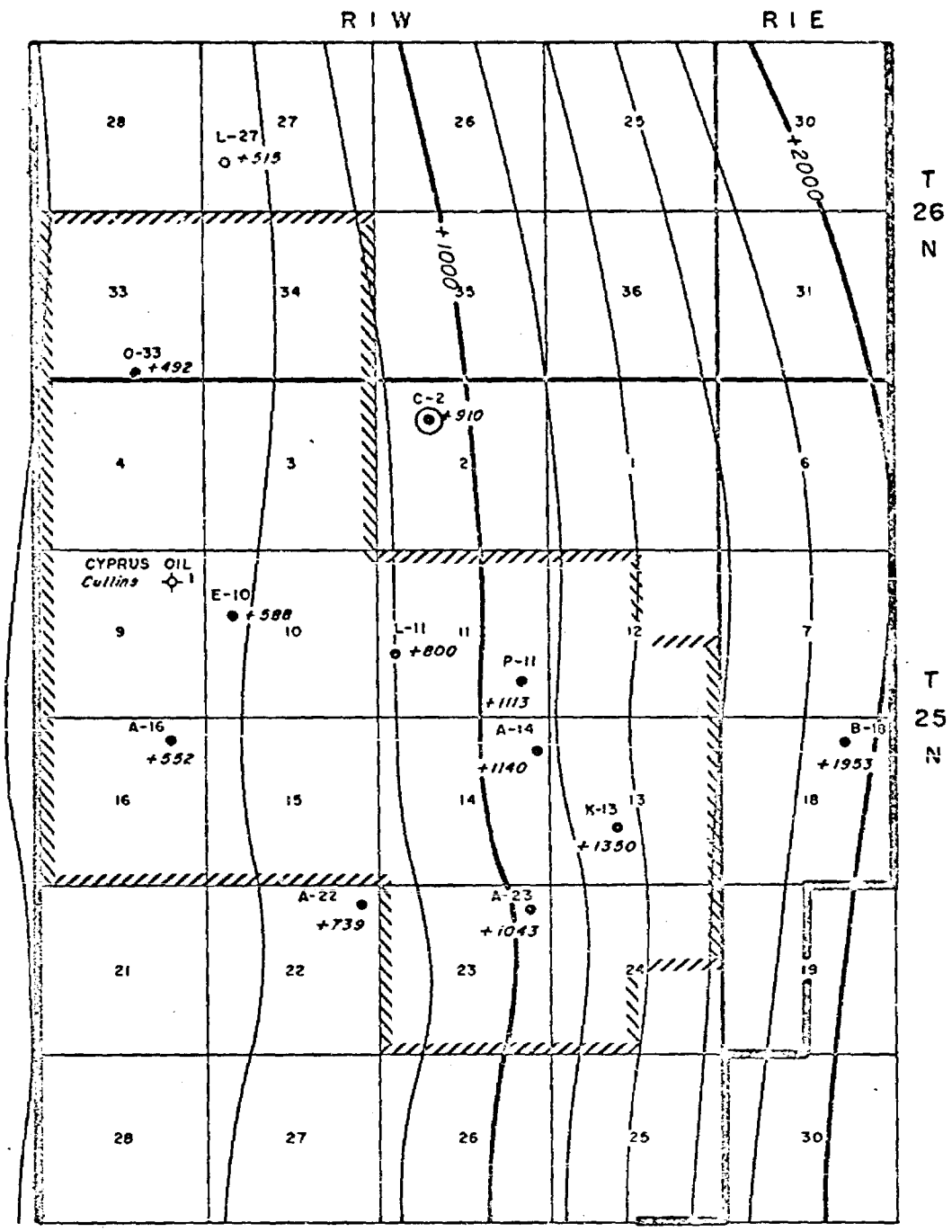
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-16

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

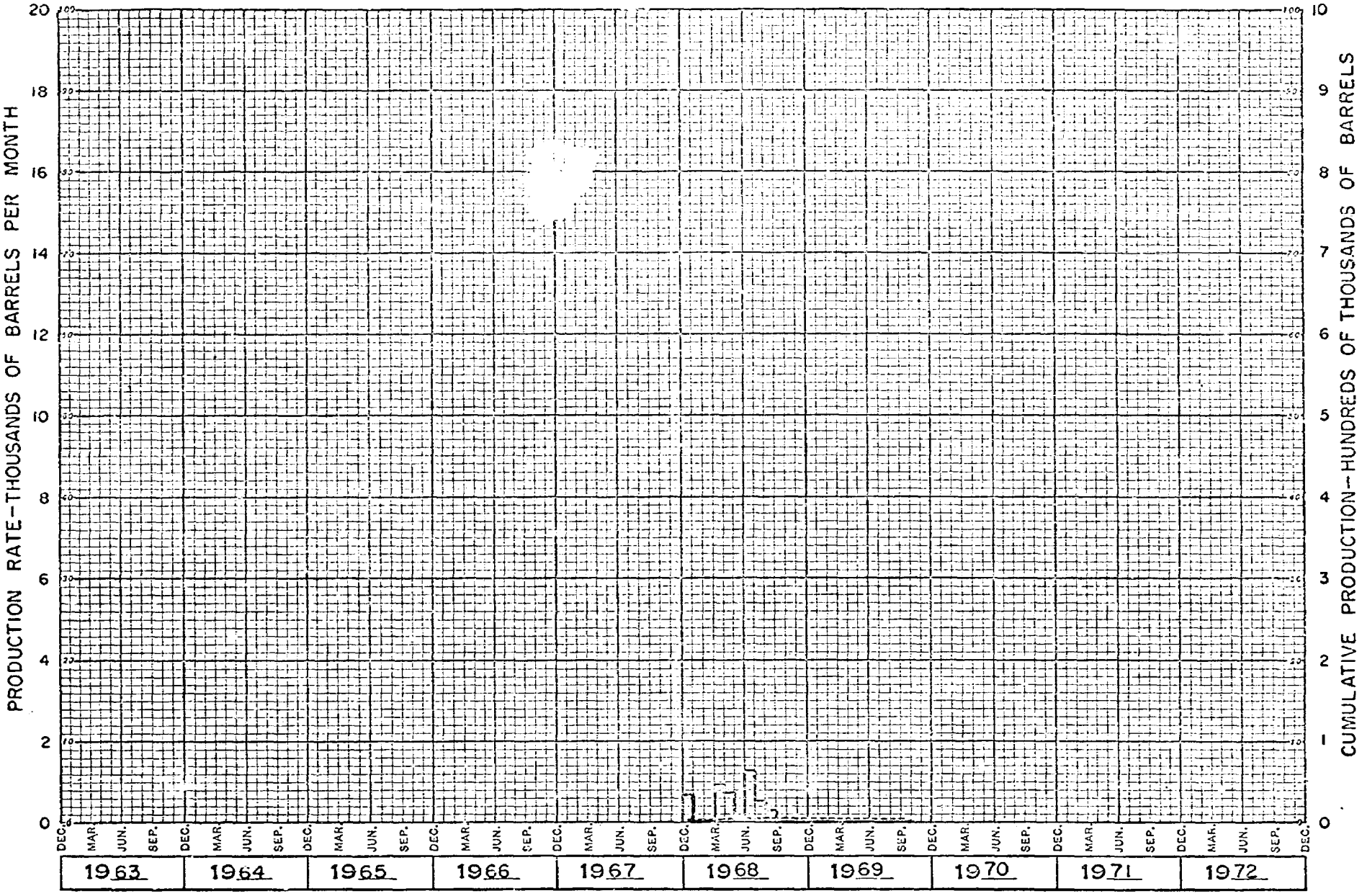
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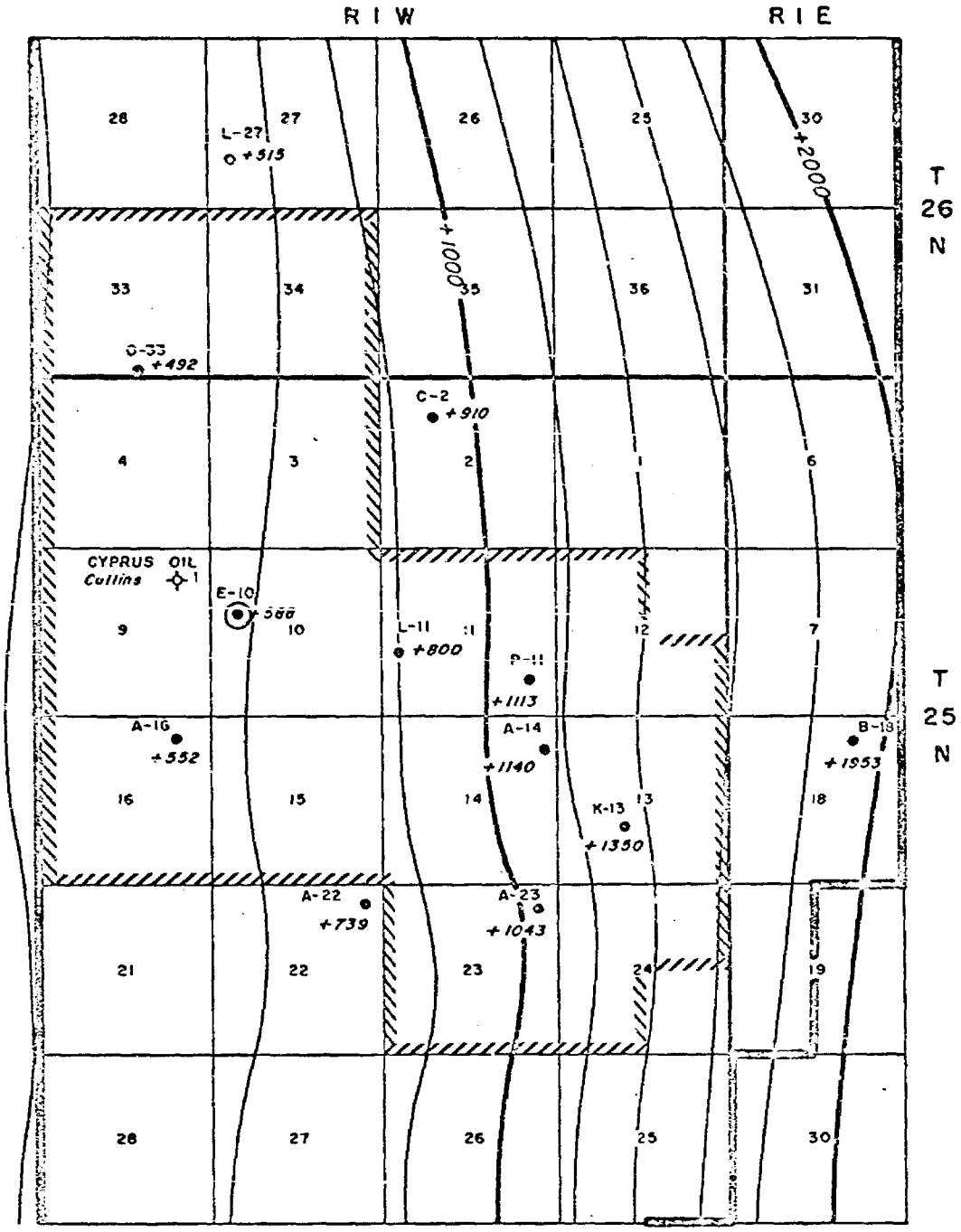
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT — # C-2

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

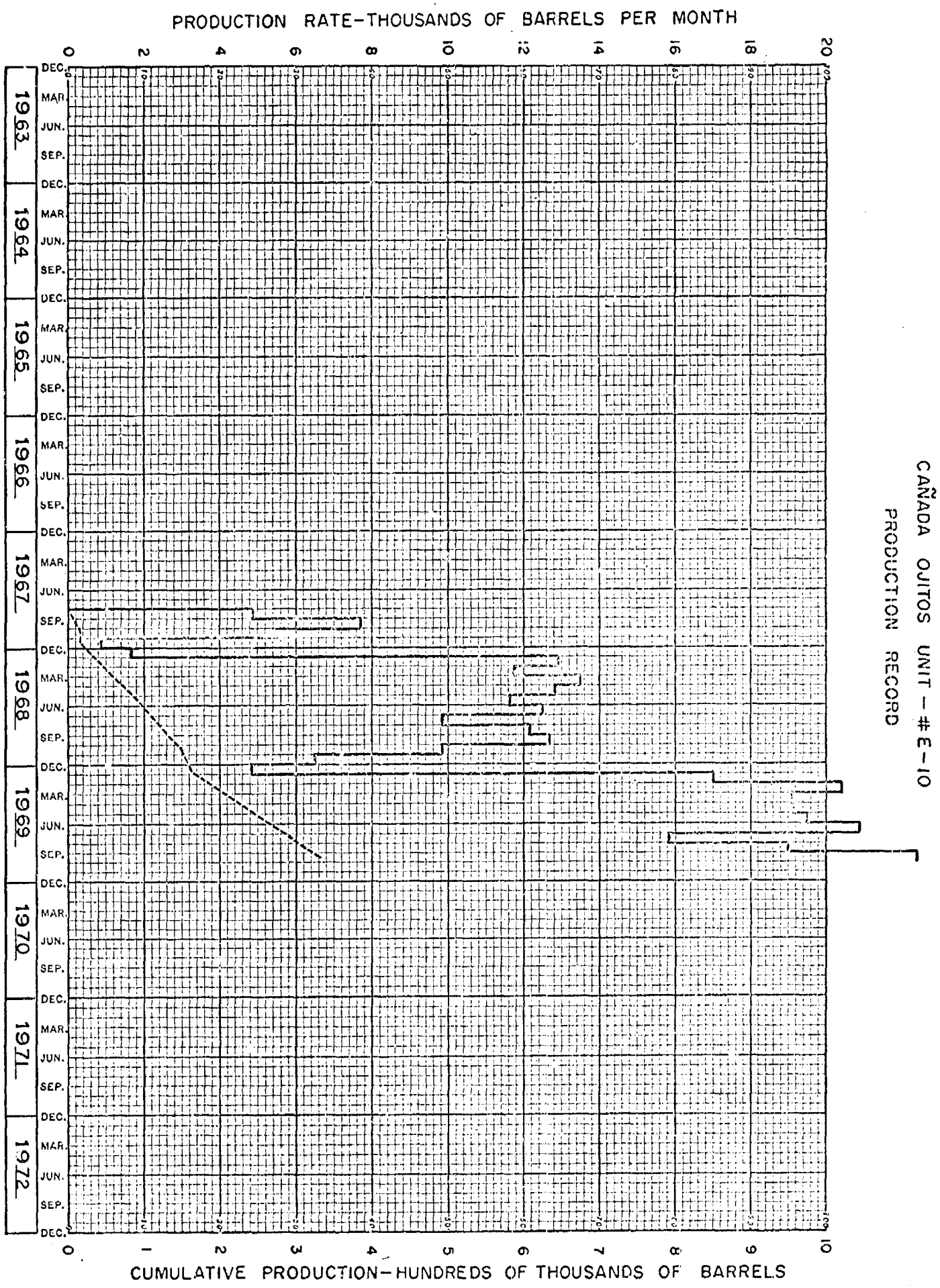
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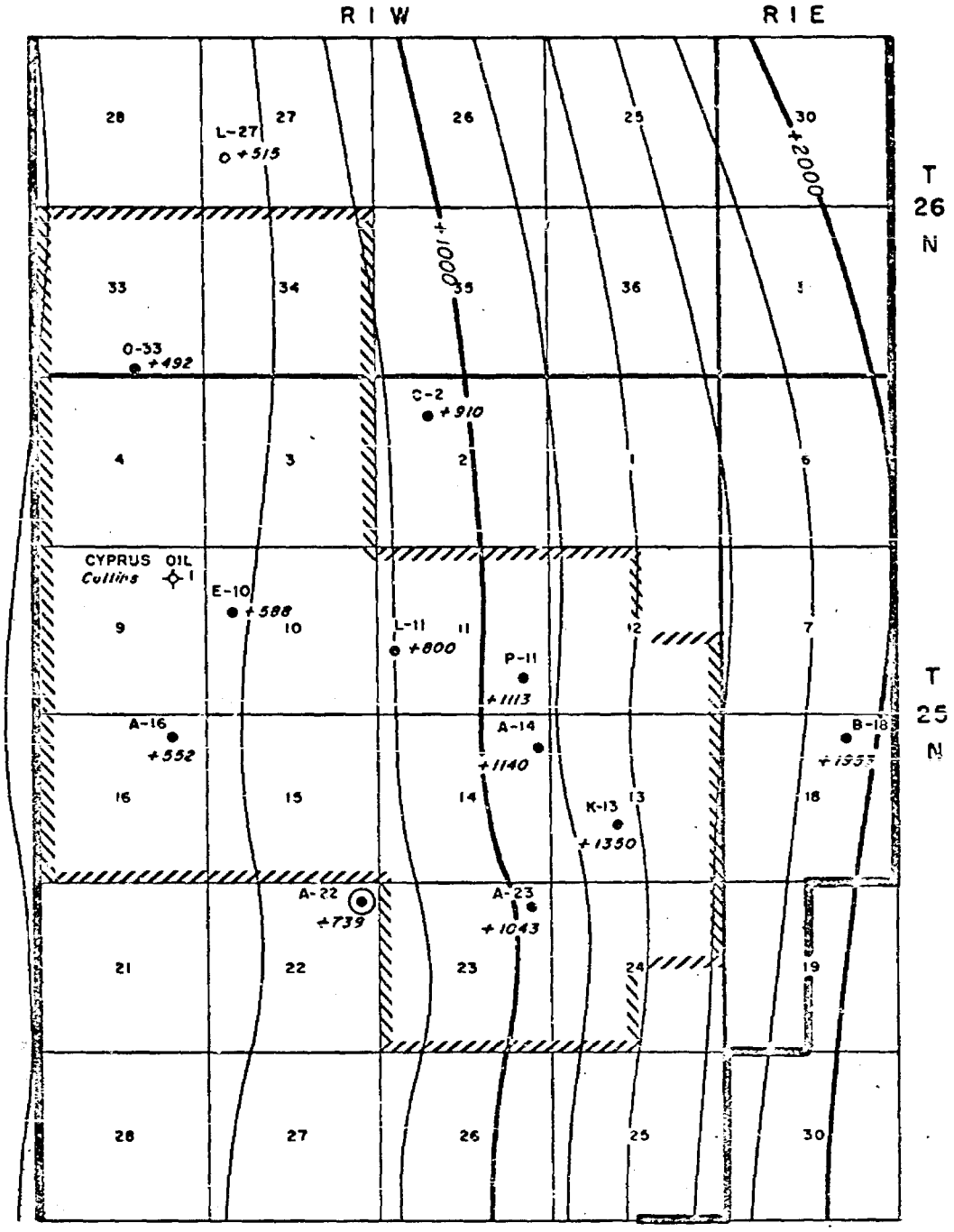
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – #E-10

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

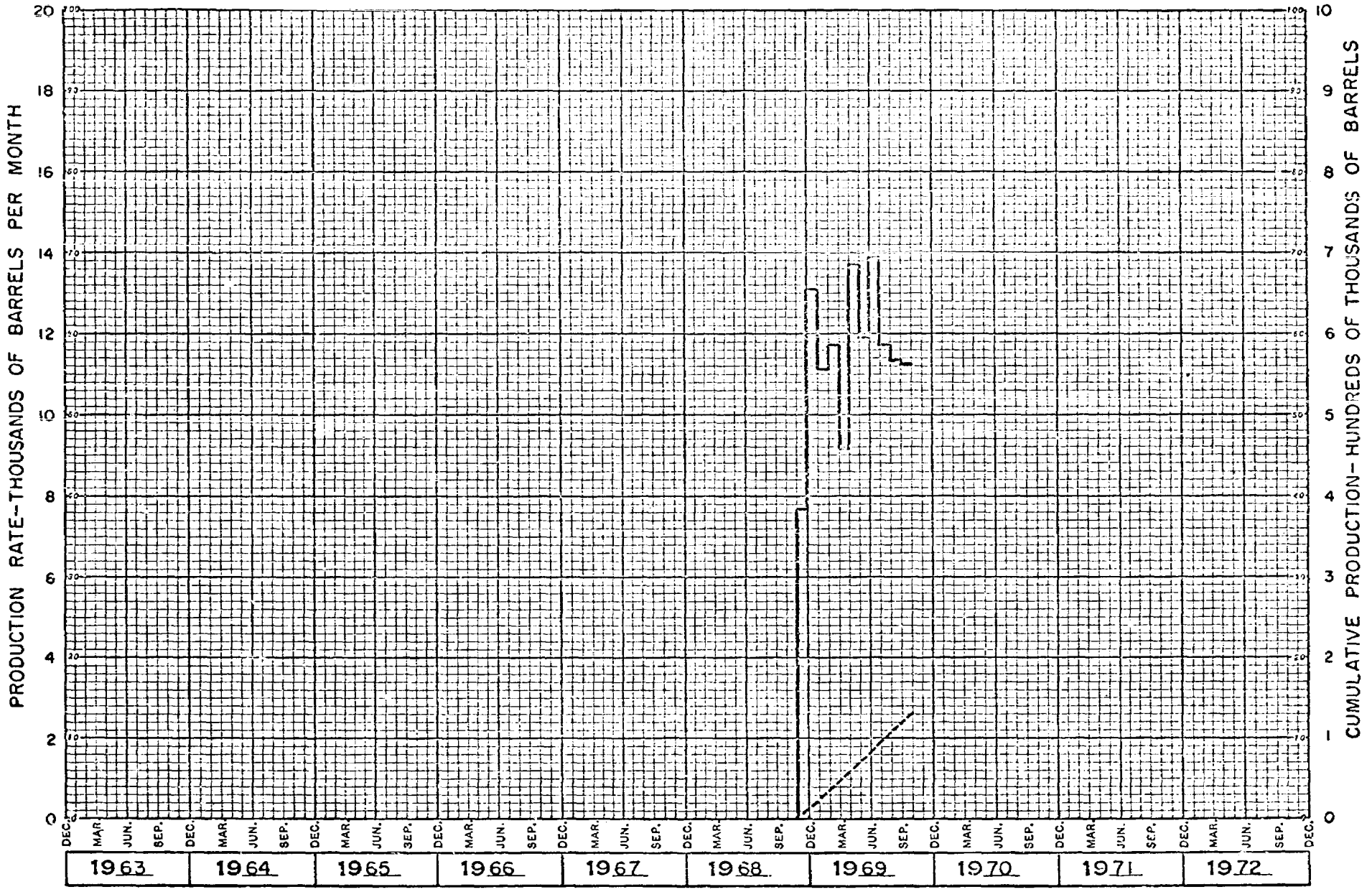
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-22

PRODUCTION RECORD



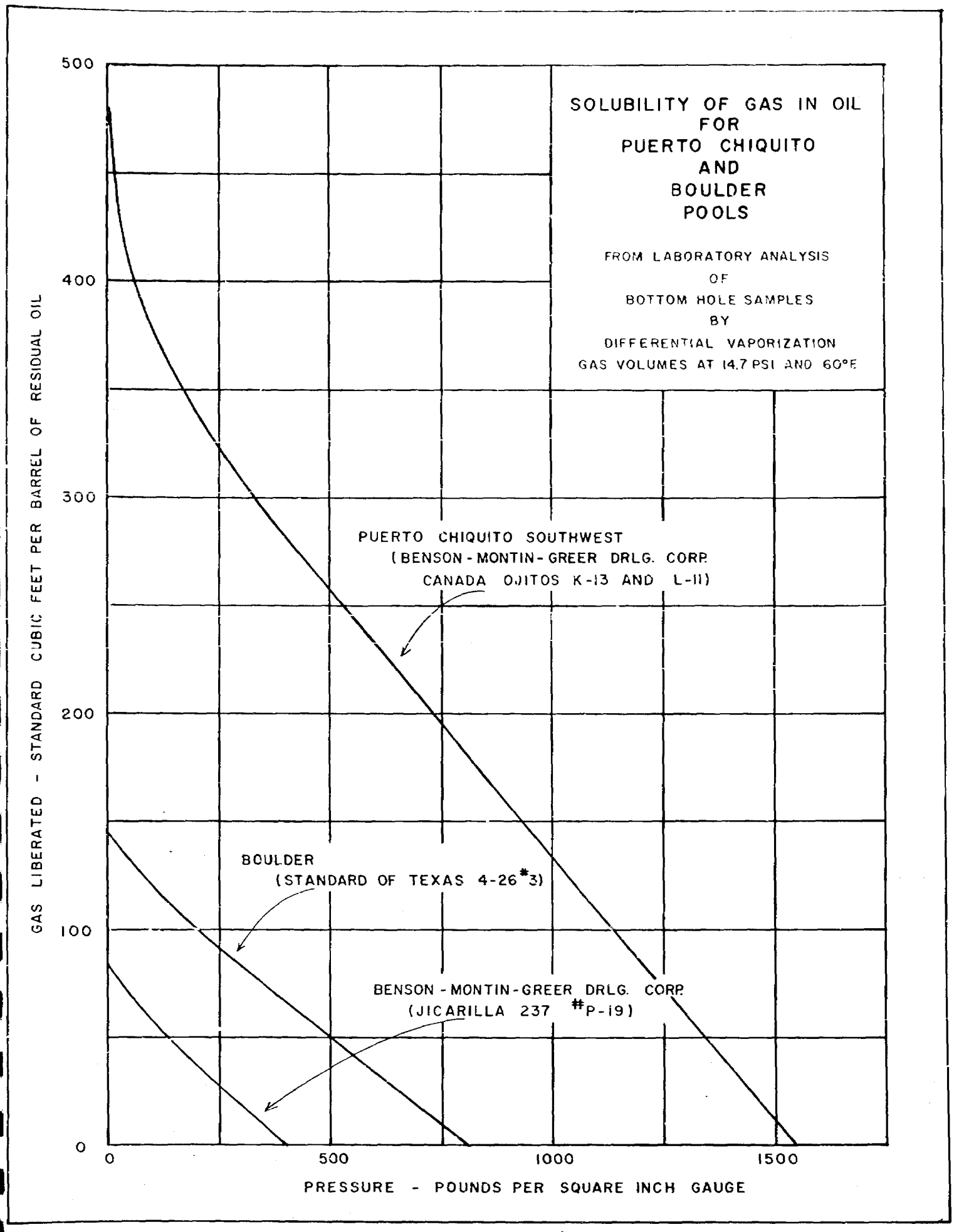

SOLUBILITY OF GAS IN OIL
FOR
PUERTO CHIQUITO
AND
BOULDER
POOLS
FROM LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
BY
DIFFERENTIAL VAPORIZATION
GAS VOLUMES AT 14.7 PSI AND 60°F
PUERTO CHIQUITO SOUTHWEST
(BENSON-MONTIN-GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 *3)
BENSON-MONTIN-GREER DRLG. CORP.
(JICARILLA 237 #P-19)
GAS LIBERATED - STANDARD CUBIC FEET PER BARREL OF RESIDUAL OIL
500
400
300
200
100
0
0
500
1000
1500
PRESSURE - POUNDS PER SQUARE INCH GAUGE

FIGURE NO. 1

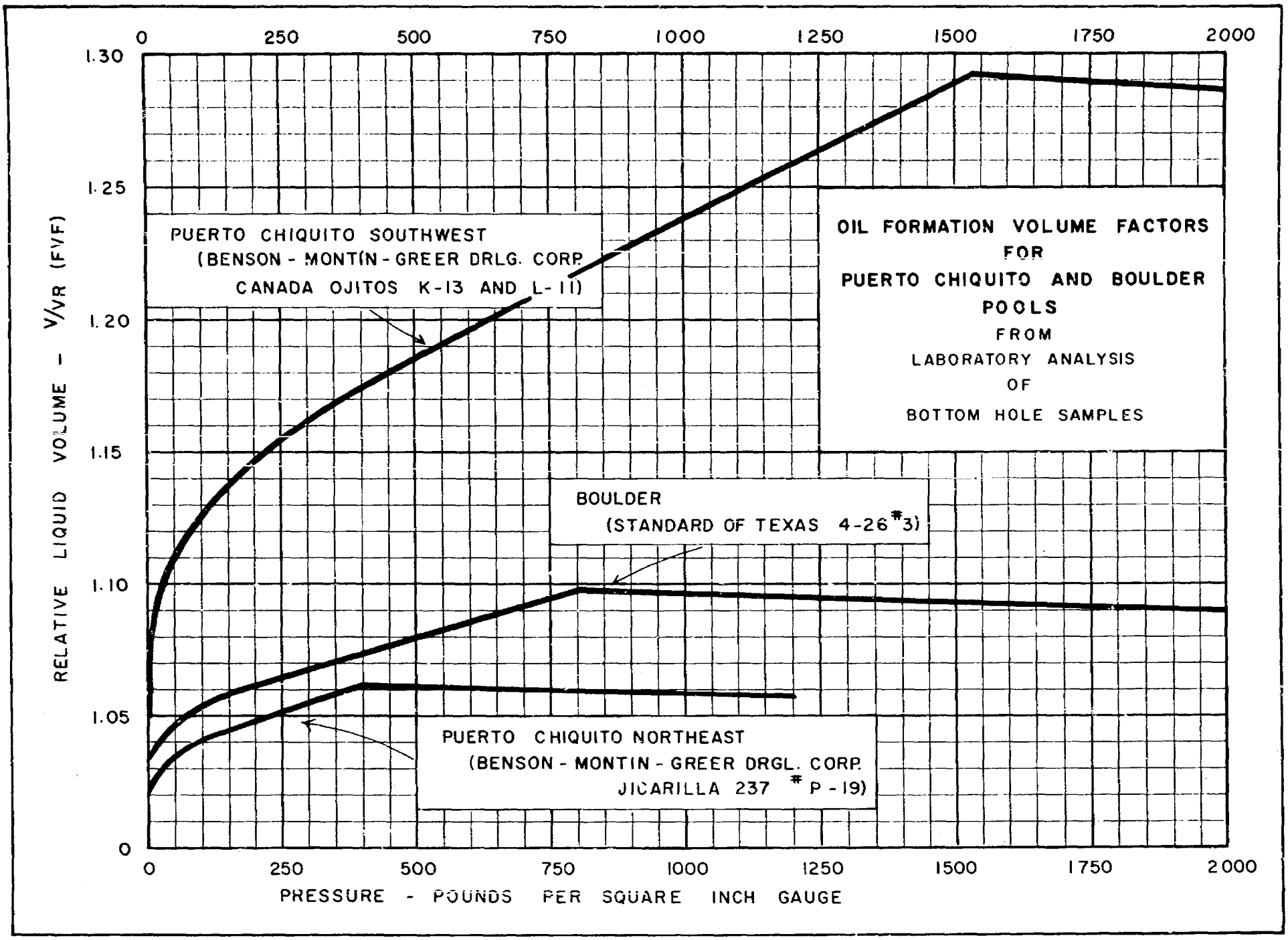

OIL FORMATION VOLUME FACTORS
FOR
PUERTO CHIQUITO AND BOULDER
POOLS
FROM
LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
PUERTO CHIQUITO SOUTHWEST
(BENSON - MONTIN - GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
PUERTO CHIQUITO NORTHEAST
(BENSON - MONTIN - GREER DRGL. CORP.
JICARILLA 237 # P-19)
RELATIVE LIQUID VOLUME - V/VR (F/F)
PRESSURE - POUNDS PER SQUARE INCH GAUGE
0
250
500
750
1000
1250
1500
1750
2000
1.30
1.25
1.20
1.15
1.10
1.05
0

FIGURE NO. 2

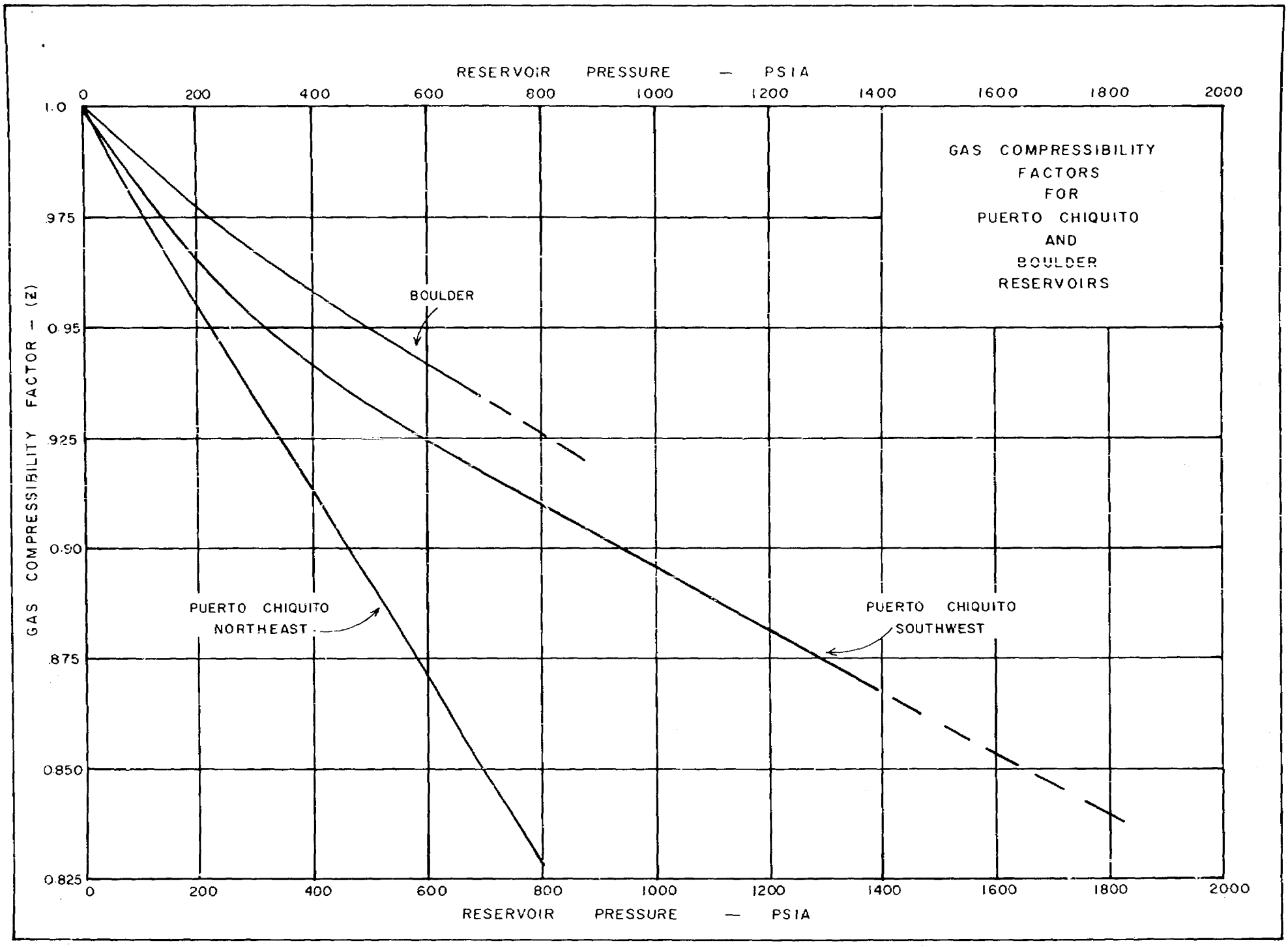

RESERVOIR PRESSURE — PSIA
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1.0
.975
0.95
.925
0.90
.875
0.850
0.825
GAS COMPRESSIBILITY FACTOR - (Z)
GAS COMPRESSIBILITY FACTORS FOR PUERTO CHIQUITO AND BOULDER RESERVOIRS
BOULDER
PUERTO CHIQUITO NORTHEAST
PUERTO CHIQUITO SOUTHWEST
RESERVOIR PRESSURE — PSIA

FIGURE NO. 3

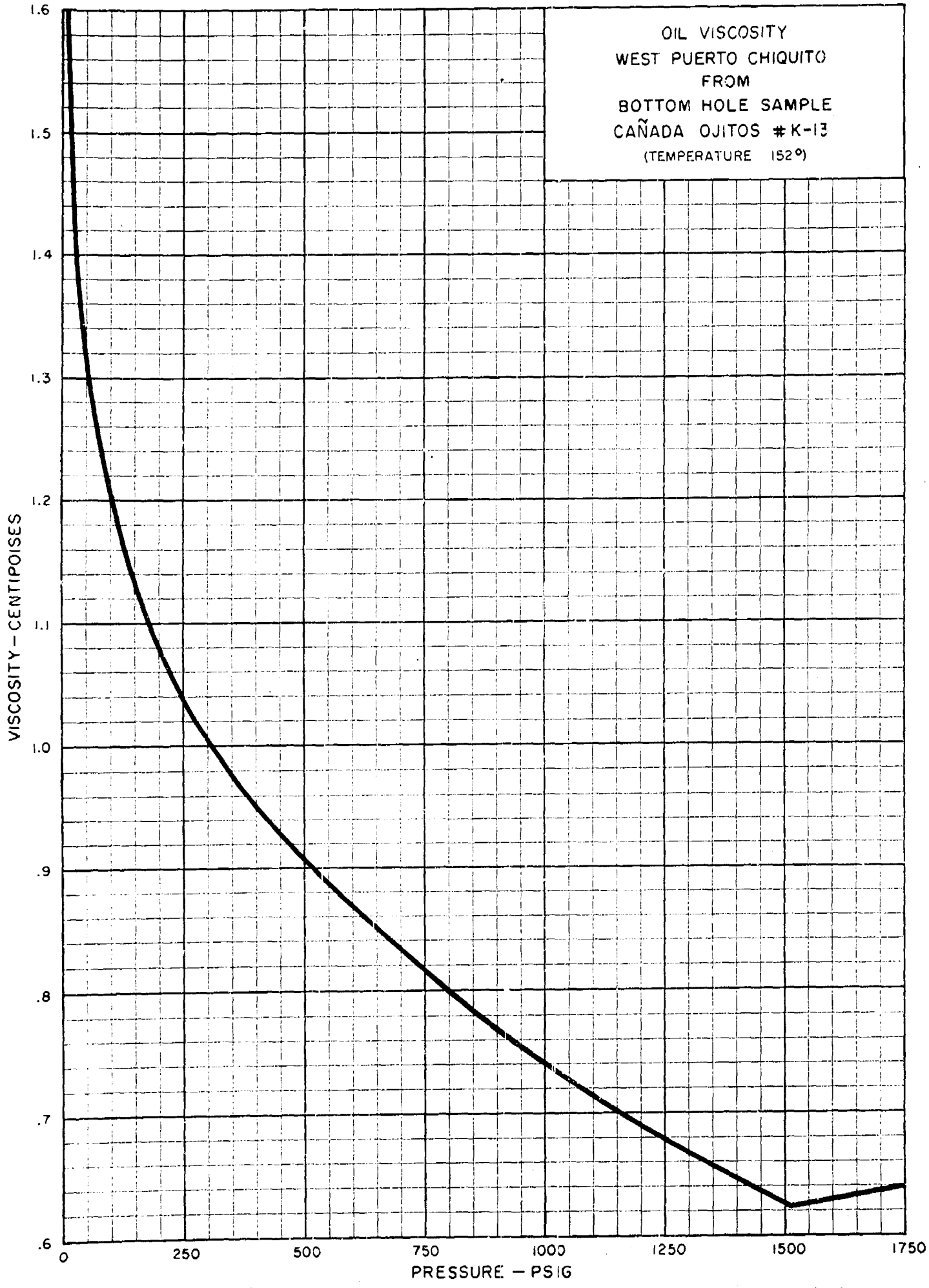

OIL VISCOSITY
WEST PUERTO CHIQUITO
FROM
BOTTOM HOLE SAMPLE
CAÑADA OJITOS # K-13
(TEMPERATURE 152°)
VISCOSITY – CENTIPOISES
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
0
250
500
750
1000
1250
1500
1750
PRESSURE – PSIG

FIGURE NO. 4

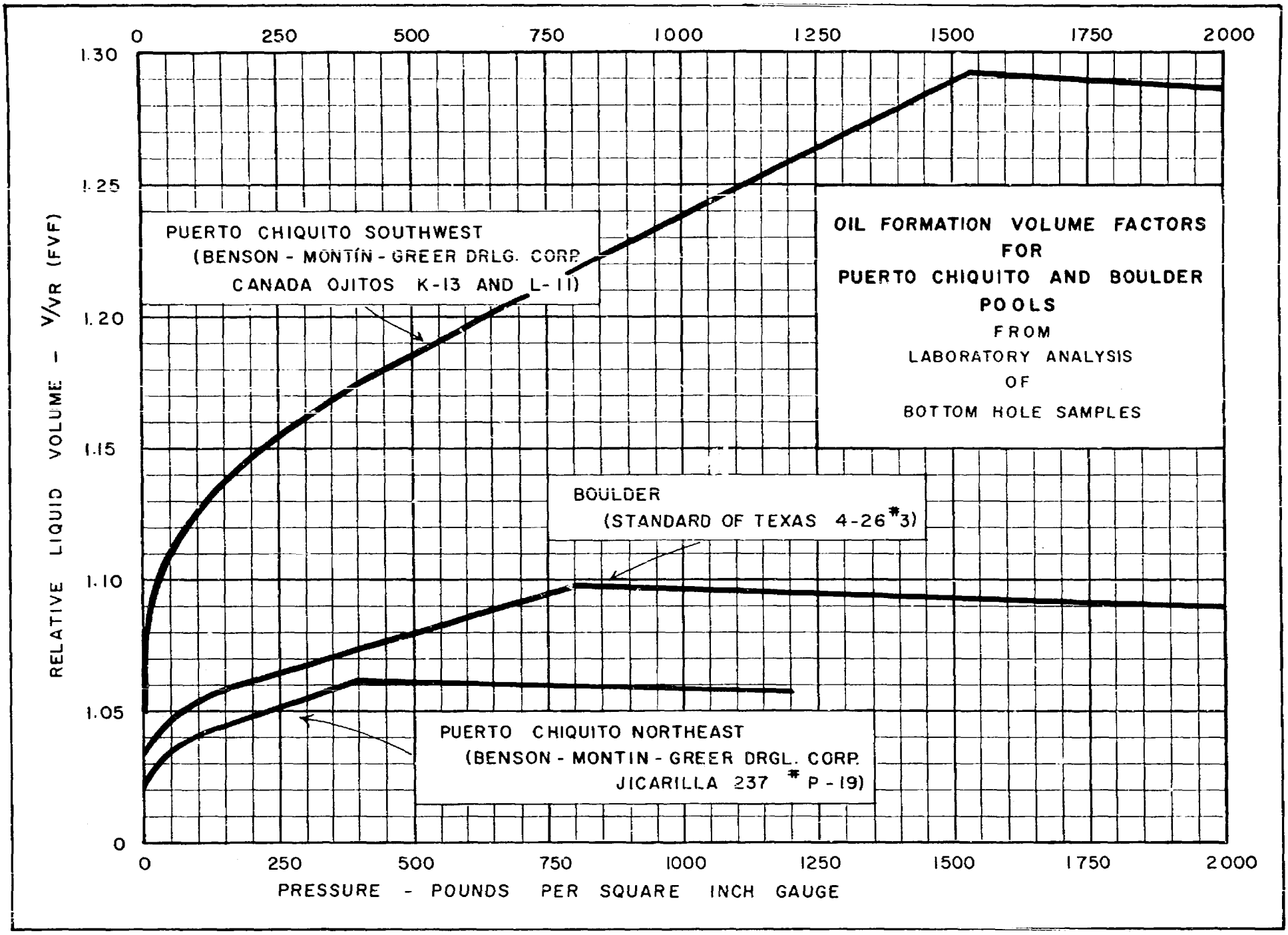

OIL FORMATION VOLUME FACTORS
FOR
PUERTO CHIQUITO AND BOULDER
POOLS
FROM
LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
PUERTO CHIQUITO SOUTHWEST
(BENSON - MONTÍN - GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26*3)
PUERTO CHIQUITO NORTHEAST
(BENSON - MONTIN - GREER DRGL. CORP.
JICARILLA 237 * P-19)
RELATIVE LIQUID VOLUME - V/VR (FVF)
PRESSURE - POUNDS PER SQUARE INCH GAUGE
0
250
500
750
1000
1250
1500
1750
2000
1.30
1.25
1.20
1.15
1.10
1.05
0

FIGURE NO. 2

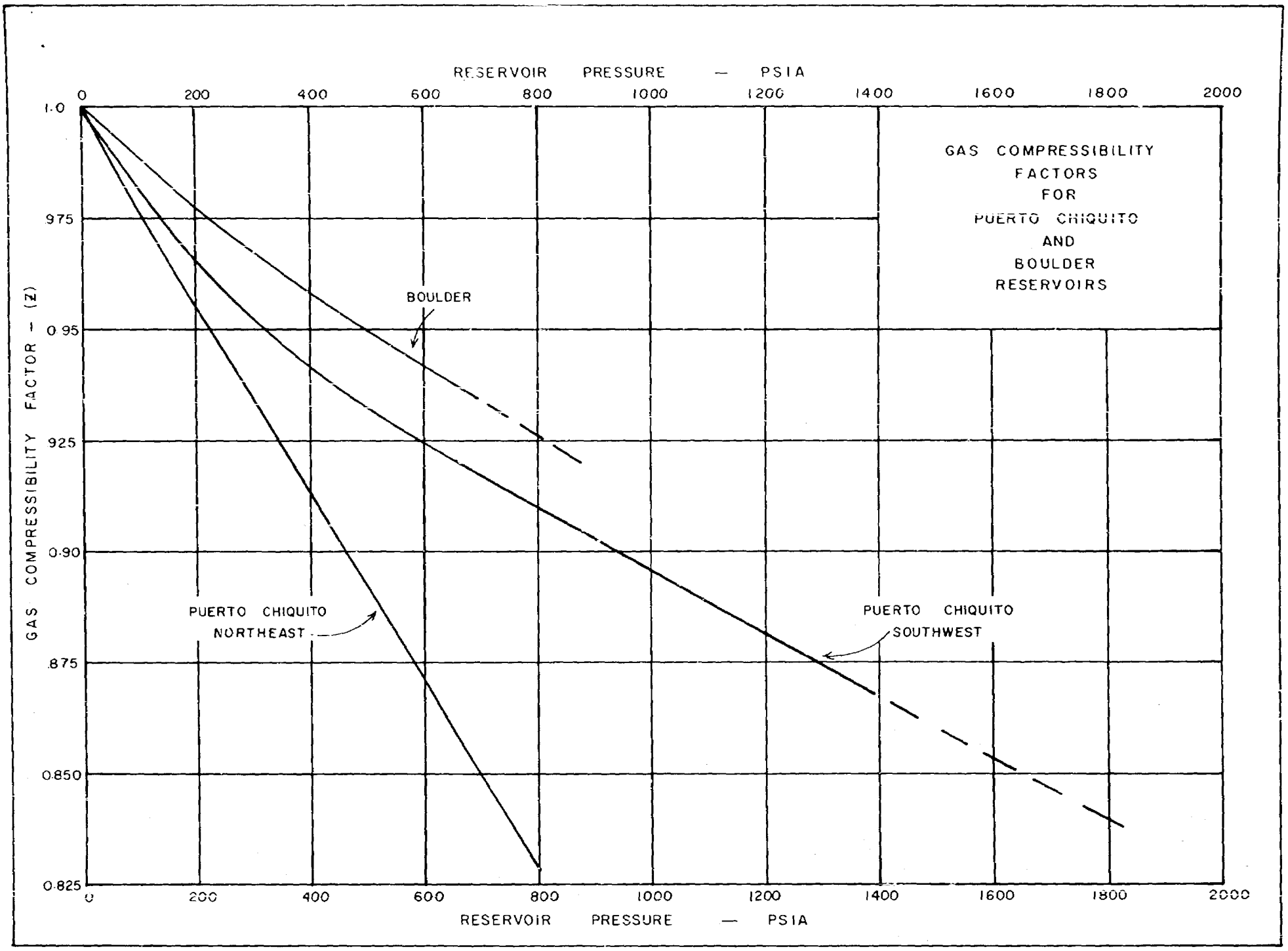

RESERVOIR PRESSURE — PSIA
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1.0
975
0 95
925
0.90
875
0.850
0.825
GAS COMPRESSIBILITY FACTOR — (Z)
GAS COMPRESSIBILITY FACTORS FOR PUERTO CHIQUITO AND BOULDER RESERVOIRS
BOULDER
PUERTO CHIQUITO NORTHEAST
PUERTO CHIQUITO SOUTHWEST
RESERVOIR PRESSURE — PSIA

FIGURE NO. 3

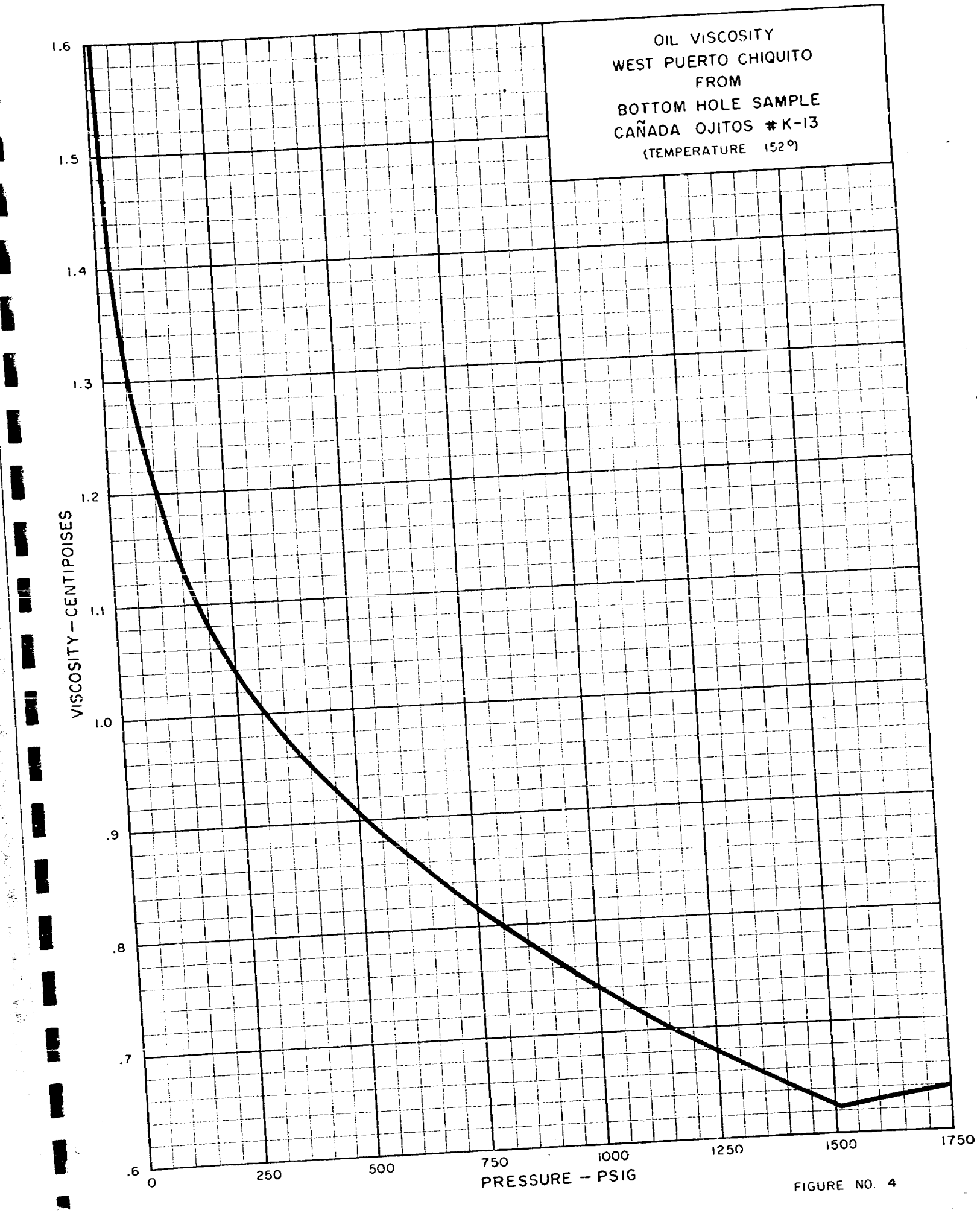

OIL VISCOSITY
WEST PUERTO CHIQUITO
FROM
BOTTOM HOLE SAMPLE
CAÑADA OJITOS #K-13
(TEMPERATURE 152°)
VISCOSITY — CENTIPOISES
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
0
250
500
750
1000
1250
1500
1750
PRESSURE — PSIG

FIGURE NO. 4

GRAVITY DRAINAGE RATES
WEST PUERTO CHIQUITO
FOR CONDITIONS OF:
OIL DENSITY 44.9#/cubic foot
GAS DENSITY 5.35#/cubic foot
OIL VISCOSITY .62 centipoises
FORMATION DIP 400 feet per mile

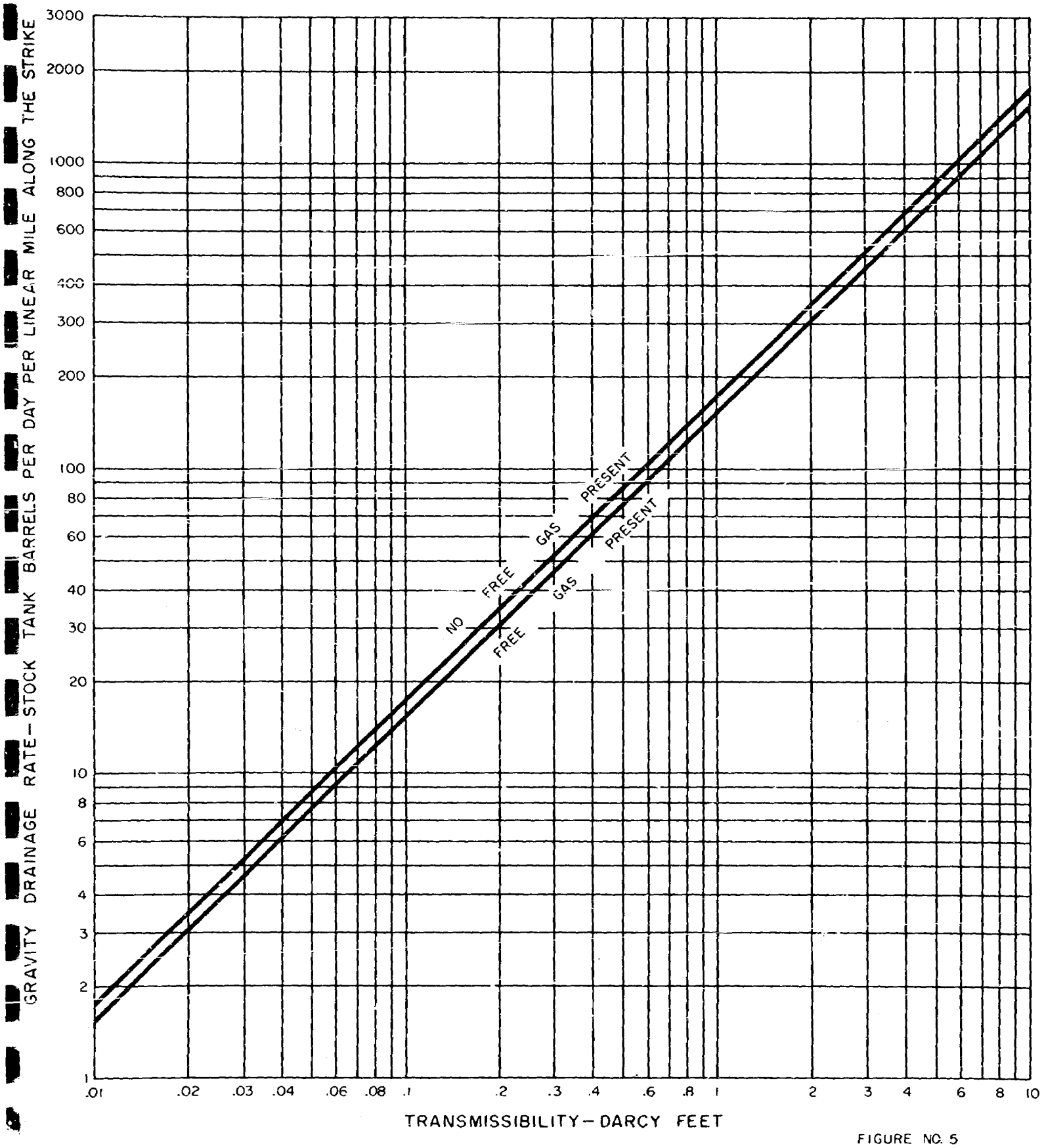


FIGURE NO. 5

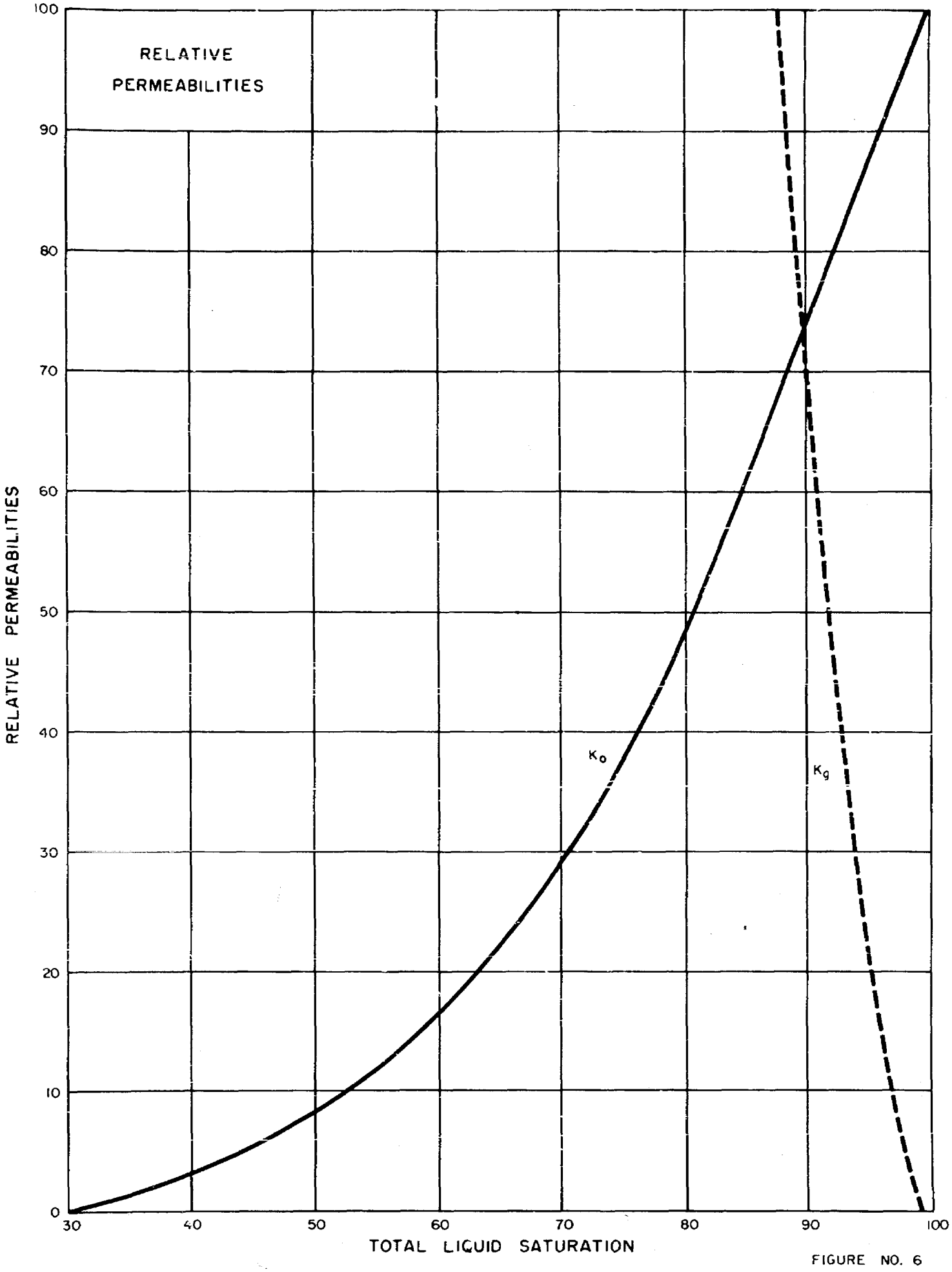

RELATIVE
PERMEABILITIES
RELATIVE PERMEABILITIES
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
K_o
K_g
TOTAL LIQUID SATURATION

FIGURE NO. 6

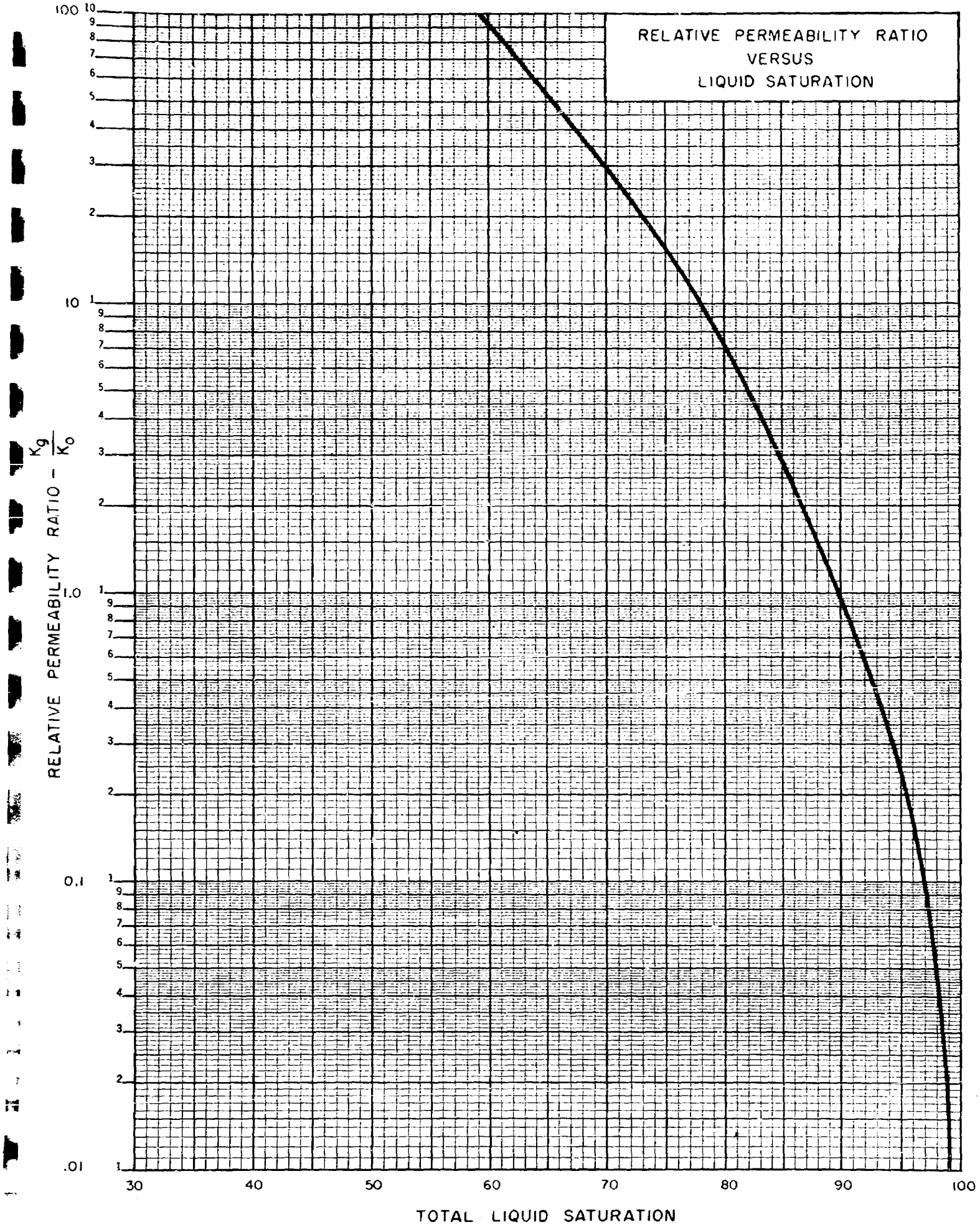

RELATIVE PERMEABILITY RATIO
VERSUS
LIQUID SATURATION
RELATIVE PERMEABILITY RATIO - $\frac{K_g}{K_o}$
100
10
1.0
0.1
.01
30
40
50
60
70
80
90
100
TOTAL LIQUID SATURATION

FIGURE NO. 7

SOLUTION GAS DRIVE
PRODUCTION HISTORY
CALCULATED FOR CONDITIONS OF:
WEST PUERTO CHIQUITO
PVT DATA
AND
K_g/K_o ESTIMATED FROM LABORATORY
DATA FOR FRACTURED FORMATIONS

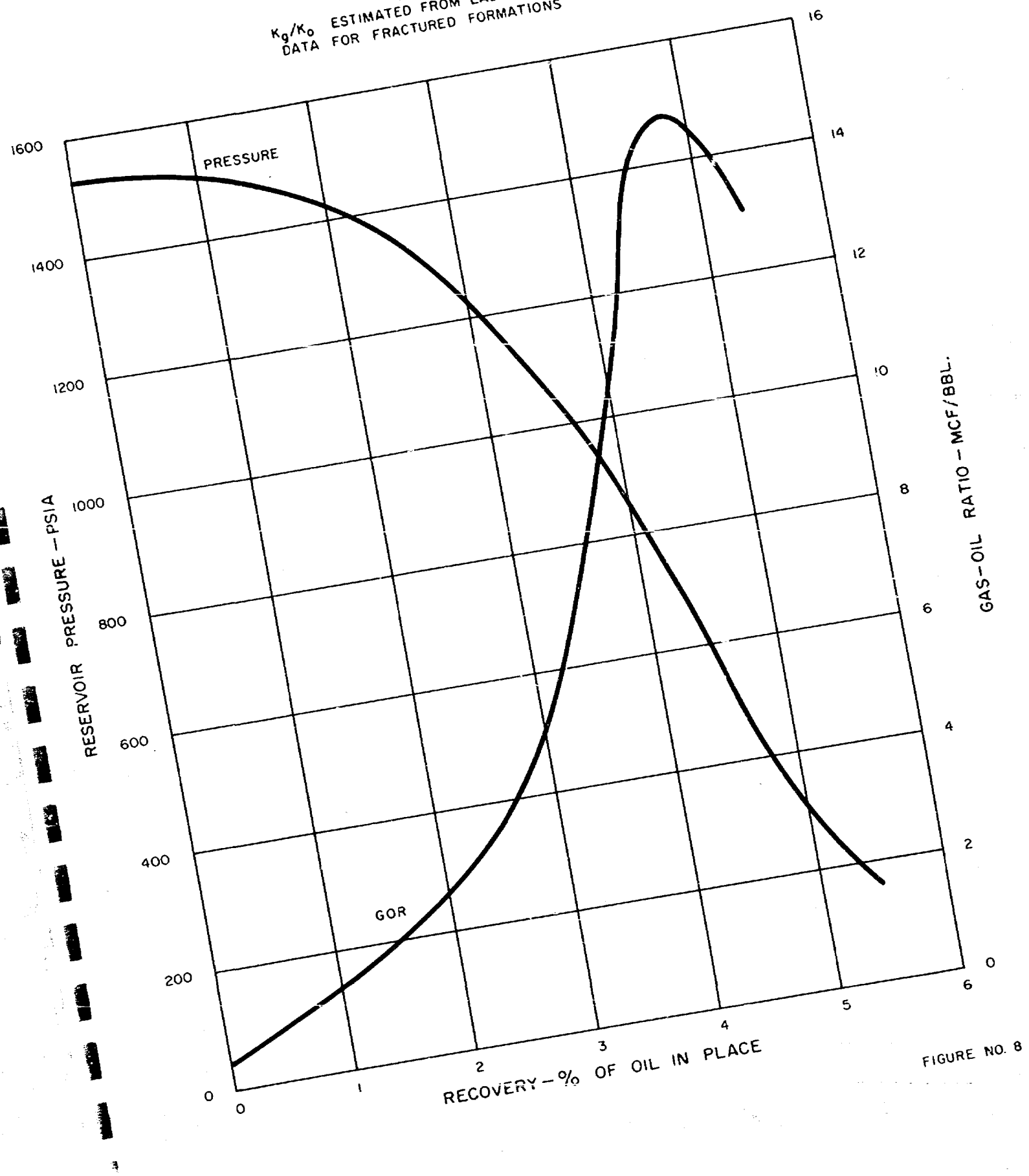


FIGURE NO. 8

GRAVITY DRAINAGE
PRODUCTION HISTORY

CALCULATED FOR CONDITIONS OF
WEST PUERTO CHIQUITO PVT DATA
ESTIMATED RELATIVE K_o
Complete Gravitational Segregation
Assumed

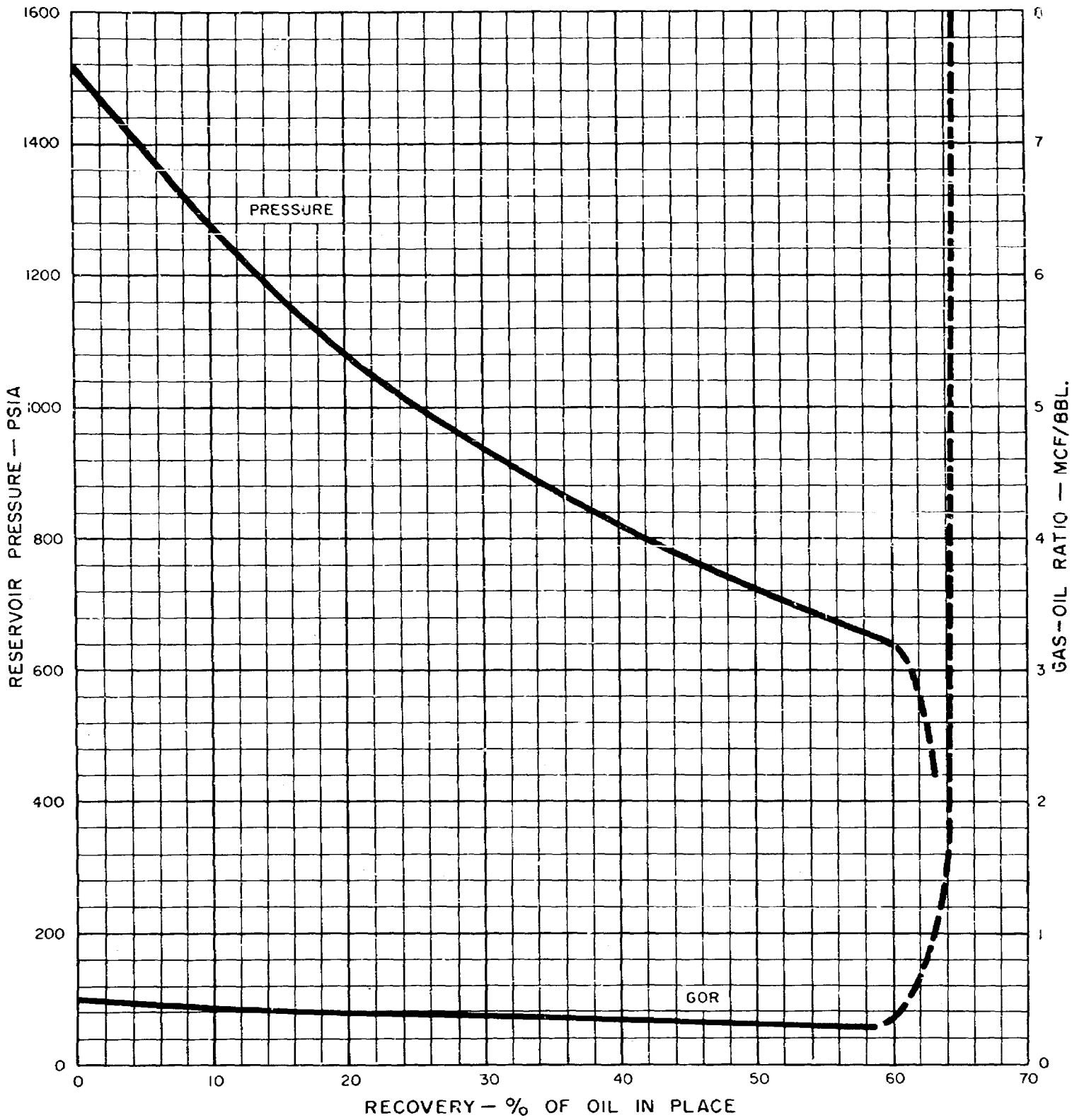


FIGURE NO. 9

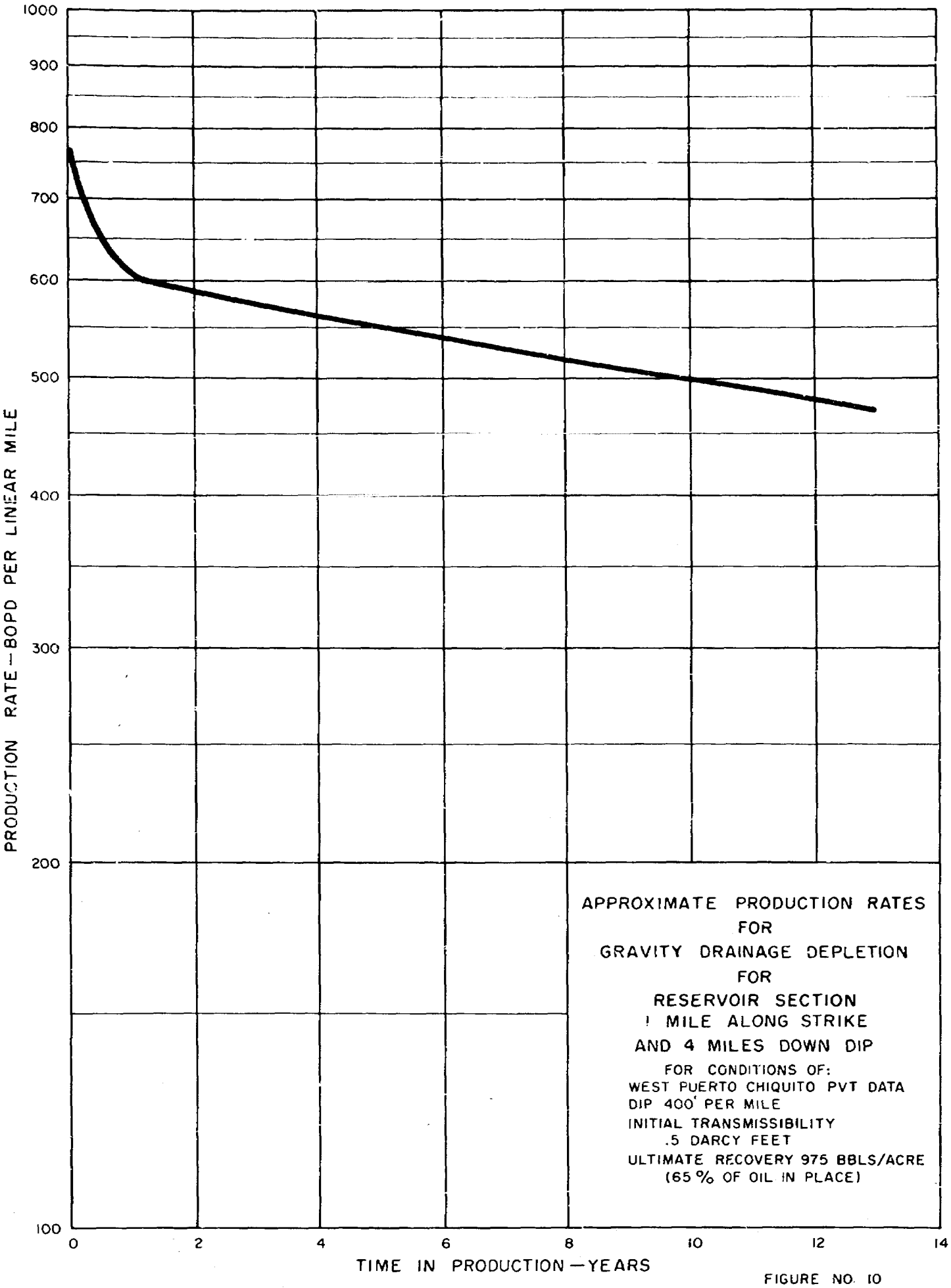
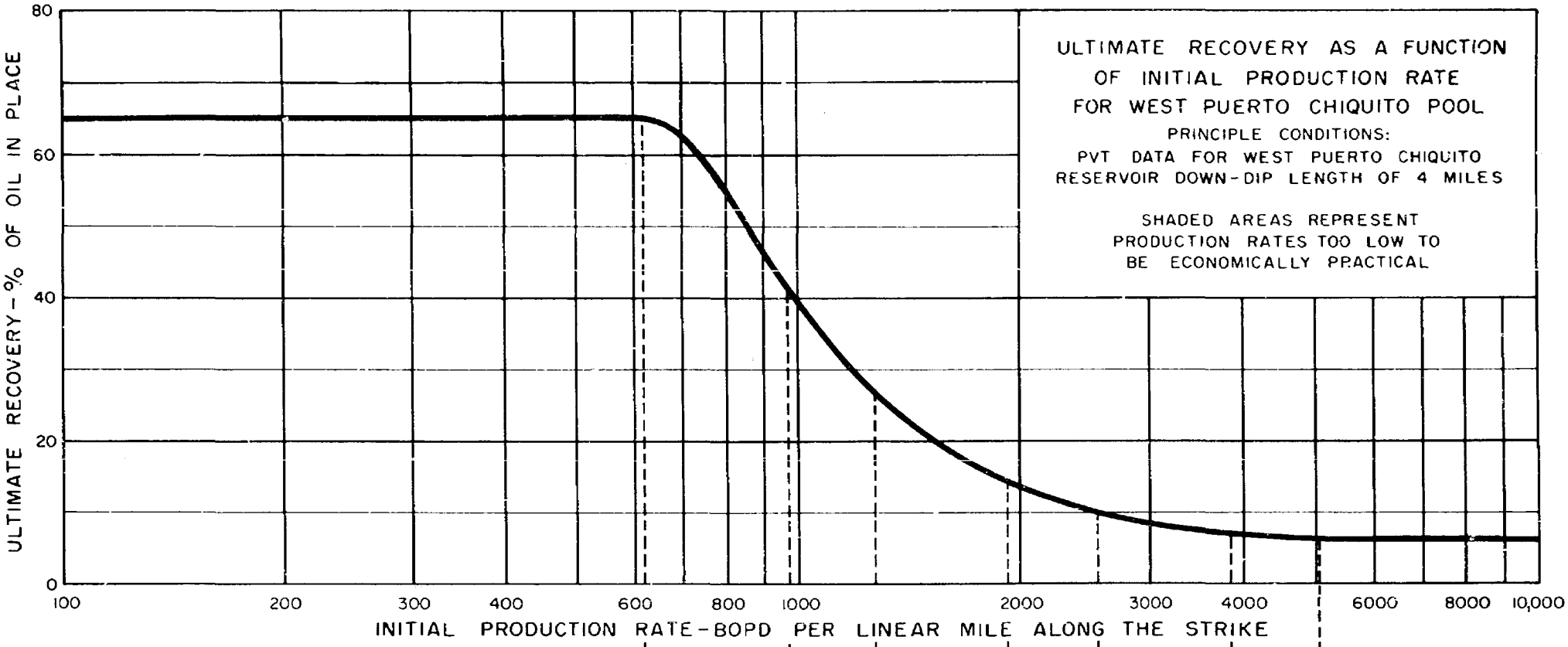

1000
900
800
700
600
500
400
300
200
100
PRODUCTION RATE – BOPD PER LINEAR MILE
0
2
4
6
8
10
12
14
TIME IN PRODUCTION – YEARS
APPROXIMATE PRODUCTION RATES
FOR
GRAVITY DRAINAGE DEPLETION
FOR
RESERVOIR SECTION
1 MILE ALONG STRIKE
AND 4 MILES DOWN DIP
FOR CONDITIONS OF:
WEST PUERTO CHIQUITO PVT DATA
DIP 400' PER MILE
INITIAL TRANSMISSIBILITY
.5 DARCY FEET
ULTIMATE RECOVERY 975 BBLS/ACRE
(65 % OF OIL IN PLACE)

FIGURE NO. 10



AVERAGE PRODUCTION RATE BOPD FOR	640 BOPD TOTAL	960 BOPD TOTAL	1280 BOPD TOTAL	1920 BOPD TOTAL	2560 BOPD TOTAL	3840 BOPD TOTAL	5180 BOPD TOTAL
40 ACRES/WELL (64 WELLS/LINEAR MILE ALONG STRIKE)	10	15	20	30	40	60	80
80 " " (32) " " " " "	20	30	40	60	80	120	160
160 " " (16) " " " " "	40	60	80	120	160	240	320
320 " " (8) " " " " "	80	120	160	240	320	480	640
640 " " (4) " " " " "	160	240	320	480	640	960	1280
1280 " " (2) " " " " "	320	480	640	960	1280	1920	2560
2560 " " (1) " " " " "	640	960	1280	1920	2560	3840	5180

FIGURE NO. 11

INCREASE IN RECOVERY
BY DEPLETION AT HIGH PRESSURE
AS COMPARED TO
DEPLETION AT LOW PRESSURE
FOR VARIOUS FINAL OIL SATURATIONS

CONDITIONS: HIGH PRESSURE 1500#
F.V.F. = 1.29
LOW PRESSURE 50#
F.V.F. = 1.11
CONNATE WATER SATURATION = 10%

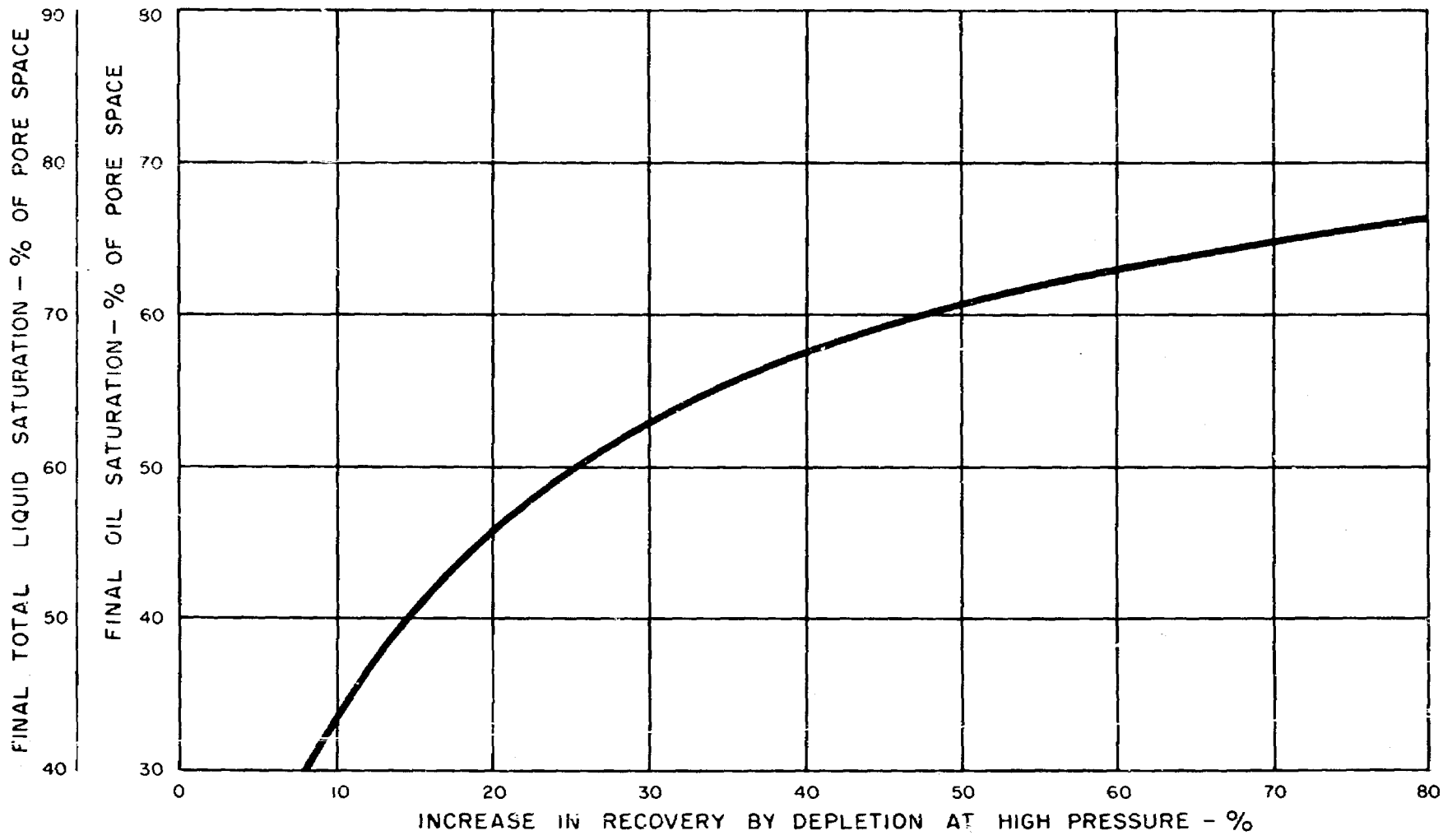


FIGURE NO. 12

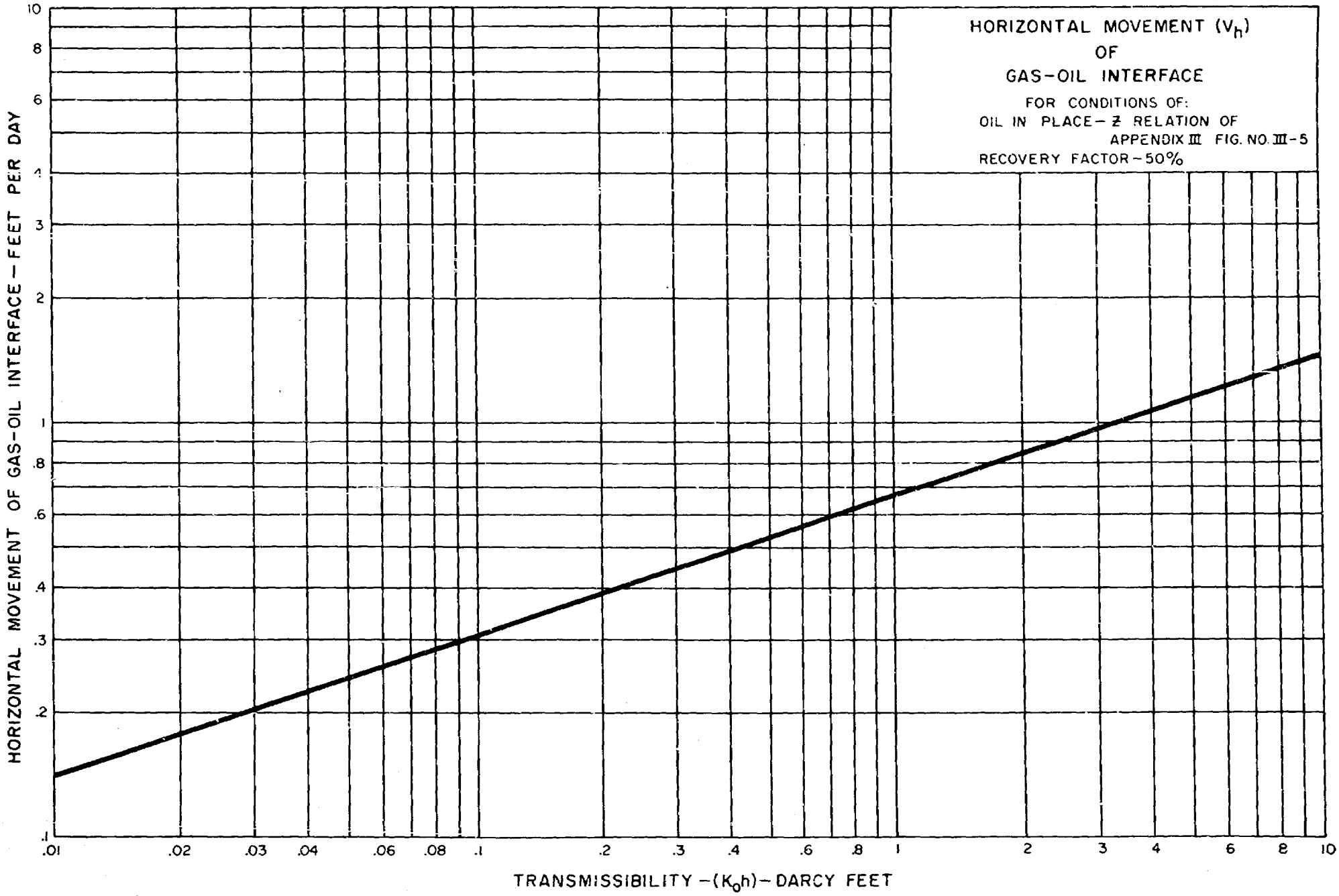

HORIZONTAL MOVEMENT (V_h)
OF
GAS-OIL INTERFACE
FOR CONDITIONS OF:
OIL IN PLACE - ∄ RELATION OF
APPENDIX III FIG. NO. III-5
RECOVERY FACTOR - 50%
HORIZONTAL MOVEMENT OF GAS-OIL INTERFACE - FEET PER DAY
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
.01
.02
.03
.04
.06
.08
.1
.2
.3
.4
.6
.8
1
2
3
4
6
8
10
TRANSMISSIBILITY - (K_oh) - DARCY FEET

FIGURE NO. 13

RELATION OF INJECTED GAS
TO
RESERVOIR DISLACEMENT VOLUME
FOR CONDITIONS OF:
RESERVOIR TEMPERATURE 150°
Z FACTORS OF WEST PUERTO CHIQUITO GAS

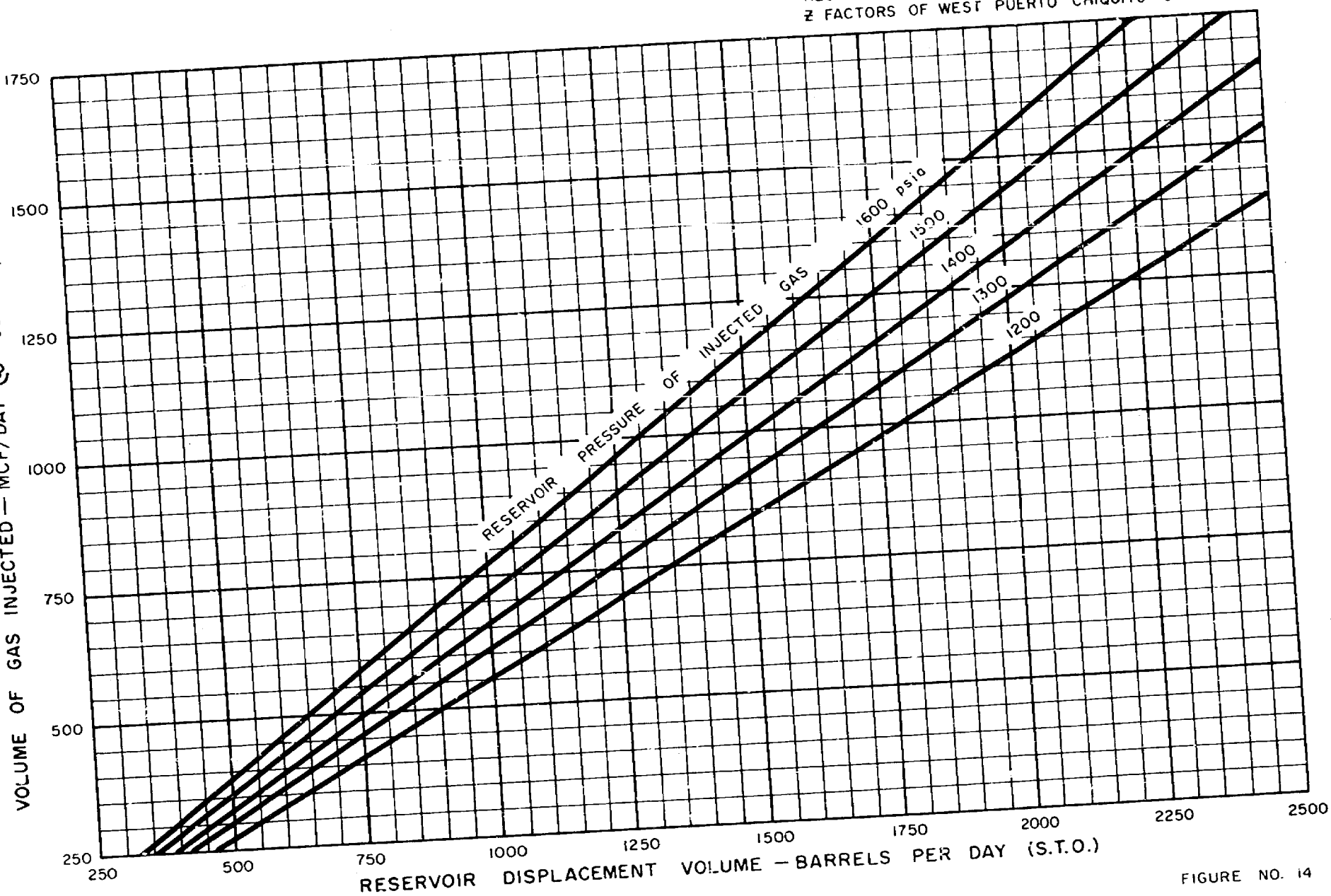


FIGURE NO. 14

APPENDIX I

PART A - INDIVIDUAL WELL TRANSMISSIBILITIES

Tests to determine individual well transmissibilities are identified below and the results are summarized as follows:

1. Cañada Ojitos Unit L-11: This is a production (pressure draw-down) test conducted September 24, 1965. Results of this test are shown on the graph at the end of this appendix, Figure No. I-1. This shows a transmissibility of .45 darcy feet, when analyzed in the conventional manner, as indicated by the calculations on the graph.

2. Cañada Ojitos Unit A-23: This is a pressure build-up test conducted May 14 to 20, 1965. Results of this test are shown in this appendix on Figure No. I-2. This test shows two distinctly different slopes. The first shows transmissibility of .025 darcy feet and the second a transmissibility of .206 darcy feet. The second slope is believed to indicate an area which more or less surrounds the first area of low transmissibility.

3. Cañada Ojitos Unit K-13: This is a pressure fall-off test conducted on the injection well K-13 on October 16, 1969, approximately 14 months after the well first went on injection. The calculated transmissibility, as shown on Figure I-3, of .0182 darcy feet results from permeability to gas. The oil saturation of the local area represented by this test is not known. The area was probably not 100 percent gas saturated at the time of the test. Accordingly initial permeability to oil when the area was completely liquid saturated probably was a little higher - perhaps .025 darcy feet.

4. Cañada Ojitos Unit E-10: A production (pressure draw-down) test was conducted on this well December 6 and 7, 1967. Data from this test were used to construct the graph at the end of this appendix, Figure I-4, which indicates a transmissibility of 1.5 darcy feet.

5. Cañada Ojitos Unit P-11: This is a pressure build-up test measured on this well in February, March and April of 1964. The data from this test is shown on the graph at the end of this appendix, Figure I-5. This indicates a transmissibility of 1 darcy feet.

Details of the tests, 1 to 5 above, are not included here. It is believed that the accuracies of the data shown on each of the graphs, Figures I-1 through I-5, are adequate for the analyses for which the data are used. In this regard the following information is offered respecting each test, along with remarks concerning suitability of the reservoir and conditioning of the wells for the tests.

Figure I-1: This test was made in conjunction with an interference test in which all of the wells in the reservoir were shut in for approximately two months and one well (P-11) put on production and produced until reservoir conditions approached those of steady state, at which time the subject well (L-11) was put on production. This well was produced for three days the first week in September, and then shut in again until the production test commenced September 24, 1965. Producing bottom hole pressures were determined by measuring the surface casing pressure and adding the calculated pressure differential from surface to the pay zone. During the test the casing was shut in and all gas and oil were produced through the bottom hole pump and up the tubing. The static

bottom hole pressure was known within one or two pounds at the time the test started, and from this information and the surface casing pressure it was possible to calculate the level of the oil in the casing above the pump at the time the test started. As the casing pressure dropped with commencement of production, the gas in the casing expanded, and from this expansion at any one time it was possible to calculate the depth of the fluid level as it dropped down the hole. Knowing the top of the fluid level, along with the pressure-volume relation of the oil with its dissolved gas (from fluid sample analysis) it was possible to calculate the working bottom hole pressure at the pay zone. Graph showing this pressure differential from surface casing pressure to the pay depth of 6,660 feet for given fluid levels is shown at the end of this appendix, Figure No. I-11. After the well has produced for some time and the fluid level has dropped to the pump, it will stabilize at approximately this position. Working bottom hole pressures determined after the fluid level has reached the pump are of course not quite as accurate as the ones calculated as described above. Such pressures are useful, however, in determining approximately the working bottom hole pressure over a period of time, and to be indicative of pressure changes and degree of stabilization. Such a method was used (bottom line of Figure I-11) to determine the stabilization of the subject well during the interference test in which the A-14 was an observation well. This test and data were recorded at the 1966 spacing hearing. As determined from these pressures measured over a period of several weeks, it is apparent that the well essentially reached stabilization, as far as the relatively tight area of .45 darcy feet around the well is concerned,

by the end of .5 days (pressure 1,490 pounds shown on Figure I-1). The change in slope of the pressure decline versus time on Figure I-1 at about 1,520 pounds could be the result either of boundary conditions leading to stabilization in .5 days, or partially due to the high compressibility of the oil below bubble point (1,520 pounds) pressures. It is doubtful that this would be a significant factor, however, as the pressure in the formation immediately outside the well's "effective well bore radius" would be substantially higher, and accordingly the pressures of the oil which would control the measured pressures of the effective well bore radius would be at levels higher than the bubble point, and accordingly would have the normal under-saturated compressibility. Therefore, except for the influence of the rather large effective well bore radius, which forms a part of the geometry of this well's immediate reservoir area (and as more fully discussed in Appendix II herein) the transmissibility of .45 darcy feet as indicated on Figure I-1 is considered quite accurate.

Figure I-2: This test was conducted within a month after the well was completed. Frac oil was recovered April 27 and the well produced for a few days at rates approximating 100 barrels per day. The well was shut in May 4 to May 11 and then produced for three days until it was shut in May 14. During this time it produced an average of 86 barrels per day, at individual daily rates as follows: 96, 80, 83. Accordingly, the figure of 85 barrels per day was used in the calculation shown on Figure I-2. As can be seen from Figure I-2, time to reach steady state conditions for this well is about 80 hours, and accordingly the three days it was produced prior to the time it was shut in for this test would be adequate to condition the well for such a test. Two bottom hole

pressures were run on this well, one on May 17 and the other on May 20 (at 79 and 152 hours respectively, following shut-in). These measured bottom hole pressures were within 1.4 pounds, the latter test being the lower, and are well within the accuracy to be expected from these instruments. Other pressures shown on the graph were determined from fluid levels, and calculated density of the oil. The density of the oil was determined from the average pressure of the two bottom hole pressure tests and the average fluid levels at the times of their measurement. From this density the pressures were calculated by multiplying by depth of fluid above the pay zone. It is possible, of course, that the density of the oil column was not exactly the same throughout the test. If a variation exists it probably would be the result of lower density of fluid entering the hole after the pressure reached 1,520 pounds, as it would be at the saturated oil density. If this were the case, the first pressure shown would be slightly higher and the resulting transmissibility also slightly higher. It could be on the order of .03 darcy feet. This is believed, however, to be the probable limit of error in this particular test. The other transmissibility, .206 darcy feet, is probably within 5 or 10 percent.

Figure I-3: This is a pressure fall-off test conducted on a gas injection well. Surface pressures at the beginning and end of the test were measured with deadweight tester and intermediate pressures determined by correlating the pressures shown on a recording pressure gauge with the deadweight pressures taken at the beginning and end of the test. The well is believed to have reached close to static conditions at the end of the test (approximately one day). This fact was determined by a subsequent pressure fall-off

test, in which the well was tested for approximately 50 hours. Working bottom hole pressures were calculated from gas gravity, temperature and deviation factors. This is believed to be a rather accurate test. As indicated in the remarks above, permeability to oil, of course, would be something greater than that shown for permeability to gas.

Figure I-4: The subject well of this test, the E-10, is a high capacity well. It was completed in August of 1967, and produced at rates of approximately 400 barrels per day for August and September, and 250 barrels per day for October and the first 20 days of November. The last 10 days of November it was produced at the rate of approximately 50 barrels per day, in order to achieve as nearly as possible a column of gas from the surface of the ground to the pump on subsequently shutting the well in. It is believed this was accomplished. Accordingly, when the test was commenced on December 6, a continuous column of gas existed from the surface to the pump depth of 6,100 feet. The well is completed through perforations at about 7,000 feet. It was produced during this test at the rate of 460 barrels per day for two days. "Stabilization" as to the area in the vicinity of the well was reached after about 24 hours. The surface casing pressure dropped about 25 pounds the first two hours and another 25 pounds in the next 24 hours. This is equivalent to a bottom hole working pressure decline of approximately 40 pounds per cycle. This 40 pounds per cycle is plotted on the graph, Figure I-4. A sensitive pressure recorder was calibrated and used for this test. Unfortunately these records are not available at this time, so the exact casing pressure cannot be plotted as was done in the other tests. However, another

uncalibrated recorder was also on the well, and although not as sensitive as the primary recorder, its chart reflects the pressure drops as quoted above. Since this recorder was not as sensitive as the primary recorder, no effort has been made to read intermediate pressure points. It is believed, however, that this pressure-time relation of 40 pounds per cycle is as accurate as ordinary field data obtained for such tests.

Figure I-5: Pressures for the first 10 days of this pressure build-up test were taken by running a bottom hole pressure bomb down a string of Kobe tubing and leaving it for 24 to 48 hours, at which time it would be retrieved, a new chart put in, and pumped back to bottom. A Humble type bomb was used, and it exhibited a certain amount of hysteresis which made the initial points more indefinite than usual. After 9 days the tubing was pulled and pressures measured in the normal fashion by running the bottom hole pressure bomb to near the pay zone. After being shut in 23 days, the offsetting well, the A-14, was shut in, and an immediate pressure reaction was observed because of this. Pressures shown on this figure have been adjusted to a datum of + 1,195 feet. Actual well pressures were approximately 100 pounds higher than this at the pay zone. Accordingly, and in view of the bubble point pressure of 1,520 pounds, it is apparent that nearly all of this test was conducted at pressures above the bubble point, and from this standpoint it can be considered a suitable test.

PART B - TRANSMISSIBILITY DATA FOR LARGE AREAS OF THE RESERVOIR

Transmissibility data for large areas of the reservoir are available from three sources. Each of these is discussed below.

i. 1965 Interference Test

This was a reservoir-wide interference test, conducted by first shutting in all wells in the reservoir and measuring interference effects on the shut-in wells as each test well was put on production. Details of this test and interpreted results were reported to the New Mexico Oil Conservation Commission at the 1966 spacing hearing. These details are not repeated here. To review briefly, however, the interference effect on the observation well is shown on the graph at the end of this appendix, Figure I-6, the results of which, as to transmissibility, are calculated from the plot of this data shown on Plate II of Figure I-7. In summary, this shows transmissibility, uncorrected for boundary effects, of 4.8 darcy feet. A 30 percent adjustment was applied for assumed but unknown boundary effects, to arrive at 6.2 darcy feet. Since the oil in all except the highest up-dip points of the reservoir was at that time at pressures above the bubble point, diffusivity constants would have been high for all points of the reservoir, even the tight parts, and accordingly this test is believed to be a fair representation of an exceptionally large part of the reservoir and its overall average. The indefinite feature, of course, is the effect of unknown boundaries. Since a nearby straight-line boundary would have a maximum effect of two to one, it is assumed that the

overall average reservoir transmissibility lies between the values of 5 and 10 darcy feet. This test is thought to be representative of a rather large area, of the order of 5,000 to 10,000 acres.

As additional information is developed on the geometry of the reservoir and other influencing features, as perhaps directional alignment of the main fractures, it may be possible to put a closer value on the transmissibility as calculated from this particular test. At this time, however, no change is suggested from that initially calculated.

ii. 1968 Interference Test

As a result of commencement of gas injection August 9, 1968, at relatively high rates (equivalent to reservoir displacement rates of approximately 1,500 barrels per day of stock tank oil) transient pressure disturbances were created. These effects were measured by the observation well pressures (as determined by fluid level measurements). The injection well was the K-13 and the observation well the A-23. Pressures in the vicinity of the injection well were some 200 pounds below the bubble point, and accordingly oil in the area affected was saturated, and the resulting diffusivity constant of this area was considerably smaller than that obtaining at the time of the first interference test in 1965. Accordingly reaction times were much greater. Even so, because of the large volume injected, interference was of a great enough magnitude that its effect on the A-23 observation well some 3,700 feet away was adequate to provide information for a satisfactory interference test and calculations of transmissibility and oil in place.

The fluid levels measured, along with production and injection data, are shown at the end of this appendix on the graph, Figure I-8. Another plot of the fluid levels is shown on Figure I-9, along with calculated curves for different assumed conditions. Because of the low diffusivity constant involved, boundary conditions affected the pressure build-up in the observation well before the time at which the exponential integral function became a straight-line relation with the logarithm of time. Consequently it was not possible to measure reservoir transmissibility directly, as was done in the 1965 interference test. To calculate transmissibility and pore volume from this test it was necessary to assume values for these properties and determine by trial and error the set of conditions which best fitted the data.

These conditions are a transmissibility of 1.8 darcy feet and a pore space of 1,600 barrels per acre of stock tank oil volume. Although not shown, variation of 30 percent of oil in place results in curve displacement from the measured data of the same order of magnitude as that shown for the curves with transmissibility of 1 and 4 darcy feet, and accordingly it is believed little error is introduced in the calculated transmissibility of 1.8 darcy feet because of the unknown value of the exact pore space.

The abrupt levelling of the fluid levels between the 50th and 55th day after start of injection is believed to be the result of some type of boundary condition. Effects of two types of possible boundary conditions have been calculated and the results shown on Figure I-10. Although the resulting curve No. 3 of this figure does not follow exactly the measured fluid levels, it does indicate that essentially stabilized conditions could exist at about

60 to 70 days after gas injection started, if the reservoir properties are those used in the calculations as shown on Figure I-9.

It is probable that the transmissibility for the area represented by this test was higher when the reservoir was first discovered than at the time of this test in 1968. It is assumed that some of the gas which evolved from the oil as the pressure dropped below the bubble point stayed in the area of the test, reducing the permeability to oil and resulting transmissibility. Also it is believed that some of the initial volumes of gas liberated migrated to the gas cap. Since just prior to the test the pressure was being constantly reduced, it would be necessary for some gas to remain in the area, simply because it would not have had time to move to the gas cap. As a result, the permeability to oil at the time of this 1968 interference test must have been substantially less than it was in the 1965 interference test. For the range of probable values of gas saturation, the permeability to oil at the time of the 1968 test is estimated to be in the range of 50 percent to 80 percent of its initial value. This means that the initial transmissibility of this area was in the range of 2.3 to 3.6 darcy feet. The area whose reservoir properties are represented by this test is believed to be about 2,000 to 3,000 acres.

iii. 1969 Steady State Line Drive Transmissibility Test

By the end of September, 1969, gas injection had been in operation for about 14 months and reservoir pressures had stabilized. The A-14 well commenced producing substantial quantities of free gas in May and caused a decline in reservoir pressure during

the months of May, June and July. This well was shut in about the middle of July, and as a result, pressures remained quite stable for the months of August and September. Flow tests were conducted on the E-10 the last of September (September 21 to 30, 1969). Summarized pressure and production data for this test are shown on the schedule at the end of this appendix, Figure I-13. This shows a productivity index of 4.2 BOPD per pound for this well while producing at the rate of approximately 770 barrels per day. From this productivity index data and the geometry of the flow system it is possible to estimate the transmissibility of the area between the A-23 observation well and the producing well, the E-10.

At this time the reservoir was unquestionably producing under steady state conditions. For over a year approximately the same volume of gas had been injected in the reservoir as reservoir space voided by the producing wells. Except for the period of time when the A-14 was producing excessive volumes of gas, pressures in the oil area were stabilized. This is evident from the pressures in the A-23 observation well, which is below the gas-oil contact, during this test. Also, the working casing pressures on the producing wells, for the same rates of flow and for the times pressures were stabilized in the A-23 observation well, were also stabilized.

It is believed the injected gas has formed a gas-saturated area in the vicinity of the injection well and spreading up-dip and along the strike northeast and southeast from the injection well. With the low viscosity of the gas as compared to oil, the gas is undoubtedly forming a secondary gas cap, with a strong tendency for the gas to form a level gas-oil interface along the strike of the

formation, which is approximately north and south. The result of this, as far as flow system for the producing wells is concerned, means that rather than the injected fluid exerting pressure, as from a point source, its effect is more in the form of a north-south line drive (moving from east to west). From wells drilled northwest and southwest of the E-10 it is apparent that the area of high transmissibility ends immediately west of the E-10. Its west line of termination probably follows the strike of the formation in a north-south direction. Although wells exist west of the E-10 in the reservoir and in communication with it, from the standpoint of the calculation of transmissibility, its variation is so great that the area just west of the E-10 will have an effect on pressure distribution as though it were a boundary. Accordingly the flow system can be likened to a north-south line drive from the observation well, the A-23, to the E-10 producing well, with a near north-south boundary west of it. The geometry of this flow system can also be compared to a semicircle with a radius distance equal to that from the E-10 up-dip to the point of known pressure (approximately 10,000 feet). The base of the semi-circle would be a north-south line running near the E-10. As shown later, the operating pressure in the E-10 would be about the same for a geometry somewhat like either of the two described above. It is believed, however, that the true situation is more like that of a line drive.

The basic line drive formula used is shown at the end of this appendix on Figure I-14. This formula is for an infinite distance from the line source past the well and beyond. To

accommodate the formula to the situation of a boundary near the well and parallel to the line drive source, it was assumed the pressure would be approximately 1.9 times that shown for the regular line drive formula. A distance of 20,000 feet was assumed for the north-south length of the line. Calculations were also made assuming the geometry of the flow system to be that of a semicircle with a radius of 10,000 feet. The results of these calculations are set out below for well bore effective radii of 1 foot and 10 feet:

r_w (Feet)	TRANSMISSIBILITY, DARCY FEET FOR FLOW SYSTEM GEOMETRY OF: Line Drive	Semicircle
1	9.5	8.7
10	7.5	6.5

From the above information it appears that the reservoir transmissibility in this area would be something in excess of 6.5 darcy feet. Other factors which influenced the test, and which could of course influence the calculated transmissibilities if their exact effects were known, are the following:

1. Two additional wells were producing in the area of the test at the time. One was the L-11 and the other the A-22. It is believed the effects of these wells in this test would be minimal, however. The wells were producing at approximately the same rates and their interference effects on the producing well, the E-10, and the observation well, the A-23, would just about cancel out. The A-22 is closer to the observation well than it is to the E-10, and accordingly would be expected to draw the pressure down in the A-23

as a result of its production to a greater extent than it would affect the E-10. The L-11, on the other hand, is closer to the E-10 than to the observation well, and it would have a similar but counteracting effect. The relative distances of these two wells is almost exactly the same, that is, the distance from the A-22 to the A-23 is almost exactly the same as the distance from the L-11 to the E-10. Also, the distance from the A-22 to the E-10 is almost the same as the distance from the L-11 to the A-23. In view of this, it is believed the interference effects of these two wells on the test would be so small that they can be disregarded. Therefore no attempt was made to adjust the calculations for these effects.

2. The working pressure in the E-10 was some 115 pounds below the bubble point. This means that the pressure draw-down is greater than it would have been had the oil been under-saturated. The effect of this, if a correction could be applied for it, would be to increase transmissibilities above those shown above.

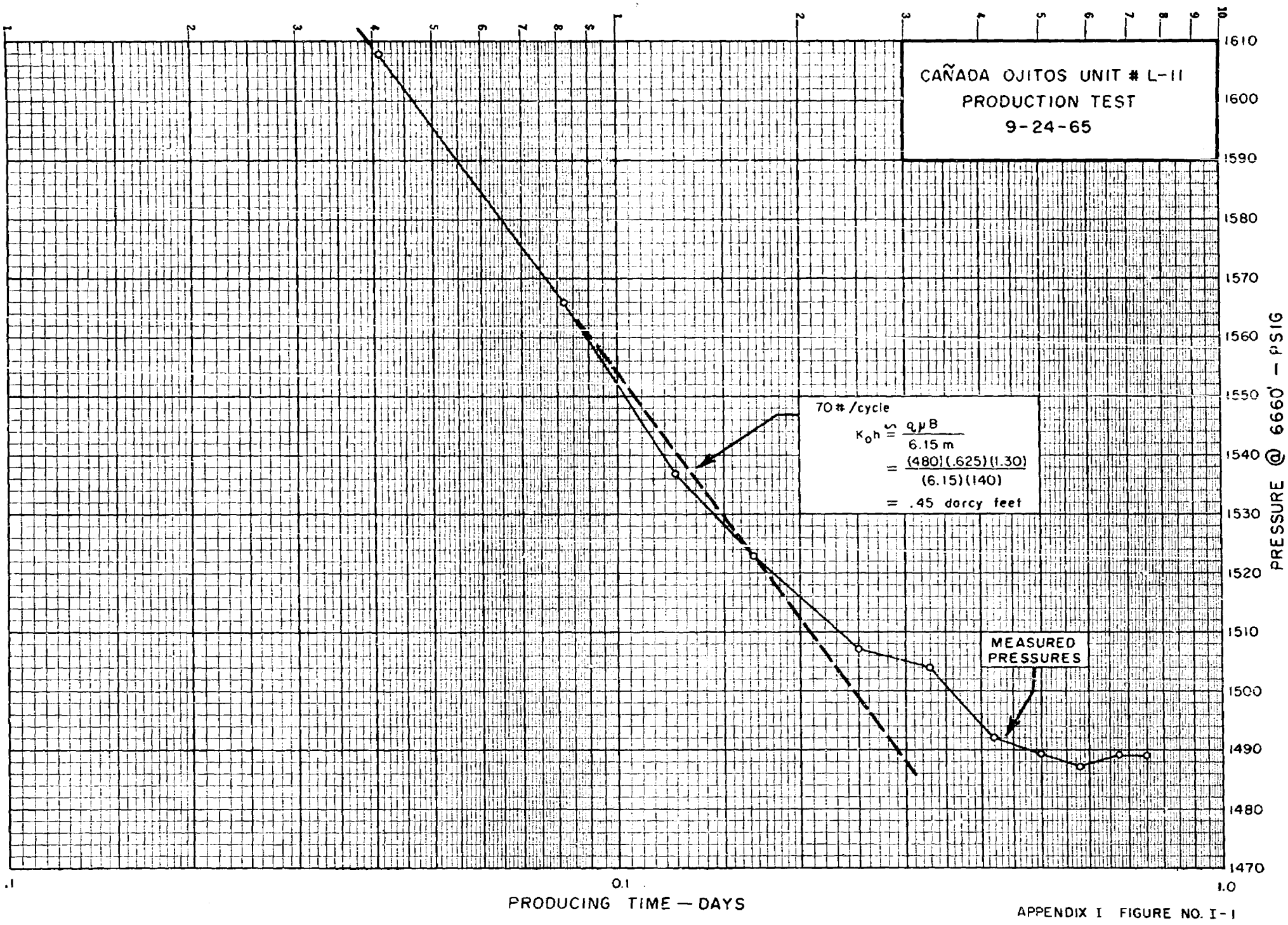
3. As shown by the interference test in this appendix, Figure I-4, this well had a transmissibility in the vicinity of the well bore of only 1.5 darcy feet. This appears to be only about 15 percent of the average reservoir transmissibility in the area of this line drive transmissibility test. Accordingly, to determine the proper pressure draw-down to be used in measuring reservoir transmissibility, a correction should be applied for this exaggerated pressure drop. This could easily be a correction of as much as 50 pounds in the 183 pound pressure draw-down. Accordingly a correction for this error would indicate the above listed transmissibilities should be increased by approximately one-third.

4. It is impossible, of course, to calculate exactly the working bottom hole pressure of the E-10 from the data available. The 183 pound pressure draw-down could be in error by as much as 20 or 30 pounds. It is believed the error would not exceed this, however. This error could be in either direction.

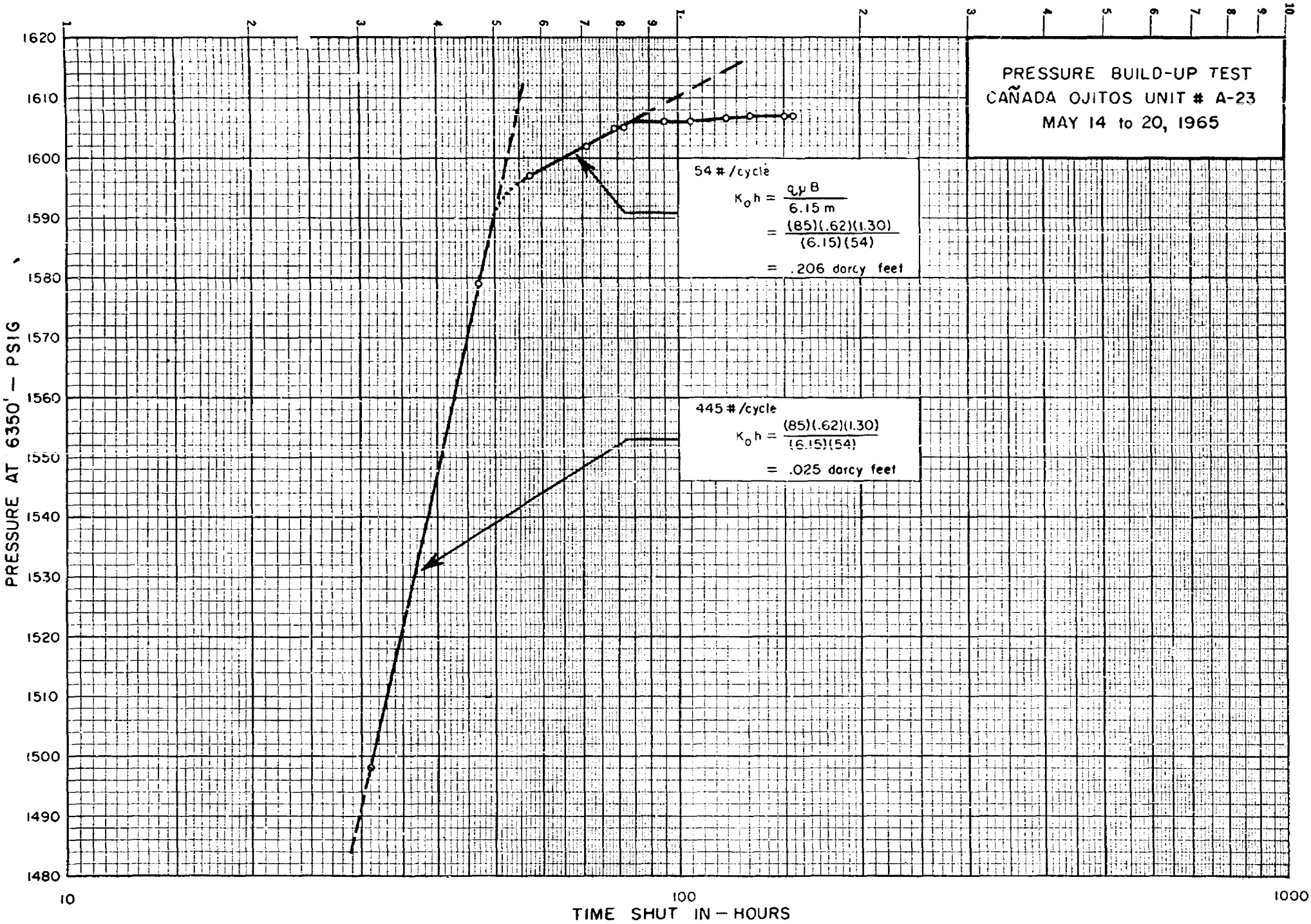
For the same reasons as stated in Item 3 above, it is probable that the effective well bore radius, under the circumstances of this test, would be rather small. An effective well bore radius of 1 foot probably would be more reasonable than the other figure shown of 10 feet. The reason for this is that with the high transmissibilities involved, the transmissibility of the area affected by the sand fracture treatment probably does not exceed that of the reservoir. For example, if a sand fracture treatment results in a transmissibility of 5 darcy feet, then the effective volume of this frac treatment would cause the associated effective well bore radius to be increased a like amount if the transmissibility of the area generally was substantially less (as for instance in the test of the L-11, as more particularly described in Appendix II hereof). If, however, the transmissibility of the reservoir is on the order of 10 darcy feet, then a sand fracture treatment resulting in a transmissibility of only 5 darcy feet around the well bore could not in any way give an effective well bore radius increase over that approximating the physical size of the hole.

All factors of the above test taken into consideration, it is believed the transmissibility indicated by the area of this test is on the order of 10 to 12 darcy feet. It is also believed that the area represented by this test is 3,000 to 4,000 acres.

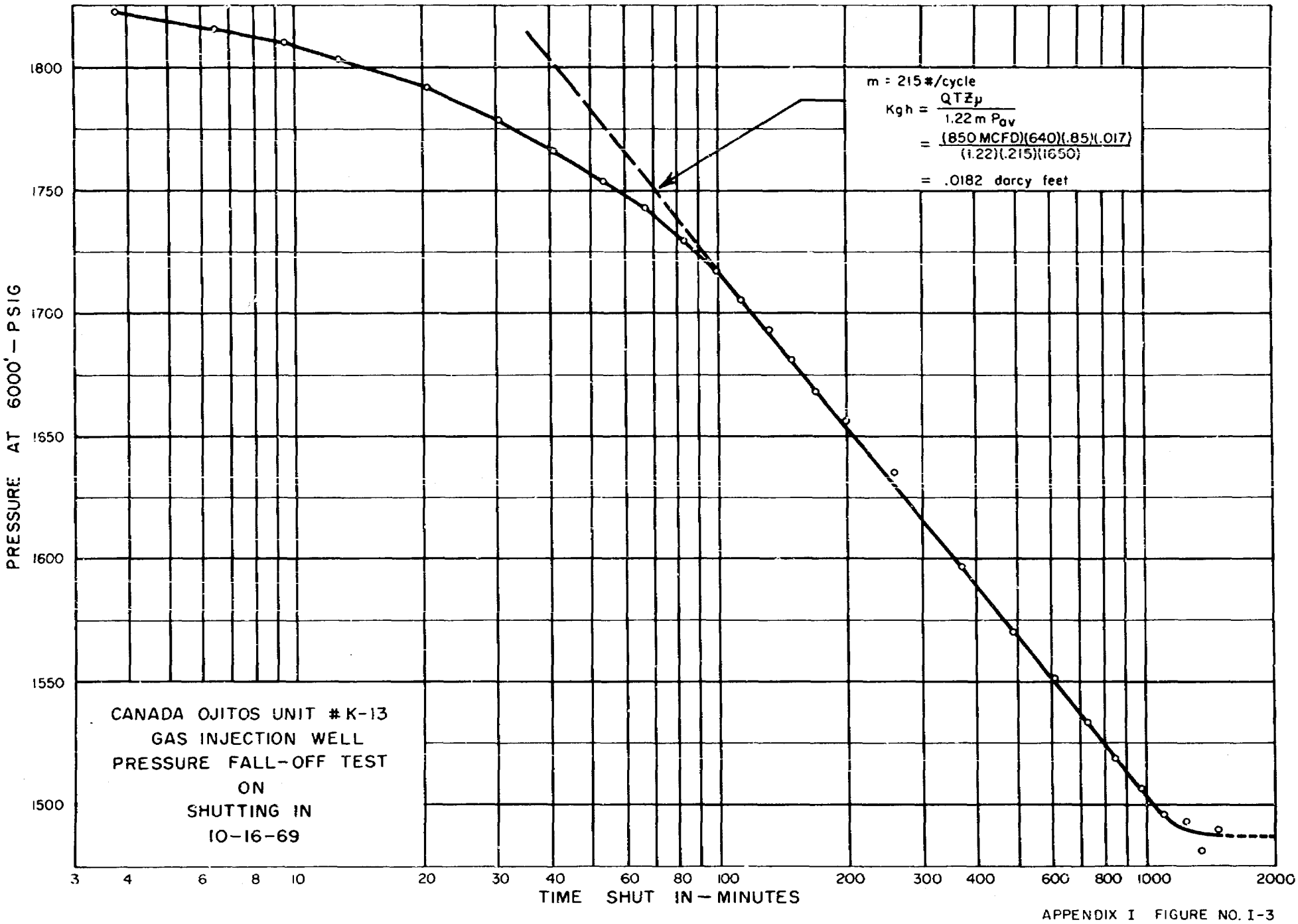
The areas of the three above-mentioned transmissibility tests are sketched on the plat at the end of this appendix, Figure I-16.



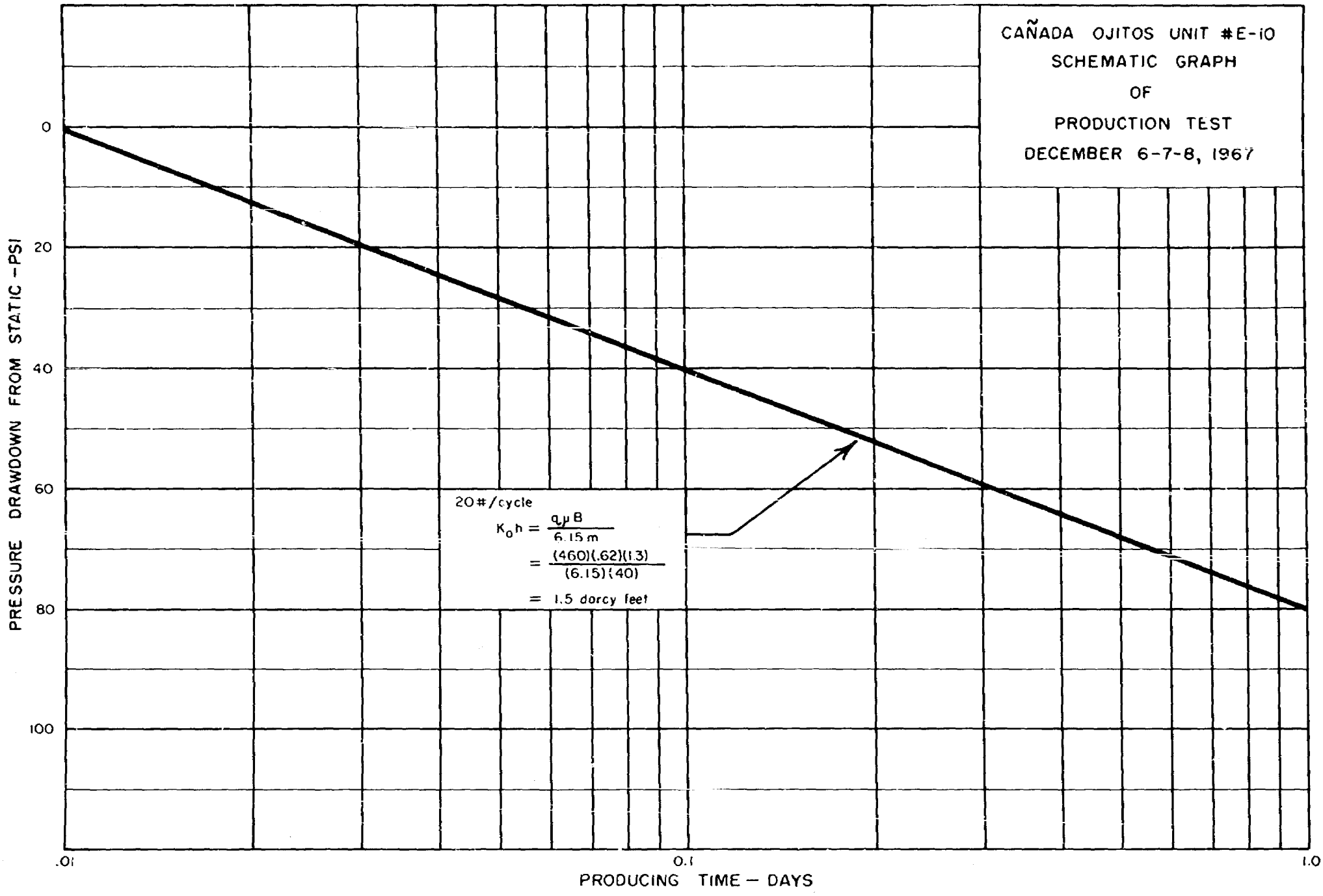
APPENDIX I FIGURE NO. I-1



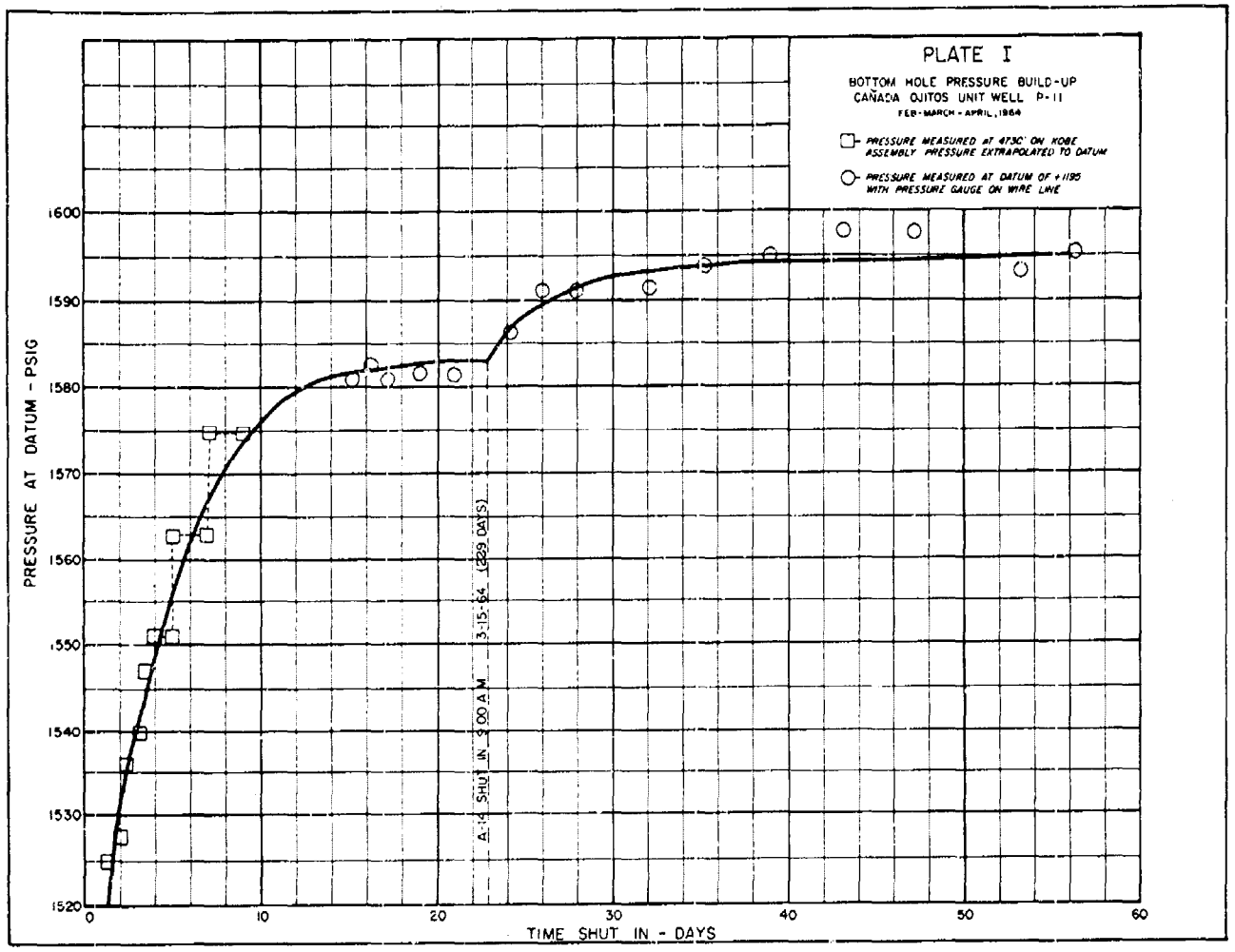
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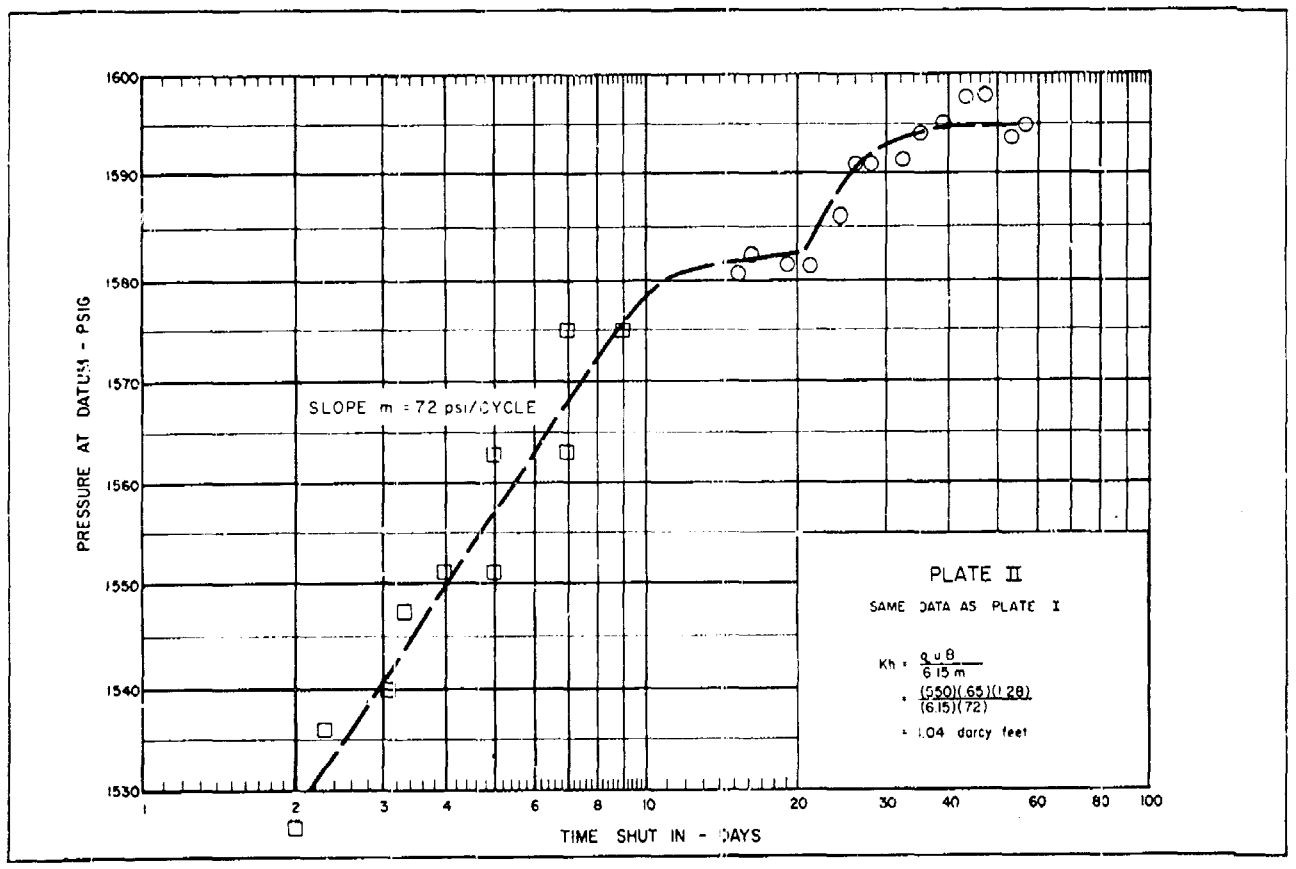


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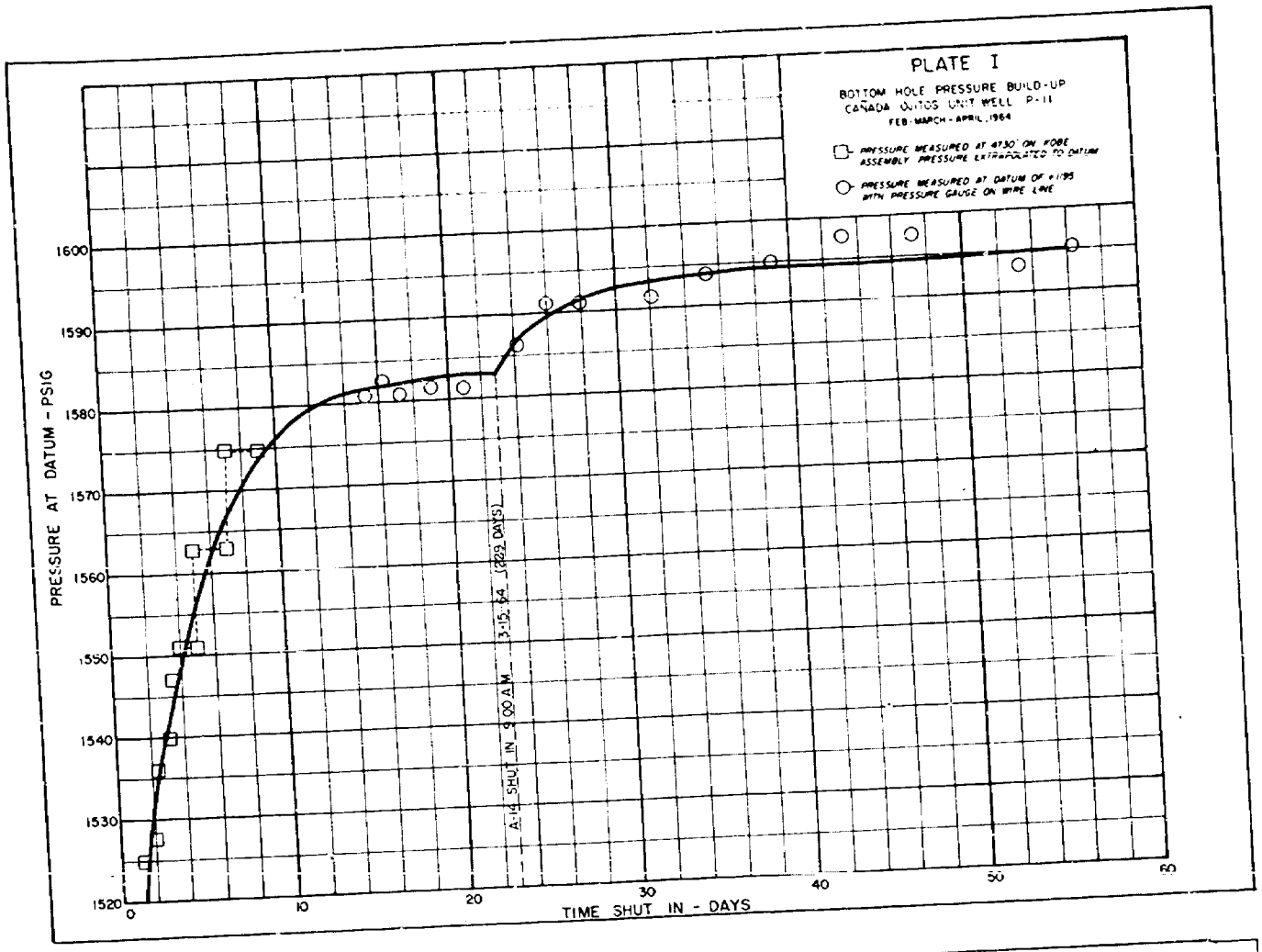


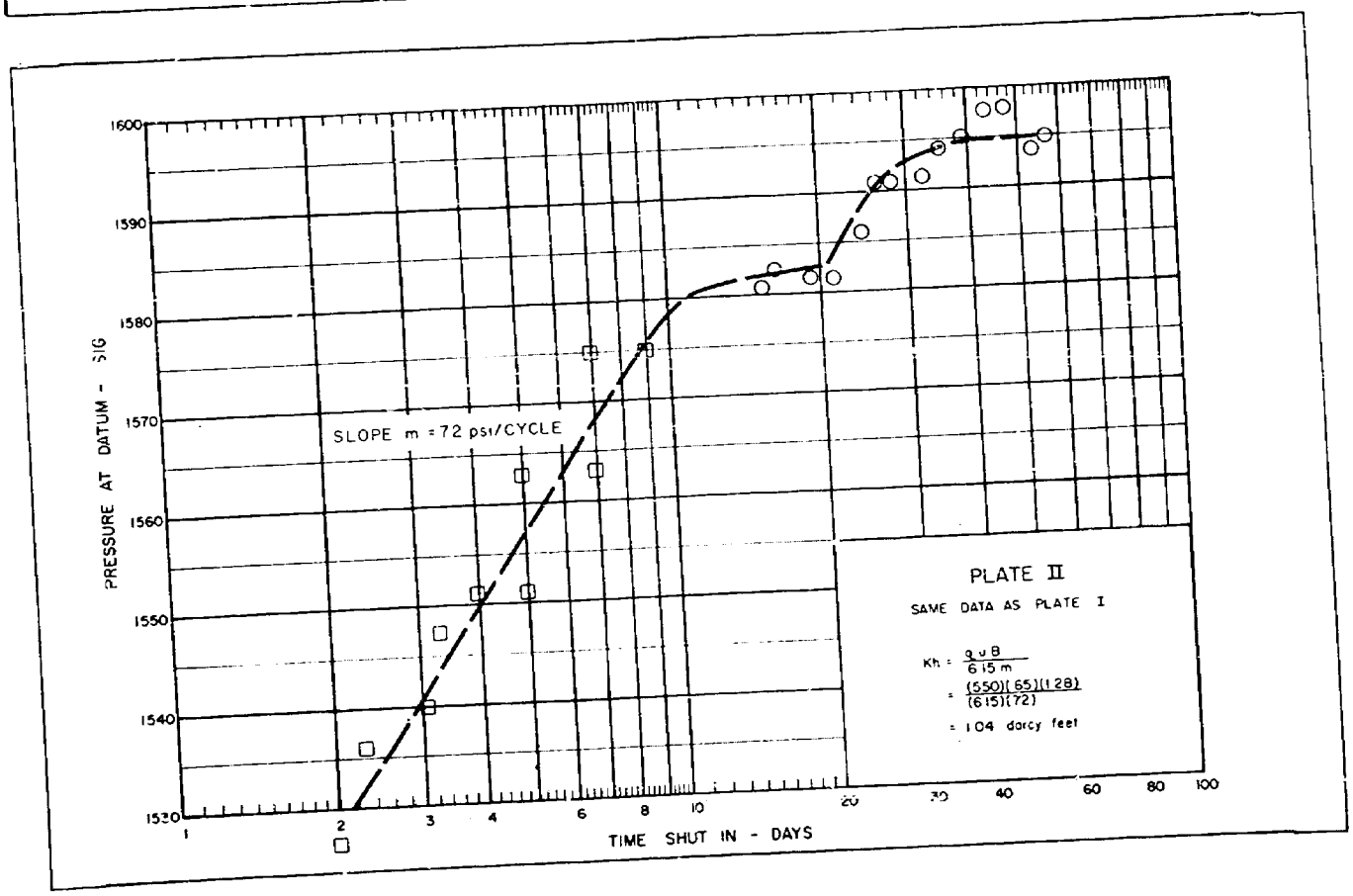
APPENDIX I FIGURE NO. I-4



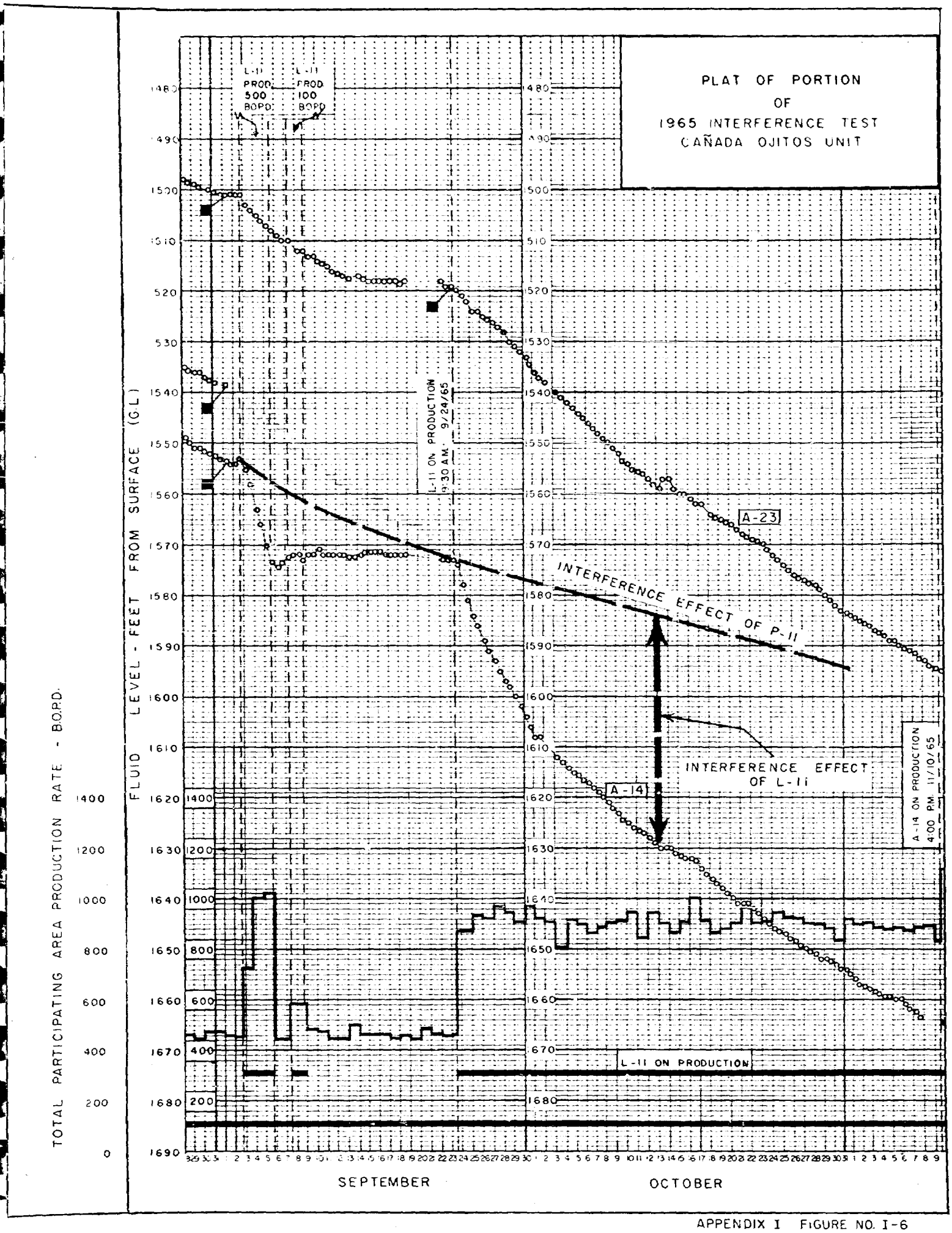


APPENDIX I FIGURE NO. I-5

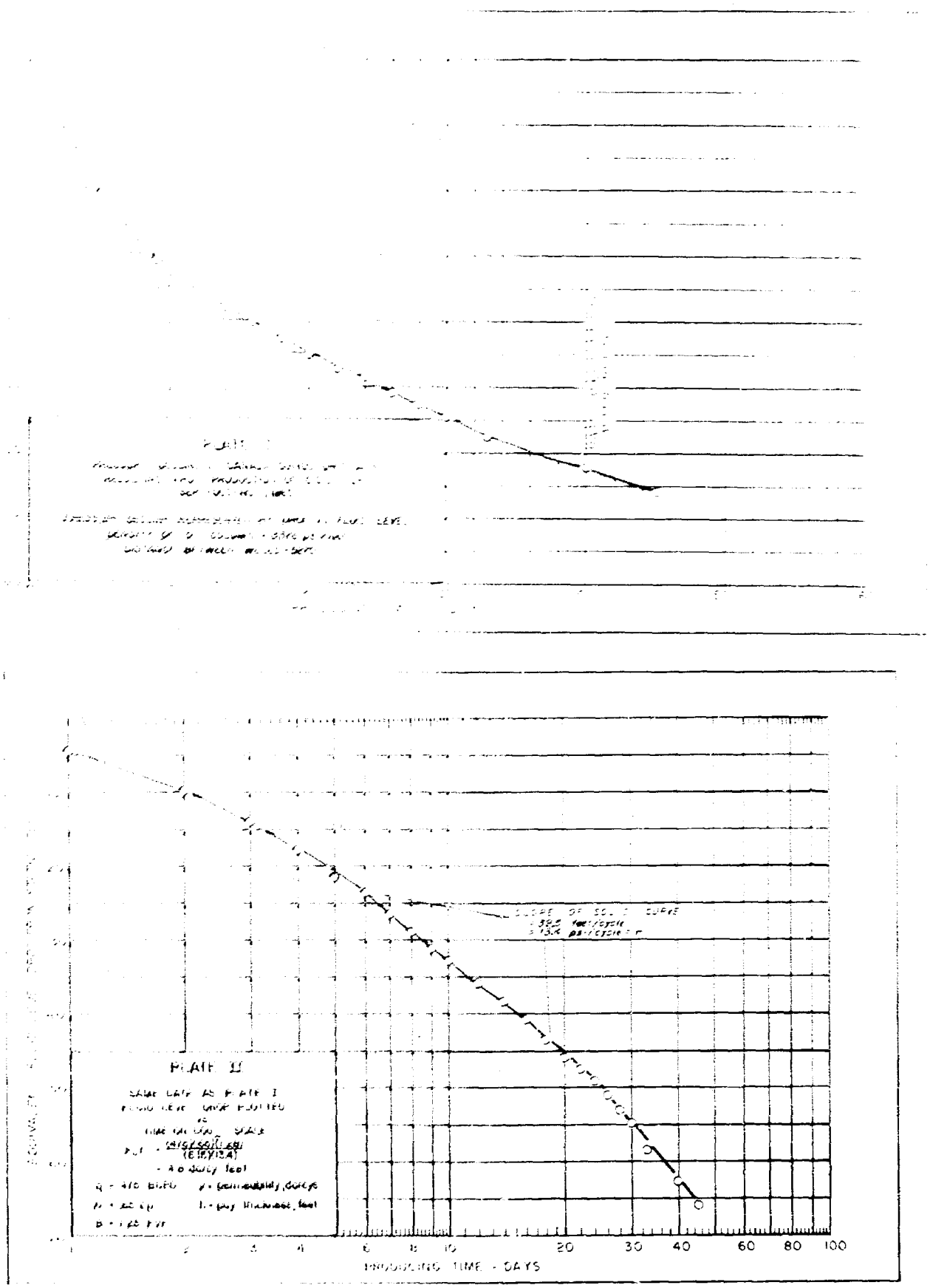




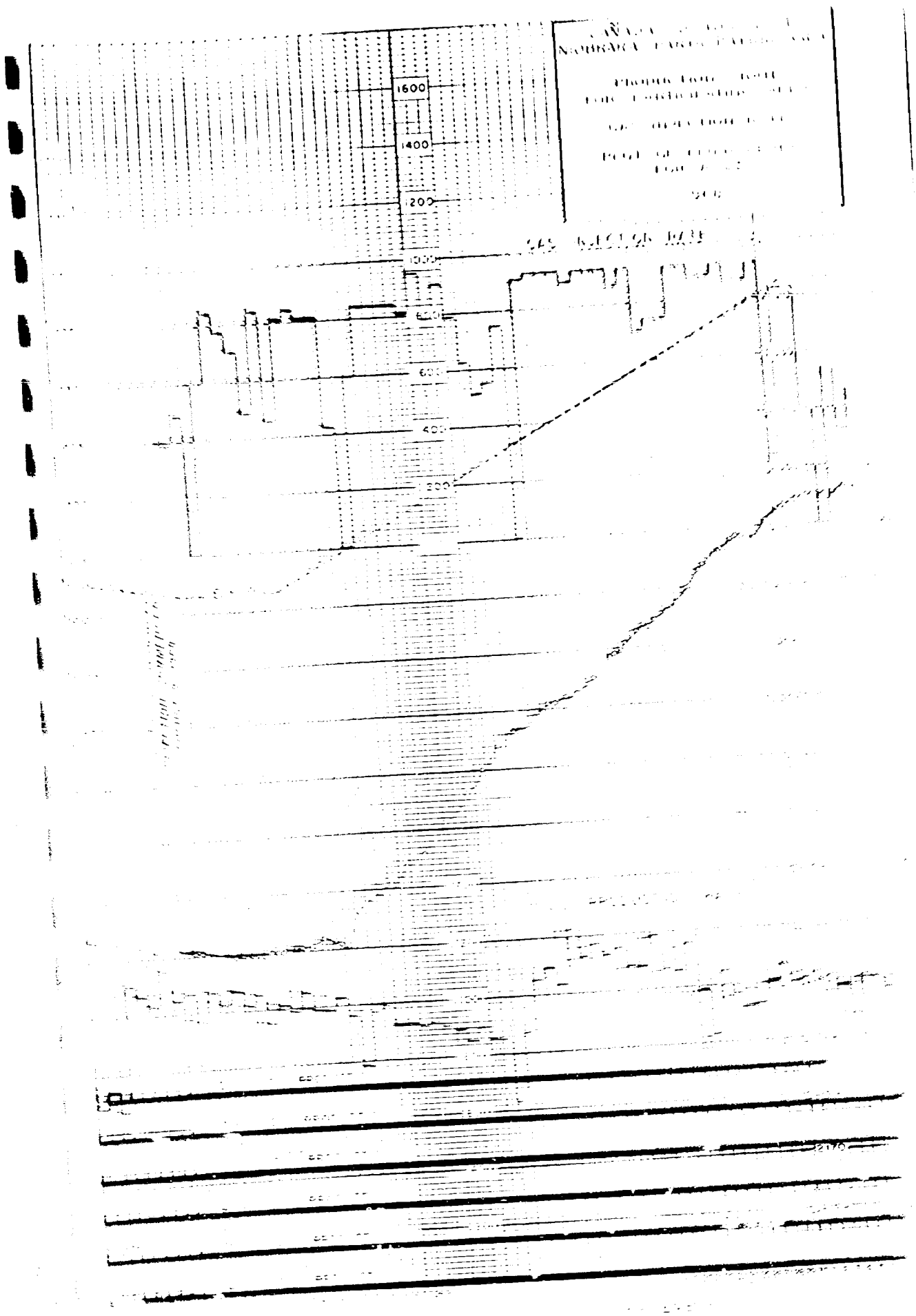
APPENDIX I FIGURE NO. I-5



APPENDIX I FIGURE NO. I-6

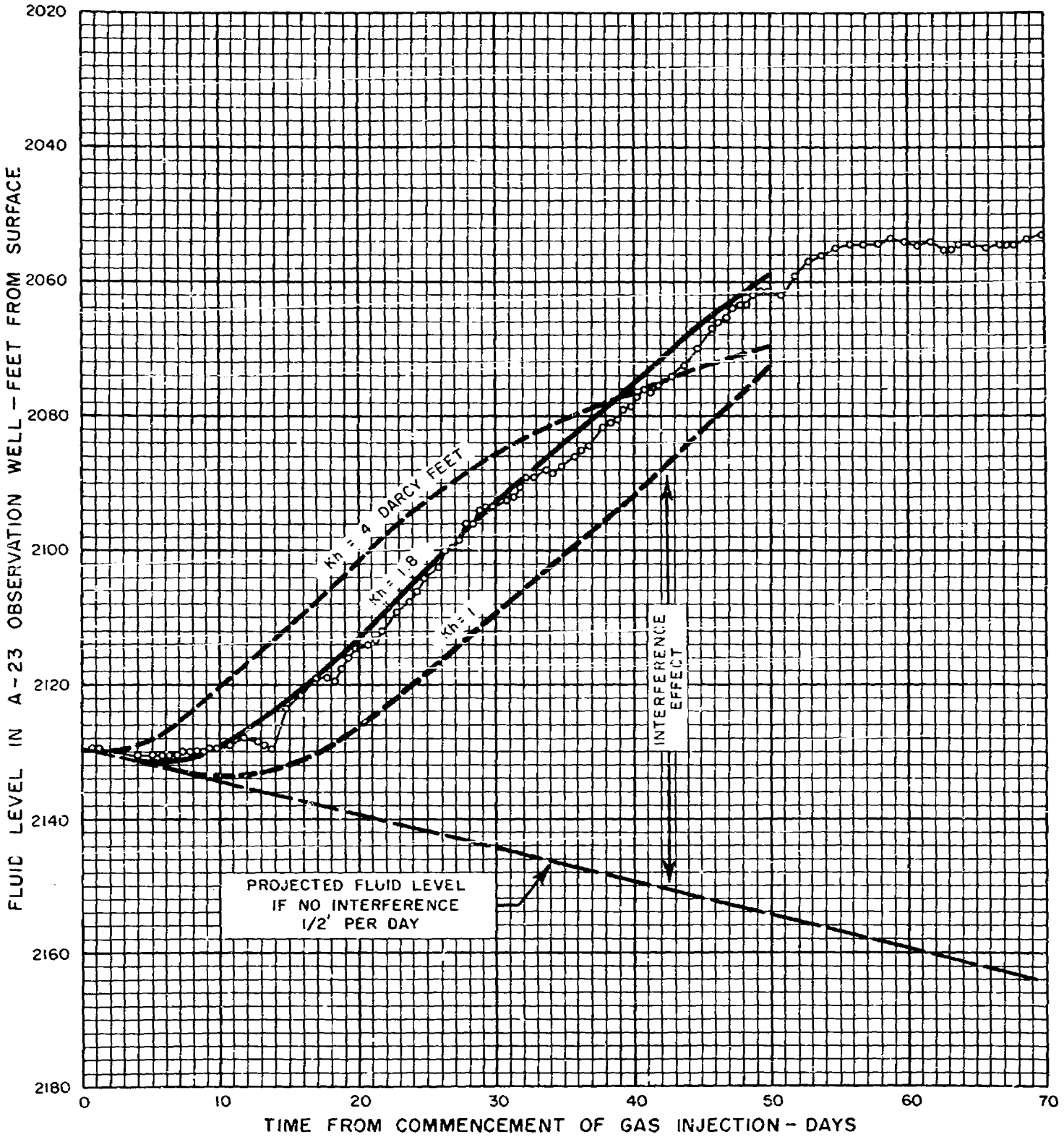


APPENDIX I FIGURE NO. I - 7


1600
1400
1200
1000
800
600
400
200

COMPARISON OF
ACTUAL INTERFERENCE EFFECT
OF INITIAL GAS INJECTION
ON FLUID LEVEL OF A-23 OBSERVATION WELL
WITH CALCULATED EFFECTS

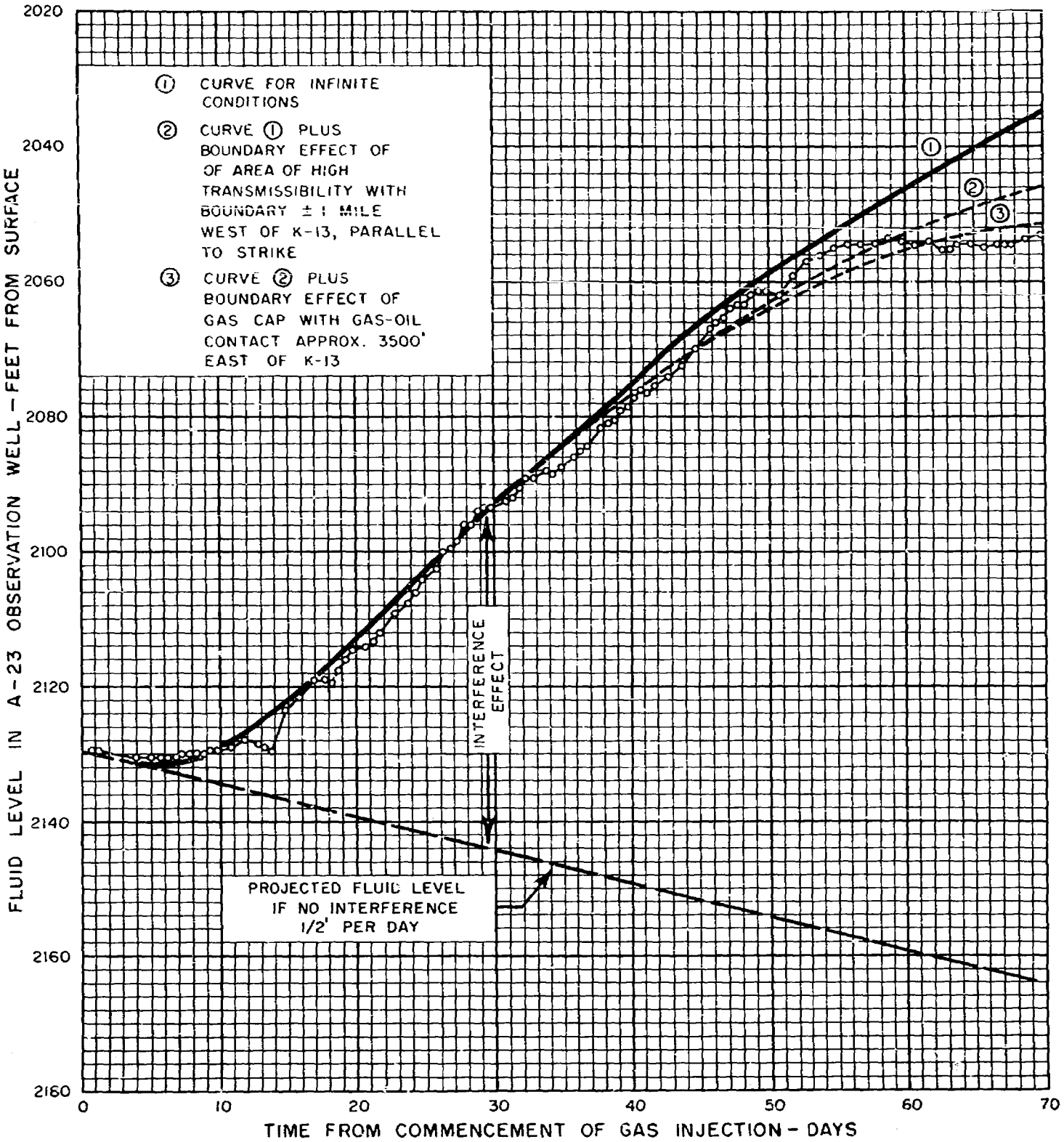
FOR CONDITIONS OF:
C_e = 415 x 10^{-6} F.V.F. = 1.28
ϕh = 1600 BBLS/ACRE STOCK TANK OIL
AND TRANSMISSIBILITIES AS SHOWN
o - MEASURED FLUID LEVELS



APPENDIX I FIGURE NO. I-9

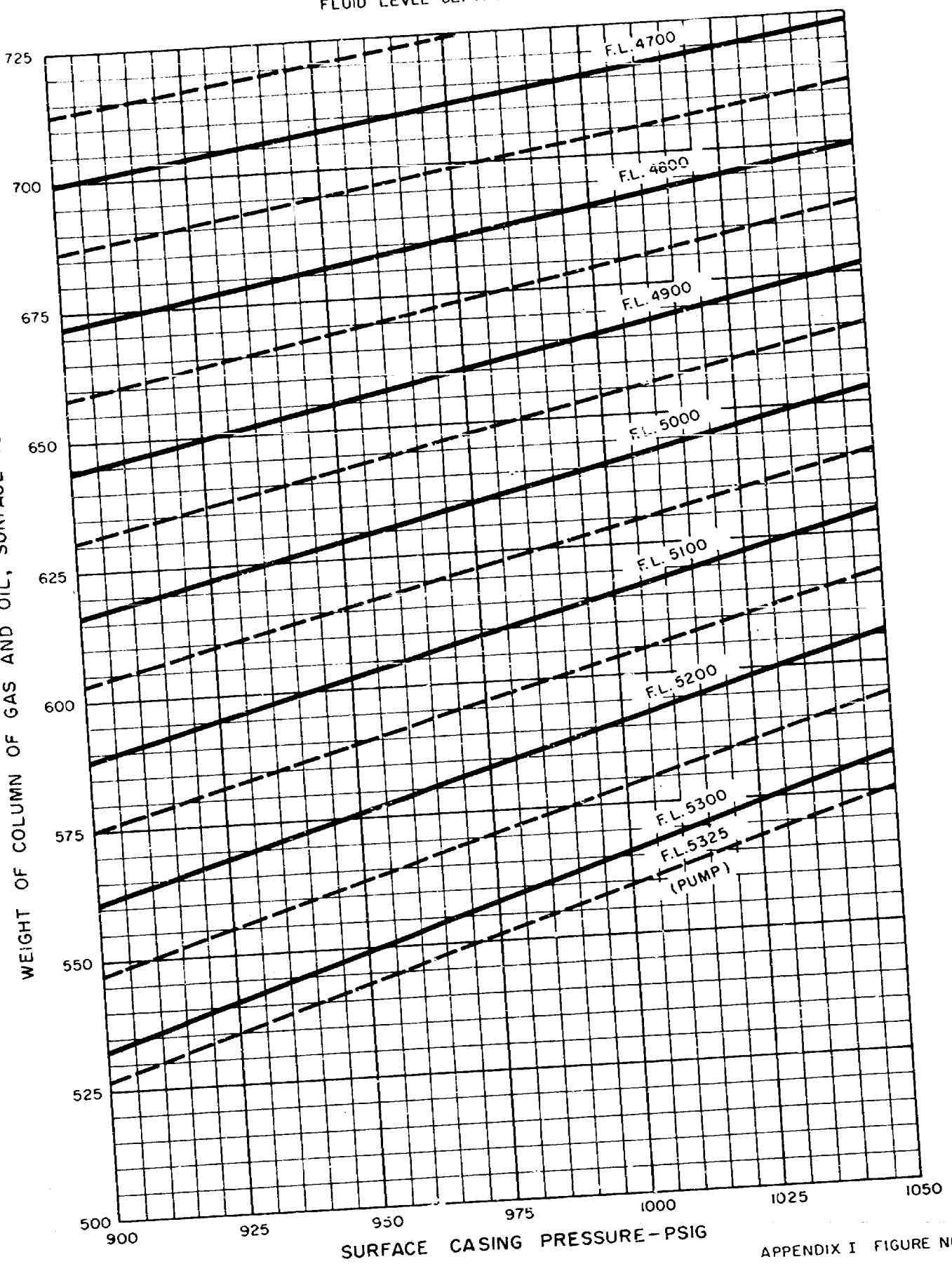
COMPARISON OF
ACTUAL INTERFERENCE EFFECT
OF INITIAL GAS INJECTION
ON FLUID LEVEL OF A-23 OBSERVATION WELL
WITH CALCULATED EFFECTS

FOR CONDITIONS OF:
C_e = 415 x 10^{-6} F.V.F. = 1.28
ϕh = 1600 BBLS/ACRE STOCK TANK OIL
TRANSMISSIBILITY = 1.8 DARCY FEET
o - MEASURED FLUID LEVELS



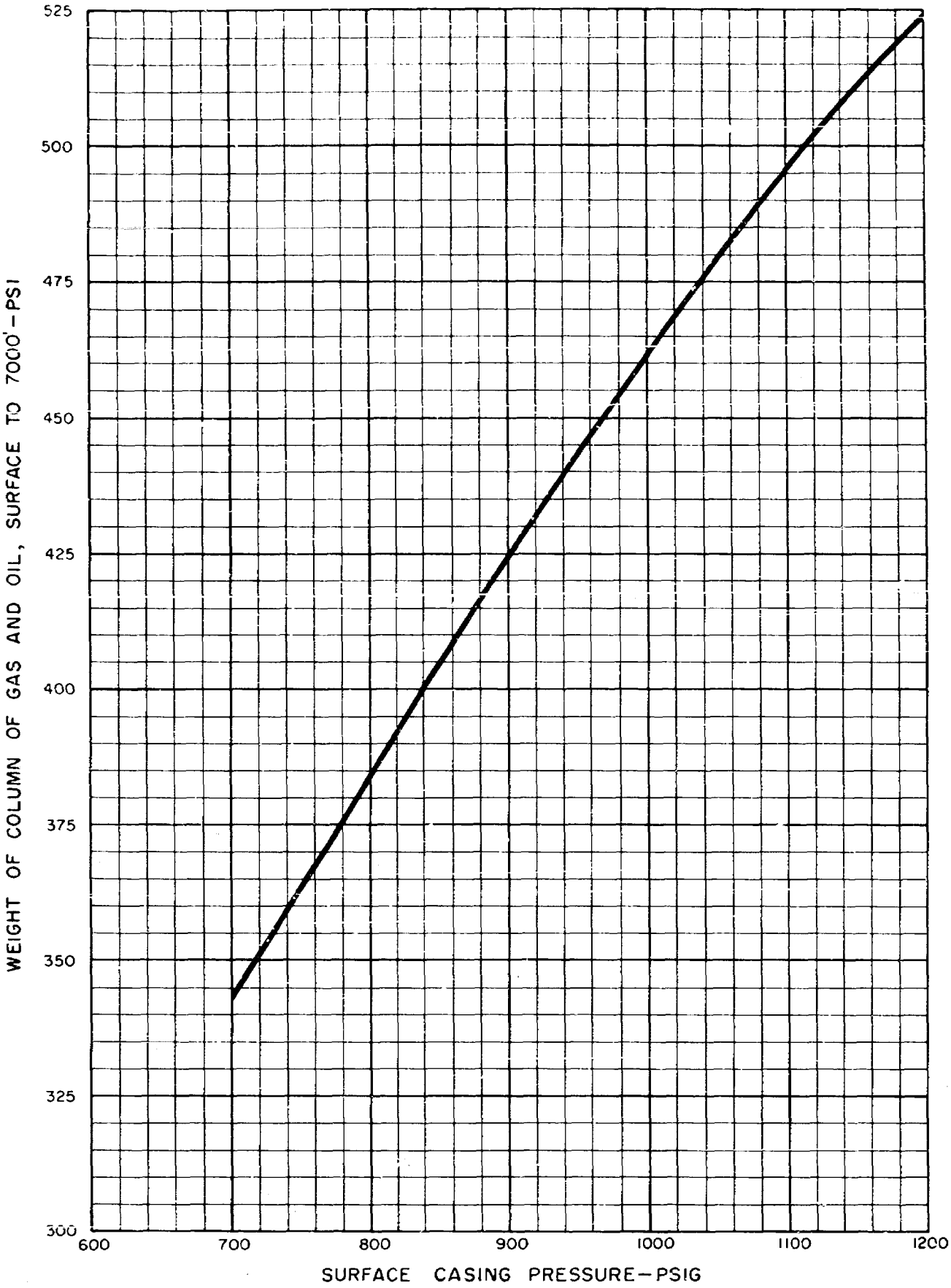
APPENDIX I FIGURE NO. I-10

CAÑADA OJITOS UNIT #L-11
WEIGHT OF OIL AND GAS COLUMN
SURFACE TO PAY ZONE
FOR
FLUID LEVEL DEPTHS SHOWN



APPENDIX I FIGURE NO. I-11

CAÑADA OJITOS UNIT #E-10
WEIGHT OF OIL AND GAS COLUMN
SURFACE TO PAY ZONE
FOR FLUID LEVEL
AT PUMP DEPTH OF 6100'



APPENDIX I FIGURE NO. I-12

PRODUCTIVITY INDEX DATA FOR
STEADY STATE LINE DRIVE TRANSMISSIBILITY TEST

CANADA OJITOS UNIT E-10

September 21-30, 1969

PRESSURE AT "LINE" SOURCE:

(FROM A-23 SURFACE POSITION AND PRESSURE)

A-23 pressure adjusted to datum of + 1195'	1,324 psig
A-23 pressure adjusted to datum of E-10 (+ 340')	+ 263
	1,587 psig

E-10 AVERAGE PRODUCING CASING PRESSURE	957 psig
Pressure differential to pay zone at 7,000' (from Figure I-12)	447
Producing pressure at pay zone	1,404

PRESSURE DRAWDOWN 1,587 - 1,404 = 183#

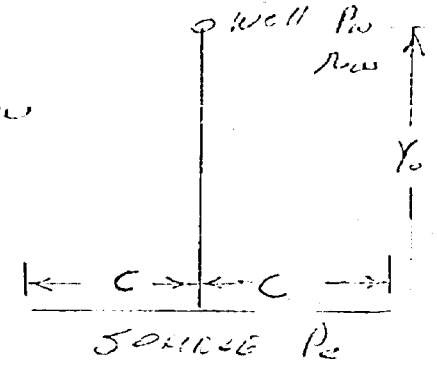
AVERAGE PRODUCTION RATE 770 BOPD

$$P.I. = \frac{770}{183} = 4.2 \text{ BOPD/\#}$$

APPENDIX I - FIGURE I-13

Transmissibility Determination from P.I. — Line Drive Formula (Steady State)

$$\Delta P = P_e - P_w$$



$$Q = \frac{2\pi K \Delta P}{\mu B \log_e 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{C^2}\right)} \qquad (I-1)$$

(Reference 5)

Introducing P.I., B, and μ of thickness, h,

$$Q = \frac{2\pi Kh \Delta P}{\mu B \log_e \frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{C^2}\right)} \qquad (I-2)$$

Changing constants to conform to oil field units (for example ref. 6)

$$Q = \frac{3.076\, Kh \Delta P}{\mu B \log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{C^2}\right)} \qquad (I-3)$$

Where:

Q = BOPD
μ = cp
K = darcys
h = feet
Y_o & r_w same units (ex: feet)

and

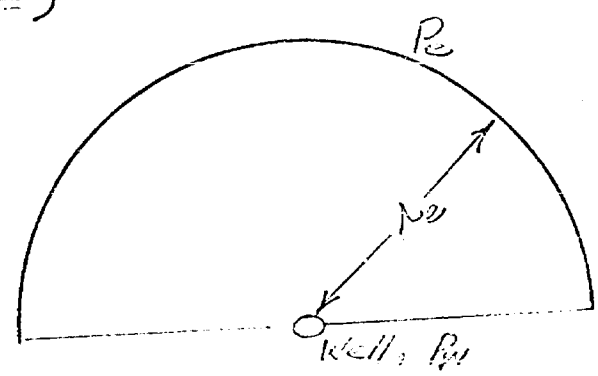
$$Kh = \left(\frac{Q}{\Delta P}\right)\left(\frac{\mu B}{3.076}\right)\log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{C^2}\right) \qquad (I-4)$$

For $B = 1.2$ & $\mu = 1$ & $\frac{Q}{\Delta P} = P.I.$

$$Kh = (P.I.)(.26)\log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{C^2}\right) \qquad (I-5)$$

Appendix I - Fig. I-1

TRANSIENT DERIVATION FOR RATE FOR GEOMETRY OF SEMI-CIRCULAR FLOW SYSTEM (STEADY STATE)



$\Delta P = P_e - P_w$

FOR CIRCULAR STEADY STATE FLOW (REFERENCE 6)

$$q = \frac{3.076\ kh\ \Delta P}{\mu B \log_{10} \frac{r_e}{r_w}} \qquad (I-6)$$

for k in darcys

FOR SEMI-CIRCLE:

q = 1/2 of that of full circle

$$q = \frac{3.076\ kh\ \Delta P}{\mu B \log_{10} \frac{r_e}{r_w}} \times 1/2 \qquad (I-7)$$

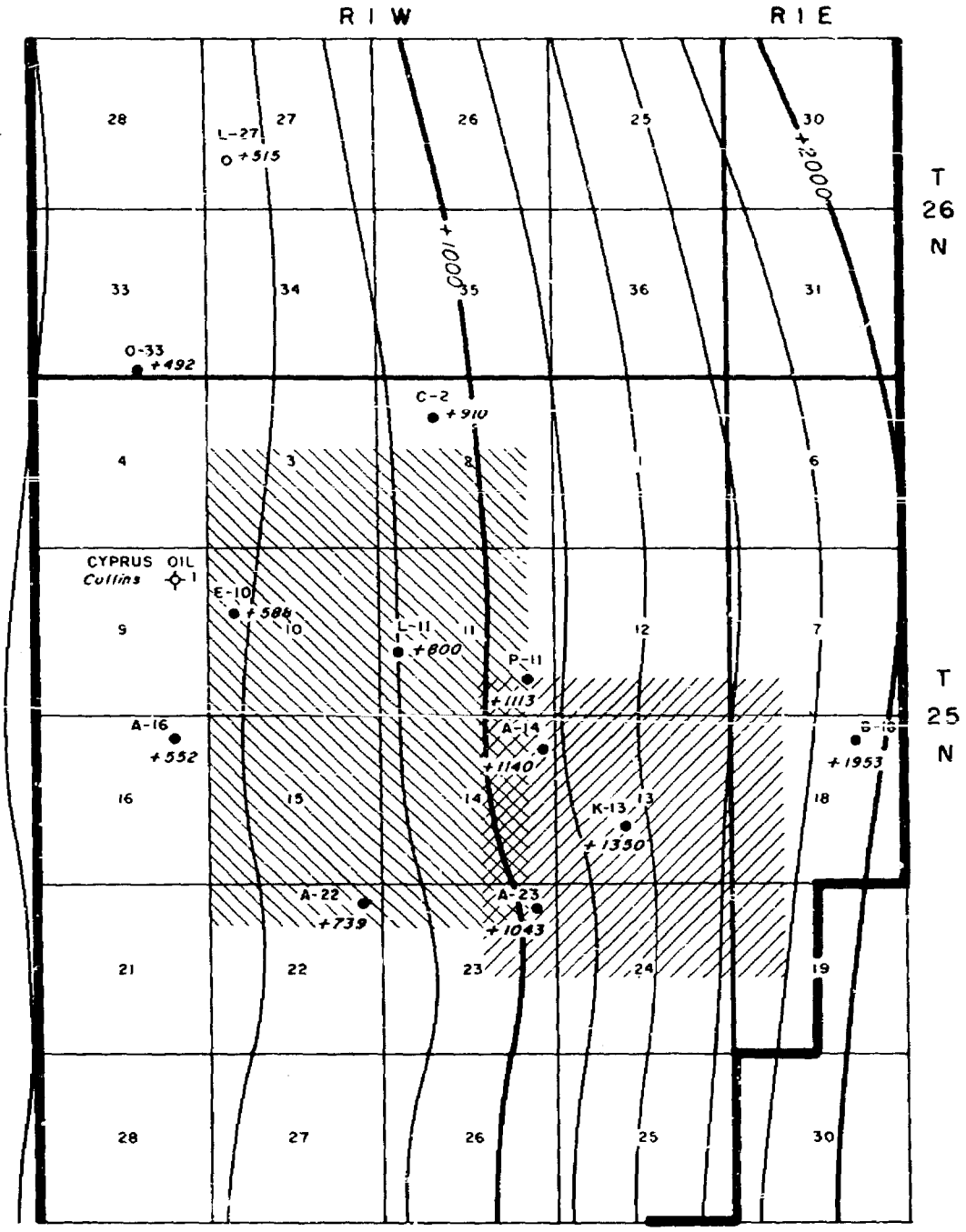
FROM WHICH:

$$kh = \left(\frac{q}{\Delta P}\right) \frac{2\mu B}{3.076} \log \frac{r_e}{r_w} \qquad (I-8)$$

FOR μ = .62 & $B = 1.29$ & $\left(\frac{q}{\Delta P}\right)$ = P.I.

$$kh = (PI)(.53) \log \frac{r_e}{r_w}$$

Appendix I - Fig I-15



PLAT OF PART
OF
CAÑADA OJITOS UNIT
SHOWING ESTIMATED
RESERVOIR TRANSMISSIBILITY
BY AREAS OF TESTS

- 2.5 TO 3.5 DARCY FEET
- 10 TO 12 DARCY FEET
- 5 TO 10 DARCY FEET

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969
BOUNDARY OF CAÑADA OJITOS UNIT

APPENDIX I FIGURE NO. I-16

APPENDIX II

CALCULATION OF SIZES OF FRACTURE BLOCKS

With the jigsaw type pattern of fracture blocks and interconnecting high capacity fracture system forming the reservoir in West Puerto Chiquito, there exists a relatively stabilized and equalized pressure at the outer boundaries of each fracture block. When a well completed in one of these fracture blocks produces, its flow system can be described mathematically as one with "constant pressure" at the flow system's boundary. It is therefore possible, from unsteady state flow data taken on a well completed in one of these tight blocks, to calculate the oil volume pore space within its block, and from this volume to approximate the areal extent of the block.

The primary method of calculation used is that shown in Part VII (Page 37) of Reference 1. This method uses bottom hole pressure build-up data as a basis. As has been adequately covered in the technical literature, a pressure build-up test results in a cancellation of the "skin" effect, such that for all other things being satisfactory, it permits the accurate determination of transmissibility in the vicinity of the well bore, and (depending upon conditions) for varying distances away from the well bore out into the reservoir.

Although the primary method of calculation is based on a pressure build-up test, it is possible to apply the same principle to, and make the same type calculation from, data from a pressure fall-off test on an injection well. In the case of an injection well, as well as for a producing well, it creates a pressure disturbance

in the reservoir, and when the well is shut in, the reservoir tends to return to static state. Therefore, the "skin" effects vanish during a pressure fall-off test in an injection well the same as they do for a pressure build-up test on a producing well, and accordingly the method of calculating the volume of a producing well's fracture block as described above will apply as well to the determination of the volume of an injection well's fracture block.

As stated above, in the instance of West Puerto Chiquito the individual fracture blocks react as individual flow systems, with constant pressure being held at the boundary by the high capacity fracture system. The shape of the fracture blocks is of course unknown, but for the purpose of this study it is not necessary to know the geometry of the individual fracture blocks, it is necessary only to determine approximately their gross dimensions. The information available and the methods of calculation are quite adequate to accomplish this.

Volumes of the reservoir space affecting the tests of the wells shown in Part A of Appendix I, Figures I-1 through I-5, have been calculated for four of the wells. These calculations are shown at the end of this appendix on Figures II-1, II-2, II-3 and II-4. Two of the tests were pressure build-up tests and one was a pressure fall-off test for an injection well. These three tests were calculated in the manner described above. One test (on the L-11, Figure I-1 in Appendix I) was a pressure draw-down test and required different treatment. Derivation of the method used for this well is shown in the figure at the end of this appendix, Figure No. II-5. This particular well, the L-11, has a relatively large effective well bore radius. Although, as described in more detail later, it is

difficult to determine the exact length or average length of this well bore radius, it is possible to determine approximately the volume of reservoir pore space within this "effective well bore radius". It approximates 3,000 barrels of reservoir pore space. This large effective well bore radius has a corresponding large influence on the pressure draw-down of the well. Because of this, the method used for calculating volumes for a pressure build-up test could not be used here. For a solution of this problem we rely on one of Muskat's (Reference No. 7) solutions of the diffusivity equation for pressure decline at the internal boundary of large reservoirs subject to constant withdrawal rate. One application of this equation, expressed in terms consistent with units used in this paper, is described in Reference 1, Page 60. Use of this equation requires the determination of the term "dimensionless time, $\bar{t}$ " which ordinarily is determined from a knowledge of permeability, porosity, length of internal radius and system compressibility, along with actual time involved, or, as shown in Reference No. 1, from the diffusivity constant and length of the internal radius. It is interesting, however, and particularly useful in the present application, to note that the interaction of the variables, porosity, pay thickness and internal radius (the factors which control the volume of the total pore space within the internal boundary) enter into the diffusivity constant in such a way that for any one given volume, the relation of pressure and production rate to time will be the same, regardless of the values of the individual variables. Expressed in another way, if the volume of the pore space within the internal boundary of the flow system is known, its pressure-production behavior

can be described by Muskat's above-referenced solution to the diffusivity equation without knowing specifically the value of any of the variables, porosity, pay thickness and internal radius.

Rearrangement of this equation of Muskat's is shown in this appendix, Figure II-5, in which the factor, dimensionless time, is shown to be expressed in terms of real time, transmissibility, volume of pore space within the internal boundary, compressibility and viscosity of the system. From this relation it is then possible, from the data of Figure I-1 of Appendix I, to calculate the volume of the pore space within the effective well bore radius of this well. The best fit of assumed values results in 3,200 barrels of pore space for volume within the internal boundary, and a transmissibility of .43 darcy feet. This transmissibility checks rather closely with the first approximation of transmissibility shown on Figure I-1. Since Figure I-1 is a pressure draw-down test and not a pressure build-up test, the method of determining transmissibility shown on Figure I-1 can only be assumed as approximate. A more accurate figure for transmissibility is the .43 darcy feet determined as described above. Example systems of different volumes within the r_w drainage area have been calculated and are plotted, along with the data of Figure I-1, to form the graph at the end of this appendix, Figure II-6. This shows that the curve represented by an internal volume of 3,200 barrels of oil pore space appears to be the best fit for the measured pressures between 1,510 pounds and 1,610 pounds. Example boundary effects are shown for one ratio of external boundary to internal boundary of 6.3. It is not necessary, of course, that the curves be matched for effect of boundary conditions in order to calculate the

transmissibility and pore volume within the internal radius. This can be done from the portion of the curve which is not affected by boundary conditions. The reason the effect of this one set of boundary conditions is shown is to give an approximation of the time at which the external boundary effects would become evident on the pressure draw-down curve. Since the curve for the 3,200 barrels internal pore space and transmissibility of .43 darcy feet has a distinctly flatter slope than that for the curve of the measured pressures, one might think at first that a system with lower transmissibility would better fit the data. This is not the case, however, as a system with lower transmissibility has a much greater draw-down pressure earlier (at a producing time of .02 to .05 of a day). In view of this, it is concluded that the difference in slope results from the fact that the shape of the r_w volume area is not circular. It is probable that the area is considerably longer than it is wide, and may in fact consist of more than one fracture extending at varying lengths from the well bore. Accordingly, one would not expect the curves calculated for a circular reservoir to fit exactly. Nevertheless, as explained in Reference No. 1 regarding calculations of reservoir properties from interference tests, it is not necessary to know the exact shape of this internal boundary to make a reasonable approximation of the value of the properties of the surrounding reservoir. It is probable that the internal volume calculated in this fashion is approximately correct, even though its exact shape is not known.

It is interesting in this particular case to compare the calculated reservoir volume of 3,200 barrels of pore space with the

volume of oil and sand used in the sand fracture treatment. It may be entirely happenstance that the volume of this r_w pore space in this well, calculated as described above and shown on Figure II-6, agrees so closely with the volume of sand and oil used in the sand fracture treatment. On the other hand, it is entirely possible that this means that most, if not all, of the oil that was used in this treatment and mixed with sand was effective in creating a larger well bore radius (the purpose, of course, for which it was used).

Assuming the method used to compute the r_w volume to apply, as described above, then under the conditions of this test, all properties are known with a high degree of accuracy, except one. The properties which are accurately known are production rate, pressure, actual time, viscosity and transmissibility. The one property which was not known rather accurately at that time was the system compressibility, C_e. For the calculations shown on Figure II-6, a system compressibility of 35×10^{-6} was used. If the true compressibility were different, the true volume would be proportionately different.

Variation of the calculated pore space of the r_w area with system compressibility is shown on the graph at the end of this appendix, Figure II-8. This shows a variation in r_w pore volume from about 2,200 to 5,600 barrels, for a variation in system compressibility from 20×10^{-6} to 50×10^{-6}. The principal factors affecting the compressibility of the system whose values are indefinite are formation compressibility and connate water. The relation of total system compressibility to formation compressibility and connate water

are shown at the end of this appendix, Figure II-7. For the range of the indefinite values of these properties, the system compressibility could range from 20×10^{-6} to 50×10^{-6}, as shown on this Figure II-7. The best estimate for system compressibility at this time is 35×10^{-6}, the area shaded on the graph, Figure II-7.

It is interesting to compare the data of Figure II-8 with the actual volumes of oil and sand used in the sand fracture treatment of this well. The data of Figure II-8 is shown again on Figure II-9 at the end of this appendix, on which has been added information regarding oil and sand volumes used in the sand fracture treatment of this well. This indicates most of the volume of the sand fracture treatment was effective in increasing the well bore radius.

Calculated transmissibilities, volumes of fracture blocks and approximate areas of fracture blocks resulting from the above-mentioned tests are set out below:

WELL	FOR EACH FRACTURE BLOCK		
	TRANSMISSIBILITY darcy feet	PORE VOLUME Stock tank barrels	AREA Acres
K-13	.018	8,000	30
A-23	.025	15,000	40
L-11	.43	57,000	70

The volumes of the tight blocks, calculated as described herein and set out above, are believed to be reasonably accurate. It is entirely possible that the true volumes would not vary more than 30 percent from those indicated above. Exact areas, of course,

can only be determined from further application of an estimate of the oil in place, the accuracy of which is unknown. It is believed the relation of transmissibility to pore volume, as described in Appendix III hereof, is reasonable, and accordingly the areas calculated above are probably within a factor of 2 to 1, that is, true volumes would probably not be smaller than one half the figures shown above nor greater than twice the figures shown above.

CALCULATION of VOLUME of AREA of TIGHT
BLOCK AROUND K-11 FROM PRESSURE
TEST of 9-24-65
(REFERENCE APPENDIX D - fig D-5)
(& graph fig I-1)

FOR Assumed $\bar{\phi}$ = .12 decimal feet
& V_k = 3200 bbls

$$\frac{12.42\ Kh\ \Delta P}{Q\mu\beta} = \frac{(12.42)(.43)\ \Delta P}{(450)(1.025)(1.217)}$$

$$= .0192\ \Delta P$$

$$V = \frac{3.54\ Kh\ \bar{t}}{Q\mu\ \bar{\phi}} \qquad \bar{t} = \frac{V\ Q\mu\ \bar{\phi}}{3.54\ Kh}$$

$$\bar{t} = \frac{(3200)(.35)(1.025)\ \bar{\phi}}{(3.54)(.43)} = .0458\ \bar{\phi}$$

P_{wf}	$\Delta P = 1688 - P_{wf}$	$\times .0192\ \Delta P$	$\bar{t}$	$\bar{t} = .0458\ \bar{t}$
1600	88	1.69	.75	.0856
1550	105	2.07	1.25	.0572
1540	125	2.46	1.95	.0893
1540	145	2.84	2.98	.136
1520	165	3.22	4.45	.204
1500	188	3.64	6.38	.292
1490	198	3.83	7.55	8.4	.346	.385
1485	203	3.93	7.54	8.9	.355	.405
1485	203	3.90	5.11	9.7	.377	.444
1480	208	3.99	8.52	12.2	.403	.559

(SEE FIG 22 OF REF No. 1)

Page 1
APP II - fig II-1

Since steady state conditions obtain after pressure declined to 1458 psi it is possible to calculate the volume in the drainage area for 1b from the steady state formula:

$$\Delta P = \frac{q \mu \ln \frac{r_e}{r_w}}{7.07 kh}$$

Volume in r_w area, $V_w = \pi r_w^2 \phi h$

" " r_e " $V_e = \pi r_e^2 \phi h$

from which: $\frac{r_e}{r_w} = \sqrt{\frac{V_e}{V_w}}$

and $\Delta P = \frac{2.3 \log \frac{r_e}{r_w} \mu B}{7.07 kh}$

or $\log \sqrt{\frac{V_e}{V_w}} = \frac{(3.07) kh \Delta P}{2.3 \mu B}$

$= \frac{(3.07)(.43)(1683 - 1458)}{(458)(.024)(1.297)}$

$= .65$

from which $\sqrt{\frac{V_e}{V_w}} = 4.8$

$\therefore V_e = (4.8)^2 V_w$

$= 23 V_w = (23)(3200)$

$= 74{,}000$ bbl

of oil per well

$\frac{74{,}000}{1.297} = 57{,}000$ bbl (S.T.D.)

At 500 lbs/sq in (Pressure of III-5) → (10 MBO/D)

Page 2
APP. III Fig. B-1

CALCULATION OF VOLUMES AND RADIUS
OF THAT BLOCK AROUND A-23
FROM BHDU DATA MAY 14-20, 1965
(ref graph fig I-2)

① First area near well bore, slope = 445 psi/log
Note that first 35 hours pressure was
below bubble point & Ce for that time in
the Nw volume would be high. Total volume
of the Nw area is accordingly small
compared to Ny area obtained by slope 445 psi
& is disregarded. Effect will be to calculate a
a larger volume than actually exists. The
higher transmissibility of the second (Nz)
area will act as "constant pressure" on
boundary of Ny area & accordingly
this Ny area can be calculated by
method of part III of reference 1.
Assume four hours (5 hrs to bubble)

ΔP = pressure drop from initial pressure
@ 30 hours (at 1.35 cp)
= 1592 − 1492 = 104 psi

$$\overline{\Delta P} = \frac{4.6\,m}{n}\,\Delta P = \frac{(4.6)(104)}{445} = .27$$

from fig 1.5 of ref 1 for $\overline{\Delta P} = .27 \rightarrow \overline{x} = .25$

$$N_y = \frac{.25\,x}{1.87\,m\,C_t\,\phi} = \frac{(.25)\,4.25}{(1.87)(.4)(.35\times10^{-3})(.25)}$$

= 15,000 bbls (solid)

page 1
APP. II - fig I-2

Area of N. Volcanic:

From fig III-5 of MMP IIA, for 1025 dary feet & between the "Y" & "Z" polygons, 4th is equivalent of to 350 bbls/acre (5ra)

$$\frac{15000 \text{ bbls}}{350 \text{ bbls/acre}} = 43 \text{ acres} \quad \left(\begin{matrix}\text{RANGE} \\ 35 \text{ to } 57\end{matrix}\right)$$

USE 40 acres

5

Calculation of Volume = Pore vol of flow path from injection well to pt of interest in producing well from Matthews Recovery Test 10-15-54

(ref: Fig I-5)

Note: "Drop" in pressure in the same as flow rate = pressure response of pressure fall off test

Eq for reason = 650 psia (ref 1 - fig 3)
(shrinkage)

Use pressure at 1400 minutes & 400 minutes:

$\Delta P = 1857^{\#} - 1578.5^{\#} = 95^{\#}$

$\Delta P = \frac{\Delta P}{in} = \frac{(615)(95)}{215} = .477$

$\Sigma = .15$ (Fig 18 of ref 1)

$t = 400$ minutes $= .277$ days

$Q =$ (Quantity in bbls of reservoir space the 850 mcfd that was being injected

$Q = (Q_s)(\frac{B_g}{B_i})(\frac{T}{1})(\frac{Z}{Z_i})(\frac{1}{5.61})$ $Q_s = 850$ mcf/pump

$= (850)\frac{(.0050)}{(.0050)} - \frac{(.85)(640)}{(1)}\frac{(1)}{(5.20)(5.61)} = 1450$ (5.70)

$= 1140$ bbl/in reservoir space $= \frac{1140}{1.07} = 1120$ bbls

$N = \frac{Qt}{(1.71)\Delta P \Sigma t} = \frac{(1120)(.277)}{(1.74)(31)(.477)(.85 \times 10^{-4})(.15)}$

$= 8,000$ ± (5.70 above)

Avg 2100 psi ⇒ Dolly ⇒
22 for 3 Co. Wells - Avg (30) Acres

APP II
fig II-3

CALCULATION OF VOLUME & AREA OF LOW (COMPARED TO RESERVOIR AVERAGE) TRANSMISSIBILITY AROUND THE P-11 WELL FROM TEST of FEB-MAR-APR 1964
(ref, fig I-5)

On light of other information, now latest (as applied for this & previous hearing) the pressure build up were as follows the measured pressure from the interpretation shown on fig I-5, result is .84 decline stabilization is the slope m = 17 psi/log

Choose 6.0 days
$\Delta P = 1581 - 1565 = 16$ psi $\bar{t} = 6.0$ days

$$\Delta \bar{P} = \frac{1.15\,\Delta P}{m} = \frac{(1.15)(16)}{89} = .21$$

$\bar{x} = .3$ (page 15 of key 1)

$$N = \frac{q\,\bar{t}}{1.74\, m\, c\, \bar{x}} = \frac{(550)(6.0)}{(1.74)(89)(3 \times 10^{-6})(.3)}$$

= 2,000,000 bbls (S.T.O.)

@ Kh = .84 BOPA = 1,000
ACRES = 2000 Acres

Application II
Fig I-4

REARRANGEMENT OF MUSKAT'S (Ref 1 fig-22) EQUATION FOR PRESSURE DECLINE AT THE INTERNAL BOUNDARY OF LARGE RESERVOIRS SUBJECT TO CONSTANT WITHDRAWAL RATE TO SUBSTITUTE VOLUME FOR THE VARIABLES ϕ, h, r

start with the equation: $$\bar{P} = \frac{6.328\, Kt}{\phi c_t \mu r^2} \qquad (1)$$

multiply the numerator & denominator by the pay thickness, h, in feet;

$$\bar{P} = \frac{6.328\, Kht}{\phi h c_t \mu r^2} \qquad (2)$$

Since Volume of pore space in the R, area is: $V = \frac{\phi h r^2 \pi (7758)}{43,560}$ bbls/acre (3)

then $\phi h r^2 = \frac{V\, 43,560}{(7758)(\pi)} = 1.787\, V$ (4)

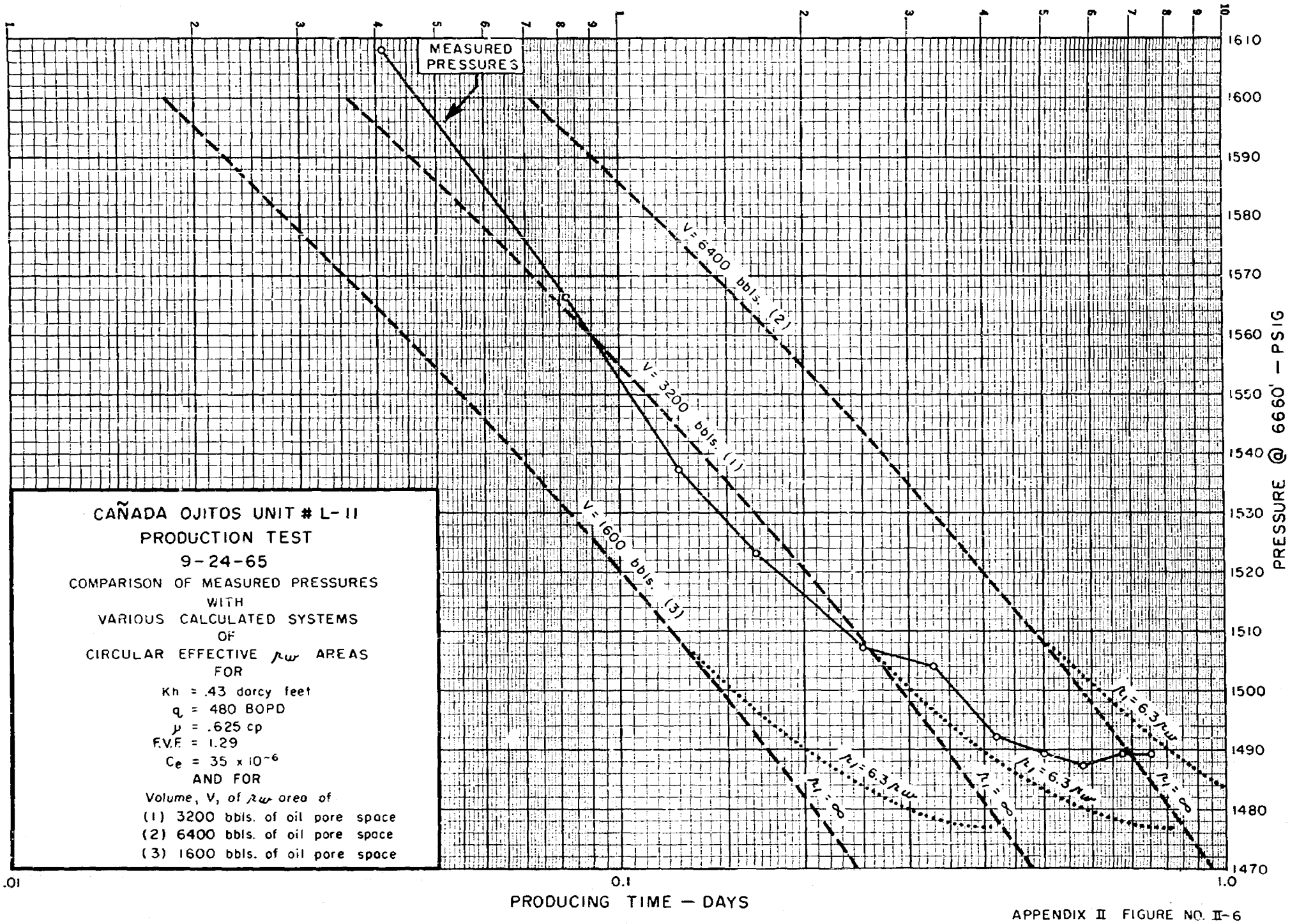
Substituting from (4) the value of $\phi h r^2$ in (2):

$$\bar{P} = \frac{6.328\, Kht}{1.787\, V c_t \mu} = \frac{3.541\, Kht}{V c_t \mu} \qquad (5)$$

& $V = \frac{3.541\, Kh\,(t)}{c_t \mu\,(t)}$ pore volume, bbls between wellbore & radius of investigation at time t

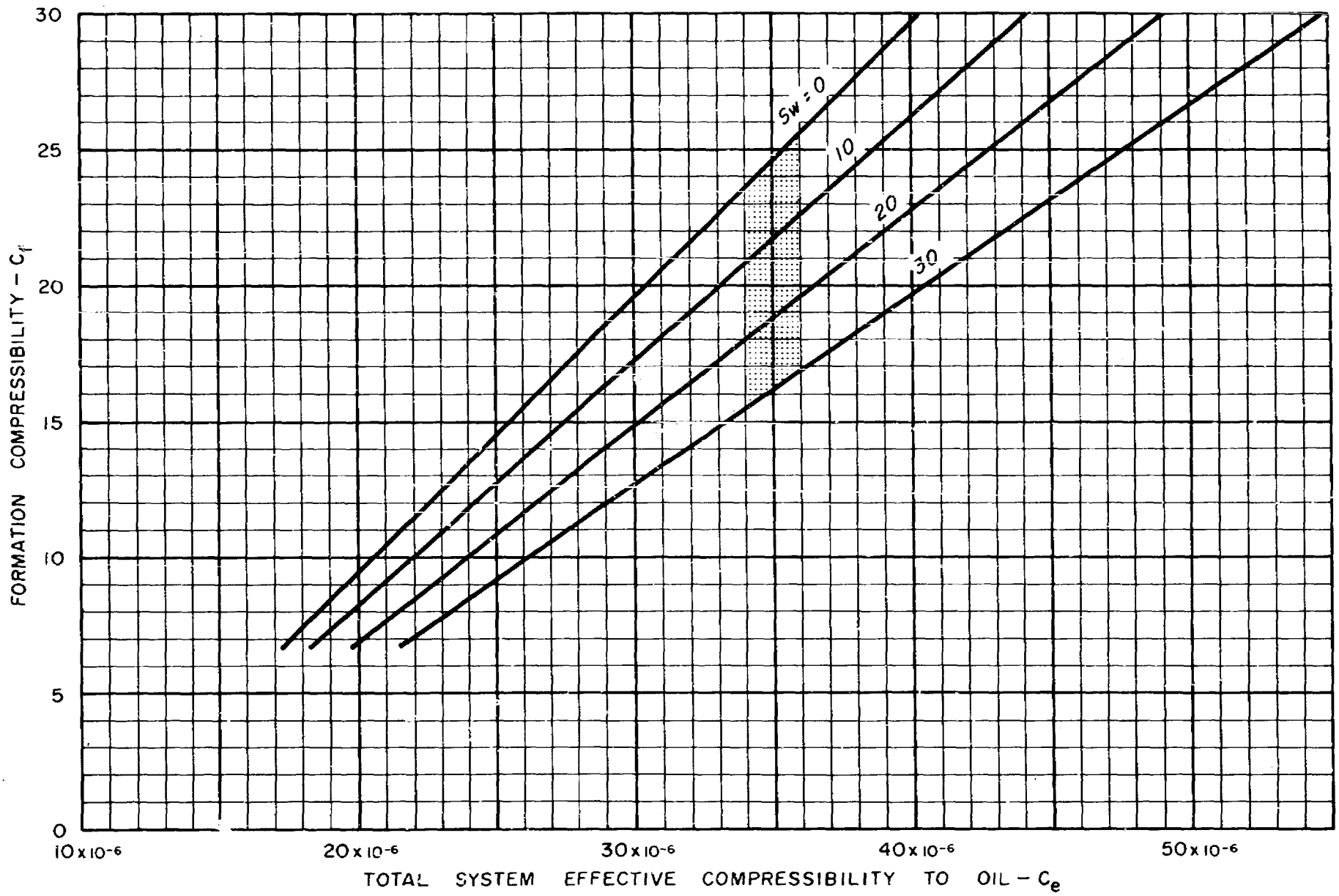
to get S.I. divide by D

APPENDIX H
Fig H-5

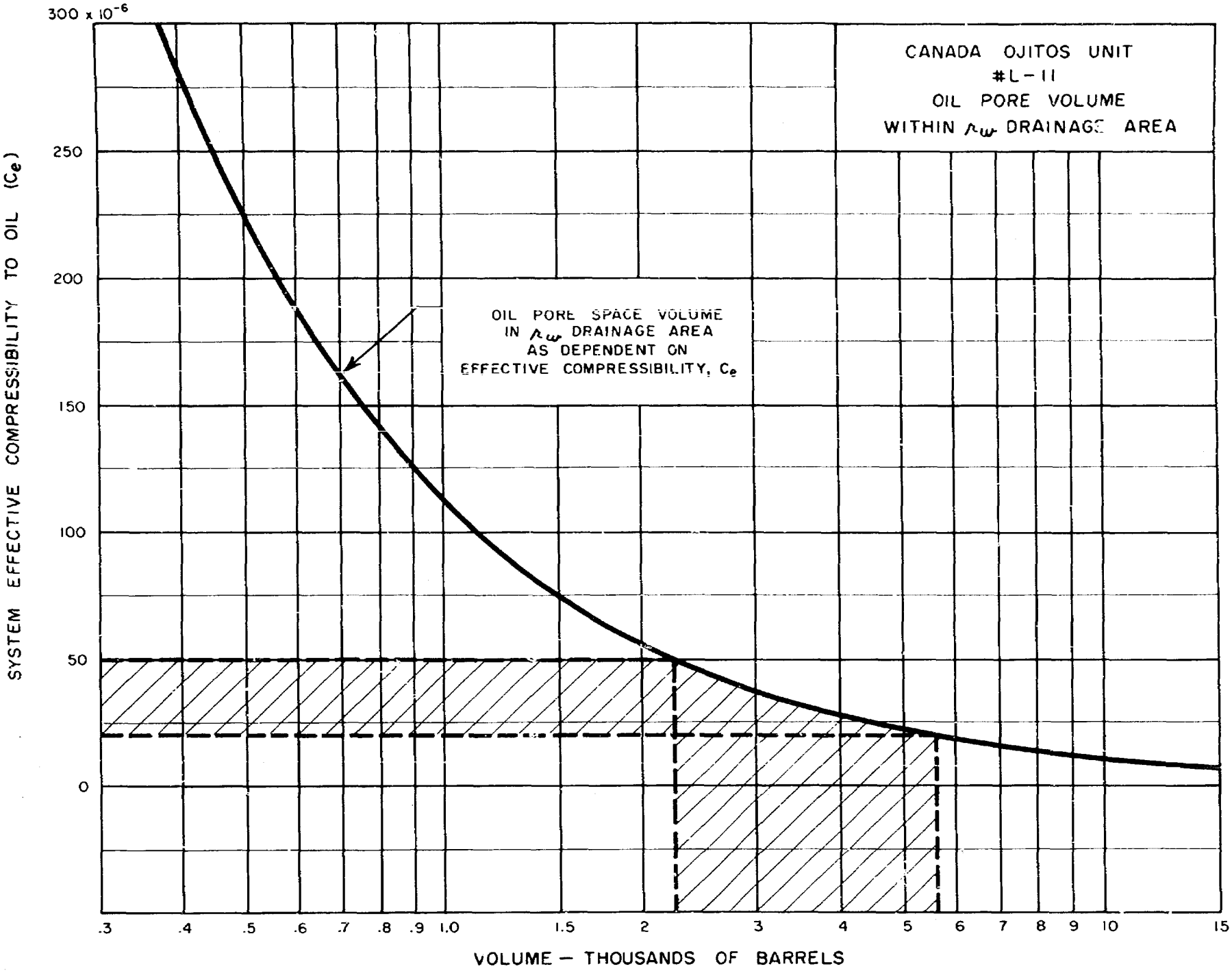


APPENDIX II FIGURE NO. II-6

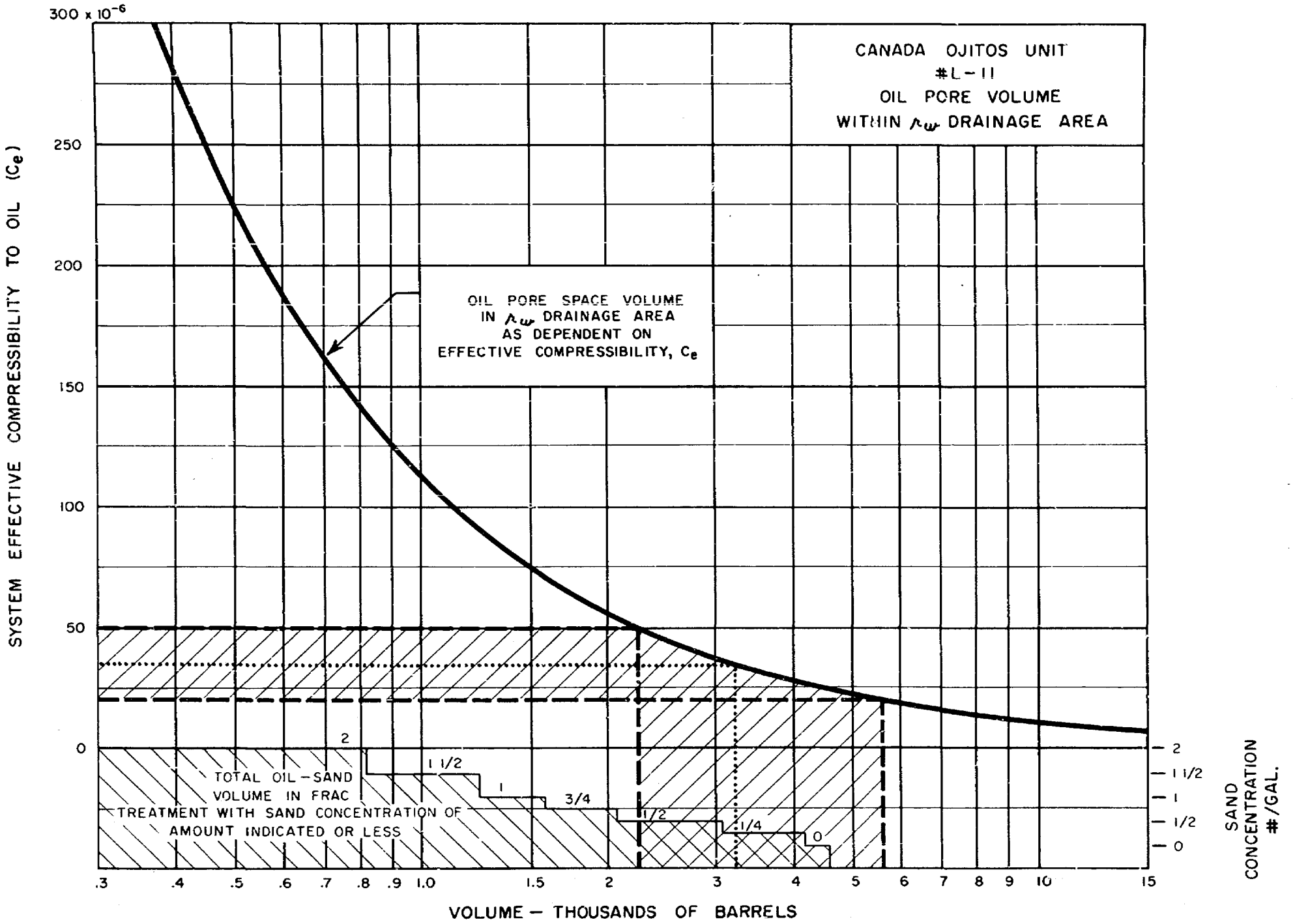
SYSTEM COMPRESSIBILITIES
FOR
PRESSURES ABOVE BUBBLE POINT
AND
NO FREE GAS SATURATION



APPENDIX II FIGURE NO. II-7

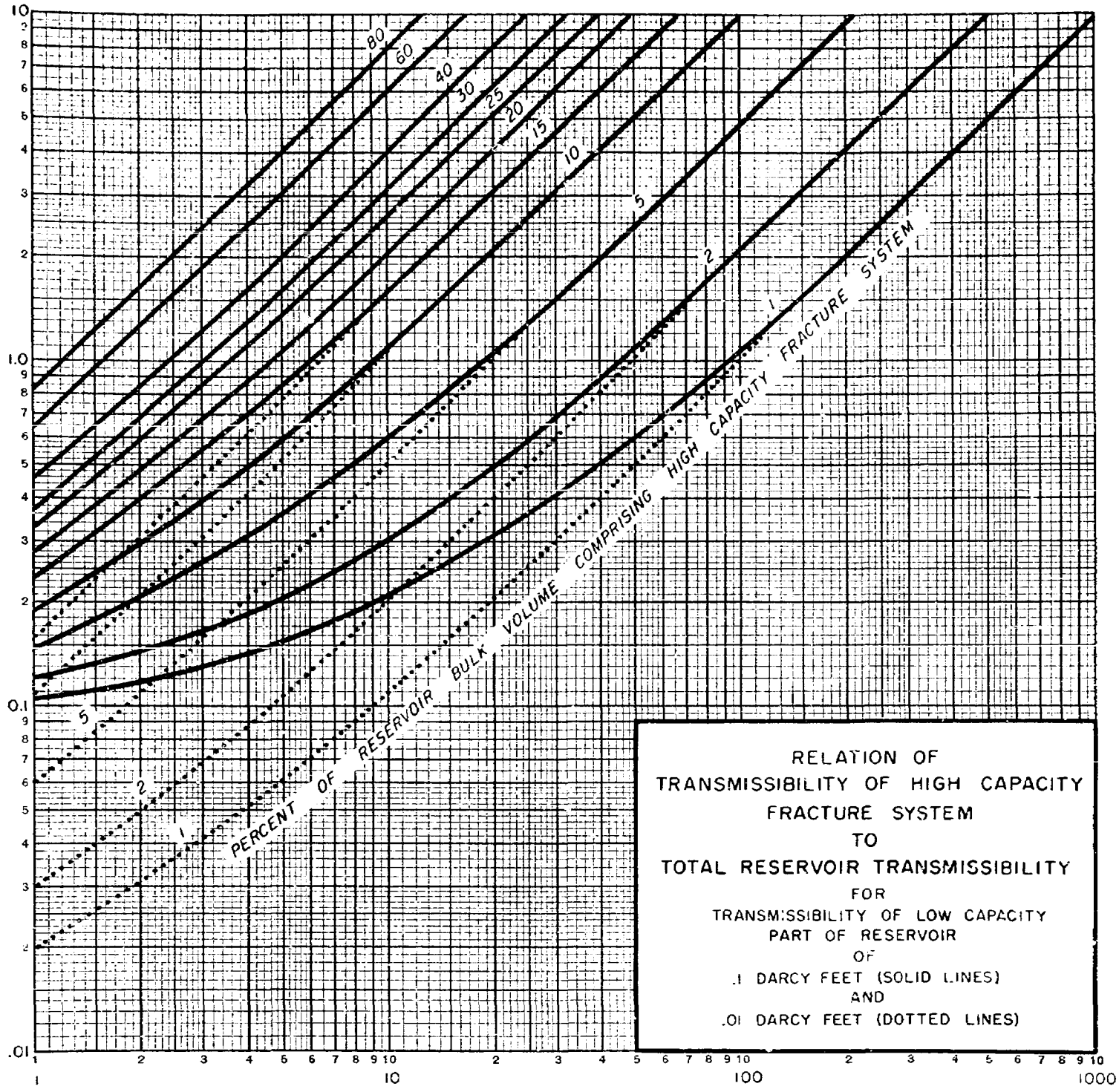


APPENDIX II FIGURE NO. II-8



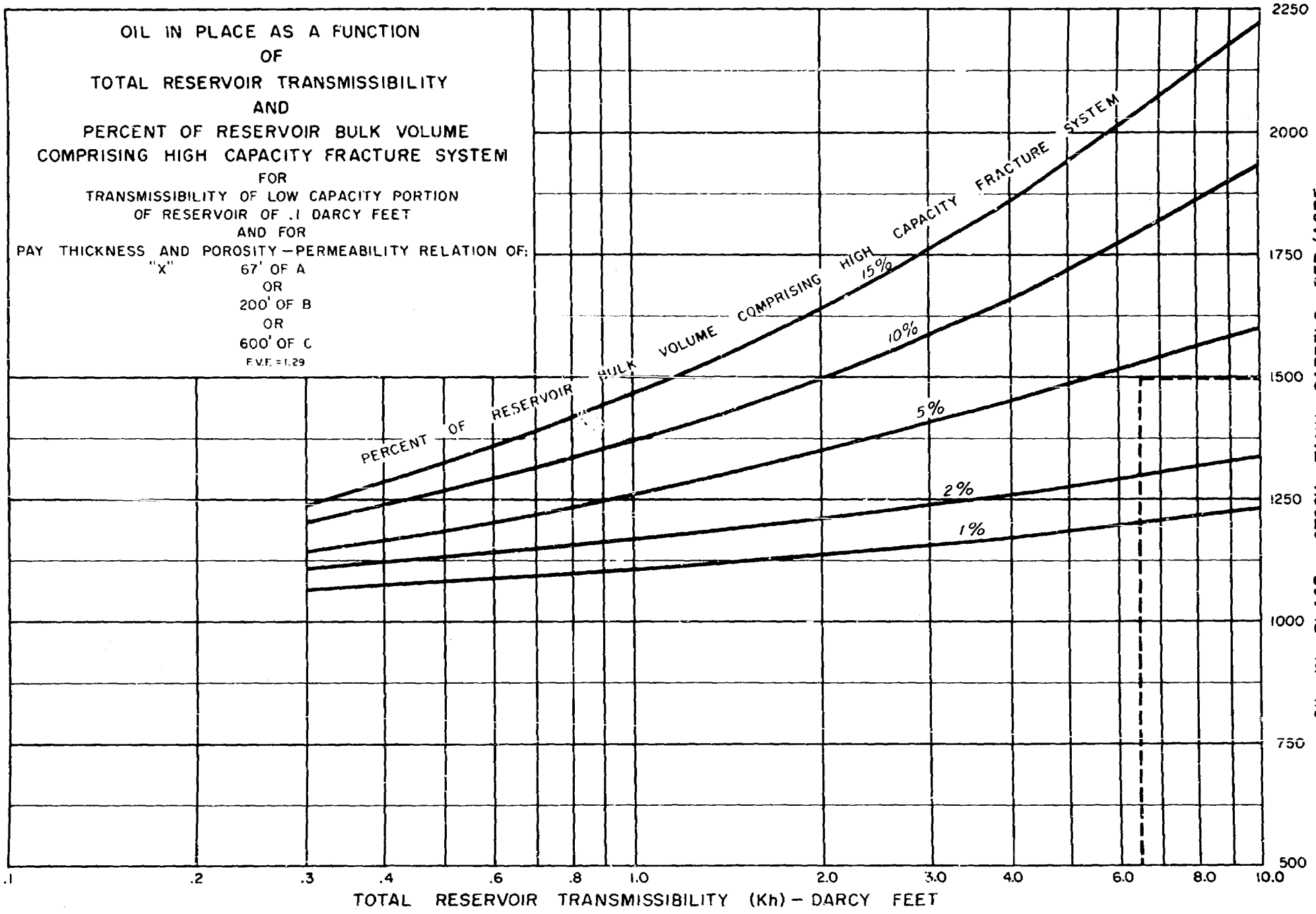
APPENDIX II FIGURE NO. II-9

APPENDIX III



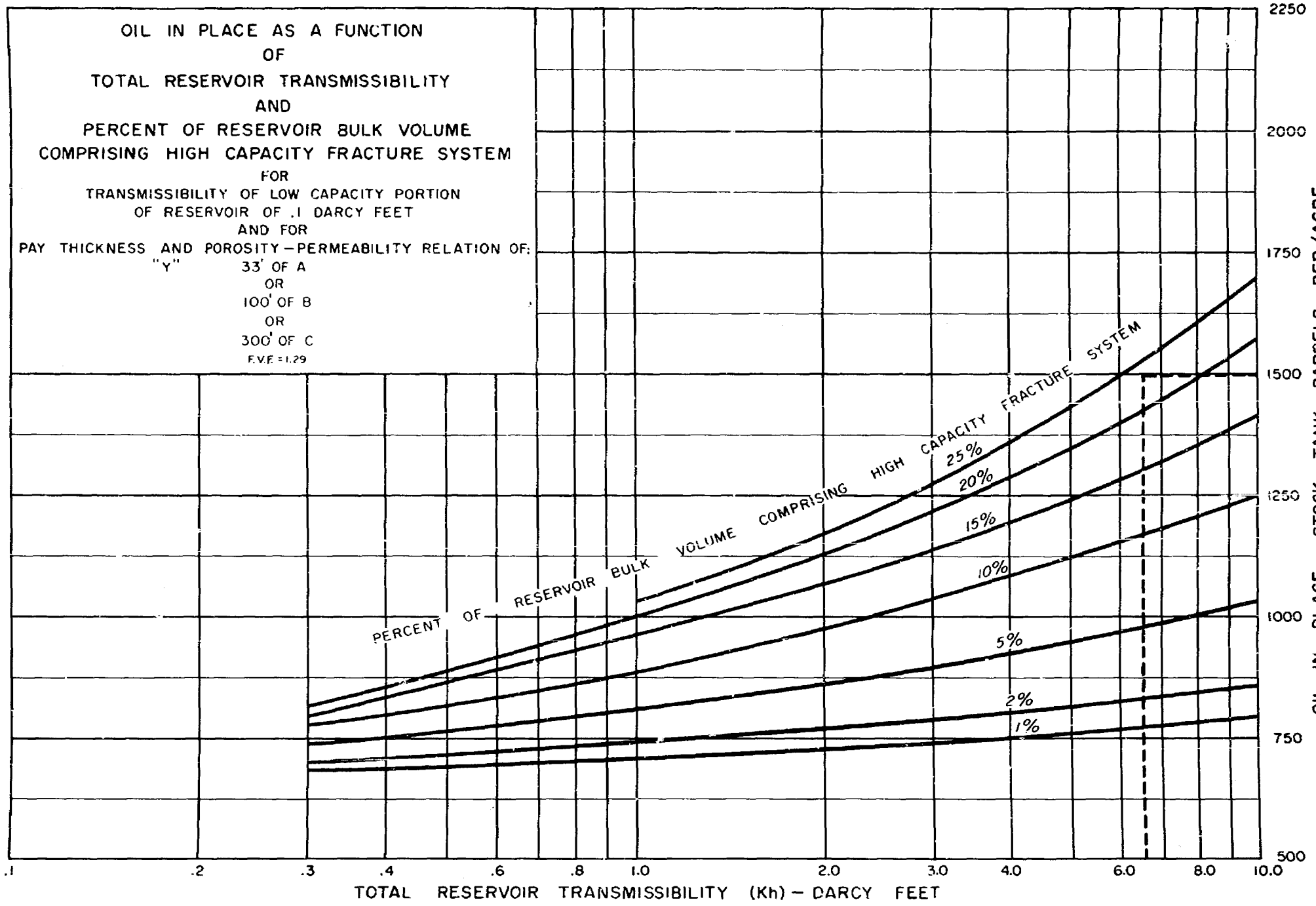
APPENDIX III FIGURE NO. III-6

OIL IN PLACE AS A FUNCTION
OF
TOTAL RESERVOIR TRANSMISSIBILITY
AND
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING HIGH CAPACITY FRACTURE SYSTEM
FOR
TRANSMISSIBILITY OF LOW CAPACITY PORTION
OF RESERVOIR OF .1 DARCY FEET
AND FOR
PAY THICKNESS AND POROSITY – PERMEABILITY RELATION OF:
"X" 67' OF A
OR
200' OF B
OR
600' OF C
F.V.F. = 1.29



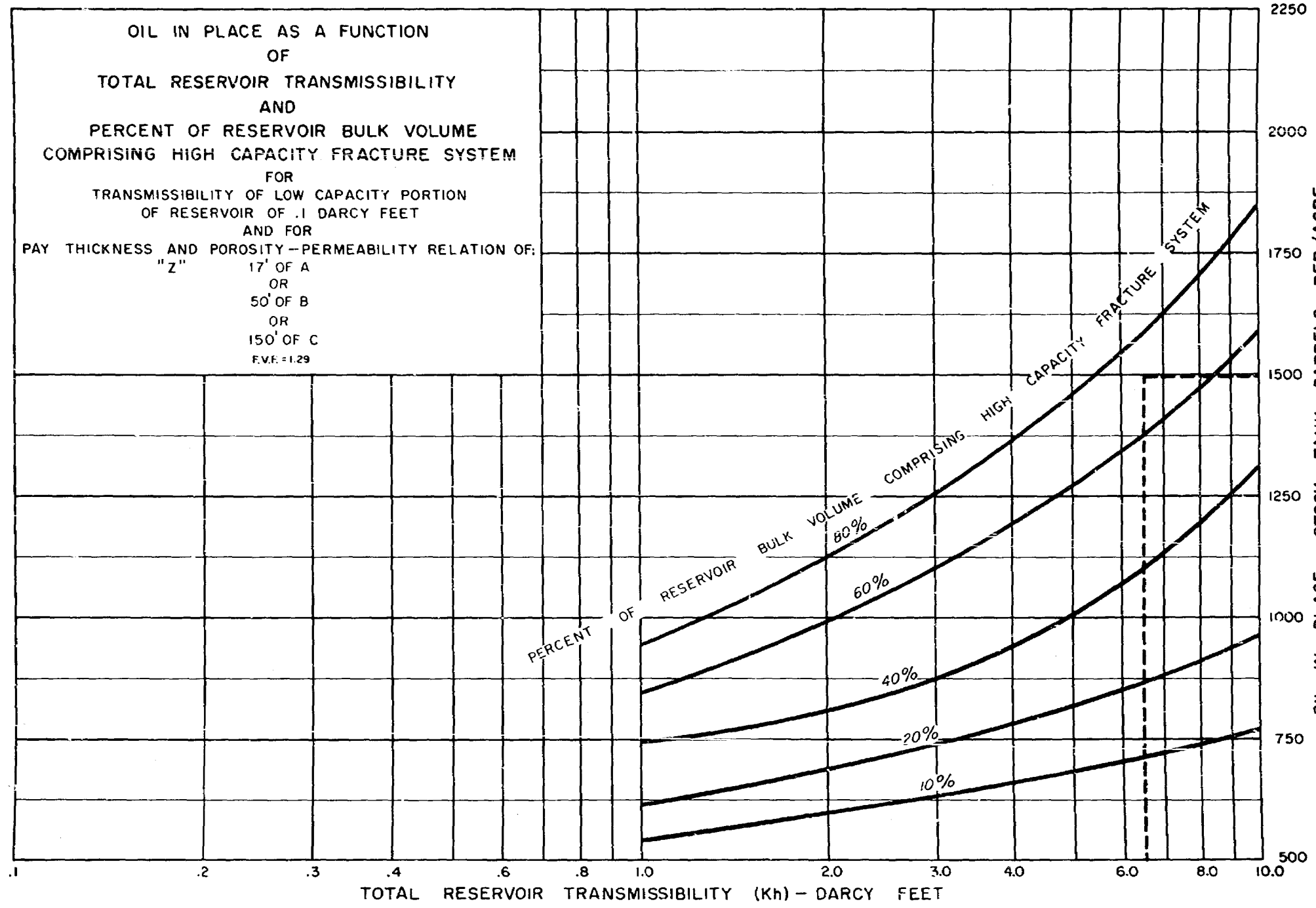
APPENDIX III FIGURE NO. III-7

OIL IN PLACE AS A FUNCTION
OF
TOTAL RESERVOIR TRANSMISSIBILITY
AND
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING HIGH CAPACITY FRACTURE SYSTEM
FOR
TRANSMISSIBILITY OF LOW CAPACITY PORTION
OF RESERVOIR OF .1 DARCY FEET
AND FOR
PAY THICKNESS AND POROSITY – PERMEABILITY RELATION OF:
"Y" 33' OF A
OR
100' OF B
OR
300' OF C
E.V.E. = 1.29



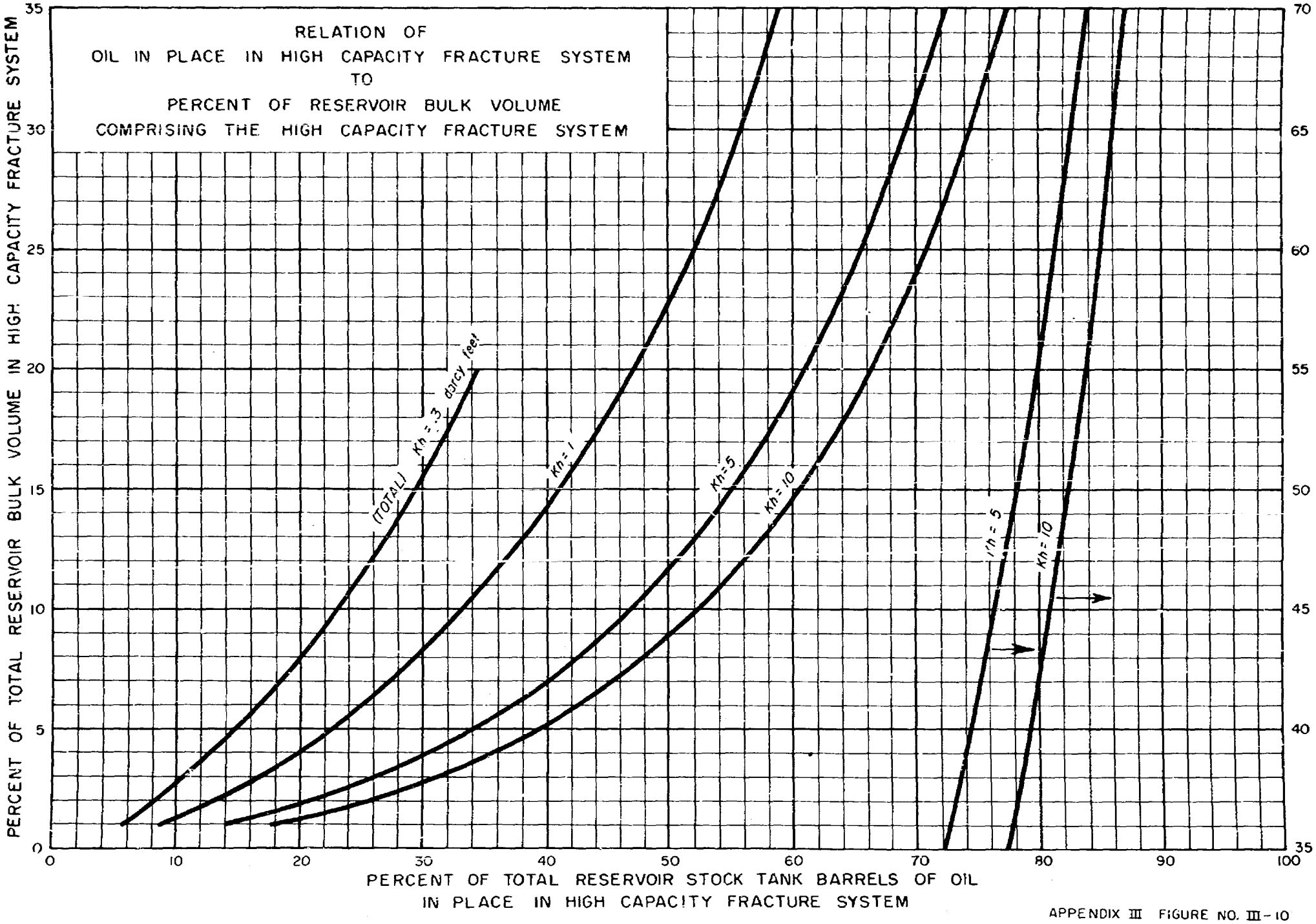
APPENDIX III FIGURE NO. III – 8

OIL IN PLACE AS A FUNCTION
OF
TOTAL RESERVOIR TRANSMISSIBILITY
AND
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING HIGH CAPACITY FRACTURE SYSTEM
FOR
TRANSMISSIBILITY OF LOW CAPACITY PORTION
OF RESERVOIR OF .1 DARCY FEET
AND FOR
PAY THICKNESS AND POROSITY – PERMEABILITY RELATION OF:
"Z" 17' OF A
OR
50' OF B
OR
150' OF C
E.V.F. = 1.29



APPENDIX III FIGURE NO. III-9

RELATION OF
OIL IN PLACE IN HIGH CAPACITY FRACTURE SYSTEM
TO
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING THE HIGH CAPACITY FRACTURE SYSTEM



APPENDIX III FIGURE NO. III-10

APPENDIX III

ESTIMATION OF PERCENT OF TOTAL RESERVOIR OIL OCCURRING IN THE HIGH CAPACITY FRACTURE SYSTEM

As described in Appendix II, this fractured shale reservoir comprises "blocks" of low transmissibility and a connecting high capacity fracture system. The combination of blocks and connecting fracture system is believed to be quite like a jigsaw puzzle. Identification of three blocks has been made, and method of measurement of contained oil volumes and surface areas of these blocks is set out in Appendix II.

Reservoir void space, which contributes to production in the high capacity fracture system, is without question fracture porosity. One must also conclude, from a study of the data available, that the same is true for the "tight" blocks forming a part of the total reservoir. Moreover, there are valid reasons indicating that a large part (half, or more) of the producible oil comes from the high capacity fracture system as opposed to the tight blocks, even though the tight blocks may form the larger part of the bulk volume of the reservoir.

If this be true, then any possible contribution of "seepage" of oil from shale matrix porosity to the oil production from the tight blocks must be inconsequential in overall reservoir performance. It is the opinion of Benson-Montin-Greer Drilling Corp. personnel that all effective reservoir porosity is fracture porosity - in the tight blocks as well as in the high capacity fracture system.

It is important in predicting reservoir performance to know approximately the share of total reservoir oil occurring in

the high capacity fracture system and in the tight blocks. From the standpoint of successful pressure maintenance by gas injection, it is imperative that a substantial part of the recoverable oil occurs in the high capacity fracture system. In time, information developed from the pressure maintenance measures now being carried on will provide this information. At this writing (December, 1969) the gas injection operations have not been conducted long enough to make such a determination, and, of course, the decision to institute pressure maintenance in the first place was made without such knowledge. The decision to initiate gas injection, insofar as the issue of share of total oil in the high capacity fracture system was concerned, was made from the analyses which follow.

The purpose of this appendix is to: (1) show the analyses and reasoning from which it was earlier concluded that a large percent of the producible oil existed in the high capacity fracture system, and (2) that for purposes of forecasting reservoir behavior under various methods of exploitation, a valid basic assumption at this time is that approximately one-half of the oil in place exists in the high capacity fracture system.

Although it is possible, as shown in Appendix II, to determine with a reasonably high degree of accuracy the transmissibilities of the tight blocks and to measure approximately their volumes and surface areas, it is impossible to measure directly either the transmissibility or the volume of the high capacity fracture system. In addition, there is no data available from other fields to aid by analogy in the solution of this problem. Our only tools are analyses of the fundamental relation of porosity and permeability of fractures and judgment of the probable physical reservoir conditions based upon logs, core analyses, observations

of cores themselves, and general well behavior.

We commence our analysis with three fundamental assumptions, each of which is discussed briefly below:

1. Pay Thickness. It is impossible to determine pay thickness exactly, and accordingly the calculations are made for a wide range of pay thicknesses in order that the effects of the variables can be appreciated. It is believed, however, that for the main producing wells in the West Puerto Chiquito Pool at this time the pay thickness of the zone contributing production is on the order of 20 to 50 feet in thickness. All of the zones which produce in either East or West Puerto Chiquito are shown on the electric log section, Figure III-1, at the end of this appendix. This log is a gamma ray induction log with induction scale of 10 ohm-meters per division. The three separate identifiable zones are shown in color. The "zip" type shading within each zone shows sections in which natural production occasionally has been found. This particular log is from a non-commercial well located in Section 18 of Township 25 North, Range 1 East. This log, however, is typical of the logs of all the wells in this area. There is no difference in logs of wells capable of commercial production and those which result in dry holes. It is apparent that the oil saturated sections are the same in the producers and non-producers. The only difference distinguishing productive from non-productive wells is the degree of fracturing and resultant fracture systems and reservoir void space.

An extensive coring program was conducted in Niobrara wells drilled in another of the San Juan Basin's fractured shale oil pools, La Plata Mancos. The resultant core analyses, when compared with gamma ray induction logs, has shown that significant oil

saturation in the Niobrara in this area exists only when induction resistivity of 20 to 30 ohm-meters or greater exists. In the oil saturated zones this high resistivity is usually accompanied by a distinctive radioactive reaction and this is registered on the radioactive side of the log. Resistivities less than 20 to 30 ohm-meters can only be water saturated. The colored intervals shown on Figure III-1 represent that part of the Niobrara in this area which is interpreted to be oil saturated. This is a total maximum pay thickness of all zones of approximately 150 feet. In this respect it should be noted that a high resistivity can also occur in zones that are highly calcareous with no oil saturation. Accordingly, the colored intervals of Figure III-1 can only be considered as representing maximum possible pay thicknesses.

To date production has not been found in all zones in any one well in either the East or West Puerto Chiquito Pools. East Puerto Chiquito produces only from Zones A and B, and so far production in West Puerto Chiquito has been only from Zone C. Free gas was encountered in Zone B in Well No. C-2 when it was first drilled, and accordingly it has been assumed that Zone B would be gas productive at structural positions higher than the datum in this well. Accordingly, completions in West Puerto Chiquito have been limited to Zone C. The relation of the C-2 well and its free gas in Zone B to the structure of the West Puerto Chiquito Pool in the vicinity of the main producing wells is shown on the plat at the end of this appendix, Figure III-2.

In the drilling, testing and completing of wells in the East and West Puerto Chiquito Pools, a considerable amount of evidence has been developed which shows separation of the zones

within the Niobrara. This existence of free gas in Zone B of the C-2 well gives further confirmation that the individual zones as shown on Figure III-1 (particularly Zone C as compared to Zones A and B) are isolated from each other from a standpoint of communication. As seen from Figure III-1, the maximum vertical separation of free gas in Zone B (top) from the oil producing interval in Zone C (base) is 200 feet. If Zones B and C were in good communication, then free gas necessarily would exist in Zone C at a structural position 200 feet up-dip from the C-2 datum. Instead, wells P-11, A-14 and K-13, which are from 200 to 440 feet up-dip from the C-2, produced oil from Zone C with no free gas. Only poor communication has been noted between Zones B and C as compared with communication within Zone C itself, and it is believed that any communication so far found between these two zones could easily be "man-made", as for instance the inadvertent connecting of the two zones through sand fracture treatments. This isolation of the zones within the Mancos is not uncommon. In the Gallegos Gallup Pool, four separate zones were identified with four different gas-oil contacts. One possible explanation for the isolation of the zones is that the productive intervals are for some reason more brittle than the rest of the shale and retain their fracture systems better than the more plastic intervening beds which either never fractured in the first place or if they did, in time "flowed" back to their original impermeable states. It is not the purpose of this paper to go into the origin of the reservoirs, and this separation of zones is noted here only for the purpose of determining the approximate range of pay thicknesses applicable to production from wells completed in Zone C.

2. Oil in place per acre. From the interference test reported at the 1966 hearing, oil in place per acre was calculated to be in the range of 1,000 to 2,500 barrels per acre, depending upon the unknown compressibility of the fractured shale reservoir rock. At this time our best estimate of total compressibility of the system to oil at the time of the interference test is 35×10^{-6}, which gives a per acre oil in place figure of 1,500 stock tank barrels. Average transmissibility was determined by the same interference test to be approximately 6.5 darcy feet. These figures of oil in place per acre and transmissibility are for Zone C only. Whether significant production will be found in other zones is not yet known. If it is found in Zone B it will, of course, have to be at positions structurally lower than the C-2 well, and accordingly can only cover a part of the reservoir. For the purpose of this study it is essential that we deal only with the one zone about which some direct knowledge is available as to average pore volume and transmissibility. Although it is, of course, impossible to determine these properties exactly, it is believed the information available provides data of sufficient accuracy to form a basis for the analyses of this Appendix III. Comparative figures are noted for other reservoirs: (a) Gallegos Gallup, 3,000 barrels per acre in place for the sum of four separate zones, calculated from material balance estimates; (b) Boulder Pool, 2,000 to 4,000 barrels per acre for all zones, calculated from material balance.

3. The reservoir comprises individual blocks of comparatively low transmissibility and an interconnecting high capacity fracture system. The per acre oil in place figure and transmissibility given above represent overall averages. That is, the average oil in place per acre is 1,500 barrels and the total transmissibility from both the high capacity fracture system and the tighter blocks is 6.5 darcy feet. A note in this respect is that this information was determined as a result of an interference test taken at a time when the reservoir pressure was above the bubble point and the resulting diffusivity constant of all parts of the reservoir, including the tighter blocks, was quite high. For example, a tight block with a transmissibility of .1 darcy feet and gross surface dimensions of approximately 1,000 feet across would require about six hours from the initiation of pressure differential to reach steady state conditions. Since the data used in the interference test was for a period of six to eighteen days, with an approximate time of thirty days for steady state conditions to be reached in the overall reservoir, it is apparent that any error introduced in the interference test as a result of lag of pressure communication across these blocks of low transmissibility would be negligible. The resulting calculations accordingly include the volume and transmissibility of these tight blocks as well as for the high capacity fracture system.

To commence our analysis, we draw on an earlier study (Reference No. III-1) in which porosity-permeability relations and diffusivity constants are compared for sandstone reservoirs and fractured reservoirs. Figure III-3 at the end of this appendix is reproduced from this reference. On this figure is shown the general

range of porosity-permeability relations for systems of fractures in which the fractures are oriented parallel to the direction of flow. The fracture systems shown are for 1, 10 and 100 fractures per foot and for various sizes and various widths of fractures. We assume, of course, that in the reservoir a large number of the fractures will be perpendicular to the direction of flow and as such will increase the porosity for any one of the systems shown on Figure III-3 at a greater rate than it will increase the permeability parallel to the direction of flow, and accordingly if we modify the systems shown on Figure III-3 by increasing porosity (through fractures at an angle to direction of flow) they would, in a sense, move upward on the graph. It is possible, of course, that the general slope of the systems also would change. It is doubtful, however, that the slope would change much, for it is axiomatic that at some point of exceptionally high porosity the permeabilities of the sandstone and fracture systems would necessarily be the same. Accordingly the two systems must converge when plotted on a graph such as Figure III-3.

One might expect core analyses to provide the information whereby the nature of the fracture system could be defined. This type information is, however, quite limited in its usefulness for this purpose. Only one well in every ten or twenty drilled in East and West Puerto Chiquito has resulted in one capable of commercial production without stimulation; and none of the wells that were cored have been capable of high rates of natural production. Accordingly the cores so far taken cannot definitely be said to be representative of that part of the reservoir which contributes significantly to production.

Information from core data that is of value to this study is briefly described as follows:

(1) Both horizontal and vertical fractures have been observed in cores.

(2) The horizontal fractures are usually of very narrow width (hairline); whereas the vertical fractures appear to possibly have comparatively greater width.

(3) Density of the horizontal hairline fractures seems to be in the range of 10 to 100 fractures per foot. Certainly 100 fractures per foot would be the maximum. An average density of the horizontal fractures in the zones where they occur would be more on the order of 10 per foot.

(4) As to density of vertical fractures, occasionally one or two sloping fractures across a 50-foot core have been observed in some cores, and in others no vertical fractures at all were found. Since the core holes were nearly vertical, as were the fractures, and hence hole and fractures nearly parallel, an ordinary well cannot be expected to adequately "sample" the vertical fracture system. In the cores taken, however, a maximum density of vertical fractures would be in the range of one per foot.

Accordingly, at this time, from the core data available, we assume that a maximum porosity to permeability relation would be a pore space of twice that shown on Figure III-3 for 100 fractures per foot, and for a minimum, twice the pore space shown thereon for 10 fractures per foot. These two relations are shown on Figure III-4 as lines A and C, with the area in between shaded and the center line of it given designation B.

From these porosity-permeability relationships it is of course possible to calculate oil in place per acre for various "mixes" of transmissibilities of tight blocks and high capacity fracture systems, and from this to reach our objective, i.e., the percent of the total oil which occurs in the high capacity fracture system.

First we determine oil in place per acre for the three porosity-permeability relationships A, B and C of Figure III-4. This has been done for various assumed thicknesses of pay section. Regarding pay thicknesses, it is noted that for the slope of the porosity-permeability relationship shown on Figure III-4 there is a 3 to 1 relation of pore space to permeability for the lines: A compared to B; and B compared to C. That is, for any given pay thickness using the porosity-permeability relationship of A, and the same total transmissibility (Kh), total oil in place (barrels per acre) can be obtained with relation B and three times the pay thickness used for A, and likewise relation C with nine times the pay thickness used for A will give the same reservoir characteristics of transmissibility to pore volume. Accordingly oil in place (stock tank barrels per acre) was calculated for the following three sets of conditions:

(1)	67	feet of pay with porosity-permeability relationship	A.
	200	" " " " " " "	B.
	600	" " " " " " "	C.
(2)	33	feet of pay with porosity-permeability relationship	A.
	100	" " " " " " "	B.
	300	" " " " " " "	C.
(3)	17	feet of pay with porosity-permeability relationship	A.
	50	" " " " " " "	B.
	150	" " " " " " "	C.

These three relationships of oil in place per acre versus transmissibility are shown at the end of this appendix, Figure III-5, and given designations X, Y and Z.

Next we determine the relation of total reservoir transmissibility to the transmissibilities of its component parts for the range of values of this property known to exist in the subject reservoir. This relation was prepared for a range of 1 to 10 darcy feet for total reservoir transmissibility, and for a range of 1 to 1,000 darcy feet for transmissibility of the high capacity fracture system; all for two different transmissibilities of the low capacity (tight) blocks of .01 darcy feet and .10 darcy feet. These relations are shown on Figure III-6. As can be seen from Figure III-6, for the ranges of total transmissibility in which we are interested (2 to 10 darcy feet) the relation of total transmissibility to transmissibility of that part of the reservoir which is high capacity fracture system is the same whether the transmissibility of the tight blocks is .01 darcy feet or .10 darcy feet. Although not shown on Figure III-6, for the range of 5 to 10 darcy feet total reservoir transmissibility, the relation also is nearly the same as that shown on Figure III-6 for systems in which the transmissibility of the tight blocks is as high as 1 darcy foot.

Accordingly for the subject reservoir we can state unqualifiedly that Figure III-6 represents the relation of total transmissibility to transmissibility of the high capacity fracture system for the percentages of bulk volume of the reservoir shown. For example, if we assume the total transmissibility is 6 darcy feet and that 2 percent of the bulk volume of the reservoir exists as high capacity fracture system, then the transmissibility of the high capacity fracture system must be 300 darcy feet.

From Figures III-5 and III-6 we can now compute the average amount of oil in place per acre for any given combination of reservoir bulk volume of high capacity fracture system and low capacity fracture blocks. The results of this for systems X, Y and Z are shown on Figures III-7, III-8 and III-9. On each of these figures is shown by dotted lines the 6.5 darcy feet and 1,500 barrels per acre values which represent the situation in West Puerto Chiquito. For the relations X, Y and Z of Figure III-5 the minimum bulk volume of the reservoir which was determined to be occupied by high capacity fracture system would be about 4 to 5 percent as shown on Figure III-7 (X relation of Figure III-5). It could be as high as 70 percent if the data of Figure III-9 were to apply (Z relation of Figure III-5). Figure III-7 (which results from the X relation of Figure III-5) is considered a maximum in terms of pay thickness. The true situation probably lies between the amounts shown between Figures III-8 and III-9 (Y and Z relations of Figure III-5) which would place the bulk volume of the high capacity fracture system between 20 and 70 percent of the total bulk volume of the reservoir.

It is interesting to note that a substantially greater percent of total oil in place lies within the high capacity fracture system than is represented by its share of the total bulk volume of the reservoir. From the calculations underlying Figures III-7, III-8 and III-9 we can determine the percent of total oil which occurs in the high capacity fracture system for any given percent of reservoir bulk volume which forms the high capacity fracture system. Oddly enough, this relation is exactly the same for all three of the X, Y and Z relations of Figure III-5 and is apparently a function

only of the slope of the line relating porosity to permeability as shown on Figure III-4. For example, for a total reservoir system with a transmissibility of 5 darcy feet, if 1 percent of the bulk volume of the reservoir exists in the high capacity fracture system, then 14 percent of the total oil in place exists in this same system. If as much as 10 percent of the bulk volume of the reservoir is in the high capacity fracture system, then 47 percent of the total oil in place exists in this same fracture system. This relation, percent of oil in place in the high capacity fracture system as a function of its percent of bulk volume, is shown on Figure III-10.

Accordingly, if the true situation is represented by something in the range of that given by Figures III-7 and III-8 (20 to 70 percent of the bulk volume of the reservoir being occupied by high capacity fracture system) then for 5 darcy feet the percent of the total oil in place that is in the high capacity fracture system lies between 61 percent and 82 percent of the total oil in place in the reservoir.

It is logical to presume that of the oil in place in the reservoir, a higher percent of that in the high capacity system will be recovered as compared to that in the low capacity part of the fracture system. Following this, then, if we think in terms of recoverable oil, that part of the oil in the high capacity fracture system must represent an even greater part of the total recoverable oil than the figures mentioned above.

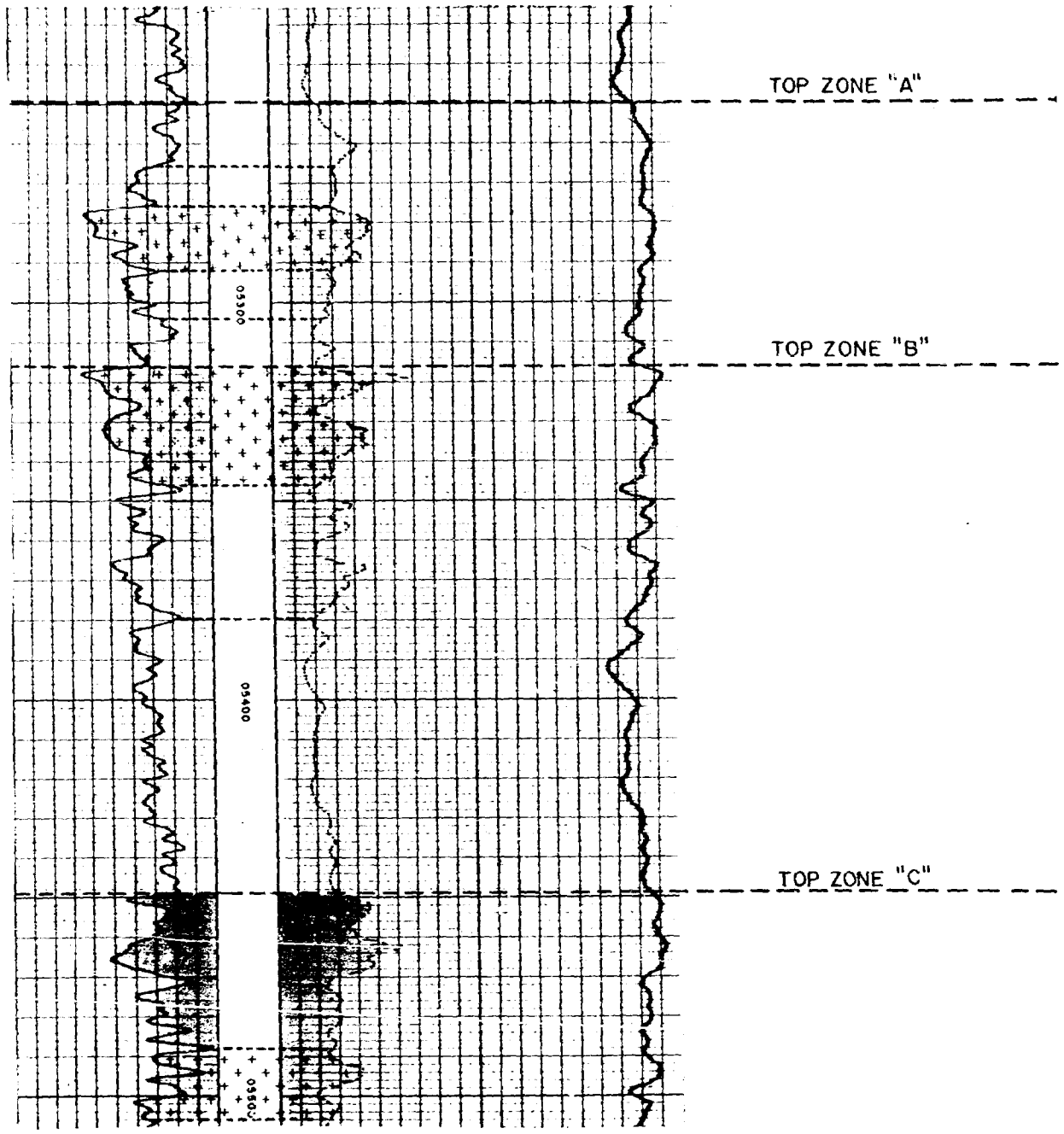
Obviously it is impossible to determine precisely the percent of oil in the high capacity fracture system. For the purposes of analysis of reservoir behavior and planning for pressure

maintenance, we believe it is reasonable to assume, from the information in this Appendix III, that approximately half of the total reservoir oil is in the high capacity fracture system and approximately half of it in the low capacity blocks.

IDENTIFICATION OF MAIN PRODUCING ZONES
NORTHEAST PUERTO CHIQUITO
AND
SOUTHWEST PUERTO CHIQUITO

BENSON-MONTIN-GREER DRLG. CORP.

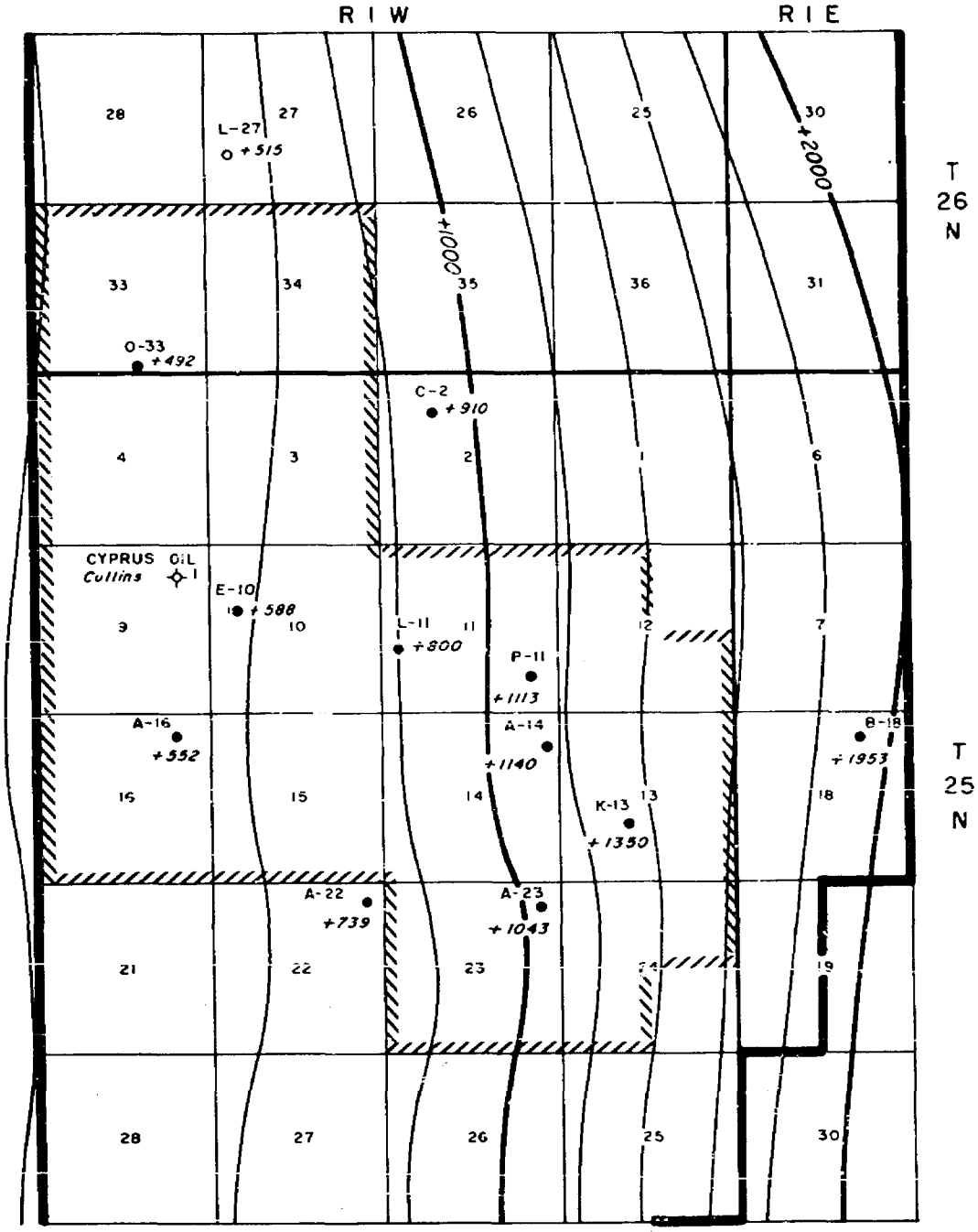
CAÑADA OJITOS UNIT NO. B-18



APPENDIX III FIGURE NO. III-1

PLAT OF PART
OF
CAÑADA OJITOS UNIT

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969



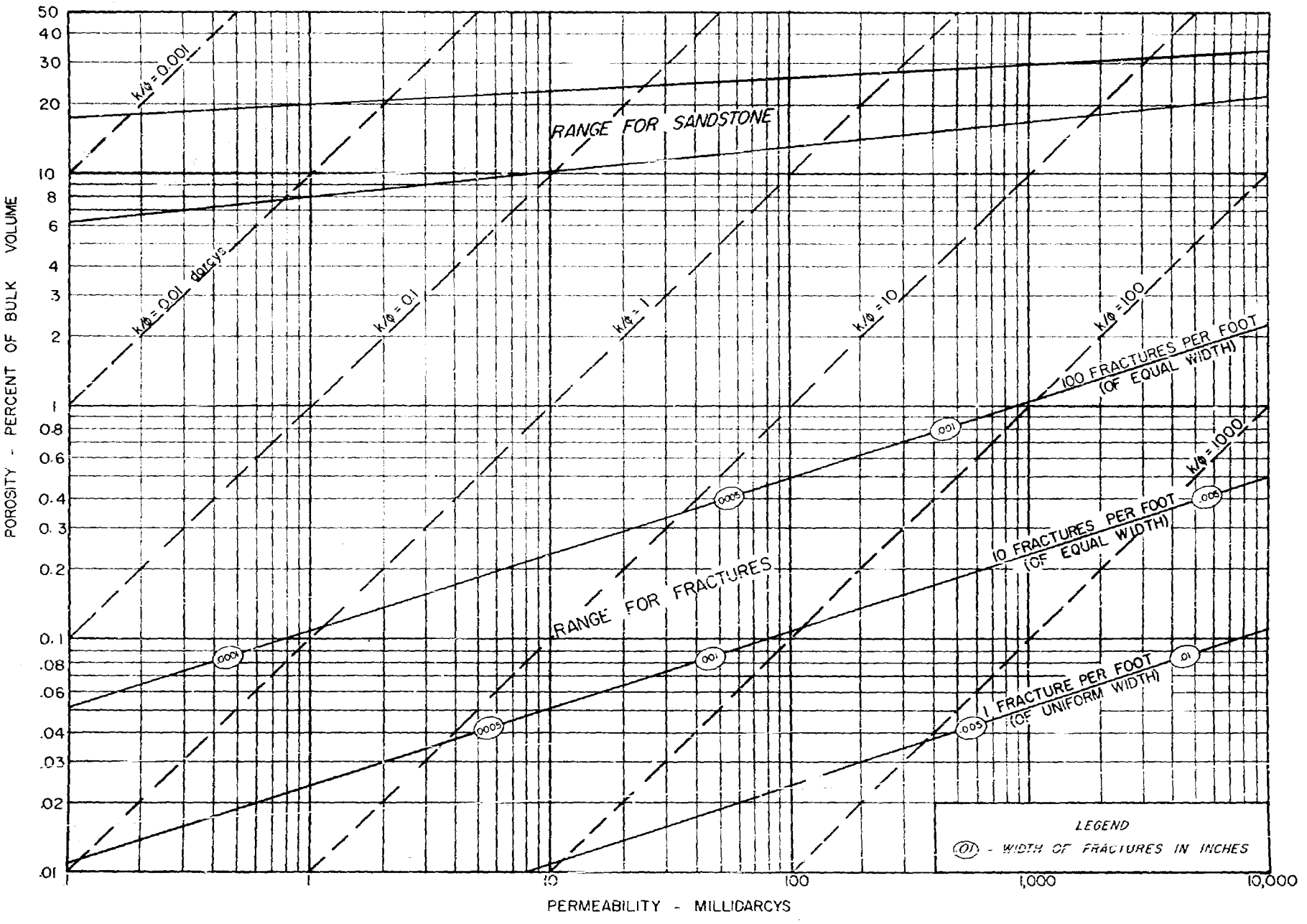
/// BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

APPENDIX III FIGURE NO. III-2

VALUES OF KΦ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

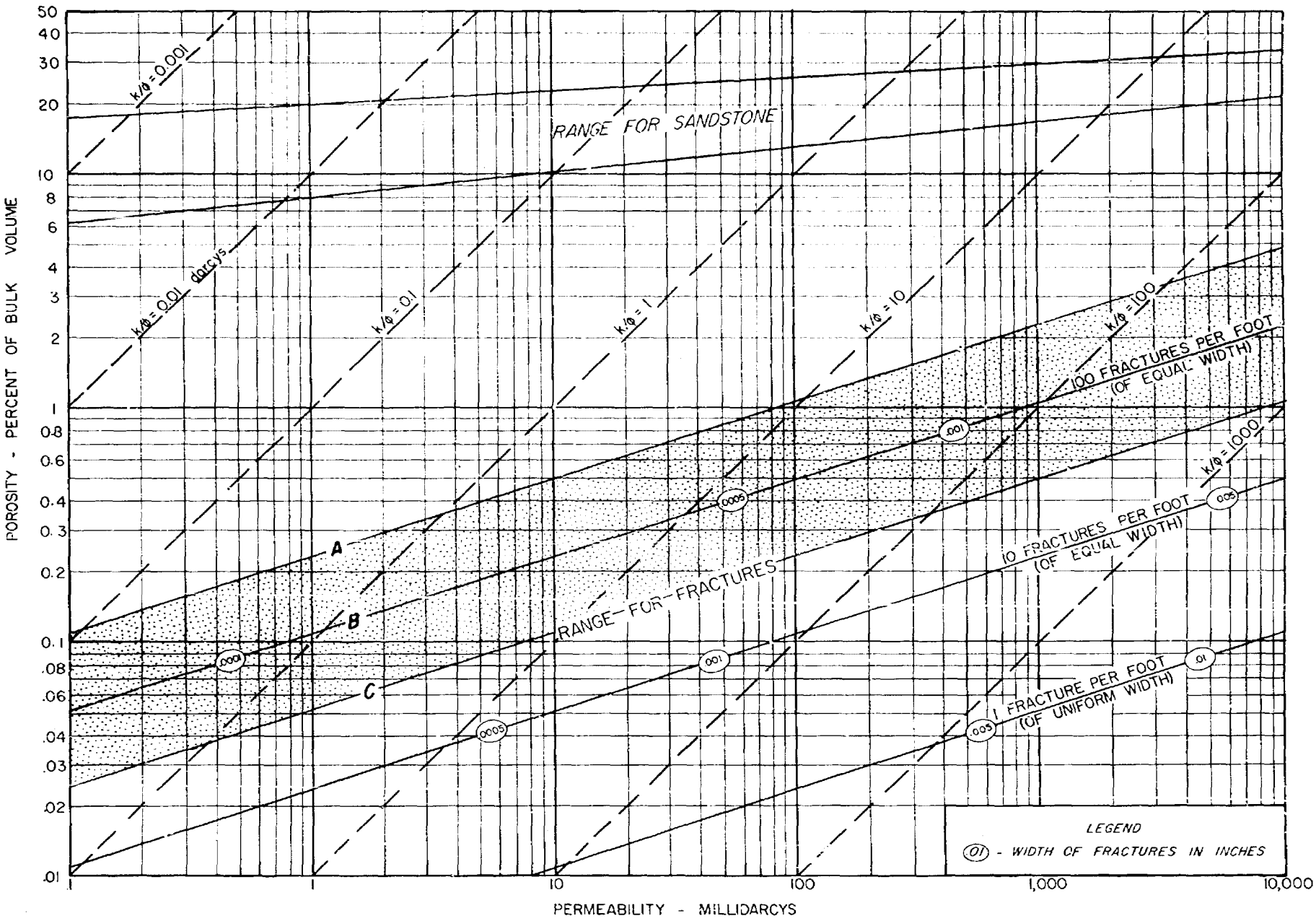
FRACTURES PARALLEL TO DIRECTION OF FLOW



APPENDIX III FIGURE NO. III-3

VALUES OF Kϕ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

FRACTURES PARALLEL TO DIRECTION OF FLOW



APPENDIX III FIGURE NO. III-4

APPENDIX IV

SOLUTION-GAS DRIVE PERFORMANCE

Anticipated performance of the subject reservoir under solution-gas drive has been investigated with calculations made in the manner shown by Muskat (Reference No. 3). Prior to the time gas injection was commenced in August, 1968, all of the oil recovered from wells in the Cañada Ojitos Unit in the West Puerto Chiquito Pool was produced at or slightly below the initial dissolved gas-oil ratio. Under these conditions, where no free gas has been produced, the relation of oil recovery in terms of oil in place as a function of reservoir pressure decline below the bubble point is a simple and accurate process to calculate. The effect of the indefinite value of the compressibility of the formation is relatively small, and accordingly can have only a minor effect in the calculations. In this instance it is disregarded. For pressures above the bubble point, however, this is a different matter. Here, however, the pressure drop with production is so fast that a large error in the estimated value of this property can exist without having a serious effect in the calculated percent of oil produced in terms of total oil in place. At this time it is believed that the system compressibility to oil initially approximated 35×10^{-6} per pound. Using this value and the PVT data from the fluid sample analysis for West Puerto Chiquito oil, the relation of reservoir pressure to oil recovery in terms of percent of oil in place at the bubble point pressure has been calculated. Calculations were made for a pressure range of about 400 pounds above the bubble point and approximately 200 pounds below the bubble point, for the condition in which the produced gas-oil ratio has been at the solution ratio or less.

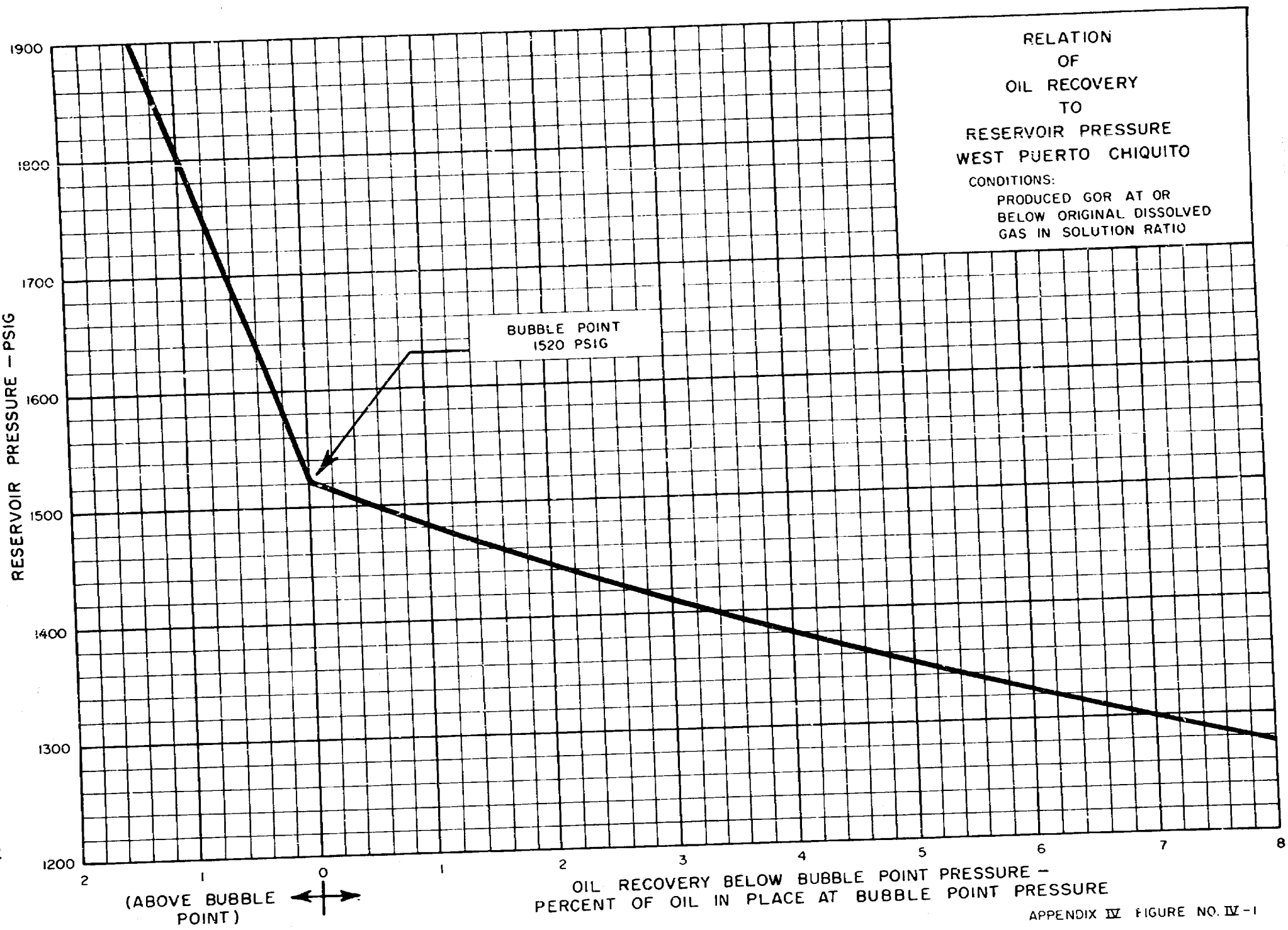
The results are shown graphically at the end of this appendix, Figure IV-1. From this figure we can determine the degree of depletion any part of the reservoir has suffered if we know its initial pressure and the pressure at which a determination is desired. In the instance of the L-11 well, which is mentioned in Section IV, Part 2, of the text, the reservoir at the structural datum of this well when the reservoir was discovered was approximately 1,500 pounds. It can be seen from Figure IV-1 that for the pressure decline from 1,800 pounds to the bubble point, 1,520 pounds, the reservoir suffered a depletion of approximately 1 percent with reference to the oil in place at the bubble point. For the additional decline in pressure from the bubble point to 1,500 pounds the reservoir suffered additional depletion of approximately .5 percent. The sum of these two figures is 1.5 percent, which is the amount of depletion the reservoir had suffered at the structural position of the L-11 well at the time gas injection was commenced in August of 1968.

To calculate the entire production history under solution gas drive requires, of course, a knowledge of the relative permeability of the formation. As stated at the 1966 hearing, information at that time available as to relative permeability of fractured formations showed such a wide variation as to be of little use in estimating recoverable oil as a function of total oil in place. However, as mentioned in the introductory remarks to this paper, under the heading General Considerations, it now appears that the field data, which indicated the extremely low values of the relative permeability ratio for given fluid saturations, may have

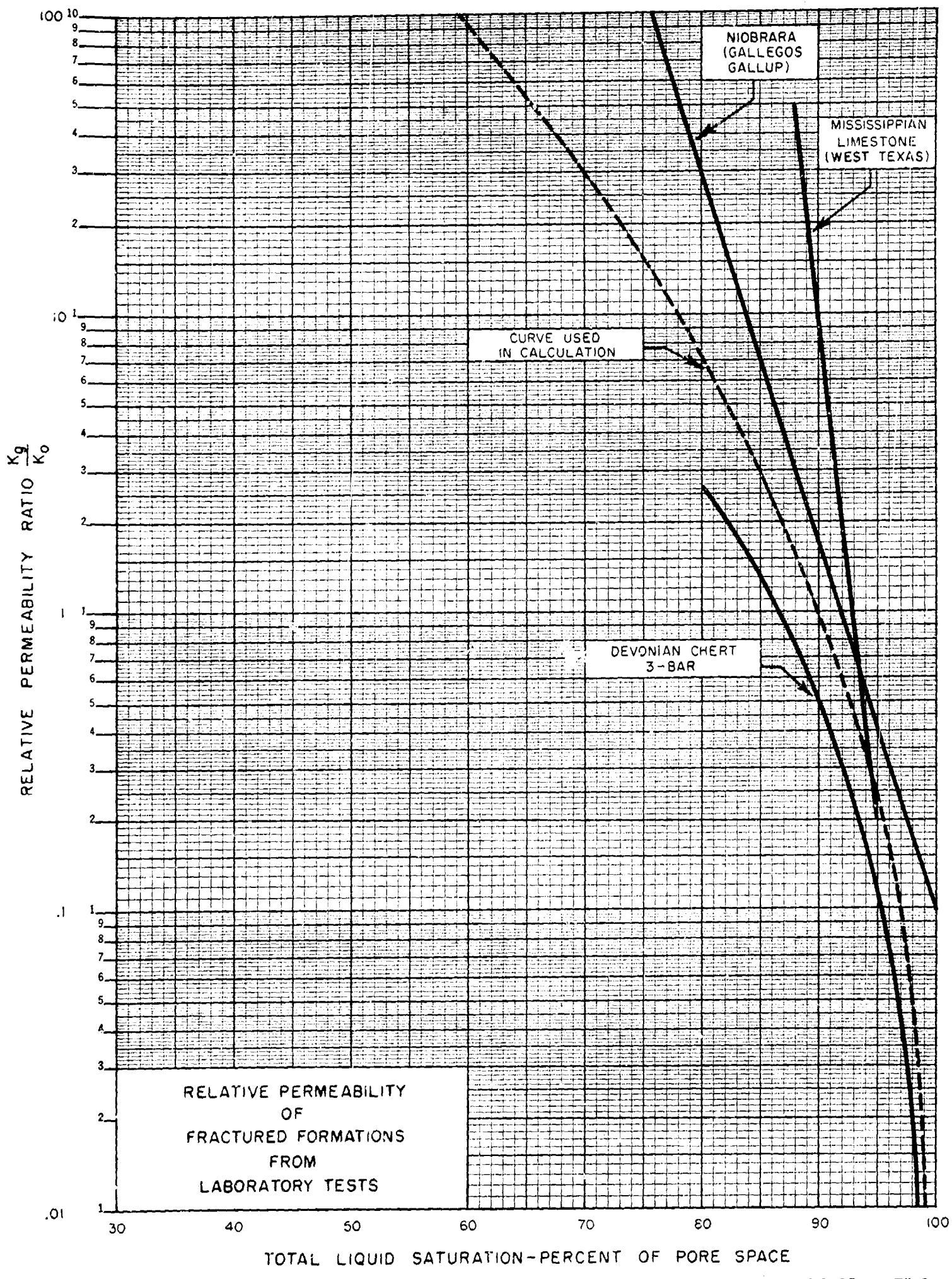
been the result mostly of gravity drainage effects. All of the laboratory data available indicates fractured formations to have comparatively high relative permeability ratios, and it is now believed that this is the true characteristic of fractured reservoirs. Some of the information developed from laboratory tests is shown on the figure at the end of this appendix, Figure IV-2. Also shown on this figure is the curve used for calculations in this paper. From this relation of relative permeability ratio, along with the PVT data for West Puerto Chiquito, the straight solution-gas drive production history was calculated. These results are shown graphically on the figure at the end of this appendix, Figure IV-3, and reproduced to form Figure 8 of the text. From this it can be seen that the ultimate recovery in terms of percent of oil in place can be expected to be on the order of 6 percent if the reservoir is depleted by the solution-gas drive mechanism.

It must be assumed that when gas injection was commenced, the bulk of the oil recovered to that time had been produced as a result of the combined effects of the oil expansion and solution-gas drive mechanisms. It is not known, of course, if the relative permeability ratio characteristics as shown on Figure IV-2 represent the true situation in the reservoir, or not. Since a substantial amount of oil has been produced, however, at the solution gas-oil ratio, with no free gas being evident in the production, we must assume either: that the formation truly has a high permeability to gas at higher liquid saturations, as indicated on Figure IV-2, and that evolved gas is moving by gravitational segregation up-dip toward the top of the structure rather than being produced with the oil; or on the other hand, that the formation has a critical gas

saturation at some substantially lower liquid saturation than is indicated on Figure IV-2, and as a result, the initial amounts of gas evolved are "trapped" in the pore spaces. In either event, it is probable that no significant oil gravity drainage has yet been realized. Even if free gas bubbles are moving to the top of the structure by gravitational segregation, appreciable benefit of oil gravity drainage cannot be realized until these bubbles reach the top of the structure, or the gas-oil contact if a gas cap exists; as it is the gravitational movement of this oil near the gas-oil interface which ultimately will determine the efficiency of the gravity drainage occurring. It is therefore assumed that the depletion process prior to the time gas injection was commenced was primarily that of oil expansion and solution-gas drive.



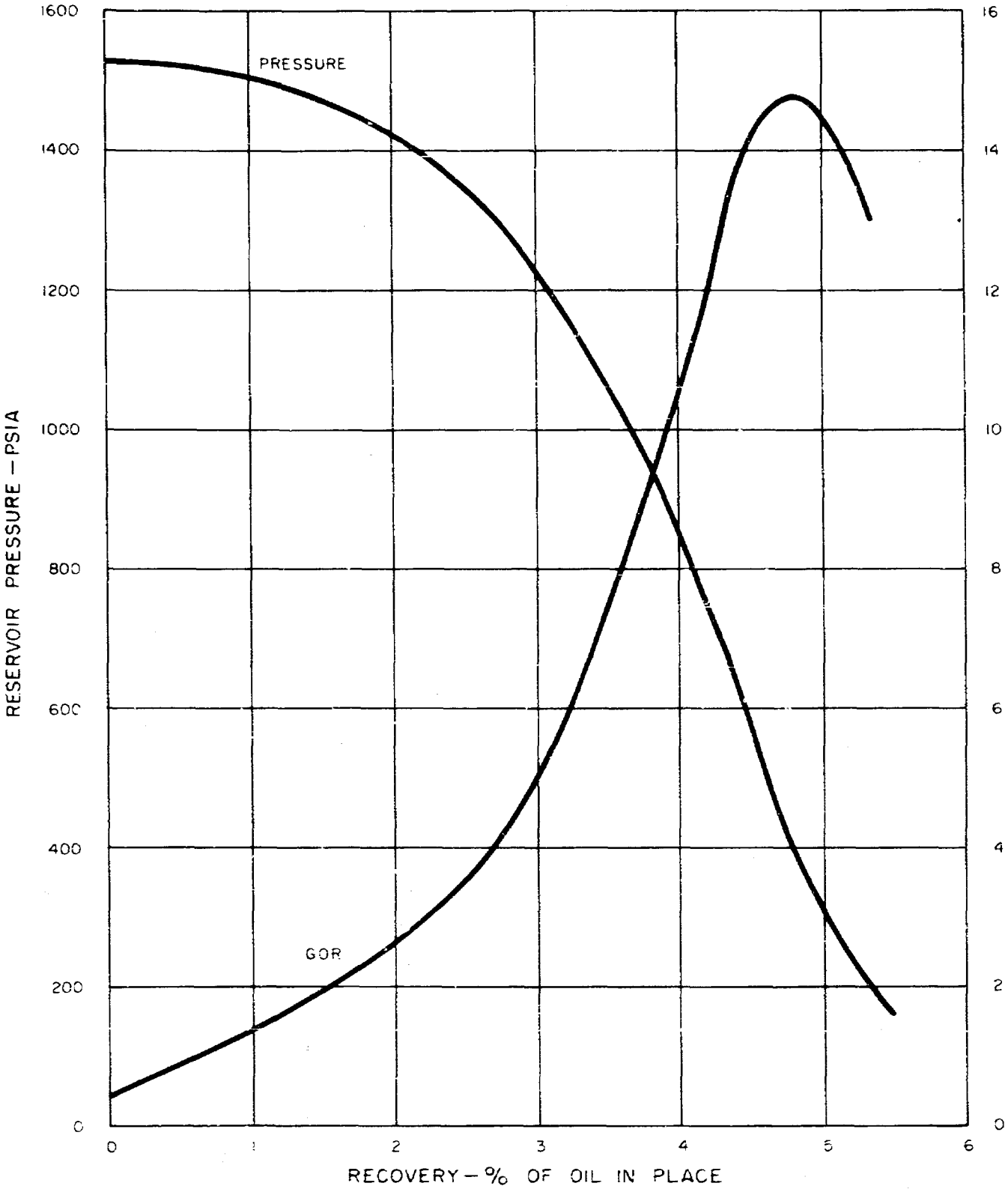
APPENDIX IV FIGURE NO. IV-1



APPENDIX IV FIGURE NO. IV-2

SOLUTION GAS DRIVE
PRODUCTION HISTORY

CALCULATED FOR CONDITIONS OF:
WEST PUERTO CHIQUITO
PVT DATA
AND
K_g/K_o ESTIMATED FROM LABORATORY
DATA FOR FRACTURED FORMATIONS



APPENDIX IV FIGURE NO IV-3

APPENDIX V

SOLUTION GAS DRIVE RECOVERY OF OIL FROM TIGHT FRACTURE BLOCKS

Comparison of drainage abilities of wells with drainage ability of the high capacity fracture system

As stated in Section IV, Part 2, of the text, the high capacity fracture system can more efficiently drain the tight fracture blocks than can wells drilled within them. This statement is perhaps best appreciated through numerical examples. By adding to the information of Appendix IV the relative permeability to oil for known liquid saturations, it is possible to compute the potential productivity of wells completed in fracture blocks for assumed reservoir pressures and a knowledge of the transmissibility of the tight block. No direct knowledge is had of the relative permeability to oil of this fractured reservoir. A relation has been assumed based somewhat on the data available on other types of formations. This relation is shown at the end of this appendix on the graph, Figure V-1. With this information, calculations have been made for an example circular reservoir with a well drilled at its center and completed with a rather successful sand fracture treatment which has resulted in an effective well bore radius of 100 feet. The flow system is obviously that of steady state, and as a result it is fairly simple to calculate potential productivities for given reservoir pressures of the high capacity fracture system. The fact that steady state conditions will exist under the subject circumstance can be readily determined from the diffusivity constants which will apply. For example, for a block with transmissibility of .10 darcy feet, steady state conditions will be reached in it in less than 10 days after production has commenced.

The results of the calculations made are shown at the end of this appendix, Figure V-2, in which these potential producing rates are shown for various assumed transmissibilities. In calculating these potential producing rates it was assumed the initial productivity indices would decline with reservoir pressure, as shown by Muskat, directly with decrease in relative permeability to oil and inversely with the viscosity and formation volume factors. It was further assumed, in determining the initial productivity index in each instance, that to account for the reduction in permeability to oil in the low pressure area around the well bore, the productivity index calculated as above, with no correction, be multiplied by one-third.

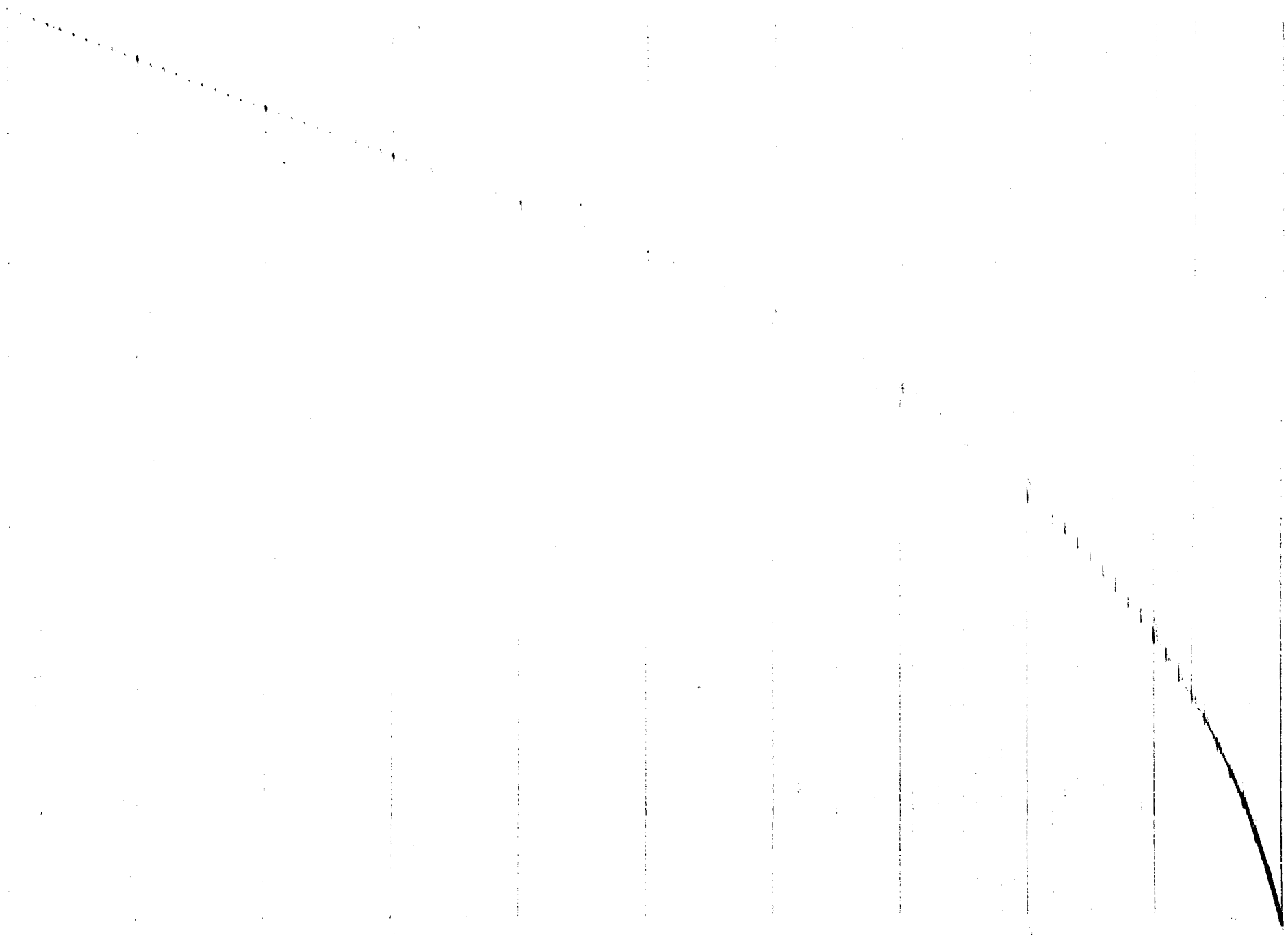
Referring now to Figure V-2 and assuming an economic limit of 15 barrels per day per well, it is evident that for fracture blocks with transmissibilities of .10 darcy feet or less, wells completed in them will have to be abandoned while there still exists in the high capacity fracture system a pressure of 300 pounds or higher. These excessively high pressures relate to unrecovered oil in the fracture blocks at the time of the wells' abandonment. This oil left in the tight fracture blocks will be recovered by the high capacity fracture system. For blocks whose transmissibilities are about .01 darcy feet or less, wells completed in them will be uneconomic to produce, even with virgin reservoir pressure. In this instance, all of the recoverable oil in the tight fracture block will be unavailable to wells drilled within the block. This oil, nevertheless, will move from the tight fracture block into the high capacity fracture system and be produced by wells that have communication with the high capacity fracture system.

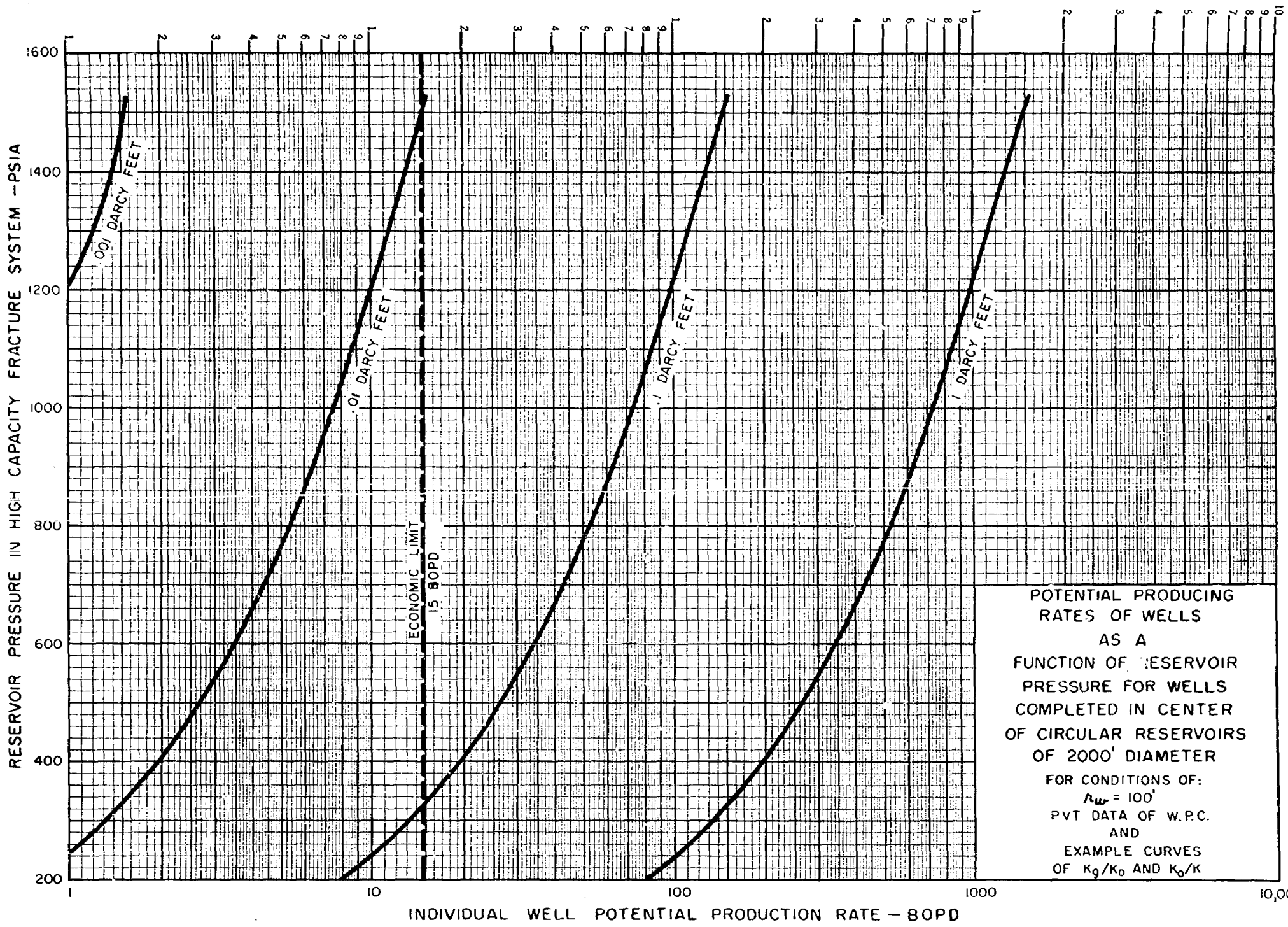
With respect to the ability of the high capacity fracture system to drain efficiently these tight fracture blocks, no attempt is made here to solve this problem explicitly. Although the flow system for a well producing from one of the tight fracture blocks, as stated above, is clearly one of steady state conditions, the flow system of a block being drained by the high capacity fracture system is obviously one of unsteady state conditions, and in view of its nature, no attempt has been made here to solve this problem exactly. The ability of the surrounding fracture system to drain the tight fracture block is hardly one to be questioned, however. That this efficiency exists is evident from a cursory examination of some of the comparative factors involved. For example, a well completed in the example reservoir that has a transmissibility of .01 darcy feet will have an initial producing ability of approximately 15 barrels per day, and will promptly be abandoned. If we view the flow process in reverse, so to speak, with oil flowing out of the tight block into the fracture system, we find, for the same pressure differential, an initial ability of the fracture block to move an incremental amount of oil at a rate of about 500 barrels per day, if we consider the 900 foot radius from the well bore and the block's boundary at 1,000 feet. As a practical matter, of course, such large differentials will never come about, because the fracture system will continually deplete the tight blocks at low pressure differentials. Nevertheless, the comparison indicates the superior drainage ability of the high capacity fracture system.

Not only this, but when oil moves through such a system to its internally located well, an equal amount of oil, under steady state conditions, must pass through any circumference at any given

radius. This means that the same amount of oil (with its contained and associated gas) that crosses the external circumference must be crowded through a circumference 1/10th as great at the 100 foot radius from the well bore. On the other hand, when the oil flows the other way, rather than all of the oil which is produced having to move through this circumference at a radius of 100 feet, the only oil which need move through it now is the oil contained inside this 100 foot radius, which is only 1 percent of the block's total contained oil volume.

In view of the considerations set out in this appendix, it is quite clear that the high capacity fracture system will adequately drain its contained tight fracture blocks if the reservoir is depleted by the solution-gas drive mechanism, with or without wells completed in them. The possibilities of depleting these blocks by other depletion mechanisms are discussed elsewhere in this paper.





APPENDIX V FIGURE NO. V-2

APPENDIX VI

APPENDIX VI

PART A - SIMPLIFIED FLOW SYSTEM SHOWING DETERMINATION OF ACTUAL HORIZONTAL FLOW VELOCITY FROM TRANSMISSIBILITY

The exact relation of transmissibility to gravity drainage rates and vertical and horizontal velocity of the gas-oil contact "plane" is given later in this appendix, Parts B and C. In order, however, to clearly visualize the distirction in actual horizontal velocity of the oil as it moves through its pore space from the velocity, Q/A, ordinarily associated with the Darcy equation, two simplified flow systems are examined here. Sketch of these two systems is shown at the end of this appendix, Figure No. VI-1.

The two systems sketched represent blocks of impermeable reservoir space with flow tubes inserted. The flow tubes are assumed to have a permeability of 1 darcy each and a pore volume of .01 barrel per foot of length. Flow through the systems will be governed by the Darcy equation which, in terms of oil field units, can be written:

(Reference 8)

$$q = \frac{1.127\ KA\ (\triangle P)}{\mu\ L} \qquad \text{(VI-1)}$$

where: q is flow rate in barrels per day

K is permeability in darcys

A is area in square feet

L is length in feet

μ is viscosity in centipoises

For simplicity in the following discussion it is assumed the constant 1.127 actually equals 1, and that the pressure across the system is 1 pound per foot of length, and that the viscosity is 1 centipoise. Accordingly each tube will then have a flow rate of 1 barrel per day. Each system with five tubes then has a flow rate of 5 barrels per day.

This flow rate can also be calculated from the transmissibility of each system. The system on the left has a transmissibility of 1 darcy foot per foot of pay section, which for 5 feet is 5 darcy feet, whereas the system on the right, with a permeability of 1 darcy for each of 5 tubes and 1 foot of pay thickness also has a transmissibility of 5 darcy feet. Substituting in Equation VI-1 the value of 5 darcy feet for each system yields the same result, 5 BOPD.

The "velocity" of such systems, as ordinarily expressed, is the flow rate in barrels per day divided by the square feet of area, which for the system on the left is 1 and for the system on the right is 5. Although this is the "velocity" associated with the Darcy equation, it is really of no value in analysis of the gravity drainage problem.

The velocity of interest in gravity drainage analysis is the actual rate of movement of the oil through the pore space of the reservoir, both vertically and horizontally. For the systems sketched on Figure VI-1, this is the velocity within the tubes (here the tubes are alike and the velocity will be the same in each). It is apparent simply from inspection of the sketch of these two systems that under the same conditions impressed on them, the rate of oil movement through the tubes for both systems will be exactly the same

(not a ratio of 5 to 1 as given by the darcy relation).

For simplicity here an example calculation of horizontal velocity (V_h) is made. This horizontal velocity is obtained by dividing the flow rate by the pore volume. It is assumed that the pore volume of each tube is .01 barrels per day per foot of length, so each system shown has a total pore volume of .05 barrels per day per foot of length. Dividing a system's flow rate in terms of barrels per day per unit of width by its vacated pore space in terms of barrels per foot of length and for the same width will yield the actual horizontal velocity in terms of feet per day; which for each system above is:

$$\frac{5 \text{ BOPD}}{.05 \text{ bbl/foot of length}} = 100 \text{ feet per day}$$

This velocity is obviously the same for both systems, since each comprises five identical flow tubes in an impermeable matrix.

If the tubes are assumed to be of finite length, lying at an angle to the horizontal, that they are full of oil at the start of a test and no oil is added, then as oil is "produced" at the down-dip end, the top of the oil column in each tube will fall. The rate (V_v) of this vertical fall of the gas-oil contact is another velocity of interest, and which can be calculated directly from oil in place per acre and transmissibility, assuming the dip of the formation is known. As indicated above, method of calculating this velocity is given in Part C of the Appendix VI.

PART B - METHOD OF CALCULATING GRAVITY DRAINAGE RATES

Muskat (Reference No. 4) has shown the equation giving maximum possible gravity drainage rates. This equation, in terms of barrels per day per surface acre of gas-oil contact, is:

$$Q = \frac{21.29\ kd\ \sin^2\theta}{\mu B} \qquad \text{(VI - 2)}$$

where Q = gravity drainage rate, barrels per day per surface acre of gas-oil contact

k = permeability to oil, md

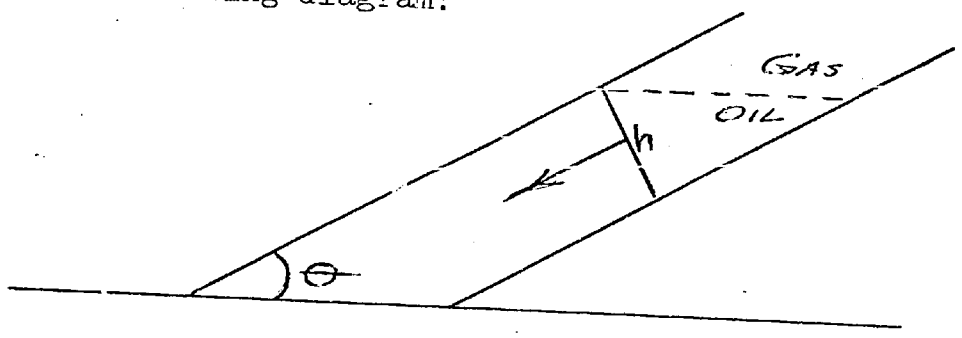
d = difference in specific gravities of oil and gas (water = 1.0)

μ = oil viscosity, cp

B = FVF of oil

θ = angle of dip of formation

The formation thickness and dip of the beds are shown schematically in the following diagram:



With reference to the above sketch, we may determine the surface area of gas-oil contact to be:

$$\text{Area of contact} = \left(\frac{h}{\sin\theta}\right)\left(\frac{5,280}{43,560}\right) = .121\ \frac{h}{\sin\theta} \qquad \text{(VI - 3)}$$

Multiplying Equation VI-2 by Equation VI-3, and converting to darcys, yields:

$$Q = \frac{2{,}580\ h\ K\ d \sin \alpha}{\mu\ B} \qquad \text{(VI - 4)}$$

where Q - gravity drainage rate in BOPD per linear mile of gas-oil contact along the strike

which is an equation useful to us, as we now have the gravity drainage rate in terms of properties we can determine directly from well tests (transmissibility) or other readily available sources. As stated in Part II of the text, this formula is used to calculate the gravity drainage rates shown on Figure 5.

PART C

SECTION 1 - RATE OF VERTICAL FALL OF THE GAS-OIL CONTACT "PLANE" UNDER GRAVITY DRAINAGE

The gravity drainage rate of fall of the gas-oil contact "plane" is: (Reference No. 4)

$$V_v = 2.744 \times 10^{-3} \frac{k\, d \sin^2 \theta}{\mu\, \bar{f}} \text{ feet/day} \qquad \text{(VI - 5)}$$

where k = permeability, md

d = difference in specific gravity of oil and gas (air = 1.0)

θ = angle of dip of formation

μ = oil viscosity, cp

$\bar{f}$ = net porosity vacated

If we let R represent the fraction of pore space vacated, then the net porosity vacated, $\bar{f}$, may be expressed:

$$\bar{f} = R\phi \qquad \text{(VI - 6)}$$

where ϕ = porosity, fraction of bulk reservoir volume

Substituting this value for $\bar{f}$ in Equation VI-5, changing from millidarcies to darcys and multiplying the numerator and denominator by the pay thickness, h, in feet we obtain:

$$V_v = \left(\frac{2.744}{R}\right)\left(\frac{Kh}{\phi h}\right) \sin^2 \qquad \text{feet/day} \qquad \text{(VI - 7)}$$

From this relation, the rate of fall of the gas-oil contact "plane" can be determined from the transmissibility, Kh, and pore volume ϕ h (both of which can be determined with reasonable

accuracy in West Puerto Chiquito) for assumed values of the fraction of net pore space vacated, R.

SECTION 2 - RATE OF HORIZONTAL MOVEMENT OF THE GAS-OIL CONTACT "PLANE" UNDER GRAVITY DRAINAGE

The rate of horizontal movement of the gas-oil contact plane can be determined from its rate of vertical fall (Equation VI-7) and the dip of the formation, which readily yields the horizontal velocity,

$$V_h = \frac{2.744}{R} \quad \frac{(Kh)}{(\phi h)} \quad \frac{d}{u} \sin \theta \cos \theta \text{ ft/day} \qquad (VI - 8)$$

where the symbols have the same meanings as shown in this appendix VI, Part C, Section 1.

This formula was used to construct the graph of Figure 13.

Respecting movement (vertically as well as horizontally) of the gas-oil interface, this movement will take place, of course, only if reservoir conditions are such that the oil actually has "room" to move down-dip.

Little, if any, actual gravity drainage will occur while pressures are dropping and oil and free gas expanding, until the equilibrium gas saturation is reached. Complexity is added here also because of the unknown rate at which the gas bubbles move up-dip. Under pressure maintenance, however, where pressures are maintained relatively constant at any point in the reservoir, the gravity drainage potential will more likely be realized.

An ideal situation for gravity drainage, from the standpoint of avoidance of influence of extraneous conditions, exists in

the tight fracture blocks when the reservoir is under pressure maintenance and the blocks are surrounded by free gas (of the high capacity fracture system). Under these conditions oil will move by gravity drainage unaffected by withdrawal rates or by injection into the block of excessively high volumes of gas and causing by-passing. This is true because it is obviously impossible to impress a pressure gradient across a fracture block (except of course ones in which injection wells are completed) for the high capacity fracture system surrounding each of these blocks will result in an equalization of pressure around them.

Time required for depletion of a tight fracture block can be determined by the above equation (VI - 8) from its transmissibility by assuming a recovery factor, R, if the pore space (ϕ h) is known. This pore space value can be approximated from the date of Appendix III from transmissibility. Therefore, time required to deplete by gravity drainage one of the tight blocks can be determined only from its transmissibility and an assumed recovery factor, R.

This relation has been calculated for a recovery factor R of 50 percent. The results are shown graphically on Figure No. 13, in which this relation is expressed by the horizontal movement of the gas-oil contact plane, in terms of feet per day, for any given transmissibility.

PART D - FACTORS AFFECTING OPTIMUM NUMBER OF DOWN-DIP RECOVERY WELLS UNDER GRAVITY DRAINAGE WITH PRESSURE MAINTENANCE

As described in Section 4 of Part II, under solution-gas drive, the high capacity fracture system will drain the tight blocks better and more efficiently than will wells drilled within the blocks. Under these circumstances, and for solution-gas drive depletion, ultimate recovery will be essentially independent of the number of wells. A different situation exists, however, under gravity drainage with respect to the number of down-dip recovery wells. Although intermediate rows of wells at positions structurally higher than the lowermost row will not increase ultimate recovery under gravity drainage, additional wells located on the down-dip row can serve to reduce the pressure draw-down in the wells at this structural position (for the same amount of production from the reservoir) and can in a way more efficiently recover the final amounts of oil as the gas-oil contact, in its movement down-dip, approaches the lowermost row of wells.

As a practical matter, however, the primary factor controlling the efficiency of recovery of this phase of the depletion process is not so much the number of wells drilled, but the physical makeup of the reservoir with respect to the tight blocks and the high capacity fracture system - a matter over which we have no control.

Aside from the other influences of these factors, as discussed elsewhere in this paper, this physical makeup of the reservoir will have a twofold controlling effect which will be

evident in the final stages of depletion. These are described as follows:

1. The potentially high efficiency of the gravity drainage depletion mechanism under pressure maintenance can be expected to be effective only as to that part of the reservoir occurring structurally up-dip from the point at which, as to each fracture block in which a down-dip recovery well is completed, good communication is established with the high capacity fracture system. For example, if the sand fracture treatments of the down-dip recovery wells result in fractures extending up-dip from the wells to points of juncture between their fracture blocks and the high capacity fracture system, then, as the gas-oil interface in its movement down-dip reaches this point, gas will rapidly channel to the recovery wells, and it will be necessary to end Phase 1 of the pressure maintenance project, as discussed in the summary of Part IV of this paper. At such a time it will be necessary to enter either Phase 2 or Phase 3 of the depletion process. Once Phase 3 has been commenced, a relatively small part of the future production can result from gravity drainage, as most of it will be the less efficient solution-gas drive mechanism. The time at which this occurs will depend not so much on the numbers of wells as it will on the physical size of the fracture blocks themselves in which the down-dip recovery wells are completed. For example, it now appears (Appendix II hereof) that these individual fracture blocks may have gross dimensions of the order of 1,500 to 2,000 feet, or approximately one-third of a mile. With fracture blocks of this size, if the distance from the up-dip side of the reservoir to the down-dip side of the recovery wells' fracture blocks is one mile, then one

would anticipate that two-thirds of the reservoir might be amenable to gravity drainage under pressure maintenance. It would be entirely impractical to plan for, or to attempt to recover by pressure maintenance, the part of the total reservoir oil represented by this one-third of a mile. In view of the other factors involved, it is questionable whether a reservoir of this makeup with only one mile of section available down-dip could be practicably depleted by pressure maintenance and the gravity drainage process. In the instance of West Puerto Chiquito, however, the down-dip length of the reservoir section approximates four miles. Under these circumstances it is believed only one twelfth (one-third of a mile out of four miles) of the reservoir is unavailable for gravity drainage recoveries, leaving some 90 percent of the surface area of the reservoir which can be successfully depleted by gravity drainage with pressure maintenance. It is obvious that insofar as this aspect of the physical character of the reservoir is concerned, the drilling of additional wells in the down-dip fracture blocks can in no way affect its "susceptibility factor" to gravity drainage depletion.

2. When gas cones down-dip into the recovery wells and Phase 2 is commenced as to this bottom row of wells, and production rates are restricted (here the controlling factor in production rates will be the capacity of the compressors to handle the produced gas) the matter of total amount of future gravity drainage recovery which can be achieved before Phase 3 is entered will again be not so much a matter of additional wells (with resulting reduction in "draw-down" pressure differentials permitting, for the same reservoir production rate, the gas-oil contact to move to a lower

structural position before abandoning Phase 2 of the project) as it will be the physical makeup of the reservoir with respect to up-dip tight fracture blocks and the amount of oil draining from them by gravity. If this source of oil forms the bulk of that being produced, the drilling of additional wells will be of little use, for the controlling factor in producing rates will not be dependent on the proximity of the gas-oil contact but the rate at which oil is moving from the upper parts of the reservoir.

In view of the above remarks, it is obvious that the practical procedure is to operate the project with the minimum number of down-dip recovery wells until coning first occurs, and at that time, and in light of the facts available then, make the determination as to whether additional down-dip recovery wells should be drilled. It is quite clear that it would be a waste of time, money and effort to drill additional recovery wells prior to the time coning has developed. These additional wells can improve reservoir recovery only as to that part of the reservoir in which coning has not developed, and until it does, all of the gravity drainage recovery from the reservoir can be efficiently produced from any well capable of handling it.

Once coning develops and the question arises as to the drilling of additional recovery wells, information regarding some of the above aspects will at that time be available, and will be useful in determining if more recovery wells should be drilled.

With regard to the future question of drilling additional wells after coning develops, an estimate of the approximate magnitude of the maximum additional recovery which might be anticipated by the drilling of additional down-dip recovery wells can be made by

analysis under the following reasoning. Pressure distribution in the high capacity fracture system will approximate that of a reservoir with uniform conditions and the same transmissibility. If the fracture blocks in which the down-dip wells are completed are relatively small, then pressure draw-downs and coning tendencies will be relatively the same as for a reservoir with uniform properties as to those distances beyond the fracture blocks in which the wells are completed. We can therefore estimate coning tendencies for various well spacings (distance along the row of the down-dip wells) and for various assumed production rates at which Phase 2 terminates and Phase 3 commences, by assuming the reservoir to be of uniform properties. To solve this problem exactly would require determination of the pressure draw-down configuration around the wells, taking into account the dip of the formation and comparing it with static reservoir pressures, recognizing the difference in density of the gas and the oil; and then determining the producing rates at which gas would break through, depending upon the distance of the gas-oil interface from the wells. It is believed the same information can be determined with less effort, and accurately enough for our purposes, by assuming that for any one set of conditions in which coning develops, the gravity drainage rate for that set of conditions can be determined from down-dip gravity flow rates and the "angle of repose" created by the shape of the cone along the plane of the formation. For the same reason that gravity drainage rates down the slope of the formation are equal to the vertical drainage rate times the sine of the angle of dip of the beds, the gravity drainage rate to a well should approximate the down-dip rate multiplied by the sine of the angle of repose.

This is perhaps best illustrated by numerical examples for the conditions of dip of formation and transmissibility for West Puerto Chiquito. The dip of the producing formation in the vicinity of the down-dip wells approximates 200 feet per mile, and the transmissibility approximates 10 or 12 darcy feet. As can be seen from Figure 5 of the text, for a dip of 400 feet per mile and this transmissibility, the gravity drainage rate would be approximately 2,000 barrels per day per linear mile along the strike. For a formation dip of 200 feet per mile the rate would be approximately half this, or about 1,000 barrels per day per linear mile. If we assume that all of the up-dip blocks have been completely drained (and the reservoir consists of uniform properties) and all of the remaining producible oil in the reservoir exists in the area below the gas-oil contact, then we can calculate angles of repose for various given rates of production at which Phase 2 would be terminated and the operation of Phase 3 commenced. A comparison is made for one, two and four wells per linear mile along the strike. If there is one well per linear mile, its angle of repose, at a rate of 100 barrels per day, would be an angle whose sine is 100 divided by 1,000, or 5.7°. If this production rate is divided between two wells, the angle of repose for each of them will be an angle whose sine is 50 divided by 1,000, which is 2.86°, and for four wells at 25 barrels per day each, the angle of repose would be 1.43°. From this information, the reservoir areas under the angle of repose for each set of conditions can be determined. The difference in these areas represents the amount of reservoir area which can be produced under Phase 2 before resorting to Phase 3. Additional recovery amounting to the difference in gravity drainage

depletion minus solution-gas drive depletion can be anticipated from this additional part of the reservoir when comparing one of the spacing densities with another. Pertinent facts of the examples discussed here are listed in the schedule below:

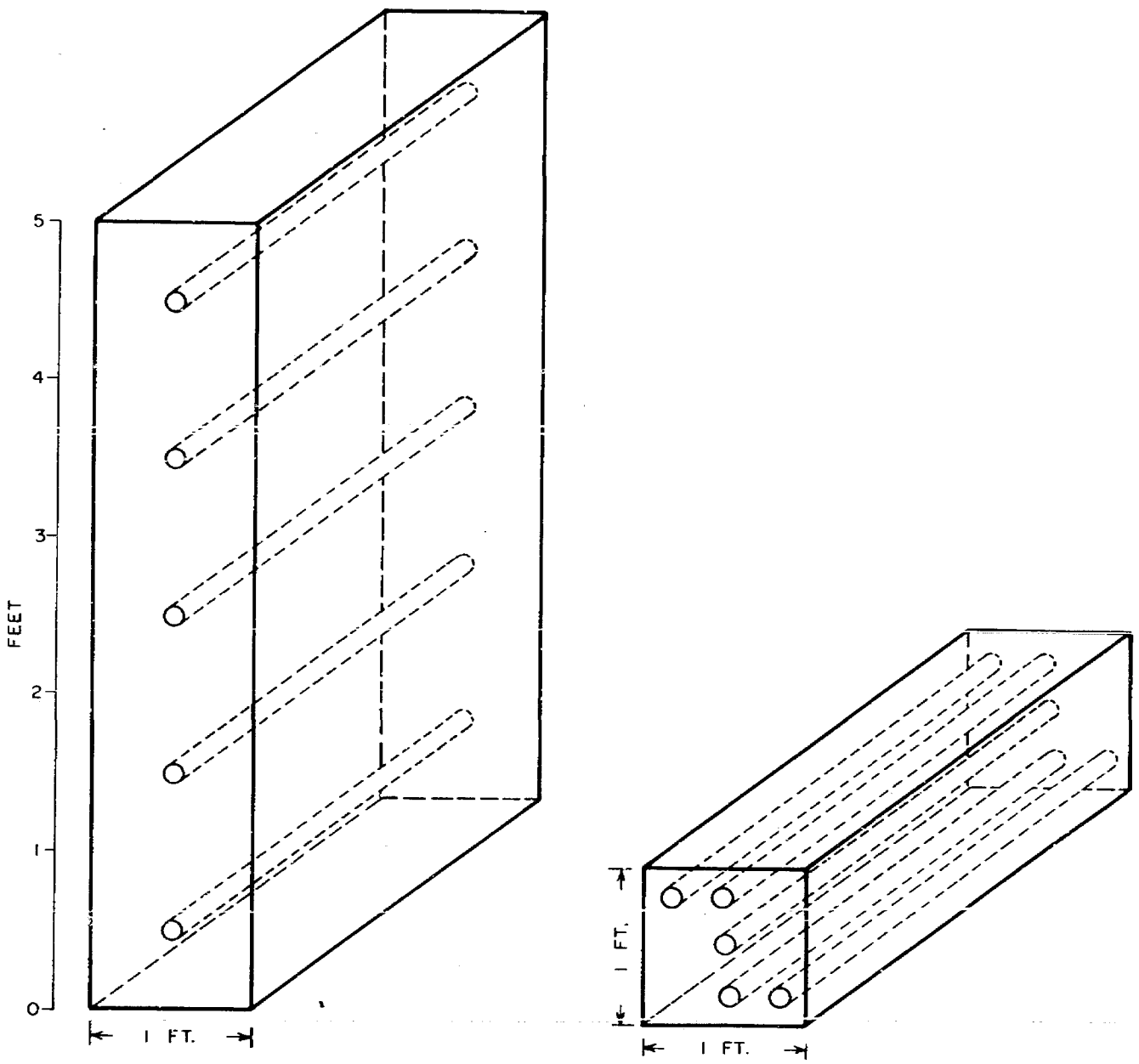
Number of recovery wells per linear mile along the strike	1	2	4
Production Rate, BOPD per well	100	50	25
Angle of Repose	5.74°	2.86°	1.43°
Area under angle of repose, acres	32	16	8

Difference per linear mile in area under angle of repose:		
2 wells/mile compared to 1	16	
4 wells/mile compared to 1		24

Increase in area of reservoir affected by gravity drainage for reservoir down-dip length of 4 miles:		
2 wells/mile compared to 1	0.62%	
4 wells/mile compared to 1		0.94%

From the above schedule it is apparent that it would be impractical to plan initially on a density greater than one recovery well per linear mile. It is probable that more than one well per linear mile will be drilled, but only for the reason that it is impossible to determine exactly the location of the down-dip boundary of the high capacity area and more than one well per section may be drilled searching for the best locations of these down-dip recovery wells.

SKETCH
OF
SIMPLIFIED FLOW SYSTEMS



APPENDIX VI FIGURE NO. VI-1

APPENDIX VII

APPENDIX VII

APPENDIX VII

PART A - SCHEMATIC COMPARISON OF "CHANNELLING POTENTIAL"

Comparison of the "channelling potentials" of injection and producing wells, as described in Section 2 of Part IV of the text of this paper, can be made with a system of pipes in an open tank. Such a system is sketched on the figure at the end of this appendix, Figure VII-1.

Plate I of Figure VII-1 shows the channelling potential of an "injection well", which is an injection pipe inserted open-ended in the tank with gas being forced out through perforations in the pipe below the top of the oil. The restriction of the perforations through which the gas is passing can be likened to the pressure differential required to inject gas into a reservoir. This pressure forces the top of the oil in the pipe to a deeper depth than the perforations, as shown in the sketch. If the pressure required to force the gas out through the perforations is 6 pounds per square inch and the density of the oil is 1/3 pound per square inch per foot, then the channelling potential, as indicated on Plate 1, is 18 feet (in this instance the density of the gas is negligible). It is obvious from an inspection of Plate 1 of Figure VII-1 that if there is no other disturbance in the tank (reservoir) it is physically impossible for the gas to drop in the pipe (channel) to a point any lower than 18 feet below the surface of the oil in the tank (interface of the gas-oil contact "plane").

Plate 2 of Figure VII-1 shows the same information with a "producing well" added by extending the pipe to the bottom of the

tank. As for the injection well, the perforations in the pipe at the bottom serve as a restriction to the flow, such that a draw-down is required to withdraw oil from the production line. If a pressure differential of 4 pounds is required to withdraw oil at the rate at which the test is conducted, it will have a producing well channelling potential of 12 feet (4 pounds divided by 1/3 pound per square inch per foot). This is shown schematically on Plate 2 of Figure VII-1. In this instance the sum of the channelling potentials is 18 feet plus 12 feet, or 30 feet. As long as the oil level in the tank is more than 30 feet above the perforations in the producing part of the pipe, there can be no channelling of gas to the "producing well", despite the direct channel (pipe) connecting them.

As stated in the text, the channelling potential calculated as shown therein, and compared schematically above, is the maximum possible. Under operating conditions, actual channelling probably will not occur until the vertical separation is much smaller than the potential.

PART B - INJECTION WELL DIFFERENTIAL PRESSURES

It is believed that the injection well differential pressures which will be of interest in determining channelling potential as defined in this paper would probably be governed by the isothermal flow of gas under viscous conditions, and will vary as the difference in the squares of the pressures over the radial distances involved. Here it is assumed that the distances of importance will be those outside the tight fracture block in which the injection well is completed, and accordingly at some distance from the well bore. It also seems probable that the operating injection pressures required to inject gas would be governed by a similar type of flow to that encountered with producing gas wells, and accordingly the volume would vary with some power of the difference of squares of the working bottom hole injection pressure and the stabilized pressure in the high capacity fracture system. No tests have been conducted in West Puerto Chiquito to attempt to analyze these characteristics, and accordingly nothing is reported here in this connection. It is of interest to note, however, that the present injection well is accepting volumes of gas equal to approximately 1,500 barrels per day with an operating differential pressure approximating 400 pounds. Before being put on gas injection, this well had a producing capacity of 100 barrels per day at solution gas-oil ratio, with an operating pressure differential of about 1,200 pounds. This means the injection well is taking approximately 15 times the volume at one-third the pressure differential when compared to the well's producing ability. This is an overall ratio of 45 to 1 in

comparative operating differentials. Since the viscosity of the oil which was being produced is nearly the same as the viscosity water would have at that temperature, were water to be injected, it can be assumed this ratio of 45 to 1 is indicative of the ratio of operating pressure differentials to be expected in comparing gas injection to water injection.

Comparison of channelling potentials (with the gradient differences as discussed in Section 2 of Part IV of the text) would accordingly have a ratio of approximately 100 to 1. This means that in the instance of West Puerto Chiquito and its K-13 injection well, this one well is equivalent, from the standpoint of channelling potential, to 100 water injection wells. Moveover, this potential exists at only one point in the reservoir. The water injection wells would have to be spread out along the strike to avoid interference with each other, and further increase the channelling potential. On the other hand, gas from the injection well, as it works its way along the strike, will have a continually lower pressure differential. No comparison has been made to determine exactly how many water injection wells would be required to reduce at all points their channelling potentials to that created by the one gas injection well, but it probably would be at least 200 to 300..

SCHEMATIC DIAGRAMS OF

"~~PRODUCING~~ POTENTIAL"

CHANNELLING)

GAS INJECTION WELL AND OIL PRODUCING WELL

PLATE I

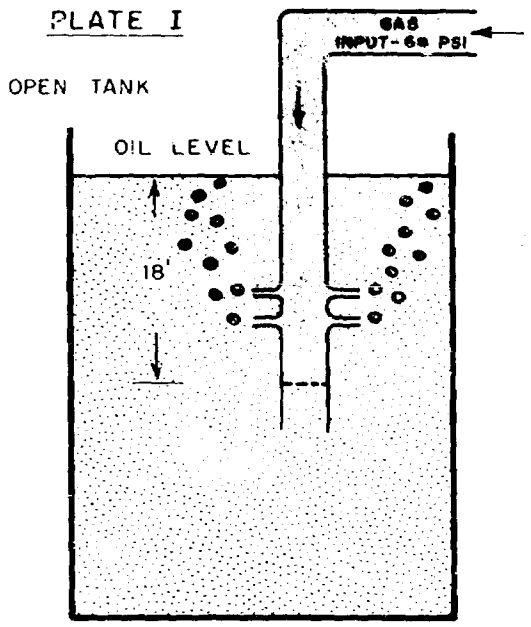
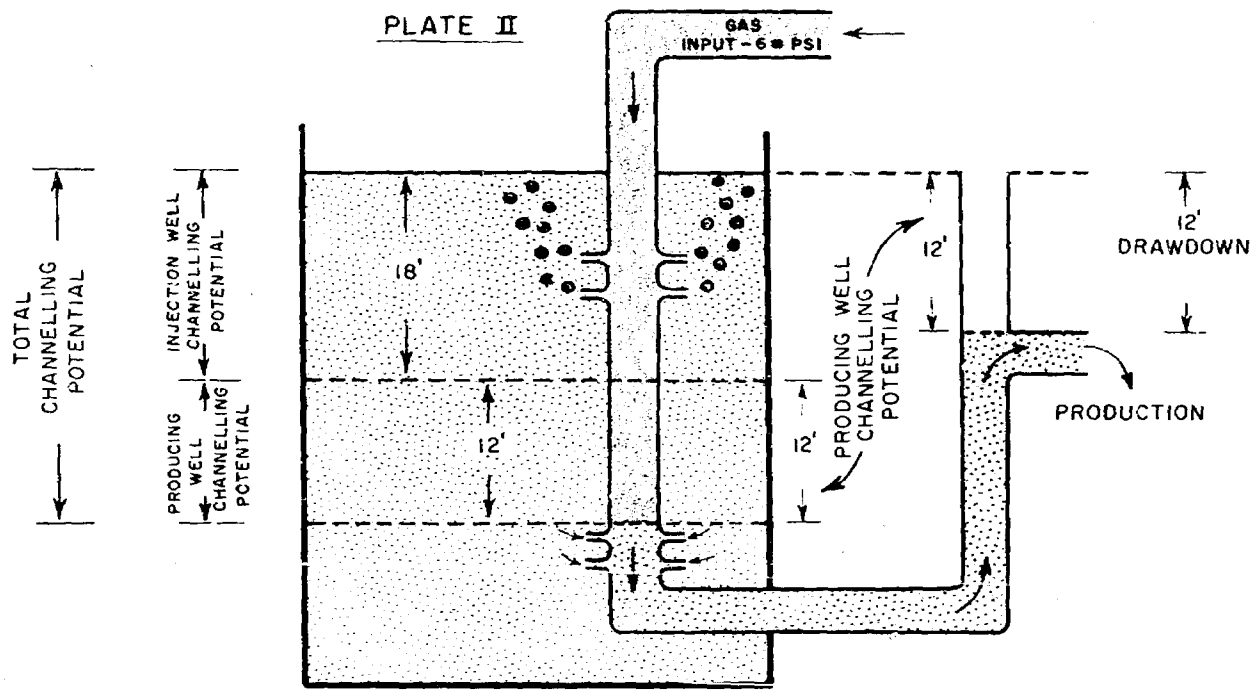


PLATE II



LEGEND

- INPUT GAS
- OIL IN "RESERVOIR"
- OIL IN PRODUCTION

APPENDIX VII FIGURE VII - 1

REFERENCES

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OIL RECOVERIES UNDER GRAVITY DRAINAGE DEPLETION AND PRESSURE MAINTENANCE AS DEPENDENT ON PHYSICAL RESERVOIR CHARACTERISTICS AND AS AFFECTED BY WELL SPACING

FRACTURED SHALE RESERVOIRS

NIOBRARA MEMBER OF THE MANCOS SHALE FORMATION

WEST PUERTO CHIQUITO POOL RIO ARRIBA COUNTY, NEW MEXICO

ALBERT R. GREER

DECEMBER, 1969

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INTRODUCTION

In accordance with the applicant's request in Case No. 3455, November 16, 1966, before the New Mexico Oil Conservation Commission, a three-year temporary spacing order of 320 acres was granted for the West Puerto Chiquito Mancos Pool, Rio Arriba County, New Mexico. In this Case, the witness for the applicant, Benson-Montin-Greer Drilling Corp., stated that a significant increase in ultimate recovery in West Puerto Chiquito might occur if advantage could be taken of the potentially high efficiency of the gravity drainage depletion mechanism, particularly if the reservoir would respond to pressure maintenance by gas injection. Gravity drainage depletion is, of course, a rate sensitive mechanism, and for the general magnitude of the physical properties involved it was apparent that the reservoir's gravity drainage ability could easily be exceeded if a large number of wells were drilled and produced at rates which would return the drilling costs in a reasonable time. Accordingly the witness further stated that a greater ultimate recovery could be anticipated with a spacing density of less than one well to 160 acres than for 160-acre or closer spacing. The purpose of the study presented here is to provide the foundation and evidence regarding potentially greater oil recoveries through wide spacing and operation of the gravity drainage mechanism, along with a discussion of the role of pressure maintenance in the depletion process of this fractured shale reservoir.

GENERAL CONSIDERATIONS

As described in another study (Reference No. 1) determination of oil in place in a fractured shale reservoir cannot be accomplished by the ordinary methods of coring and logging. Urder certain conditions, oil in place can be calculated from results of a properly conducted interference test. This has been done for West Puerto Chiquito, and the results recorded at the second spacing hearing (Case No. 3455, November 1966) before the Oil Conservation Commission. To arrive at the amount of oil which may ultimately be produced one must know, of course, in addition to the amount of oil in place, the share of this oil in place that is producible. For a fractured shale reservoir this recovery factor, in itself, is just as difficult to determine as oil in place, and consequently compounds the problem of estimating recoverable oil from a fractured shale reservoir. This study is concerned only with recovery factors, particularly the difference in recoveries as dependent upon the method of exploitation, rather than with determination of oil in place. It is believed that the relative recovery factors determined herein will apply even though the true value of oil in place may be different than that here assumed.

A general range of per acre recoveries was earlier made by analogy with other fields. At the time of the first (1963) spacing hearing, approximate recoveries of 500 barrels per acre were estimated for West Puerto Chiquito by analogy with the Verde Gallup Pool recoveries on the west side of the San Juan Basin, some ninety miles away. By the time of the 1966 hearing a closer pool, Boulder Mancos, only ten or fifteen miles from West Puerto Chiquito, was

essentially depleted and provided a means of more direct comparison. The average recovery in Boulder was approximately 60,000 barrels per well on 80-acre spacing, or approximately 700 barrels per acre. Since this recovery fell well within the previously determined 500 to 1,000 barrels per acre recovery for the Verde Gallup Pool, one might merely rationalize that this simply confirmed the general range of 500 to 1,000 barrels per acre recovery that could be anticipated for the fractured shale reservoirs in the Mancos Formation in the San Juan Basin, and accordingly would be applicable to West Puerto Chiquito.

Analysis of the facts, however, gave rise to concern about recoveries in West Puerto Chiquito, should this pool be produced in the same "uncontrolled" manner as were the older and other non-unitized pools in the San Juan Basin. (The term "uncontrolled" as used in this paper means that wells are produced under competitive methods under the rules of the New Mexico Oil Conservation Commission, whereby high gas-oil ratio wells are merely limited in total reservoir space voided, rather than being shut in, and that no regard is given to maintaining field production rates at the reservoir gravity drainage ability).

The cause for concern about recoveries in West Puerto Chiquito, arising from a review of the Boulder Mancos history, stemmed from a comparison of two of the characteristics of the two fields. One characteristic, transmissibility, appeared to be substantially higher in Boulder than in West Puerto Chiquito. This was evidenced not only by tests reported by Standard of Texas, as measured in some of its wells, but by the fact that some of the wells in Boulder were completed natural for high capacities, one

well even flowing in excess of 4,000 barrels per day, whereas in West Puerto Chiquito all of the wells have required sand fracture treatments in order to produce at commercial rates. A rather high capacity fracture system has been measured in West Puerto Chiquito, but it does not appear to be as high as was the fracture system in Boulder. Not only that, but it appeared possible that in West Puerto Chiquito a substantial part of the reservoir would prove to be made up of rather tight "blocks", and although it is presumed the same occurred in Boulder, it also seemed probable that in West Puerto Chiquito a higher percent of the reservoir was occupied by these tight blocks than in Boulder.

The other physical characteristic was the difference in the oil formation volume factors. These were approximately 1.10 for Boulder and 1.30 for West Puerto Chiquito. This meant a shrinkage of approximately three times as great (30 percent compared to 10 percent) for West Puerto Chiquito as compared with Boulder. Accordingly, for solution gas drive depletion, a substantially lower recovery would be anticipated for West Puerto Chiquito than for Boulder. The shrinkage factor is, of course, partially offset by lower viscosity of the West Puerto Chiquito oil. It is probable, however, that the adverse effects of the high shrinkage factor in West Puerto Chiquito would far outweigh the benefits of lower viscosity under solution gas drive depletion.

Therefore, by analogy with the closest and most comparable field, Boulder, we must conclude not that recoveries in West Puerto Chiquito by solution gas drive can be expected to be 500 to 1,000 barrels per acre, but rather that the recovery must be somewhat less than Boulder's 700 barrels per acre. Depending

upon the relative permeability characteristics of the two reservoirs, along with the unfavorable shrinkage of West Puerto Chiquito, the recovery at West Puerto Chiquito might by analogy be estimated to be considerably less than 500 barrels per acre if production from both pools were from solution gas drive only.

Further study indicates that the situation could be even more serious than this. Because of the high transmissibility of Boulder, part of its recovery must have resulted from gravity drainage, despite the fact that the field was produced in an uncontrolled fashion. It is entirely possible that a very substantial part of the Boulder production was a result of gravity drainage rather than solution gas drive, simply because of its high transmissibility and possibly high percent of the reservoir being occupied by a high capacity fracture system. Here again the relatively high shrinkage factor at West Puerto Chiquito would result in a comparatively rapid decrease in permeability to oil as pressure depletes, and all other factors being the same, West Puerto Chiquito's gravity drainage recovery could be expected to be considerably less than was Boulder's. Under such circumstances, considering both solution gas drive and gravity drainage, recoveries in West Puerto Chiquito could be seriously less than was Boulder's, with recoveries possibly as low as 200 to 300 barrels per acre, if West Puerto Chiquito were to be produced in the same fashion as Boulder.

Fortunately from the standpoint of those economically interested parties (including royalty owners) the commercial part of the West Puerto Chiquito reservoir lies wholly within a unitized area, and it is accordingly possible to exploit the reservoir in

the most efficient manner practicable. It is necessary only to determine what method of exploitation is the most efficient, and if it can be economically accomplished.

To determine this most efficient method of exploitation an attempt was made to better understand the producing mechanisms of the various Niobrara reservoirs in the San Juan Basin and reasons for differences in recoveries. The study was extended to the Gallegos Gallup Pool, where a greater degree of similarity with Boulder and West Puerto Chiquito was found than was anticipated at the outset. Although in Gallegos Gallup the Niobrara exhibited a sand development of sorts, core analyses of some twenty wells showed porosity characteristics more like those of shale than of sand. Three of the four zones showed average porosities of 5 percent or less, with total liquid saturations of 84 percent to 91 percent. This leaves a net effective porosity of .5 percent or less of the bulk volume of the reservoir, and is quite similar to analyses of the Niobrara where it is pure shale. Reported material balance calculations for Gallegos Gallup show that initial oil in place approximated 3,000 barrels per acre. Ultimate primary recovery in Gallegos Gallup approximated 150 barrels per acre, or about 5 percent of the oil in place. Gallegos Gallup exhibited an early high permeability to gas which, when taken with its dissolved gas and shrinkage factors as high as West Puerto Chiquito, was responsible for the low solution gas drive recovery of its primary production phase.

This high Kg/Ko relation is not uncommon for fractured reservoirs. Some have been reported (Reference No. 2) in the technical literature to have early high permeabilities to gas.

Other fractured reservoirs have apparently had "good" Kg/Ko relationships; however, in such instances it is entirely possible that the net result as calculated from field performance was primarily caused by beneficial effects of gravity drainage rather than a low ratio of the relative permeability characteristic in itself.

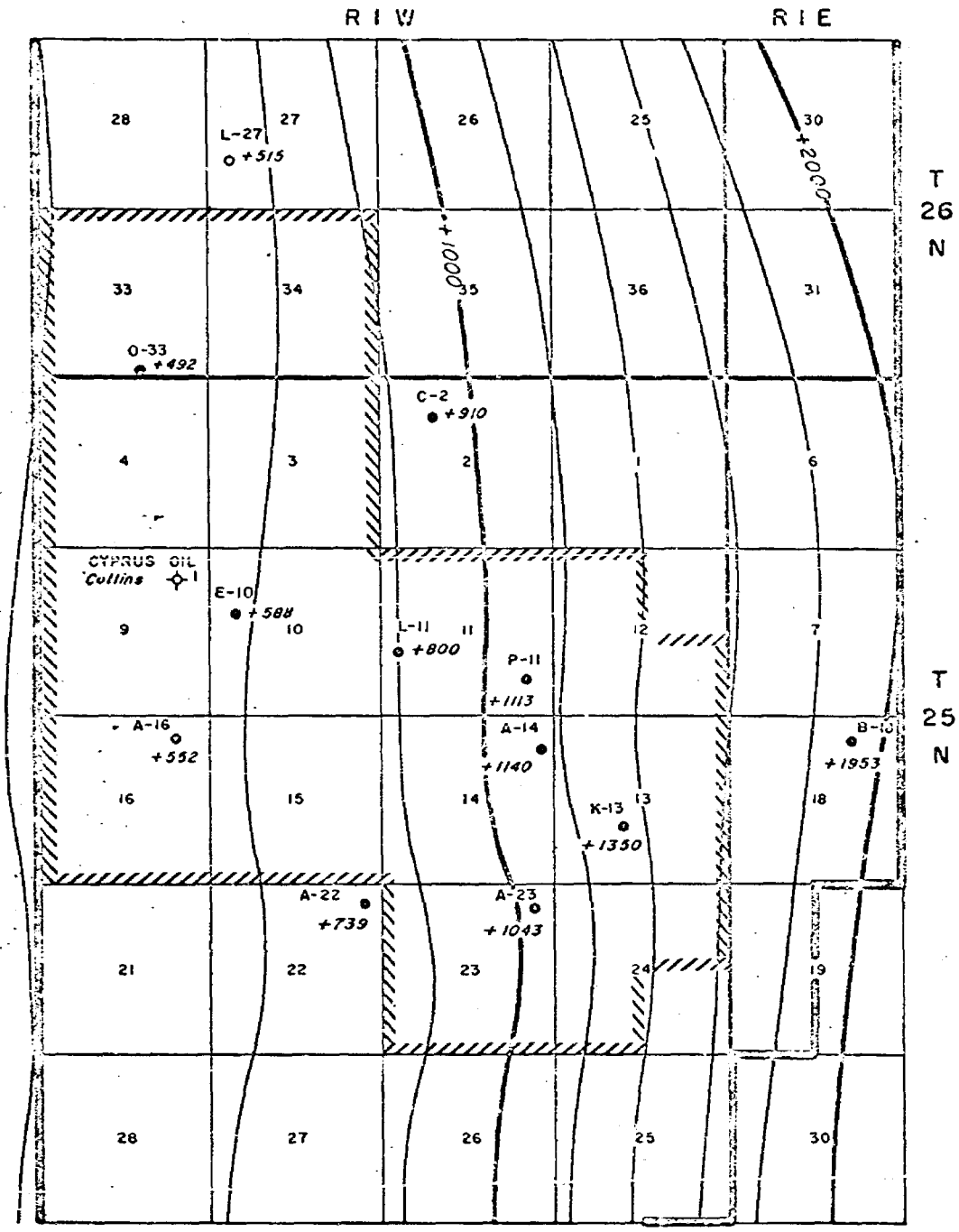
Considering all aspects of depletion mechanisms and the remarks above, as one studies the recoveries and physical reservoir characteristics of the various Niobrara Pools in the San Juan Basin the set of conditions which most probably would cause the various recoveries experienced are:

1. A high relative permeability to gas, which when combined with a high shrinkage factor (as for Gallegos Gallup and West Puerto Chiquito) will yield low solution-gas drive recoveries.

2. In comparison of one reservoir with others, there is a varying "mix" of transmissibilities of tight blocks and high capacity fracture systems.

Under such conditions it is to be expected that a wide range of recoveries will result from these fractured reservoirs, even though they may contain, in virgin conditions, an equal pore space, and otherwise appear quite similar. Although the reservoir rock properties are not good for solution-gas drive, they are good for gravity drainage when combined with steep formation dips. Good gravity drainage performance is possible for reservoirs with a high percent of reservoir oil in the high capacity fracture system, steep dips, low shrinkage and low viscosity. A variation of the order of ten to one is possible when comparing the recovery from a steeply dipping reservoir, whose production rate is restricted to the reservoir's gravity drainage ability, to a similar but horizontal reservoir produced strictly by solution gas drive. At least a two to

one variation is to be expected in a steeply dipping reservoir resulting from depletion under different production methods (controlled production with pressure maintenance versus uncontrolled production methods) and a variation of five to one under such conditions is possible.



PLAT OF PART
OF
CAÑADA OJITOS UNIT

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

PART I - SUMMARY OF DEVELOPMENT AND SPACING ORDERS

Most of the development and production in West Puerto Chiquito has been in and near the participating area of the Cañada Ojitos Unit. This study is confined to this area. On the page facing is a structural contour map of the main area of interest. It is a portion of the Cañada Ojitos Unit within the West Puerto Chiquito Pool. The map is contoured on top of an electric log marker, which for the purpose of this paper has been designated Zone A. An electric log section showing this marker is given in Appendix III, Figure III-1.

First production was obtained in this area with the drilling of the K-13 in Section 13, Township 25 North, Range 1 West, in 1962. This well had an initial natural producing ability of approximately 15 barrels per day. First commercial production was obtained from the A-14 in Section 14, also drilled in 1962, with first production in December of 1962. Productions graphs for these wells, along with subsequently drilled wells, are shown at the end of this text.

The first spacing hearing was in the fall of 1963, at which time temporary 160-acre spacing was established. Pursuant to regulations established in the order following the 1963 hearing, extensive interference tests were conducted during the years 1965 and 1966. These tests indicated wells would be capable of draining exceptionally large areas. Accordingly in November of 1966 a temporary spacing of 320 acres per well was requested, and witness for the applicant stated that under wider spacing than 160 acres per well a greater ultimate recovery would result. Also, if the

request for 320-acre spacing were granted, the applicant proposed to institute pressure maintenance by gas injection as an aid to the increased recovery by wider spacing. The application for a 320-acre temporary spacing order was approved by the Commission, to be effective until November, 1969.

Following the Commission's order for 320-acre spacing, plans were made to commence pressure maintenance by gas injection in the subject area. It was planned to inject gas up-dip and produce oil down-dip. To provide adequate down-dip producing ability, two high capacity recovery wells were drilled in the down-dip area near (within one mile of) the initial producing wells, one in 1967 and one in 1968. A gas gathering system from the producing wells was completed and arrangements made for purchase and transmission of make-up gas, along with installation of compression facilities. These arrangements were completed in the summer of 1968 and gas injection was commenced in August of 1968.

At the present time, after a little more than a year of operation, it appears that the reservoir is properly responding to gas injection, and accordingly an increased ultimate recovery as a result of wide spacing and pressure maintenance is anticipated. A third down-dip recovery well is currently (fall of 1969) being drilled some three miles north of the main producing area. Depending upon results of completion of this well, gas injection will probably be extended to the north part of the Cañada Ojitos Unit.

PART II - DESCRIPTION OF RESERVOIR CHARACTERISTICS AND DRAINAGE ABILITY OF WELLS

GENERAL

The subject reservoir rock is a fractured shale. Production is from the Niobrara Member of the Mancos Shale Formation, with wells presently completed in the interval designated Zone C as shown on the electric log section, Appendix III, Figure III-1.

The producing interval is believed to be from 20 to 50 feet thick. As discussed in more detail later in this Part II and in Appendix II, the reservoir comprises fracture blocks of relatively low transmissibility (.01 to 1 darcy feet) and a high capacity fracture system with transmissibilities of perhaps as high as 500 darcy feet. Total overall reservoir transmissibility approximates 2 to 10 darcy feet. Oil in place approximates 1,500 stock tank barrels per acre. Oil characteristics of gas in solution, formation volume factors and gas deviation factors are shown respectively in Figures 1, 2 and 3 following Part IV. These graphs also show characteristics for oil produced from the East Puerto Chiquito and Boulder Pools. Oil viscosity variation with pressure is shown on Figure 4.

SECTION 1 - TRANSMISSIBILITY

Transmissibilities have been measured from data of individual wells and from this information transmissibilities of the "tight" blocks have been determined. Transmissibility data for

larger sections of the reservoir have been determined as a result of concurrent pressure data from two or more wells, including two interference tests. These data give information as to overall reservoir transmissibility, or at least the transmissibilities for large segments of the reservoir.

Details of individual well transmissibilities are described in Appendix I, Part A.

Details of reservoir transmissibilities determined from interference tests and concurrent pressure data from more than one well are described in Appendix I, Part B.

SECTION 2 - MEASUREMENT OF SIZE OF FRACTURE BLOCKS

As indicated earlier, the reservoir comprises individual fracture "blocks" joined by a high capacity fracture system. It is believed the greater part of the bulk volume of the reservoir is formed by these fracture blocks, and that the high capacity connecting fracture system forms a relatively small part of the bulk volume of the reservoir. Accordingly, one may expect on the drilling of a well to penetrate not the fracture system but rather one of the fracture blocks. This is apparently what has happened in West Puerto Chiquito. Only occasionally does a well encounter natural production, and these natural production rates have never been high enough to indicate direct communication with the high capacity fracture system. It is only after sand-fracture treatments that wells capable of producing at high rates have been developed.

In some instances it is possible, from the transmissibility data of individual wells such as those given in Appendix I, Part A, to calculate approximately the size of these small fracture

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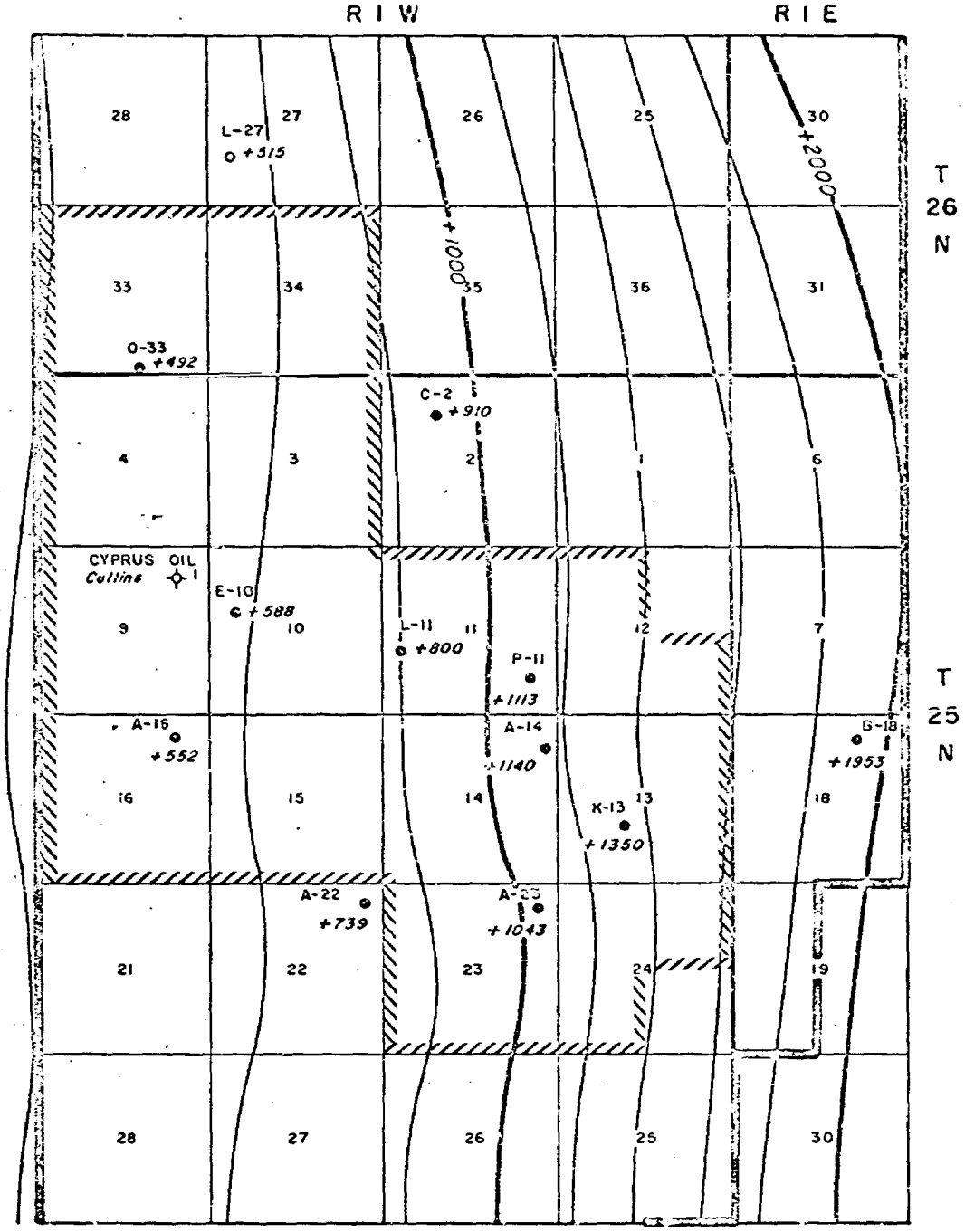
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BOUNDARY OF CAÑADA OJITOS UNIT

blocks. The primary method used is that shown in Part VII (Page 37) of Reference 1. Another method, along with its derivation and the details of all the calculations made of sizes of fracture blocks, is given in Appendix II.

These calculations show the tight blocks to contain oil volumes of the order of 10,000 to 50,000 barrels (stock tank oil) each, and individual surface areas are estimated to be of the order of 30 to 70 acres. The test shown in Appendix I, Figure I-5, apparently covers a much greater area and is believed to be not one uniform block but rather a sort of sub-system of the entire reservoir, the average transmissibility of which approximates 1 darcy feet.

SECTION 3 - OIL IN PLACE PER ACRE AND RELATION OF TRANSMISSIBILITY TO PORE SPACE

Two interference tests have been conducted whereby a direct calculation of oil in place per acre has been made. The first was in 1965, and reported at the November, 1966, spacing hearing. The other was the interference test resulting from the commencement of gas injection. Both of these tests are discussed above and in Appendix I with respect to transmissibility. With regard to oil in place per acre and for the two tests respectively, the following additional comments are made:

1. 1965 Interference Test: For a transmissibility of 6.2 darcy feet as assumed at the 1966 hearing and as discussed in Appendix I, the range of values for oil in place as determined from this test is 1,000 to 2,500 barrels per acre. This variation results primarily from the unknown compressibility of the formation

and its effect in the calculation. Another variation could occur if the true average transmissibility of the formation at the time of the test was different from 6.2 darcy feet, as the oil in place per acre will vary directly with this transmissibility. At this time it seems doubtful that true value of the average reservoir transmissibility could be significantly different from this. Accordingly at this time and from this test the same conclusion is reached as expressed at the 1966 spacing hearing, which is that the figures of 1,000 and 2,500 probably represent extremes and the actual average is estimated to be 1,500 to 2,000 barrels per acre. It is believed this test is representative of a large part of the reservoir - an area of the order of 5,000 to 10,000 acres.

2. 1968 Interference Test: As discussed in Appendix I, in which the details of this test are related, because of the low diffusivity constant and the distances involved it is not possible to determine transmissibility from a direct plot of pressures versus log time for the interference well data. It was necessary to assume values of oil in place and transmissibility, and by trial and error determine the values which best fitted the data. Even so, it is believed that this test and resulting calculations have yielded a value of oil in place with an accuracy comparable to, if not greater than, that of the 1965 test. With respect to accuracy, one significant feature of the 1968 test is that with lower compressibility of the oil, the indefinite value of the formation compressibility is much less important. For the 1965 test the variation of this unknown quantity could result in a variation of oil in place of the order of two to one. For the 1968 test the same variation in formation compressibility could cause an error of only 4 or 5 percent.

Because of the low diffusivity constant and proximity of the injection well to the up-dip field boundary, the area of this test is much smaller than that of the 1965 test. It is believed this test represents an area of 2,000 to 3,000 acres.

This test indicates a pore volume of 1,600 stock tank barrels per acre and a transmissibility of 1.8 darcy feet. At the time of the 1968 interference test some of this pore space, of course, was occupied by free gas which had been liberated from the oil. Total pore space, however, in terms of stock tank barrels per acre calculates to be about 1,600. As stated in Appendix I, this is for a part of the reservoir in which the initial transmissibility is estimated to have been from 2.3 to 3.6 darcy feet.

A range of values for oil in place was not calculated for this second interference test. It is believed, however, that the figure of 1,600 barrels per acre would be within 20 percent of the true value.

This compares with the range of estimates of 1,500 to 2,000 barrels per acre reported at the 1966 spacing hearing.

Under the circumstances, and in view of the wide variation of transmissibilities throughout the reservoir, it is remarkable that these two interference tests show such close agreement for value of oil in place per acre. At the time the first interference test was run, it was assumed that it would show only the general magnitude of value of oil in place, i.e., whether it is 200 barrels per acre, 2,000 barrels per acre or 20,000 barrels per acre. Instead, it now appears that this type interference test is an excellent tool with which to estimate rather consistently, and perhaps accurately, value of oil in place per acre.

In order to analyze reservoir performance and to aid in planning a pressure maintenance program for this reservoir, particularly with reference to attempting to recover the maximum practicable amount of oil from the tight blocks, an effort was made to determine the per acre oil in place in these tight blocks and in the high capacity fracture system. In addition, in order to properly analyze pressure maintenance performance once it was commenced, it was necessary to know approximately the percent of oil in place in the high capacity fracture system and in the tight blocks. Accordingly a study was undertaken directed toward this end. The results of this study are recorded in Appendix III.

This appendix shows that from a completely theoretical relation of permeability to pore space for fracture systems, it is possible, for the pay thicknesses of the wells in West Puerto Chiquito, to calculate transmissibilities and pore space values of fracture systems which agree rather closely with those which apparently exist in the fractured shale reservoirs which have been reviewed in connection with this study.

For some of the comparisons made in Appendix III, a value of 6.5 darcy feet and 1,500 barrels per acre of stock tank oil in place were used. Only slight variations in the conclusions reached would result if the true value of oil in place per acre were to vary from the figures used by 20 or 25 percent, which is the range of error now believed to be the maximum variation of true conditions from those calculated by interference tests.

Two significant conclusions can be drawn from a study of Appendix III. These are: (1) for low transmissibilities, of the order of .02 to .03 darcy feet, stock tank barrels per acre of oil

in place are estimated to be of the order of 300 to 400 (between the Y and Z relations of Appendix III, Figure III-5); and (2) a relatively high percent of the total oil in place occurs in the high capacity fracture system, despite the fact that this high capacity fracture system probably constitutes only a small percent of the bulk volume of the reservoir. For example, from Figure III-10 of Appendix III, for only 1 percent of the bulk volume of the reservoir being occupied by the high capacity fracture system, oil in place in this high capacity system will be from 14 to 18 percent of total reservoir oil if the average reservoir transmissibility is 5 to 10 darcy feet. If the high capacity fracture system occupies as much as 10 percent of the bulk volume of the reservoir, then half of the oil in place will be in the high capacity fracture system. For the purposes of analyzing reservoir behavior and forecasting pressure maintenance operations for West Puerto Chiquito, it is accordingly concluded that it is reasonable at this time to assume approximately half of the oil in place occurs in the high capacity fracture system and half in the tight blocks.

SECTION 4 - SOLUTION-GAS DRIVE DRAINAGE ABILITY

Wells in West Puerto Chiquito have demonstrated amazing abilities to drain large areas. The capacity to do this was forecast from the interference test taken in 1965. By 1968, at the start of gas injection operations, the facts were almost unbelievable. For example, at the start of gas injection in August, 1968, one well, the L-11, had produced 470,000 barrels of oil, and was producing at the rate of about 300 barrels per day. The well was capable of producing at higher rates, but its production had been restricted in

order to commence gas injection operations with the minimum possibility of gas channelling. This 470,000 barrels of oil is equivalent to the ultimate production from eight average wells in the Boulder Pool, which in itself is evidence of exceptional drainage. The striking aspect, however, is that after having produced this amount of oil, the reservoir at the datum of this well had suffered a depletion from initial oil in place of only 1.5 percent.

Determination of the depletion of the reservoir at this well's datum results from a rather simple and accurate calculation. Muskat (Reference No. 3) has shown the relation of pressure to depletion for solution gas drive reservoirs if the physical facts of the reservoir are known. In this instance, in which no free gas has been produced, the analysis depends only on the character of the oil as determined from a bottom hole sample analysis. This information is available, and the relation of pressure to percent of oil produced is given in Appendix IV. Pressure in the reservoir was accurately known as a result of data from the observation well, the A-23, which has been in a continual observation status since it was completed.

Accordingly this figure of 1.5 percent can be relied on as being quite accurate for indicating at that time the maximum depletion of the reservoir at this well's datum. This figure cannot, of course, be used to forecast ultimate recovery from the well, but it does clearly show the reservoir's amazing capacity to permit oil migration and to point up the fact that recovery for any given area, structural datum, or reservoir as a whole, will be essentially independent of the number of wells drilled.

This exceptional drainage ability of wells in the West Puerto Chiquito Pool undoubtedly results from the high transmissibility of the high capacity fracture system. It is apparent that this system not only forms a reservoir of excellent drainage qualities, but also forms a system for efficient (to the extent possible under solution gas drive) drainage of the low capacity fracture blocks. Each of the fracture blocks of 30 to 100 acres whose area has been measured (as discussed in Part I) is unquestionably surrounded completely by the high capacity fracture system. Under such circumstances, the large surface area of each block which is exposed to the fracture system will cause the oil within the block to be drained much more effectively than can be accomplished by the drilling of a well inside the block. In fact, it is possible to recover oil into the high capacity fracture system from a block whose transmissibility is too low to allow a well completed in it to produce at commercial rates. It is perfectly clear that wells with good connection to the high capacity fracture system can more efficiently recover (through the high capacity fracture system) the oil from another well's low capacity fracture "block" in which it is completed, than can the well itself. This statement will hold true even though the "recovery" wells are two or three miles away from the subject well whose tract is being drained. Details of analysis showing, for one of these tight blocks, the drainage ability of a well drilled in it as compared to the surrounding fracture system's ability are discussed and examples given in Appendix V.

PART III - GRAVITY DRAINAGE

Gravity drainage has undoubtedly been a contributing factor in the depletion mechanism of many oilfields. Its exact effect, however, is difficult to analyze from field performance. Because of the competitive nature of the exploitation of most oilfields, it is ordinarily impossible to deliberately utilize the gravity drainage depletion mechanism, and its role in oil recovery is usually happenstance in overall field production.

Insofar as analyzing gravity drainage effects for a field such as West Puerto Chiquito is concerned, there is very little in the technical literature of practical value. It has been necessary to develop the useful equations from more fundamental relationships. Since the formulae used have not been reported in the literature, their derivations are shown herein.

For the subject reservoir, no knowledge is available as to effects of capillary forces, and these capillary effects are disregarded throughout the calculations of this paper. The amount of error in the calculations caused by this omission is not known. It is believed, however, that the general results and conclusions reached would not be materially changed from those given herein, had it been possible to include these capillary effects in the calculations.

Gravity drainage equations are usually designed to yield the gravity drainage rate in terms of barrels per day per surface area of exposed gas-oil contact. This relation requires a knowledge of the permeability of the formation as well as the surface area of the gas-oil contact. In the instance of West Puerto Chiquito,

neither permeability nor pay thickness (from which resulting surface area can be determined) is available. Accordingly gravity drainage was studied to ascertain if the information required about it could be determined from other data. Reasonly accurate information has been developed for values of transmissibility and pore space, and the study was particularly directed toward solution of gravity drainage aspects from these data only.

The results of this study showed that to evaluate gravity drainage behavior it is not necessary to know permeability and surface area of the gas-oil contact. As can be seen from the analysis that follows, all of the essential relations can be determined from a knowledge of transmissibility and pore space.

Insofar as West Puerto Chiquito is concerned, the most important facts to be determined are:

1. The gravity drainage rate in terms of barrels per day per unit of distance along the strike of the producing formation, and

2. Rate of movement (horizontally and vertically) of the gas-oil contact "plane".

That these essential facts can be calculated from a knowledge only of transmissibility and pore volume is illustrated by comparison of simplified flow systems such as those given in Appendix VI, Part A.

The gravity drainage rates shown herein are for assumed positions of horizontal gas-oil contact plane. Any such assumed horizontal plane will intersect the producing formation parallel to its strike. Accordingly, in this study of West Puerto Chiquito, the gravity drainage rate is expressed in terms of barrels per day per

near mile along the strike of the formation.

This gravity drainage rate is given by the relation:

$$Q = 2{,}580 \frac{h\ K\ d \sin \theta}{\mu\ B} \qquad (1)$$

where Q = gravity drainage rate, barrels per day per linear mile of gas-oil contact along the strike

K = permeability to oil, darcys

d = difference in specific gravities of oil and water (air = 1.0)

μ = oil viscosity, cp

B = FVF of oil

θ = angle of dip of formation

Derivation of this equation is given in Appendix VI, Part B.

For the values of oil viscosity and oil and gas density, Equation 1 has been used to calculate, for various transmissibilities, the rate of gravity drainage which can be expected in West Puerto Chiquito for that part of the reservoir in which the dip is 400 feet per mile. This relation of transmissibility to gravity drainage rate in terms of barrels per day per linear mile is shown at the end of Part IV on the graph, Figure No. 5.

As stated by Muskat, if no free gas is present and only an oil phase exists, the gas gravity term can be dropped from the equations, resulting in a higher rate of gravity drainage. For Figure No. 5, rates are shown both with and without a gas phase present. For a gas phase present, a pressure of 1,500 psia has been used to calculate gas density.

Formulae for calculating horizontal and vertical rates of movement of the gas-oil contact "plane" are derived in Appendix VI, Part C. Use of these relations is discussed in the appendix, along with graphs to facilitate calculations and comparison of data observed in West Puerto Chiquito.

From the gravity drainage properties discussed above, along with oil characteristics and relative permeability of the formation, it is possible to calculate gravity drainage recovery under various conditions and to compare this recovery with solution-gas drive recovery. Comparisons have been made assuming a reservoir of uniform transmissibility and a constant dip. For the examples calculated, permeability relationships that were used are shown on Figure 6. The resulting relative permeability relation, Kg/Ko, is shown on Figure 7.

It is not known what the true relative permeability characteristics of this fractured shale formation are, but for purposes of comparison of depletion under various methods it is not necessary to know the exact relationships. The differences in recovery will be somewhat the same for one type of depletion compared to another for any given relative permeability characteristic. We are, of course, interested in making an accurate estimate of ultimate recovery. More important, however, is the <u>difference</u> in recovery of one type of depletion mechanism as opposed to the other, and for this purpose it is not necessary to know exactly the relative permeability characteristics of the formation.

Figure 8 shows the production history of a reservoir with relative permeability characteristics of Figure 6 and West Puerto Chiquito oil, for strictly solution-gas drive recovery,

assuming no additional help from gravity drainage. Figure 9 shows the production history for the same reservoir for strictly gravity drainage depletion, assuming that the dip of the formation is 400 feet per mile and that the production rate is constantly being adjusted downward so as not to exceed the gravity drainage rate at the gas-oil contact. In this calculation it is assumed that oil is produced only from down-dip wells, and that upon reaching a free gas saturation of 1 percent all gas commences to migrate up-dip to form a secondary gas cap, and that the gas saturation increases upward to the gas-oil contact, at which point it is 8 percent. The gravity drainage rate for the reservoir, then, is determined by the viscosity of the oil at the gas-oil contact and the relative permeability to oil at the gas-oil contact for a free gas saturation of 8 percent. The time required to produce the oil under gravity drainage depletion as outlined is shown on Figure No. 10.

Under actual producing conditions one would expect the recovery to be somewhere between the two amounts shown on Figures 8 and 9, and ordinarily this will be the case. This is not always so, however, as field recovery could be somewhat less than the normal solution-gas drive recovery shown if the field is produced under competitive methods and the up-dip wells have adequate capacity to produce high volumes of gas. This is because, in view of the high permeability to gas and its tendency to migrate up-dip, if the up-dip wells are produced under standard rules of the Oil Conservation Commission the up-dip wells can produce gas at a higher rate than the strict solution-gas drive calculations would indicate. Accordingly the pressure may drop faster and the oil viscosity increase more rapidly and ultimate recovery be less than that

indicated on Figure No. 8. This will, of course, be partly offset by the incidental gravity drainage benefits of the down-dip wells, but whether one will balance the other will depend upon the physical reservoir characteristics and well capacities existing for the particular reservoir. The situation is, of course, aggravated by increased numbers of wells.

For the example reservoir produced under conditions in which both the gravity drainage and solution-gas drive mechanisms are operating, the ultimate recovery essentially for any section of the reservoir (section of the reservoir as used here is one linear mile along the strike and four miles down the dip) will be a function of the rate at which oil is produced from that section of the reservoir (assuming no interference from other sections). Accordingly recovery can be plotted against production rate in terms of barrels per day for the linear mile of reservoir section along the strike. This production rate will of course decline as the field nears depletion. For practical purposes, however, this initial production rate is adequate to define the conditions.

Calculations for the example reservoir have been made of ultimate recovery versus production rate in terms of barrels per day per linear mile of strike. This is compared with resulting per well production rates for various assumed spacings. The results are summarized on the graph, Figure No. 11. The shaded area represents, for the per mile production rate shown, the individual well producing rates (and resulting well spacings) which are too low to permit drilling costs to be returned in a reasonable time. This figure shows clearly the detriment to ultimate recovery which would result from development of the pool on well spacings usually

considered "normal" when compared to optimum spacings to achieve gravity drainage benefits.

Concerning the adequate number of wells required to deplete a section of the reservoir, it is of interest to review the effect of increased numbers of wells on the gravity drainage recovery alone. In this connection (and assuming sufficient wells are drilled in the lowermost row of wells on the down-dip side of the reservoir) it is impossible through the drilling of additional wells (even an infinite number of additional wells) to increase the gravity drainage recovery.

For any given part of a reservoir there will be only one gravity drainage rate available, and it can be produced by one row of wells on the down-dip side of the reservoir. If intervening rows of wells are drilled and produced at additional rates, these new wells will succeed only in increasing the total production from the reservoir; and having exceeded the reservoir gravity drainage rate, the production will take on the characteristics of the less efficient solution-gas drive.

Not only will the up-dip rows of wells fail to increase the gravity drainage recovery of the reservoir, but they will serve to decrease the reservoir's ultimate recovery to the extent the gravity rate is exceeded and the less efficient solution-gas drive becomes operative.

Moreover, the up-dip rows of wells cannot expect to share even a part of the gravity drainage recovery. They are committed only to solution-gas drive recoveries. This statement can best be understood by visualizing an intermediate row of wells along the strike and assuming this row of wells has a drainage area which

extends halfway up-dip to the next row of wells and halfway down-dip to the next lower row of wells. All other conditions being the same, one can presume that at any given time in the history of the reservoir, the pressure at the up-dip boundary of the drainage area of the subject row of wells will be less than the pressure at the down-dip boundary of the same drainage area. As a result, at any time, and at all times, the oil viscosity on the up-dip boundary will be more than the viscosity on the down-dip boundary and free gas saturation will be greater at the up-dip boundary than at the down-dip boundary, causing the permeability to oil to be less at the up-dip boundary than at the down-dip boundary. Accordingly, as far as gravity drainage is concerned, at any time there will be more oil moving away from the drainage area of an intermediate row of wells than is moving in to it.

From this reasoning it is obvious that if the lowermost row of wells produces at the reservoir's gravity drainage rate, or higher, this row of wells is the only one that can benefit substantially from gravity drainage. All the others will have minimum benefit from this source. Their recoveries must be nearly all from the solution-gas drive mechanism. Any attempt to capture the gravity drainage potential by drilling of additional up-dip wells can result only in a reversal of pressure gradients and an increased solution-gas drive recovery of oil in the up-dip area. It is, of course, possible, by the drilling of additional up-dip wells, to deny the down-dip wells part of the gravity drainage recovery, but in so doing the up-dip area will be produced at so high a rate that there will be virtually no gravity drainage recovery from it. The end result, then, of drilling additional up-dip wells

is to reduce overall reservoir gravity drainage and consequently, ultimate recovery.

Conversely, the drilling of additional down-dip wells cannot increase the reservoir's gravity drainage rate, and minimum benefit can be expected from the drilling of more down-dip wells than are required to produce the reservoir's gravity drainage potential. Some benefit can, of course, result from such additional wells if, by reducing the per well producing rates, their presence causes the wells' pressure "drawdown" differentials to be lowered to points that prevent serious channelling that otherwise would occur. The subject of optimum number of down-dip wells is discussed in Appendix VI, Part D.

PART IV - PRESSURE MAINTENANCE IN FRACTURED RESERVOIRS

SECTION 1 - INCREASED RECOVERY BY DEPLETION AT HIGH PRESSURE

In depletion of a reservoir by gravity drainage or by waterflooding, greater recoveries can be expected (from those parts of the reservoir in which gravity drainage or waterflooding is the responsible recovery mechanism) by operating the project at higher pressures. Optimum pressure is the bubble point. No increased recovery can be expected by operating at pressures higher than the bubble point, although it may be desirable for other reasons (i.e., production by flowing, or gas lift, as opposed to pumping).

This increased recovery at higher pressure, for all other things being the same, is caused primarily by the benefits of no shrinkage of the oil (FVF remains high) and the lower viscosity of the oil.

The combined effects of these properties, along with the other influencing factors, are shown later herein with numerical examples. It is interesting, however, to examine at this time the effect of shrinkage alone in comparing recovery at high versus low pressure. As it affects different reservoirs, of course, the higher the shrinkage factor the greater will be the benefit of depletion at high pressure. For West Puerto Chiquito, with its shrinkage of approximately 30 percent, the benefit of depletion at high pressure is significant.

The fractional recovery of oil from a reservoir in

depletion from one pressure to another can be expressed as the difference in oil in place at the first pressure and that remaining in place at the second pressure (Reference 3):

$$\text{Fractional Recovery} = \left(\frac{So}{B}\right)_1 - \left(\frac{So}{B}\right)_2 \qquad (2)$$

where So = Oil saturation, fraction of pore space

B = FVF

and subscripts 1 and 2 refer to Conditions 1 and 2.

With this relation we can compare recoveries at various pressures. One comparison is made (Figure 12) assuming the low pressure recovery is for 50 pounds and the high pressure recovery is for 1,500 pounds.

The variations in recovery are for various final oil saturations, but the saturation is assumed to be the same for the specific high and low pressure depletion. No information is available for determining exactly final oil saturation, so Figure 12 is prepared for a wide range, and it can be seen that increased recoveries by operation at high pressure for any given final oil saturation are significant.

SECTION 2 - "SWEEP" EFFICIENCIES OF GAS AND WATER AND CHANNELLING TENDENCIES

In view of the extremely great differences in transmissibilities throughout the reservoir, as mentioned earlier and as discussed particularly in Appendix III, it is believed that the type of "flood" project in which either water or gas is used to "sweep" the oil from the formation would have very little chance of success in a fractured shale reservoir. Even in reservoirs of

relatively uniform permeabilities, experience has shown that once gas breaks through there is a rapid increase in gas-oil ratios, and the gas is merely "cycled" with very little sweep effect and very little additional recovery resulting from the gas injection. This is particularly true of a reservoir at or near depletion, in which the free gas saturation is relatively high at the commencement of injection. Water, on the other hand, having a viscosity more nearly the same as oil, has a much greater sweep efficiency, and can be expected in most instances to have a far greater benefit with substantially greater ultimate recoveries than with gas. Once free gas saturation has resulted in a high capacity fracture in a fractured shale reservoir, one can be assured that gas will channel, and channel at extremely high rates, much higher in fact than has been experienced in other reservoirs.

Because of the situation as described above, most operators are fearful of attempting gas injection in a fractured shale reservoir, although some have tried waterflooding. Reports available on waterflood projects are quite discouraging, and the writer knows of no other gas injection projects attempted in fractured shale reservoirs.

Despite the reluctance of operators to attempt gas injection in fractured shale, and the fact that in waterflood projects the water has channelled seriously, and that usually one expects gas to channel even worse than water, there are certain theoretical aspects of pressure maintenance by gas injection in a fractured reservoir which indicate that if the project is properly carried on there is no reason why it should not be successful, and every reason to believe a substantial increase in ultimate recovery will result.

It is considered axiomatic that excessive channelling would result in a fractured shale reservoir if gas injection were not commenced until the reservoir was partially depleted and gas saturations were high. In other words, secondary recovery by gas injection is considered completely hopeless. The discussion here is confined entirely to pressure maintenance commenced early in the life of the reservoir when gas saturations are low.

Upon investigation we find that the very quality (low viscosity) of gas which causes it to channel at high rates once the reservoir, or part of it, reaches "critical" gas saturation, is a quality which will operate in the first instance to avoid channelling. When compared with water it is strikingly superior. It is of interest to examine the circumstances which cause channelling and to compare gas and water from a standpoint of their "channelling potential", when used as an injecting fluid for pressure maintenance. A pressure maintenance project cannot, of course, be successful if serious channelling occurs. To prevent serious channelling one must, of course, understand how and why it can occur, and operate the pressure maintenance project in line with measures which will prevent its occurrence.

It is helpful in this analysis to place numerical values on this characteristic and for the purpose of this study the term "channelling potential" is coined and defined as follows:

(a) For an injection well it is the differential pressure (in pounds per square inch) required to inject its fluid divided by the difference in density (in pounds per square inch per foot of depth) of the injecting fluid and the reservoir oil.

(b) For a producing well it is the differential (drawdown) pressure (in pounds per square inch) divided by the density of the reservoir oil (in pounds per square inch per foot of depth).

The result in each instance is in terms of vertical feet. It is assumed that the gas will be injected on the up-dip side of a reservoir, and the channelling potential is therefore measured down-dip from the injection well. It is assumed that water would be injected on the down-dip side of a reservoir, and consequently the channelling potential for a water injection well will be measured vertically up-dip from it.

If there is one injection well and one producing well, the channelling potential will be the sum of the individual channelling potentials.

If, for example, there are two wells in the reservoir, one an injection well up-dip and the other a producing well down-dip, and the vertical separation of the two wells is 1,000 feet, then at commencement of gas injection there can be absolutely no channelling from the injection well to the producing well if the sum of the channelling potentials of the two wells is less than 1,000 feet.

If there are more than one injection well (located at the same datum) and more than one producing well (producing wells at one datum) the maximum channelling potential will be the sum of the channelling potentials for the injection well with the greatest channelling potential and the producing well with the greatest channelling potential.

For multiple well systems, where the wells are completed at different structural datums, it becomes necessary (as to each well) to reduce the channelling potential to a structural datum. This is accomplished by adding (or subtracting as the case may be) the channelling potential of a well to its structural datum. Comparison then of the datums of the channelling potentials so calculated will reveal if channelling could occur.

In actual practice, of course, if there is any communication at all throughout the reservoir other than in the channel, then injection pressure will tend to equalize the reservoir pressure with the pressure in the channel, so that the actual channelling tendency will be far less than the "potential". The channelling potential, calculated as described above, determines the absolute maximum value. One can be assured that it will be somewhat less than this, depending upon the equalization of pressure throughout the reservoir.

The differential pressure to use in calculating channelling potential is not necessarily the difference in the well's operating pressure at the pay zone and the reservoir static pressure at that datum. If there is a substantial distance between the injection well and the producing well (by "substantial" is meant a relatively large part of the reservoir will exist outside the separate local fracture blocks in which the injection and producing wells are completed) the differential pressure to be used in determining channelling potential is the pressure drawdown from static in the high capacity fracture system at the point nearest the well where the high capacity fracture system and the well's low capacity fracture "block" join.

As the gas-oil contact moves down-dip it forms the datum from which the injection well's channelling potential is to be subtracted in arriving at the datum of the injection well's channelling potential. In this instance the injection well's differential pressure to be used in calculating channelling potential is the differential pressure above static caused by the injection well at the gas-oil contact.

As indicated above, for multiple well systems the channelling potential is not cumulative. Channelling cannot occur if vertical separation exists between the highest datum of the producing well's channelling potential and the lowest datum of the injection well's channelling potential (for pressure maintenance by gas injection).

Actually, of course, additional wells can serve to reduce the channelling potential if the total injection and withdrawal rates are maintained the same (by distributing the fluid requirements and lowering the per well rates). The numbers of injection and producing wells required to avoid channelling will depend, of course, upon the particular physical reservoir characteristics, and no general statement can be made as to number of wells required to reduce the channelling potential to a practicable level. Dip of the formation obviously is important here. Where producing rates are held at or near the gravity drainage rate, ordinarily the producing wells' differential (drawdown) pressures will be quite low, and relatively few wells are required to keep the channelling potential within reasonable limits if a dip of several hundred feet per mile exists in the vicinity of the recovery wells.

If reservoir production rates are maintained within the gravity drainage rate, then the gas-oil contact will drop within the reservoir much as the oil level in an open tank No free gas will evolve, and there will be a continuous solid column of oil from the gas-oil contact to the producing wells. Accordingly, under these conditions the channelling potential for the gas injection and oil producing wells can be simply and accurately described by comparison with pipes in an open tank. Such a comparison is discussed in Appendix VII, Part A.

Once the conclusion is reached that it is impractical to attempt to sweep oil through a fractured reservoir, either with water or gas, but that an effort will be made to achieve the potentially greater recoveries by operating the reservoir at high pressures (as discussed in Section 1 above) then two choices of pressure maintenance operation remain to be considered: (1) gravity drainage down-dip under gas, and (2) "gravity drainage" up-dip over water. There is probably very little difference in overall efficiency of displacement of oil by these two methods, if in each instance production rates are maintained at or below the respective "gravity drainage" rates. There is, however, a striking difference in the practical aspects of the two operations, particularly with regard to the number of injection wells required.

It is here that we find the low viscosity of the gas to be extremely beneficial. Although other factors are also involved (as more particularly described in Appendix VII, Part B) one may estimate approximately the ratio of injection pressure differentials of a water injection well to a gas injection well from the ratios of their viscosities, which for the reservoir

temperatures of West Puerto Chiquito is in the range of 25 to 30. Accordingly for the same reservoir space displaced, operating differential pressures for a gas injection well can be expected to be about 1/25th that of a water injection well.

A comparison of overall channelling tendency requires, in addition to the pressure differential as discussed above, a consideration of density differences of the injecting fluid and reservoir oil. The difference in density of oil and gas is nearly twice as great as the difference in density of oil and water. Since the channelling potential as defined earlier for an injection well results from its pressure differential divided by the difference in density of the two fluids, we find that the channelling potential for the same injection pressure differential is twice as great for a water injection well as for a gas injection well. When we combine this factor with the producing differential relation described above, we find that a gas injection well can maintain reservoir pressure with about 1/50th of the injection pressure differential required by a water injection well. Expressed in another manner, it will take 50 water injection wells to inject the same volume of reservoir space as one gas injection well and maintain the channelling potential of the water injection project to the same point as the channelling potential of the gas injection project.

So, although in most pressure maintenance projects water is selected over gas because of its sweep efficiency and less channelling tendency, we find for our purposes in this fractured shale reservoir that gas is far superior from a standpoint of avoidance of channelling in the first instance. Also, under the

gravity drainage concept of depletion, we are not interested in sweep efficiency of the displacing fluid as such. All we expect from the injecting fluid is to maintain pressure. The rest of the depletion mechanism takes place naturally. With the above considerations in mind, for the pressure maintenance project in the Cañada Ojitos Unit in West Puerto Chiquito gas was selected as the injecting fluid.

SECTION 3 - OIL RECOVERY FROM THE LOW CAPACITY FRACTURE BLOCKS

A study of pressure maintenance for this fractured shale reservoir is not complete without consideration being given to the possibilities of gravity drainage depletion under pressure maintenance of the low capacity fracture blocks.

Under normal solution-gas drive depletion, as discussed in Part III, some gravity drainage benefits can be expected from the high capacity fracture system. It is doubtful, however, that under such conditions there will be significant gravity drainage oil recovery from the tight blocks. Pressures can be expected to be equalized all around the individual fracture blocks, and the density of the oil in the high capacity fracture system surrounding the blocks will be approximately the same as the density of the oil within the tight blocks. Consequently there will be no pressure differential between a tight block and its adjoining fracture system due to density differences within and outside the fracture block. Moreover, any gravity drainage of oil out of the down-dip side of a tight block will more than likely be offset at least partially by gravity drainage into the block on its up-dip side.

Under pressure maintenance, however, an interesting possibility exists whereby a substantial amount of gravity drainage may be anticipated from the tight blocks. In the first stages of pressure maintenance, since there will be no expansion of oil due to declining pressures (pressures will be maintained constant at any one point in the reservoir) oil will drain down-dip in the high capacity fracture system and leave above it a gas cap or channels of gas surrounding the up-dip fracture blocks. Just as described above for solution-gas drive depletion, at times when a fracture block is surrounded by oil, any gravity drainage out of the down-dip side of the fracture block will probably be offset by gravity drainage into the block on the up-dip side. Once, however, the block is entirely surrounded by gas, there will be no gravity drainage into the up-dip side of the block, and the oil which gravitates out of the down-dip side will likely find its way into the high capacity channels and continue its down-dip path to producing wells.

It is possible to calculate approximately the time required to deplete one of these fracture blocks by gravity drainage from its transmissibility and length of its down-dip dimension, if the dip of the formation is known. This is discussed in detail in Appendix VI, Part C. The rate of down-dip movement of the gas-oil contact plane as dependent on transmissibility is shown on the graph, Figure 13, in terms of feet per day. From this velocity and knowledge of the length of the down-dip dimension of a tight block, one can determine the time required to deplete it by gravity drainage.

From this figure it can be seen, for example, that for

a low capacity fracture block with a transmissibility of only .03 darcy feet, a horizontal movement of oil under gravity drainage would be .20 feet per day. This means for a fracture block with a down-dip dimension of 1,500 feet, its contained oil could be depleted by gravity drainage in about 20 years. This is not an untenably long period of time to deplete a reservoir if the producing wells can be maintained at reasonably high rates of production.

With regard to rates of production available from these tight blocks, it is interesting to note that a fractured reservoir offers far greater potential for gravity drainage of "tight" areas than a reservoir with "uniform" properties. The reason is that the gravity drainage rates from individual fracture blocks can be cumulative. As distinct from the rows of wells which were discussed in Part III, gravity drainage production from fracture blocks surrounded by gas will be additive, such that the production rate available for the down-dip wells can be expected to be the sum of the rates from the individual fracture blocks exposed. As can be seen from Figure 5, if the average transmissibility of the tight blocks is .1 darcy feet, their average gravity drainage rates would be 15 barrels per day per linear mile. If there are three fracture blocks per mile and three miles of fracture blocks exposed down-dip, the sum would be 135 barrels per day in gravity drainage from these tight blocks. If there is to be supported the operating cost of only one producing well per linear mile in the down-dip recovery area, it is apparent that the project can be economically continued until the blocks are substantially depleted by gravity drainage.

In view of the above remarks, it is to be anticipated that the fall of the gas-oil interface in the high capacity fracture system will initially be at a rather high rate, but that as it drops down-dip and exposes additional fracture blocks, the gravity drainage volumes will be increased by the amounts available from the exposed fracture blocks, so that the rate of fall of this interface should continually decrease (for the same reservoir withdrawal rate). In West Puerto Chiquito the operator of the Cañada Ojitos Unit proposes to make periodic determinations of the rate of fall of the gas-oil contact to determine if this in fact does occur. The rate of the fall of the gas-oil interface in the high capacity fracture system will be determined by adjusting injection volumes and production rates so that steady state conditions obtain, and then determining the rate of fall of the gas-oil interface by the increase in pressure in the gas cap. (It is apparent that if the oil zone pressures remain constant as oil is produced and the gas-oil interface drops down-dip, the pressure in the gas cap will necessarily increase). The rate of increase of pressure in the gas cap will afford a measurement on the rate of fall of the gas-oil interface. For any given pressure increase, the vertical fall of the gas-oil interface can be determined by dividing this pressure rise, in pounds per square inch, by the difference in density of the gas and the oil in terms of pounds per square inch per foot.

The volumes of injected gas required to maintain the reservoir pressure constant in the oil zone for given rates of production for West Puerto Chiquito are shown on the graph at the end of this Part IV, Figure 14. That the injected gas volumes are displacing almost exactly the reservoir space voided by the oil is

evident from the stabilization of pressure in the oil zone, as shown by operating pressures of the wells, and the pressure in the observation well, the A-23.

SECTION 4 - NOTE REGARDING RELATIVE PERMEABILITY EFFECTS

Consideration of relative permeability effects under pressure maintenance requires first a general consideration of relative permeability as we know it, without regard to pressure maintenance. Here, of course, with the paucity of information available as to relative permeability characteristics of fractured formations, there are many unanswered questions, and to solve our problems it is necessary to make assumptions based on judgment of such facts as are available.

One of the puzzles, of course, is the true relationship of permeability to oil at different liquid saturations. It would appear from the high ratios of relative permeabilities at high liquid saturation, as indicated by laboratory tests, that there must be practically no permeability to oil at liquid saturations as high as 85 to 90 percent. There is some question, however, that the horizontal permeability to oil would be the same as the vertical permeability to oil. One can visualize a rather wide fracture with oil draining by gravity down each side and an opening in the middle through which gas would flow without "sweeping" the oil along horizontally, even though oil is draining vertically down-dip. Accordingly, if one assumes the relative permeability ratio shown on Figure IV-2 and the permeability to oil shown on Figure V-1, the resulting permeability to gas has the odd relationship shown on Figure 6. For the reason just mentioned, the relations of Figure 6

cannot be entirely discounted, as this may very well present the different situations where horizontal permeability to oil may be different from vertical permeability to oil, and where drainage is an important contributing factor to the producing mechanism. It would perhaps appear more reasonable to show the relative permeability to oil to decline more rapidly than is shown on Figure 6. However, for the purposes of this paper, particularly with regard to the matter of Appendix V, it was believed desirable to show calculations which include a favorable relative permeability to oil.

With such a relative permeability to oil as shown on Figure 6, one might assume that higher gravity drainage recoveries might exist following an initial depletion cycle under solution-gas drive than is shown on Figure 11, under the assumption that once the gas has been evolved, dissipated and produced, the remaining oil would simply drain down-dip by gravity. Whether such a cycle can happen, of course, depends primarily on shrinkage factor of the oil, as for instance in Boulder with its low shrinkage such a process probably did occur to a certain extent. In West Puerto Chiquito, with its higher shrinkage factor, however, this is less likely.

Also, as pointed out in Appendix IV, actual gravity drainage benefits cannot be realized as long as the bulk volume of the oil in the reservoir is "expanding" as a result of gas breaking out of solution. Until these gas bubbles have worked their way to the top of the structure or to the gas cap, true benefits from gravity drainage cannot be realized. Any oil which tends to move down-dip at the gas-oil contact (top of the structure) is very

effectively moved back up-dip by the expanding gas bubbles. This situation, of course, has no particular influence in a reservoir in which the bubbles can rapidly migrate vertically up-dip and where a relatively large volume of oil per acre exists. In West Puerto Chiquito, where the bubbles have actual horizontal distances to move of three to four miles up a relatively gentle slope, this does become a significant factor. It is particularly important when involved, as it is in West Puerto Chiquito, with a relatively small volume of oil in place per acre. Under these conditions, and under relatively close spacing (less than 320 acres per well) and normal production rates, the depletion process will evidently follow the solution gas drive mechanism almost completely until such time as extremely high permeability to gas exists and the gas can move at high rates to the gas cap. Unfortunately at this time the pressure and permeability to oil will be low, and the viscosity high, before gravity drainage can even begin.

In view of the effects of these factors, the per well productivities, as shown on Figure V-2, can be extremely low, and only those wells with exceptionally good connection with the high capacity fracture system can produce at commercial rates at the time the gravity drainage mechanism begins to work. It is therefore unlikely that in West Puerto Chiquito significant gravity drainage recoveries can be anticipated following an initial production cycle of solution-gas drive.

As indicated earlier, because of the complexity of the situation it is difficult, from analysis of production behavior of depleted fields, to exactly identify these gravity drainage and relative permeability effects. At this time only general comparisons

can be made. For example, it is believed that the recoveries in Boulder were approximately 15 to 30 percent of the oil in place. Boulder was developed on 80-acre spacing, and it might appear at first that with reference to Figure No. 11 this range of recovery is not consistent with recoveries suggested on this Figure 11 for 80-acre spacing. It must be recognized, however, that in Boulder the shrinkage factor was only about 10 percent, reducing (by comparison with West Puerto Chiquito) this detrimental effect to ultimate recovery discussed above. Possibly more important, however, is the relation of the Boulder Pool's surface area to the dip of the formation. This pool is approximately three miles in length, along the strike, with only one mile of width, down the dip. All other factors being equal, with only one mile down-dip at Boulder, whereas there are four miles at West Puerto Chiquito, a well density of four to one could be used at Boulder (wells produced at equal rates) when compared to West Puerto Chiquito to give the same relative production rate in terms of barrels per day per linear mile along the strike, and accordingly have the same impact on gravity drainage recoveries. Further in this regard, with Boulder's initial viscosity of 3 cp, FVF of 1.10, formation dip of approximately 1,000 feet per mile and assumed transmissibility of 10 darcy feet, its initial gravity drainage rate would be estimated at (Equation _, Page 21 herein) approximately 1,000 barrels per day per linear mile. Boulder's highest production rate was about 1,500 barrels per day, or 500 barrels per day per mile along the strike. Accordingly, a high gravity drainage recovery should have been realized at Boulder, and a recovery of 30% of the oil in place (considering the "uncontrolled" manner by

which Boulder was produced) is quite consistent with the principles of calculation underlying Figure 11.

From these remarks it can be seen that the resolution of true relative permeability characteristics is difficult to make from a simple analysis of field performance, and field data can only be interpreted generally. One particular interpretation, however, should be noted with respect to the apparent range of the ratio of relative permeabilities of fractured formations (as shown on Figure IV-2). The early high permeability to gas, which indicates a "poor" Kg/Ko relation as far as solution-gas drive depletion is concerned, is a "good" characteristic for gravity drainage, and gravity drainage under pressure maintenance. High permeability to gas at low gas saturations does not necessarily mean that gas will "channel" immediately under pressure maintenance, rather the gravitational forces will tend to establish a more uniform gas-oil contact "plane" than if the gas had a lower relative permeability for the same gas saturation. This statement is best understood by visualizing permeability to gas to have an infinite value. If this were the case, immediately upon breaking out of solution (under producing conditions of reducing pressure) gas would by gravitational segregation instantly move to the gas cap, if the gravity drainage rate was not exceeded by the producing wells. Also, gas entering the reservoir from a gas injection well would likewise instantly rise to the gas cap. On the other hand, if under gas injection, where this high Kg/Ko relation exists, the oil producing rate exceeds the gravity drainage ability of the reservoir, gas "break-through" would be anticipated earlier than for a reservoir with a lower Kg/Ko relation. Such break-through times and recoveries can be calculated (Reference 9). Such calculations

reveal that it is impossible to hasten the gravity drainage process, for if the gravity drainage rate of production is exceeded, lower ultimate recoveries will result under pressure maintenance, the same (although for different reasons) as gravity drainage without pressure maintenance, where the production rate exceeds the reservoir's gravity drainage ability and the solution-gas drive mechanism becomes operative.

The end result of such analyses is simply that production rates under pressure maintenance should be restricted to approximately the gravity drainage ability of the reservoir.

SECTION 5 - SUMMARY

Benefits from pressure maintenance by gas injection in most reservoirs ordinarily is expected to include only slight benefit in additional ultimate recovery. The main benefit is probably faster rate of recovery. In the instance of West Puerto Chiquito, however, because of its unusual nature, a substantial increase in ultimate recovery is anticipated from use of pressure maintenance, as compared to producing the pool without it. The primary reason, of course, is that pressure maintenance will insure that the gravity drainage depletion mechanism actually has an opportunity to be effective. In this connection the following remarks are offered:

1. As to the volume of the oil in the high capacity fracture system, now thought to be perhaps half of the oil in the reservoir, there will be no "free gas phase" affecting the gravity drainage rate, and accordingly under pressure maintenance the slightly higher gravity drainage rate, as shown on Figure No. 5,

for the condition of no free gas present, will obtain.

2. By maintaining the pressure, the viscosity will always stay low, and the gravity drainage rate will not decrease with stage of depletion of the reservoir. Also, the oil saturation will stay high and the relative permeability to oil will stay high. These things taken into account, it should be possible to deplete the reservoir in one-third to one-half the time which would otherwise be required and at the same time enjoy the high gravity drainage recoveries.

3. The gravity drainage process will commence as soon as steady state conditions are reached under the gas injection project, avoiding the hazard of gas expansion and the time required for the gas bubbles to migrate to the gas-oil contact, as discussed in Section 4 of this Part IV. This phenomenon is believed to be extremely detrimental to potential gravity drainage recoveries, and its hazard is completely eliminated under pressure maintenance.

4. A higher recovery of oil from the tight blocks is anticipated under gravity drainage and pressure maintenance, as discussed in Section 3 preceding.

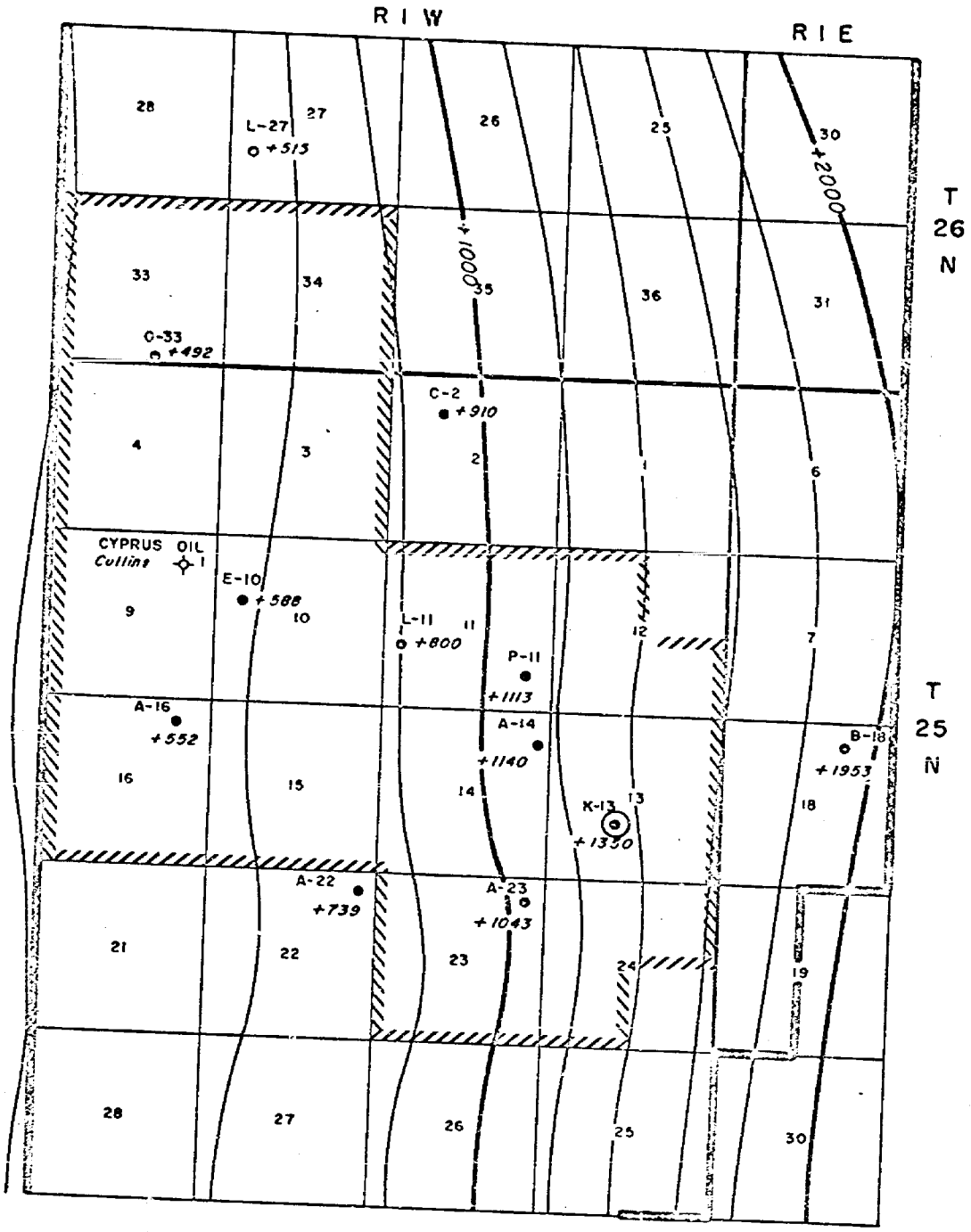
5. Although little benefit in ultimate recovery is ordinarily anticipated under pressure maintenance as compared to gravity drainage without pressure maintenance, this is because, among other things, one usually anticipates the final liquid saturation under gravity drainage to be quite low. If it is, then of course there is little difference in ultimate recovery with or without pressure maintenance. If, however, the final liquid saturation is as much as 50 or 60 percent of the total pore space,

then very substantial increases in ultimate recovery will result, as discussed earlier and shown on Figure No. 12. Not knowing the value of this final liquid saturation, it is only prudent to use pressure maintenance to "be safe" in recovering the maximum possible amount of oil, as long as its cost is not prohibitive.

6. If the down-dip wells do not have high capacity communication with the main fracture system, wells will reach economic limits while there is still a substantial amount of oil which might otherwise be recovered. The additional pressure of the pressure maintenance project will insure this final amount of oil will be recovered.

The pressure maintenance project is visualized as comprising three phases. The first phase is drainage of the high capacity system. This will be at times when the pressure in the oil zone (below the gas-oil interface in the high capacity fracture system) is maintained constant and the pressure in the gas cap is continually increasing. The second phase will be essentially a gas cycling phase, at which time the same volume of gas which is produced is returned to the reservoir, and thence cycled. During this period of time the reservoir pressure will decline slightly by the amount of oil withdrawn which is not replaced by gas. The third phase will be a period of rapidly declining pressures, during which gas will not be returned to the reservoir, or if returned, will be returned in quantities less than produced. During this time part, if not all, of the gas will be marketed and the producing mechanism for the down-dip areas will be a combination of gravity drainage and solution-gas drive. The extent to which gravity drainage or solution-gas drive will dominate in the recovery of oil from the down-dip areas will of course depend strictly on the

economics of the situation and the degree to which producing rates can practicably be restricted. At that time, however, some 80 to 90 percent of the ultimate recovery will have been realized through the efficient gravity drainage mechanism, and even though the rest of the reservoir were to be depleted by strictly solution-gas drive, the overall recovery would be highly efficient as compared to either solution-gas drive alone or gravity drainage depletion without pressure maintenance.



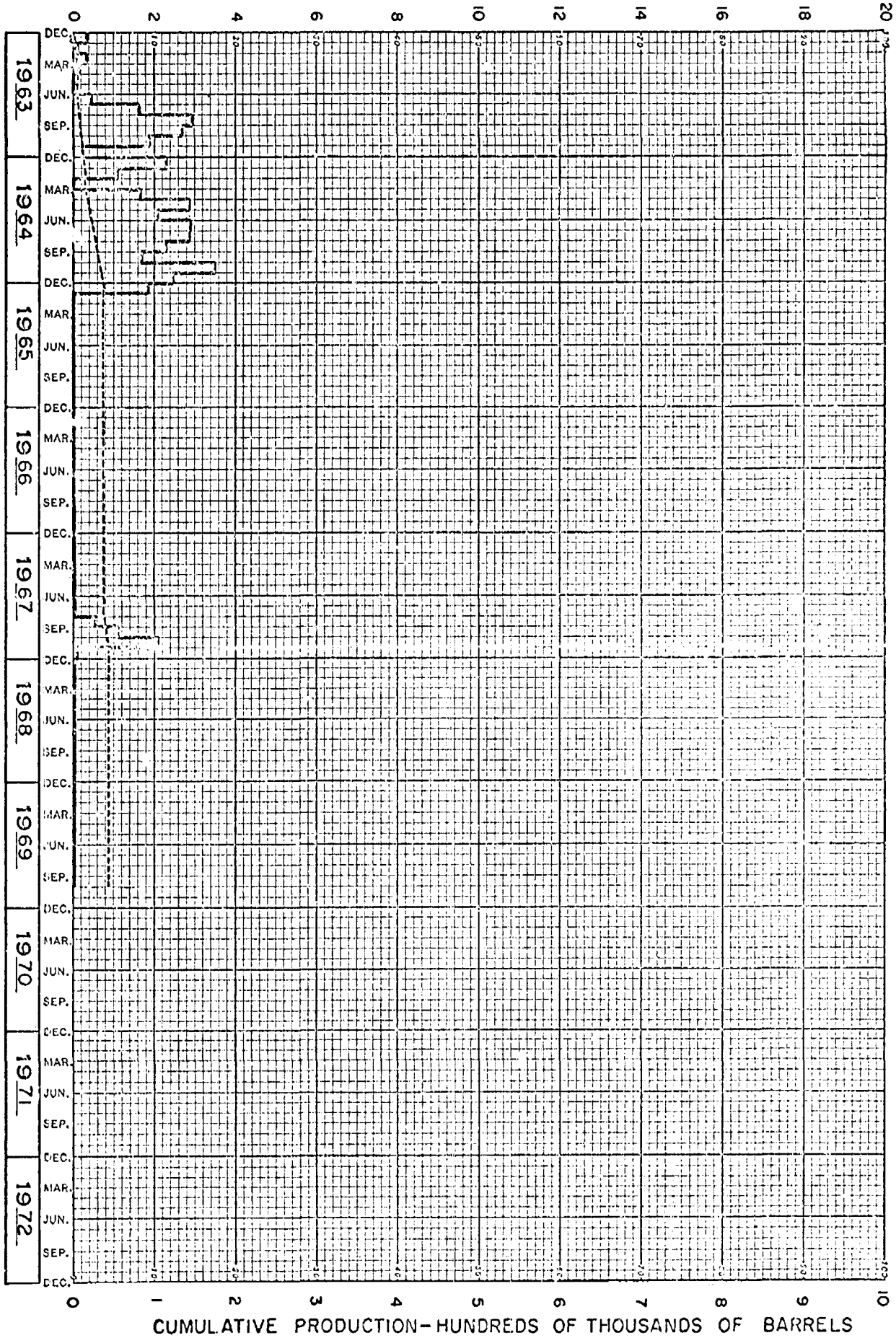
PLAT OF PART
OF
CAÑADA OJITOS UNIT

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

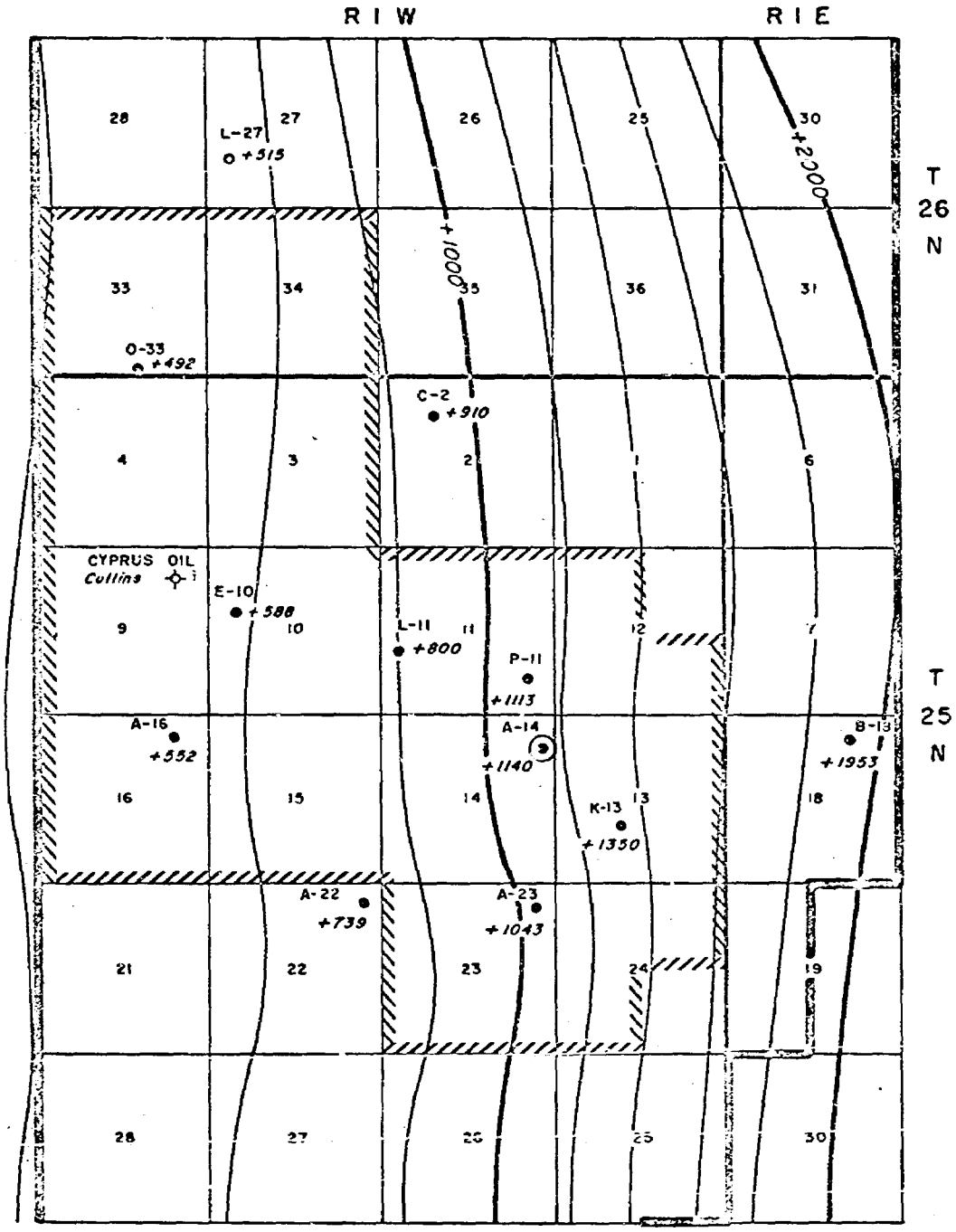
BOUNDARY OF CAÑADA OJITOS UNIT

PRODUCTION RATE–THOUSANDS OF BARRELS PER MONTH



CAÑADA OJITOS UNIT – # K-13

PRODUCTION RECORD



PLAT OF PART
OF
CAÑADA OJITOS UNIT

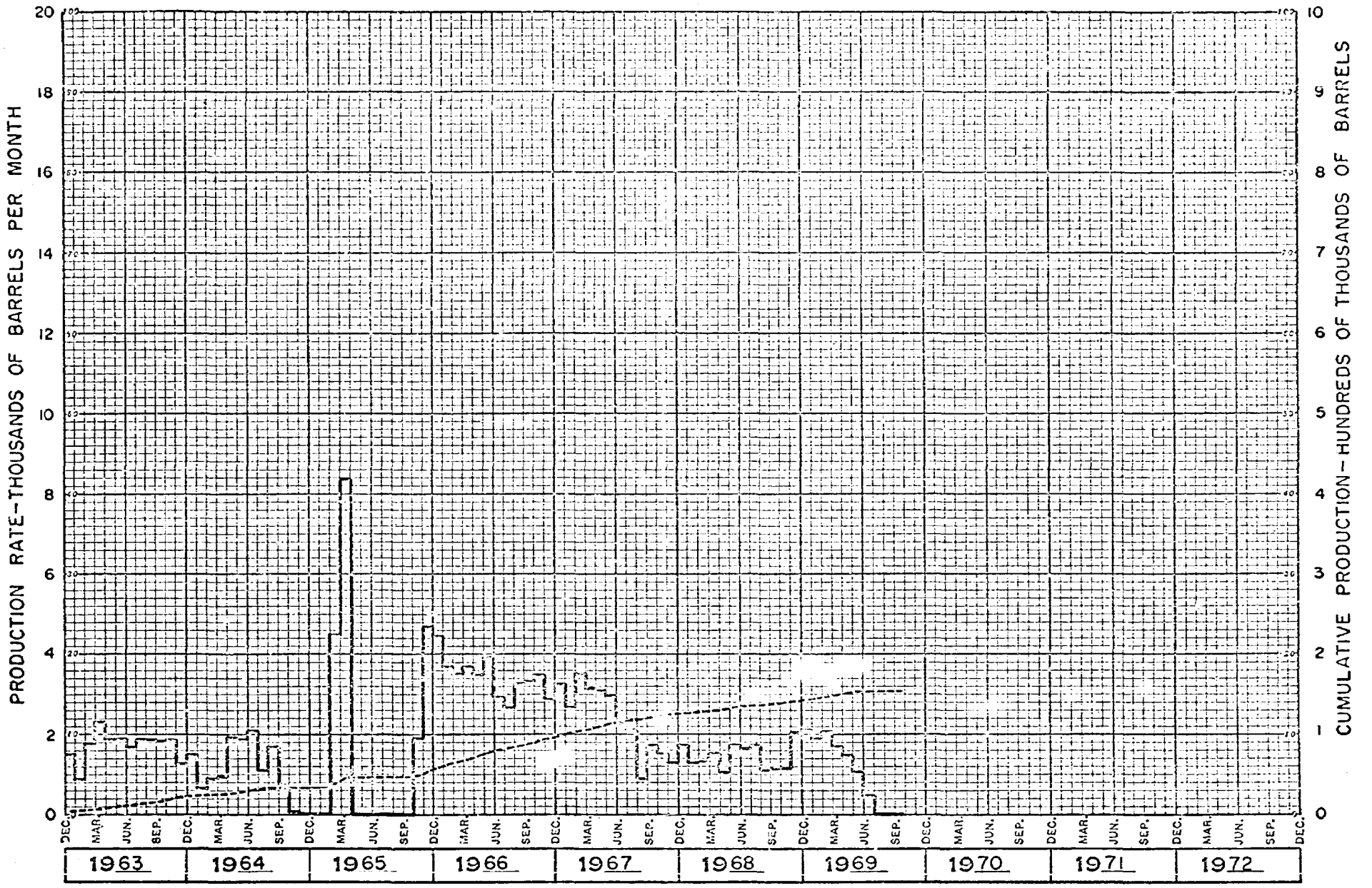
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

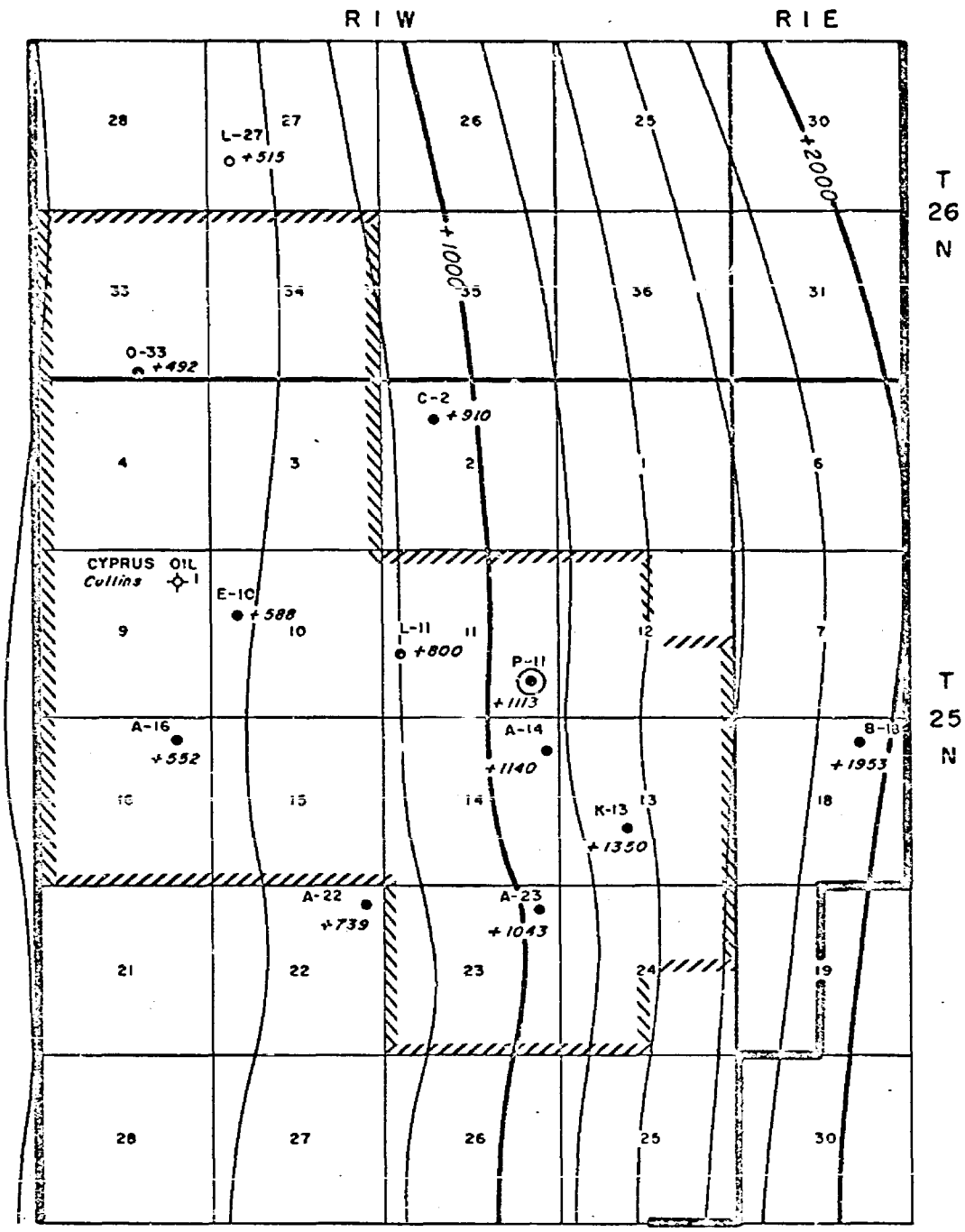
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT — # A-14

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

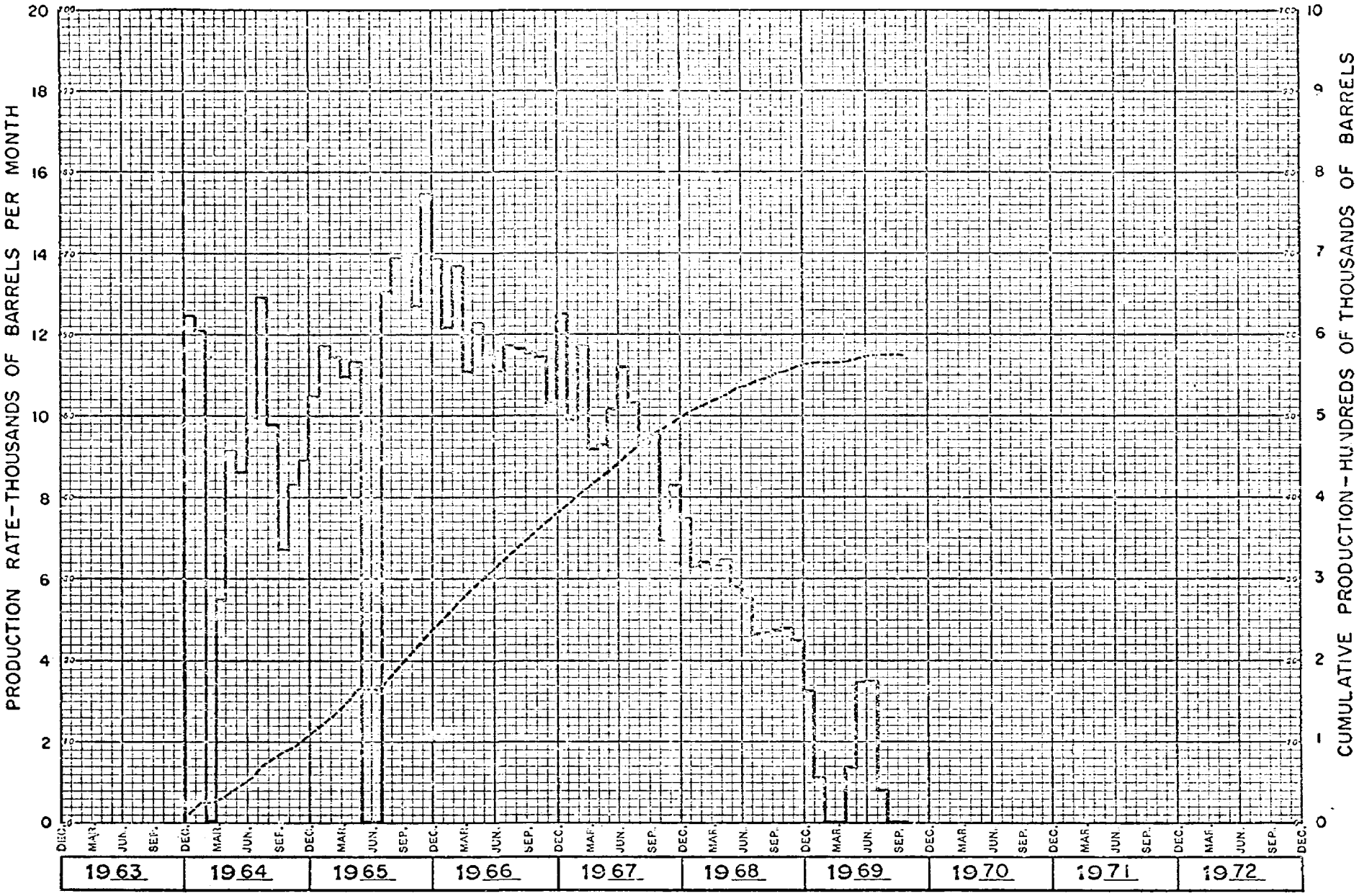
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NOVEMBER, 1969

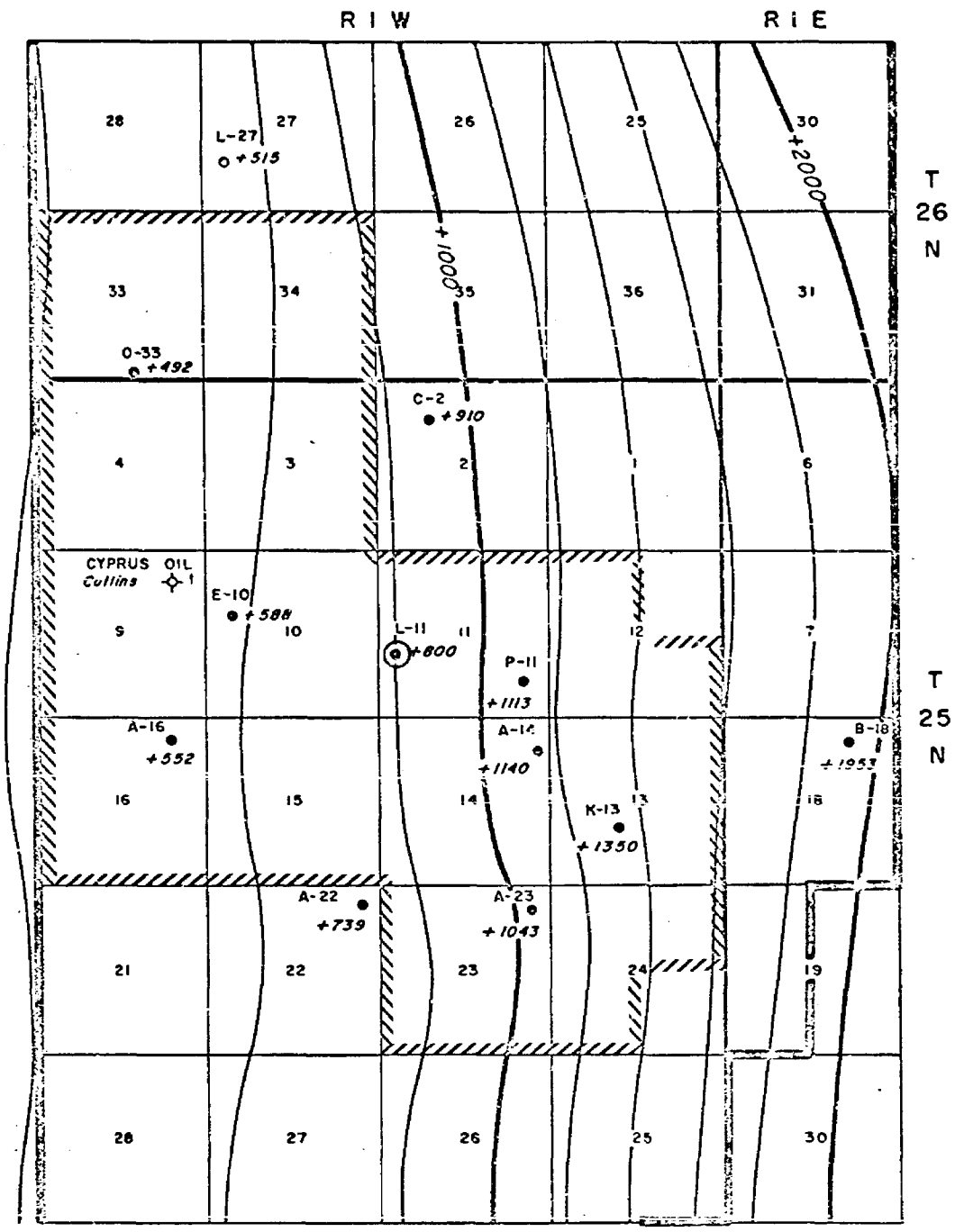
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # P-11

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

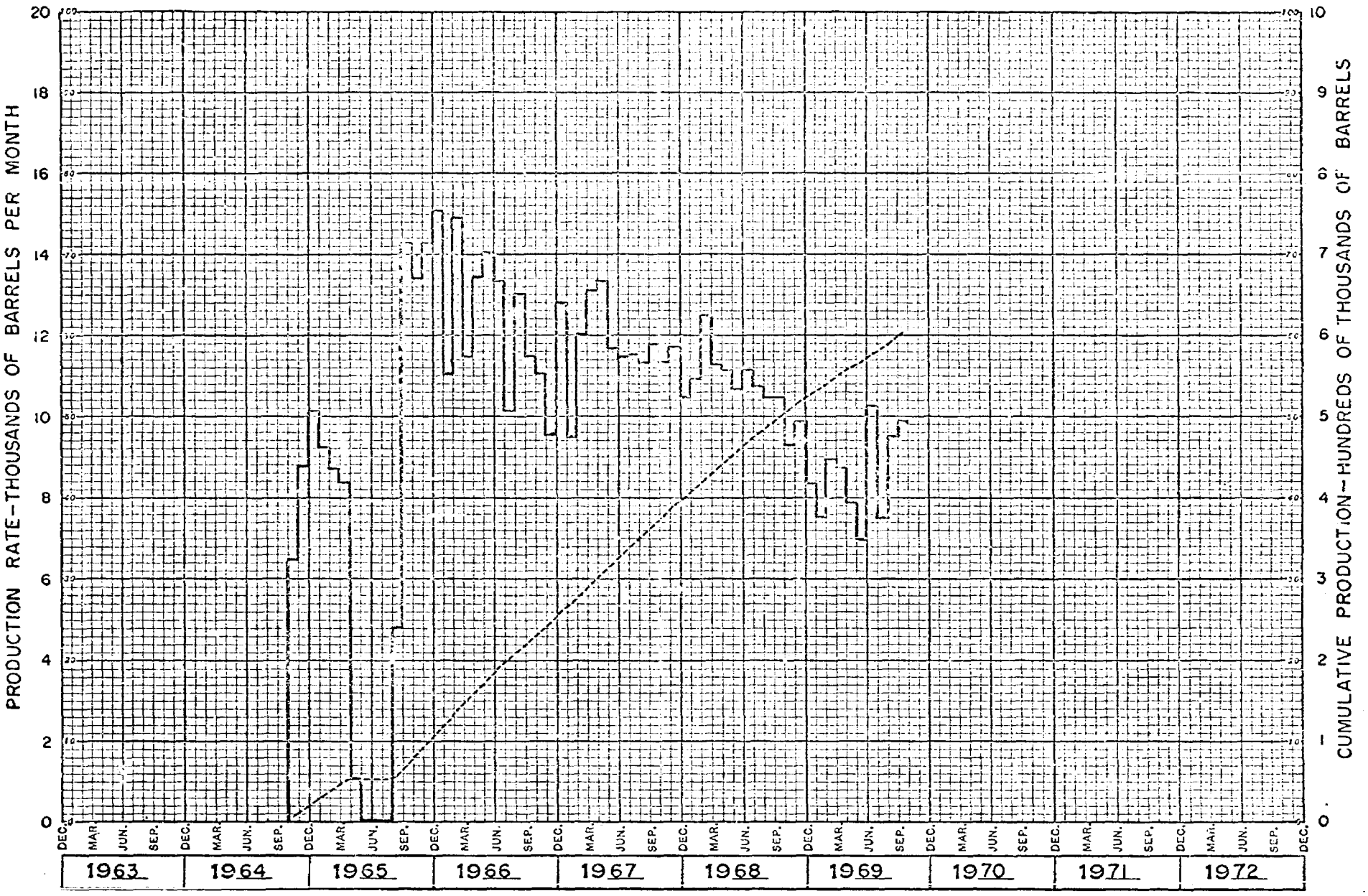
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C. I. 200'
NOVEMBER, 1969

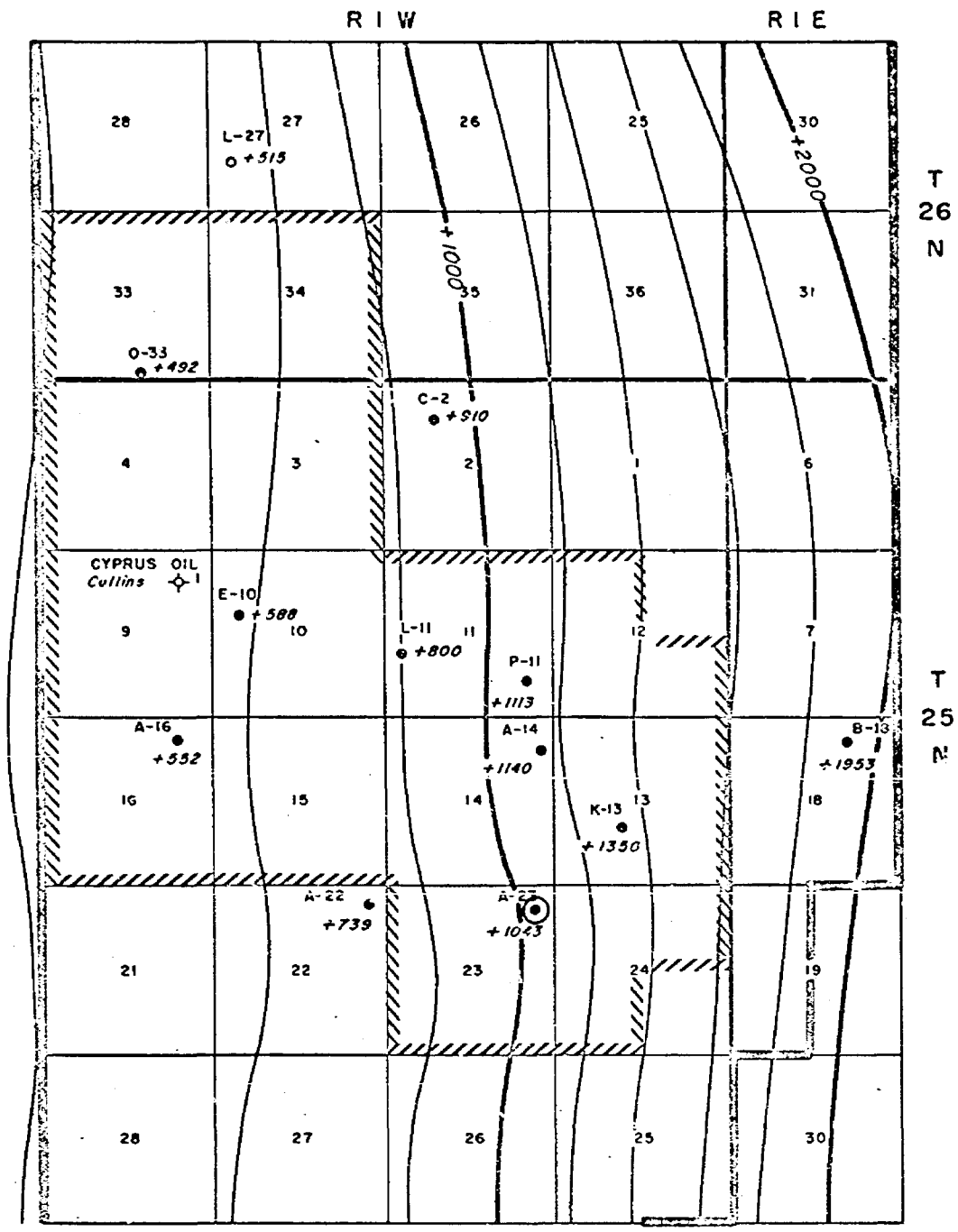
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # L-11

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

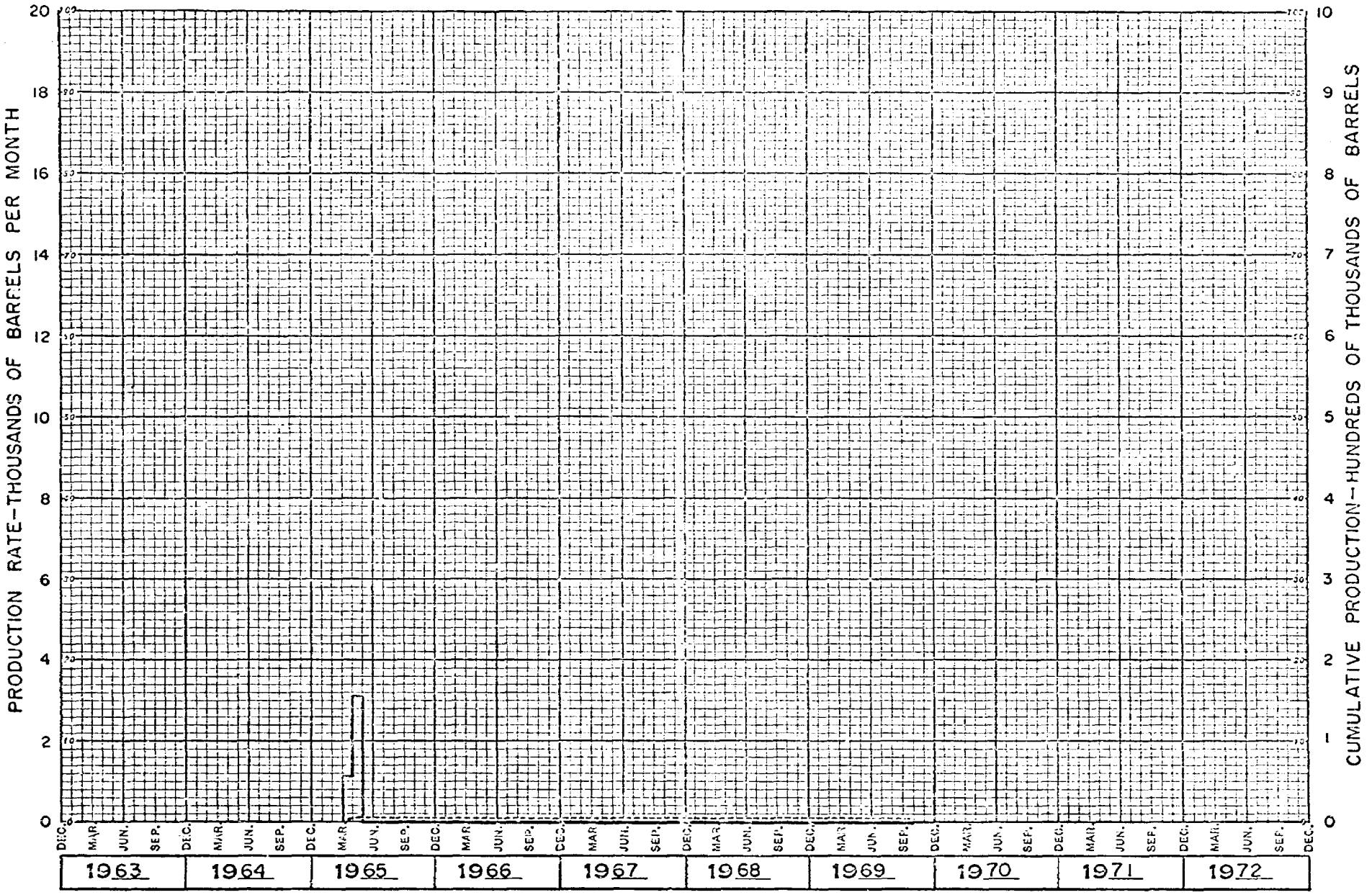
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

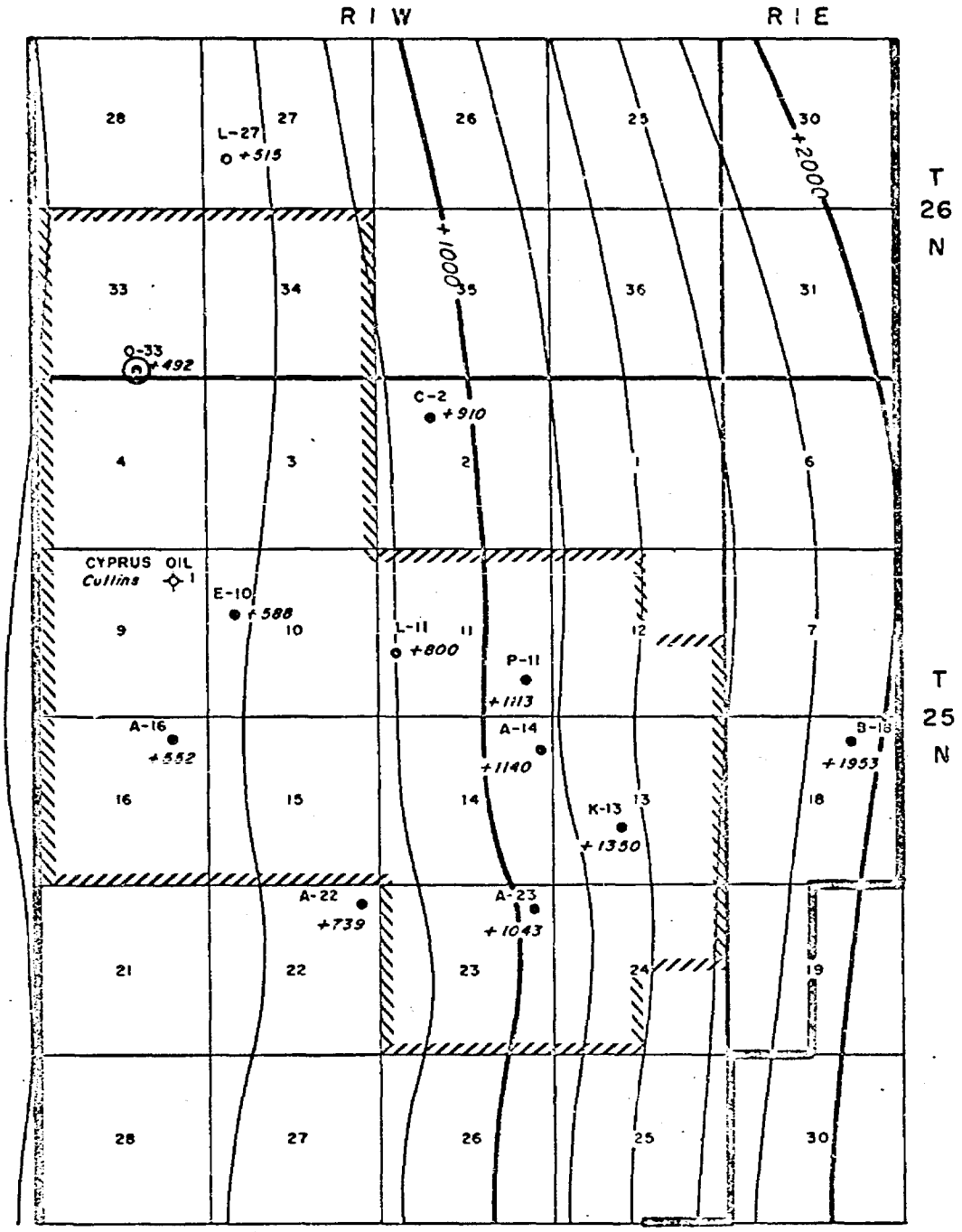
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-23

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

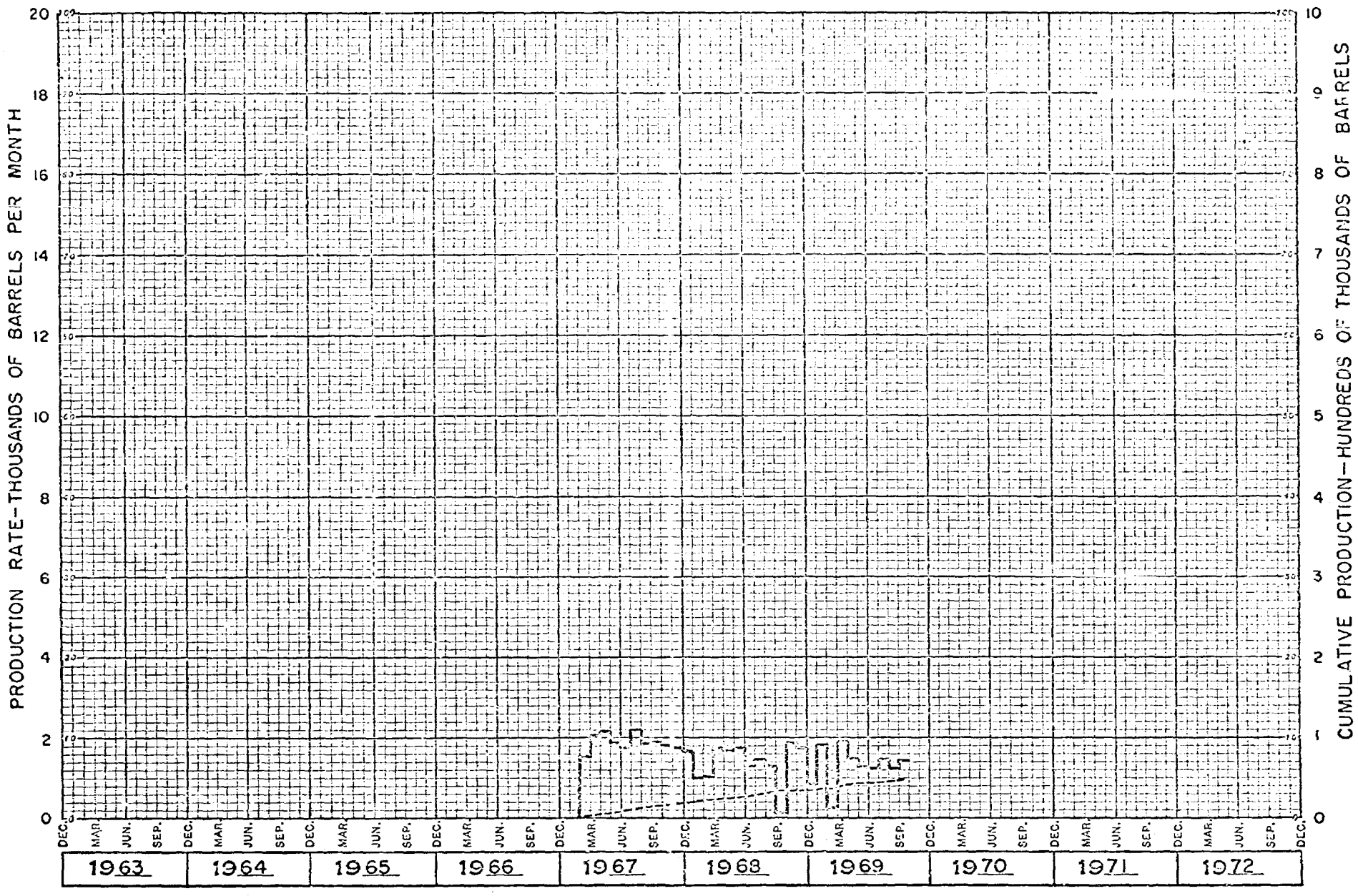
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C. I. 200'
NOVEMBER, 1969

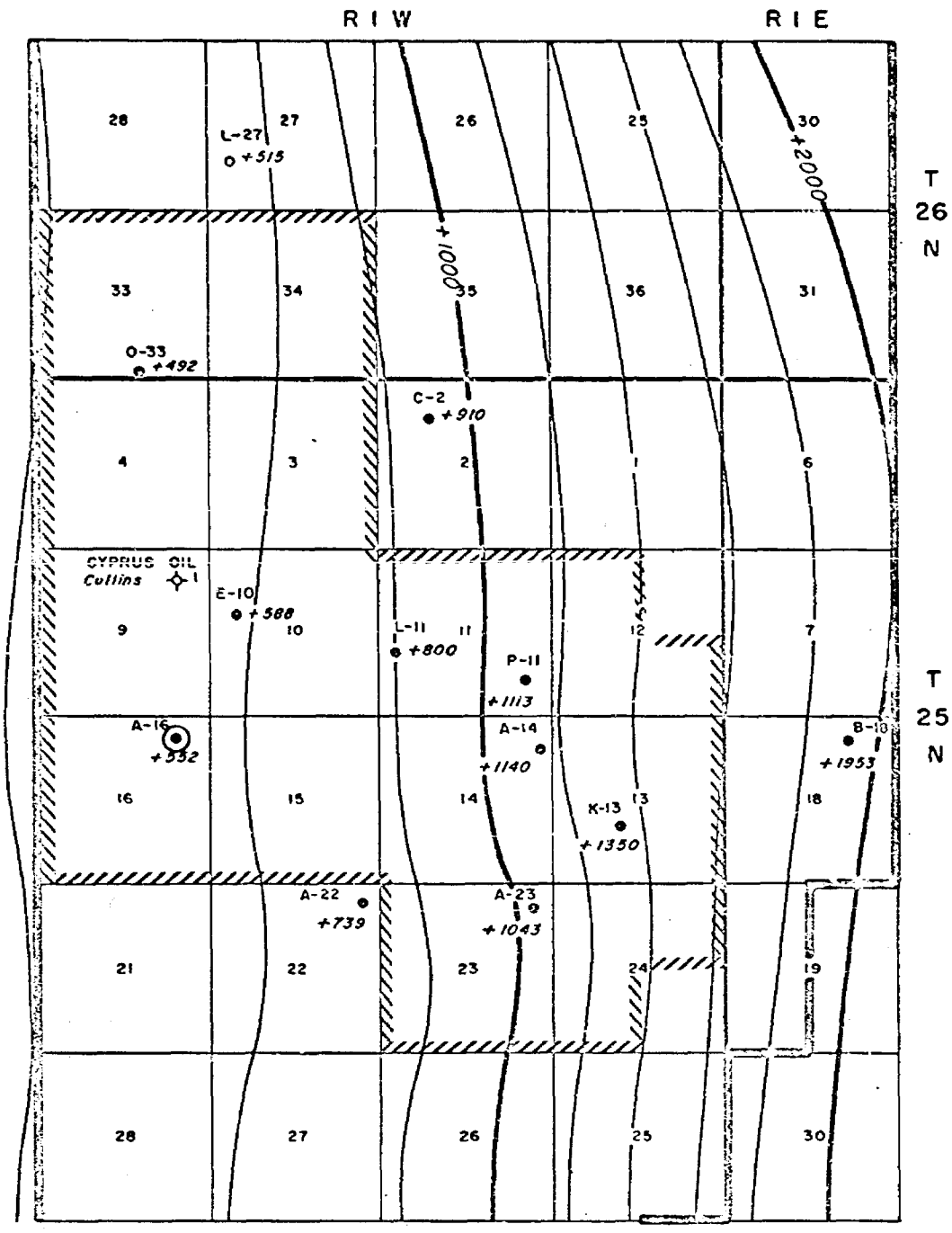
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # O-33

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

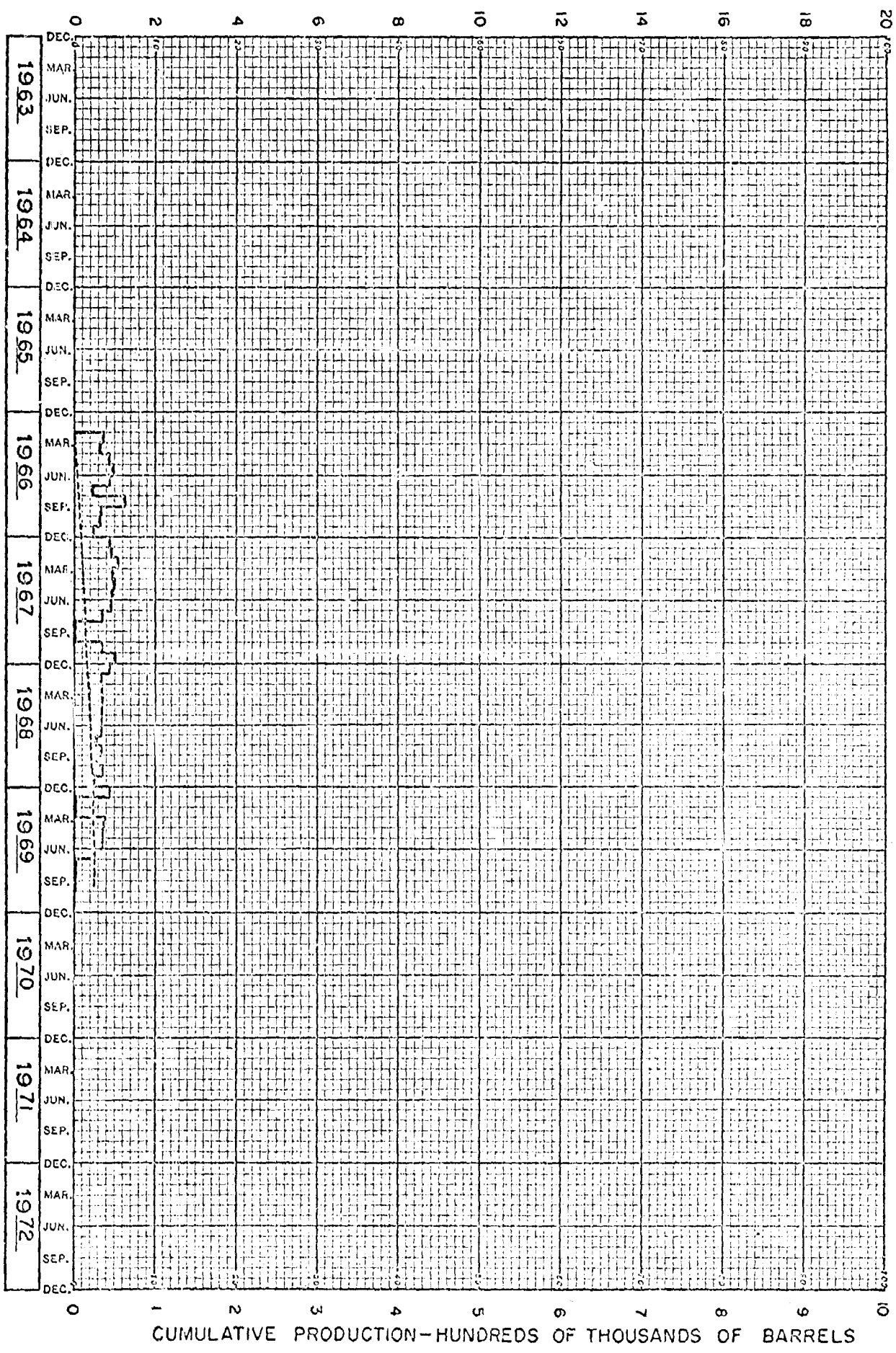
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C. I. 200'
NOVEMBER, 1969

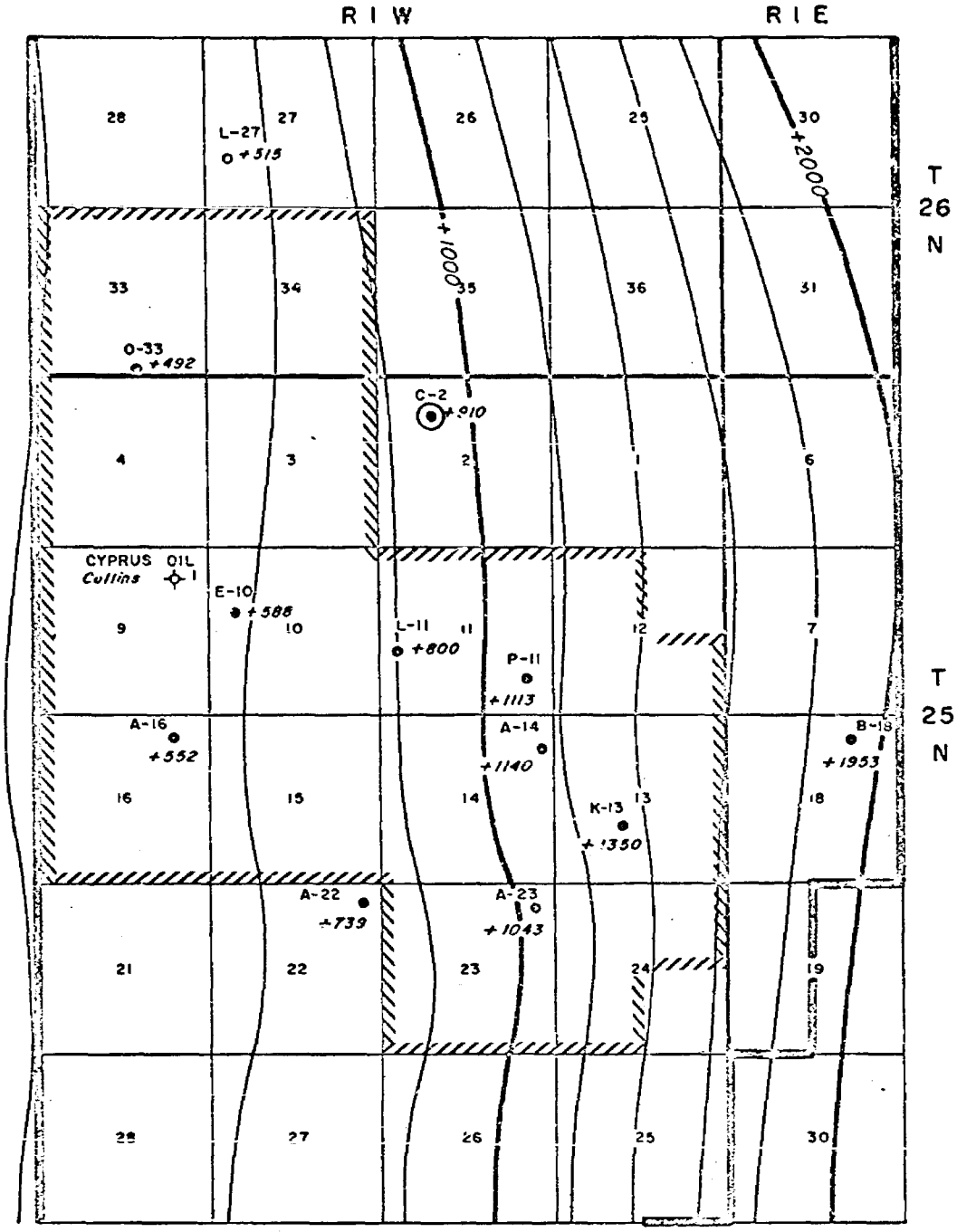
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-16

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

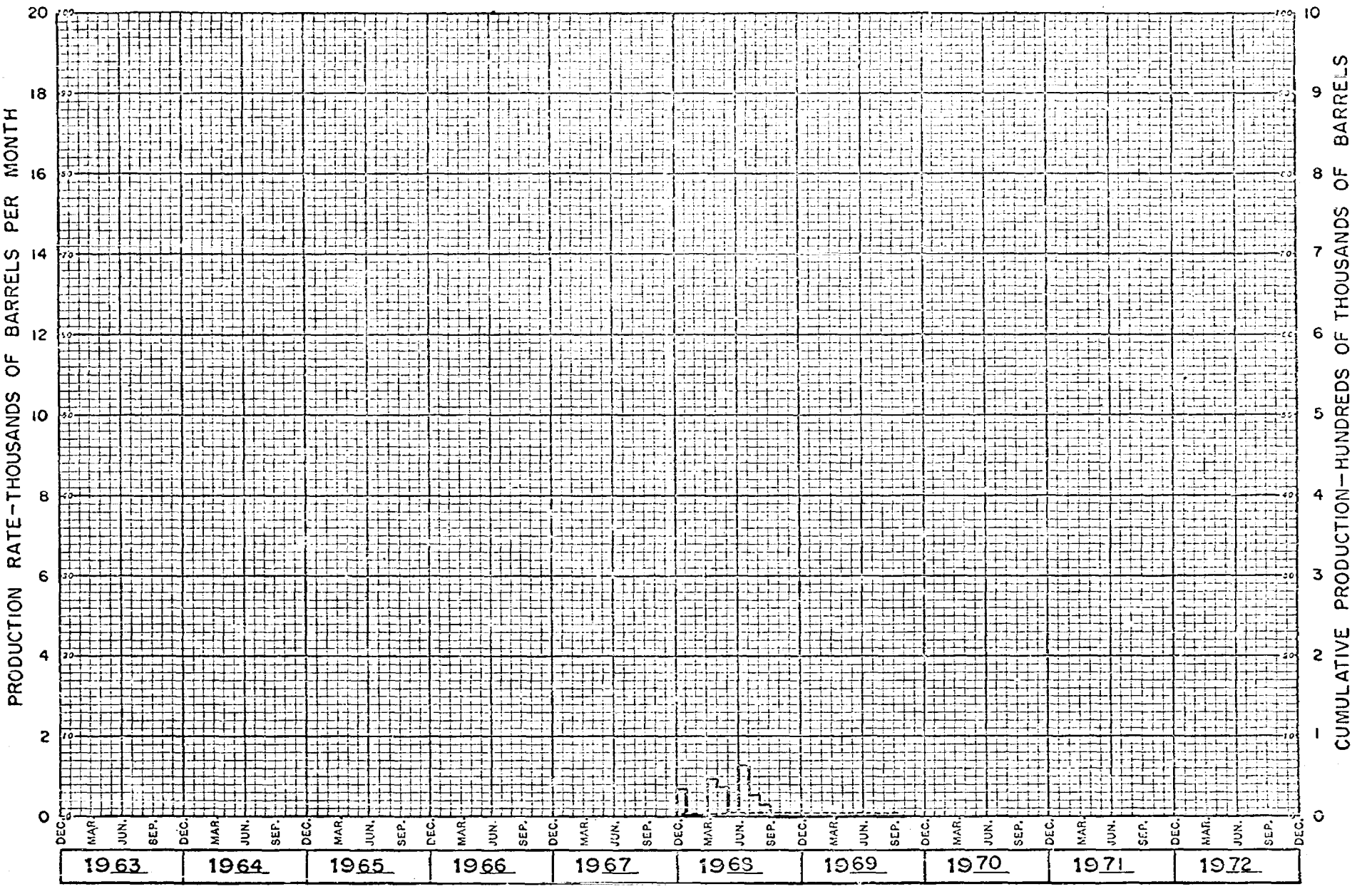
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

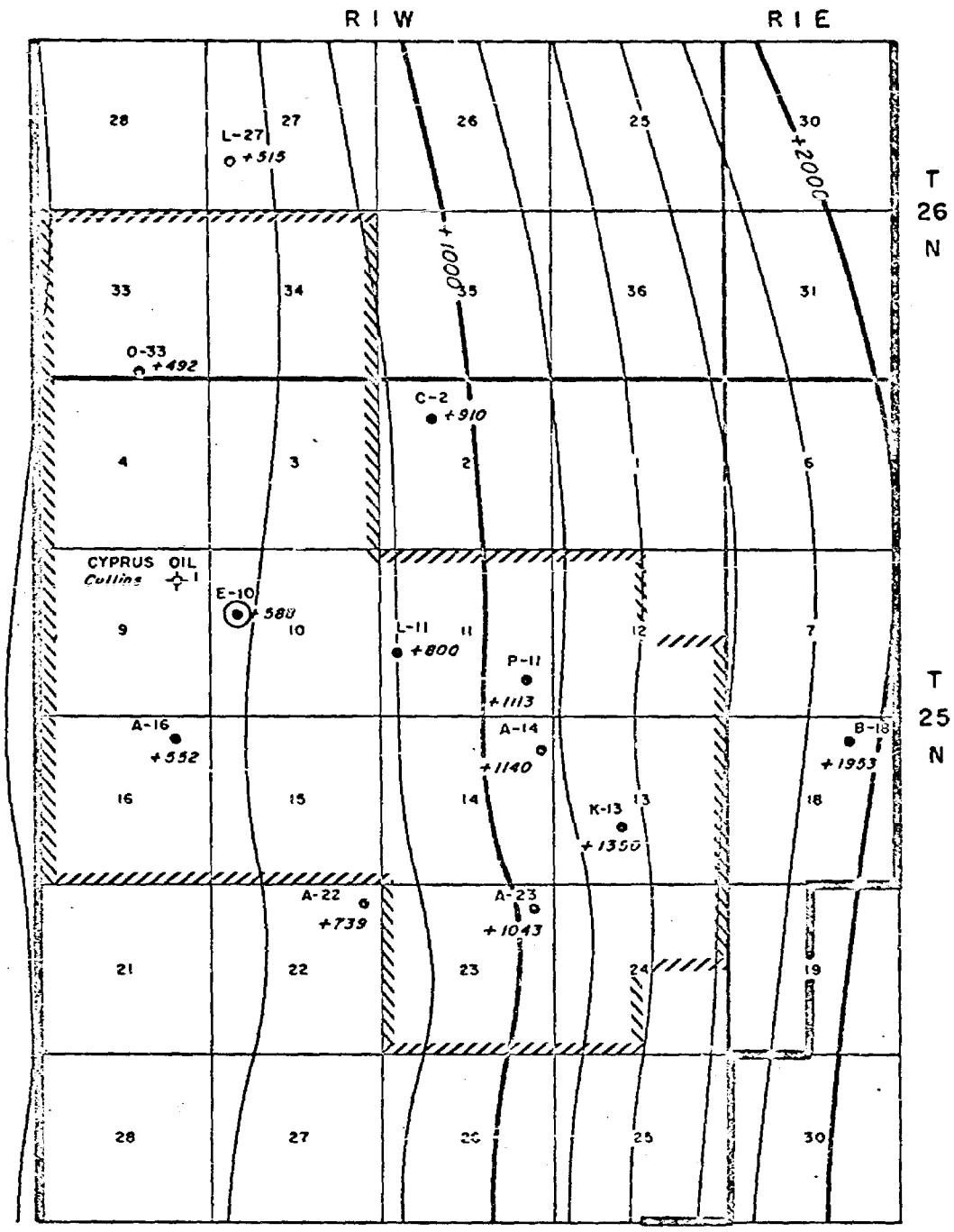
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT — # C-2

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

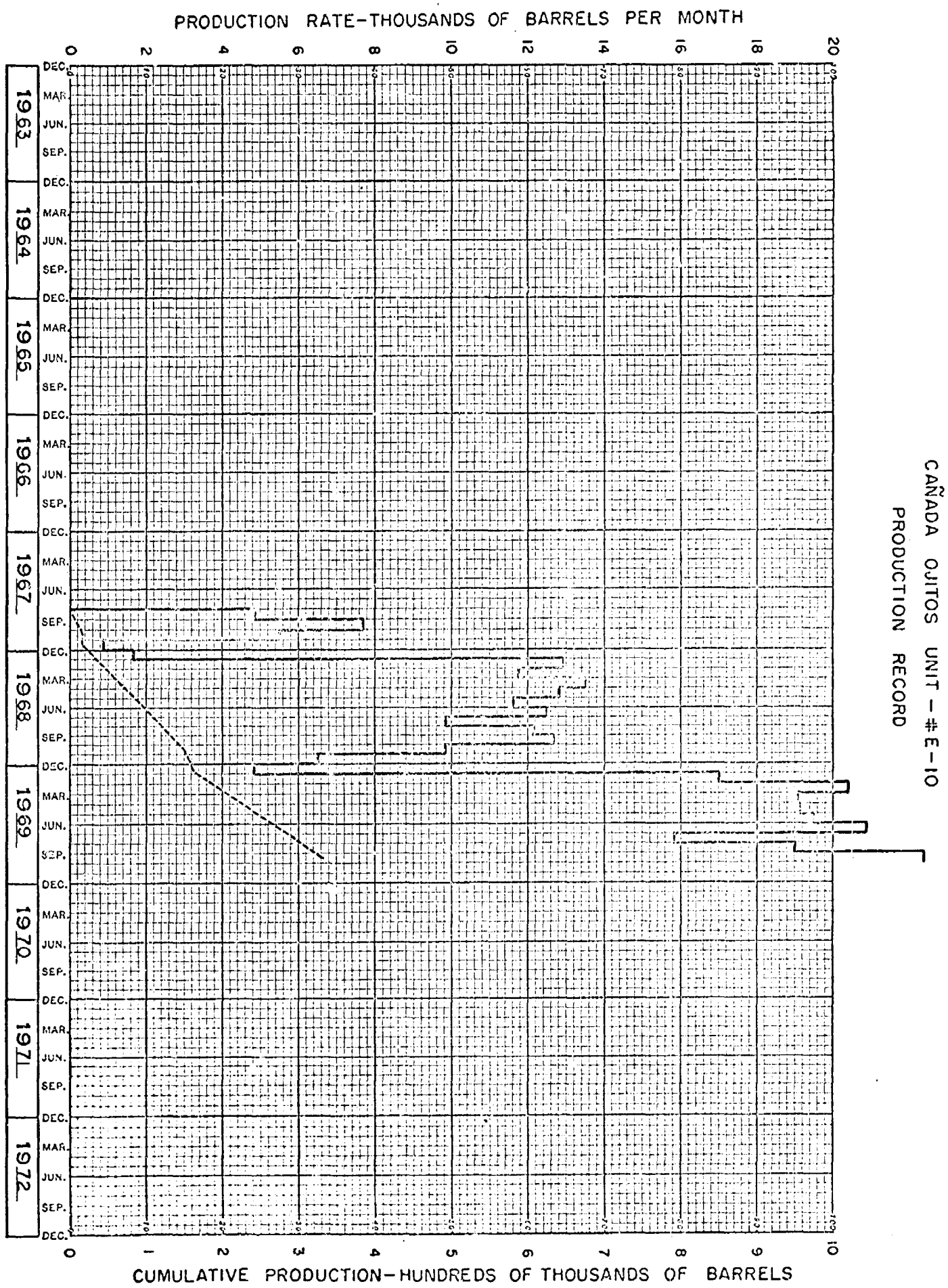
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

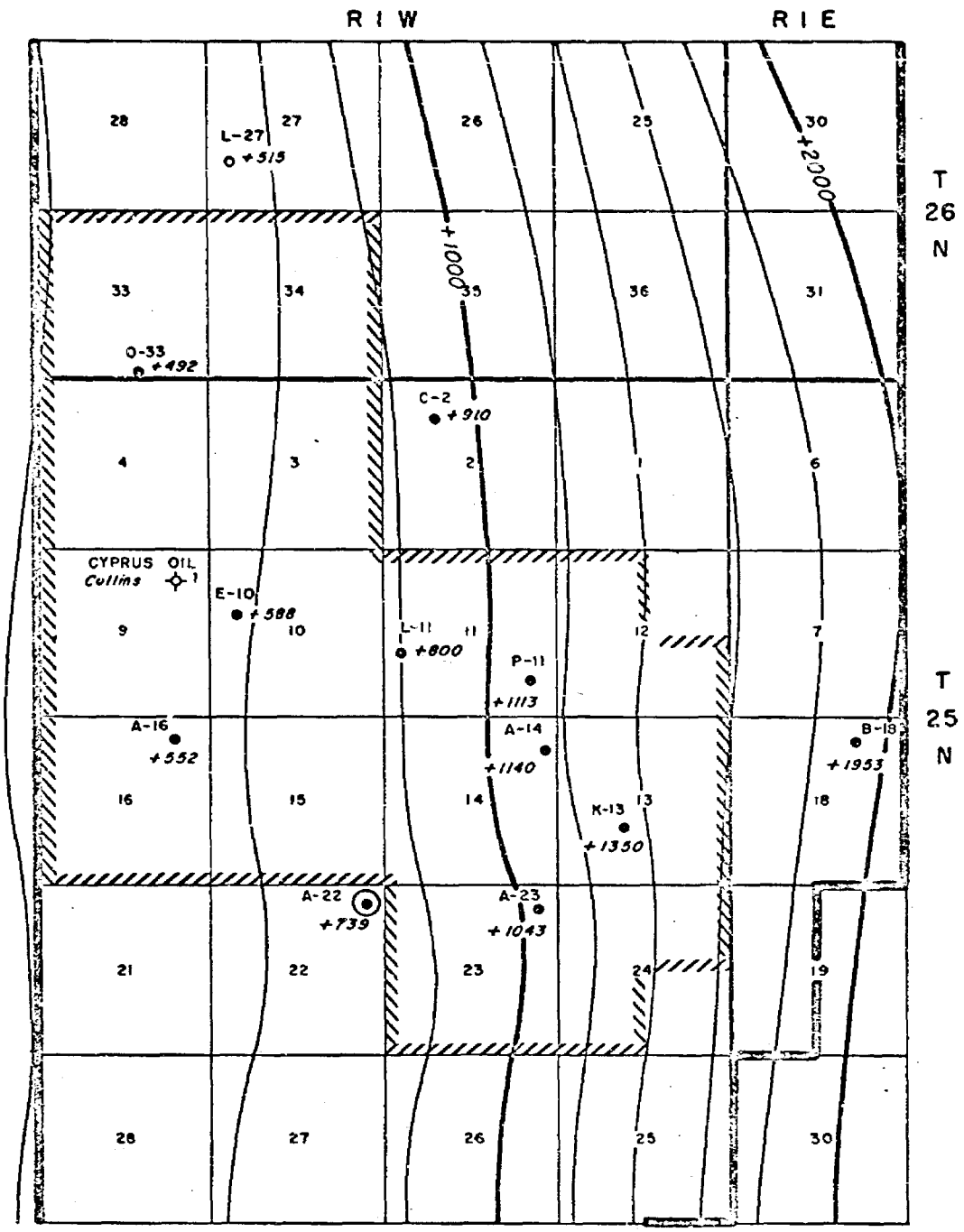
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT - #E-10

PRODUCTION RECORD





PLAT OF PART
OF
CAÑADA OJITOS UNIT

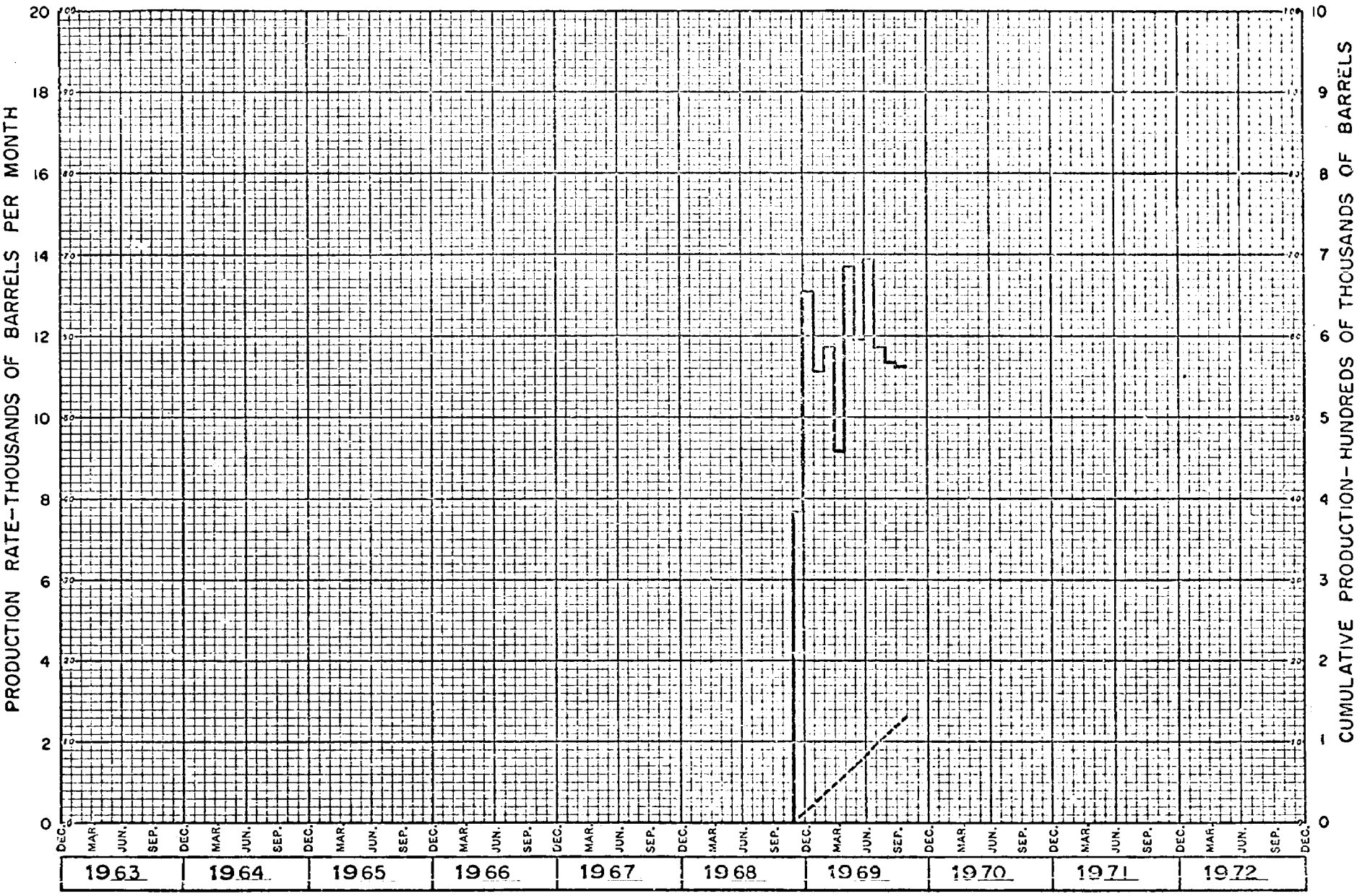
CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969

BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

CAÑADA OJITOS UNIT – # A-22

PRODUCTION RECORD



FIGURES

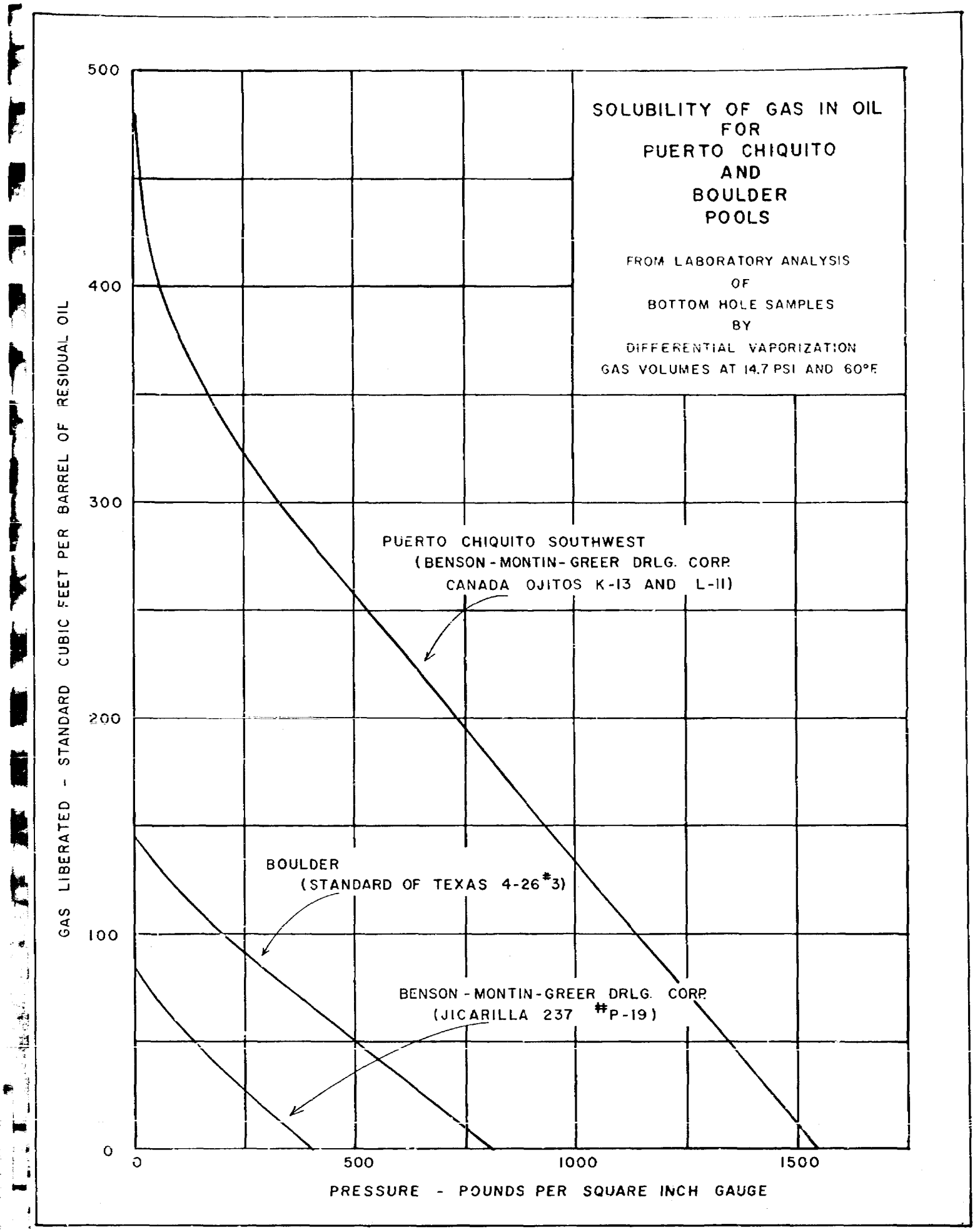

SOLUBILITY OF GAS IN OIL
FOR
PUERTO CHIQUITO
AND
BOULDER
POOLS
FROM LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
BY
DIFFERENTIAL VAPORIZATION
GAS VOLUMES AT 14.7 PSI AND 60°F
PUERTO CHIQUITO SOUTHWEST
(BENSON-MONTIN-GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
BENSON-MONTIN-GREER DRLG. CORP.
(JICARILLA 237 #P-19)
GAS LIBERATED - STANDARD CUBIC FEET PER BARREL OF RESIDUAL OIL
500
400
300
200
100
0
0
500
1000
1500
PRESSURE - POUNDS PER SQUARE INCH GAUGE

FIGURE NO. 1

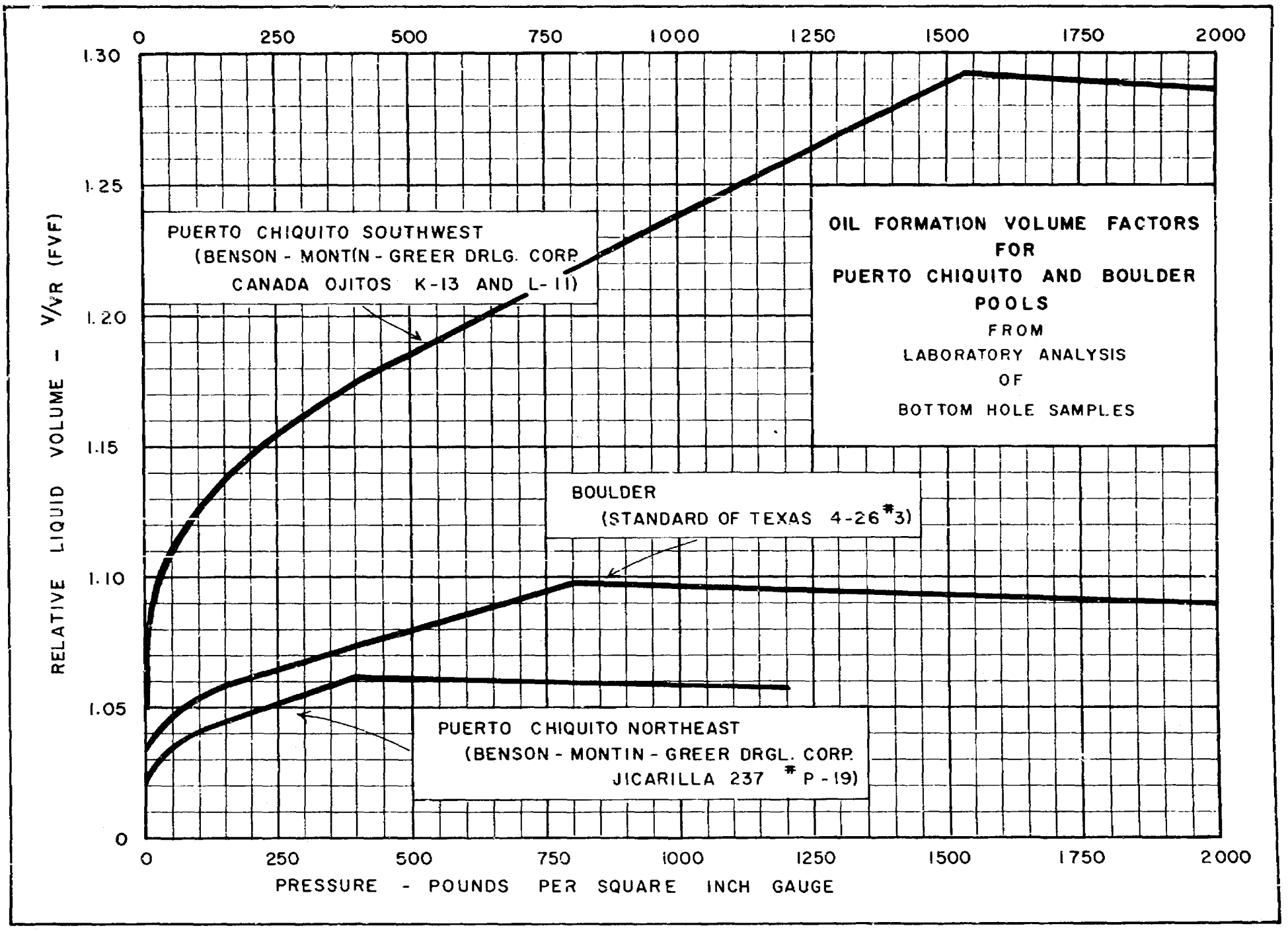

OIL FORMATION VOLUME FACTORS
FOR
PUERTO CHIQUITO AND BOULDER
POOLS
FROM
LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
PUERTO CHIQUITO SOUTHWEST
(BENSON - MONTIN - GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
PUERTO CHIQUITO NORTHEAST
(BENSON - MONTIN - GREER DRGL. CORP.
JICARILLA 237 # P-19)
RELATIVE LIQUID VOLUME - V/VR (FVF)
1.30
1.25
1.20
1.15
1.10
1.05
0
0
250
500
750
1000
1250
1500
1750
2000
PRESSURE - POUNDS PER SQUARE INCH GAUGE

FIGURE NO. 2

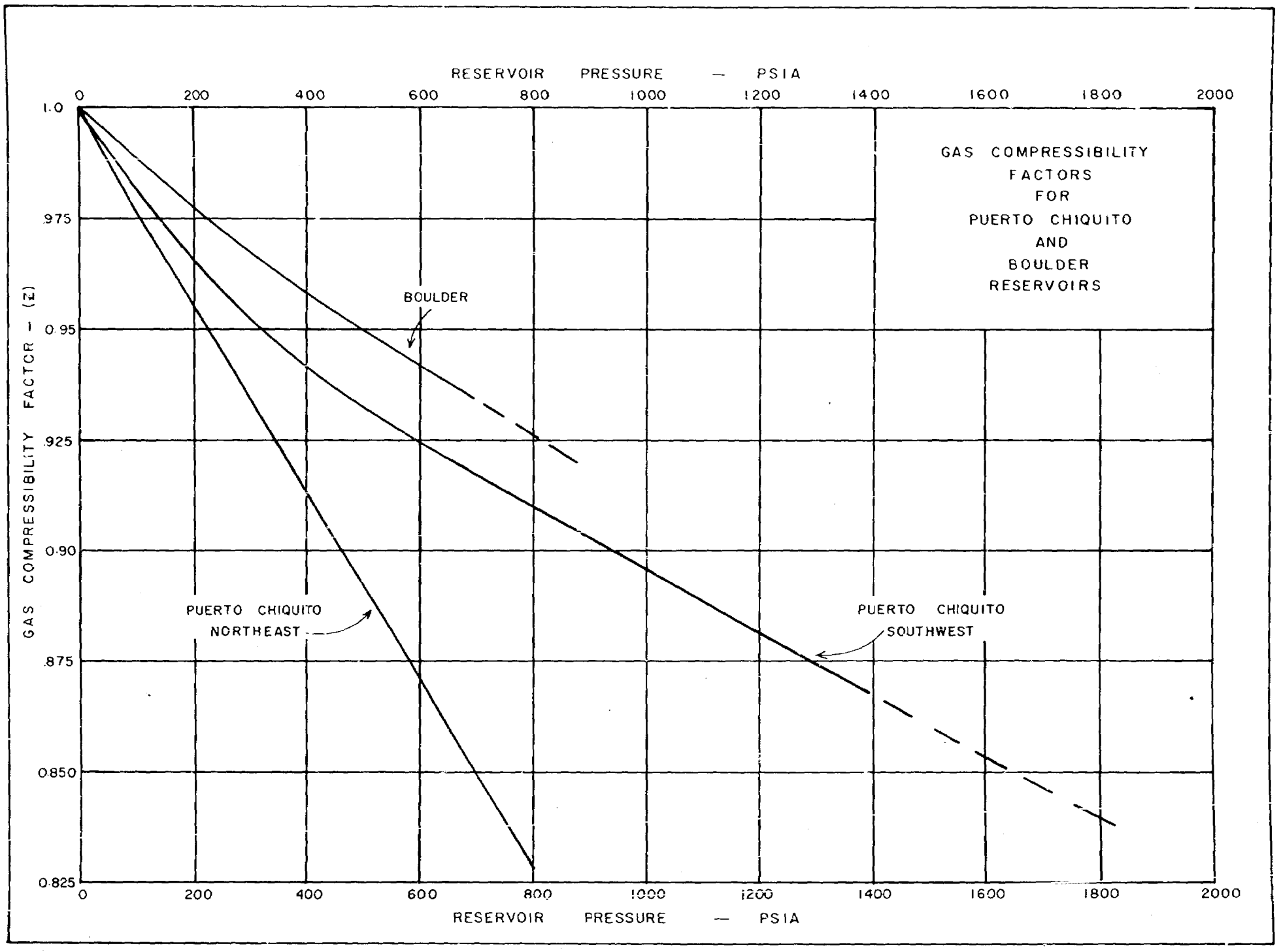

RESERVOIR PRESSURE — PSIA
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1.0
.975
0.95
.925
0.90
.875
0.850
0.825
GAS COMPRESSIBILITY FACTOR - (Z)
GAS COMPRESSIBILITY FACTORS FOR PUERTO CHIQUITO AND BOULDER RESERVOIRS
BOULDER
PUERTO CHIQUITO NORTHEAST
PUERTO CHIQUITO SOUTHWEST

FIGURE NO. 3

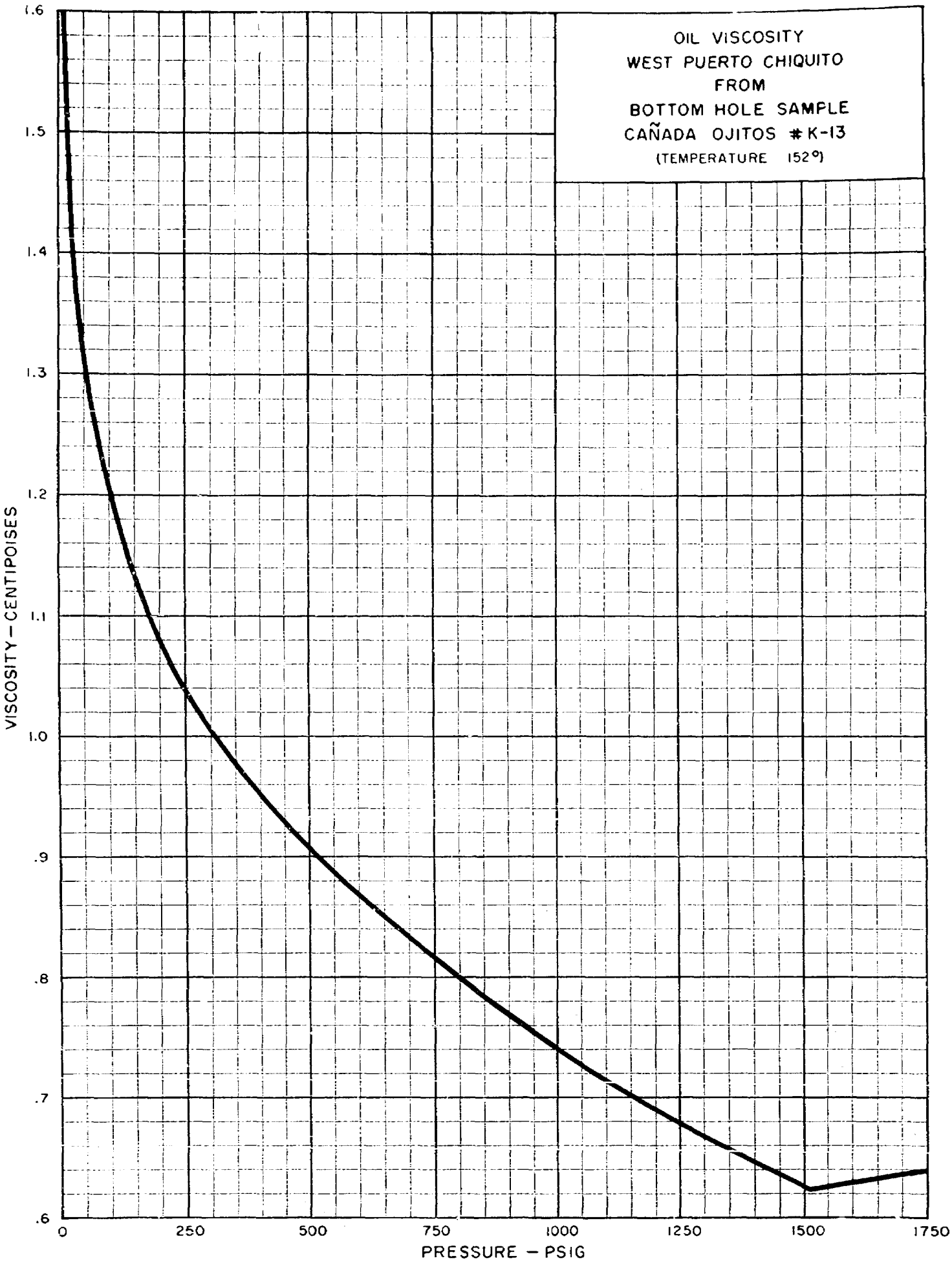

OIL VISCOSITY
WEST PUERTO CHIQUITO
FROM
BOTTOM HOLE SAMPLE
CAÑADA OJITOS # K-13
(TEMPERATURE 152°)
VISCOSITY — CENTIPOISES
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
0
250
500
750
1000
1250
1500
1750
PRESSURE — PSIG

FIGURE NO. 4

GRAVITY DRAINAGE RATES
WEST PUERTO CHIQUITO
FOR CONDITIONS OF:
OIL DENSITY 44.9#/cubic foot
GAS DENSITY 5.35#/cubic foot
OIL VISCOSITY .62 centipoises
FORMATION DIP 400 feet per mile

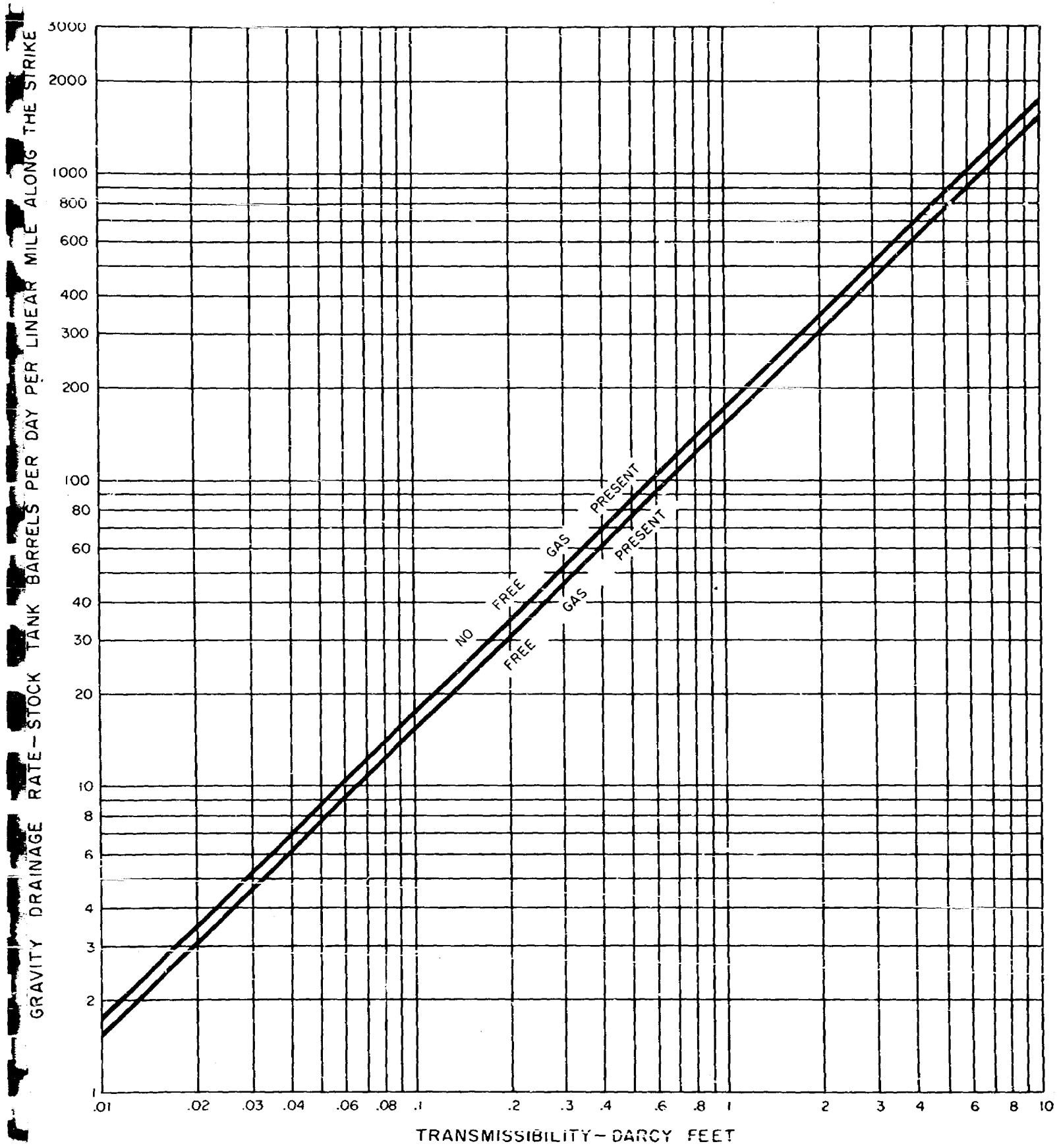


FIGURE NO. 5

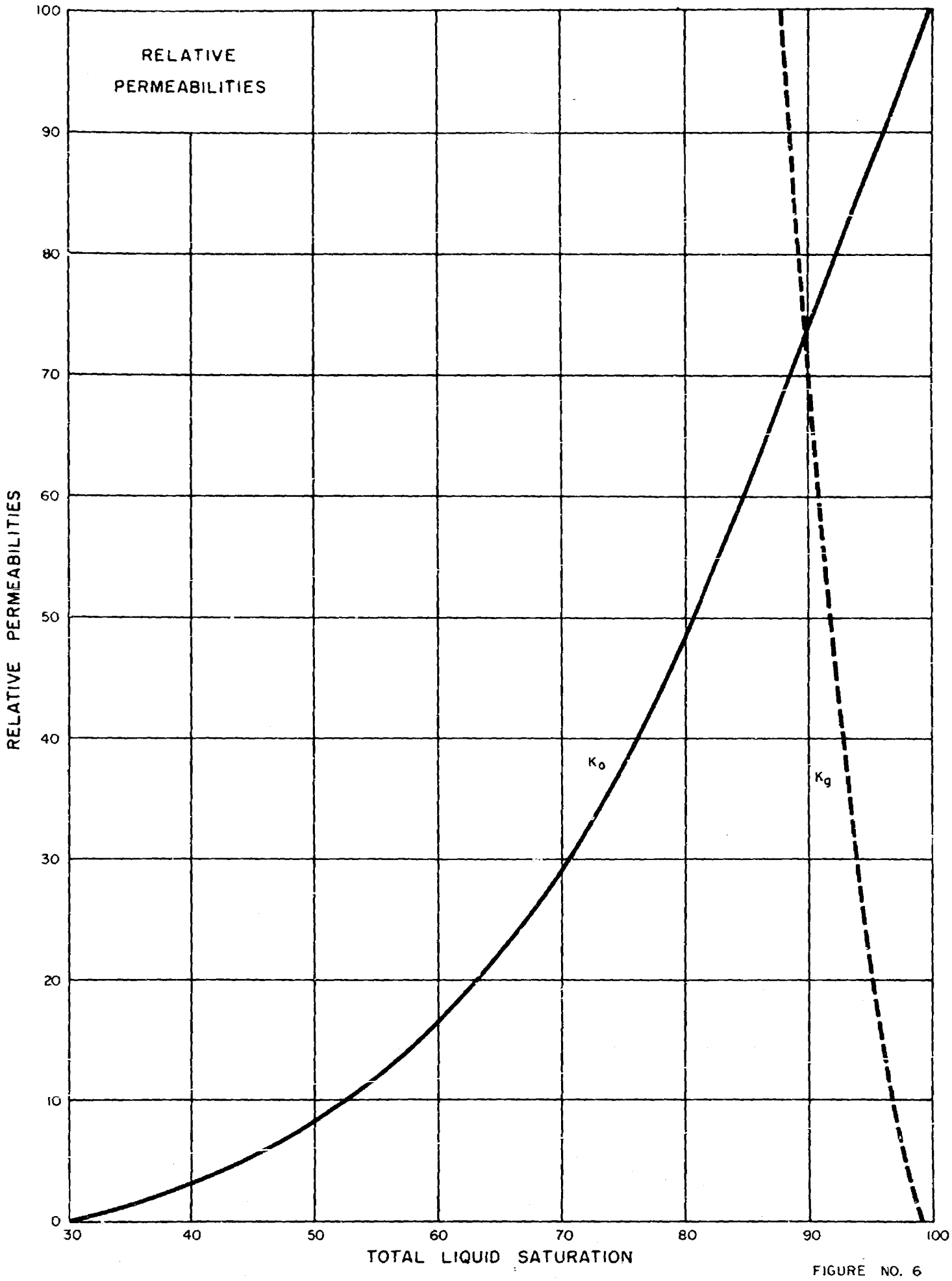

RELATIVE
PERMEABILITIES
RELATIVE PERMEABILITIES
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
TOTAL LIQUID SATURATION
K_o
K_g

FIGURE NO. 6

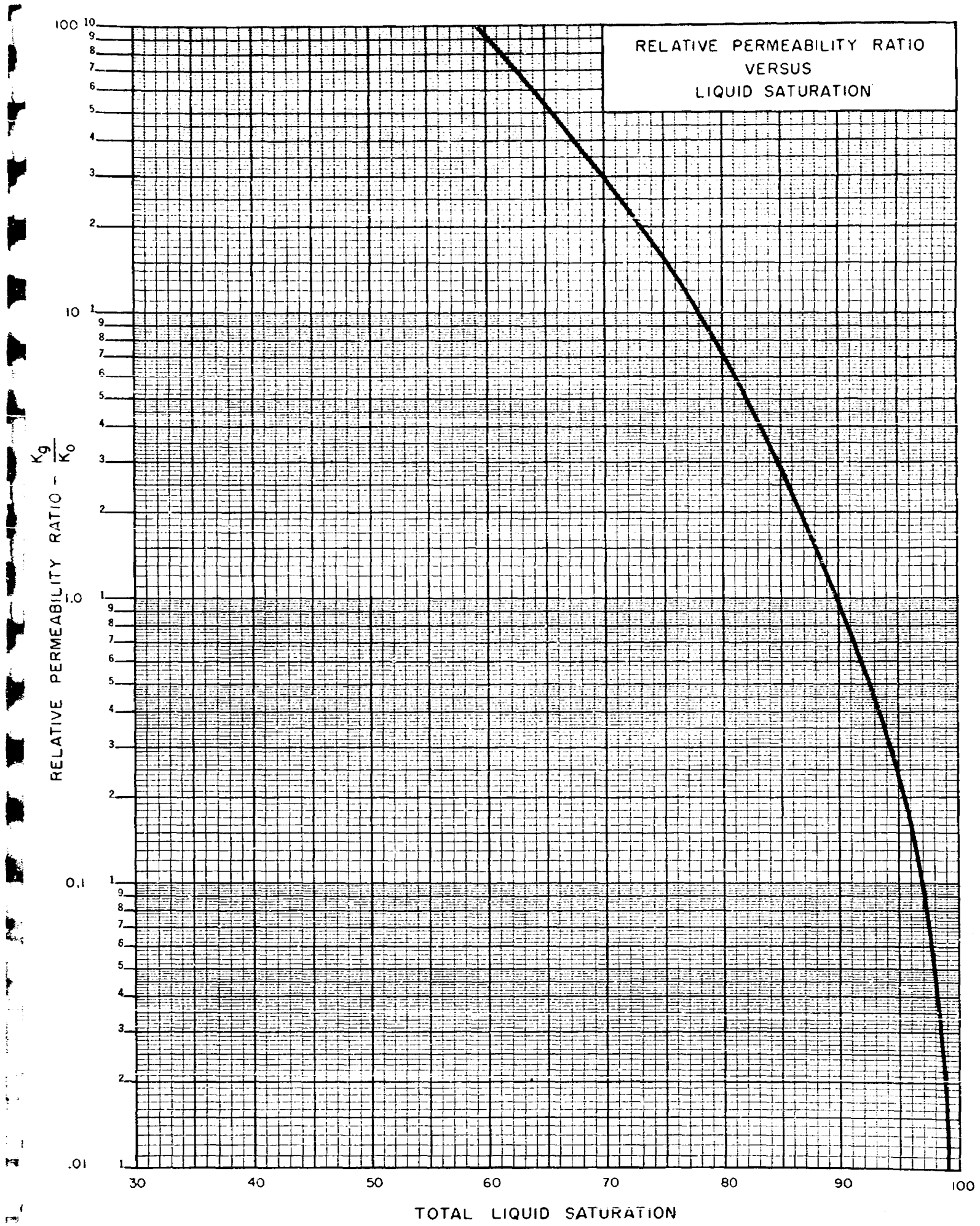

RELATIVE PERMEABILITY RATIO
VERSUS
LIQUID SATURATION
RELATIVE PERMEABILITY RATIO - $\frac{K_g}{K_o}$
100
10
1.0
0.1
.01
30
40
50
60
70
80
90
100
TOTAL LIQUID SATURATION

FIGURE NO. 7

SOLUTION GAS DRIVE
PRODUCTION HISTORY
CALCULATED FOR CONDITIONS OF
WEST PUERTO CHIQUITO
PVT DATA
AND
K_g/K_o ESTIMATED FROM LABORATORY
DATA FOR FRACTURED FORMATIONS

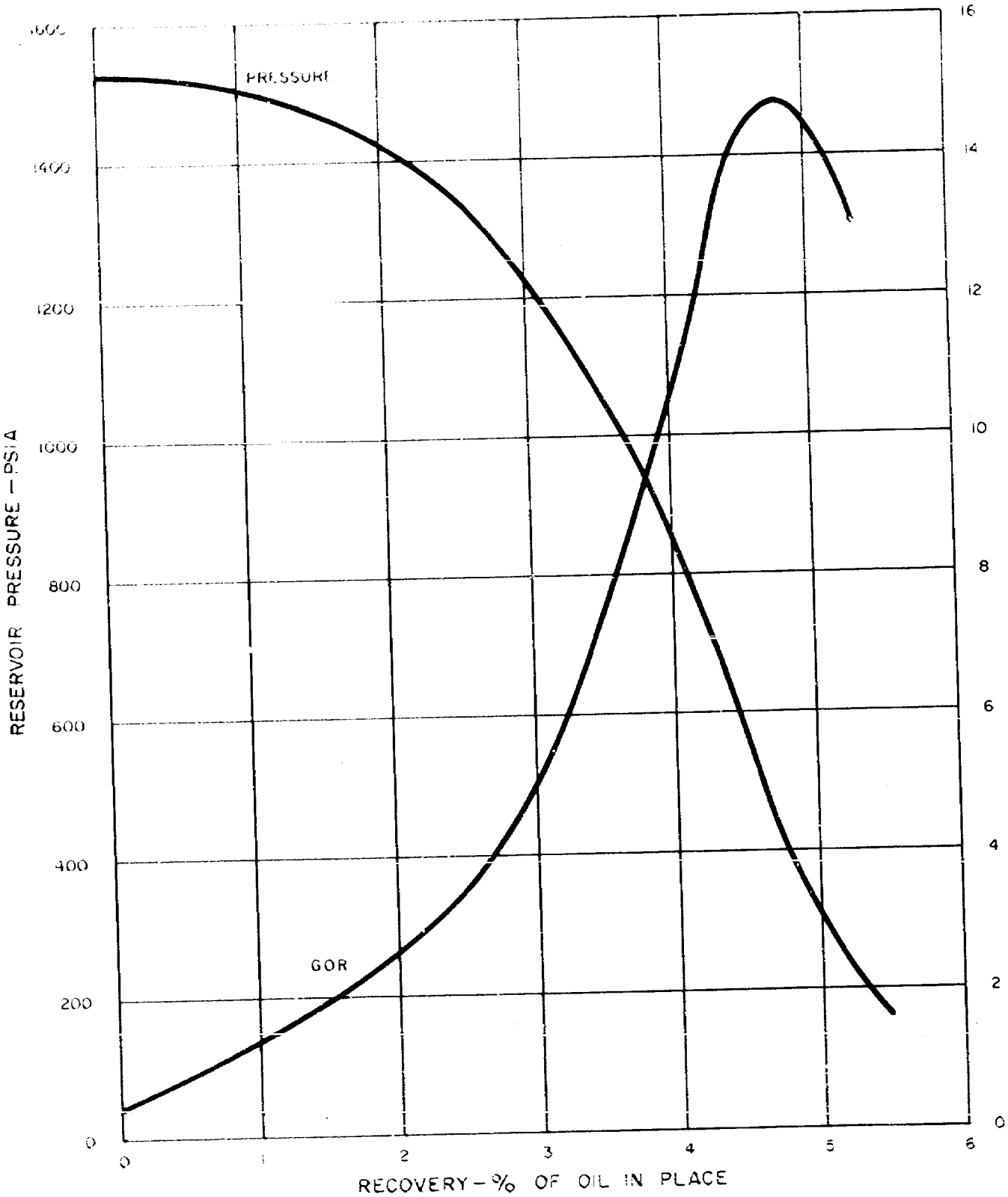


FIGURE NO 8

GRAVITY DRAINAGE
PRODUCTION HISTORY

CALCULATED FOR CONDITIONS OF:
WEST PUERTO CHIQUITO PVT DATA
ESTIMATED RELATIVE K_o
Complete Gravitational Segregation
Assumed

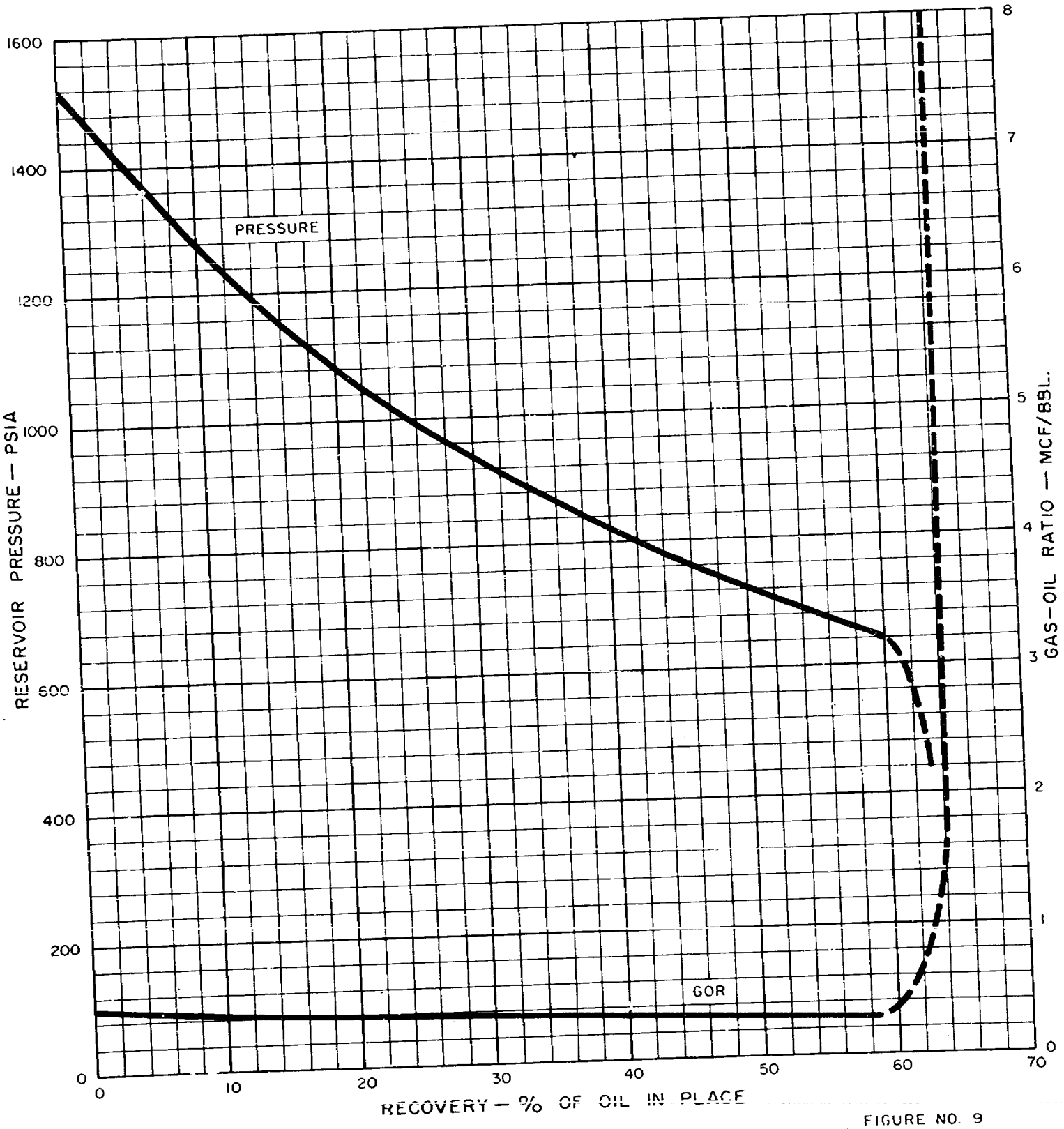


FIGURE NO. 9

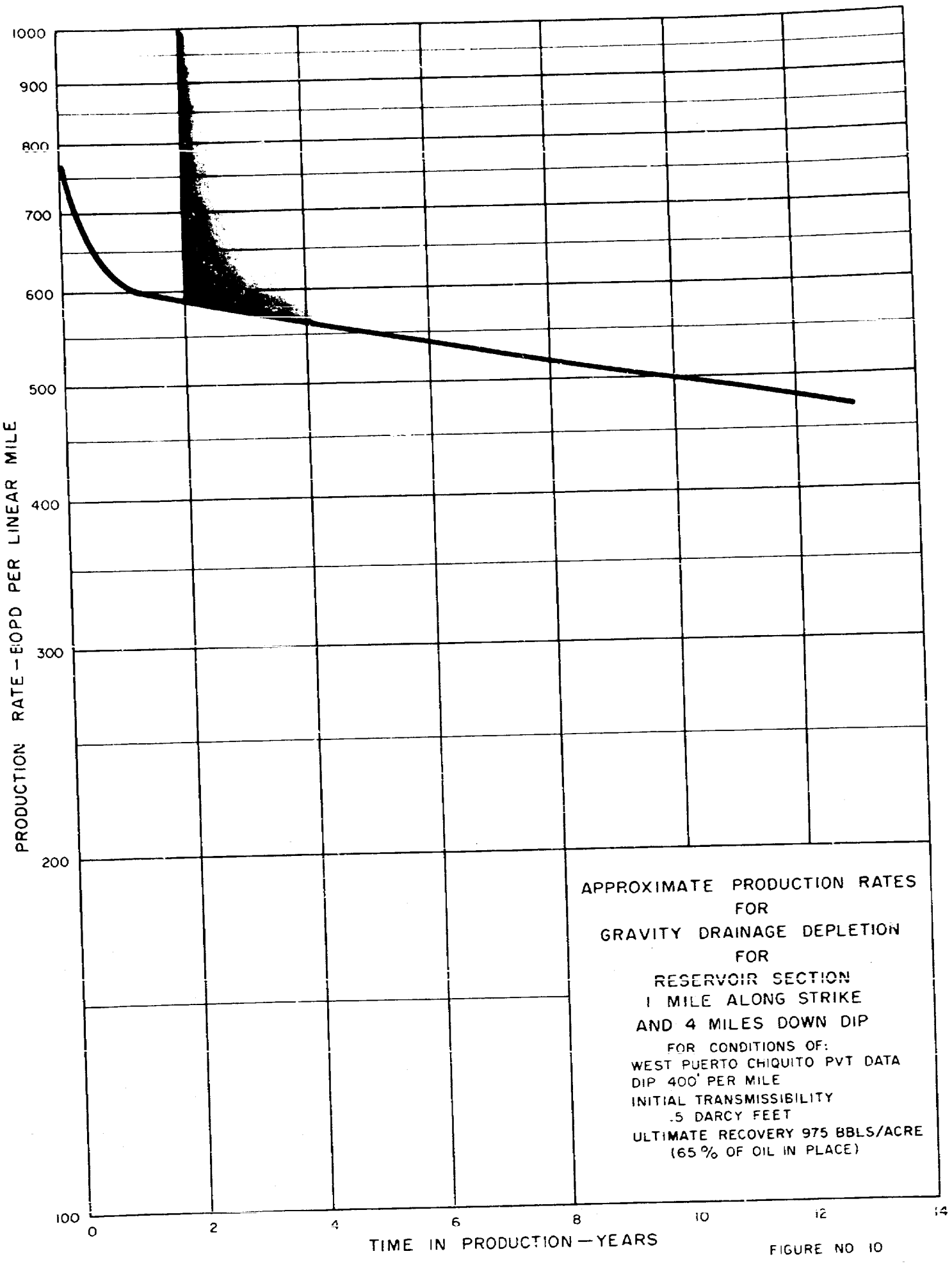
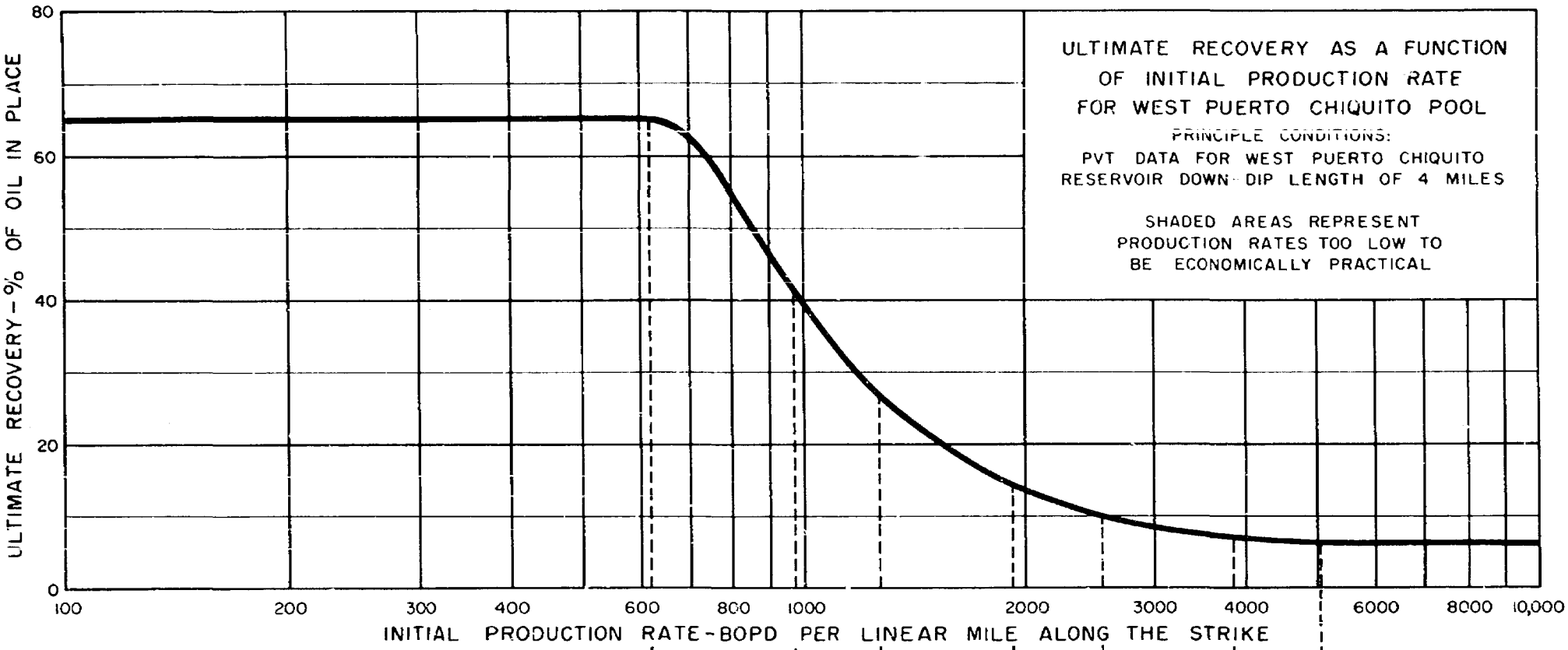

PRODUCTION RATE – BOPD PER LINEAR MILE
1000
900
800
700
600
500
400
300
200
100
0
2
4
6
8
10
12
14
TIME IN PRODUCTION – YEARS
APPROXIMATE PRODUCTION RATES
FOR
GRAVITY DRAINAGE DEPLETION
FOR
RESERVOIR SECTION
1 MILE ALONG STRIKE
AND 4 MILES DOWN DIP
FOR CONDITIONS OF:
WEST PUERTO CHIQUITO PVT DATA
DIP 400' PER MILE
INITIAL TRANSMISSIBILITY
.5 DARCY FEET
ULTIMATE RECOVERY 975 BBLS/ACRE
(65% OF OIL IN PLACE)

FIGURE NO 10



AVERAGE PRODUCTION RATE BOPD FOR	640 BOPD TOTAL	960 BOPD TOTAL	1280 BOPD TOTAL	1920 BOPD TOTAL	2560 BOPD TOTAL	3840 BOPD TOTAL	5180 BOPD TOTAL
40 ACRES/WELL (64 WELLS/LINEAR MILE ALONG STRIKE)	10	15	20	30	40	60	80
80 " " (32) " " " " " "	20	30	40	60	80	120	160
160 " " (16) " " " " " "	40	60	80	120	160	240	320
320 " " (8) " " " " " "	80	120	160	240	320	480	640
640 " " (4) " " " " " "	160	240	320	480	640	960	1280
1280 " " (2) " " " " " "	320	480	640	960	1280	1920	2560
2560 " " (1) " " " " " "	640	960	1280	1920	2560	3840	5180

FIGURE NO. 11

INCREASE IN RECOVERY
BY DEPLETION AT HIGH PRESSURE
AS COMPARED TO
DEPLETION AT LOW PRESSURE
FOR VARIOUS FINAL OIL SATURATIONS

CONDITIONS: HIGH PRESSURE 1500#
F.V.F. = 1.29
LOW PRESSURE 50#
F.V.F. = 1.11
CONNATE WATER SATURATION = 10%

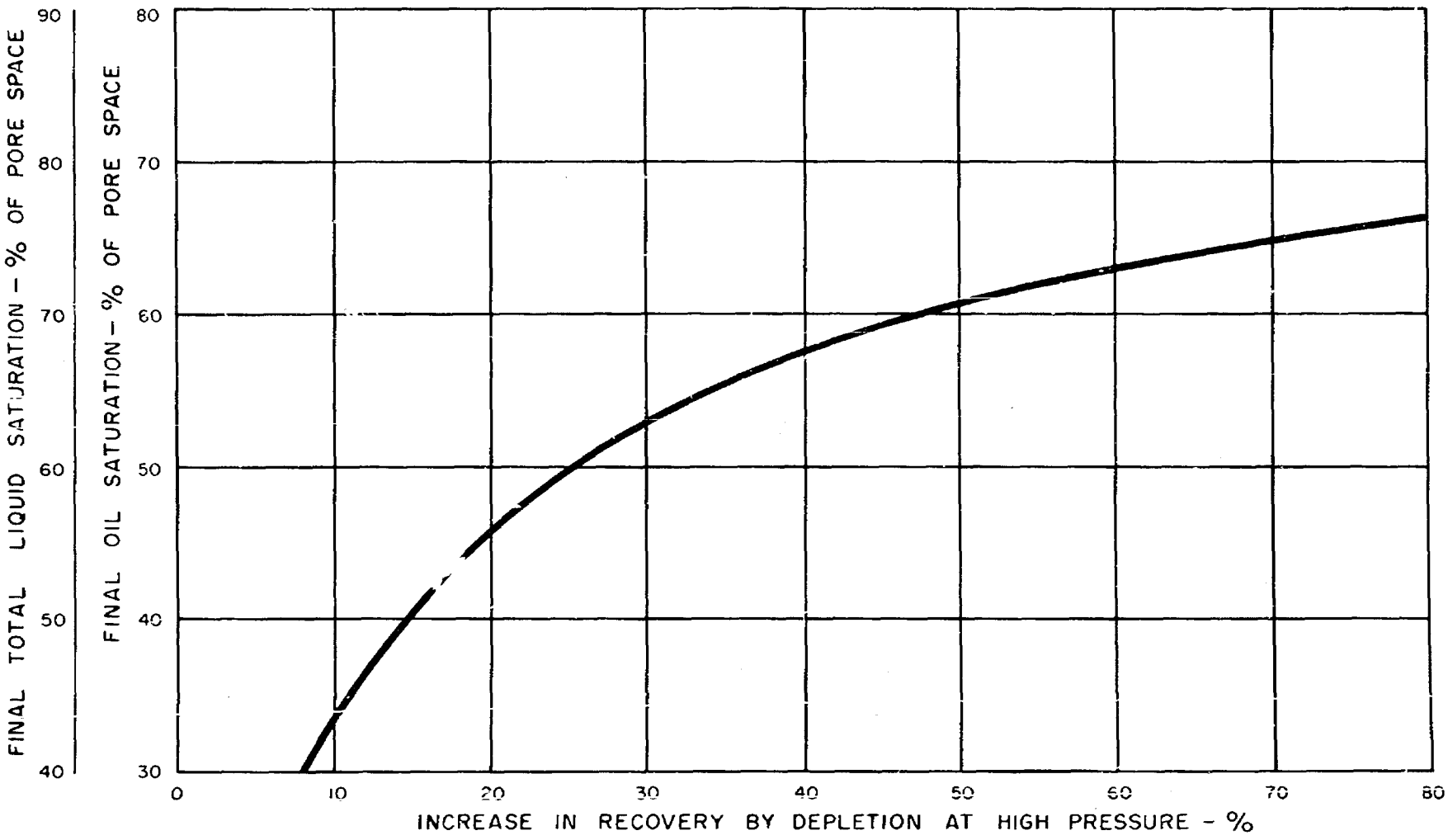


FIGURE NO. 12

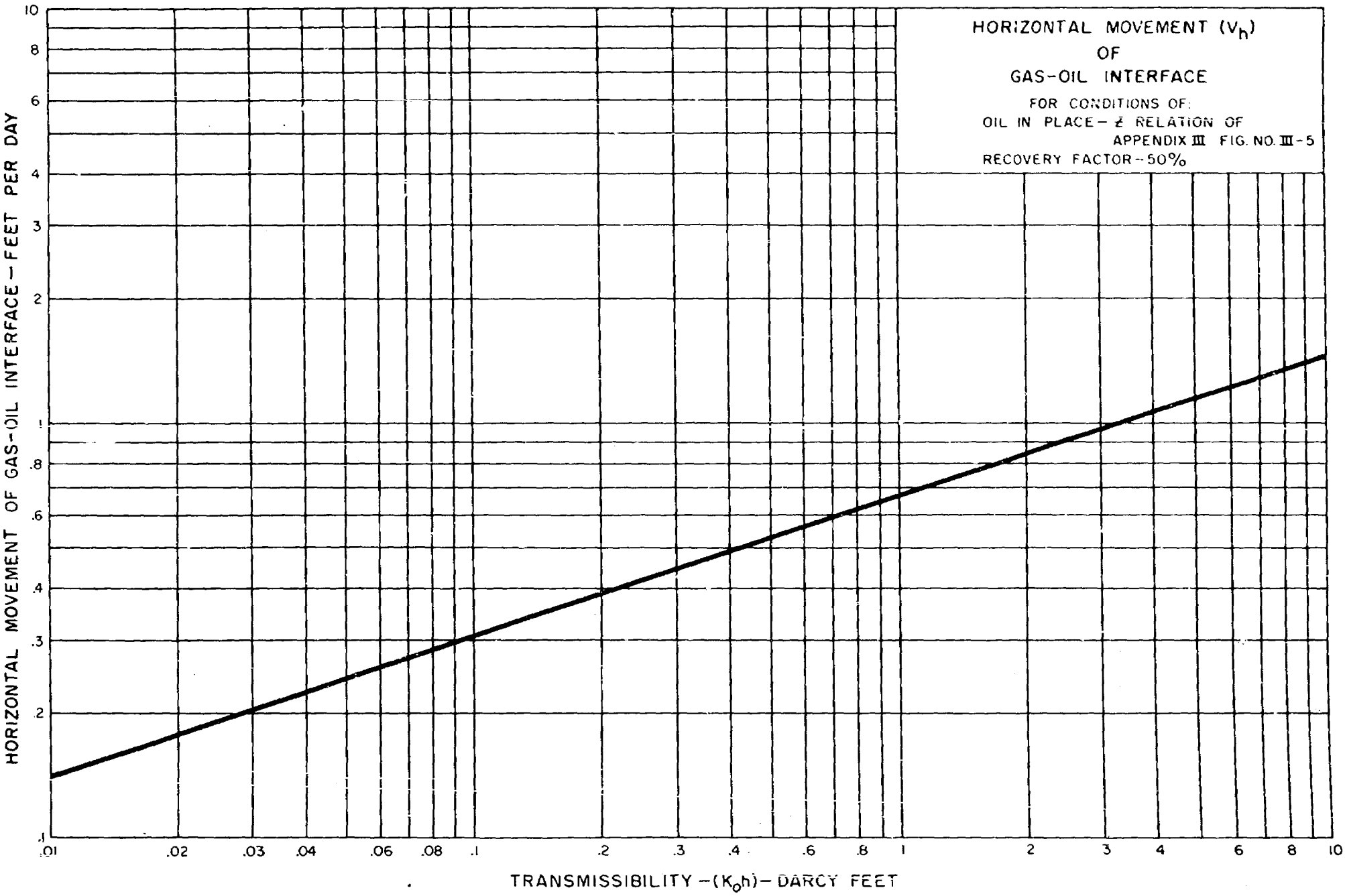

HORIZONTAL MOVEMENT (V_h)
OF
GAS-OIL INTERFACE
FOR CONDITIONS OF:
OIL IN PLACE – ∑ RELATION OF
APPENDIX III FIG. NO. III-5
RECOVERY FACTOR – 50%
HORIZONTAL MOVEMENT OF GAS-OIL INTERFACE – FEET PER DAY
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
.01
.02
.03
.04
.06
.08
.1
.2
.3
.4
.6
.8
1
2
3
4
6
8
10
TRANSMISSIBILITY – (K_oh) – DARCY FEET

FIGURE NO. 13

RELATION OF INJECTED GAS
TO
RESERVOIR DISLACEMENT VOLUME
FOR CONDITIONS OF:
RESERVOIR TEMPERATURE 150°
Z FACTORS OF WEST PUERTO CHIQUITO GAS

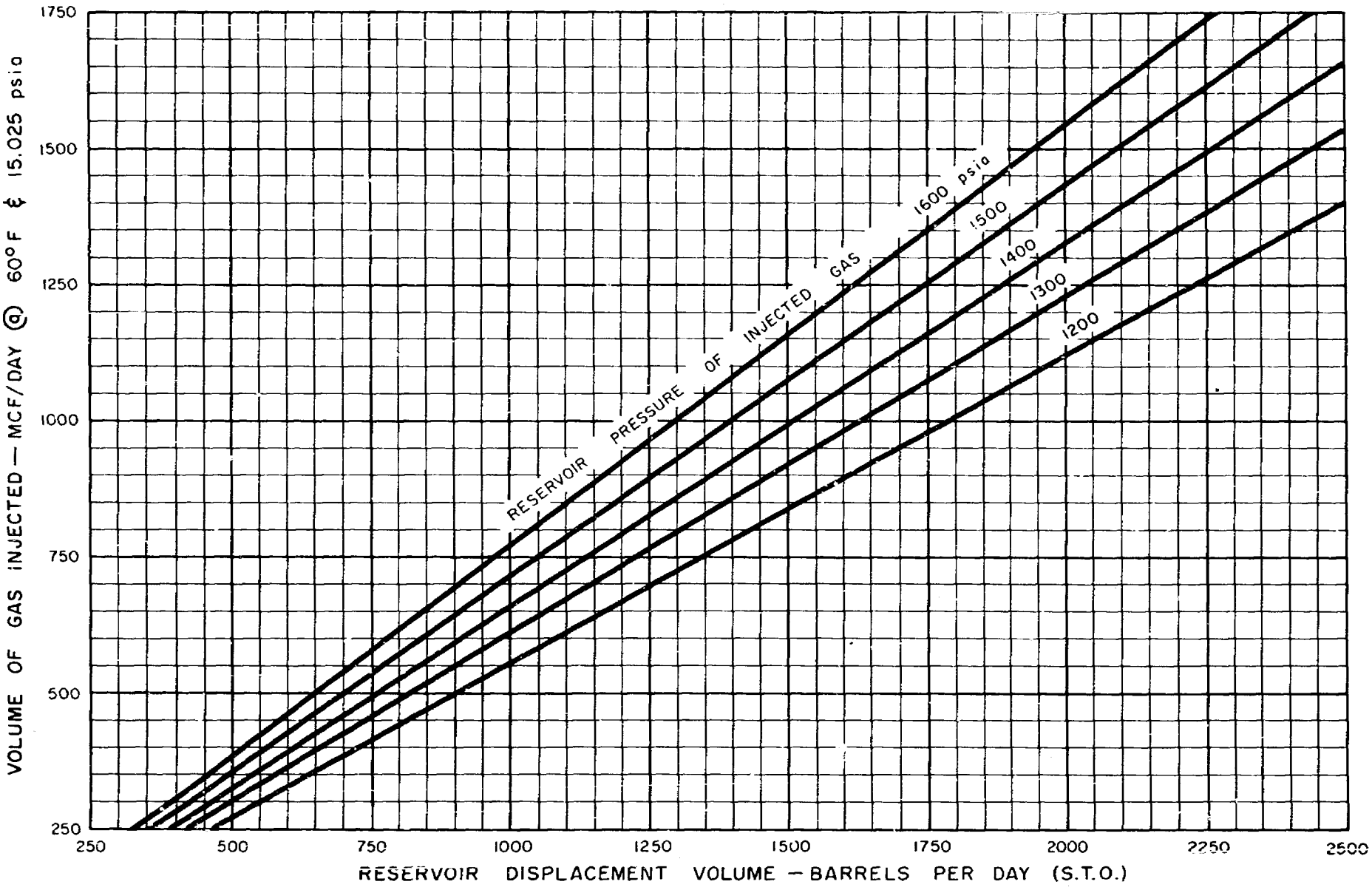


FIGURE NO. 14

APPENDIX I

APPENDIX I

PART A - INDIVIDUAL WELL TRANSMISSIBILITIES

Tests to determine individual well transmissibilities are identified below and the results are summarized as follows:

1. Cañada Ojitos Unit L-11: This is a production (pressure draw-down) test conducted September 24, 1965. Results of this test are shown on the graph at the end of this appendix, Figure No. I-1. This shows a transmissibility of .45 darcy feet, when analyzed in the conventional manner, as indicated by the calculations on the graph.

2. Cañada Ojitos Unit A-23: This is a pressure build-up test conducted May 14 to 20, 1965. Results of this test are shown in this appendix on Figure No. I-2. This test shows two distinctly different slopes. The first shows transmissibility of .025 darcy feet and the second a transmissibility of .206 darcy feet. The second slope is believed to indicate an area which more or less surrounds the first area of low transmissibility.

3. Cañada Ojitos Unit K-13: This is a pressure fall-off test conducted on the injection well K-13 on October 16, 1969, approximately 14 months after the well first went on injection. The calculated transmissibility, as shown on Figure I-3, of .0182 darcy feet results from permeability to gas. The oil saturation of the local area represented by this test is not known. The area was probably not 100 percent gas saturated at the time of the test. Accordingly initial permeability to oil when the area was completely liquid saturated probably was a little higher - perhaps .025 darcy feet.

4. Cañada Ojitos Unit E-10: A production (pressure draw-down) test was conducted on this well December 6 and 7, 1967. Data from this test were used to construct the graph at the end of this appendix, Figure I-4, which indicates a transmissibility of 1.5 darcy feet.

5. Cañada Ojitos Unit P-11: This is a pressure build-up test measured on this well in February, March and April of 1964. The data from this test is shown on the graph at the end of this appendix, Figure I-5. This indicates a transmissibility of 1 darcy feet.

Details of the tests, 1 to 5 above, are not included here. It is believed that the accuracies of the data shown on each of the graphs, Figures I-1 through I-5, are adequate for the analyses for which the data are used. In this regard the following information is offered respecting each test, along with remarks concerning suitability of the reservoir and conditioning of the wells for the tests.

Figure I-1: This test was made in conjunction with an interference test in which all of the wells in the reservoir were shut in for approximately two months and one well (P-11) put on production and produced until reservoir conditions approached those of steady state, at which time the subject well (L-11) was put on production. This well was produced for three days the first week in September, and then shut in again until the production test commenced September 24, 1965. Producing bottom hole pressures were determined by measuring the surface casing pressure and adding the calculated pressure differential from surface to the pay zone. During the test the casing was shut in and all gas and oil were produced through the bottom hole pump and up the tubing. The static

bottom hole pressure was known within one or two pounds at the time the test started, and from this information and the surface casing pressure it was possible to calculate the level of the oil in the casing above the pump at the time the test started. As the casing pressure dropped with commencement of production, the gas in the casing expanded, and from this expansion at any one time it was possible to calculate the depth of the fluid level as it dropped down the hole. Knowing the top of the fluid level, along with the pressure-volume relation of the oil with its dissolved gas (from fluid sample analysis) it was possible to calculate the working bottom hole pressure at the pay zone. Graph showing this pressure differential from surface casing pressure to the pay depth of 6,660 feet for given fluid levels is shown at the end of this appendix, Figure No. I-11. After the well has produced for some time and the fluid level has dropped to the pump, it will stabilize at approximately this position. Working bottom hole pressures determined after the fluid level has reached the pump are of course not quite as accurate as the ones calculated as described above. Such pressures are useful, however, in determining approximately the working bottom hole pressure over a period of time, and to be indicative of pressure changes and degree of stabilization. Such a method was used (bottom line of Figure I-11) to determine the stabilization of the subject well during the interference test in which the A-14 was an observation well. This test and data were recorded at the 1966 spacing hearing. As determined from these pressures measured over a period of several weeks, it is apparent that the well essentially reached stabilization, as far as the relatively tight area of .45 darcy feet around the well is concerned,

by the end of .5 days (pressure 1,490 pounds shown on Figure I-1). The change in slope of the pressure decline versus time on Figure I-1 at about 1,520 pounds could be the result either of boundary conditions leading to stabilization in .5 days, or partially due to the high compressibility of the oil below bubble point (1,520 pounds) pressures. It is doubtful that this would be a significant factor, however, as the pressure in the formation immediately outside the well's "effective well bore radius" would be substantially higher, and accordingly the pressures of the oil which would control the measured pressures of the effective well bore radius would be at levels higher than the bubble point, and accordingly would have the normal under-saturated compressibility. Therefore, except for the influence of the rather large effective well bore radius, which forms a part of the geometry of this well's immediate reservoir area (and as more fully discussed in Appendix II herein) the transmissibility of .45 darcy feet as indicated on Figure I-1 is considered quite accurate.

Figure I-2: This test was conducted within a month after the well was completed. Frac oil was recovered April 27 and the well produced for a few days at rates approximating 100 barrels per day. The well was shut in May 4 to May 11 and then produced for three days until it was shut in May 14. During this time it produced an average of 86 barrels per day, at individual daily rates as follows: 96, 80, 83. Accordingly, the figure of 85 barrels per day was used in the calculation shown on Figure I-2. As can be seen from Figure I-2, time to reach steady state conditions for this well is about 80 hours, and accordingly the three days it was produced prior to the time it was shut in for this test would be adequate to condition the well for such a test. Two bottom hole

pressures were run on this well, one on May 17 and the other on May 20 (at 79 and 152 hours respectively, following shut-in). These measured bottom hole pressures were within 1.4 pounds, the latter test being the lower, and are well within the accuracy to be expected from these instruments. Other pressures shown on the graph were determined from fluid levels, and calculated density of the oil. The density of the oil was determined from the average pressure of the two bottom hole pressure tests and the average fluid levels at the times of their measurement. From this density the pressures were calculated by multiplying by depth of fluid above the pay zone. It is possible, of course, that the density of the oil column was not exactly the same throughout the test. If a variation exists it probably would be the result of lower density of fluid entering the hole after the pressure reached 1,520 pounds, as it would be at the saturated oil density. If this were the case, the first pressure shown would be slightly higher and the resulting transmissibility also slightly higher. It could be on the order of .03 darcy feet. This is believed, however, to be the probable limit of error in this particular test. The other transmissibility, .206 darcy feet, is probably within 5 or 10 percent.

Figure I-3: This is a pressure fall-off test conducted on a gas injection well. Surface pressures at the beginning and end of the test were measured with deadweight tester and intermediate pressures determined by correlating the pressures shown on a recording pressure gauge with the deadweight pressures taken at the beginning and end of the test. The well is believed to have reached close to static conditions at the end of the test (approximately one day). This fact was determined by a subsequent pressure fall-off

test, in which the well was tested for approximately 50 hours. Working bottom hole pressures were calculated from gas gravity, temperature and deviation factors. This is believed to be a rather accurate test. As indicated in the remarks above, permeability to oil, of course, would be something greater than that shown for permeability to gas.

Figure I-4: The subject well of this test, the E-10, is a high capacity well. It was completed in August of 1967, and produced at rates of approximately 400 barrels per day for August and September, and 250 barrels per day for October and the first 20 days of November. The last 10 days of November it was produced at the rate of approximately 50 barrels per day, in order to achieve as nearly as possible a column of gas from the surface of the ground to the pump on subsequently shutting the well in. It is believed this was accomplished. Accordingly, when the test was commenced on December 6, a continuous column of gas existed from the surface to the pump depth of 6,100 feet. The well is completed through perforations at about 7,000 feet. It was produced during this test at the rate of 460 barrels per day for two days. "Stabilization" as to the area in the vicinity of the well was reached after about 24 hours. The surface casing pressure dropped about 25 pounds the first two hours and another 25 pounds in the next 24 hours. This is equivalent to a bottom hole working pressure decline of approximately 40 pounds per cycle. This 40 pounds per cycle is plotted on the graph, Figure I-4. A sensitive pressure recorder was calibrated and used for this test. Unfortunately these records are not available at this time, so the exact casing pressure cannot be plotted as was done in the other tests. However, another

uncalibrated recorder was also on the well, and although not as sensitive as the primary recorder, its chart reflects the pressure drops as quoted above. Since this recorder was not as sensitive as the primary recorder, no effort has been made to read intermediate pressure points. It is believed, however, that this pressure-time relation of 40 pounds per cycle is as accurate as ordinary field data obtained for such tests.

Figure I-5: Pressures for the first 10 days of this pressure build-up test were taken by running a bottom hole pressure bomb down a string of Kobe tubing and leaving it for 24 to 48 hours, at which time it would be retrieved, a new chart put in, and pumped back to bottom. A Humble type bomb was used, and it exhibited a certain amount of hysteresis which made the initial points more indefinite than usual. After 9 days the tubing was pulled and pressures measured in the normal fashion by running the bottom hole pressure bomb to near the pay zone. After being shut in 23 days, the offsetting well, the A-14, was shut in, and an immediate pressure reaction was observed because of this. Pressures shown on this figure have been adjusted to a datum of + 1,195 feet. Actual well pressures were approximately 100 pounds higher than this at the pay zone. Accordingly, and in view of the bubble point pressure of 1,520 pounds, it is apparent that nearly all of this test was conducted at pressures above the bubble point, and from this standpoint it can be considered a suitable test.

PART B - TRANSMISSIBILITY DATA FOR LARGE AREAS OF THE RESERVOIR

Transmissibility data for large areas of the reservoir are available from three sources. Each of these is discussed below.

i. 1965 Interference Test

This was a reservoir-wide interference test, conducted by first shutting in all wells in the reservoir and measuring interference effects on the shut-in wells as each test well was put on production. Details of this test and interpreted results were reported to the New Mexico Oil Conservation Commission at the 1966 spacing hearing. These details are not repeated here. To review briefly, however, the interference effect on the observation well is shown on the graph at the end of this appendix, Figure I-6, the results of which, as to transmissibility, are calculated from the plot of this data shown on Plate II of Figure I-7. In summary, this shows transmissibility, uncorrected for boundary effects, of 4.8 darcy feet. A 30 percent adjustment was applied for assumed but unknown boundary effects, to arrive at 6.2 darcy feet. Since the oil in all except the highest up-dip points of the reservoir was at that time at pressures above the bubble point, diffusivity constants would have been high for all points of the reservoir, even the tight parts, and accordingly this test is believed to be a fair representation of an exceptionally large part of the reservoir and its overall average. The indefinite feature, of course, is the effect of unknown boundaries. Since a nearby straight-line boundary would have a maximum effect of two to one, it is assumed that the

overall average reservoir transmissibility lies between the values of 5 and 10 darcy feet. This test is thought to be representative of a rather large area, of the order of 5,000 to 10,000 acres.

As additional information is developed on the geometry of the reservoir and other influencing features, as perhaps directional alignment of the main fractures, it may be possible to put a closer value on the transmissibility as calculated from this particular test. At this time, however, no change is suggested from that initially calculated.

ii. 1968 Interference Test

As a result of commencement of gas injection August 9, 1968, at relatively high rates (equivalent to reservoir displacement rates of approximately 1,500 barrels per day of stock tank oil) transient pressure disturbances were created. These effects were measured by the observation well pressures (as determined by fluid level measurements). The injection well was the K-13 and the observation well the A-23. Pressures in the vicinity of the injection well were some 200 pounds below the bubble point, and accordingly oil in the area affected was saturated, and the resulting diffusivity constant of this area was considerably smaller than that obtaining at the time of the first interference test in 1965. Accordingly reaction times were much greater. Even so, because of the large volume injected, interference was of a great enough magnitude that its effect on the A-23 observation well some 3,700 feet away was adequate to provide information for a satisfactory interference test and calculations of transmissibility and oil in place.

The fluid levels measured, along with production and injection data, are shown at the end of this appendix on the graph, Figure I-8. Another plot of the fluid levels is shown on Figure I-9, along with calculated curves for different assumed conditions. Because of the low diffusivity constant involved, boundary conditions affected the pressure build-up in the observation well before the time at which the exponential integral function became a straight-line relation with the logarithm of time. Consequently it was not possible to measure reservoir transmissibility directly, as was done in the 1965 interference test. To calculate transmissibility and pore volume from this test it was necessary to assume values for these properties and determine by trial and error the set of conditions which best fitted the data.

These conditions are a transmissibility of 1.8 darcy feet and a pore space of 1,600 barrels per acre of stock tank oil volume. Although not shown, variation of 30 percent of oil in place results in curve displacement from the measured data of the same order of magnitude as that shown for the curves with transmissibility of 1 and 4 darcy feet, and accordingly it is believed little error is introduced in the calculated transmissibility of 1.8 darcy feet because of the unknown value of the exact pore space.

The abrupt levelling of the fluid levels between the 50th and 55th day after start of injection is believed to be the result of some type of boundary condition. Effects of two types of possible boundary conditions have been calculated and the results shown on Figure I-10. Although the resulting curve No. 3 of this figure does not follow exactly the measured fluid levels, it does indicate that essentially stabilized conditions could exist at about

60 to 70 days after gas injection started, if the reservoir properties are those used in the calculations as shown on Figure I-9.

It is probable that the transmissibility for the area represented by this test was higher when the reservoir was first discovered than at the time of this test in 1968. It is assumed that some of the gas which evolved from the oil as the pressure dropped below the bubble point stayed in the area of the test, reducing the permeability to oil and resulting transmissibility. Also it is believed that some of the initial volumes of gas liberated migrated to the gas cap. Since just prior to the test the pressure was being constantly reduced, it would be necessary for some gas to remain in the area, simply because it would not have had time to move to the gas cap. As a result, the permeability to oil at the time of this 1968 interference test must have been substantially less than it was in the 1965 interference test. For the range of probable values of gas saturation, the permeability to oil at the time of the 1968 test is estimated to be in the range of 50 percent to 80 percent of its initial value. This means that the initial transmissibility of this area was in the range of 2.3 to 3.6 darcy feet. The area whose reservoir properties are represented by this test is believed to be about 2,000 to 3,000 acres.

iii. 1969 Steady State Line Drive Transmissibility Test

By the end of September, 1969, gas injection had been in operation for about 14 months and reservoir pressures had stabilized. The A-14 well commenced producing substantial quantities of free gas in May and caused a decline in reservoir pressure during

the months of May, June and July. This well was shut in about the middle of July, and as a result, pressures remained quite stable for the months of August and September. Flow tests were conducted on the E-10 the last of September (September 21 to 30, 1969). Summarized pressure and production data for this test are shown on the schedule at the end of this appendix, Figure I-13. This shows a productivity index of 4.2 BOPD per pound for this well while producing at the rate of approximately 770 barrels per day. From this productivity index data and the geometry of the flow system it is possible to estimate the transmissibility of the area between the A-23 observation well and the producing well, the E-10.

At this time the reservoir was unquestionably producing under steady state conditions. For over a year approximately the same volume of gas had been injected in the reservoir as reservoir space voided by the producing wells. Except for the period of time when the A-14 was producing excessive volumes of gas, pressures in the oil area were stabilized. This is evident from the pressures in the A-23 observation well, which is below the gas-oil contact, during this test. Also, the working casing pressures on the producing wells, for the same rates of flow and for the times pressures were stabilized in the A-23 observation well, were also stabilized.

It is believed the injected gas has formed a gas-saturated area in the vicinity of the injection well and spreading up-dip and along the strike northeast and southeast from the injection well. With the low viscosity of the gas as compared to oil, the gas is undoubtedly forming a secondary gas cap, with a strong tendency for the gas to form a level gas-oil interface along the strike of the

formation, which is approximately north and south. The result of this, as far as flow system for the producing wells is concerned, means that rather than the injected fluid exerting pressure, as from a point source, its effect is more in the form of a north-south line drive (moving from east to west). From wells drilled northwest and southwest of the E-10 it is apparent that the area of high transmissibility ends immediately west of the E-10. Its west line of termination probably follows the strike of the formation in a north-south direction. Although wells exist west of the E-10 in the reservoir and in communication with it, from the standpoint of the calculation of transmissibility, its variation is so great that the area just west of the E-10 will have an effect on pressure distribution as though it were a boundary. Accordingly the flow system can be likened to a north-south line drive from the observation well, the A-23, to the E-10 producing well, with a near north-south boundary west of it. The geometry of this flow system can also be compared to a semicircle with a radius distance equal to that from the E-10 up-dip to the point of known pressure (approximately 10,000 feet). The base of the semi-circle would be a north-south line running near the E-10. As shown later, the operating pressure in the E-10 would be about the same for a geometry somewhat like either of the two described above. It is believed, however, that the true situation is more like that of a line drive.

The basic line drive formula used is shown at the end of this appendix on Figure I-14. This formula is for an infinite distance from the line source past the well and beyond. To

accommodate the formula to the situation of a boundary near the well and parallel to the line drive source, it was assumed the pressure would be approximately 1.9 times that shown for the regular line drive formula. A distance of 20,000 feet was assumed for the north-south length of the line. Calculations were also made assuming the geometry of the flow system to be that of a semi-circle with a radius of 10,000 feet. The results of these calculations are set out below for well bore effective radii of 1 foot and 10 feet:

r_w (Feet)	TRANSMISSIBILITY, DARCY FEET FOR FLOW SYSTEM GEOMETRY OF:	
	Line Drive	Semicircle
1	9.5	8.7
10	7.5	6.5

From the above information it appears that the reservoir transmissibility in this area would be something in excess of 6.5 darcy feet. Other factors which influenced the test, and which could of course influence the calculated transmissibilities if their exact effects were known, are the following:

1. Two additional wells were producing in the area of the test at the time. One was the L-11 and the other the A-22. It is believed the effects of these wells in this test would be minimal, however. The wells were producing at approximately the same rates and their interference effects on the producing well, the E-10, and the observation well, the A-23, would just about cancel out. The A-22 is closer to the observation well than it is to the E-10, and accordingly would be expected to draw the pressure down in the A-23

as a result of its production to a greater extent than it would affect the E-10. The L-11, on the other hand, is closer to the E-10 than to the observation well, and it would have a similar but counteracting effect. The relative distances of these two wells is almost exactly the same, that is, the distance from the A-22 to the A-23 is almost exactly the same as the distance from the L-11 to the E-10. Also, the distance from the A-22 to the E-10 is almost the same as the distance from the L-11 to the A-23. In view of this, it is believed the interference effects of these two wells on the test would be so small that they can be disregarded. Therefore no attempt was made to adjust the calculations for these effects.

2. The working pressure in the E-10 was some 115 pounds below the bubble point. This means that the pressure draw-down is greater than it would have been had the oil been under-saturated. The effect of this, if a correction could be applied for it, would be to increase transmissibilities above those shown above.

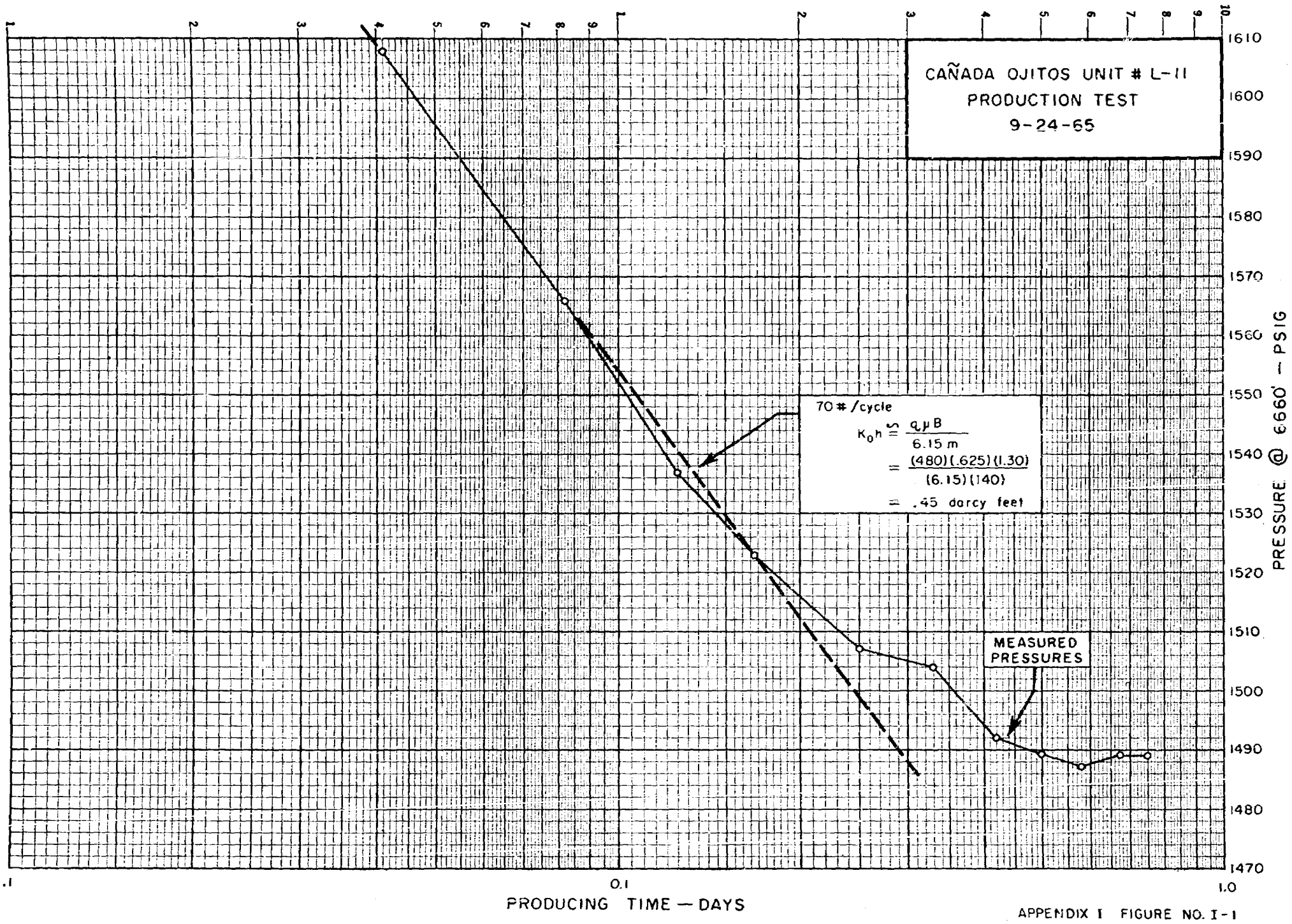
3. As shown by the interference test in this appendix, Figure I-4, this well had a transmissibility in the vicinity of the well bore of only 1.5 darcy feet. This appears to be only about 15 percent of the average reservoir transmissibility in the area of this line drive transmissibility test. Accordingly, to determine the proper pressure draw-down to be used in measuring reservoir transmissibility, a correction should be applied for this exaggerated pressure drop. This could easily be a correction of as much as 50 pounds in the 183 pound pressure draw-down. Accordingly a correction for this error would indicate the above listed transmissibilities should be increased by approximately one-third.

4. It is impossible, of course, to calculate exactly the working bottom hole pressure of the E-10 from the data available. The 183 pound pressure draw-down could be in error by as much as 20 or 30 pounds. It is believed the error would not exceed this, however. This error could be in either direction.

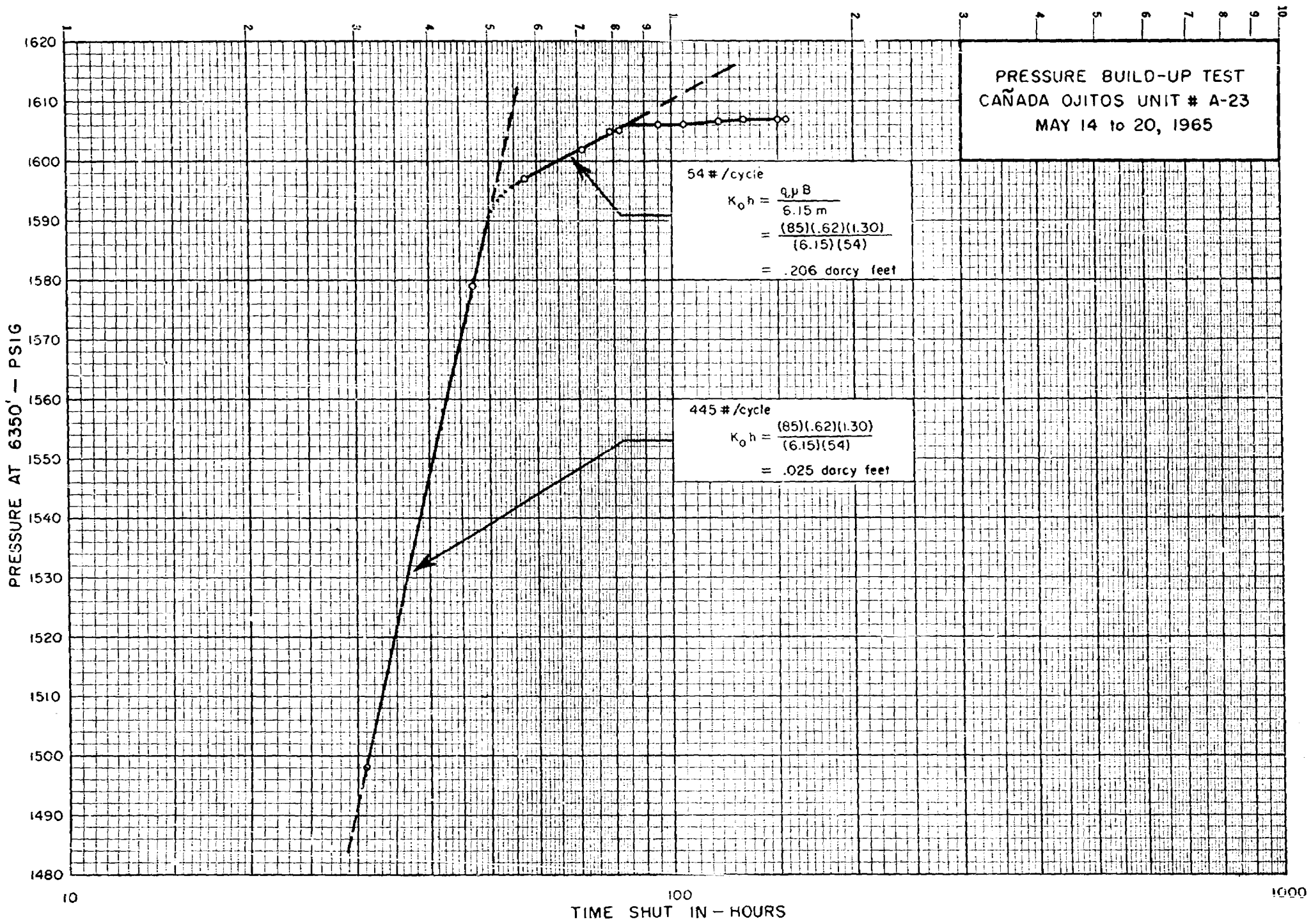
For the same reasons as stated in Item 3 above, it is probable that the effective well bore radius, under the circumstances of this test, would be rather small. An effective well bore radius of 1 foot probably would be more reasonable than the other figure shown of 10 feet. The reason for this is that with the high transmissibilities involved, the transmissibility of the area affected by the sand fracture treatment probably does not exceed that of the reservoir. For example, if a sand fracture treatment results in a transmissibility of 5 darcy feet, then the effective volume of this frac treatment would cause the associated effective well bore radius to be increased a like amount if the transmissibility of the area generally was substantially less (as for instance in the test of the L-11, as more particularly described in Appendix II hereof). If, however, the transmissibility of the reservoir is on the order of 10 darcy feet, then a sand fracture treatment resulting in a transmissibility of only 5 darcy feet around the well bore could not in any way give an effective well bore radius increase over that approximating the physical size of the hole.

All factors of the above test taken into consideration, it is believed the transmissibility indicated by the area of this test is on the order of 10 to 12 darcy feet. It is also believed that the area represented by this test is 3,000 to 4,000 acres.

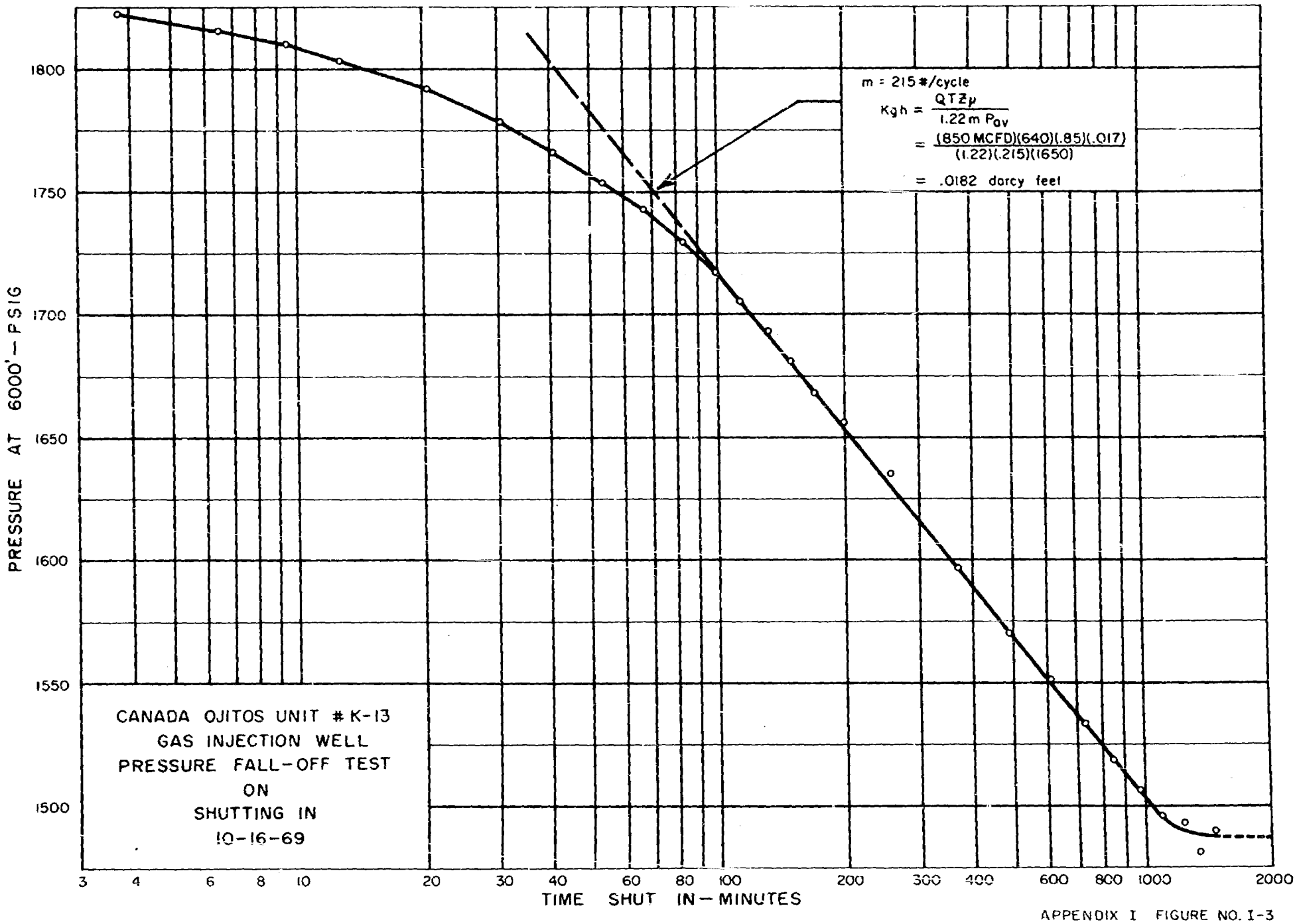
The areas of the three above-mentioned transmissibility tests are sketched on the plat at the end of this appendix, Figure I-16.



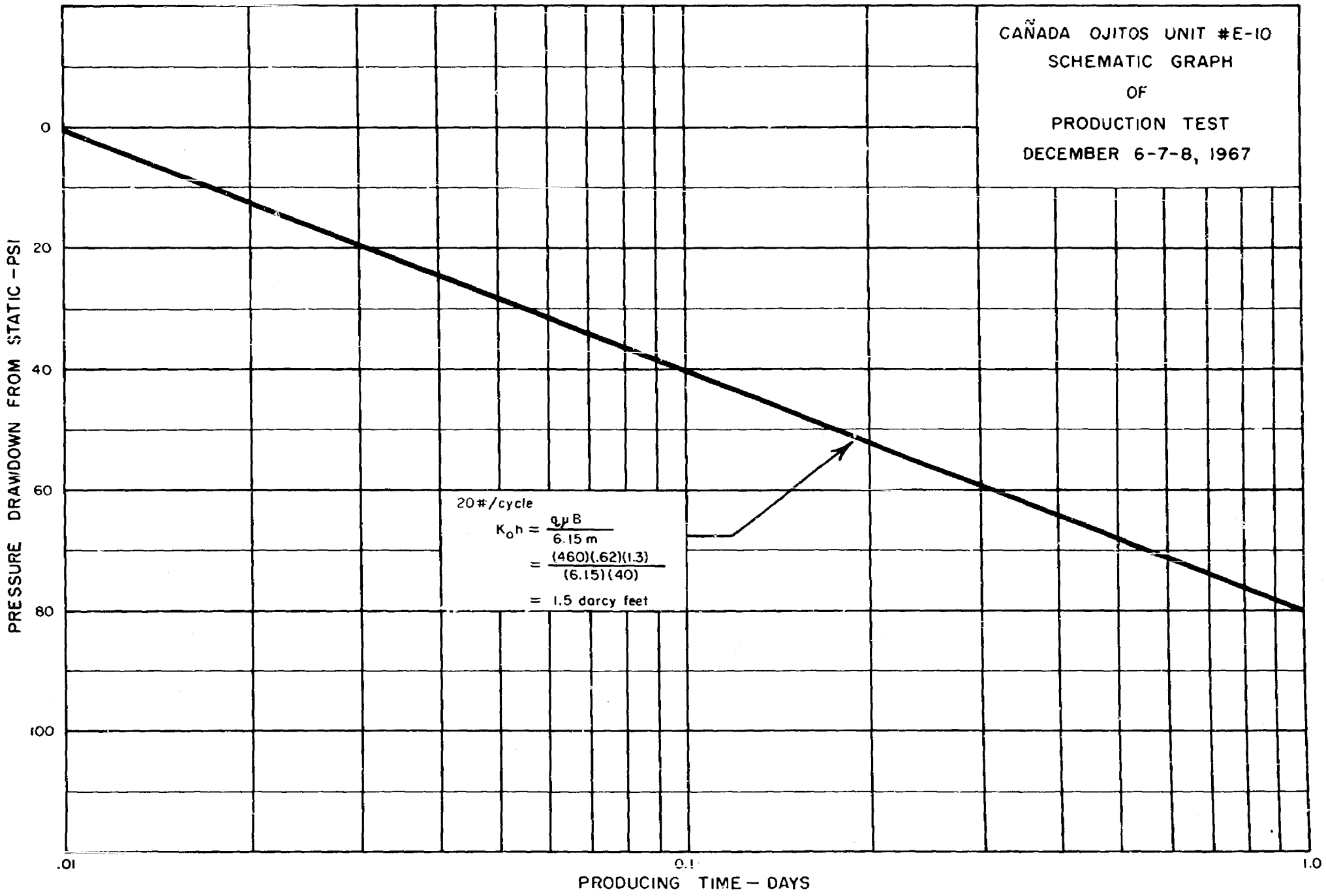
APPENDIX I FIGURE NO. I-1



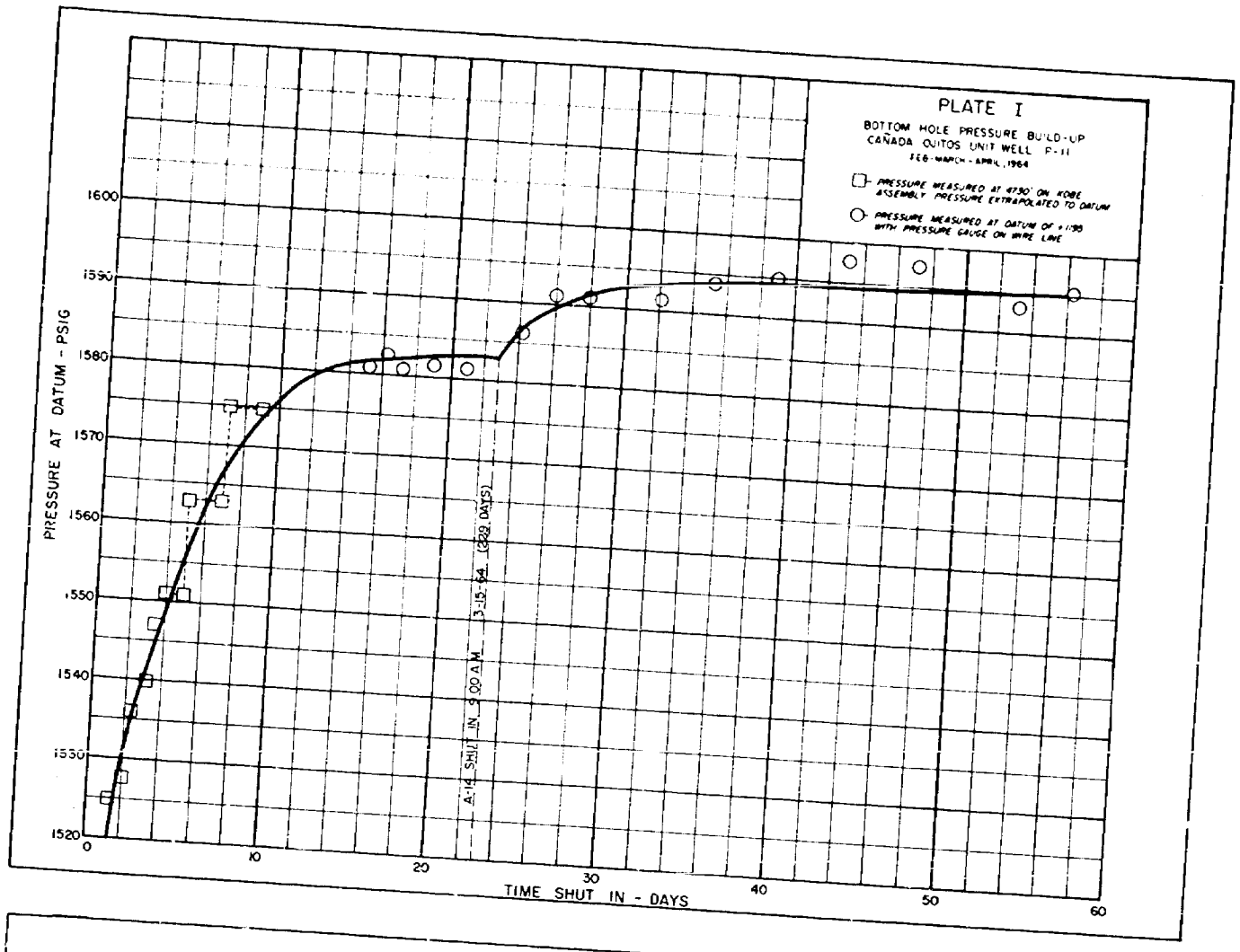
APPENDIX I FIGURE NO T-2

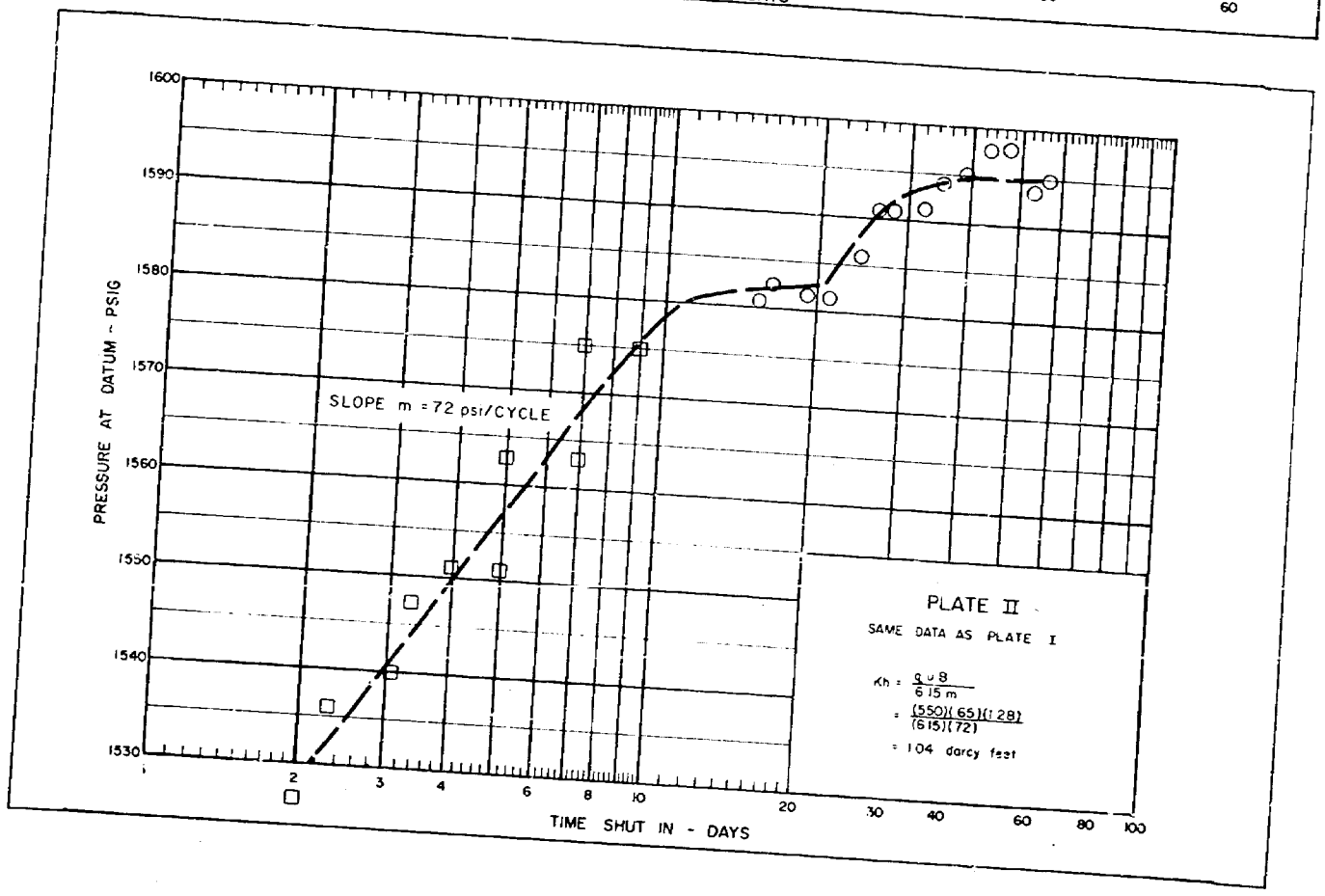


APPENDIX I FIGURE NO. I-3



APPENDIX I FIGURE NO. I-4





APPENDIX I FIGURE NO. I-5

PLAT OF PORTION
OF
1965 INTERFERENCE TEST
CAÑADA OJITOS UNIT

L-11 PROD 500 BOPD

L-11 PROD 100 BOPD

L-11 ON PRODUCTION 9:30 A.M. 9/24/65

A-23

INTERFERENCE EFFECT OF P-11

A-14

INTERFERENCE EFFECT OF L-11

A-14 ON PRODUCTION 4:00 P.M. 11/10/65

L-11 ON PRODUCTION

FLUID LEVEL - FEET FROM SURFACE (GL)

480 490 500 510 520 530 540 550 560 570 580 590 600 610 620 630 640 650 660 670 680 690

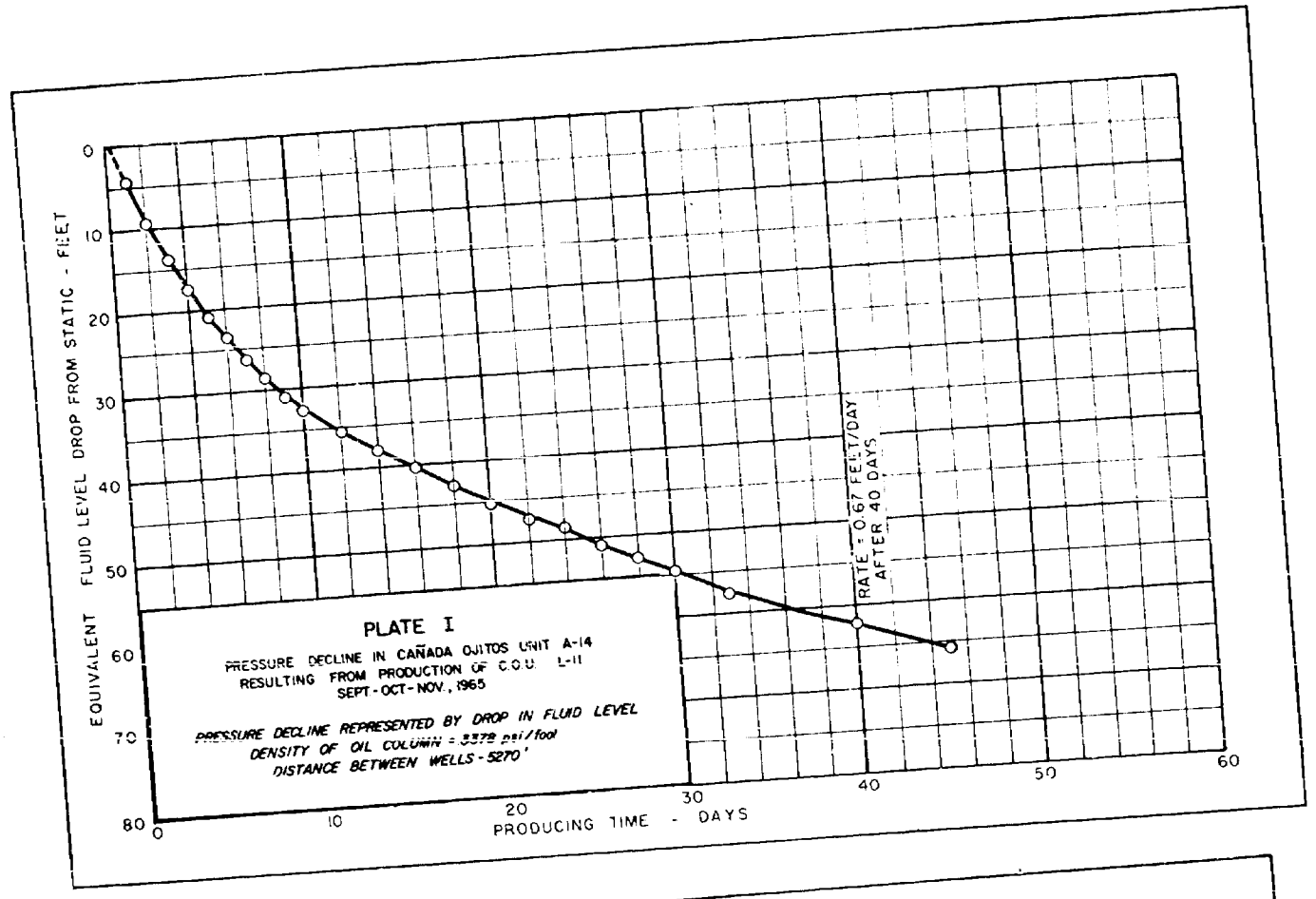
TOTAL PARTICIPATING AREA PRODUCTION RATE - BOPD

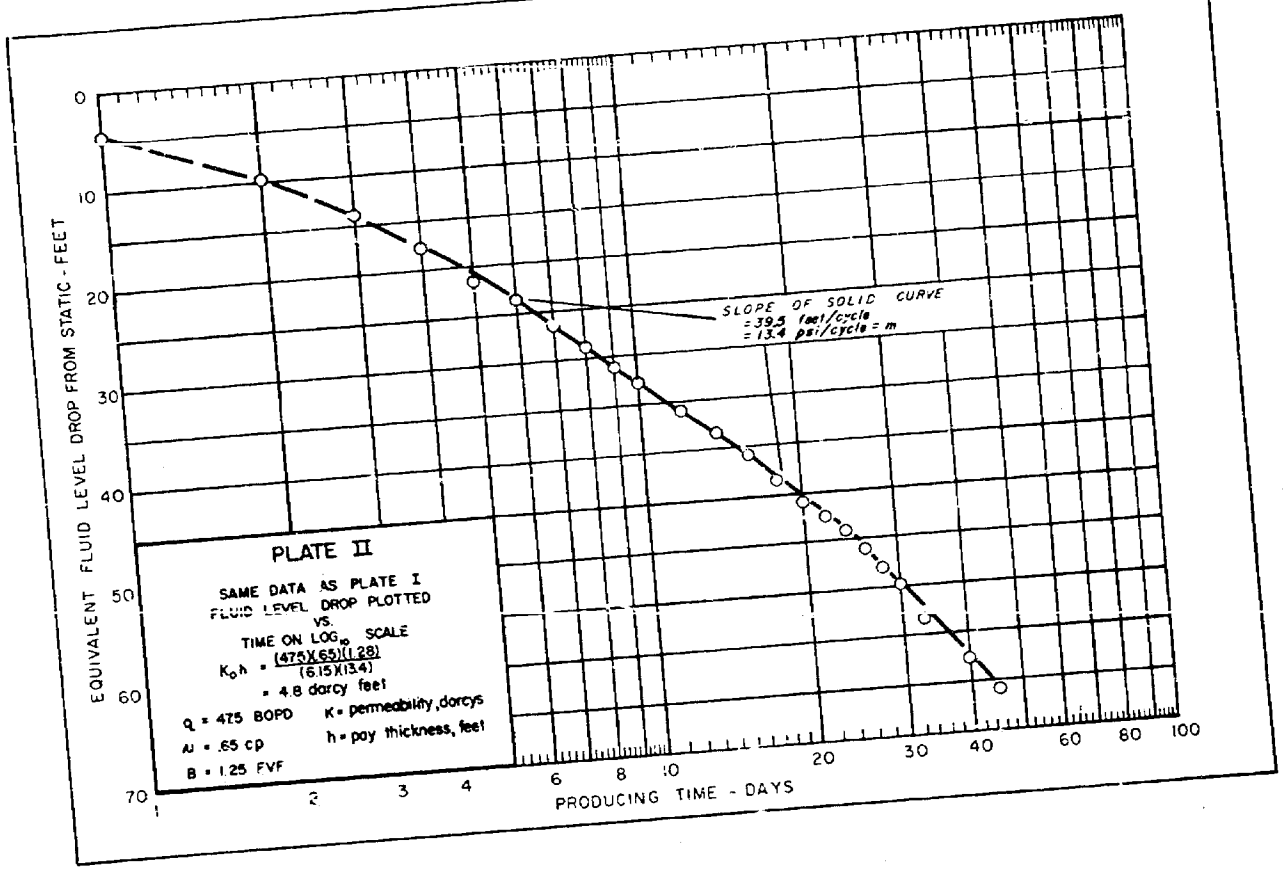
1400 1200 1000 800 600 400 200 0

SEPTEMBER

OCTOBER

APPENDIX I FIGURE NO. I-6





APPENDIX I FIGURE NO. I-7

CAÑADA OJITOS UNIT
NIOBRARA PARTICIPATING AREA

PRODUCTION RATE
FOR PARTICIPATING AREA

GAS INJECTION RATE

PLOT OF FLUID LEVEL
FOR A-23

1968

GAS INJECTION RATE

OIL PRODUCTION RATE

B.H.P.

F.L.

GAS INJECTION COMMENCED AUGUST 9, 1968

O-33 ON PRODUCTION

A-16 ON PRODUCTION

A-14 ON PRODUCTION

L-11 ON PRODUCTION

P-11 ON PRODUCTION

E-10 ON PRODUCTION

AUGUST

SEPTEMBER

FLUID LEVEL - FEET FROM SURFACE (G.L.)

TOTAL PARTICIPATING AREA PRODUCTION RATE -- B.O.P.D.

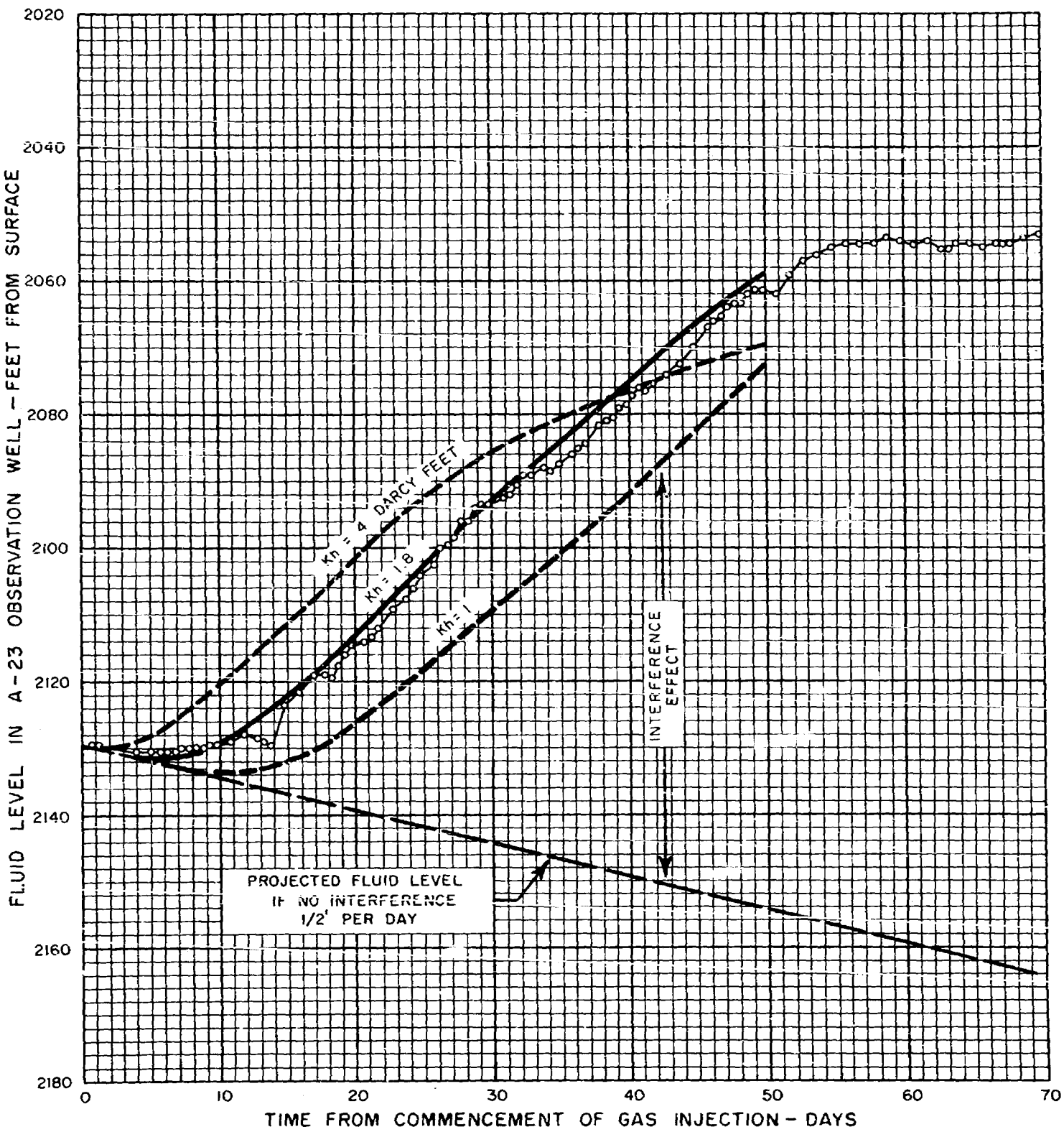
GAS INJECTION RATE - MCF/DAY

BOTTOM HOLE PRESSURE (6300') IN A-23 - psig

APPENDIX I FIGURE NO. I-8

COMPARISON OF
ACTUAL INTERFERENCE EFFECT
OF INITIAL GAS INJECTION
ON FLUID LEVEL OF A-23 OBSERVATION WELL
WITH CALCULATED EFFECTS

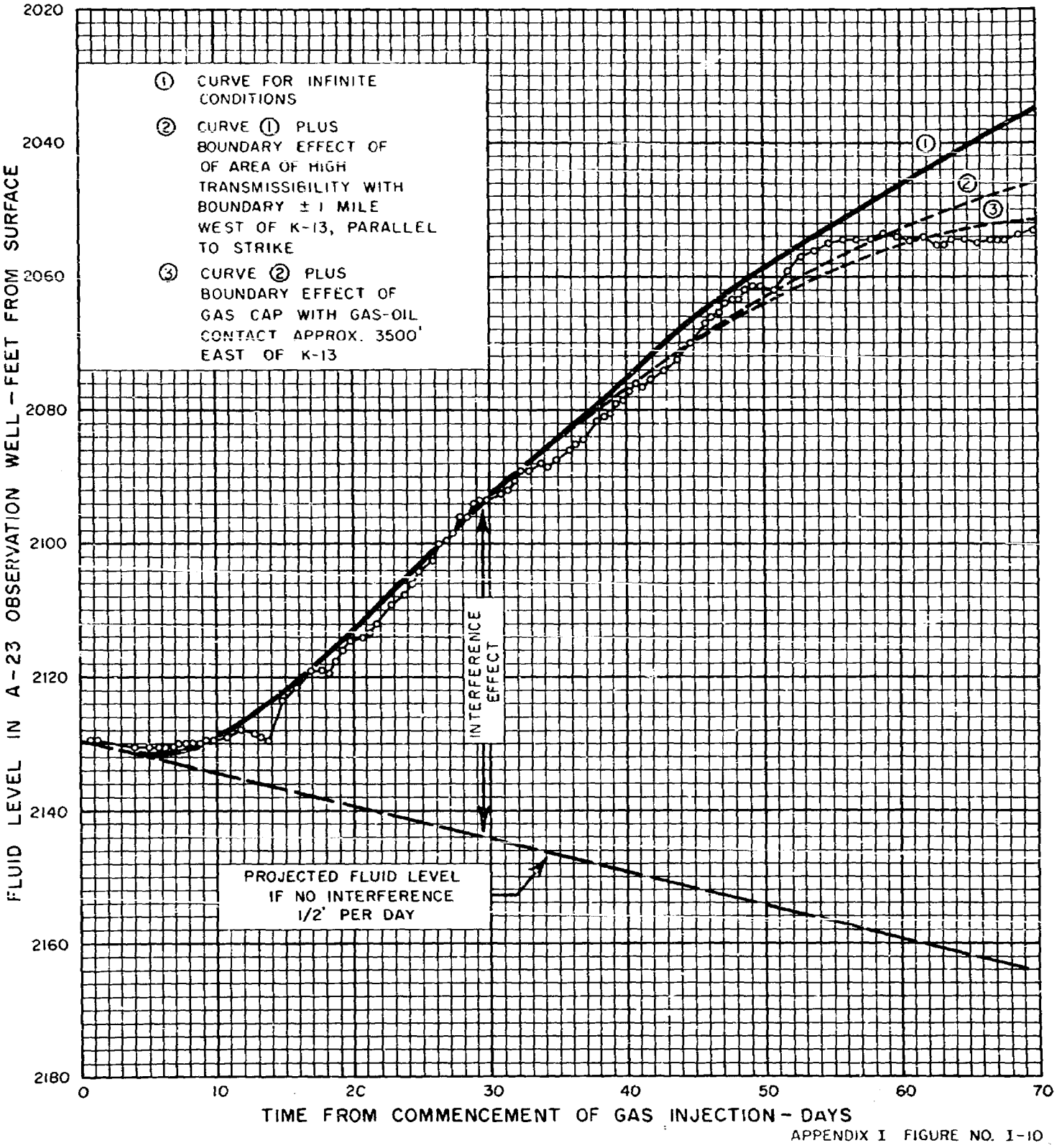
FOR CONDITIONS OF:
C_e = 415 x 10^{-6} F.V.F. = 1.28
ϕh = 1600 BBLS/ACRE STOCK TANK OIL
AND TRANSMISSIBILITIES AS SHOWN
o – MEASURED FLUID LEVELS



APPENDIX I FIGURE NO. I-9

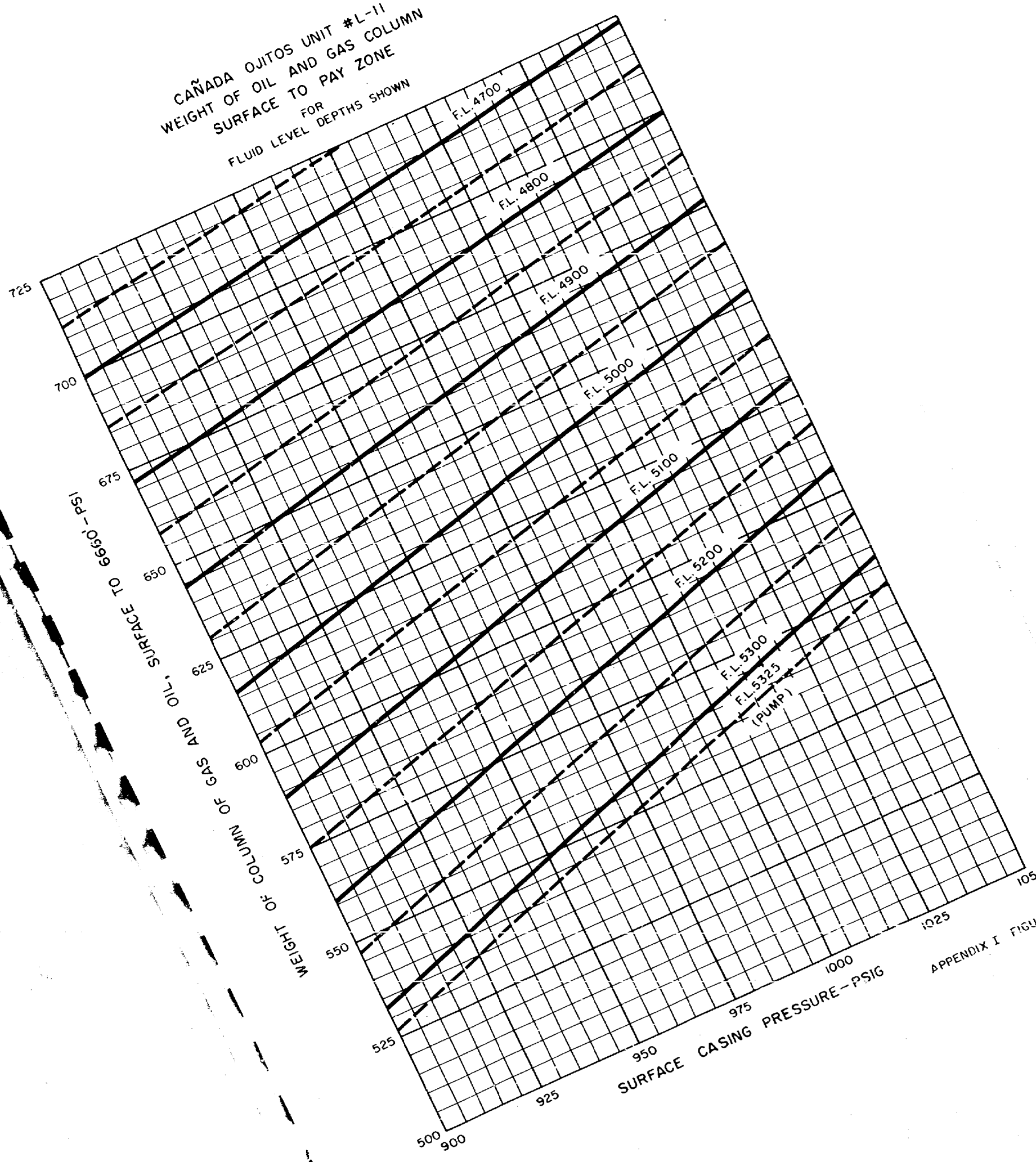
COMPARISON OF
ACTUAL INTERFERENCE EFFECT
OF INITIAL GAS INJECTION
ON FLUID LEVEL OF A-23 OBSERVATION WELL
WITH CALCULATED EFFECTS

FOR CONDITIONS OF:
C_e = 415 x 10^{-6} F.V.F. = 1.28
ϕh = 1600 BBLS/ACRE STOCK TANK OIL
TRANSMISSIBILITY = 1.8 DARCY FEET
o - MEASURED FLUID LEVELS



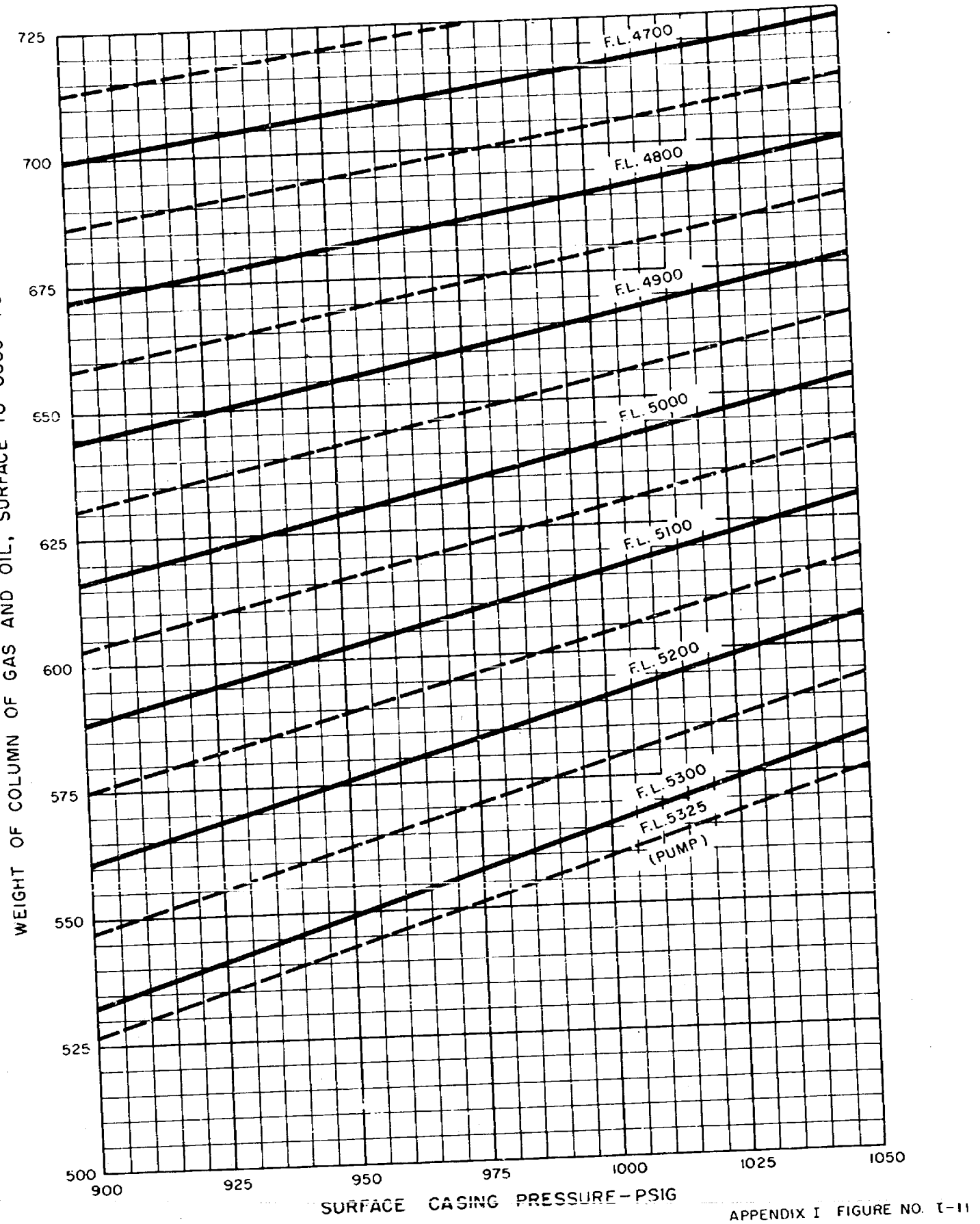
APPENDIX I FIGURE NO. I-10

CAÑADA OJITOS UNIT #L-11
WEIGHT OF OIL AND GAS COLUMN
SURFACE TO PAY ZONE
FOR
FLUID LEVEL DEPTHS SHOWN



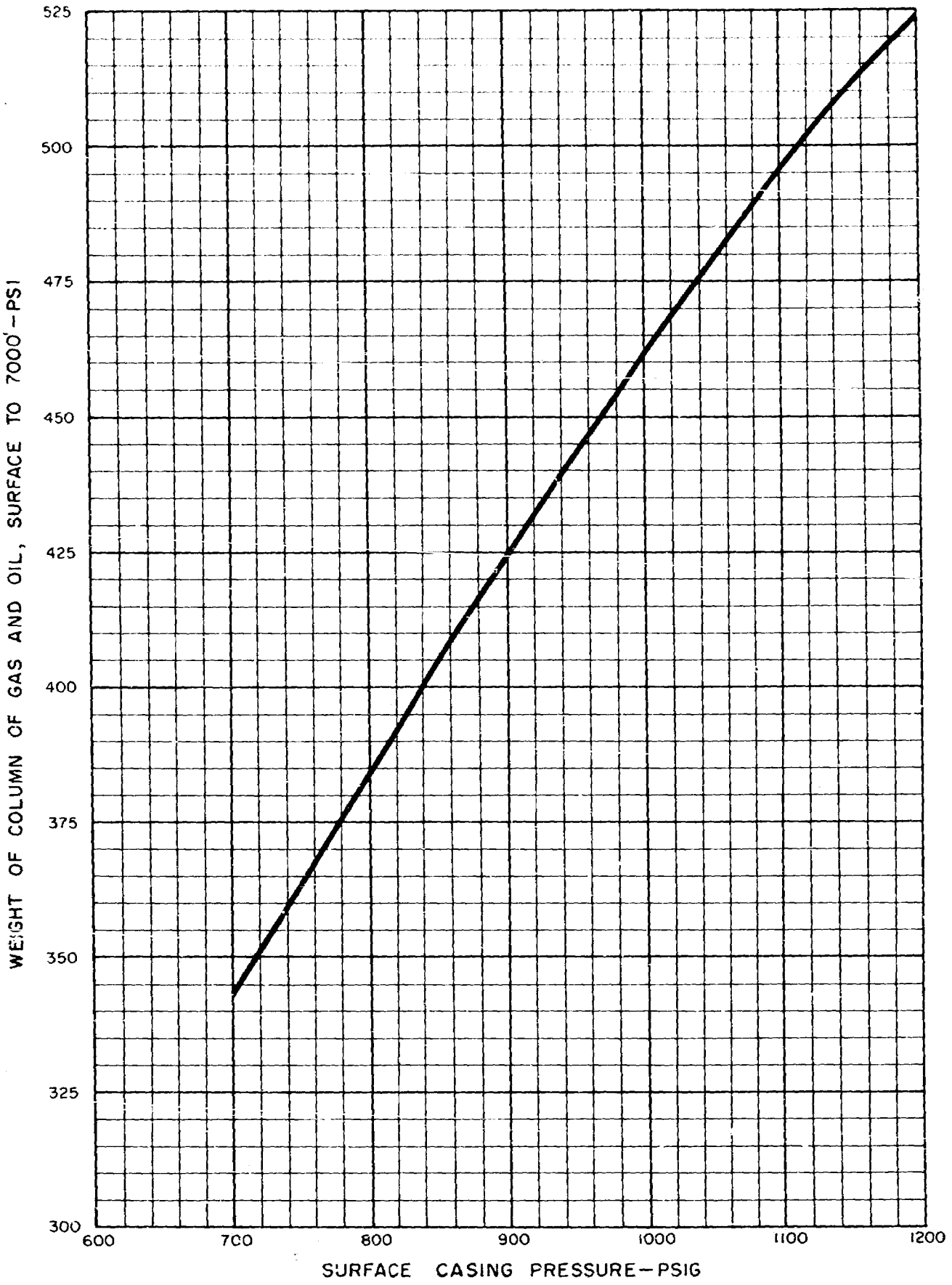
APPENDIX I FIGURE NO. I-11

CAÑADA OJITOS UNIT #L-11
WEIGHT OF OIL AND GAS COLUMN
SURFACE TO PAY ZONE
FOR
FLUID LEVEL DEPTHS SHOWN



APPENDIX I FIGURE NO. I-11

CAÑADA OJITOS UNIT #E-10
WEIGHT OF OIL AND GAS COLUMN
SURFACE TO PAY ZONE
FOR FLUID LEVEL
AT PUMP DEPTH OF 6100'



APPENDIX I FIGURE NO. I-12

PRODUCTIVITY INDEX DATA FOR
STEADY STATE LINE DRIVE TRANSMISSIBILITY TEST

CANADA OJITOS UNIT E-10

September 21-30, 1969

PRESSURE AT "LINE" SOURCE:

(FROM A-23 SURFACE POSITION AND PRESSURE)

A-23 pressure adjusted to datum of + 1195'	1,324 psig
A-23 pressure adjusted to datum of E-10 (+ 340')	+ 263
	1,587 psig

E-10 AVERAGE PRODUCING CASING PRESSURE	957 psig
Pressure differential to pay zone at 7,000' (from Figure I-12)	447
Producing pressure at pay zone	1,404

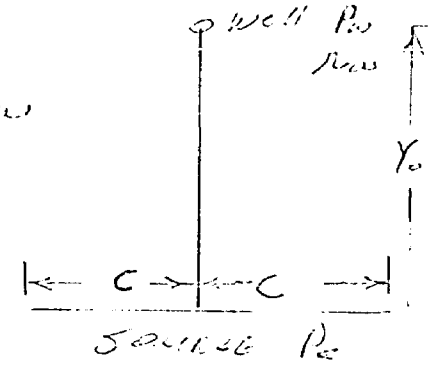
PRESSURE DRAWDOWN 1,587 - 1,404 = 183#

AVERAGE PRODUCTION RATE 770 BOPD

$$P.I. = \frac{770}{183} = 4.2 \text{ BOPD/\#}$$

Transient Solution from P.I. - Line Drive Formula

(Steady State)



$$\Delta P = P_e - P_w$$

$$Q = \frac{2\pi K \Delta P}{\mu B \log_e 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{c^2}\right)} \qquad (I-1)$$

(Reference 5)

Introducing Fvf, B, and pay thickness, h,

$$Q = \frac{2\pi Kh \Delta P}{\mu B \log_e \frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{c^2}\right)} \qquad (I-2)$$

Changing constants to conform to oil field units

(for example ref. 6)

$$Q = \frac{3.076\ Kh\ \Delta P}{\mu B \log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{c^2}\right)} \qquad (I-3)$$

Where:

Q = BOPD
μ = cp
K = darcys
h = feet
Y_o & r_w same units (as feet)

and

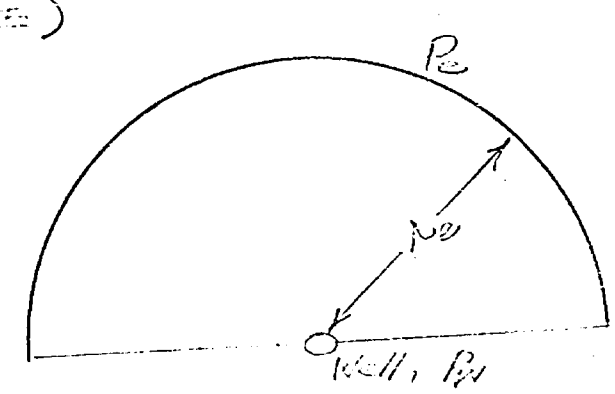
$$Kh = \left(\frac{Q}{\Delta P}\right)\left(\frac{\mu B}{3.076}\right)\log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{c^2}\right) \qquad (I-4)$$

For $B = 1.29$ & $\mu = 1 \& 2$ & $\frac{Q}{\Delta P} = P.I.$

$$Kh = (P.I.)(.26)\log_{10} 2\frac{Y_o}{r_w}\left(1+\frac{Y_o^2}{c^2}\right) \qquad (I-5)$$

Appendix I - Fig. I-1

TIME-DRAWDOWN DERIVATION FOR GEOMETRY OF SEMI-CIRCULAR FLOW SYSTEM (STEADY STATE)



$$\Delta P = P_e - P_w$$

FOR CIRCULAR STEADY STATE FLOW (REFERENCE 6)

$$\varphi = \frac{3.076\ Kh\ \Delta P}{\mu B \log_{10} \frac{r_e}{r_w}} \qquad (I-6)$$

for K in darcys

FOR SEMI-CIRCLE:

φ = 1/2 of that of full circle

$$\varphi = \frac{3.076\ Kh\ \Delta P}{\mu B \log_{10} \frac{r_e}{r_w}} \times 1/2 \qquad (I-7)$$

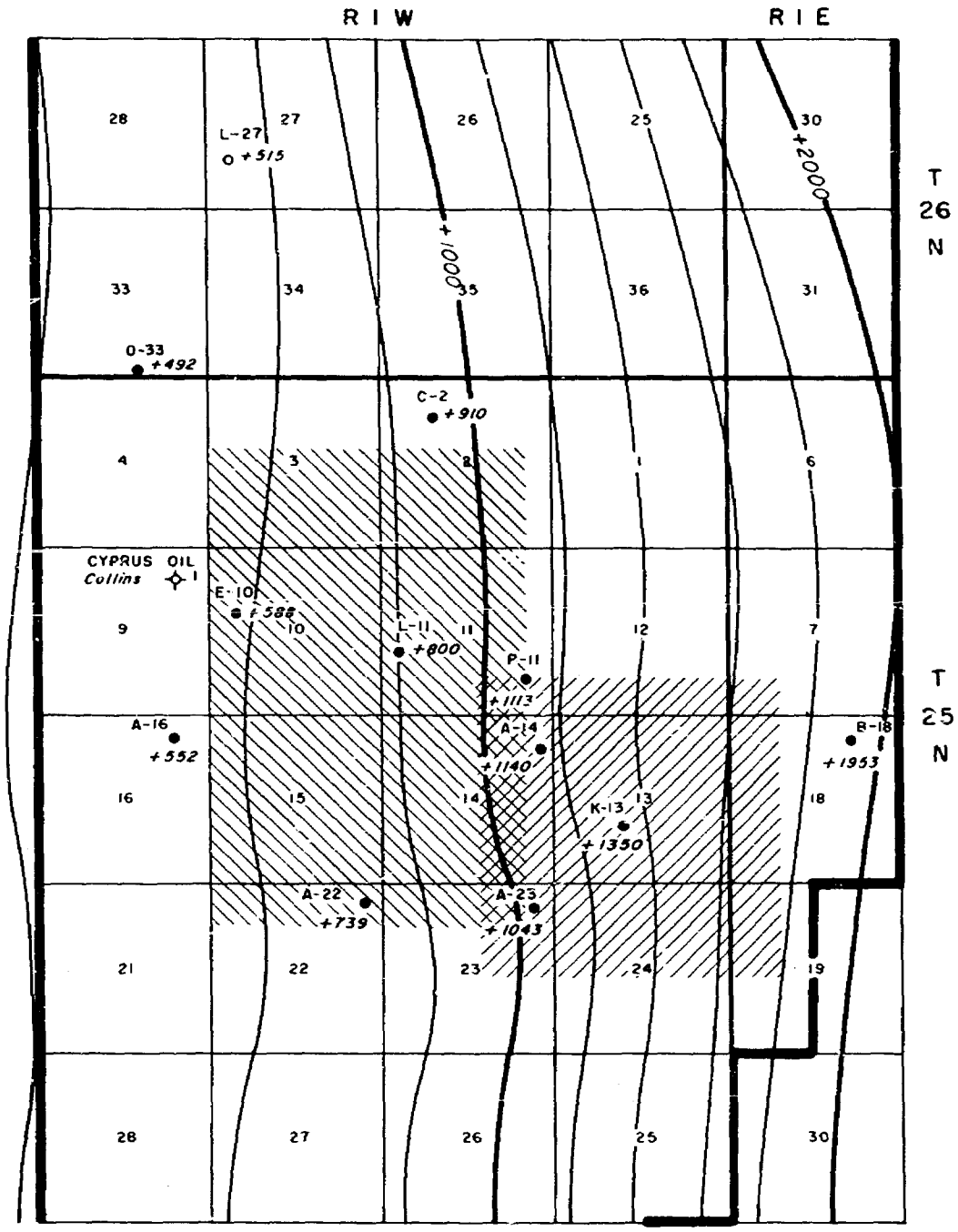
FROM WHICH:

$$Kh = \left(\frac{Q}{\Delta P}\right) \frac{2\mu B}{3.076} \log_{10} \frac{r_e}{r_w} \qquad (I-8)$$

FOR $\mu = .62$ & $B = 1.29$ & $\left(\frac{Q}{\Delta P}\right) = P.I.$

$$Kh = (PI)(.52) \log_{10} \frac{r_e}{r_w}$$

APPENDIX I - Fig. I-15



PLAT OF PART
OF
CAÑADA OJITOS UNIT
SHOWING ESTIMATED
RESERVOIR TRANSMISSIBILITY
BY AREAS OF TESTS

- 2.5 TO 3.5 DARCY FEET
- 10 TO 12 DARCY FEET
- 5 TO 10 DARCY FEET

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969
BOUNDARY OF CAÑADA OJITOS UNIT

APPENDIX I FIGURE NO. I-16

APPENDIX II

APPENDIX II

CALCULATION OF SIZES OF FRACTURE BLOCKS

With the jigsaw type pattern of fracture blocks and interconnecting high capacity fracture system forming the reservoir in West Puerto Chiquito, there exists a relatively stabilized and equalized pressure at the outer boundaries of each fracture block. When a well completed in one of these fracture blocks produces, its flow system can be described mathematically as one with "constant pressure" at the flow system's boundary. It is therefore possible, from unsteady state flow data taken on a well completed in one of these tight blocks, to calculate the oil volume pore space within its block, and from this volume to approximate the areal extent of the block.

The primary method of calculation used is that shown in Part VII (Page 37) of Reference 1. This method uses bottom hole pressure build-up data as a basis. As has been adequately covered in the technical literature, a pressure build-up test results in a cancellation of the "skin" effect, such that for all other things being satisfactory, it permits the accurate determination of transmissibility in the vicinity of the well bore, and (depending upon conditions) for varying distances away from the well bore out into the reservoir.

Although the primary method of calculation is based on a pressure build-up test, it is possible to apply the same principle to, and make the same type calculation from, data from a pressure fall-off test on an injection well. In the case of an injection well, as well as for a producing well, it creates a pressure disturbance

in the reservoir, and when the well is shut in, the reservoir tends to return to static state. Therefore, the "skin" effects vanish during a pressure fall-off test in an injection well the same as they do for a pressure build-up test on a producing well, and accordingly the method of calculating the volume of a producing well's fracture block as described above will apply as well to the determination of the volume of an injection well's fracture block.

As stated above, in the instance of West Puerto Chiquito the individual fracture blocks react as individual flow systems, with constant pressure being held at the boundary by the high capacity fracture system. The shape of the fracture blocks is of course unknown, but for the purpose of this study it is not necessary to know the geometry of the individual fracture blocks, it is necessary only to determine approximately their gross dimensions. The information available and the methods of calculation are quite adequate to accomplish this.

Volumes of the reservoir space affecting the tests of the wells shown in Part A of Appendix I, Figures I-1 through I-5, have been calculated for four of the wells. These calculations are shown at the end of this appendix on Figures II-1, II-2, II-3 and II-4. Two of the tests were pressure build-up tests and one was a pressure fall-off test for an injection well. These three tests were calculated in the manner described above. One test (on the L-11, Figure I-1 in Appendix I) was a pressure draw-down test and required different treatment. Derivation of the method used for this well is shown in the figure at the end of this appendix, Figure No. II-5. This particular well, the L-11, has a relatively large effective well bore radius. Although, as described in more detail later, it is

difficult to determine the exact length or average length of this well bore radius, it is possible to determine approximately the volume of reservoir pore space within this "effective well bore radius". It approximates 3,000 barrels of reservoir pore space. This large effective well bore radius has a corresponding large influence on the pressure draw-down of the well. Because of this, the method used for calculating volumes for a pressure build-up test could not be used here. For a solution of this problem we rely on one of Muskat's (Reference No. 7) solutions of the diffusivity equation for pressure decline at the internal boundary of large reservoirs subject to constant withdrawal rate. One application of this equation, expressed in terms consistent with units used in this paper, is described in Reference 1, Page 60. Use of this equation requires the determination of the term "dimensionless time, $\bar{t}$ " which ordinarily is determined from a knowledge of permeability, porosity, length of internal radius and system compressibility, along with actual time involved, or, as shown in Reference No. 1, from the diffusivity constant and length of the internal radius. It is interesting, however, and particularly useful in the present application, to note that the interaction of the variables, porosity, pay thickness and internal radius (the factors which control the volume of the total pore space within the internal boundary) enter into the diffusivity constant in such a way that for any one given volume, the relation of pressure and production rate to time will be the same, regardless of the values of the individual variables. Expressed in another way, if the volume of the pore space within the internal boundary of the flow system is known, its pressure-production behavior

can be described by Muskat's above-referenced solution to the diffusivity equation without knowing specifically the value of any of the variables, porosity, pay thickness and internal radius.

Rearrangement of this equation of Muskat's is shown in this appendix, Figure II-5, in which the factor, dimensionless time, is shown to be expressed in terms of real time, transmissibility, volume of pore space within the internal boundary, compressibility and viscosity of the system. From this relation it is then possible, from the data of Figure I-1 of Appendix I, to calculate the volume of the pore space within the effective well bore radius of this well. The best fit of assumed values results in 3,200 barrels of pore space for volume within the internal boundary, and a transmissibility of .43 darcy feet. This transmissibility checks rather closely with the first approximation of transmissibility shown on Figure I-1. Since Figure I-1 is a pressure draw-down test and not a pressure build-up test, the method of determining transmissibility shown on Figure I-1 can only be assumed as approximate. A more accurate figure for transmissibility is the .43 darcy feet determined as described above. Example systems of different volumes within the r_w drainage area have been calculated and are plotted, along with the data of Figure I-1, to form the graph at the end of this appendix, Figure II-6. This shows that the curve represented by an internal volume of 3,200 barrels of oil pore space appears to be the best fit for the measured pressures between 1,510 pounds and 1,610 pounds. Example boundary effects are shown for one ratio of external boundary to internal boundary of 6.3. It is not necessary, of course, that the curves be matched for effect of boundary conditions in order to calculate the

transmissibility and pore volume within the internal radius. This can be done from the portion of the curve which is not affected by boundary conditions. The reason the effect of this one set of boundary conditions is shown is to give an approximation of the time at which the external boundary effects would become evident on the pressure draw-down curve. Since the curve for the 3,200 barrels internal pore space and transmissibility of .43 darcy feet has a distinctly flatter slope than that for the curve of the measured pressures, one might think at first that a system with lower transmissibility would better fit the data. This is not the case, however, as a system with lower transmissibility has a much greater draw-down pressure earlier (at a producing time of .02 to .05 of a day). In view of this, it is concluded that the difference in slope results from the fact that the shape of the r_w volume area is not circular. It is probable that the area is considerably longer than it is wide, and may in fact consist of more than one fracture extending at varying lengths from the well bore. Accordingly, one would not expect the curves calculated for a circular reservoir to fit exactly. Nevertheless, as explained in Reference No. 1 regarding calculations of reservoir properties from interference tests, it is not necessary to know the exact shape of this internal boundary to make a reasonable approximation of the value of the properties of the surrounding reservoir. It is probable that the internal volume calculated in this fashion is approximately correct, even though its exact shape is not known.

It is interesting in this particular case to compare the calculated reservoir volume of 3,200 barrels of pore space with the

volume of oil and sand used in the sand fracture treatment. It may be entirely happenstance that the volume of this r_w pore space in this well, calculated as described above and shown on Figure II-6, agrees so closely with the volume of sand and oil used in the sand fracture treatment. On the other hand, it is entirely possible that this means that most, if not all, of the oil that was used in this treatment and mixed with sand was effective in creating a larger well bore radius (the purpose, of course, for which it was used).

Assuming the method used to compute the r_w volume to apply, as described above, then under the conditions of this test, all properties are known with a high degree of accuracy, except one. The properties which are accurately known are production rate, pressure, actual time, viscosity and transmissibility. The one property which was not known rather accurately at that time was the system compressibility, C_e. For the calculations shown on Figure II-6, a system compressibility of 35×10^{-6} was used. If the true compressibility were different, the true volume would be proportionately different.

Variation of the calculated pore space of the r_w area with system compressibility is shown on the graph at the end of this appendix, Figure II-8. This shows a variation in r_w pore volume from about 2,200 to 5,600 barrels, for a variation in system compressibility from 20×10^{-6} to 50×10^{-6}. The principal factors affecting the compressibility of the system whose values are indefinite are formation compressibility and connate water. The relation of total system compressibility to formation compressibility and connate water

are shown at the end of this appendix, Figure II-7. For the range of the indefinite values of these properties, the system compressibility could range from 20 x 10^{-6} to 50 x 10^{-6}, as shown on this Figure II-7. The best estimate for system compressibility at this time is 35 x 10^{-6}, the area shaded on the graph, Figure II-7.

It is interesting to compare the data of Figure II-8 with the actual volumes of oil and sand used in the sand fracture treatment of this well. The data of Figure II-8 is shown again on Figure II-9 at the end of this appendix, on which has been added information regarding oil and sand volumes used in the sand fracture treatment of this well. This indicates most of the volume of the sand fracture treatment was effective in increasing the well bore radius.

Calculated transmissibilities, volumes of fracture blocks and approximate areas of fracture blocks resulting from the above-mentioned tests are set out below:

	FOR EACH FRACTURE BLOCK		
WELL	TRANSMISSIBILITY darcy feet	PORE VOLUME Stock tank barrels	AREA Acres
K-13	.018	8,000	30
A-23	.025	15,000	40
L-11	.43	57,000	70

The volumes of the tight blocks, calculated as described herein and set out above, are believed to be reasonably accurate. It is entirely possible that the true volumes would not vary more than 30 percent from those indicated above. Exact areas, of course,

can only be determined from further application of an estimate of the oil in place, the accuracy of which is unknown. It is believed the relation of transmissibility to pore volume, as described in Appendix III hereof, is reasonable, and accordingly the areas calculated above are probably within a factor of 2 to 1, that is, true volumes would probably not be smaller than one half the figures shown above nor greater than twice the figures shown above.

Calculation of Volume of Area of Tunnel
Block Around L-11 from Plan (Appendix II-)
Test of 9-24-65
(Reference Appendix II - fig II-5)
(& graph fig I-1)

For Assumed $\bar{x}$ = .45 decay feet
& V_{tr} = 3200 bbls

$$\frac{1.27 \times 10^{-3} \, kh \, \Delta P}{q \mu B} = \frac{(1.27)(.43)\Delta P}{(480)(1.035)(1.2)}$$

$$= .0192 \, \Delta P$$

$$V = \frac{3.54 \, kh \, t}{c_t \mu \phi} \qquad t = \frac{V c_t \mu \phi}{3.54 \, kh}$$

$$t = \frac{(3200)(3.5 \times 10^{-6})(.425)}{(3.54)(.43)} \bar{x} = .0458 \, \bar{x}$$

P_{wf}	$\Delta P = 1688 - P_{wf}$	$.0192 \times \Delta P$	$\bar{x}$	$t = .0458 \, \bar{x}$
1600	88	1.69	.75	.0856
1570	105	2.07	1.25	.0572
1540	125	2.46	1.95	.0893
1540	145	2.84	2.98	.136
1520	165	3.23	4.45	.204
1500	188	3.61	6.38	.292
1490	198	3.80	7.55	.346
1488	200	3.84	7.84	.355
1485	203	3.90	8.51	.374
1480	208	3.99	8.82	.403

$\bar{x}$ =	$\bar{x}$ =
6.3	8.4
7.7	9.9
12.2	15.6

(See Fig 22 of Rpt No. 1)

page 1
Appendix II - fig II-1

Since study of gas condition obtain after pressure declined to 1485 psi it is possible to calculate the volume in the drainage area for the 15 from the steady state formula:

$$\Delta P = \frac{q\mu B}{7.07\,Kh}\log_e \frac{r_e}{r_w}$$

Volume in r_w area, $V_w = \pi r_w^2 \phi h$

" " r_e " $V_e = \pi r_e^2 \phi h$

from which: $\frac{r_e}{r_w} = \sqrt{\frac{V_e}{V_w}}$

and $\Delta P = \frac{q\mu B}{7.07\,Kh}\log_e \sqrt{\frac{V_e}{V_w}}$

or $\log_e \sqrt{\frac{V_e}{V_w}} = \frac{(7.07)Kh\,\Delta P}{q\mu B}$

$= \frac{(7.07)(.43)(1685-1485)}{(450)(.024)(1.297)}$

$= .65$

from which $\sqrt{\frac{V_e}{V_w}} = 4.8$

$V_e = (4.8)^2 V_w$

$= 23\,V_w = (23)(32\text{ac})$

$= \pm 74{,}000$ bbl

of oil per square

$\frac{74{,}000}{1.297} = 57{,}000$ bbl (S.T.C.)

At 300 Bbls/acre (Y=2 relation of III-5) → 70% (pump 2) → APP. II fig II-1

CALCULATION OF VOLUME AND DIMENSIONS
OF TIGHT SAND AREA AROUND A-23
FROM BUILD DATA MAY 14-20, 1965
(ref graph fig E-2)

① First area near well bore, slope = 445 #/log cycle
Note that first 35 hours pressure was
below bubble point so Co for that time in
the Nw volume would be high. Total volume
of the Nw area is accordingly small
compared to my area obtained by only 445 #/
cycle drop noted. Effect will be to calculate
a larger volume than actually exists. The
higher transmissibility of the second (Nz)
area will act as "constant pressure" on
boundary of my area & accordingly
this my area can be calculated by
method of part III of reference 1.
Assume two times (Sphere Bubble)

ΔP = press @ 35 hours minus pressure
@ 80 hours (Nw 1.25 cycles)
= 1534 - 1492 = 104 #

$$\overline{\Delta P} = \frac{1.15\,\Delta P}{m} = \frac{(1.15)(104)}{445} = .27$$

from fig 15 of ref 1 for $\overline{\Delta P} = .27 \rightarrow \overline{t} = .36$

$$N_1 = \frac{5.615}{1.87\,m\,C_t\,\overline{t}} = \frac{(5.5)(4.25)}{(1.74)(.0005)(15\times10^{-6})(.36)}$$

= 15,000 bbls (3.7 ac.)

page 1
APP. II - fig II-1

Area of N. Volcano:

From fig III-5 & AIM III, for 1.025
dairy feet & between the "Y" & "Z" relations,
qh is equivalent to 350 bbls/acre (5%)

$\frac{15000 \text{ lbs.}}{350 \text{ lbs/acre}} = 43 \text{ acres}$ (RANGE 35-55%)

USE 40 acres

Page 2
APPENDIX II
fig II-2

Calculation of Volume of Flow Block around the M-13 Injection Well from Pressure Fall-off Test 10-16-64.

(ref. fig I-3)

Note: "Skin" effects using the same as for Drill. - Accordingly method of Pwf at end of use 1 applies.

ζ for 1.50" = 680 x10-6 (ref 1 - fig 3)

(stabilized)

Use pressures at 1400 minutes & 400 minutes:

$\Delta P = 1457^{\#} - 1358^{\#} = 93^{\#}$

$\overline{\Delta P} = \frac{.115\,\Delta P}{m} = \frac{(.115)(93)}{215} = .497$

$\overline{\zeta} = .15$ (slight ref 1)

$t = 400 \text{ minutes} = .277 \text{ days}$

$Q =$ (Converting to bbls of reservoir space) the 850 mcfd that was being injected

$Q = (Q_s)\left(\frac{P_s}{P}\right)\left(\frac{Z}{1}\right)\left(\frac{T}{T_s}\right)\left(\frac{1}{5.61}\right)$ Q_s = mcf/min

$= (850)\frac{(15.025)}{(1650)}\frac{(.85)}{(1)}\frac{(640)}{(520)}\frac{(1)}{(5.61)} = 1490$ (5.7=)

$= 1440$ bbls/day reservoir space $= \frac{1440}{1.27} = 1120$ bbls

$N = \frac{qt}{(1.74)m\,\zeta\overline{\zeta}} = \frac{(1120)(.277)}{(1.74)(21)(4.850\times10^{-6})(.15)}$

$= 5,000$ M (5000 thousand)

for 220 to 300 Depth =>

22 to 36 Wells - Avg (30) M

App II
Fig II-5

CALCULATION OF VOLUME & AREA OF LOAM (COMPARED TO RESERVOIR AVERAGE)
TRANSMISSIBILITY AROUND THE P-11 WELL
FROM TEST OF FEB-MAR-APR 1964
(ref. fig I-5)

① In light of other information, (as applied to the entire basin) new interpretation of the pressure buildup data as follows: the measured pressures than the interpretation shown on fig I-5, result is .84 decrease of stabilization is 42 days $m = 84^{\#}/cycle$

choose 6.0 days
$\Delta P = 1581 - 1565 = 16^{\#}$ $t = 6.0$ days

$$\Delta P = \frac{1.15\,\Delta P}{m} = \frac{(1.15)(16)}{89} = .21$$

$F = .3$ (page 15 of text)

$$N = \frac{q\,t}{1.74\,m\,c_t\,F} = \frac{(550)(6.0)}{(1.74)(89)(3 \times 10^{-6})(.3)}$$

$= 2,000,000$ bbls (STO)

@ $Kh = .84$. Bonus = 1,000
Actual: 1,000 Acres

Fig I-11
fig I-4

REARRANGEMENT OF MUSKAT'S (ref 1 fig 22) EQUATION FOR PRESSURE DECLINE AT THE INTERNAL BOUNDARY OF LARGE RESERVOIRS SUBJECT TO CONSTANT WITHDRAWAL RATE TO SUBSTITUTE VOLUME FOR THE VARIABLES ϕ, h, N

start with the equation: $$\frac{t}{} = \frac{6.328\, K t}{\phi\, 6\mu\, r^2} \quad (1)$$

multiply the numerator & denominator by the pay thickness, h; in fact;

$$\frac{t}{} = \frac{6.328\, Kht}{\phi h\, 6\mu r^2} \quad (2)$$

since Volume of pore space in the N, acre is: $V = \frac{\phi b r^2 \pi (7758)}{43,560}$ bbls/acre (3)

then $\phi h r^2 = \frac{V\, 43,560}{(7758)(\pi)} = 1.757\, V$ (4)

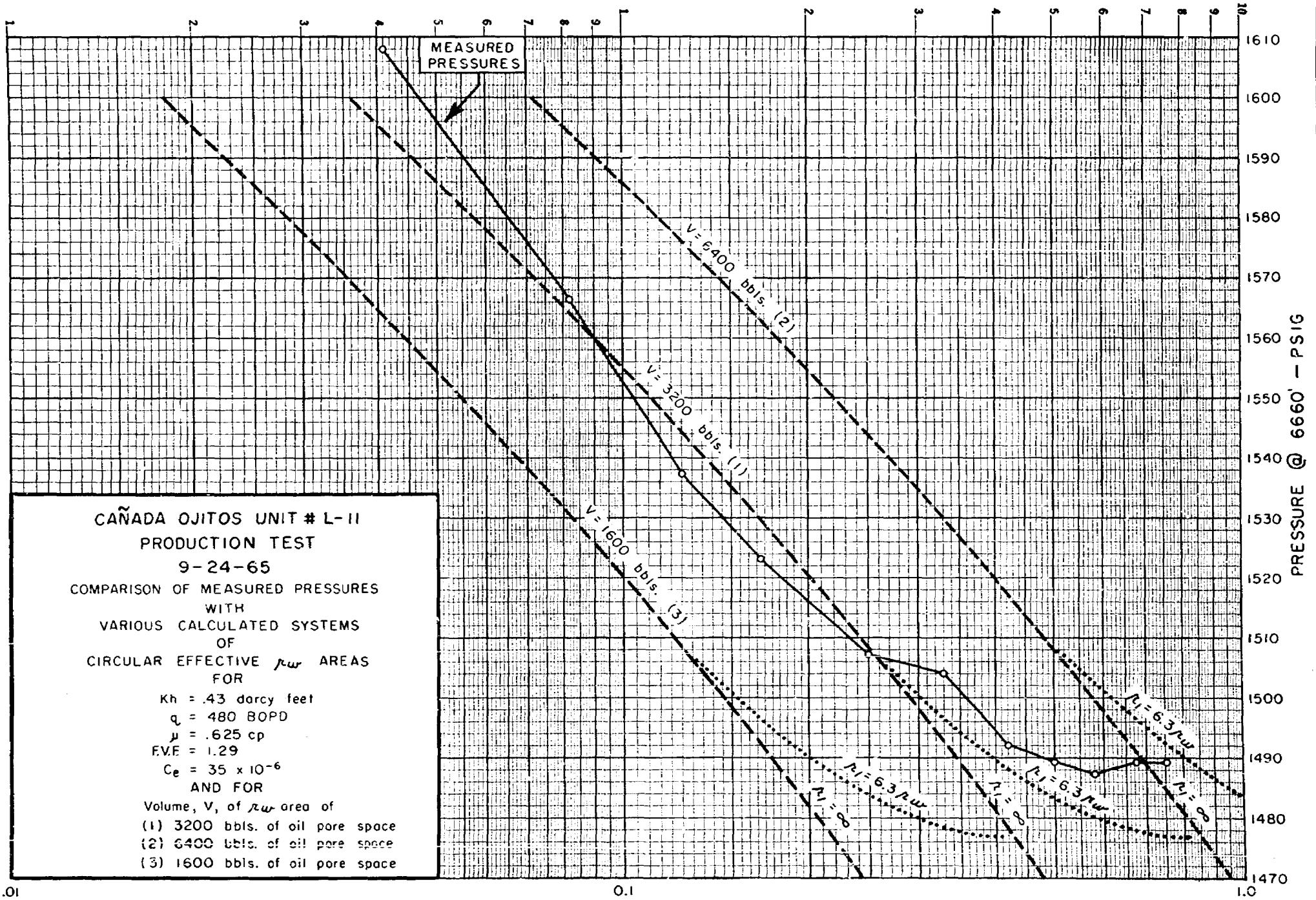
Substituting from (4) the value of $\phi h r^2$ in (2):

$$\frac{t}{} = \frac{6.328\, Kht}{1.787\, V\, 6\mu} = \frac{3.541\, Kht}{V\, 6\mu} \quad (5)$$

& $V = \frac{3.541\, Kh\,(t)}{6\mu\,(t)}$ bbls pore space / acre-ft

APPENDIX II fig II-5

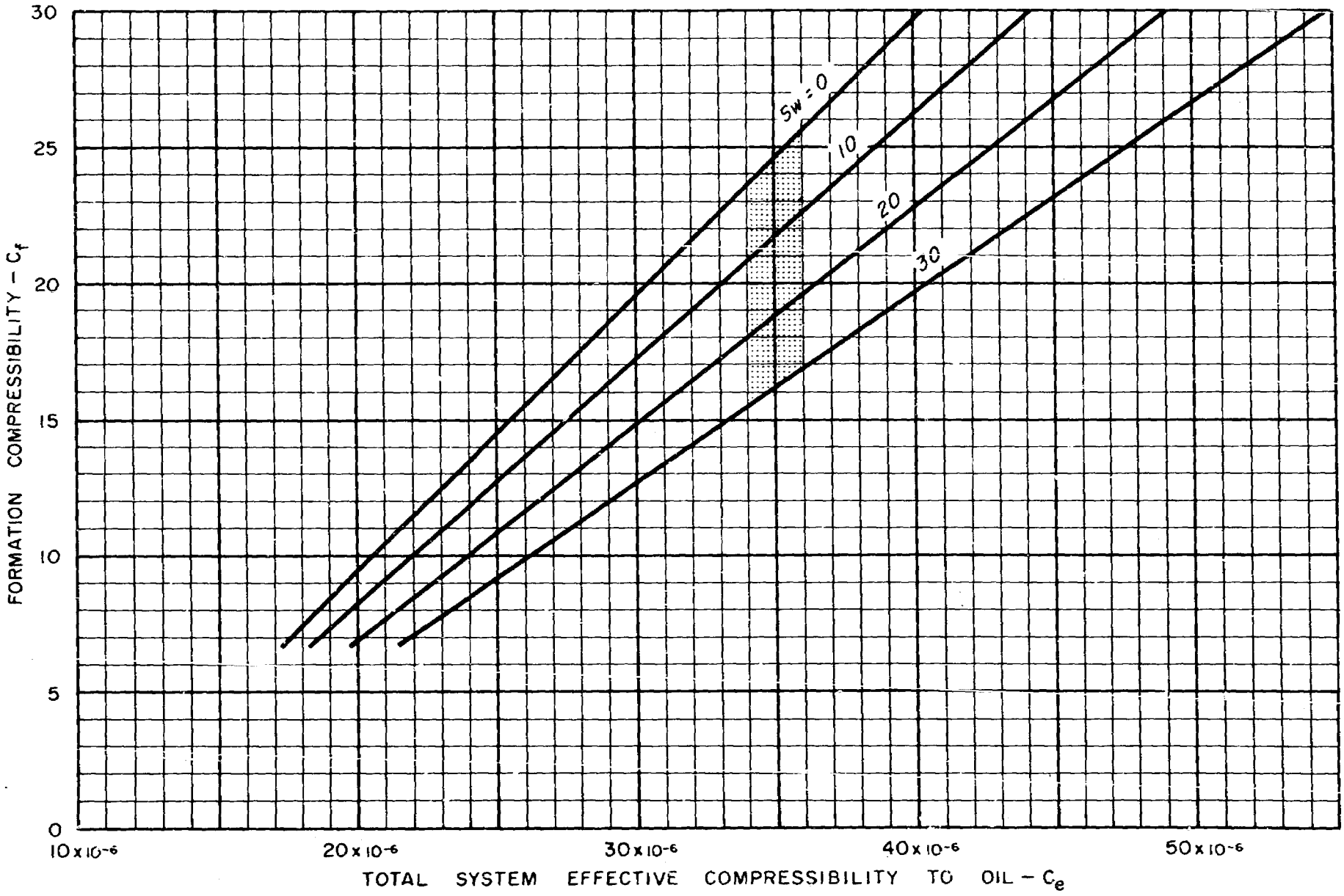
to get S.T.B. divide by B



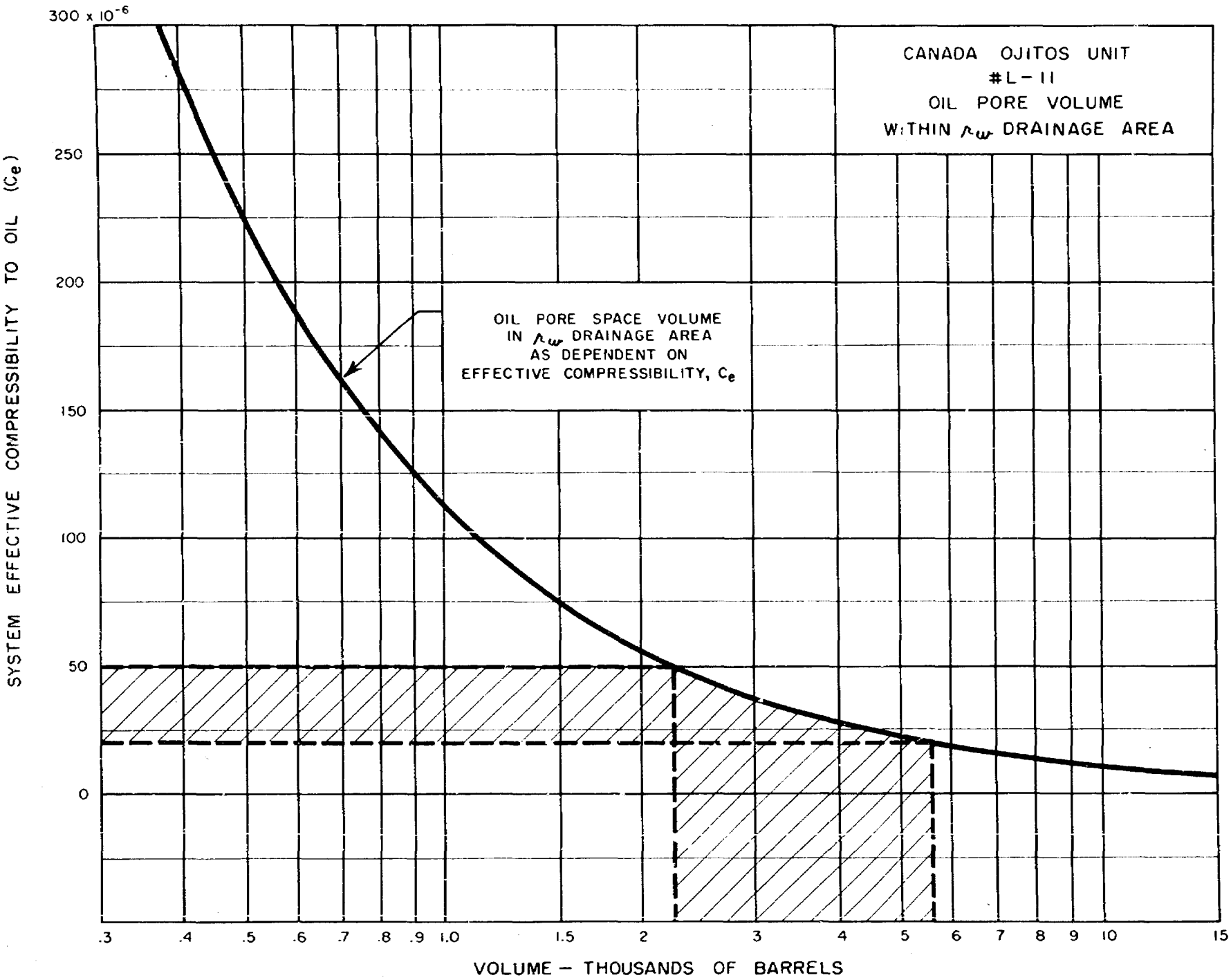
CAÑADA OJITOS UNIT # L-11
PRODUCTION TEST
9-24-65
COMPARISON OF MEASURED PRESSURES
WITH
VARIOUS CALCULATED SYSTEMS
OF
CIRCULAR EFFECTIVE r_w AREAS
FOR
Kh = .43 darcy feet
q = 480 BOPD
μ = .625 cp
F.V.F = 1.29
$C_e = 35 \times 10^{-6}$
AND FOR
Volume, V, of r_w area of
(1) 3200 bbls. of oil pore space
(2) 6400 bbls. of oil pore space
(3) 1600 bbls. of oil pore space

APPENDIX II FIGURE NO. II-6

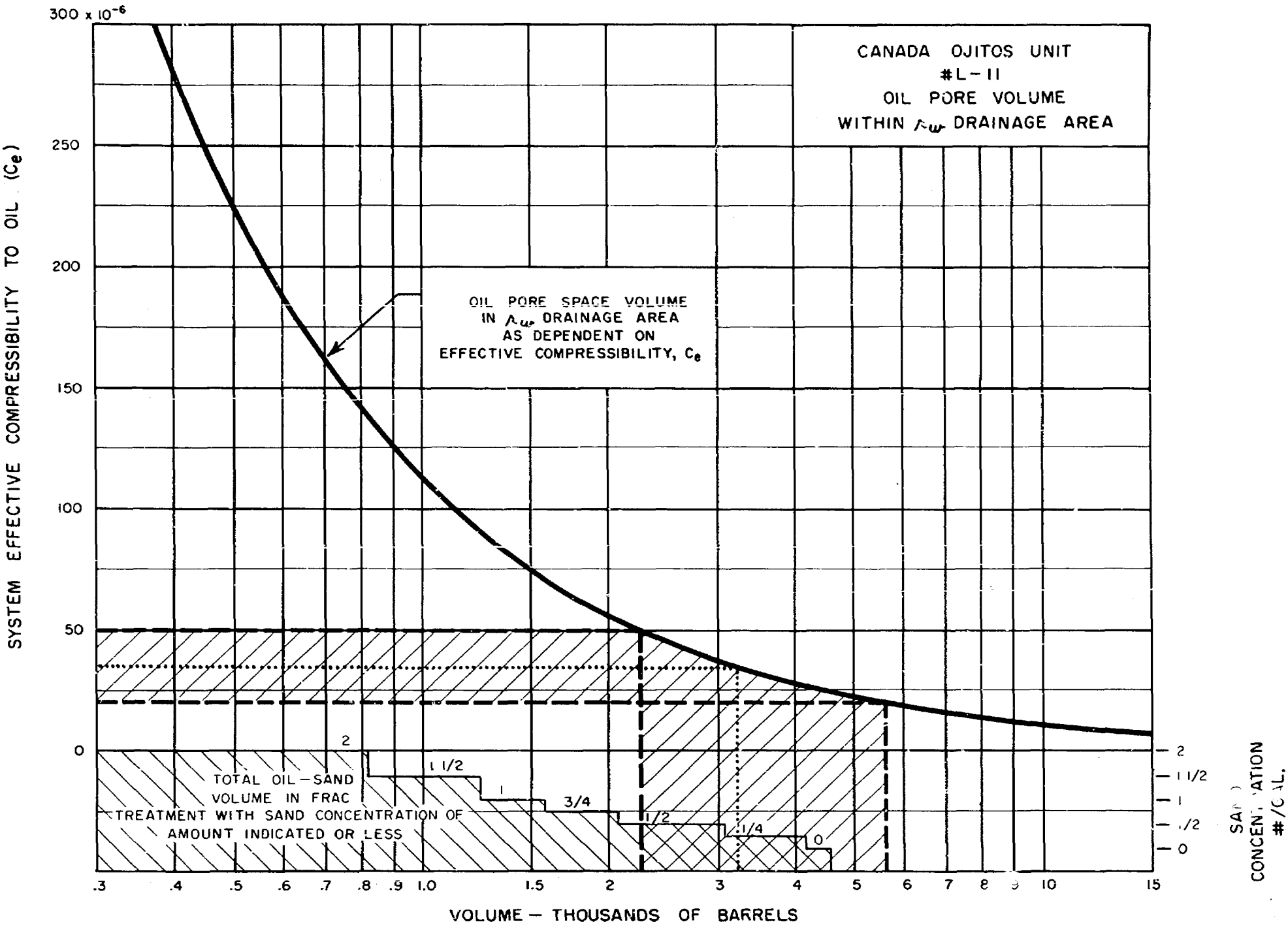
SYSTEM COMPRESSIBILITIES
FOR
PRESSURES ABOVE BUBBLE POINT
AND
NO FREE GAS SATURATION



APPENDIX II FIGURE NO. II-7



APPENDIX II FIGURE NO. II-8



APPENDIX II FIGURE NO. II-9

APPENDIX III

APPENDIX III

ESTIMATION OF PERCENT OF TOTAL RESERVOIR OIL OCCURRING IN THE HIGH CAPACITY FRACTURE SYSTEM

As described in Appendix II, this fractured shale reservoir comprises "blocks" of low transmissibility and a connecting high capacity fracture system. The combination of blocks and connecting fracture system is believed to be quite like a jigsaw puzzle. Identification of three blocks has been made, and method of measurement of contained oil volumes and surface areas of these blocks is set out in Appendix II.

Reservoir void space, which contributes to production in the high capacity fracture system, is without question fracture porosity. One must also conclude, from a study of the data available, that the same is true for the "tight" blocks forming a part of the total reservoir. Moreover, there are valid reasons indicating that a large part (half, or more) of the producible oil comes from the high capacity fracture system as opposed to the tight blocks, even though the tight blocks may form the larger part of the bulk volume of the reservoir.

If this be true, then any possible contribution of "seepage" of oil from shale matrix porosity to the oil production from the tight blocks must be inconsequential in overall reservoir performance. It is the opinion of Benson-Montin-Greer Drilling Corp. personnel that all effective reservoir porosity is fracture porosity - in the tight blocks as well as in the high capacity fracture system.

It is important in predicting reservoir performance to know approximately the share of total reservoir oil occurring in

the high capacity fracture system and in the tight blocks. From the standpoint of successful pressure maintenance by gas injection, it is imperative that a substantial part of the recoverable oil occurs in the high capacity fracture system. In time, information developed from the pressure maintenance measures now being carried on will provide this information. At this writing (December, 1969) the gas injection operations have not been conducted long enough to make such a determination, and, of course, the decision to institute pressure maintenance in the first place was made without such knowledge. The decision to initiate gas injection, insofar as the issue of share of total oil in the high capacity fracture system was concerned, was made from the analyses which follow.

The purpose of this appendix is to: (1) show the analyses and reasoning from which it was earlier concluded that a large percent of the producible oil existed in the high capacity fracture system, and (2) that for purposes of forecasting reservoir behavior under various methods of exploitation, a valid basic assumption at this time is that approximately one-half of the oil in place exists in the high capacity fracture system.

Although it is possible, as shown in Appendix II, to determine with a reasonably high degree of accuracy the transmissibilities of the tight blocks and to measure approximately their volumes and surface areas, it is impossible to measure directly either the transmissibility or the volume of the high capacity fracture system. In addition, there is no data available from other fields to aid by analogy in the solution of this problem. Our only tools are analyses of the fundamental relation of porosity and permeability of fractures and judgment of the probable physical reservoir conditions based upon logs, core analyses, observations

of cores themselves, and general well behavior.

We commence our analysis with three fundamental assumptions, each of which is discussed briefly below:

1. Pay Thickness. It is impossible to determine pay thickness exactly, and accordingly the calculations are made for a wide range of pay thicknesses in order that the effects of the variables can be appreciated. It is believed, however, that for the main producing wells in the West Puerto Chiquito Pool at this time the pay thickness of the zone contributing production is on the order of 20 to 50 feet in thickness. All of the zones which produce in either East or West Puerto Chiquito are shown on the electric log section, Figure III-1, at the end of this appendix. This log is a gamma ray induction log with induction scale of 10 ohm-meters per division. The three separate identifiable zones are shown in color. The "zip" type shading within each zone shows sections in which natural production occasionally has been found. This particular log is from a non-commercial well located in Section 18 of Township 25 North, Range 1 East. This log, however, is typical of the logs of all the wells in this area. There is no difference in logs of wells capable of commercial production and those which result in dry holes. It is apparent that the oil saturated sections are the same in the producers and non-producers. The only difference distinguishing productive from non-productive wells is the degree of fracturing and resultant fracture systems and reservoir void space.

An extensive coring program was conducted in Niobrara wells drilled in another of the San Juan Basin's fractured shale oil pools, La Plata Mancos. The resultant core analyses, when compared with gamma ray induction logs, has shown that significant oil

saturation in the Niobrara in this area exists only when induction resistivity of 20 to 30 ohm-meters or greater exists. In the oil saturated zones this high resistivity is usually accompanied by a distinctive radioactive reaction and this is registered on the radioactive side of the log. Resistivities less than 20 to 30 ohm-meters can only be water saturated. The colored intervals shown on Figure III-1 represent that part of the Niobrara in this area which is interpreted to be oil saturated. This is a total maximum pay thickness of all zones of approximately 150 feet. In this respect it should be noted that a high resistivity can also occur in zones that are highly calcareous with no oil saturation. Accordingly, the colored intervals of Figure III-1 can only be considered as representing maximum possible pay thicknesses.

To date production has not been found in all zones in any one well in either the East or West Puerto Chiquito Pools. East Puerto Chiquito produces only from Zones A and B, and so far production in West Puerto Chiquito has been only from Zone C. Free gas was encountered in Zone B in Well No. C-2 when it was first drilled, and accordingly it has been assumed that Zone B would be gas productive at structural positions higher than the datum in this well. Accordingly, completions in West Puerto Chiquito have been limited to Zone C. The relation of the C-2 well and its free gas in Zone B to the structure of the West Puerto Chiquito Pool in the vicinity of the main producing wells is shown on the plat at the end of this appendix, Figure III-2.

In the drilling, testing and completing of wells in the East and West Puerto Chiquito Pools, a considerable amount of evidence has been developed which shows separation of the zones

within the Niobrara. This existence of free gas in Zone B of the C-2 well gives further confirmation that the individual zones as shown on Figure III-1 (particularly Zone C as compared to Zones A and B) are isolated from each other from a standpoint of communication. As seen from Figure III-1, the maximum vertical separation of free gas in Zone B (top) from the oil producing interval in Zone C (base) is 200 feet. If Zones B and C were in good communication, then free gas necessarily would exist in Zone C at a structural position 200 feet up-dip from the C-2 datum. Instead, wells P-11, A-14 and K-13, which are from 200 to 440 feet up-dip from the C-2, produced oil from Zone C with no free gas. Only poor communication has been noted between Zones B and C as compared with communication within Zone C itself, and it is believed that any communication so far found between these two zones could easily be "man-made", as for instance the inadvertent connecting of the two zones through sand fracture treatments. This isolation of the zones within the Mancos is not uncommon. In the Gallegos Gallup Pool, four separate zones were identified with four different gas-oil contacts. One possible explanation for the isolation of the zones is that the productive intervals are for some reason more brittle than the rest of the shale and retain their fracture systems better than the more plastic intervening beds which either never fractured in the first place or if they did, in time "flowed" back to their original impermeable states. It is not the purpose of this paper to go into the origin of the reservoirs, and this separation of zones is noted here only for the purpose of determining the approximate range of pay thicknesses applicable to production from wells completed in Zone C.

2. Oil in place per acre. From the interference test reported at the 1966 hearing, oil in place per acre was calculated to be in the range of 1,000 to 2,500 barrels per acre, depending upon the unknown compressibility of the fractured shale reservoir rock. At this time our best estimate of total compressibility of the system to oil at the time of the interference test is 35×10^{-6}, which gives a per acre oil in place figure of 1,500 stock tank barrels. Average transmissibility was determined by the same interference test to be approximately 6.5 darcy feet. These figures of oil in place per acre and transmissibility are for Zone C only. Whether significant production will be found in other zones is not yet known. If it is found in Zone B it will, of course, have to be at positions structurally lower than the C-2 well, and accordingly can only cover a part of the reservoir. For the purpose of this study it is essential that we deal only with the one zone about which some direct knowledge is available as to average pore volume and transmissibility. Although it is, of course, impossible to determine these properties exactly, it is believed the information available provides data of sufficient accuracy to form a basis for the analyses of this Appendix III. Comparative figures are noted for other reservoirs: (a) Gallegos Gallup, 3,000 barrels per acre in place for the sum of four separate zones, calculated from material balance estimates; (b) Boulder Pool, 2,000 to 4,000 barrels per acre for all zones, calculated from material balance.

3. The reservoir comprises individual blocks of comparatively low transmissibility and an interconnecting high capacity fracture system. The per acre oil in place figure and transmissibility given above represent overall averages. That is, the average oil in place per acre is 1,500 barrels and the total transmissibility from both the high capacity fracture system and the tighter blocks is 6.5 darcy feet. A note in this respect is that this information was determined as a result of an interference test taken at a time when the reservoir pressure was above the bubble point and the resulting diffusivity constant of all parts of the reservoir, including the tighter blocks, was quite high. For example, a tight block with a transmissibility of .1 darcy feet and gross surface dimensions of approximately 1,000 feet across would require about six hours from the initiation of pressure differential to reach steady state conditions. Since the data used in the interference test was for a period of six to eighteen days, with an approximate time of thirty days for steady state conditions to be reached in the overall reservoir, it is apparent that any error introduced in the interference test as a result of lag of pressure communication across these blocks of low transmissibility would be negligible. The resulting calculations accordingly include the volume and transmissibility of these tight blocks as well as for the high capacity fracture system.

To commence our analysis, we draw on an earlier study (Reference No. III-1) in which porosity-permeability relations and diffusivity constants are compared for sandstone reservoirs and fractured reservoirs. Figure III-3 at the end of this appendix is reproduced from this reference. On this figure is shown the general

range of porosity-permeability relations for systems of fractures in which the fractures are oriented parallel to the direction of flow. The fracture systems shown are for 1, 10 and 100 fractures per foot and for various sizes and various widths of fractures. We assume, of course, that in the reservoir a large number of the fractures will be perpendicular to the direction of flow and as such will increase the porosity for any one of the systems shown on Figure III-3 at a greater rate than it will increase the permeability parallel to the direction of flow, and accordingly if we modify the systems shown on Figure III-3 by increasing porosity (through fractures at an angle to direction of flow) they would, in a sense, move upward on the graph. It is possible, of course, that the general slope of the systems also would change. It is doubtful, however, that the slope would change much, for it is axiomatic that at some point of exceptionally high porosity the permeabilities of the sandstone and fracture systems would necessarily be the same. Accordingly the two systems must converge when plotted on a graph such as Figure III-3.

One might expect core analyses to provide the information whereby the nature of the fracture system could be defined. This type information is, however, quite limited in its usefulness for this purpose. Only one well in every ten or twenty drilled in East and West Puerto Chiquito has resulted in one capable of commercial production without stimulation; and none of the wells that were cored have been capable of high rates of natural production. Accordingly the cores so far taken cannot definitely be said to be representative of that part of the reservoir which contributes significantly to production.

Information from core data that is of value to this study is briefly described as follows:

(1) Both horizontal and vertical fractures have been observed in cores.

(2) The horizontal fractures are usually of very narrow width (hairline); whereas the vertical fractures appear to possibly have comparatively greater width.

(3) Density of the horizontal hairline fractures seems to be in the range of 10 to 100 fractures per foot. Certainly 100 fractures per foot would be the maximum. An average density of the horizontal fractures in the zones where they occur would be more on the order of 10 per foot.

(4) As to density of vertical fractures, occasionally one or two sloping fractures across a 50-foot core have been observed in some cores, and in others no vertical fractures at all were found. Since the core holes were nearly vertical, as were the fractures, and hence hole and fractures nearly parallel, an ordinary well cannot be expected to adequately "sample" the vertical fracture system. In the cores taken, however, a maximum density of vertical fractures would be in the range of one per foot.

Accordingly, at this time, from the core data available, we assume that a maximum porosity to permeability relation would be a pore space of twice that shown on Figure III-3 for 100 fractures per foot, and for a minimum, twice the pore space shown thereon for 10 fractures per foot. These two relations are shown on Figure III-4 as lines A and C, with the area in between shaded and the center line of it given designation B.

From these porosity-permeability relationships it is of course possible to calculate oil in place per acre for various "mixes" of transmissibilities of tight blocks and high capacity fracture systems, and from this to reach our objective, i.e., the percent of the total oil which occurs in the high capacity fracture system.

First we determine oil in place per acre for the three porosity-permeability relationships A, B and C of Figure III-4. This has been done for various assumed thicknesses of pay section. Regarding pay thicknesses, it is noted that for the slope of the porosity-permeability relationship shown on Figure III-4 there is a 3 to 1 relation of pore space to permeability for the lines: A compared to B; and B compared to C. That is, for any given pay thickness using the porosity-permeability relationship of A, and the same total transmissibility (Kh), total oil in place (barrels per acre) can be obtained with relation B and three times the pay thickness used for A, and likewise relation C with nine times the pay thickness used for A will give the same reservoir characteristics of transmissibility to pore volume. Accordingly oil in place (stock tank barrels per acre) was calculated for the following three sets of conditions:

(1)	67	feet of pay with porosity-permeability relationship	A.
	200	" " " " " " "	B.
	600	" " " " " " "	C.
(2)	33	feet of pay with porosity-permeability relationship	A.
	100	" " " " " " "	B.
	300	" " " " " " "	C.
(3)	17	feet of pay with porosity-permeability relationship	A.
	50	" " " " " " "	B.
	150	" " " " " " "	C.

These three relationships of oil in place per acre versus transmissibility are shown at the end of this appendix, Figure III-5, and given designations X, Y and Z.

Next we determine the relation of total reservoir transmissibility to the transmissibilities of its component parts for the range of values of this property known to exist in the subject reservoir. This relation was prepared for a range of 1 to 10 darcy feet for total reservoir transmissibility, and for a range of 1 to 1,000 darcy feet for transmissibility of the high capacity fracture system; all for two different transmissibilities of the low capacity (tight) blocks of .01 darcy feet and .10 darcy feet. These relations are shown on Figure III-6. As can be seen from Figure III-6, for the ranges of total transmissibility in which we are interested (2 to 10 darcy feet) the relation of total transmissibility to transmissibility of that part of the reservoir which is high capacity fracture system is the same whether the transmissibility of the tight blocks is .01 darcy feet or .10 darcy feet. Although not shown on Figure III-6, for the range of 5 to 10 darcy feet total reservoir transmissibility, the relation also is nearly the same as that shown on Figure III-6 for systems in which the transmissibility of the tight blocks is as high as 1 darcy foot.

Accordingly for the subject reservoir we can state unqualifiedly that Figure III-6 represents the relation of total transmissibility to transmissibility of the high capacity fracture system for the percentages of bulk volume of the reservoir shown. For example, if we assume the total transmissibility is 6 darcy feet and that 2 percent of the bulk volume of the reservoir exists as high capacity fracture system, then the transmissibility of the high capacity fracture system must be 300 darcy feet.

From Figures III-5 and III-6 we can now compute the average amount of oil in place per acre for any given combination of reservoir bulk volume of high capacity fracture system and low capacity fracture blocks. The results of this for systems X, Y and Z are shown on Figures III-7, III-8 and III-9. On each of these figures is shown by dotted lines the 6.5 darcy feet and 1,500 barrels per acre values which represent the situation in West Puerto Chiquito. For the relations X, Y and Z of Figure III-5 the minimum bulk volume of the reservoir which was determined to be occupied by high capacity fracture system would be about 4 to 5 percent as shown on Figure III-7 (X relation of Figure III-5). It could be as high as 70 percent if the data of Figure III-9 were to apply (Z relation of Figure III-5). Figure III-7 (which results from the X relation of Figure III-5) is considered a maximum in terms of pay thickness. The true situation probably lies between the amounts shown between Figures III-8 and III-9 (Y and Z relations of Figure III-5) which would place the bulk volume of the high capacity fracture system between 20 and 70 percent of the total bulk volume of the reservoir.

It is interesting to note that a substantially greater percent of total oil in place lies within the high capacity fracture system than is represented by its share of the total bulk volume of the reservoir. From the calculations underlying Figures III-7, III-8 and III-9 we can determine the percent of total oil which occurs in the high capacity fracture system for any given percent of reservoir bulk volume which forms the high capacity fracture system. Oddly enough, this relation is exactly the same for all three of the X, Y and Z relations of Figure III-5 and is apparently a function

only of the slope of the line relating porosity to permeability as shown on Figure III-4. For example, for a total reservoir system with a transmissibility of 5 darcy feet, if 1 percent of the bulk volume of the reservoir exists in the high capacity fracture system, then 14 percent of the total oil in place exists in this same system. If as much as 10 percent of the bulk volume of the reservoir is in the high capacity fracture system, then 47 percent of the total oil in place exists in this same fracture system. This relation, percent of oil in place in the high capacity fracture system as a function of its percent of bulk volume, is shown on Figure III-10.

Accordingly, if the true situation is represented by something in the range of that given by Figures III-7 and III-8 (20 to 70 percent of the bulk volume of the reservoir being occupied by high capacity fracture system) then for 5 darcy feet the percent of the total oil in place that is in the high capacity fracture system lies between 61 percent and 82 percent of the total oil in place in the reservoir.

It is logical to presume that of the oil in place in the reservoir, a higher percent of that in the high capacity system will be recovered as compared to that in the low capacity part of the fracture system. Following this, then, if we think in terms of recoverable oil, that part of the oil in the high capacity fracture system must represent an even greater part of the total recoverable oil than the figures mentioned above.

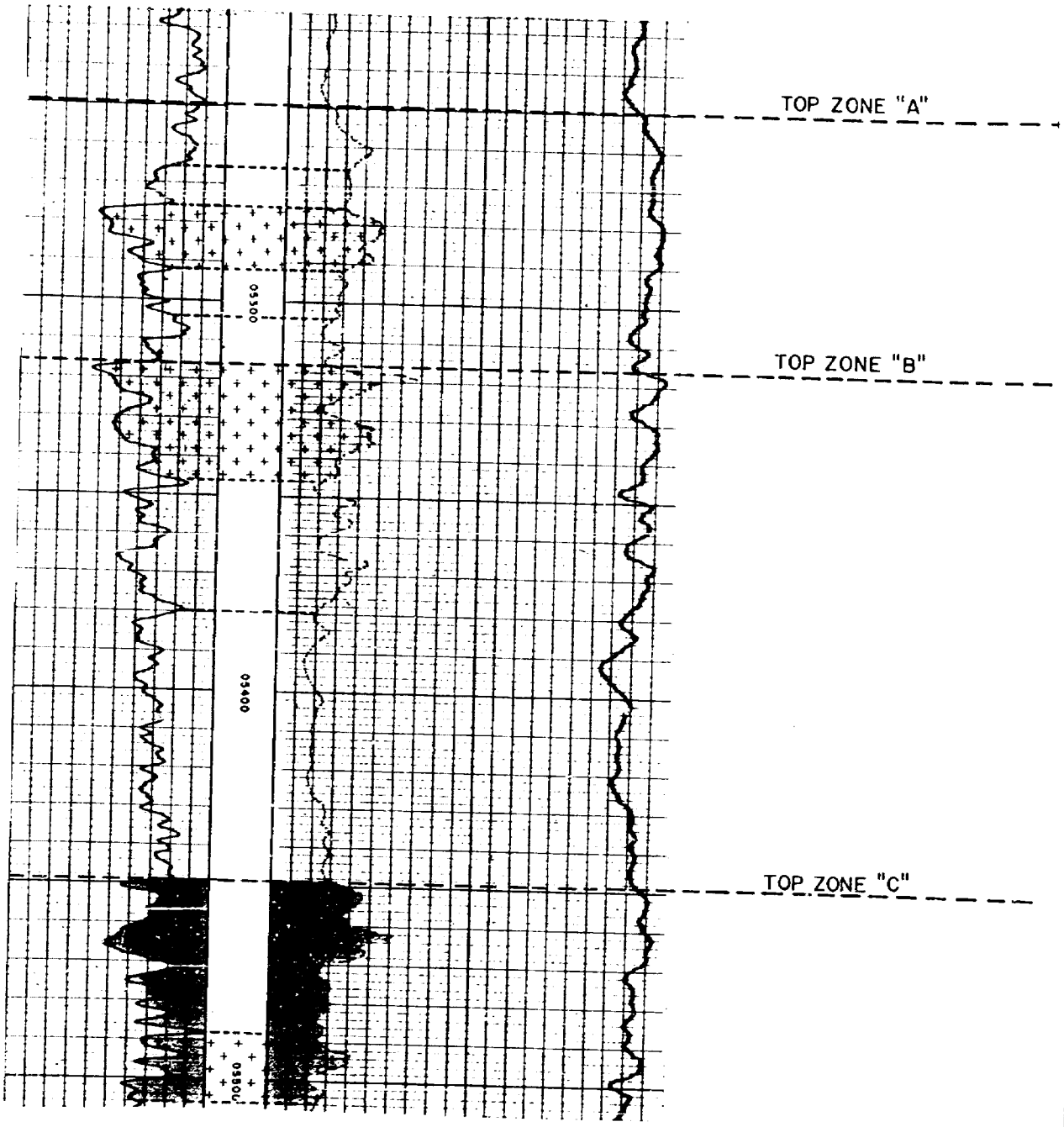
Obviously it is impossible to determine precisely the percent of oil in the high capacity fracture system. For the purposes of analysis of reservoir behavior and planning for pressure

maintenance, we believe it is reasonable to assume, from the information in this Appendix III, that approximately half of the total reservoir oil is in the high capacity fracture system and approximately half of it in the low capacity blocks.

IDENTIFICATION OF MAIN PRODUCING ZONES
NORTHEAST PUERTO CHIQUITO
AND
SOUTHWEST PUERTO CHIQUITO

BENSON-MONTIN-GREER DRLG. CORP.

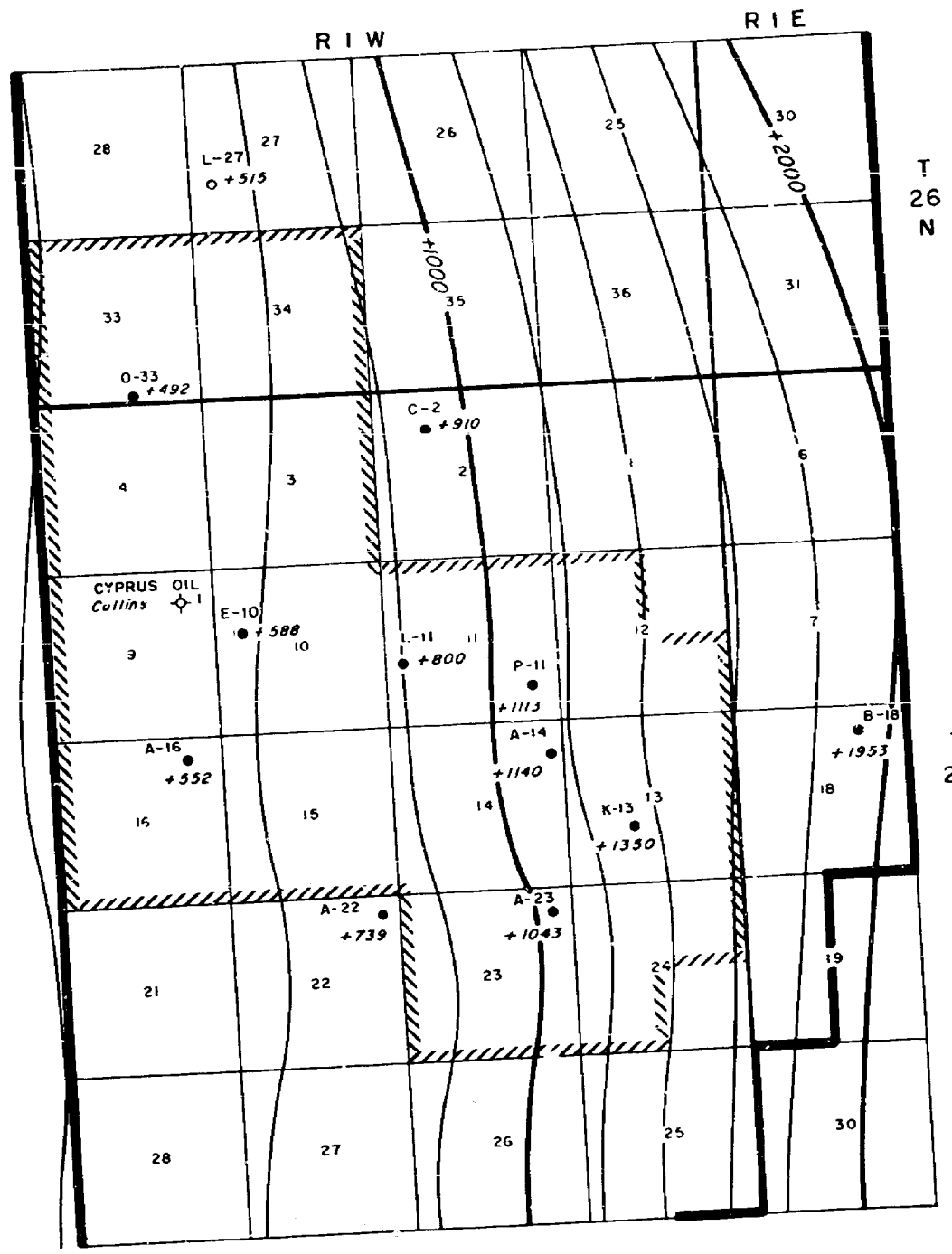
CAÑADA OJITOS UNIT NO. B-18



APPENDIX III FIGURE NO. III-1

PLAT OF PART
OF
CAÑADA OJITOS UNIT

CONTOURED ON TOP OF "A" MARKER
C. I. 200'
NOVEMBER, 1969



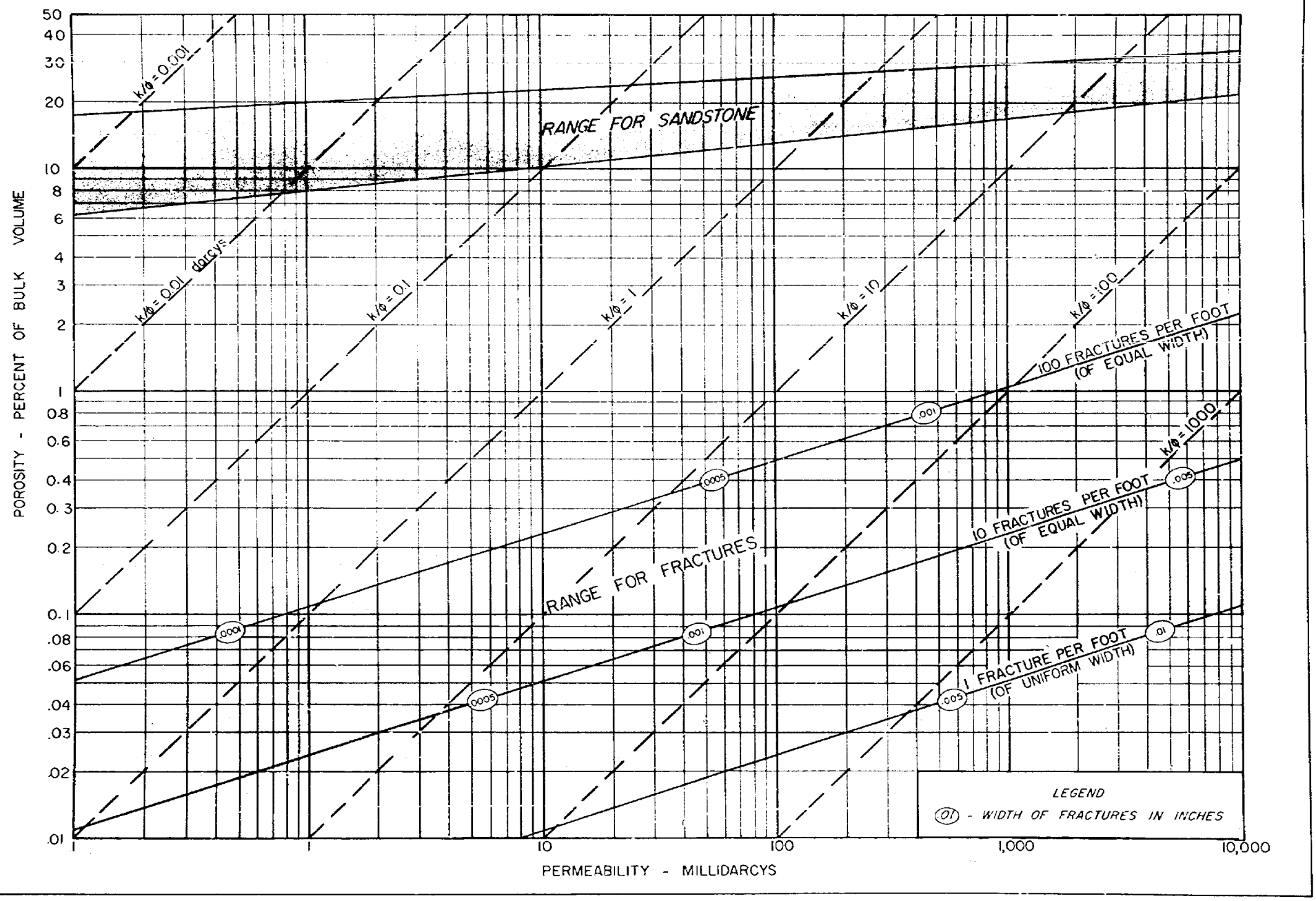
BOUNDARY OF PARTICIPATING AREA AFTER FIFTH EXPANSION

BOUNDARY OF CAÑADA OJITOS UNIT

APPENDIX III FIGURE NO. III-2

VALUES OF K/φ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

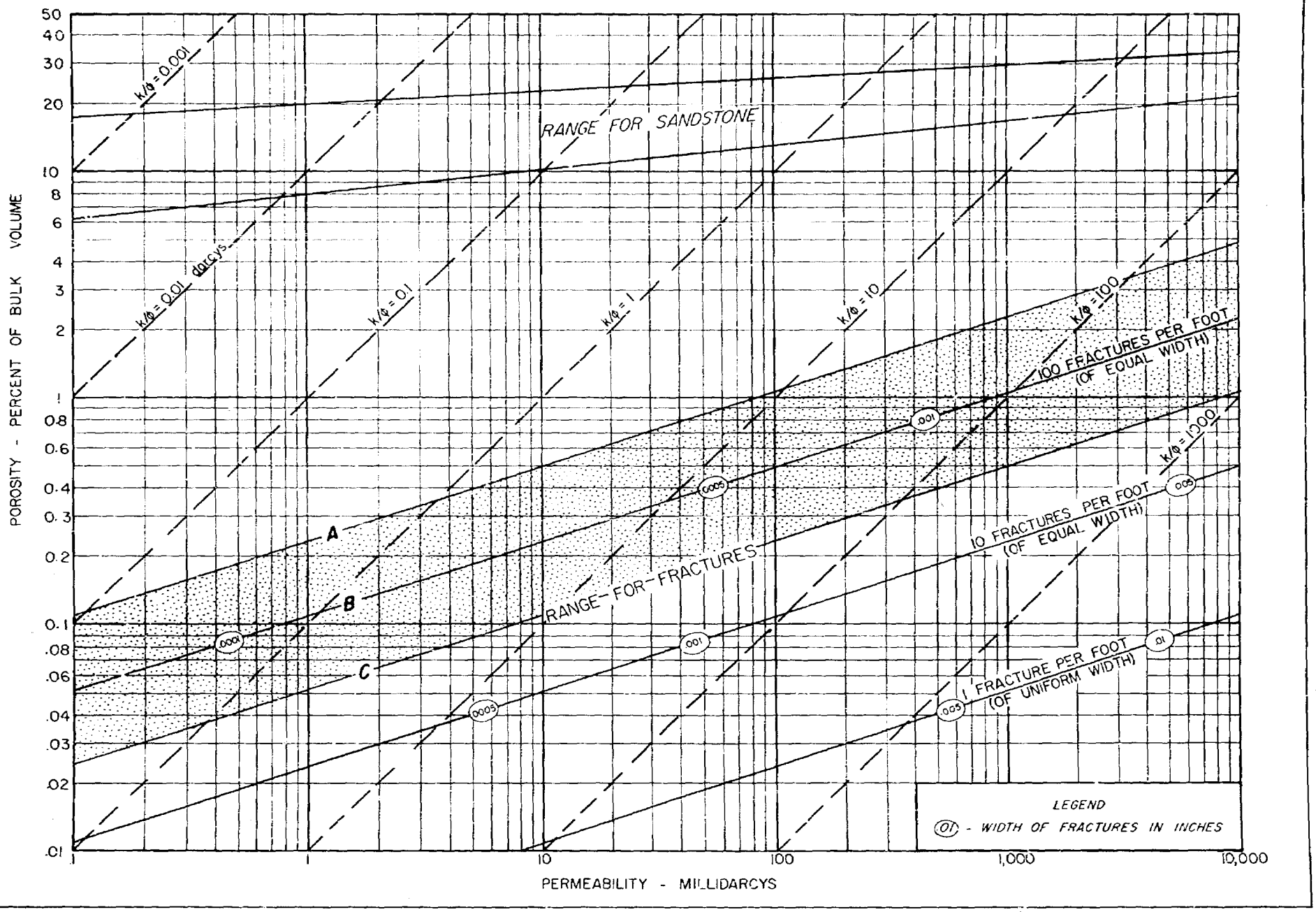
FRACTURES PARALLEL TO DIRECTION OF FLOW



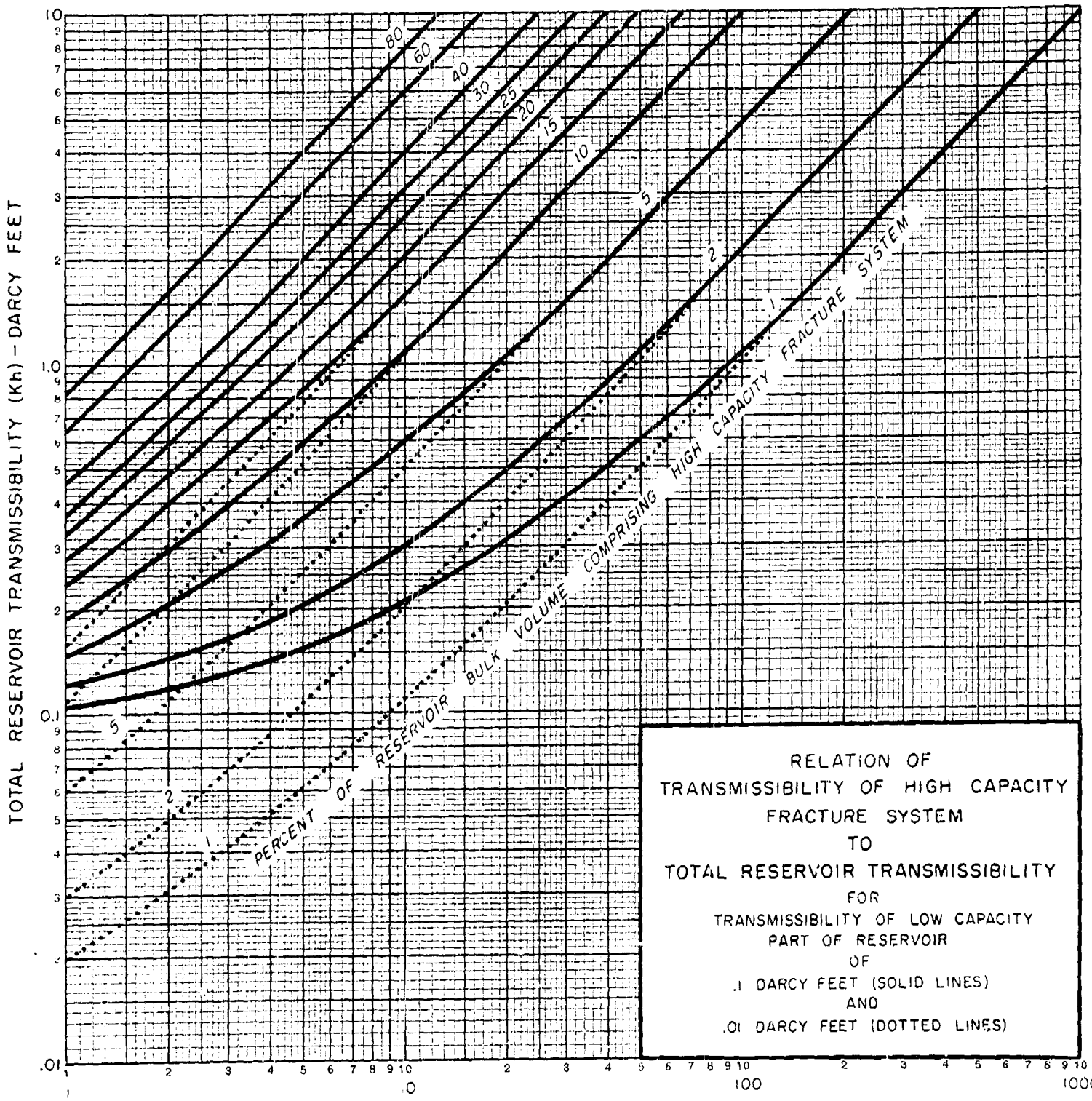
APPENDIX III FIGURE NO. III-3

VALUES OF KΦ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

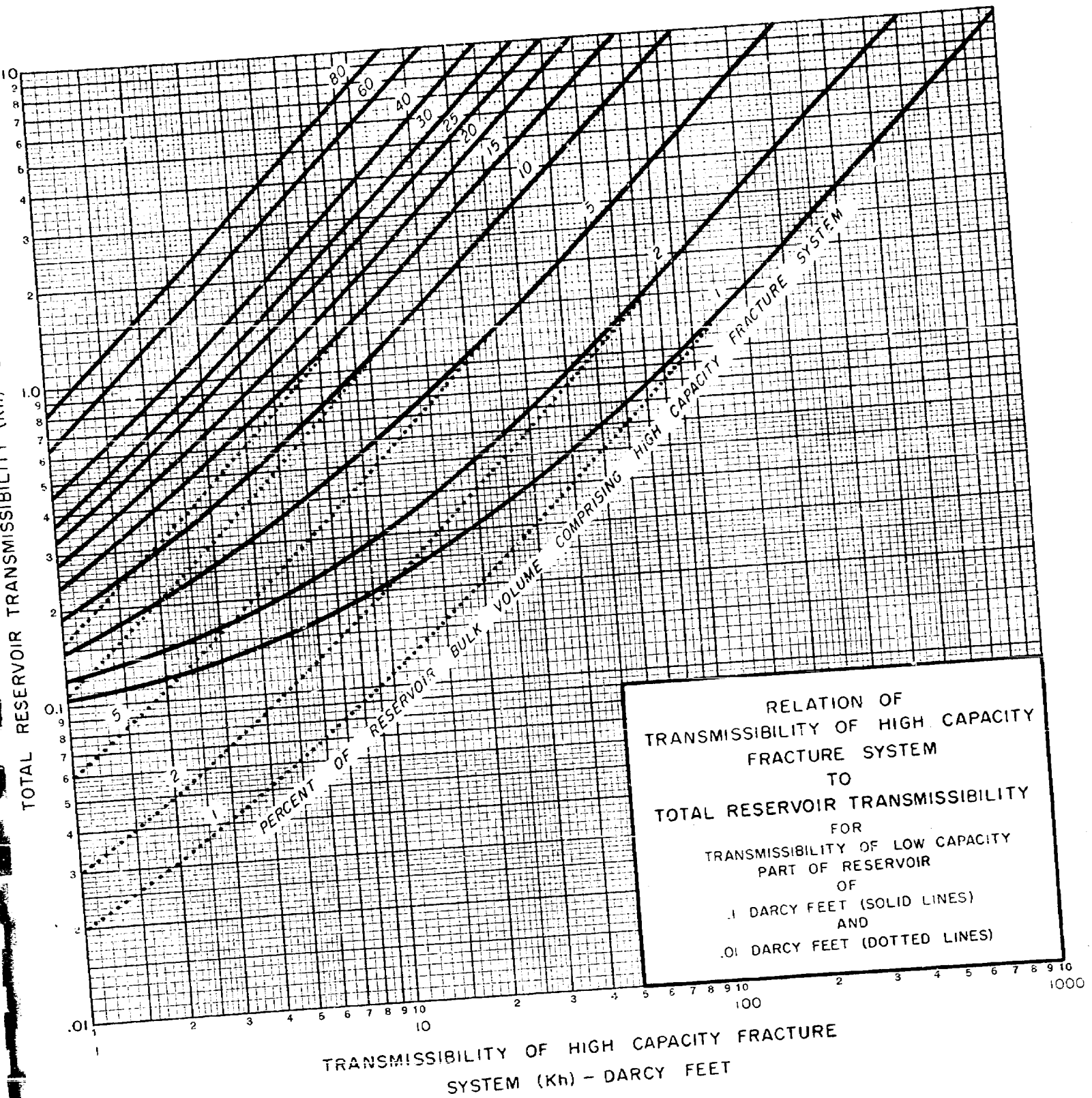
FRACTURES PARALLEL TO DIRECTION OF FLOW



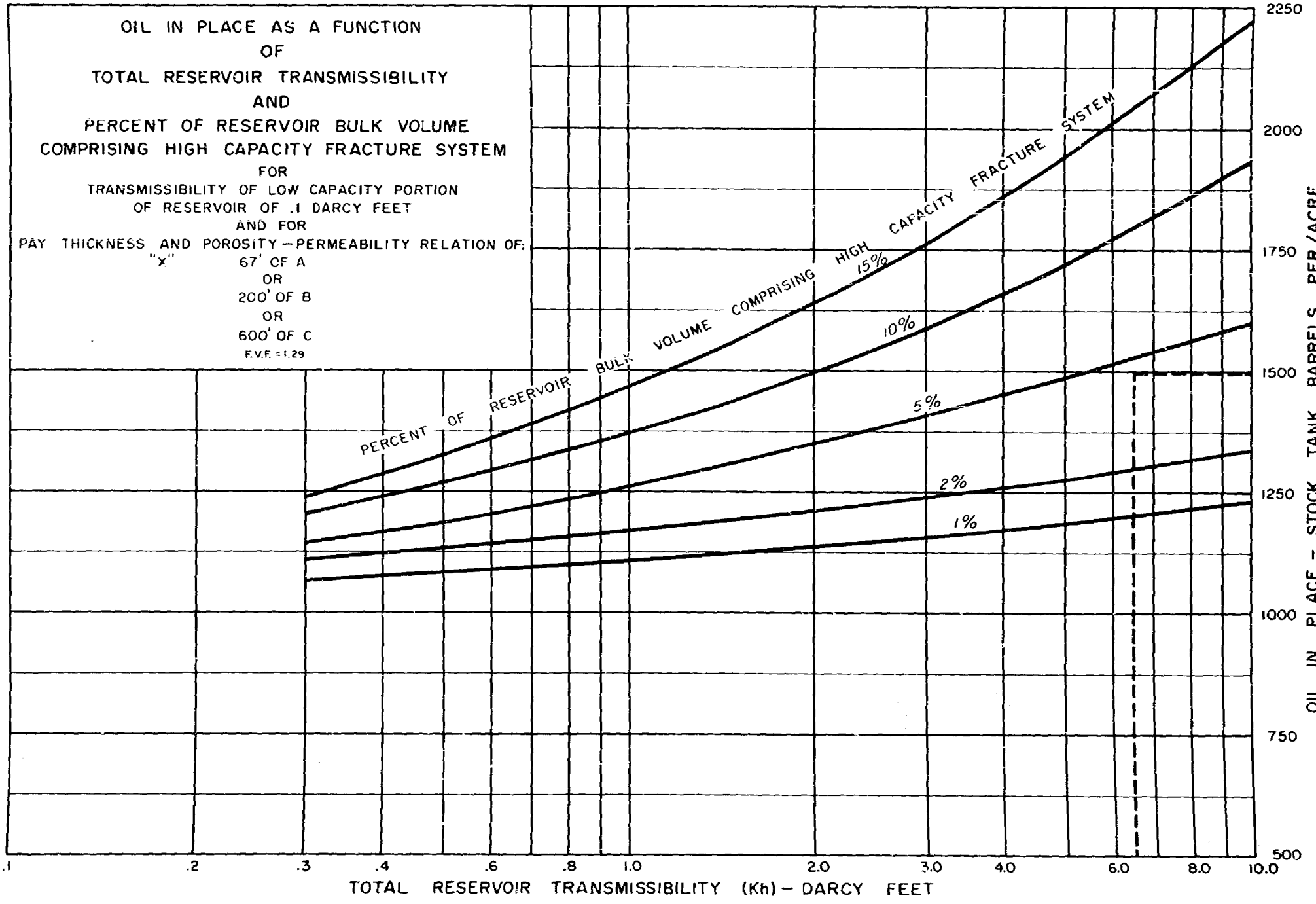
APPENDIX III FIGURE NO. III-4



APPENDIX III FIGURE NO. III-6

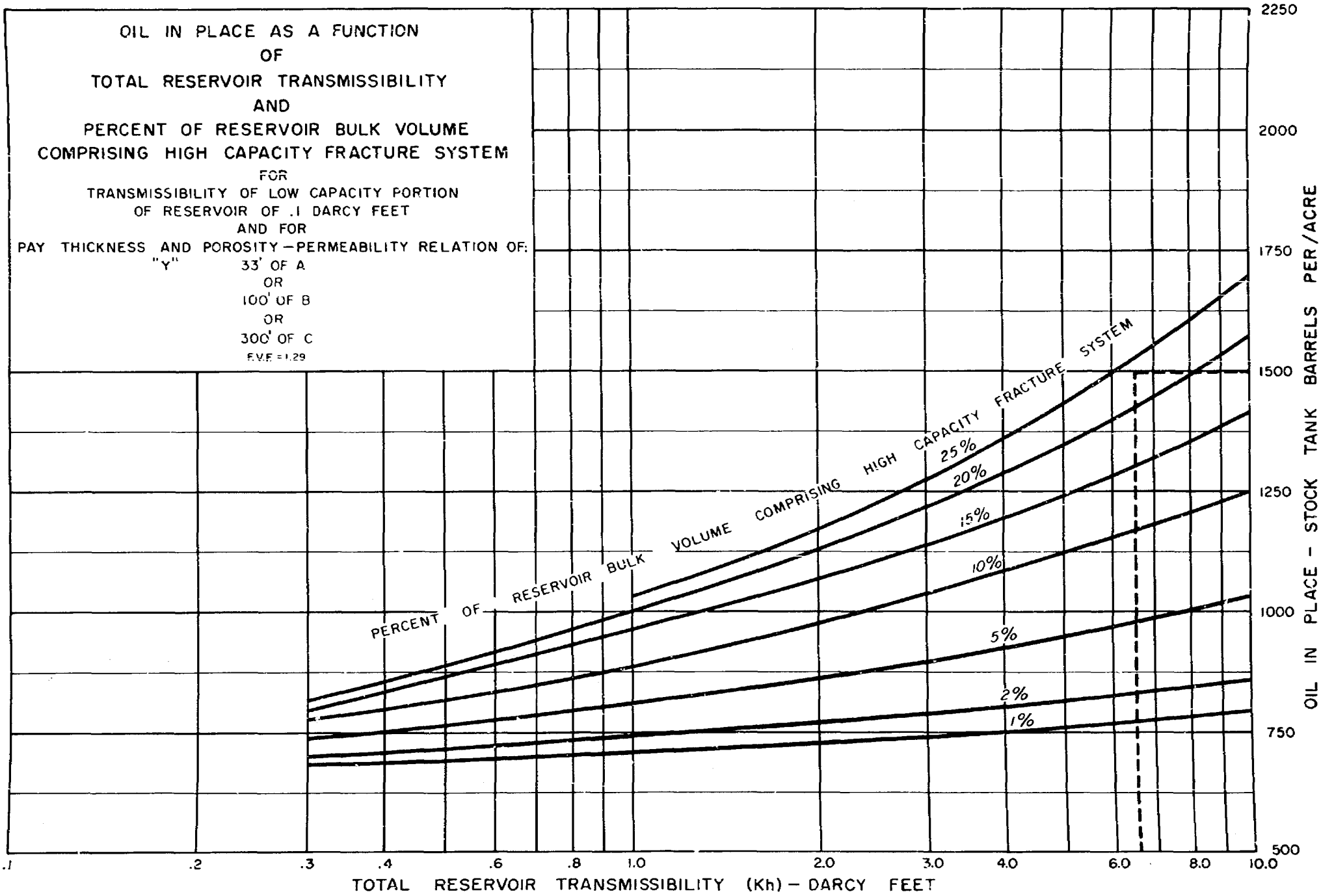


APPENDIX III FIGURE NO. III-6



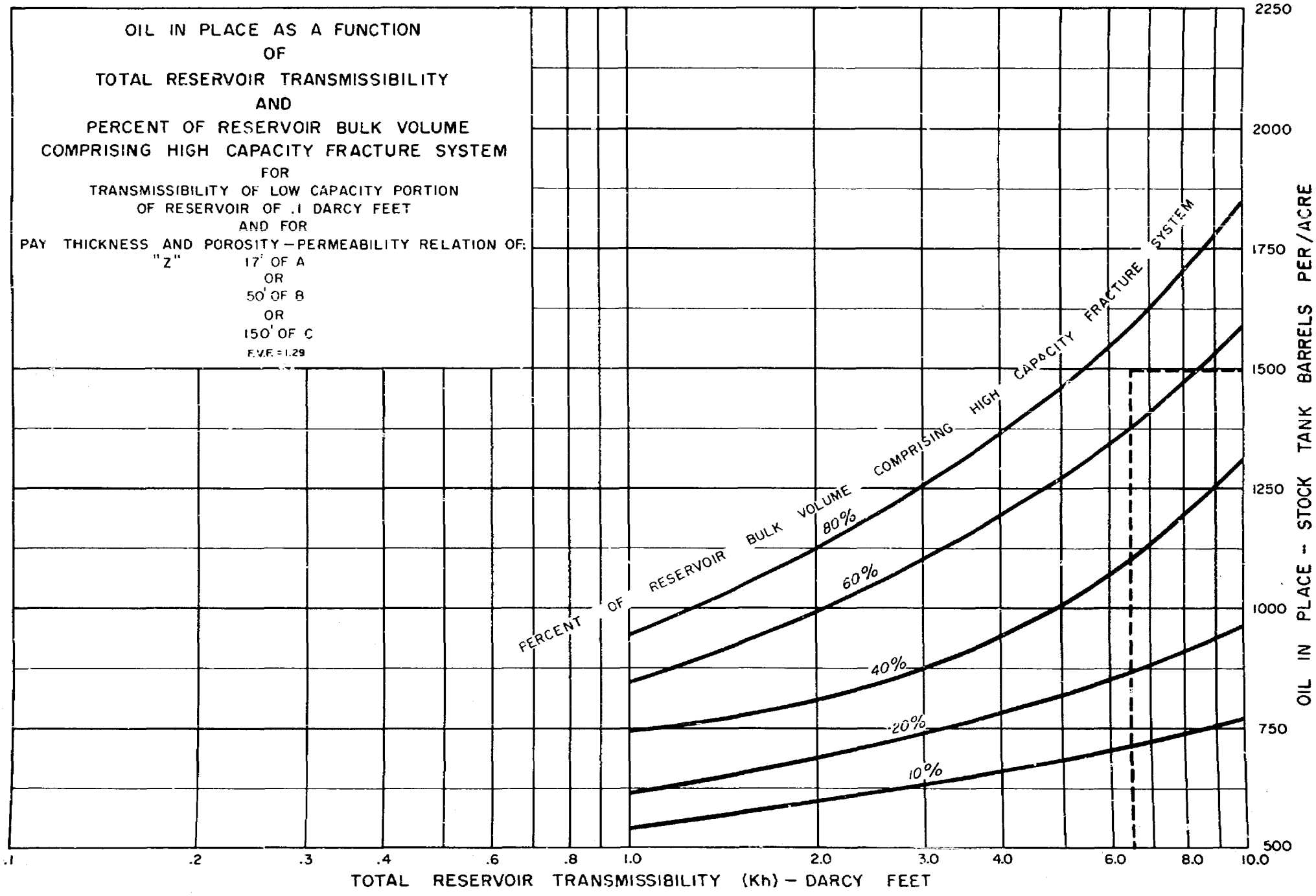
APPENDIX III FIGURE NO. III-7

OIL IN PLACE AS A FUNCTION
OF
TOTAL RESERVOIR TRANSMISSIBILITY
AND
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING HIGH CAPACITY FRACTURE SYSTEM
FOR
TRANSMISSIBILITY OF LOW CAPACITY PORTION
OF RESERVOIR OF .1 DARCY FEET
AND FOR
PAY THICKNESS AND POROSITY – PERMEABILITY RELATION OF:
"Y" 33' OF A
OR
100' OF B
OR
300' OF C
E.V.F. = 1.29



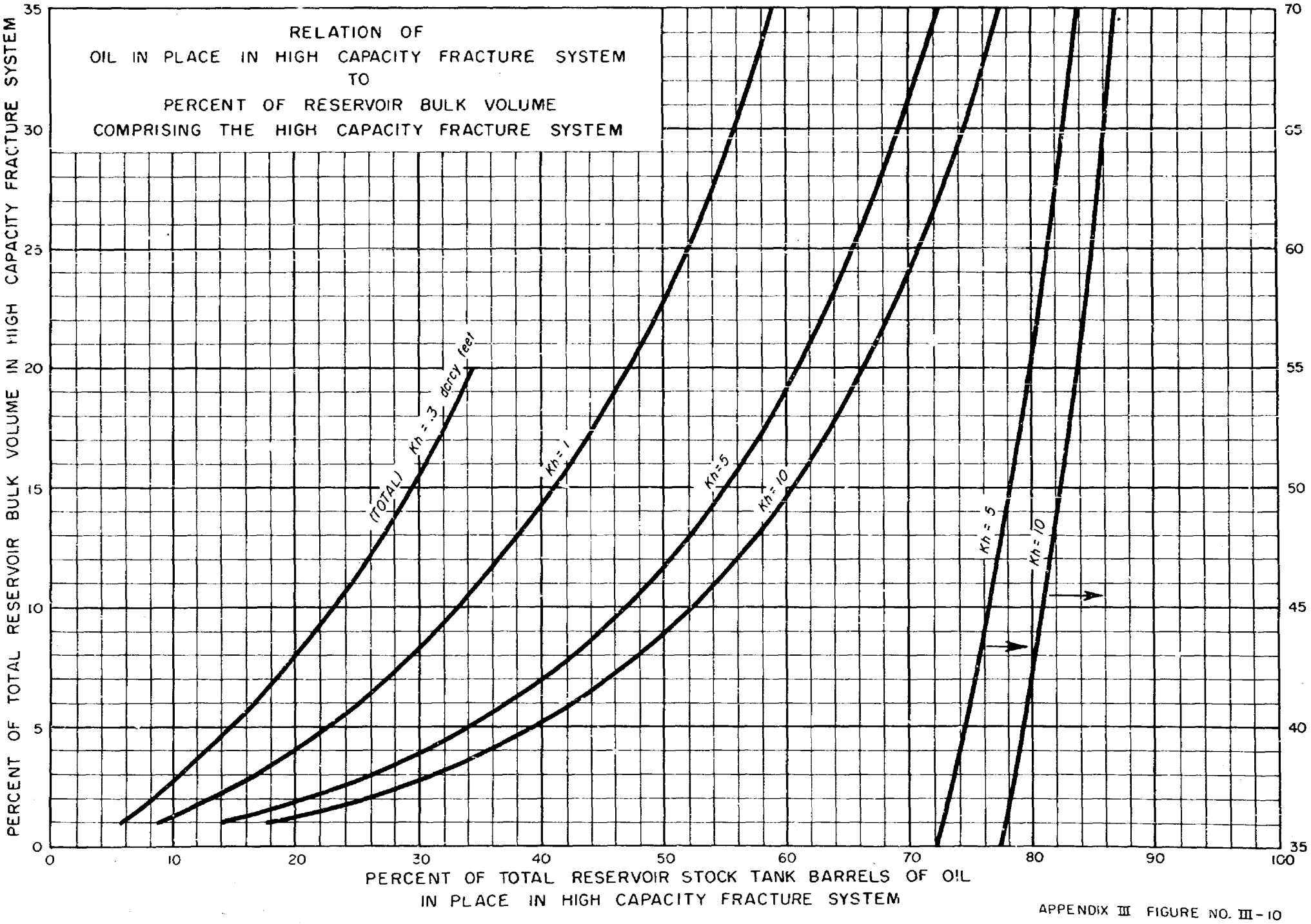
APPENDIX III FIGURE NO. III-8

OIL IN PLACE AS A FUNCTION
OF
TOTAL RESERVOIR TRANSMISSIBILITY
AND
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING HIGH CAPACITY FRACTURE SYSTEM
FOR
TRANSMISSIBILITY OF LOW CAPACITY PORTION
OF RESERVOIR OF .1 DARCY FEET
AND FOR
PAY THICKNESS AND POROSITY—PERMEABILITY RELATION OF:
"Z" 17' OF A
OR
50' OF B
OR
150' OF C
F.V.F. = 1.29



APPENDIX III FIGURE NO. III-9

RELATION OF
OIL IN PLACE IN HIGH CAPACITY FRACTURE SYSTEM
TO
PERCENT OF RESERVOIR BULK VOLUME
COMPRISING THE HIGH CAPACITY FRACTURE SYSTEM



APPENDIX III FIGURE NO. III-10

APPENDIX IV

APPENDIX IV

SOLUTION-GAS DRIVE PERFORMANCE

Anticipated performance of the subject reservoir under solution-gas drive has been investigated with calculations made in the manner shown by Muskat (Reference No. 3). Prior to the time gas injection was commenced in August, 1968, all of the oil recovered from wells in the Cañada Ojitos Unit in the West Puerto Chiquito Pool was produced at or slightly below the initial dissolved gas-oil ratio. Under these conditions, where no free gas has been produced, the relation of oil recovery in terms of oil in place as a function of reservoir pressure decline below the bubble point is a simple and accurate process to calculate. The effect of the indefinite value of the compressibility of the formation is relatively small, and accordingly can have only a minor effect in the calculations. In this instance it is disregarded. For pressures above the bubble point, however, this is a different matter. Here, however, the pressure drop with production is so fast that a large error in the estimated value of this property can exist without having a serious effect in the calculated percent of oil produced in terms of total oil in place. At this time it is believed that the system compressibility to oil initially approximated 35×10^{-6} per pound. Using this value and the PVT data from the fluid sample analysis for West Puerto Chiquito oil, the relation of reservoir pressure to oil recovery in terms of percent of oil in place at the bubble point pressure has been calculated. Calculations were made for a pressure range of about 400 pounds above the bubble point and approximately 200 pounds below the bubble point, for the condition in which the produced gas-oil ratio has been at the solution ratio or less.

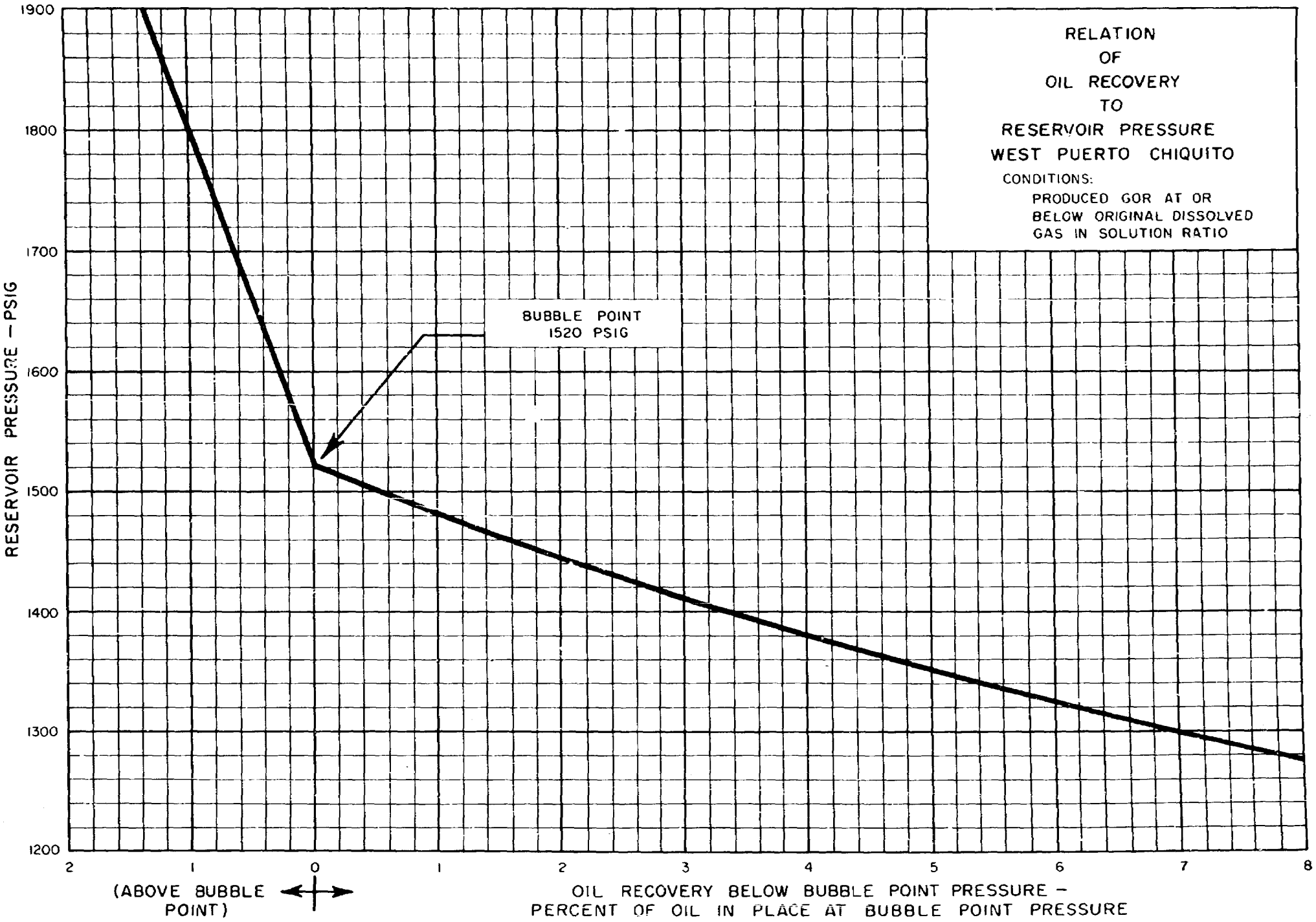
The results are shown graphically at the end of this appendix, Figure IV-1. From this figure we can determine the degree of depletion any part of the reservoir has suffered if we know its initial pressure and the pressure at which a determination is desired. In the instance of the L-11 well, which is mentioned in Section IV, Part 2, of the text, the reservoir at the structural datum of this well when the reservoir was discovered was approximately 1,500 pounds. It can be seen from Figure IV-1 that for the pressure decline from 1,800 pounds to the bubble point, 1,520 pounds, the reservoir suffered a depletion of approximately 1 percent with reference to the oil in place at the bubble point. For the additional decline in pressure from the bubble point to 1,500 pounds the reservoir suffered additional depletion of approximately .5 percent. The sum of these two figures is 1.5 percent, which is the amount of depletion the reservoir had suffered at the structural position of the L-11 well at the time gas injection was commenced in August of 1968.

To calculate the entire production history under solution gas drive requires, of course, a knowledge of the relative permeability of the formation. As stated at the 1966 hearing, information at that time available as to relative permeability of fractured formations showed such a wide variation as to be of little use in estimating recoverable oil as a function of total oil in place. However, as mentioned in the introductory remarks to this paper, under the heading General Considerations, it now appears that the field data, which indicated the extremely low values of the relative permeability ratio for given fluid saturations, may have

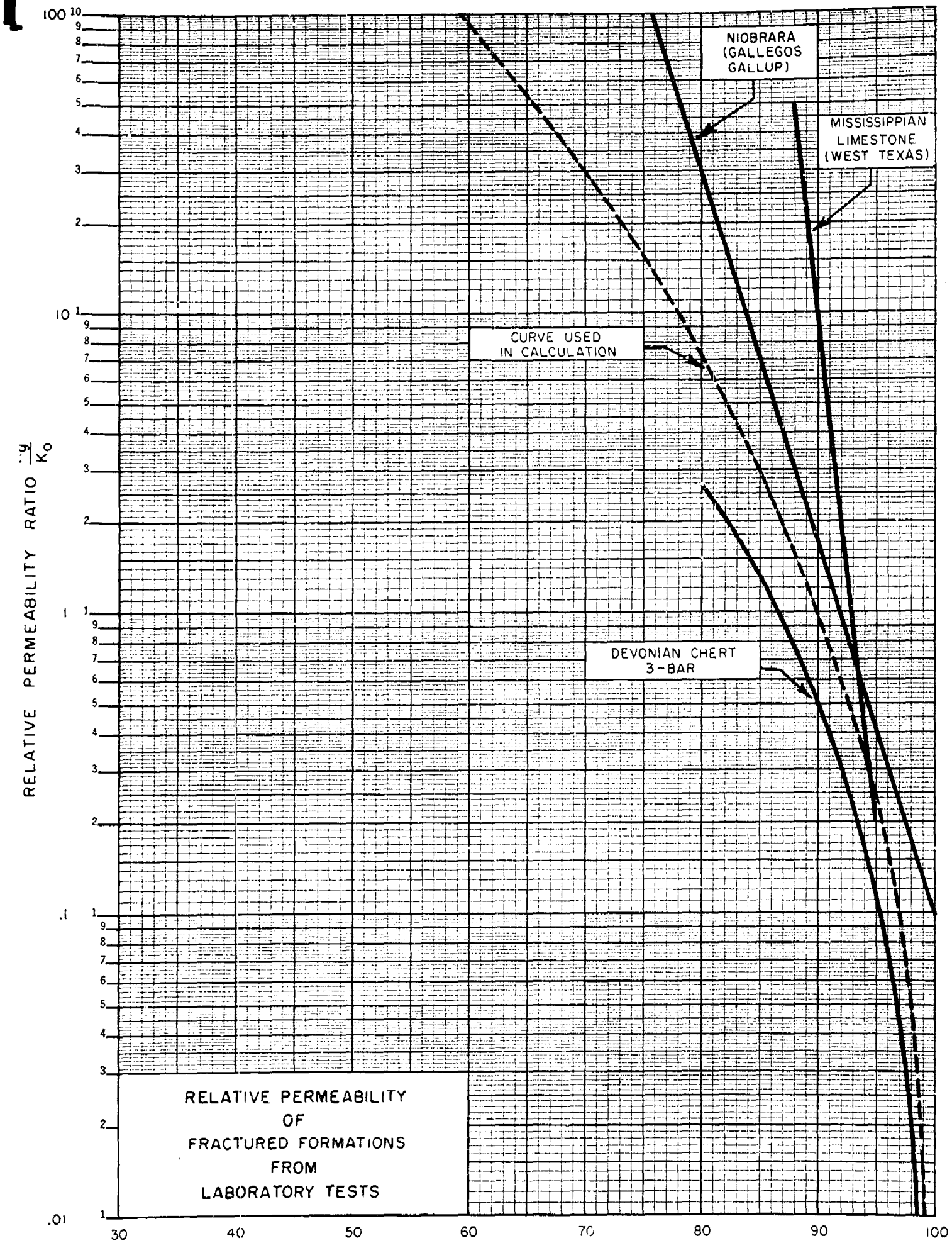
been the result mostly of gravity drainage effects. All of the laboratory data available indicates fractured formations to have comparatively high relative permeability ratios, and it is now believed that this is the true characteristic of fractured reservoirs. Some of the information developed from laboratory tests is shown on the figure at the end of this appendix, Figure IV-2. Also shown on this figure is the curve used for calculations in this paper. From this relation of relative permeability ratio, along with the PVT data for West Puerto Chiquito, the straight solution-gas drive production history was calculated. These results are shown graphically on the figure at the end of this appendix, Figure IV-3, and reproduced to form Figure 8 of the text. From this it can be seen that the ultimate recovery in terms of percent of oil in place can be expected to be on the order of 6 percent if the reservoir is depleted by the solution-gas drive mechanism.

It must be assumed that when gas injection was commenced, the bulk of the oil recovered to that time had been produced as a result of the combined effects of the oil expansion and solution-gas drive mechanisms. It is not known, of course, if the relative permeability ratio characteristics as shown on Figure IV-2 represent the true situation in the reservoir, or not. Since a substantial amount of oil has been produced, however, at the solution gas-oil ratio, with no free gas being evident in the production, we must assume either: that the formation truly has a high permeability to gas at higher liquid saturations, as indicated on Figure IV-2, and that evolved gas is moving by gravitational segregation up-dip toward the top of the structure rather than being produced with the oil; or on the other hand, that the formation has a critical gas

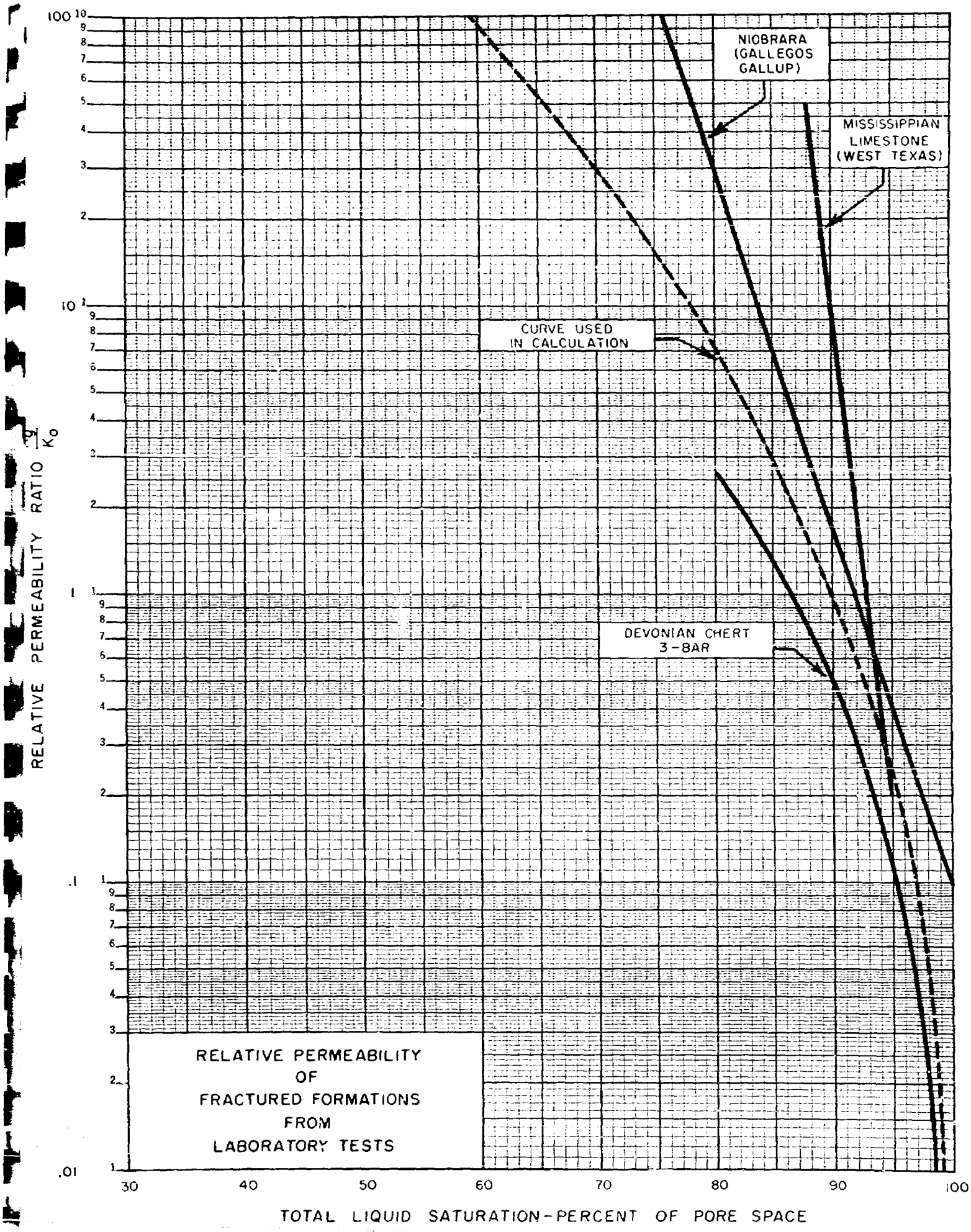
saturation at some substantially lower liquid saturation than is indicated on Figure IV-2, and as a result, the initial amounts of gas evolved are "trapped" in the pore spaces. In either event, it is probable that no significant oil gravity drainage has yet been realized. Even if free gas bubbles are moving to the top of the structure by gravitational segregation, appreciable benefit of oil gravity drainage cannot be realized until these bubbles reach the top of the structure, or the gas-oil contact if a gas cap exists; as it is the gravitational movement of this oil near the gas-oil interface which ultimately will determine the efficiency of the gravity drainage occurring. It is therefore assumed that the depletion process prior to the time gas injection was commenced was primarily that of oil expansion and solution-gas drive.



APPENDIX IV FIGURE NO. IV-1

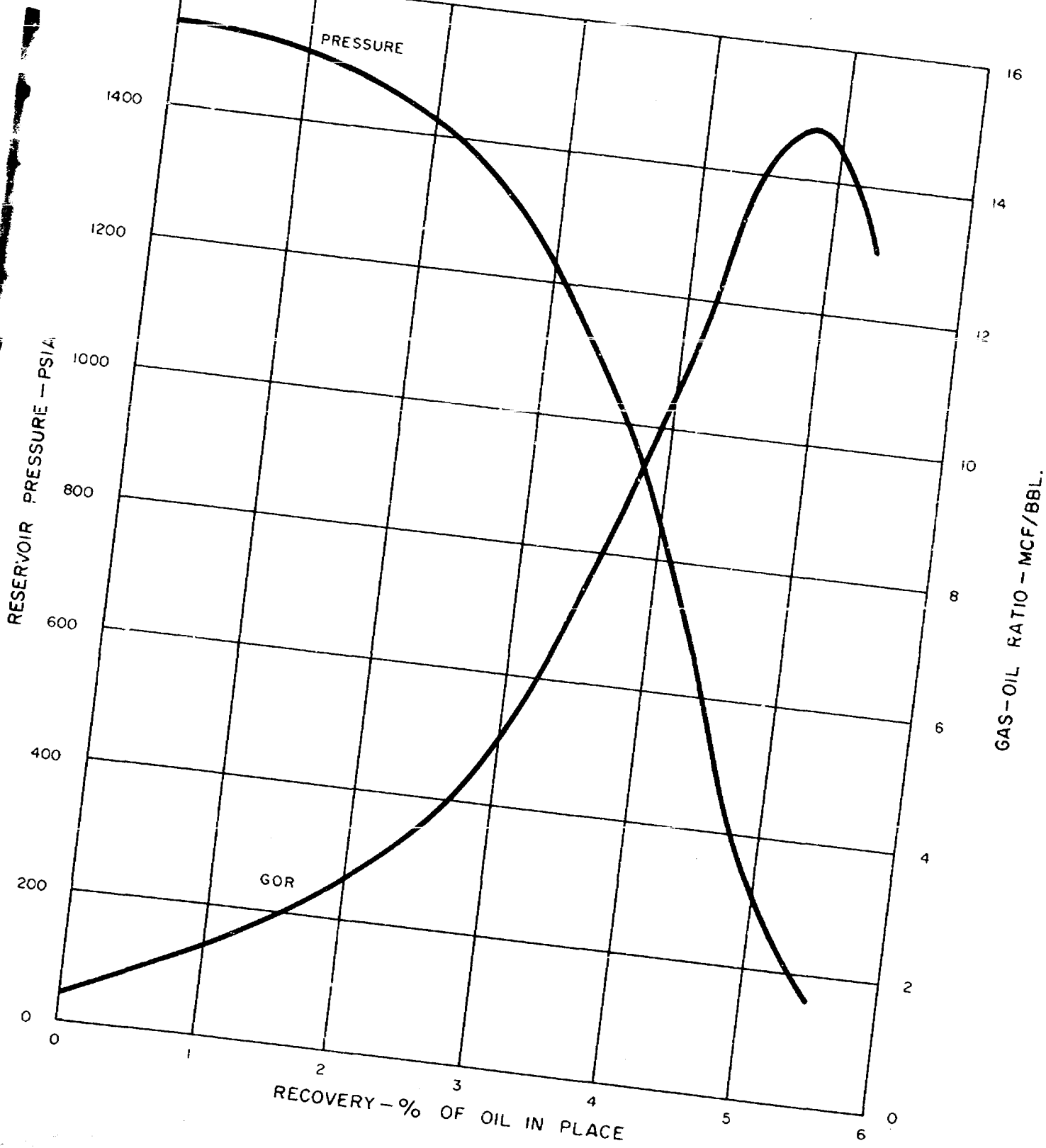


APPENDIX IV FIGURE NO. IV-2



APPENDIX IV FIGURE NO. IV 2

SOLUTION GAS DRIVE
PRODUCTION HISTORY
CALCULATED FOR CONDITIONS OF:
WEST PUERTO CHIQUITO
PVT DATA
AND
K_g/K_o ESTIMATED FROM LABORATORY
DATA FOR FRACTURED FORMATIONS



APPENDIX IV FIGURE NO. IV-3

APPENDIX V

APPENDIX V

SOLUTION GAS DRIVE RECOVERY OF OIL FROM TIGHT FRACTURE BLOCKS

Comparison of drainage abilities of wells with drainage ability of the high capacity fracture system

As stated in Section IV, Part 2, of the text, the high capacity fracture system can more efficiently drain the tight fracture blocks than can wells drilled within them. This statement is perhaps best appreciated through numerical examples. By adding to the information of Appendix IV the relative permeability to oil for known liquid saturations, it is possible to compute the potential productivity of wells completed in fracture blocks for assumed reservoir pressures and a knowledge of the transmissibility of the tight block. No direct knowledge is had of the relative permeability to oil of this fractured reservoir. A relation has been assumed based somewhat on the data available on other types of formations. This relation is shown at the end of this appendix on the graph, Figure V-1. With this information, calculations have been made for an example circular reservoir with a well drilled at its center and completed with a rather successful sand fracture treatment which has resulted in an effective well bore radius of 100 feet. The flow system is obviously that of steady state, and as a result it is fairly simple to calculate potential productivities for given reservoir pressures of the high capacity fracture system. The fact that steady state conditions will exist under the subject circumstance can be readily determined from the diffusivity constants which will apply. For example, for a block with transmissibility of .10 darcy feet, steady state conditions will be reached in it in less than 10 days after production has commenced.

The results of the calculations made are shown at the end of this appendix, Figure V-2, in which these potential producing rates are shown for various assumed transmissibilities. In calculating these potential producing rates it was assumed the initial productivity indices would decline with reservoir pressure, as shown by Muskat, directly with decrease in relative permeability to oil and inversely with the viscosity and formation volume factors. It was further assumed, in determining the initial productivity index in each instance, that to account for the reduction in permeability to oil in the low pressure area around the well bore, the productivity index calculated as above, with no correction, be multiplied by one-third.

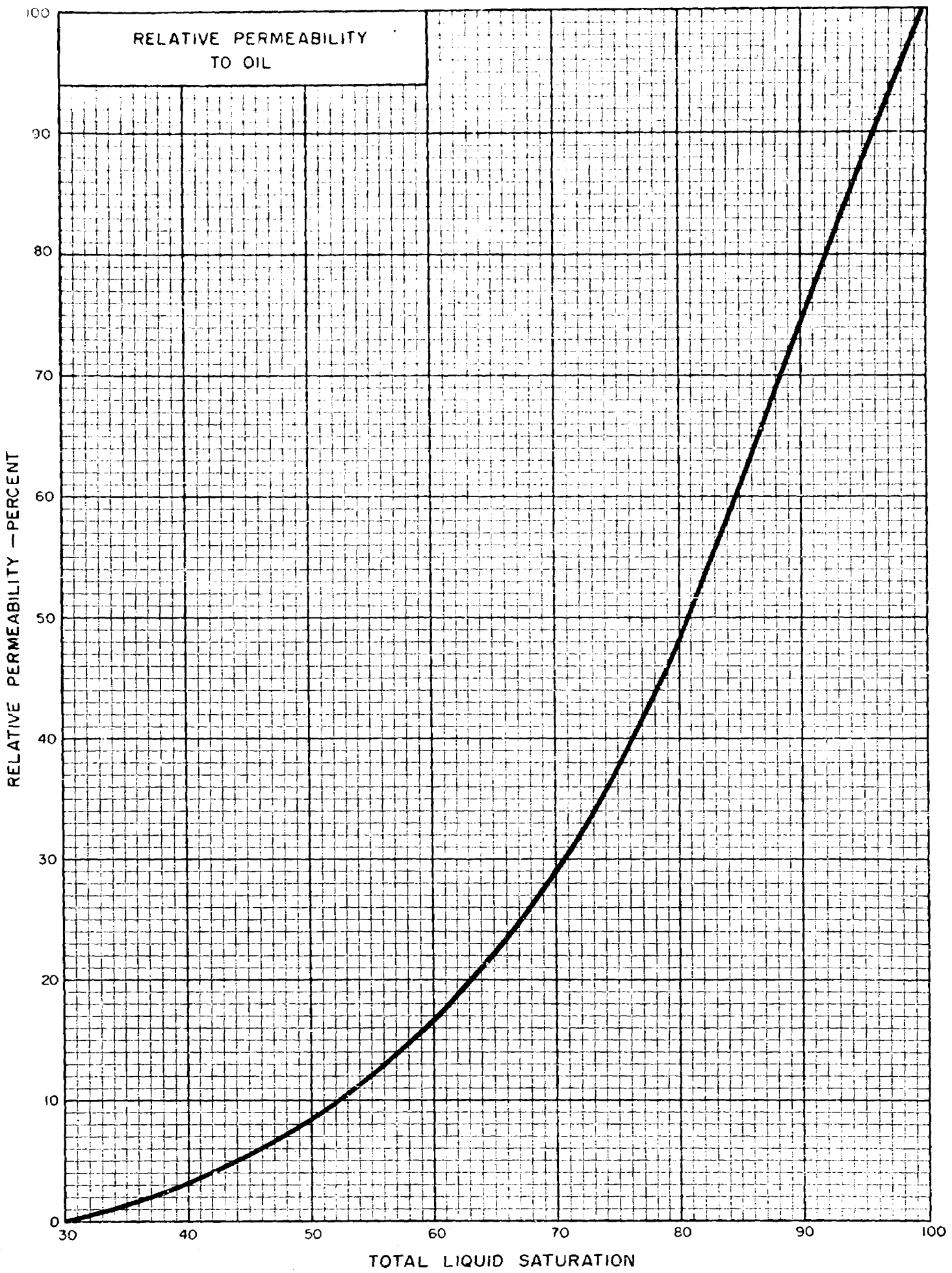
Referring now to Figure V-2 and assuming an economic limit of 15 barrels per day per well, it is evident that for fracture blocks with transmissibilities of .10 darcy feet or less, wells completed in them will have to be abandoned while there still exists in the high capacity fracture system a pressure of 300 pounds or higher. These excessively high pressures relate to unrecovered oil in the fracture blocks at the time of the wells' abandonment. This oil left in the tight fracture blocks will be recovered by the high capacity fracture system. For blocks whose transmissibilities are about .01 darcy feet or less, wells completed in them will be uneconomic to produce, even with virgin reservoir pressure. In this instance, all of the recoverable oil in the tight fracture block will be unavailable to wells drilled within the block. This oil, nevertheless, will move from the tight fracture block into the high capacity fracture system and be produced by wells that have communication with the high capacity fracture system.

With respect to the ability of the high capacity fracture system to drain efficiently these tight fracture blocks, no attempt is made here to solve this problem explicitly. Although the flow system for a well producing from one of the tight fracture blocks, as stated above, is clearly one of steady state conditions, the flow system of a block being drained by the high capacity fracture system is obviously one of unsteady state conditions, and in view of its nature, no attempt has been made here to solve this problem exactly. The ability of the surrounding fracture system to drain the tight fracture block is hardly one to be questioned, however. That this efficiency exists is evident from a cursory examination of some of the comparative factors involved. For example, a well completed in the example reservoir that has a transmissibility of .01 darcy feet will have an initial producing ability of approximately 15 barrels per day, and will promptly be abandoned. If we view the flow process in reverse, so to speak, with oil flowing out of the tight block into the fracture system, we find, for the same pressure differential, an initial ability of the fracture block to move an incremental amount of oil at a rate of about 500 barrels per day, if we consider the 900 foot radius from the well bore and the block's boundary at 1,000 feet. As a practical matter, of course, such large differentials will never come about, because the fracture system will continually deplete the tight blocks at low pressure differentials. Nevertheless, the comparison indicates the superior drainage ability of the high capacity fracture system.

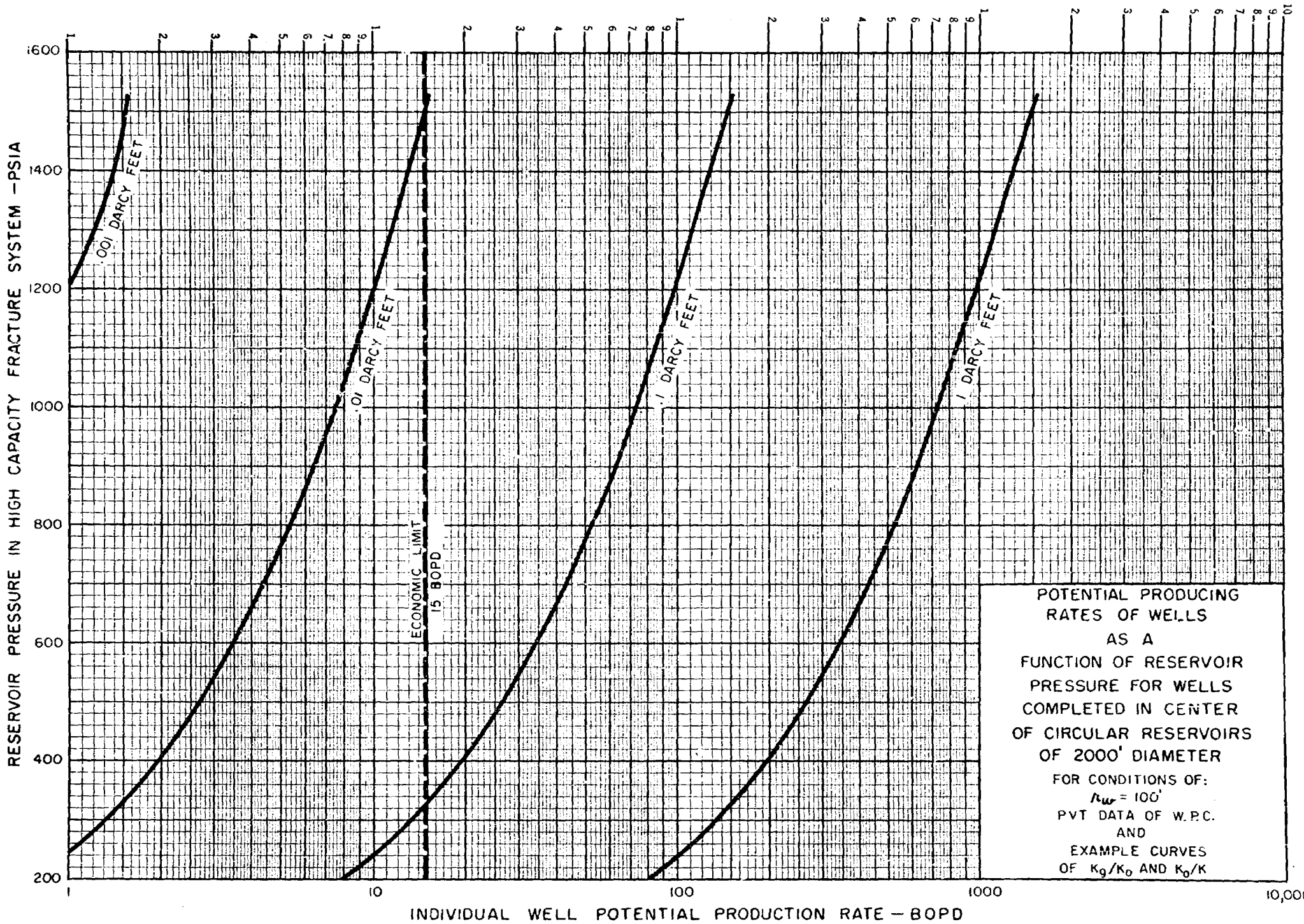
Not only this, but when oil moves through such a system to its internally located well, an equal amount of oil, under steady state conditions, must pass through any circumference at any given

radius. This means that the same amount of oil (with its contained and associated gas) that crosses the external circumference must be crowded through a circumference 1/10th as great at the 100 foot radius from the well bore. On the other hand, when the oil flows the other way, rather than all of the oil which is produced having to move through this circumference at a radius of 100 feet, the only oil which need move through it now is the oil contained inside this 100 foot radius, which is only 1 percent of the block's total contained oil volume.

In view of the considerations set out in this appendix, it is quite clear that the high capacity fracture system will adequately drain its contained tight fracture blocks if the reservoir is depleted by the solution-gas drive mechanism, with or without wells completed in them. The possibilities of depleting these blocks by other depletion mechanisms are discussed elsewhere in this paper.



APPENDIX V FIGURE NO. V-1



APPENDIX V FIGURE NO. V-2

APPENDIX VI

APPENDIX VI

PART A - SIMPLIFIED FLOW SYSTEM SHOWING DETERMINATION OF ACTUAL HORIZONTAL FLOW VELOCITY FROM TRANSMISSIBILITY

The exact relation of transmissibility to gravity drainage rates and vertical and horizontal velocity of the gas-oil contact "plane" is given later in this appendix, Parts B and C. In order, however, to clearly visualize the distinction in actual horizontal velocity of the oil as it moves through its pore space from the velocity, Q/A, ordinarily associated with the Darcy equation, two simplified flow systems are examined here. Sketch of these two systems is shown at the end of this appendix, Figure No. VI-1.

The two systems sketched represent blocks of impermeable reservoir space with flow tubes inserted. The flow tubes are assumed to have a permeability of 1 darcy each and a pore volume of .01 barrel per foot of length. Flow through the systems will be governed by the Darcy equation which, in terms of oil field units, can be written:

(Reference 8)

$$q = \frac{1.127\ KA\ (\triangle P)}{\mu\ L} \qquad \text{(VI-1)}$$

where: q is flow rate in barrels per day

K is permeability in darcys

A is area in square feet

L is length in feet

μ is viscosity in centipoises

For simplicity in the following discussion it is assumed the constant 1.127 actually equals 1, and that the pressure across the system is 1 pound per foot of length, and that the viscosity is 1 centipoise. Accordingly each tube will then have a flow rate of 1 barrel per day. Each system with five tubes then has a flow rate of 5 barrels per day.

This flow rate can also be calculated from the transmissibility of each system. The system on the left has a transmissibility of 1 darcy foot per foot of pay section, which for 5 feet is 5 darcy feet, whereas the system on the right, with a permeability of 1 darcy for each of 5 tubes and 1 foot of pay thickness also has a transmissibility of 5 darcy feet. Substituting in Equation VI-1 the value of 5 darcy feet for each system yields the same result, 5 BOPD.

The "velocity" of such systems, as ordinarily expressed, is the flow rate in barrels per day divided by the square feet of area, which for the system on the left is 1 and for the system on the right is 5. Although this is the "velocity" associated with the Darcy equation, it is really of no value in analysis of the gravity drainage problem.

The velocity of interest in gravity drainage analysis is the actual rate of movement of the oil through the pore space of the reservoir, both vertically and horizontally. For the systems sketched on Figure VI-1, this is the velocity within the tubes (here the tubes are alike and the velocity will be the same in each). It is apparent simply from inspection of the sketch of these two systems that under the same conditions impressed on them, the rate of oil movement through the tubes for both systems will be exactly the same

(not a ratio of 5 to 1 as given by the darcy relation).

For simplicity here an example calculation of horizontal velocity (V_h) is made. This horizontal velocity is obtained by dividing the flow rate by the pore volume. It is assumed that the pore volume of each tube is .01 barrels per day per foot of length, so each system shown has a total pore volume of .05 barrels per day per foot of length. Dividing a system's flow rate in terms of barrels per day per unit of width by its vacated pore space in terms of barrels per foot of length and for the same width will yield the actual horizontal velocity in terms of feet per day; which for each system above is:

$$\frac{5 \text{ BOPD}}{.05 \text{ bbl/foot of length}} = 100 \text{ feet per day}$$

This velocity is obviously the same for both systems, since each comprises five identical flow tubes in an impermeable matrix.

If the tubes are assumed to be of finite length, lying at an angle to the horizontal, that they are full of oil at the start of a test and no oil is added, then as oil is "produced" at the down-dip end, the top of the oil column in each tube will fall. The rate (V_v) of this vertical fall of the gas-oil contact is another velocity of interest, and which can be calculated directly from oil in place per acre and transmissibility, assuming the dip of the formation is known. As indicated above, method of calculating this velocity is given in Part C of the Appendix VI.

PART B - METHOD OF CALCULATING GRAVITY DRAINAGE RATES

Muskat (Reference No. 4) has shown the equation giving maximum possible gravity drainage rates. This equation , in terms of barrels per day per surface acre of gas-oil contact, is:

$$Q = \frac{21.29\ kd\ \sin^2 \theta}{\mu B} \qquad \text{(VI - 2)}$$

where Q = gravity drainage rate, barrels per day per surface acre of gas-oil contact

k = permeability to oil, md

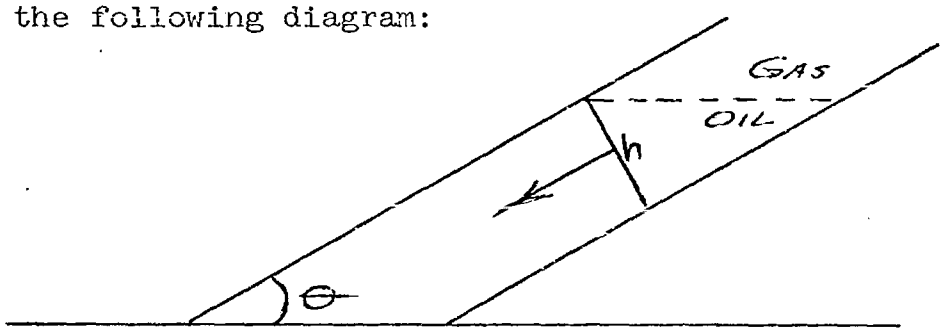
d = difference in specific gravities of oil and gas (water = 1.0)

μ = oil viscosity, cp

B = FVF of oil

θ = angle of dip of formation

The formation thickness and dip of the beds are shown schematically in the following diagram:



With reference to the above sketch, we may determine the surface area of gas-oil contact to be:

$$\text{Area of contact} = \left(\frac{h}{\sin \theta}\right)\left(\frac{5,280}{43,560}\right) = .121\ \frac{h}{\sin \theta} \qquad \text{(VI - 3)}$$

Multiplying Equation VI-2 by Equation VI-3, and converting to darcys, yields:

$$Q = \frac{2{,}580\ h\ K\ d\ \sin\ \Theta}{\mu\ B} \qquad \text{(VI - 4)}$$

where Q - gravity drainage rate in BOPD per linear mile of gas-oil contact along the strike

which is an equation useful to us, as we now have the gravity drainage rate in terms of properties we can determine directly from well tests (transmissibility) or other readily available sources. As stated in Part II of the text, this formula is used to calculate the gravity drainage rates shown on Figure 5.

PART C

SECTION 1 - RATE OF VERTICAL FALL OF THE GAS-OIL CONTACT "PLANE" UNDER GRAVITY DRAINAGE

The gravity drainage rate of fall of the gas-oil contact "plane" is: (Reference No. 4)

$$V_v = 2.744 \times 10^{-3} \frac{k\, d \sin^2 \theta}{\mu\, \bar{f}} \text{ feet/day} \qquad \text{(VI - 5)}$$

where k = permeability, md

d = difference in specific gravity of oil and gas (air = 1.0)

θ = angle of dip of formation

μ = oil viscosity, cp

$\bar{f}$ = net porosity vacated

If we let R represent the fraction of pore space vacated, then the net porosity vacated, $\bar{f}$, may be expressed:

$$\bar{f} = R\phi \qquad \text{(VI - 6)}$$

where ϕ = porosity, fraction of bulk reservoir volume

Substituting this value for $\bar{f}$ in Equation VI-5, changing from millidarcies to darcys and multiplying the numerator and denominator by the pay thickness, h, in feet we obtain:

$$V_v = \left(\frac{2.744}{R}\right)\left(\frac{Kh}{\phi h}\right) \sin^2 \qquad \text{feet/day} \qquad \text{(VI - 7)}$$

From this relation, the rate of fall of the gas-oil contact "plane" can be determined from the transmissibility, Kh, and pore volume ϕ h (both of which can be determined with reasonable

accuracy in West Puerto Chiquito) for assumed values of the fraction of net pore space vacated, R.

SECTION 2 - RATE OF HORIZONTAL MOVEMENT OF THE GAS-OIL CONTACT "PLANE" UNDER GRAVITY DRAINAGE

The rate of horizontal movement of the gas-oil contact plane can be determined from its rate of vertical fall (Equation VI-7) and the dip of the formation, which readily yields the horizontal velocity,

$$V_h = \frac{2.744}{R} \quad \frac{(Kh)}{(\phi h)} \quad \frac{d}{u} \sin \theta \cos \theta \text{ ft/day} \quad \text{(VI - 8)}$$

where the symbols have the same meanings as shown in this appendix VI, Part C, Section 1.

This formula was used to construct the graph of Figure 13.

Respecting movement (vertically as well as horizontally) of the gas-oil interface, this movement will take place, of course, only if reservoir conditions are such that the oil actually has "room" to move down-dip.

Little, if any, actual gravity drainage will occur while pressures are dropping and oil and free gas expanding, until the equilibrium gas saturation is reached. Complexity is added here also because of the unknown rate at which the gas bubbles move up-dip. Under pressure maintenance, however, where pressures are maintained relatively constant at any point in the reservoir, the gravity drainage potential will more likely be realized.

An ideal situation for gravity drainage, from the standpoint of avoidance of influence of extraneous conditions, exists in

the tight fracture blocks when the reservoir is under pressure maintenance and the blocks are surrounded by free gas (of the high capacity fracture system). Under these conditions oil will move by gravity drainage unaffected by withdrawal rates or by injection into the block of excessively high volumes of gas and causing by-passing. This is true because it is obviously impossible to impress a pressure gradient across a fracture block (except of course ones in which injection wells are completed) for the high capacity fracture system surrounding each of these blocks will result in an equalization of pressure around them.

Time required for depletion of a tight fracture block can be determined by the above equation (VI - 8) from its transmissibility by assuming a recovery factor, R, if the pore space (ϕ h) is known. This pore space value can be approximated from the date of Appendix III from transmissibility. Therefore, time required to deplete by gravity drainage one of the tight blocks can be determined only from its transmissibility and an assumed recovery factor, R.

This relation has been calculated for a recovery factor R of 50 percent. The results are shown graphically on Figure No. 13, in which this relation is expressed by the horizontal movement of the gas-oil contact plane, in terms of feet per day, for any given transmissibility.

PART D - FACTORS AFFECTING OPTIMUM NUMBER OF DOWN-DIP RECOVERY WELLS UNDER GRAVITY DRAINAGE WITH PRESSURE MAINTENANCE

As described in Section 4 of Part II, under solution-gas drive, the high capacity fracture system will drain the tight blocks better and more efficiently than will wells drilled within the blocks. Under these circumstances, and for solution-gas drive depletion, ultimate recovery will be essentially independent of the number of wells. A different situation exists, however, under gravity drainage with respect to the number of down-dip recovery wells. Although intermediate rows of wells at positions structurally higher than the lowermost row will not increase ultimate recovery under gravity drainage, additional wells located on the down-dip row can serve to reduce the pressure draw-down in the wells at this structural position (for the same amount of production from the reservoir) and can in a way more efficiently recover the final amounts of oil as the gas-oil contact, in its movement down-dip, approaches the lowermost row of wells.

As a practical matter, however, the primary factor controlling the efficiency of recovery of this phase of the depletion process is not so much the number of wells drilled, but the physical makeup of the reservoir with respect to the tight blocks and the high capacity fracture system - a matter over which we have no control.

Aside from the other influences of these factors, as discussed elsewhere in this paper, this physical makeup of the reservoir will have a twofold controlling effect which will be

evident in the final stages of depletion. These are described as follows:

1. The potentially high efficiency of the gravity drainage depletion mechanism under pressure maintenance can be expected to be effective only as to that part of the reservoir occurring structurally up-dip from the point at which, as to each fracture block in which a down-dip recovery well is completed, good communication is established with the high capacity fracture system. For example, if the sand fracture treatments of the down-dip recovery wells result in fractures extending up-dip from the wells to points of juncture between their fracture blocks and the high capacity fracture system, then, as the gas-oil interface in its movement down-dip reaches this point, gas will rapidly channel to the recovery wells, and it will be necessary to end Phase 1 of the pressure maintenance project, as discussed in the summary of Part IV of this paper. At such a time it will be necessary to enter either Phase 2 or Phase 3 of the depletion process. Once Phase 3 has been commenced, a relatively small part of the future production can result from gravity drainage, as most of it will be the less efficient solution-gas drive mechanism. The time at which this occurs will depend not so much on the numbers of wells as it will on the physical size of the fracture blocks themselves in which the down-dip recovery wells are completed. For example, it now appears (Appendix II hereof) that these individual fracture blocks may have gross dimensions of the order of 1,500 to 2,000 feet, or approximately one-third of a mile. With fracture blocks of this size, if the distance from the up-dip side of the reservoir to the down-dip side of the recovery wells' fracture blocks is one mile, then one

would anticipate that two-thirds of the reservoir might be amenable to gravity drainage under pressure maintenance. It would be entirely impractical to plan for, or to attempt to recover by pressure maintenance, the part of the total reservoir oil represented by this one-third of a mile. In view of the other factors involved, it is questionable whether a reservoir of this makeup with only one mile of section available down-dip could be practicably depleted by pressure maintenance and the gravity drainage process. In the instance of West Puerto Chiquito, however, the down-dip length of the reservoir section approximates four miles. Under these circumstances it is believed only one twelfth (one-third of a mile out of four miles) of the reservoir is unavailable for gravity drainage recoveries, leaving some 90 percent of the surface area of the reservoir which can be successfully depleted by gravity drainage with pressure maintenance. It is obvious that insofar as this aspect of the physical character of the reservoir is concerned, the drilling of additional wells in the down-dip fracture blocks can in no way affect its "susceptibility factor" to gravity drainage depletion.

2. When gas cones down-dip into the recovery wells and Phase 2 is commenced as to this bottom row of wells, and production rates are restricted (here the controlling factor in production rates will be the capacity of the compressors to handle the produced gas) the matter of total amount of future gravity drainage recovery which can be achieved before Phase 3 is entered will again be not so much a matter of additional wells (with resulting reduction in "draw-down" pressure differentials permitting, for the same reservoir production rate, the gas-oil contact to move to a lower

structural position before abandoning Phase 2 of the project) as it will be the physical makeup of the reservoir with respect to up-dip tight fracture blocks and the amount of oil draining from them by gravity. If this source of oil forms the bulk of that being produced, the drilling of additional wells will be of little use, for the controlling factor in producing rates will not be dependent on the proximity of the gas-oil contact but the rate at which oil is moving from the upper parts of the reservoir.

In view of the above remarks, it is obvious that the practical procedure is to operate the project with the minimum number of down-dip recovery wells until coning first occurs, and at that time, and in light of the facts available then, make the determination as to whether additional down-dip recovery wells should be drilled. It is quite clear that it would be a waste of time, money and effort to drill additional recovery wells prior to the time coning has developed. These additional wells can improve reservoir recovery only as to that part of the reservoir in which coning has not developed, and until it does, all of the gravity drainage recovery from the reservoir can be efficiently produced from any well capable of handling it.

Once coning develops and the question arises as to the drilling of additional recovery wells, information regarding some of the above aspects will at that time be available, and will be useful in determining if more recovery wells should be drilled.

With regard to the future question of drilling additional wells after coning develops, an estimate of the approximate magnitude of the maximum additional recovery which might be anticipated by the drilling of additional down-dip recovery wells can be made by

analysis under the following reasoning. Pressure distribution in the high capacity fracture system will approximate that of a reservoir with uniform conditions and the same transmissibility. If the fracture blocks in which the down-dip wells are completed are relatively small, then pressure draw-downs and coning tendencies will be relatively the same as for a reservoir with uniform properties as to those distances beyond the fracture blocks in which the wells are completed. We can therefore estimate coning tendencies for various well spacings (distance along the row of the down-dip wells) and for various assumed production rates at which Phase 2 terminates and Phase 3 commences, by assuming the reservoir to be of uniform properties. To solve this problem exactly would require determination of the pressure draw-down configuration around the wells, taking into account the dip of the formation and comparing it with static reservoir pressures, recognizing the difference in density of the gas and the oil; and then determining the producing rates at which gas would break through, depending upon the distance of the gas-oil interface from the wells. It is believed the same information can be determined with less effort, and accurately enough for our purposes, by assuming that for any one set of conditions in which coning develops, the gravity drainage rate for that set of conditions can be determined from down-dip gravity flow rates and the "angle of repose" created by the shape of the cone along the plane of the formation. For the same reason that gravity drainage rates down the slope of the formation are equal to the vertical drainage rate times the sine of the angle of dip of the beds, the gravity drainage rate to a well should approximate the down-dip rate multiplied by the sine of the angle of repose.

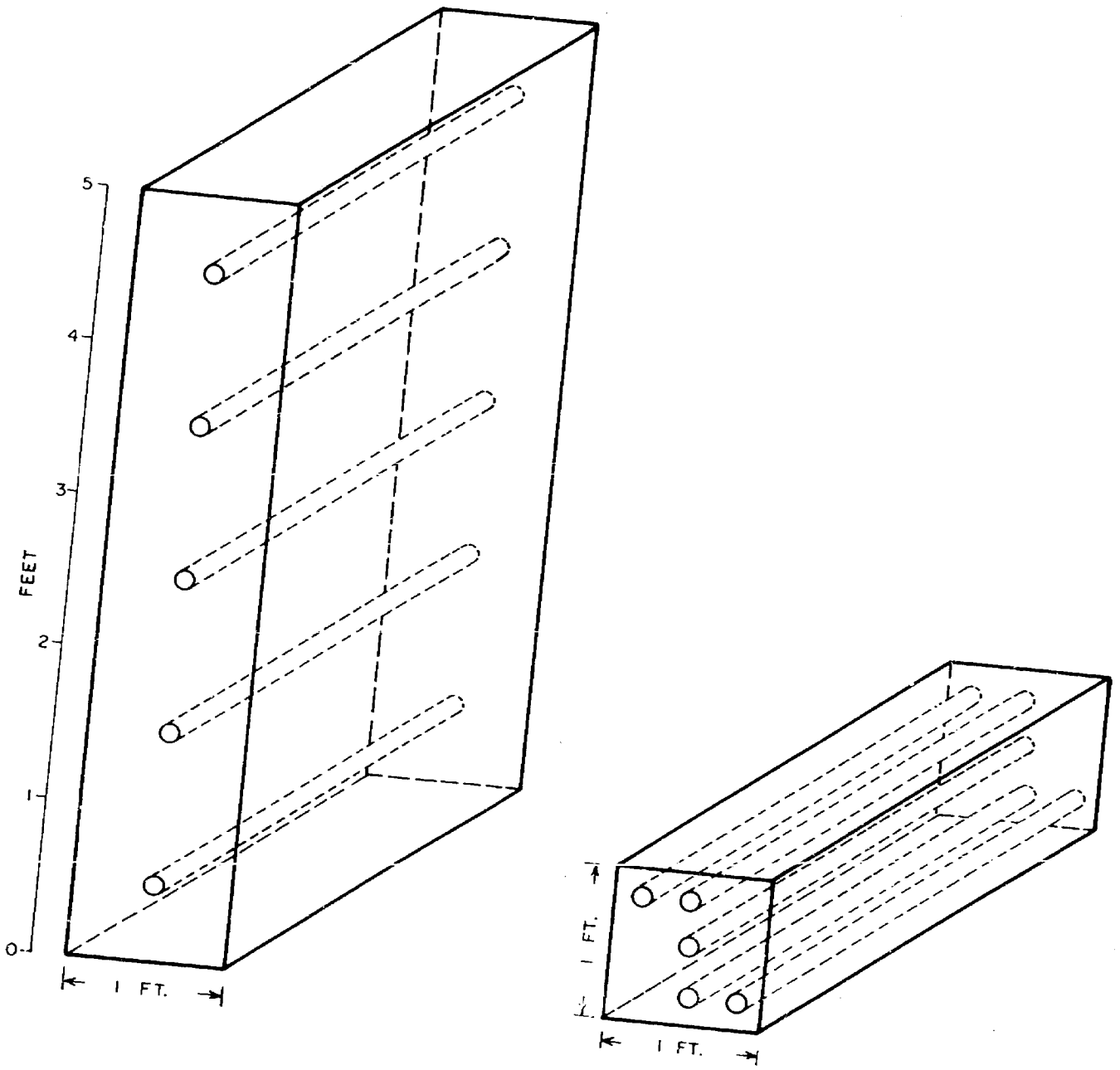
This is perhaps best illustrated by numerical examples for the conditions of dip of formation and transmissibility for West Puerto Chiquito. The dip of the producing formation in the vicinity of the down-dip wells approximates 200 feet per mile, and the transmissibility approximates 10 or 12 darcy feet. As can be seen from Figure 5 of the text, for a dip of 400 feet per mile and this transmissibility, the gravity drainage rate would be approximately 2,000 barrels per day per linear mile along the strike. For a formation dip of 200 feet per mile the rate would be approximately half this, or about 1,000 barrels per day per linear mile. If we assume that all of the up-dip blocks have been completely drained (and the reservoir consists of uniform properties) and all of the remaining producible oil in the reservoir exists in the area below the gas-oil contact, then we can calculate angles of repose for various given rates of production at which Phase 2 would be terminated and the operation of Phase 3 commenced. A comparison is made for one, two and four wells per linear mile along the strike. If there is one well per linear mile, its angle of repose, at a rate of 100 barrels per day, would be an angle whose sine is 100 divided by 1,000, or 5.7^{o}. If this production rate is divided between two wells, the angle of repose for each of them will be an angle whose sine is 50 divided by 1,000, which is 2.86^{o}, and for four wells at 25 barrels per day each, the angle of repose would be 1.43^{o}. From this information, the reservoir areas under the angle of repose for each set of conditions can be determined. The difference in these areas represents the amount of reservoir area which can be produced under Phase 2 before resorting to Phase 3. Additional recovery amounting to the difference in gravity drainage

depletion minus solution-gas drive depletion can be anticipated from this additional part of the reservoir when comparing one of the spacing densities with another. Pertinent facts of the examples discussed here are listed in the schedule below:

Number of recovery wells per linear mile along the strike	1	2	4
Production Rate, BOPD per well	100	50	25
Angle of Repose	5.74°	2.86°	1.43°
Area under angle of repose, acres	32	16	8
Difference per linear mile in area under angle of repose:			
2 wells/mile compared to 1		16	
4 wells/mile compared to 1			24
Increase in area of reservoir affected by gravity drainage for reservoir down-dip length of 4 miles:			
2 wells/mile compared to 1		0.62%	
4 wells/mile compared to 1			0.94%

From the above schedule it is apparent that it would be impractical to plan initially on a density greater than one recovery well per linear mile. It is probable that more than one well per linear mile will be drilled, but only for the reason that it is impossible to determine exactly the location of the down-dip boundary of the high capacity area and more than one well per section may be drilled searching for the best locations of these down-dip recovery wells.

SKETCH
OF
SIMPLIFIED FLOW SYSTEMS



APPENDIX VI FIGURE NO. VI-1

APPENDIX VII

APPENDIX VII

PART A - SCHEMATIC COMPARISON OF "CHANNELLING POTENTIAL"

Comparison of the "channelling potentials" of injection and producing wells, as described in Section 2 of Part IV of the text of this paper, can be made with a system of pipes in an open tank. Such a system is sketched on the figure at the end of this appendix, Figure VII-1.

Plate I of Figure VII-1 shows the channelling potential of an "injection well", which is an injection pipe inserted open-ended in the tank with gas being forced out through perforations in the pipe below the top of the oil. The restriction of the perforations through which the gas is passing can be likened to the pressure differential required to inject gas into a reservoir. This pressure forces the top of the oil in the pipe to a deeper depth than the perforations, as shown in the sketch. If the pressure required to force the gas out through the perforations is 6 pounds per square inch and the density of the oil is 1/3 pound per square inch per foot, then the channelling potential, as indicated on Plate 1, is 18 feet (in this instance the density of the gas is negligible). It is obvious from an inspection of Plate 1 of Figure VII-1 that if there is no other disturbance in the tank (reservoir) it is physically impossible for the gas to drop in the pipe (channel) to a point any lower than 18 feet below the surface of the oil in the tank (interface of the gas-oil contact "plane").

Plate 2 of Figure VII-1 shows the same information with a "producing well" added by extending the pipe to the bottom of the

tank. As for the injection well, the perforations in the pipe at the bottom serve as a restriction to the flow, such that a draw-down is required to withdraw oil from the production line. If a pressure differential of 4 pounds is required to withdraw oil at the rate at which the test is conducted, it will have a producing well channelling potential of 12 feet (4 pounds divided by 1/3 pound per square inch per foot). This is shown schematically on Plate 2 of Figure VII-1. In this instance the sum of the channelling potentials is 18 feet plus 12 feet, or 30 feet. As long as the oil level in the tank is more than 30 feet above the perforations in the producing part of the pipe, there can be no channelling of gas to the "producing well", despite the direct channel (pipe) connecting them.

As stated in the text, the channelling potential calculated as shown therein, and compared schematically above, is the maximum possible. Under operating conditions, actual channelling probably will not occur until the vertical separation is much smaller than the potential.

PART B - INJECTION WELL DIFFERENTIAL PRESSURES

It is believed that the injection well differential pressures which will be of interest in determining channelling potential as defined in this paper would probably be governed by the isothermal flow of gas under viscous conditions, and will vary as the difference in the squares of the pressures over the radial distances involved. Here it is assumed that the distances of importance will be those outside the tight fracture block in which the injection well is completed, and accordingly at some distance from the well bore. It also seems probable that the operating injection pressures required to inject gas would be governed by a similar type of flow to that encountered with producing gas wells, and accordingly the volume would vary with some power of the difference of squares of the working bottom hole injection pressure and the stabilized pressure in the high capacity fracture system. No tests have been conducted in West Puerto Chiquito to attempt to analyze these characteristics, and accordingly nothing is reported here in this connection. It is of interest to note, however, that the present injection well is accepting volumes of gas equal to approximately 1,500 barrels per day with an operating differential pressure approximating 400 pounds. Before being put on gas injection, this well had a producing capacity of 100 barrels per day at solution gas-oil ratio, with an operating pressure differential of about 1,200 pounds. This means the injection well is taking approximately 15 times the volume at one-third the pressure differential wher compared to the well's producing ability. This is an overall ratio of 45 to 1 in

comparative operating differentials. Since the viscosity of the oil which was being produced is nearly the same as the viscosity water would have at that temperature, were water to be injected, it can be assumed this ratio of 45 to 1 is indicative of the ratio of operating pressure differentials to be expected in comparing gas injection to water injection.

Comparison of channelling potentials (with the gradient differences as discussed in Section 2 of Part IV of the text) would accordingly have a ratio of approximately 100 to 1. This means that in the instance of West Puerto Chiquito and its K-13 injection well, this one well is equivalent, from the standpoint of channelling potential, to 100 water injection wells. Moveover, this potential exists at only one point in the reservoir. The water injection wells would have to be spread out along the strike to avoid interference with each other, and further increase the channelling potential. On the other hand, gas from the injection well, as it works its way along the strike, will have a continually lower pressure differential. No comparison has been made to determine exactly how many water injection wells would be required to reduce at all points their channelling potentials to that created by the one gas injection well, but it probably would be at least 200 to 300..

SCHEMATIC DIAGRAMS OF
"PRODUCING POTENTIAL"
OF
GAS INJECTION WELL AND OIL PRODUCING WELL

PLATE I

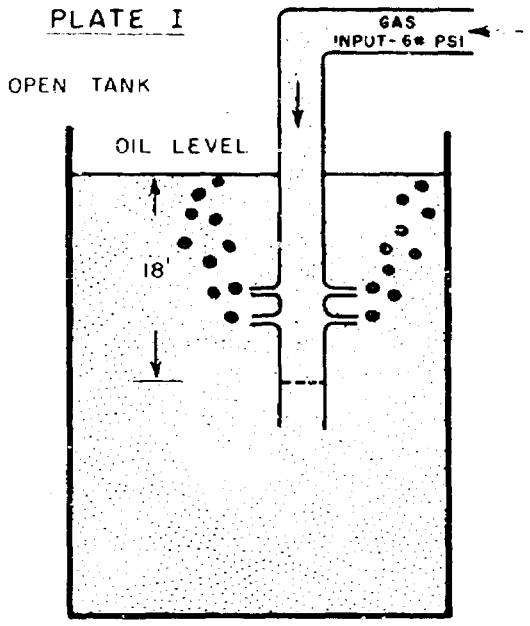
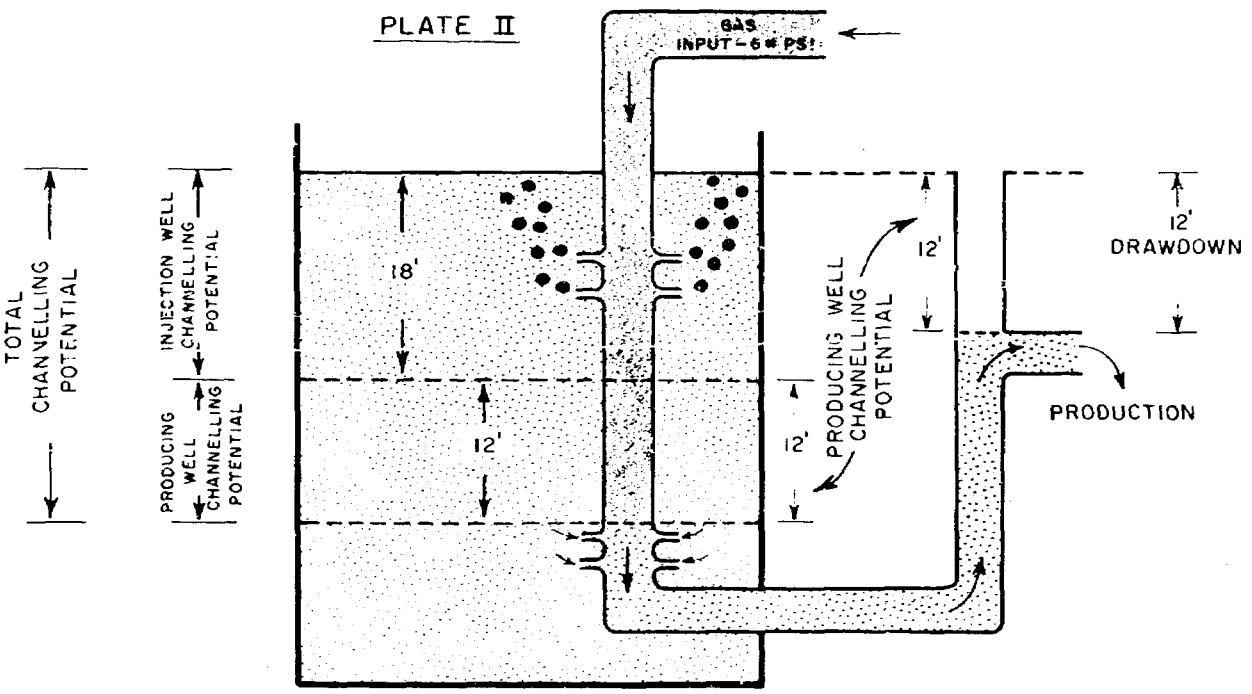


PLATE II



LEGEND

- INPUT GAS
- OIL IN "RESERVOIR"
- OIL IN PRODUCTION

APPENDIX VII FIGURE VII - 1

REFERENCES

REFERENCES

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2. PHYSICAL PRINCIPLES OF OIL PRODUCTION - Page 485. Morris Muskat, 1949.

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9. IMPROVING OIL RECOVERY - Page 102. University of Texas Department of Petroleum Engineering. "MECHANICS OF FLUID INJECTION - GAS". Claude R. Hocott.

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BEFORE THE NEW MEXICO
OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
November 16, 1966

EXAMINER HEARING

In the Matter of:	
Application of Benson-Montin-Greer Drilling Corporation for division of oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico.	CASE NUMBER 3455

BEFORE:

DANIEL S. NUTTER, Examiner

TRANSCRIPT OF HEARING

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MR. PORTER: The Applicant in Case 3455 has requested a recess until 10:00 o'clock, until they can post some exhibits and assemble some models that they intend to use in the case, so the Hearing will recess until 10:00 o'clock or as long as it takes to assemble these things.

(Whereupon, a recess was taken)

MR. PORTER: The Hearing will come to order. The Commission will take up Case 3455.

MR. HATCH: Case 3455. Continued from the September 14th, 1966 Regular Hearing, Application of Benson-Montin-Greer Drilling Corporation for division of oil pool into two pools and for special rules for each, Rio Arriba County, New Mexico.

MR. PORTER: Mr. Verity?

MR. VERITY: George L. Verity for the Applicant Benson-Montin and Greer and actually, these other parties who really, through Benson, Montin and Greer, their operators are joining in the application. That's Tom Bolack, Jack London, Junior, William V. Montin, Alfred C. Montin, Albert Greer, Virgil L. Stoaks, Richard Bramblett, Montin-Harbert Pipeline Construction Company, General American Oil Company, and F. H. Carpenter, and I believe Mr. Cooley has another -- who is also representing these parties, has another client.

MR. COOLEY: In addition to representing the

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applicant in this case, or applicants, Burr and Cooley also represent Plato, Inc. Refining Corporation whose principal base is Farmington.

MR. PORTER: Are there any other appearances to be made in Case 3455?

MR. VERITY: Your Honor, before we proceed with this case, Shell has representatives here and one of them would like to make, Mr. Moore, I believe, would like to make a statement to the Commission and inasmuch as they have another Hearing they have to proceed to, I advised them that I thought the Commission would indulge them to make their statement at this juncture, rather than at the close, and we would appreciate them being given that opportunity now.

MR. PORTER: Mr. Moore, are you going to make a statement for Shell?

MR. MOORE: Yes.

MR. PORTER: You may proceed.

MR. MOORE: Shell Oil Company receives and purchases the oil from Chavez Pipe Line, we receive oil from Chavez Pipe Line Company and purchase the oil in the area in question.

We just wanted to advise that there is a market for any increased production which might come from this area as a result of any new rules and regulations that might be set for the area.

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We understand that wider spacing, three hundred -- temporary 320-acre spacing would cause more drilling and exploration and more oil to be produced. We stand ready and able to purchase it, we actually desire it and would be in favor of anything that would cause more production to rise from the area that is keeping the sound conservation practices determined by the Commission.

MR. CAMPBELL: Does that oil go to your West Coast market?

MR. MOORE: No, sir. On occasion some of it does, most of it goes to our local refinery.

MR. PORTER: This was a refinery that was formerly operated by El Paso?

MR. MOORE: By El Paso, yes, sir.

MR. PORTER: And your answer is just more crude oil to supply your present demands?

MR. MOORE: That's right. To explain the logistics and marketing situation in the area, most all of the production which we buy along the old El Paso system goes to the Cineza. When they were in business we purchased oil from them when they had surplus oil and in the wintertime, when it comes to where production increases in the area, we do sometimes have more than enough to supply the Cineza Refinery, and on occasions the sum of the composite stream of all the oil gathered

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in the area moves to the West Coast. This is usually only in the winter. Under normal conditions we use it all at the local refinery, but we have a market both on the West Coast and for the local refinery.

MR. PORTER: Thank you, Mr. Moore.

MR. VERITY: Your Honor, I assume that the Commission will accord this statement the same credence as if it were under oath, if not, I think the witness would be willing to make it the same as he made earlier, I believe, under oath.

MR. PORTER: The Commission doesn't feel that it's necessary for the witness to be sworn in this instance, Mr. Verity.

MR. MOORE: May I be excused?

MR. PORTER: You may be excused. Mr. Verity?

MR. VERITY: If the Commission will permit it, I believe that it would be helpful to the Commission and to us if I might be permitted to make an opening statement and that even further, aside from that, I would like to make a personal observation, if you would permit that, this is really coming home to me, and it's real nice to be back in Santa Fe and New Mexico and again to be permitted to be before this Commission.

I'm sure that the Commission will recall, or at least the two members that were here three years ago, this case and the Hearing that we had at that time. At that juncture,

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Puerto Chiquito Pool in the eastern edge of the San Juan Basin was in its infancy. We didn't begin to know at that juncture the things about this pool that we now know with certainty, and most of our proof at that time was by analogy. Fortunately for us, and we think for the Commission and the State, we had a very good analogy or actually two or three very good analogies that we could make, particularly with regard to Verde-Gallup, which was a very similar reservoir in the same basin in northwestern New Mexico, which had been developed on 40-acre spacing by order, and 80-acre spacing, a good share of it voluntarily, and wherein we could, we thought by analogy, and the Commission accepted it, demonstrate very much what was going to happen in the Puerto Chiquito Pool.

We thought that we could show pretty well, within certain limits what drainage would be and what recoveries would be. We think that these analogies were correct and we believe that today we can show you that those analogies were correct.

We also had something to say at that time with regard to the Cha-Cha Gallup Pool which this Commission is well aware was an economic tradegy and the conservation tragedy that occurred through no fault of this Commission but wherein the operators, because of all the problems

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that existed only asked for 80-acre spacing and then far too late began to conserve the gas in the pool long after this Commission had pressed them to do so, and as a result of that narrow spacing, literally thousands of barrels of oil and millions of cubic feet of gas and many dollars were lost to the operators in the pool and to the State of New Mexico, and the Federal Government in the way of taxes and royalties.

We asked at that time that the Commission space a large area which we felt was in this one common source of supply and that they grant an order that gave a temporary spacing for one hundred sixty acres and grant to the applicant the opportunity to run interference tests and transfer allowables. The Commission granted that order, I think possibly with some concern as to whether or not it was proper. We believe today that we can show that this was a most wise thing for the Commission to do, and that everything we said at that time was true, only more so. For instance, at that juncture, because we were reasoning from analogy, our proof said that we believed that one well would drain a minimum of 460 acres in the area. Actually, on cross examination, and if you care to refer to the record, you will find at page 101 Mr. Greer said, "That in his opinion, one well would drain far in excess of that, he thought, a thousand or two thousand acres."

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We will demonstrate to you now that one well will drain approximately eight thousand acres -- Excuse me, approximately six thousand acres; that there is drainage across 8890 feet and we think probably much more than this. But, we are now, we believe by mathematical and engineering deduction and certainty able to demonstrate to you that we can drain six thousand acres in this area. And at this juncture, we are now in position to do what we would like to have had done before, and that is ask for 320-acre spacing in the deep part of it.

There is one place where our opinion at that time has not been exactly borne out by the facts. We thought this was one reservoir; we now know with later development, with the information that we have now developed, that it's two, there is an eastern part and a western part, and this is two reservoirs.

I think fortunately, for the conservation order of the Commission, the eastern part is in the shallow side and the western part is in the deep side, and for this reason, also because of the fact that we have already got a pretty good share of development up there on 160 acres, and we can't undrill a hundred and sixty acre well, so now we are asking the Commission to recognize the east and west pool and divide the two pools into the east and west and to go ahead and make

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the hundred and sixty acres temporary spacing in the east side permanent; that they give us a temporary order for 320-acre spacing on the west side, and that they grant us further opportunity to extend the investigation that we have made of the pool on that side.

Now, we believe that the applicant has really kept faith with this Commission and the opportunity that the Commission afforded to it with its order three years ago. As a matter of fact, in the western area of this, this applicant has done something that I daresay has never before been done. We conducted an interference test, not by shutting in a well and producing those around it to demonstrate communication and production characteristics of the pool, we shut in the whole pool in that part. We shut it in for two months, so that pressures would equalize and then we started out by producing one well and observing interference in the other four. The magnitude of the work that the applicant has done, and the money that it has expended in arriving at the information that we will today present to the Commission, I think, is impressive.

I am proud to represent this client. They have spent $70,000 in money that was not necessary to spend to produce this area in order to obtain the information that we will present. The magnitude of it cannot help but impress

you. Not only have they taken these interference tests in two areas, they also have gone to great extent to recover indigenous samples of reservoir oil. This sounds simple for the lawyer to stand up and say it was done. Actually, it's a complicated and expensive process, whereby they have to take a sample of the oil under pressure before any changes have occurred to it which normally change -- which normally do occur when you produce it. They have gone into considerable research to make studies upon things with regard to the compressibility of reservoir rock in addition to compressibility of oil.

They have taken reservoir pressures in a great magnitude and I am confident at this time to tell you that I am certain there never at any other conservation hearing anywhere has been collected the amount of information that this applicant has with regard to this area.

Finally, we think that we can demonstrate all of the theories which we acknowledge are somewhat complicated by a working model, or I should say two working models, to demonstrate and illustrate to you that a fractured shale reservoir comparable to the one that we have here under consideration must receive an entirely different category of conservation treatment from a reservoir of the normal type which has a matrix porosity such as the ordinary assigned reservoir or

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the ordinary lime reservoir which has vugular porosity. These two types of reservoirs are just not to be compared because in the one we have here, it's a low grade reservoir with very low reserve by comparison and by this model we believe that we will demonstrate to you the fact that although you may have a matrix reservoir with large reserve in comparison to the fractured shale reservoir producing at an equivalent rate initially the fractured shale reservoir will quit producing all of a sudden just like this and you have no more reserve to recover, whereas your matrix porosity reservoir such as your sand or vugular porosity reservoir will go on producing ten times or more oil and here we are actually going to demonstrate this fact.

This is the critical thing with regard to this type of reservoir and it is difficult to believe, but the truth of the matter is that a fractured shale will produce at the same rate of a sand reservoir that has ten to fifteen times as much oil and recoverable oil in place.

With that opening statement, I would like to call our first witness, Mr. Al Greer.

MR. CAMPBELL: You are so persuasive, George, I don't know if you need any witnesses.

MR. VERITY: You are kind, Governor. This is one reason I enjoy New Mexico.

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(Whereupon, an off the record discussion was held.)

ALBERT R. GREER, called as a witness on behalf of the applicant, having been first duly sworn, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. VERITY:

Q Would you please state your name?

A Albert R. Greer.

Q Mr. Greer, what is your educational background?

A I was graduated from New Mexico School of Mines with a Bachelor of Science degree in Petroleum Engineering.

Q And I believe that you have testified before this Commission as an expert petroleum engineer on numerous occasions?

A Yes, sir, I have.

Q Have you made a particular study of the petroleum engineering history and the situation in the San Juan Basin and particularly in the Puerto Chiquito Pool?

A Yes, sir, I have.

Q Have you devised any particular techniques for coming to ~~sound~~ petroleum engineering conclusions with regard to the Puerto Chiquito?

A Yes, sir. We have found that these fractured shale

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reservoirs, because of their unusual character, require unusual methods of calculation to determine oil in place and to estimate recoverable oil. And accordingly, we prepared a booklet which sets out the manner of interpretation which we use in our calculations with respect to these reservoirs.

MR. VERITY: Would you please mark these as exhibits?

(Whereupon, Applicant's Exhibits 1 through 5 were marked for identification.)

Q (By Mr. Verity) I hand you, having reference to which has been marked as Exhibits 1 and 2, are these the technical papers that you referred to?

A Yes, sir, they are.

Q These are, I observe, in considerable detail, especially with regard to mathematical and engineering principles and formulas.

A Yes, sir.

Q You have prepared these?

A Yes.

Q Have you submitted them to the technical staff of the Commission and also, I believe the USGS?

A Yes, sir, we submitted these approximately two weeks prior to this hearing in order that the engineers have time to review the manner of calculation which we would use and accordingly, save as much time as we could here at the hearing

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today. It will take quite awhile to go through these procedures and we feel it's unneccary since we have sent them to the Commission engineers ahead of time.

Q These two exhibits, Mr. Greer, present the engineering methods that you have used in your calculations rather than facts with regard to reservoirs?

A This is true, just the method of calculation. The only facts that we refer to in these exhibits are particularly with refcrence to another pool, the Boulder Pool, which is analogous to the Puerto Chiquito and we do have a few facts with respect to that reservoir.

MR. VERITY: We offer these two exhibits in evidence and if it please the Commission, we are not prepared to go into technicalities of the engineering science and method that is presented to you. We have stated, it has been presented to the staff so that they could familiarize themselves with it and can make any corrections upon it if desired. But we do desire to enter it in the record so that it will be reflected in all detail that anyone might want to examine how we have arrived at our factual conclusions and factual observations.

MR. NUTTER: Which ones are you talking about? You are talking about the green book?

MR. VERITY: The green one and the yellow one.

MR. NUTTER: The tan one is the attachment to the

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green one.

MR. VERITY: Yes. It really was attached to the green one, but they are introduced as two exhibits and these are the two that I believe were presented.

MR. PORTER: How are you designating these exhibits?

MR. VERITY: I believe these have been designated as Exhibits 1 and 2.

MR. CAMPBELL: Applicant's Exhibits 1 and 2.

MR. VERITY: Applicant's Exhibits 1 and 2. Thank you, Governor.

MR. PORTER: Does anyone have any questions concerning these two exhibits, the Applicant's Exhibits 1 and 2, any of the engineering staff, local or visitor's staff have a question concerning these exhibits?

MR. NUTTER: We went over those pretty thoroughly the other day, those two exhibits.

MR. PORTER: If thee are no questions or objections, the exhibits will be admitted into the record.

MR. VERITY: Mr. Greer has an observation to make about this division.

Q (By Mr. Verity) What have you got, an editorial typographical --

A Well, the first copies which we submitted to the Commission engineers were produced rather hurriedly in order

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to get them to them as fast as we could. They had a few typographical errors in them which we sent the ratio sheets out to show the errors. This particular copy is marked on the front page November 10th edition and this one had the typographical errors corrected in it and the official exhibit we feel probably has no typographical in it.

MR. PORTER: That fact is now reflected in the record and the staff, I believe did have an opportunity to go into these exhibits thoroughly at a prior session and so there are no questions so the exhibits have been admitted.

Q (By Mr. Verity) At this time, I want to identify the other three exhibits that we will have. The Commission will readily see the comment I made about the magnitude of information in evidence. It is true. We have a red exhibit, a blue one and a gray one which I believe have been marked Applicant's Exhibits 3, 4 and 5. And we will introduce these later, but at this juncture, I would like to call your attention to the red one, which is Exhibit 3. And will you tell us, briefly, Mr. Greer, what has occurred in San Juan Basin since the last hearing, particularly with regard to Puerto Chiquito, in a general way, please?

A In Puerto Chiquito we have had a continuous development program. Our production has steadily increased since the hearing three years ago which will be reflected on

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some of the graphs we will show later and with the exception of shut-in periods for times when we were running tests.

Q Now, in Exhibit 3, I believe that you have, "A" is an area map?

A Yes, sir.

Q And this just shows, generally, the general area of the San Juan Basin?

A Yes, sir.

Q And Exhibit "B", then, will you tell us what it shows?

A Before we get into that, would it be advisable to review the table of contents?

Q Yes. Tell us, if you will, please, what all you have collected in Exhibit "A" and in what order you have arranged it for presentation -- in Exhibit 3.

A Exhibit 3, if we will refer to the index, I believe it will help as we proceed with our presentation. We have divided our presentation into several parts. Part 1 is just general information, Part 2 is data relative to the extent of each common source of supply in the two pools; Part 3 has to do with communication and drainage in the southwest part of the area; Part 4, the same information regarding the northeast part; Part 5 is an estimate of oil in place and recoverable oil by analogy with another field which is Boulder; Part 6

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then is a direct determination of oil in place per acre which we calculated from our interference test; Part 7 is estimation of total oil in place in the southwest Puerto Chiquito and approximate areal extent of the reservoir; Part 8, the same information regarding the northeast part of the pool; Part 9, data relative to efficiency and drainage; and Part 10, comparison of characteristics of fractured shale reservoir with sandstone; and then 11 is information regarding ownership and position of other operators respecting our application.

Then in the little white booklet is information regarding economics which would be Exhibit 5.

Q The blue?

A And Exhibit 4, the blue book, is a statistical record of flood level measurements which were taken during the interference test. (Third,) it's quite a mass of data, but we believe the way we have arranged it, we will not have to dwell very long on the statistical records and accordingly, that we can put most of this information into the record in a comparatively short time.

MR. PORTER: Exhibit 5 is the blue book?

MR. VERITY: Yes, sir.

MR. COOLEY: 4 is the blue book. Exhibit 5 is the gray one.

MR. PORTER: Thank you.

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MR. VERITY: Thank you. I stand corrected.

Q (By Mr. Verity) Now, Mr. Greer, coming back to Part 1 of Exhibit 3, which is General Information, what is important to us at this time about general information in the area?

A We would just like to briefly bring the Commission up-to-date which counsel already has proceeded quite a way in that respect, and to make a comparison of our area with the rest of San Juan Basin respecting production. We've already discussed Section "A", the area map.

Q Yes. At this juncture I believe it would be proper if you would refer to the exhibit which has also been placed on the wall, the map. Will you point it out on the map on the wall and show us what wells have been drilled since the last hearing?

A The map on the wall --

Q It's Exhibit "D" of 3 in your book, and we also have it on the wall.

A The official exhibit will be the one that is in the book. The one on the wall, it would be helpful, I think, if I just point to some of the areas in order to acquaint everyone with the areas we are concerned with.

MR. PORTER: Is this referred to as Exhibit 3-D?

MR. VERITY: 3-D. That is correct, Your Honor, but

actually, 3-D in the book will be the official.

MR. PORTER: Yes, sir.

A The outline of the Puerto Chiquito Pool is shown as this area or this line which I am pointing to with the pointer here. The proposed division is this cross-hatched line which runs approximately down the center from north to south. We propose that the area east of that be the East Puerto Chiquito Pool and the area west of it the West Puerto Chiquito Pool.

Now, within the West Puerto Chiquito Pool is a Federal unit, the Canada Ojetos unit, which is indicated by this coundary which I am pointing to. In the East Puerto Chiquito there is another Federal Unit, the Puerto Chiquito Unit and I will point to its boundary.

Q Roughly, the middle third of the east part of the pool, right?

A That is true.

Q And the Federal Unit on the other side is roughly the south three-fourths or two-thirds of the west pool?

A That is true. And the two boundaries coincide at the point at which we recommend the pool be divided in this area here. Within the West Puerto Chiquito Unit is a participating area which is indicated by this cross-hatching boundary line and we will refer to this with respect to one of our interference tests which was conducted in Southwest Puerto Chiquito, was

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wholly within this partcipating area.

In the Northeast Puerto Chiquito we conducted interference tests in an area which is covered roughly by the dashed line which I am pointing to now. The colored wells are wells which have been drilled since 1963. The red wells are wells which have been completed. The green wells are wells which are drilling or have not been completed.

Q Now, proceeding on to area development since the last hearing, tell us what has occurred.

A Would you like to refer to Section --

Q Exhibit "B"?

A -- Section "B" of Ehibit 3?

Q Of Exhibit 3.

A Section "B" is a graph showing the comparison of oil production in the Puerto Chiquito Pool with the total of other Northwest New Mexico pools and primarily here we just want to point out that Puerto Chiquito at our 1963 hearing was producing approximately two per cent of the oil in the San Juan Basin or the Northwest New Mexico and we are now producing in Puerto Chiquito approximately ten per cent. We have had a gradual increase in Puerto Chiquito whereas the rest of Northwest New Mexico has been relatively static. Tocito-Dome and Horseshoe Water Flood are indicated to have given an increase in 1965 and that is shown on the plat.

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I would like to point out the effect of dense drilling in a fractured shale reservoir on our Northwest New Mexico total production, the little peak in the year 1961 was caused primarily by Cha-Cha-Gallup and Totah-Gallup which produced for a few months and the field was effectively depleted in just a short length of time.

Q Mr. Greer, if I read that right, Exhibit "B" reflects the Cha-Cha-Gallup and Totah-Gallup had a very marked increase over a three month period and then, an even more marked decline over the following six months, so that nine months after you started your increase, the pool had peaked out and was below where it started at the start of the nine months?

A That is correct.

Q Do you have anything further with regard to Exhibit "B"?

A No, sir.

Q Exhibit "D", I believe you have already discussed. Let me see if there is anything else.

A Sir, I would like to mention a few things about Section "C", if I might.

MR. VERITY: I'm sorry you are having a hard time with your lawyer.

MR. CAMPBELL: You might change chairs.

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MR. VERITY: Will you explain Exhibit "C"?

A Section "C" of Exhibit 3 is a schedule which shows the well-numbering nomenclature which we have added in order to clearly designate the wells which were producing three years ago and which have been drilled since that time, and in view of the different types of numbering systems which we have been, which we have experimented with, we have been concerned about having a permanent well number for each well that -- well, our experience has been, in most of the areas that we operate, that sooner or later our leases would become unitized and hopefully to recover additional oil and when we do and we have numbered each of the leases with well numbers starting 1, 2, 3, 4, and 5; when we put two leases together, then we have a combined unit with two wells, two wells number 1, two wells number 2, and so forth. Accordingly, we have decided to use for our permanent well designation the Commission's unit letters. This is shown on the left-hand column on this exhibit, then we have a current sequence number which is shown in the next column and this is the one which is required by the Commission's computer which works out the proration schedule. It has to have a sequence number, it's my understanding, in order to properly orient the wells on the allowable schedule.

The current sequence number is shown here. The previous sequence numbers are also indicated as well as the

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permanent designation. All of our maps and exhibits will carry the permanent designation as we feel that, from time to time, the others will change and we would like to have some semblance of permanency in the record which we are putting before the Commission.

Q I notice that this says Canada Ojetos Unit. Is this the Federal Unit you mentioned in the West Pool?

A That is true, is the Canada Ojetos.

Q Anything further with regard to Exhibit "C"?

A No, sir.

Q We have covered "D", I believe, out of turn, a moment ago and you don't have anything further about it, do you?

A No, sir.

Q Then I direct your attention, I would ask you, if you will, if there has been any change in your opinion about this pool over three years ago, particularly with regard to the geology?

A The main change is that we are now determined that we have two pools, at least two pools rather than one.

Q And what information has come to your attention in the last three years that has brought this knowledge?

A Well, we have two or three different types of things which now definitely prove that we have more than one pool. I think we might discuss them individually as we get to

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them.

Q One of these helps has been logged, I'm sure, and I direct your attention to Exhibit "E", that is to Section "E". Will you tell us what it is?

A Yes, sir. Exhibit -- Section "E" is a plat which shows sections of typical logs in this area and we have colored on this exhibit, which incidentally is a reproduction of one of the exhibits which we had at our 1963 hearing.

Q I believe that was Exhibit "Q-1" at the previous hearing.

A I believe that is correct. Now, as distinct from that exhibit, we have colored on this one the part of the Niobrara member of the Mancos shale formation which we have currently or in the last three years have completed wells in this area and the only purpose of this exhibit is to orient ourselves with respect to that part of the formation that is being produced.

Q And this is the same orientation as indicated?

A Yes, sir.

Q Turning now to Section "F", will you tell us what that is?

A Section "F" is a, you might say a blowup of the section which we just looked at under Section "E" which allows us to inspect with a little more detail the particular zones

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that we are producing. I think it's important to point out that we have found Zones "A" and "B" to produce in East Puerto Chiquito, whereas in West Poerto Chiquito we have found only Zone "C" to be oil productive.

Q Now, is there a difference in depth between the east and the west side of the pool?

A Yes, sir. There is several thousand feet difference in depth of the producing wells, although they produce from approximately the same interval.

Q If I understand you, then, you have actually taken a part of the yellow section, the yellow portion or yellow interval out of the "E" exhibit or a log similar to the "E" exhibit and blown it up and shown it here?

A Yes.

Q Is this the tool you used to find continuity across this pool or these pools, actually?

A This is true. We -- these logs are easily correlated. They are quite -- and they show quite similar characteristics throughout both East and West Puerto Chiquito. We have found that reaching the southern boundary of Puerto Chiquito, we can detect a difference in character, but as far as East and West Puerto Chiquito are concerned, they are quite similar. We cannot distinguish different reservoirs from this alone. This would indicate that we have quite similar sections in

East and West.

Q Do all of the logs in the east and west pool show these three identifiable zones?

A Yes, sir.

Q Do they produce everywhere?

A Zones"A" and "B" produce in the east -- northeast Puerto Chiquito. Zone "C" produces in southwest Puerto Chiquito.

Q Now, can you tell just basically from the log, alone, whether or not it will produce?

A No, sir.

Q I notice you have marked a portion of the colored zones with plus marks in each one of them. Would you explain that indication to us?

A The shaded area within each colored zone is that part of the zone in which we have found production. Now, perhaps the rest of the zone will produce in some areas, but so far, only the area that is shaded or that part of it that is shaded has been found to be productive, and we have found oil at various parts in the pool in those shaded areas.

Q Do you have any indication that there might be vertical communication between these zones?

A We have found vertical communication, vertical fracturing in cores within one zone, but we have found no

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vertical communication between zones. As a matter of fact, we have several instances in which we have positive proof of no vertical communication between any of these three zones. Now, perhaps they are connected at some part in the pool, at some place in the pool, but we have not yet found vertical communication anywhere, although we have found extensive horizontal communication.

Q Does this log compare in any way with logs taken in the Boulder Pool to the north?

A We have not attempted to correlate these particular zones exactly with Boulder, but we do know that Boulder produces from approximately this same section and produces from at least two or three zones which is distinct from Southwest Puerto Chiquito, particularly in which we have only one zone that is productive.

Q Still a part of Section "F" I notice a cross section of logs. Will you explain that to us?

A Yes, sir. This is simply a cross section from south to north, the cross section on the -- the well on the left is in the south part of the pool, well on the right is in the north part of the pool and this section shows the continuity of each individual zone across the entire pool and the ease with which these zones are identified and correlated.

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Q I believe you said awhile ago that you could take any log in the entire pool of any well and demonstrate this same continuity?

A Yes, sir.

Q You chose these because they ran the expanse of the pool?

A This is correct, and we will --

Q Does this exhibit, this section indicate on the right the location of the wells from which the logs were taken on the cross section?

A This is true, and I would like to point out that we can detect a slight change in character in Zone "C" which is the brown zone at the bottom of the map in the well on the left-hand side, which is the Standard Oil Company of Texas, Federal 1732 Number 1, located in the south part of the pool which indicates to us a possible change in character in Zone "C" in the south part of the pool and we would accordingly believe that this will be, probably close to the boundary.

Q And I believe, if I follow you, that it actually is right on the southern boundary of the area that has been spaced?

A This is true.

Q Anything further with regard to this cross section?

A I believe we should point out that this is a duplication of Section "F" of our main exhibit at the 1963

hearing. Nothing has changed since then to at least believe that there is anything different in that respect.

Q Then turning to Section "G", will you tell us what this sketch and what it illustrates?

A The sketch under Section "G" illustrates how one might detect when a well has crossed a fault. We have found in this area that we have faulting and this is how it can be detected. There is a loss of section, for instance, we can note from this sketch a distance between the geologic marker "X" and geologic marker "Y" as they are indicated on the sketch, which after a fault has occurred, the interval reduces. The well then drilled at Location "B" which would cross the fault at the point indicated would have a smaller section, then between geologic marker "X" and geologic marker "Y", than the normal Wells "A" and "C".

Q Turning the page and still remaining in Section "G", I notice you have three logs presented. Will you explain those to us?

A Yes, sir. The logs on the left and on the right are typical logs of nearly all the wells in this part of the pool. The center well is well identified as our Hickory at 237 Number F30, which cut a fault as the well was drilled, and this is indicated by the section which was absent and is shown in the center of the cross section.

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Q Would you indicate on the map on the wall which is a reproduction of Section "D" where the well is that this centering log was taken from which shows that a fault was cut?

A This is the well that I am pointing to in Section 30, Township 27 North, Range 1 East, and is within a mile or so of the suggested dividing line of the two pools.

Q While you are there, before you sit down, tell us is there another well that was drilled in that general area which also indicated fault?

A Yes, sir. Our P-13 about a mile and a half northwest of this well also cut a fault. We have not yet completed this well, but we have an electric log on it and it indicated to also have crossed a fault, but whether it's the same fault or another fault, we do not know, but it also crossed a fault.

Q What do these logs and these faults indicate to you?

A Faulting, of course, at times can, if it's not too severe, can increase the fracturing system and increase permeability in the vicinity of the fault. If the faulting is -- covers a great enough vertical distance and other conditions being correct, it will also effectively separate one side of the fault from the other as far as communication of oil and gas.

In the instance in which we have found faults here it appears that we are having an effective separation of the producing interval on one side of the fault as compared to the

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other.

Now, we have not found barrier to communication across any one fault, but it appears that we may have a zone of faulting with enough of them finally stopping the communication as far as the time intervals in which we produce oil is concerned.

Q Have you presented this zone of faulting on a section of our exhibit?

A Yes, sir.

Q I believe this is "H"?

A Yes, sir, Section "H" depicts the zone of faulting the way we now believe it to exist. The shaded area covers the part of the pool in which we believe the most faulting occurs and which we believe there is a definite separation of communication from the east part to the west part. The exact location of this zone of faulting is a little bit difficult to determine and we cannot say it is exactly in one point, that the communication on one side ceases to be effective on the other side which approximately down this shaded area which we have suggested the dividing line between the two pools be.

Q And I believe on Section "H" you have a cross-hatched line running from north to south with one offset in the township, in the middle of Township 26, that, do you suggest and recommend to divide the two pools?

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A This is true.

Q And this was drawn as practically and nearly as you could to your zone fault?

A Yes.

Q Anything else with regard to the division of the two pools?

A Yes, sir. We have additional information regarding separation of the pools.

Q You are referring to Section "I"?

A Yes, sir.

Q Would you explain it to us?

A Section "I", there is information taken from fluid sample analysis in Northeast Puerto Chiquito, Southwest Puerto Chiquito and Boulder Pool. Primarily what this information shows is that for the greater depths and the higher pressures that more gas is dissolved in solution in the oil. For instance, in Northeast Puerto Chiquito with its lower pressure of approximately 400 pounds, it has only about 80 cubic feet per barrel. Boulder had a higher pressure and approximately 140 cubic feet per barrel. Southwest Puerto Chiquito had over 1500 pounds and about 480 cubic feet per barrel.

Now, if there is no separation of the pools, we would expect, then, this same situation to occur as we drill

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to deeper depths and high pressures we would have more gas in solution. Now, we have found contrary to that in any one pool as we drilled to deeper depths and in turn, higher pressures we do not have a greater volume of gas dissolved in solution, but the same. Now, this is difficult to detect exactly and it has to be measured carefully. In Northeast Puerto Chiquito we went to great lengths to determine exactly the amount of gas dissolved in our deepest well which we would anticipate to have nearly as much gas dissolved in it as Boulder because of its depth and pressure. If there were no vertic -- no communication.

Now, contrary to that, we have found no more gas in solution than is indicated on here for the shallower wells, so this means to ask that it has to be the same oil as far as these two wells are concerned, and these wells are in communication with other wells in that part of the pool. Now, when we moved to Southwest Puerto Chiquito, we have the same situation there. We had a fluid sample analysis which was in the record three years ago. Since that time, we have obtained another bluid sample analysis from a well deeper, farther down the structure, higher pressure but still the same amount of gas dissolved in the oil and the same bubble point. Now, this particular well was the Canada Ojetos L-11 and we have indicated both the initial fluid sample analysis K-13, from the Well K-13 and from

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the L-11 to be the same line on this particular graft because it's so close that we couldn't tell the difference. It's rather expensive to obtain this.

Q How do you obtain those samples, Mr. Greer? And, if you can tell us in a few words.

A Yes, sir. The crystal thing in obtaining a fluid sample analysis in which you are interested in the bubble point is that the oil enter the well bore at a pressure above the bubble point so that you do not artificially create a lower bubble point than exists in the reservoir. In other words, if the reservoir pressure is, say about 1700 pounds as it was in the 1211 and the bubble point is only on the order of about 1500 pounds, if we can get the oil to enter the well bore at a pressure in excess of 1500 and in this instance we tried to do it with a pressure of 1600 pounds or more, then we have a sample which will give us valid information as to the bubble point. If, however, we produce the well under certain conditions in which the pressure in the well bore is lowered below the bubble point, as for instance 1400 pounds, then the gas that is dissolved in that oil will escape to that point and when the sample is brought to the surface and tested it will show a bubble point of 1400 pounds rather than the true bubble point of 1520 as it was in this instance.

Q Is that a costly thing to accomplish?

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A Yes, sir. When the bubble point pressure and the reservoir pressure are close together, then it's difficult to condition the well and particularly a pumping well such as this was in order that the oil in the well bore be not conteminated and that enough oil is being produced out of the formation into the well to be assured that we have a good sample. In this instance, we spent about $8,000 conditioning the well before we obtained a sample, and then, of course, the cost of running samples on top of that.

Q Do we have in our exhibits any place the fluid sample information that you obtained there?

A Yes, sir. The fluid sample analysis are in Exhibit 2.

Q That was submitted to the staff?

A Yes, sir. And that's been submitted to the staff.

Q Mr. Greer, by having this information, has it enabled you to make more accurate conclusions with regard to things like oil in place and the amount of oil in place?

A Oh, yes, sir. In addition to establishing separation of pools, we have used these, as a matter of fact, primarily we have used them for the purpose of calculating oil in place and oil in place per acre.

Q I believe you have another part to Section "I" which is a graft and will you explain it to us?

A Section "I" is just the resulting formation volume factors and bubble point pressures which occur because of the different amounts of gas dissolved in solution which we looked at on the previous graft. For example, in Southwest Puerto Chiquito with the larger volume of gas dissolved in the oil we have a bubble point pressure on the order of 1500 pounds which is shown where the curves break at the top of the graft; and the same information for Boulder and for Northeast Puerto Chiquito with the lower bubble point and lower formation volume factors.

Q Now, from the information you have gone over with us, you have made the conclusion with regard to separation of the pools?

A Yes, sir.

Q Do you have anything else in that regard before we go on to Part 3?

A Well, yes, sir. We have observed extensive communication within the areas in which we have tested within a reservoir as we defined them here. And we have across this boundary found no communication as for instance in the south part of the pool we have found no, we believe there is no communication between the wells on the east side of this boundary and the wells on the west side of the boundary. I am now pointing to the Standard Texas Wells in Section 32, 25 North, Range 1 East. No communication was found between these wells

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and the wells in the Niobrara Participating area in Canada Ojetos just west of that, although we have found communication over distances approximately that great within the Southwest Puerto Chiquito Pool, itself.

Q Going to the next section of our presentation, Part 3, in Exhibit 3, which I believe takes up in detail the interference test area in the Southwest Section of the Pool. Will you tell us in a few words what you did in conducting interference tests in that area?

A Yes, sir. I would like to explain, first, some of the serious problems which arose and why we felt we had to conduct special tests.

At the hearing three years ago, we indicated that the best of our information showed that approximately 500 barrels per acre is all the oil that we could expect to recover from Southwest Puerto Chiquito and in one of the exhibits which we presented at that time we showed that we could not have a profitable operation at that recovery, we would lose, I think, about $100,000 a well at 500 barrels per acre on 160-acre spacing. And I,also, in that same exhibit we showed that we could have a profit on 320-acre spacing. Now, at that time, we did not ask for more than 160-acre spacing because we didn't have the facts that we would like to have had.

We did believe, however, from analogy that this

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would be the situation. We also knew that our best comparative pool which was Boulder, would probably in this three year period be sufficiently depleted that we could then compare with Boulder, and sure enough, within six months of the 1963 hearing, Boulder was on its decline and we definitely determined then that the recovery in Boulder was going to be as we had feared, that is less than 1,000 barrels an acre. We had indicated that at 1,000 barrels an acre we could have a profit on 160-acre spacing.

Now, by analogy with Boulder, we feel that we cannot expect as much recovery as Boulder had because for one thing, Boulder had at least two, maybe three sections producing. Boulder had excellent wells natural. I think one well actually got out of control and flowed several thousand barrels a day. Most of the wells were completed naturally. In Southwest Puerto Chiquito we have yet to complete a well which will produce an economic rate without stimulating it with the fracture treatment.

In addition to that, we have the higher pressures, higher gas in solution and higher bubble point which we just looked at on previous sections which would also give us a lower recovery if everything else is the same. Accordingly, our fears were realized. Boulder is going to produce on the order of 700 barrels an acre and by analogy we would

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expect, then, less than 700 barrels an acre in Southwest Puerto Chiquito. Accordingly, we were faced with a critical economic situation, mainly even with 160-acre spacing there is no way that we can produce or develop the field at a profit.

Accordingly, we had to determine if the wells would efficiently drain a greater area than 160 acres and also we wanted to make a direct determination of oil in place per acre. We had some productivities and one, sometimes, is misled by high productivities being an indicator of a large amount of oil in place and we needed to know if there is a spacing on which this field could economically be developed. Hopefully, it could be done on 320 acres. Now, we conducted these tests, then, to determine more than just communication. We wanted to know could we effectively and efficiently drain the oil on wider spacing than 160 acres. We needed to know another factor and that is, are all the wells essentially connected? Are there any isolated parts of the pool? Now, in most interference tests, this could not be detected. Ordinarily one produces several wells of all the wells in a reservoir and you shut one in and you determine communication. And, of course, in that instance, it is possible that only two wells are in communication and the others are in another isolated part of the pool.

The only way we could detect this, then, is to shut all the wells in and produce one and observe the others to see

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if there was interference effects in it. Now, of course, this becomes expensive. When all the wells are shut in, of course we have no income and when only one well is producing and the others are shut in we are producing at quite a low rate.

Accordingly, we asked and had, we made an application to the Commission specifically regarding one test in Southwest Puerto Chiquito to allow us to make up this allowable that we would lose during this particular test in event the wells had the capacity to make it up. At the time we had that hearing, we were completing two wells and we hoped that they would have the capacities of two of our other better wells and that we would have the ability to make up this allowable. Well, actually, when the wells were completed, they were small wells, comparatively, about 100 to 150 barrel-a-day wells, and we could see that there was no way that we could make up all of the allowable..

Nevertheless, the situation was so critical that we decided to go ahead and conduct a test on the basis which we had planned, realizing that we would probably lose the allowable.

Q How much production in income has been lost or at least deferred by virtue of what you did?

A We have experienced a delayed income at this point of approximately $300,000.

Q Do you have any way of knowing whether or not you

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will get all of that back?

A No, sir. We feel, of course, that ultimately we will get all of this oil unless, of course, some other operator is successful in completing wells in the same reservoir and takes a part of the oil away from us.

Q In any event, you have lost the use of the money?

A In any event, we have lost the use of the money over, we don't know what period of time, it could be ten, fifteen or twenty years, and of course interest on that is substantial.

Q The interference test you conducted, is it different from the normal one that is run by the industry in a pool?

A Yes, sir. To the extent that I pointed out awhile ago.

Q Actually, if I understand what you really did, it amounted to many interference tests going on at once, or actually when you started producing the one well you had four interference tests at once because you were measuring the interference for four other wells. Is this correct?

A This is true.

Q I believe this has been illustrated in Section "J" and also, I believe, a copy of Section "J" has been put on the board. Will you please indicate how this was done and the wells that were affected?

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A Yes, sir. This plat indicates the four different phases in which we divided the interference test. Now, this particular interference test is in the Southwest Puerto Chiquito in the participating areas within the Canada Ojetos Unit.

The little plat at the upper left-hand corner of Phase 1 shows that all oils were shut in and this plat, Phase 1, shows the exact footage location of the wells from the section line.

Phase 2, we produced the one well marked P-11 while the other four wells were shut in. Now, during Phase 2 we had the tubing pulled from all of the shutin wells except the K-13 in Section 13. Accordingly, we were able to measure fluid level in these three wells. The well in Section 13 with tubing in it, we measured only bottom hole pressure. We could not measure the fluid level in it. Then in Phase 3 we put a second well on and observed the additional interference effect caused by this well on the shutin well and then in Phase 4 we put the third well on with two wells shut in. And we started this test in June of 1965 and we are still continuing now in Phase 4 of the test.

Q If I understand you, then, you still have two wells shut in?

A This is true.

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Q Now, you made reference to taking bottom hole pressure in K-13 and then in the other wells measuring fluid level. Why did you measure fluid level in three wells and does this give you any greater information or is it any better tool of interference?

A Yes, sir. We were, wanted to obtain the pressure decline in the shutin wells to the highest possible degree of accuracy in order that we could use this information to calculate oil in place per acre where the ordinary pressure bombs, of course, are only accurate within 5 to 10 pounds and the pressure dropped interval in which we were concerned is one which would probably be on that order, 10 to perhaps 20 pounds. Accordingly, we could not measure with the pressure bomb accurately enough to perform these calculations so we measured fluid level decline.

Now, the fluid level drop represents, of course, drop in bottom hole pressure and we can determine, actually, the drop in pressure from the drop in fluid level. Approximately three feet of oil is equivalent to one pound per square inch. We could measure these fluid levels within about a half a foot and accordingly, we had an accuracy then instead of on the order of 10 pound, an accuracy approaching a sixth of a pound. Now, this is, I think, a degree of accuracy which would result from the same individual measuring the fluid level. Now, different

people measuring the same fluid level will actually check within one or two feet. The same person, in measuring a fluid level drop, will probably have a higher degree of accuracy which I think would approach a half a foot.

Q If I understand Section "J" and directing your attention first to the second Phase 2 of it, your interference test there indicated communication between the L-11 and the A-23 and those wells are 6950 feet apart?

A This is true. We noticed interference over a distance of nearly 7,000 feet on those two wells.

Q And communication also to the L-11 and other wells there, but they were at shorter distances?

A In Phase 2, yes, sir.

Q Was, then, in Phase 3, what were the distances of interference measured?

A The Phase 3, one well which is the A-14 is approximately one mile from the L-11. The other two wells were approximately 8800 feet, that's 8,000, 800 feet, from the producing well being the L-11.

Q Now, is the degree of interference indicated here, does it indicate to you what type of oil communication this would support? Do you have an effective communication observed here?

A Oh, yes. We have effective communication and I would

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say effective drainage.

Q So that any of these wells would drain any other well?

A Oh, yes.

Q And if you took an area that had a radius of your 8800 feet, how much acreage area would this cover and show effective drainage on?

A It would be an area of approximately 6,000 acres and we probably should point out that this well nearly 9,000 feet away from the A-23 can drain the area around the A-23 more efficiently than the well itself.

Q Would you please indicate on the map that is on the wall, which is Section "D", where the other well that you are talking about, is-- is located?

A I am pointing to the L-11 in Section 11 which was the producing well and the shutin observation well, the A-23 in Section 23, nearly 9,000 feet apart.

Q And that demonstrates your effective drainage of 6,000 acres?

A Yes, sir.

Q Mr. Greer, outside of this interference test, has there been any observable pressure reduction in other wells at a greater distance? Have you observed any pressure interference other than these that you have indicated to us--

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A Yes, sir.

Q -- in the area? Would you please tell us about it?

A Well, we come to that in another section.

Q All right.

A I think it would be perhaps best to discuss it then.

Q All right. Turning to the second part of Exhibit "J", will you please explain it to us?

A Yes, sir. Exhibit -- the second sheet of Section "J" shows how we adjusted, adjusted our survey pressure to common datum in Southwest Puerto Chiquito. We went to rather great measures to obtain accurate information on, as to pressures, and to correct them to common datum. For instance, we made correction even for the whole deviation as to its affect on the true depth of the well. This schedule shows the amount of correction from the measured pressures in each of these wells to convert the measured pressure to a common datum of plus 1195 feet.

Q I notice on your third well down the A-14, that you have a correction with a minus 19 which is considerably lower than the other three. Is there a reason for that?

A Yes, sir. This is a well in which we had to directionally drill on a recompletion job because of the fact that the well when originally drilled, the pay section was covered with a string of drill cullers which we lost as a result

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of a downhole fire. Accordingly, that well is more crooked and has more correction for diviation.

Q Then I believe the next page of that same section is the bottom hole pressure summary?

A Yes, sir.

Q Will you please explain it, please?

A Well, the next pages which there are 1, 2, 3, which there are five sheets are statistical records of the pressure measured in the wells in the interference test area during the period of the test and I would just like to call attention to the method here that we used and some of the procedures in order to achieve the highest possible degree of accuracy from these bottom, from our bottom hole pressure maintenance.

Q Is this indicated in the sheet that is headed "Bottom Hole Pressure Summary"?

A Yes, sir. For each of the wells. The five sheets which I am referring to are the statistical records. Where, wherever possible, if we had both of our pressure gauges working we would run two pressure gauges each time we made a survey rather than just one in order to determine if there was one of the instruments, was getting out of calibration. In addition to running two bombs, we would make several stops with each bomb and using an average radiant we would then average several points, adjust each point to the survey depth and then average

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these points in order to again increase the accuracy. Now, probably the degree of accuracy that these bombs could be depended on would be something like five pounds, maybe ten on any one measurement, but by taking several measurements and averaging them and using two bombs, we believe we reduced this error to probably two or three pounds.

Q Actually, all these readings were taken from bombs and that is something separate and different from your fluid level reading?

A This is in addition to that. I would like to point out that, for instance, on the first sheet which is styled Canada Ojetos Unit 11, the bottom line, for instance, the Amarada Number 42 Bomb, 1676.5 pounds; Amarada Number 3, 1675.5. In that instance they checked within one pound and throughout the test they checked pretty close, two or three pounds. Now, once in awhile, they would get as much as five or six pounds off and then, of course, we would check our calibrations and determine if something had gone wrong.

Q Do these bomb pressure readings confirm the accuracy of the fluid level reading?

A Yes, sir. Being we found very close correlation between the drop in fluid level converted to pressure by using the density of the fluid column and then the pressure drops themselves measured by the bomb.

Q I notice next, in Section "J", is a graft, and I believe that it is the same one that you have on the wall.

A Yes, sir.

Q Indicating on the wall, if you will, will you explain this graft to us and what it indicates?

A First, I would like to say this: That the exhibits in the book have in addition to the information shown on the graft on the wall the various phases of the test. As you may recall, we said there were four phases and these phases are shown on the official exhibit. I'll point out Phase 1 was from about June the 8th until August the 4th, in which all the wells were shut in and the fluid levels were rising. This means the bottom hole pressure was rising. At this point, August the 4th, this is all in 1965, the P-11 was put on production and this is Phase 2.

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Now, when this well was put on production, the fluid levels dropped in all of the other wells, as for instance the L-11 dropped, oh, a measurable amount in just twenty-four hours. Approximately four or five feet. Now, this communication was so, so striking that we would have communication over these large distances; that we asked the Commission and the USGS Engineers to witness some of these tests and in this instance these engineers did come out and witness the beginning of Phase 2 and the points which they witnessed are noted on the exhibit by the little dark squares. P-11 was produced for approximately fifty days which we considered then the end of Phase 2 and then the L-11 was put on production which commences then Phase 3.

Now, during part of Phase 2 the L-11 was produced for a short period of time to condition. This is indicated in the period around September the 3rd to the 6th. Then when the L-11 was put on production at a high rate on September 24th a sharp drop in fluid level was noted in the adjoining well which is shown at the point I'm indicating here. Now, on this graph we have shown production by the line I am pointing to here in terms of barrels per day for all of the wells in the participating area that were producing. The heavy dark line shows which wells were producing as for instance in, on March the 14th the A-14 was put on production and produced as indicated by these dark lines. Phase 3 was ended in November and

Phase 4 commenced at that time by putting on the A-14 at this point. Now, the A-14 is a small well and we were producing approximately 900 barrels a day of the other two wells and this A-14 produced, oh, from 150 to 200 barrels a day and did not have a sharp drop or did not cause the short drop in fluid level that the larger wells did.

It's my opinion, however, that the effect was noticeable at that time, particularly here at the time I'm pointing to on the graph around November 12th, 13th and 14th.

Q Mr. Greer, if I understand this exhibit, then it actually plots and charts the production during the period of time that you were shutting in wells and reading pressures and the pressures in the wells that were shut in and interfered with?

A Yes, sir.

Q I'm not quite sure it was clear, but -- although you did cover it, but I would like to go back over it just a little bit, your first point of measurement of interference -- well, let me back up a minute. The left-hand part of this chart shows that you were producing wells, right?

A Yes, sir.

Q And then you came along to the 7th day of June and it shows that all production was terminated --

A Yes, sir.

Q -- at that point and that termination continued to

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the 4th day of August or the 3rd day of August except for forty-eight hours on the 23rd and 24th of July. Is that correct?

A That's true.

Q Now, how many wells did you produce for that forty-eight hours? One well?

A One well.

Q How much?

A At approximately 2-- barrels per day for forty-eight hours.

Q That is only 400 barrels of production if I understand you.

A That is true.

Q And yet you read pressure decline in the other three wells?

A Yes, sir. As indicated on the circles that I am pointing to on the left hand side.

Q Well, this certainly would indicate then that that well could actually produce the oil from those other three wells, would it not?

A Yes, sir.

Q Or does it not?

A Yes, sir.

Q Then grading across this exhibit to the right and it's

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not indicated on the one on the blackborad, but the section of Exhibit 3, it does indicate Phase 1, Phase 2, Phase 3 and Phase 4 and that correlates back to the start of the four Phases of the interference tests --

A Yes, sir.

Q -- referred to. Then in Phase 2 you began producing one well. In Phase 3 you began producing three wells.

A Two wells.

Q Two wells. And then in Phase 4 you began producing three wells and that is continuing at the present time?

A Yes, sir.

Q Now, this means that interference test has been continuing since the eighth day of June, 1965?

A Yes, sir.

Q In other words, for a period of eighteen months.

A Yes, sir.

Q And is going on now?

A The continuation of it is shown on the next graph.

Q All right, let's turn to the next graph that is still a part of this same section. Actually, it is just a continuation of the graph you had here, is it not?

A Yes, sir. This is just a continuation of the first graph in which the one well, the A-23, is still shut in and we are measuring fluid levels in it and then of course also

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the K-13 is shut in but we are just measuring bottom hole pressures in it.

Q Do the bottom hole pressures confirm generally the fluid level measurement?

A Yes, sir. They do.

Q I noticed this line on the latter part of this exhibit, there is only one line which is the continuation of the top line on the other.

A Yes, sir.

Q You have a little circle. There are two in each day. Does each one of those circles mean a pressure reading or fluid level reading?

A Yes, sir. Each one of those circles represents an actual measurement of fluid level in which a man went to the well, lowered the float on the wire line to the top of the fluid and measured, actually measured the fluid level and recorded it and reported it. Now, those -- that record of fluid level has been summarized and it forms our Exhibit No. 4. The little blue folder.

Q I noticed in June of 1966 again we have two of the black flags -- black squares. Does that again mean that the Commission or USGS officials observed those readings on those days?

A Yes, sir. Actually we had asked the Commission

Engineers to witness a critical point in the interference test in the northeast part of the pool, but while they were out there we asked them also to witness the continuation of this test, which they did.

Q Anything further with regard to this section?

A I think not -- oh, the section, yes, sir. The next graph within this same section is --

Q Yes?

A -- the graph of the bottom hole pressures which were, the statistics of which were shown in the first part of this section.

Q Now, actually --

A The same general character is evidence here that we found in the fluid level measurements in that during the shut in period, the pressures rise. When the wells are produced the shut in wells suffer a decline in pressure. Now, this is rather a severe drop in fluid level and pressure. The fluid level in the A-23 has dropped some 400 feet in the last year and a half in which it has been shut in and the closest producer to it is a mile away.

Q Actually, this last churt that you are referring to now, it is really a presentation of the same thing as the previous one except here you are showing the pressure bomb readings rather than the fluid level readings.

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A That is true, and of course we don't have as many bomb readings and each one is not quite as accurate as the fluid level.

Q But each one confirms the other?

A Yes, sir.

Q Is there one particular well that has never produced that has had a real large fluid variation, fluid level change during the period?

A Yes, sir. I just said the A-23 had suffered a 400 foot drop in fluid level. That's a large drop in pressure, something over 100 pounds pressure drop and the well has not produced a drop in this year and a half.

Q Anything further with regard to Section "J"?

A No, sir.

Q This brings us, then, to the data relative -- to Part 4, the data relative to communication and effective drainage in Northeast Puerto Chiquito. Did you conduct a similar type of test in the northeast area to establish communication and effective drainage between wells there?

A Yes, sir, except in Northeast Puerto Chiquito we conducted a more or less normal, customary type of interference test in that most of the wells were produced and only two or three wells shut in. And the reason we did this in the northeast part of the pool is that the producers are small and that if

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we had attempted the same kind of a test as in the southwest part of the pool we would have no hope of producing all of the allowable currently from just a few wells and not only would we lose the allowable for the time which the wells were shut in, but we would lose current allowable. It would be a prohibitive procedure cost-wise to make the same type of an interference test as we did in the southwest. However, we did conduct a very effective test in Northeast Puerto Chiquito.

Q Now, I believe you have previously indicated the area of this test on the Section "B" that is on the wall?

A Yes, sir. I will point to it again, the area in Northeast Puerto Chiquito in which we conducted an interference test is the one I am pointing to.

Q And that is the one that has the dark dotted line circling the wells and area up there?

A Yes, sir.

Q Well, turning then to Exhibit "K", does it give us the information on this test?

A Yes, sir. Exhibit "K" gives us -- the first sheet in Exhibit "K" is the statistical summary of the pressures which were measured during the interference test in Northeast Puerto Chiquito. And in addition, the fluid level measurements which were taken are also shown in Exhibit 4, recorded there

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as they were taken in the field. Then graphically we have presented both the fluid levels and the pressures on the graphs within Section "K". The first one is for a well P-19 and shown on this graph is the location of the well.

Q That's in the upper right-hand or in the upper side, in the right middle of the graph?

A Yes, sir.

Q That shows the areas and the wells involved?

A Yes, sir. The well colored in red is the P-19 which was the subject shut in well. The wells colored in green are two additional wells which were shut in, and the well colored in hellow is one in which we gave the well a sand fracture treatment during the period of the test.

Q Did you even observe a sand fracture treatment across this area?

A Yes, sir. It was rather interesting. The well which was given the sand fracture treatment was about a mile away from the shut in well and a definite change in the fluid level was shown as a result of this, or resulted from this sand fracture treatment. This is shown in July, toward the end of July. It is noted on the graph where we pumped 150 barrels of oil in the formation, cleaning out the C-5 preparatory to fracing it. Then the next day where we fraced, and then the following day the fluid level rose some ten or twelve feet

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from what it had been previously.

Q Was this actually a planned portion of this test?

A No, sir, it wasn't. It just happened that we fraced the well during the period of the test, and --

Q And it actually dramatically shows the interference in reverse of what the other measurements are?

A That is true. Instead of taking oil out of the reservoir, we were putting it in and so the fluid level went back up instead of coming down.

Q Now, basically, this chart shows the same as in southwest except here, I believe, you plotted both your fluid level and your bomb pressures on the one chart?

A Yes, sir. And I should perhaps briefly explain. We shut the P-19 well in, we shut all the wells in the first of March, and the P-19 had been shut in for about ten days in the latter part of February and we can see how the fluid level tended to stabilize in the P-19. Then the first of March we shut all the wells in and then the pressure rose over that period of ten days and was still rising when we started the wells to producing. Then for the rest of March, April and May various wells were produced in this area and it can be seen from the graph how the pressure -- the fluid level moves up and down as different wells were taken off and put on production. Then in June --

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Q Actually, you can correlate this graph in relation to your stopping and starting production on the various wells?

A Yes, sir. Some of the wells seem to have more effect than others. Then in June we shut all the wells in again and asked that the Commission Engineers witness the beginning of the shutin period and the beginning of the producing period which they did, and that's indicated on the graph at the middle and end of June. Then during the period July, August, September and October we've tried to keep our production rate as stable as possible and accordingly, we have a little more definite decline in the fluid level in this particular well than we did for the months March, April and May, in which various wells were on and off production period.

Q Again, Mr. Greer, you lost ten days production at the start of March and eleven days production, or ten or eleven days production in June?

A Yes, sir, and it's pretty obvious from the graph that we did not make up the lost production. These wells in this part of the pool produced pretty close to capacity all the time, or at least if not capacity, the wells' capacity of equipment we have on them and --

Q Tell us, if you will, whether or not the information obtained in this interference and communication test shows communication in the wells?

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A Yes, sir. In this instance, the closest producer to this well is a half a mile away, which would be approximately one section per well drainage.

Q Is that an effective drainage as you observed at the other place also?

A Yes.

Q So that this well could drain oil from under the shutin well?

A Oh, yes, sir.

Q Is this test still continuing as the other one is?

A Yes, sir.

Q Do you still have the well shut in?

A Yes, sir.

Q I believe you have another -- now, I believe before, your testimony was that one well would drain 460 acres.

A A minimum of four hundred --

Q A minimum of 460 acres?

A Yes, sir.

Q Actually, as I pointed out in my statement, you said your opinion was far greater, probably 2,000 acres. Now have you actually in any of your production in Puerto Chiquito demonstrated that a well can produce over 460 -- can drain an area of 460 acres or more?

A Yes, sir. We, since the last hearing, we have

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produced, our two wells have produced more oil than that, more oil than the 230,000 barrels which would represent recoverable oil from 460 acres at 500 barrels per acre.

Q So in addition --

A Now, these wells, incidentally, are in the Southwest Puerto Chiquito, although we are currently looking at Northeast Puerto Chiquito.

Q Yes. And this actually demonstrates not just by communication but by actual production, that they produced the oil from a greater area than 460 acres. What is the present condition and attitude of production of those wells?

A Oh, they are still producing at high rate.

Q Would you say they are still producing at maximum efficiency?

A Oh, yes, sir, they are producing at maximum efficiency.

Q Directing your attention, now, to the next portion of our Section "K" which again is, I believe, a continuation of the previous graph?

A Yes, sir -- no. The next one is for the P-20 for the year 1965.

Q This is in the northeast yet?

A Yes, sir. And here again, the little plat within the graph shows which well is shut in, the other two,

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observation wells, and again the well which was fraced. Now, the well which was fraced, during the period of this test, was fraced in 1966. We considered this test to be over 1965 and '66. Then the next graph is a continuation for the P-20 for the year 1966 and it will be noted that although these wells, this well, now, has been shut in ever since it -- ever since it was drilled.

Q This is the P-20 --

A Yes, sir.

Q -- that you are referring to?

A Yes, sir. It has never been produced and the pressure is nevertheless dropping and it's at about the same level, if referred to the same datum as the P-19 which has produced a lot of oil.

Now, the pressures shown on these graphs are pressures at the depth at which the measurements were made in each of the wells. These pressures in Northeast Puerto Chiquito have not been referred to a datum as we did in Southwest Puerto Chiquito.

Q Now, I notice again your black squares in June on this graph indicate, I presume, that the Commission staff witnessed the taking of the fluid level?

A Yes, sir. We might -- I notice here in the pressures in the middle of June the readings that the group made, and

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which the engineers witnessed, the measurement was about two feet difference or different from that which our representative measured earlier in the day. That is about the greatest difference in measurement that we have noted between different individuals in taking the fluid level.

Q It still indicates the --

A Oh, yes, sir.

Q -- the interference? Now, the P-20, did it, prior to this production test, was it, or interference test, was it a producing well?

A No, sir. The P-20 encountered water in the producing interval although it's high on the structure, nevertheless it's in pressure communication with the other well, as is indicated here. It's just one of those unusual situations with which we have to cope in this field. It indicates that it's a hazardous field in which to drill.

Q Didn't this well produce some oil prior to the time that you had this?

A This is true. This well produced from a zone above the main producing zone, oh, I think five or six barrels a day for a short period of time and then when we ran a log on it and found that it was apparently faulted in that area and the main pay was another one or two hundred feet deeper. When we drilled the well on down to the main pay, then we found not

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oil but water, so when I say the well never produced oil, I mean it never produced oil from the main interval.

Q Your next part of this same section is continuation--

A Yes, sir.

Q -- of another well?

A Yes, sir.

Q Or graph of another well?

A Yes, sir. The next one is a graph showing information for Well Number F-6. I will point to that on the map in Section 6, 26 North, Range 1 East.

That well also made water and we feel that it's across one fault and the communication has been restricted somewhat, but not completely, because the fluid level and bottom hole pressure is declining in this area just as in the others.

Q Again this confirms the same thing as before. Now, actually your first graph was communication across a half mile. What is your distance here?

A Well, the closest producer to this well is again about a half mile away which is the other well in the northeast quarter of that same section. That well, however, is a small producer and I doubt that it had much effect on the F-6. Probably the major effect or the major production

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which is causing the pressure to drop in F-6 are wells which are about a mile away from it.

Q So actually, that would be considerably in excess of one section that you testified to before?

A Yes.

Q That is a real conservative statement, I take then, on your one section drainage?

A Yes, sir. In spite of the fact the well makes water, we think the communication is still established, you know, if it were oil in the well it would still move the same as water.

Q I believe we have later today an exhibit that will explain how that can occur?

A I'm saying now that although there is water in the well, rather than oil, the fact that the pressure drops in these wells means that we have communication and oil would drain across there although what we are measuring is a drop in pressure in the water.

Q In the fluid, is it not, you measured the same pressure?

A That's right.

Q Do you have anything further with regard to Part 4 and your interference test in Northeast?

A No.

Q This brings us, then, to Part 5 of our presentation

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and this is data relative to oil employees and recoverable oil and analogy with the Boulder Pool?

A Yes.

Q How far away is the Boulder Pool that we have been talking about here?

A Well, it's about, it's about ten miles.

Q I believe it is shown on the area map in Section A as being immediately to the north.

A Yes, sir, it would be about eight to ten miles from this area we are discussing.

Q What are the similarities between those two?

A Well, both pools produce from the -- both pools produce from the Niobrara member of the Mancos Shale. They are both in a steeply, dipping area, both had undersaturated oil when discovered. Both probably had some saturated oil and perhaps a little free gas. Both areas, and when I say "both," I am referring now to Boulder as one and all Puerto Chiquito as another, all of these reservoirs apparently produce from fractured shale. We can detect nothing in Boulder that indicates anything different from what we have found in Puerto Chiquito other than that they had better, higher capacity wells natural than we had.

Q Is there any matrix porosity in the Boulder Pool?

A Not as far as I know. We do not drill any wells in

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Boulder, but all that has been reported is that the engineers concerned thought that it was fractured --

Q What do you mean when you say "matrix porosity," Mr. Greer?

A Well, as a sandstone that has pore space between the grains is sometimes referred to as matrix porosity.

Q Does this give you much greater oil in place than what we are talking about here with fractured shale?

A Oh, yes, sir, for the same volume of reservoir or same thickness, say it's ten feet of sand and ten feet of shale, you would have much more oil in the sand than in the shale, even the tightest and finest sand.

Q Does Puerto Chiquito, either east or west, have any matrix porosity?

A Not to our knowledge. We have an exhibit we will come to later regarding the core analysis, but it is my opinion that any sand stringers or sandy shale stringers contribute, that might be within the section, contribute nothing to the production.

Q Now, what does the Boulder Pool and the information that we have about it at this juncture, it's largely depleted, you said earlier, did you not?

A Yes, sir.

Q Now, all of the information you have about that, what

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does it tell you and what can it tell you with regard to our Puerto Chiquito Pool?

A The main bit of information that we can determine from Boulder now, I believe, is approximately the per cent of oil in place that is recoverable from a fractured shale reservoir. Now, even here the information is not as good as we would like to have, but we believe it's better than anything else that we have at this time as a yardstick for the per cent of the total oil in place that might be produced. Now, in addition, we have just the general information that it's going to produce about 700 barrels an acre, and generally the areas are comparable, Boulder with -- Puerto Chiquito with --

Q In Exhibit "L" have you presented information with regard to the Boulder Pool?

A Yes, sir.

Q Will you refer to Section "L" and tell us what the first part of it is, a graph?

A The first part is a graph which shows the production rate in Boulder, how its decline, and the fact that there is very little additional recoverable oil that we expect from Boulder. Now, there is some -- the statement on the graph regarding estimated future production from January 1st, 1964 which really has no bearing in this particular hearing. We

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were embarrassed as we were putting our exhibits together and found that we had not plotted or had not prepared a graph for Boulder and we used one which we had prepared in nineteen, early 1964 respecting the economics of a pipe line in the area and this is the reason that we felt that we needed this graph and this exhibit, so we put it in.

Q Well, your projection at that time was correct today, was it not, practically?

A Yes, sir. I would see no reason to change the estimate.

Q And referring to the next part of Section "L" --

A Next part of Section "L" is a graph which is the pressure production and gas-oil history of Boulder. From information which we have obtained from the companies that operated in this pool, we can see that the pressure has pretty well declined. It's less than 100 pounds in this particular observation well which is indicated with a gas well symbol upon this little graph and actually is pressures measured in a gas well which was completed at the south end of the pool. This again is another well which has never been produced. When it was completed, it was a gas well and the company shut it in and it's been used only as an observation well to show pressure decline in the pool.

I would like to point out that we have computed oil

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in place from this pressure production data at two periods of time. One is for a period up until the first 200,000 barrels of oil was produced which was approximately October 1, 1966 which is shown on the graph. And then for another period of time from about January 1 of '63 to May of '63 which are some pressures which were taken by Standard of Texas when they were running an interference test preparatory to a spacing hearing before the Commission. We have used this data from these two time periods to estimate total oil in place in Boulder which is shown in the next two graphs.

Q Explain the next two graphs in order to please. These are the two graphs, I believe, that have a band of green at the top left?

A Yes, sir.

Q And at the bottom left on the second one?

A Yes, sir.

Q The first one with the green at the top, it says "Range of Assumed Saturation." Explain that graph to us.

A This graph shows a total volume of oil in place in the reservoir which we would anticipate from the pressure information from the previous graph for the period from January 1, '62 to October 1, '62. The right-hand curve is for the conditions in which there is no free gas saturation

and a formation compressibility factor of ten times ten to the minus six.

The second line is for the condition in which there is no free gas. By second, I mean second from the right, and a formation factor of three-five times ten to the minus six. Now, the reason we have used these two formation factors is that we just don't know what the compressibility of the fractured shale is. I personally think it will be within that range. Then the line on the left, then, is also for a formation factor, compressibility factor of thirty-five times ten to the minus six plus five per cent of the reservoir space filled with free gas.

We think it's possible, in fact, there was free gas in Boulder. We don't know how much. But this gives us a maximum and a minimum amount of oil in place which could have been computed from information at that time, which, of course, admittedly, is a pretty wide range from three and a half million to fifteen million barrels of oil, but is as close as anyone could estimate oil in place in Boulder as of that time, primarily because a large part of the oil was still unsaturated and it has quite an effect on the pressures and the volume of oil that's computed.

The next graph, then --

Q That was in 1962 --

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A Yes, sir. Information as of --

Q -- information available?

A Yes, sir.

Q Then referring to the next graph which is similar, but I believe covers the time period from January 1, '63 to May 1, '63, is that correct?

A That is correct. And at this time, most of the oil, we believe, was saturated rather than unsaturated and we now have more information which will give us more accurate range of oil in place at Boulder. In this instance, we think roughly from around a half to nine million barrels is what we would estimate for oil in place in Boulder at that time.

Q You now have more accurate knowledge and information as is platted?

A Right. And it's my opinion that this is about as close as we will ever know to what the original amount of oil in place was in Boulder.

Q Now, Boulder being mostly depleted, you know with considerable accuracy the total amount of oil that will be produced there, do you not?

A Yes, sir.

Q What is this?

A Oh, around 400,000 to 500,000 barrels, just an estimate.

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Q And what percentage of the oil in place does that mean will be produced?

A Well, if there was a minimum shown here of about four and a half million barrels, then that would be roughly about a third of the total oil in place would be recovered or if the total oil in place was originally nine million barrels, then that would be about one-sixth of the total oil in place will be recovered, so in view of this study of Boulder, it's my opinion that the recoverable oil will be in the range of one-sixth to one-third of the total oil in place.

I think we should point out here that we do not have the one tool which is often available for the determining total oil in place from a depleted pool that has produced under solution gas drive and that is often you can measure the total amount of gas over the life of the pool and then knowing how much gas was dissolved in oil we can compute back to determine how much oil was originally in the pool. Now, in this instance, I believe there were stringers, pay zones, above the main producing pay in Boulder which produced only free gas, not a lot, but some. This is indicated on the earlier graph in which the initial produced gas-oil ratio was two or three times as high as the solution ratio. This meant that there is some free gas coming from somewhere and it's my opinion it was probably from zones which again, if the same situation exists in Boulder

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that exists in the area in which we have drilled wells and there is no vertical communication with this free gas, then we would have a situation in which we cannot compute oil in place from the total gas produced.

Accordingly, we are denied this one method which is often a useful tool.

Q Well, this one-sixth to one-third recovery of oil in place on a fractured shale reservoir, is this in the range of what you would expect?

A Well, unfortunately, we have very little information on the fractured shale reservoirs as to the efficiency of recovery. We do have some information on relative permeability ratios of fractured formation which shows an extremely wide range and we have computed these which we will get to later on, but they cover such a wide range that from a practical standpoint, they are not much help to us.

Q Do you think that it's sound to analyze or from analogy to reason that we will have the cause of the great similarity of these two pools a range of recovery of the same magnitude of the same variation?

A Yes, sir.

Q Within the same limit in Puerto Chiquito?

A Yes, sir. We have to take into account the difference in the viscosity in gas dissolved in oil and such

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as that.

Q But when you consider it --

A Yes.

Q And you have made those calculations?

A Only to the extent that we can expect in Southwest Puerto Chiquito the recovery to be less because of the higher amount of gas dissolved in the oil and in Northeast Puerto Chiquito roughly the same, perhaps a little bit higher recovery because of the lower amount of gas dissolved in the oil.

Q Anything else with regard to this analogy and calculation involved?

A No, sir.

MR. PORTER: Mr. Verity, before we proceed to Section "N", suppose we recess the hearing until 1:30?

MR. VERITY: Thank you, Your Honor.

(Whereupon, recess was taken.)

MR. PORTER: The hearir .ill come to order, please, Mr. Verity.

MR. VERITY: Mr. Greer, I believe just before recess, we had just completed the presentation testimony with regard to Part 5. This brings us to Part 6 which is "Direct Determination of Oil in Place in Southwest Puerto Chiquito," and I notice that Exhibit 3 says "of oil in place," and this is actually oil in place per acre, is it not?

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A Yes, sir.

Q I wonder if we might not correct the official exhibit.

(Whereupon, an off the record discussion was held.)

MR. VERITY: That is in Section 6 in the Index. Thus, on the Index the heading on that section should read "Direct Determination of Oil in Place Per Acre."

Q Have you made a calculation on Puerto Chiquito with regard to oil in place per acre, Mr. Greer?

A Yes, sir, I have.

Q And have you done this by analogy or is it done by mathematical engineering calculation?

A It was done by calculation of information developed during the interference test. There is no analogy or comparison with any other pool in this type of calculation. We just used the actual interference data and calculate oil in place per acre from that.

Q Did you have a lot of variables to consider in making this type of calculation?

A Yes, sir, there are.

Q What are the variables that you have considered and taken into consideration?

A Well, primarily the compressibility of the different fluids and the formation. They are the most indeterminate ones.

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Simply stated, the, this type of calculation can be made during the first phase of pressure disturbance which moves through a reservoir. It can be compared to the diffusion of heat from a source of heat in, from conductive material. We can see how the pressure decline changes with time when we first start an interference test. As for example, on the graph on the wall we can see that when we first start producing the well, the observation well pressures drop rather rapidly at first and then as time goes on they tend to level off, and of course here we put another well on the pressures drop rapidly and then they level off. By "level off," I mean the rate of decline becomes constant, As for instance, the A-14 after this first transient period has passed, the fluid levels become rather constant in terms of time. Every day they drop about the same amount. The same is true for the other wells.

Now, for example, when we first put the P-11 on production in August of 1965 the pressures started dropping rapidly in the wells closest to the producing well so whereas the fluid levels were close together when we first started the test, the wells closest to the producing well dropped faster than the wells that were further away.

After a certain period of time which we refer to as the transient phase of this pressure disturbance moving

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through the reservoir, then the all pressures tend to reach the same drop in terms of feet per day or pounds per day such as is shown here.

Now, for this period of time in which the rate of change in fluid levels is different is the period in which the, the period which we refer to as the first phase or transient phase. During this period of time that pressure is dependent not only on the factors that influence the pressure decline after the first phase passes, but is dependent also on porosity and permeability of the reservoir.

Now, this being the case, we can then from information taken during this part of the test compute oil in place per acre. Now, the nature of the calculation is such and the unknowns are such in this area that we cannot determine the exact number of feet of pay or the exact porosity but we determine a factor which is the product of porosity times feet of pay which is simply the pore space of the reservoir and this can be done by the transient flow equations from information taken at the particular part of the interference test.

Now, this we have done. There are, of course, certain requirements that have to be met for any test to be valid and to be useful for such a calculation. I believe that the test that we have used meets all the requirements and that we have a reasonable calculation resulting from that.

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The results of that calculation are shown under Section "M", the first sheet.

Q Turning, then to Section "M", the first sheet, will you explain it?

A I have chosen for this part of the calculation the period in which the pressure declined in the A-14 from the last part of September until about the middle of October.

Q Mr. Greer, pardon me just a minute. You are indicating, I believe, on the wall to the Exhibit or to Section "J" the first chart in Section "J". Pardon my interruption, but I thought they needed to know where to find that.

A Right .... right.

Q The chart he is referring to on the wall is the first chart in Section "J".

A I have used the period of time from the last of September until about the middle of October for the pressure interference effect in the A-14 caused by putting the L-11 on production commencing September 24th. The result of that, I have computed for various time periods during the test the amount of oil in place per acre for two different assumed compressibilities which I believe covers the probable range. These are shown in the two right-hand columns. These are oil in place stock tank barrels per acre. For instance, with information at the end of one day I compute 250 barrels per

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acre on the high side or 890 barrels per acre by using the other compressibility at the other extreme. At the end of fourteen days the information indicates approximately the same. In other words, there is a range of about 1,000 barrels per acre to 2500 barrels per acre that we can compute as being oil in place in Southwest Puerto Chiquito.

Now, in my opinion, the compressibility is probably between these two extremes and I would estimate probably 1500 to 2,000 barrels per acre is a fair estimate at this time of oil in place per acre in Southwest Puerto Chiquito from this interference test.

Now, it is important that we make these calculations over a period of time as indicated here to determine that the results are fairly constant and the fact that they are constant does not necessarily mean that this is a correct answer for the oil in place, but it does eliminate the possibility of extreme directional permeability as for instance, a large fracture between the producing well and the test well. If that were to occur, we would calculate at the end of one day a low volume of oil in place per acre and then as time went on it would increase. Now, this would mean that we could not use this method to calculate oil in place. We might approximate it, but I would hesitate to use it. The test we used, I believe, is a good test, and from that standpoint,

really our only variables are the unknown compressibilities primarily of the fractured shale which brings about the range from 1,000 to 2500.

Q Turning, then, to the next page in Section N, will you explain it?

A This is a graph which just shows how we determine the effect of the interference which the P-11 caused on the subject well, the A-14. Part of the pressure drop in the A-14 was, of course, caused by the previous well, the P-11, which had been put on production earlier. It's pretty easy to estimate or to extrapolate the effect of the first well on the fluid level decline in the A-14.

Q If I might interrupt, this is actually a section taken out of the chart that we referred to in "J", is it not?

A Yes.

Q Or the one that is on the wall.

A This is correct.

Q A section taken out in September and October.

A Right. We just took out a part of that same plat.

Q Yes.

A Then the next graph shows how we, part of the information we used in computing oil in place. It has two plates, Plate 1 and Plate 2 and here we have plotted the net effect or equivalent fluid level drop from static which is

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indicated on the previous graph showing a zero drop to begin with and ending in about forty-five days with about sixty-five or six feet of fluid level decline, resulting from the production of the L-11. Now, when we plot that same information on the lower plate, Plate 2 of that sheet, we note that there is a straight line portion of the curve on this particular type of a plot which is indicated from the sixth day to about the eighteenth day. We can use that information to determine transmissibility of the formation and we have indicated that here to be 13.4 pounds per cycle and that is determined from a fluid level drop of about thirty-nine and a half feet per cycle times the density of oil column converted to pounds per square inch gives us 13.4 pounds per square inch.

Then the next two pages are simply a statistical summary of the net amount of the fluid level drop resulting from this particular test. Following that, there are three pages of pencil notations which says the calculations of this particular test and the only reason these are included is because it's an unusual type test and in the event engineers want to check the calculations, why, they are here where they are readily available.

I will point out on Page 3 item circled number 4; by this type of calculation we determine a very, very accurately the ratio of permeability to porosity. To go from that factor

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to oil in place, we need also to have a true value of transmissibility which we refer to as KH. That's permeability times feet of pay. Now, if there happens to be an unknown boundary, field boundary close to either the producing well or the test well, this will not affect the first calculation which is permeability divided by porosity, but it will affect the slope of the curve and the resulting calculation of transmissibility.

Now, the maximum effect that this could have if there were a nearby boundary would be a two to one ratio. Now, I know that there is an area of lower permeability near these test wells because the P-11 was completed in it. Now, this will have the effect of a partial boundary. I have just made an arbitrary estimate that it might affect as much as one-third of difference from no effect to maximum effect. This gives a slightly higher value of KH than would otherwise be obtained. It also gives about thirty per cent more oil in place per acre than if we used a straight calculation without this assumption.

This is one thing -- this is one point that I could not make a direct measurement of and had to estimate to that extent. The next sheets are statistics of the actual daily production. They are styled "Daily Production Rates for Canada Ojetos Unit P-11 and L-11 are two sheets and the reason

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these are included is in order to show that the actual production rate was relatively constant during the period of this test; if for instance, there was a marked increase or decrease in production rate over the period of the test this could affect the calculation. They were fairly constant and close enough that, I believe, that we have a valid test resulting from these production rates. Now, the production rate that is plotted on the graph is the production as reported by our field people to the office every day and sometimes that will cover a twenty-three hour period or twenty-five hour period and the unadjusted figures are the ones that appear on the graphs in Section "J", where as the one shown on these two schedules are the exact rates.

Then the next graphs following those two sheets, there are two graphs, these graphs show the producing pressure differential from the surface of the ground or from the surface casing pressure to the producing formation, one for the P-11 and one for the L-11.

Now, the purpose for including these is to estimate the working bottom hole pressure while the wells were producing and we need this in order to determine that the producing wells were in a, in that part of the reservoir, which is similar to the observation well. If, for instance, one of the wells is in a tighter zone and in this instance one was, the

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pressure will drop much faster in a producing well than in the observation well and accordingly, you could not make a calculation of this type for that period of time. Now, this occurred for the P-11 which was the first well we put on production and accordingly, we could not use this well for a calculation of this type. The result of these calculations are shown on the next schedule. There are three pages for the P-11 and one page for the L-11.

I would like to point out on the right-hand column of the schedule marked P-11 that the bottom hole working pressure in the first twenty days dropped approximately one hundred pounds, one hundred and forty pounds. Now, this is a drop of eight or ten times as much as the offset wells and is too great a difference accordingly to use for this type of calculation. Now, the L-11, on the other hand, dropped such a small amount that it was hard to detect with the type of measurement that we, measuring equipment that we have, to estimate the working bottom hole pressure. In the L-11 during the first eight hours the pressure dropped at a rate which would indicate a transmissibility on the order of one to two darce feet. At the period from eight hours on, the rate of pressure drop was markedly decreased which indicated that the radius of drainage then had reached an area of high permeability on the order of five to seven milodarcies or five

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to seven darce feet, which is approximately the reservoir average. There is practically no measurable decline in pressure as indicated for the first ten or fifteen days from the figures on the right-hand side in this particular well. Now, it's difficult to estimate the pressures exactly from this method, but I would judge that they are within ten or fifteen pounds of the right amount. This, to me, means that we have made, that we have a test which is suitable for this type of calculation and that the results are accordingly reliable within the limits indicated.

Q And causes you to conclude that the oil in place per acre is how much?

A The extremes are 1,000 to 2500 barrels per acre and I would, my best estimate would be 1500 to 2,000, would be the range.

Q Anything further with regard to oil in place per acre?

A No, sir.

Q And that brings us to Part 7 which is "Estimations of Total Oil in Place in Southwest Puerto Chiquito and Areal Extent of the Reservoir." From the same factual data that you have already developed, have you been able to make conclusions with regard to this preference?

A Yes, sir, I have.

Q Will you give them to us, please?

A The Section "N" contains entirely statistics of bottom hole pressures and fluid level measurements regarding static pressures taken at various times during the production history of the pool. I think that all of this information is set out on graphs in the next section and I just feel that all we need to do at this point is identify these statistics.

Q Which are placed in detail throughout "N" which consists of several sheets.

A Yes, sir. I would like to go to Section "O" in which we indicate --

Q "O", of course, is still a part of a major premise under Section 7?

A Yes, sir.

Q All right. Proceed.

A This shows how we estimated the pressure in December of 1963 as a result of a fracture treatment in Canada Ojetos P-11. After the fracture treatment the pressure dropped off which is normal and at the time the pressure levels off we feel that we then have a fairly good static pressure. In this instance it was about 1581 pounds, the depth at which the survey was made, and I feel that for the instruments we had at that time which had a range of accuracy of five to ten pounds that that was about what the pressure was at that time.

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Then the next graph shows a plot of pressure build up in the P-11 in February, March and April, 1964, and we will note here that after the well being shut in about twenty-three days we show on the graph that is 22.9 days, the well 2,000 feet away from us which was also producing at the time, was shut in and we can see the effect of the shutting in of the other well. That information is plotted then in the customary similar log plot on Plate 2 from which we can determine the slope of the build-up curve and can calculate transmissibility from that which we do at a later time.

Then the next graph is how we determined the bottom hole pressure in October of 1964 from the L-11 which had just been given a fracture treatment. Pressure was falling off in the L-11 as indicated on this graph while the other wells were producing. Then when the other wells were shut in the pressure then, instead of falling, reversed its direction and built up and we felt that within about ten or twelve days it would reach a point fairly close to static.

Q Mr. Greer, if I might interrupt you for just a moment, on Plate 1, the proceeding two-plate page, --

A Yes.

Q --this refers to P-19, is that correct?

A Oh, that's a drafting mistake. I failed to notice. This is Well P-11. The plate shows P-19, but it should be P-11.

Q Thank you for that. Then had you finished the graph, October, '64?

A Yes, sir.

Q Turning, then, to the next one --

A The next one shows a plot of fluid level build up during the shut-in period in the summer of 1965. Now, that information is a plot of fluid levels against time on a log scale and is for the same period of time as I will point out here on the graph on the wall, while the pressures were building up over this period of time there appears to be a curve on a plot such as the one under Section "J", on semi-log paper it comes out as a straight line. Now, we can strapolate then this, -- this curves, and although we do not have a theory that will apply to how far the fluid levels will rise before they finally reach static, we can tell how far they will rise in any particular period of time by just following the little dotted lines as are indicated on there. For instance, the fluid levels would probably not build up more than another twenty or thirty feet in an additional hundred days.

It is doubtful that the static pressure would be much higher than that. In other words, we feel that we had a pressure at that time that was probably within twenty or thirty feet of oil column of static pressure which is equivalent to some

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ten pounds of reservoir pressure.

Then from that information and the statistics of production which are shown in the sheets following the graph which we have just been looking at we can make a plot of pressures versus comulative production and this information is summarized, then, in Section "P", the first sheet, where we have -- well, we refer to several key well pressures and cumulative production as of the time those pressures were taken. The statistics on the first sheet. The plot of that information is on the graph which follows next. Now we can see that the first, up until about the first 150,000 barrels of oil was produced, we have a rather straight line relation of pressure and production. It's 2650 barrels per pound. Now, actually, I doubt that our information was as exact as indicated by these points.

They do, however, fall on a straight line which we would anticipate if our measurements were accurate enough and actually, of course, they didn't fall on a straight line until we made the final corrections we did in 1965 after resurveying the elevations and correcting for elevations and correcting for hole deviations. At that, after we made those corrections, the points then assumed this straight line relation. So I would judge that this is a pretty good representation of the initial pressure drop in Southwest Puerto Chiquito, namely

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2,650 barrels per pound.

Now, after that point, part of the oil that was saturated was undersaturated, turned to saturated oil as the pressures declined and as a result, the rate of drop then of pressure of production began to level off and I would estimate that by August of 1965 with 300,000 barrels produced that the rate -- that this relation was as high as 3,000 barrels per pound as is indicated by the right-hand part of the heavy solid line on this graph.

Q Is this the same as saying that at that point they reached the bubble point?

A In that part, in the part of the reservoir.

Q Was that observation?

A Yes, sir. This, of course, is one of the complicating features of analysis of this type of a reservoir. In other words, it's not so difficult to take this into account in a rather horizontal reservoir in which throughout the reservoir you reach the bubble point at one time and this type of a reservoir the bubble point is reached high structurally and then gradually moves down the reservoir as pressures decrease. So at this time I would say just the upper part of the reservoir then was below the bubble point.

Q The next chart is the one entitled the Canada Ojetos Niobrara Participating Area?

A Yes, sir.

Q Would you explain it?

A Now, on this one the heavy solid line is the one which we just viewed on the last graph. The points from that time forward are ones which were taken during our interference test and we can see that immediately upon starting the interference test that because of the interference of the producing well the pressure in the shut-in well dropped rapidly at first and then tended to level off. We can see by August 30th, 1966 the furtherest right-hand point, that we are up to about 6,000 barrels per pound. Now, this means to me that, that more and more of the oil is coming below the bubble point and this is the reason the pressures are leveling off.

It's important to realize that this is what's happening in our calculations which we make later on of total oil in place.

Q Why do the pressures level off when you reach the bubble point?

A All the gas that has been dissolved in solution, once the pressures drop below the bubble point, the gas tends to break out of solution and acts as a gas and gives compressibility or expansibility to the reservoir fluid. At pressures above the bubble point the gas is dissolved in the oil and the oil acts as a single phase fluid just like water and there is no

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material change in it as the pressures have changed.

Q Then that takes place in the reservoir?

A This takes place in the reservoir.

Q And the gas that comes out of the oil or bubbles out is never produced?

A Well, initially when the pressures are just slightly below the bubble point, the -- we feel that the gas stays in the reservoir and the oil moves around it just like it moves around grains of sand until as the pressures drop lower and the gas bubble gets larger, finally they join and when they do, then you have a measurable probability to gas and the gas moves rapidly through the reservoir and out the producing well, and of course at that point then the pressures drop faster than previous.

Q Is that a critical point in the reservoir with regard to production?

A Yes, sir. Sometimes referred to as critical gas saturation.

Q What effect does it have on production when it's reached?

A Well, the productivities of the wells will decline. All the time that the bubbles are expanding the permeability to oil becomes less. It's just as though, in fact, there is less space for the oil to move.

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Q Your next chart is headed "Plot of Total Reservoir Oil in Place Versus Variable Factors of Fluid Saturation and Fluid in Rock Compressibility." Will you explain that to us?

A Yes, sir. This is a similar graph to the one we viewed earlier respecting the Boulder calculations. This has been prepared from the data we just looked at in the preceding section and the first graph, the one in which is indicated to be for the time period of August 1, '62 to August 1, '65, indicates to me that there may be from about twenty-two million to ninety barrels of oil in place in Southwest Puerto Chiquito, depending upon the values of these various factors which we cannot determine exactly their values. For instance, if we have a high, the maximum compressibility of the rock that the oil produces from and if we have five per cent free gas saturation, then we would, the oil in place would be represented by the left-hand solid line, curved line, which slopes from about nine million barrels at the bottom to thirty-two million at the top.

On the other hand, the maximum amount was represented by the right-hand curve and at this particular time I would judge that somewhere from five to twenty per cent of the reservoir would be saturated and the rest undersaturated and this is the range of assumed saturations which I have used. In other words, eight-tenths to ninety-five hundredths of the reservoir is

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occupied by undersaturated oil.

Then the next graph shows the next calculation which we make when more of the reservoir is undersaturated. Now, contrary to the two analysis we have made for Boulder, the pressures in Puerto Chiquito have not yet dropped far enough for us to be in the range that we can have a higher degree of accuracy. Here again, with the information from the time period May 1, '66 to October, '66, I would judge from the green area which covers the shaded part of the curves, again something like twenty-two or twenty-three million minimum to approximately ninety million maximum barrels of oil in place.

Unfortunately, we can't compute it any closer than this and there is a possibility that our pressures have been held up somewhat by an unknown gas cap that we have not yet discovered. If so, we could have a smaller volume of oil. So far, we have found no free gas in Southwest Puerto Chiquito.

Q If you actually found free gas, would that reduce or increase the amount of your reserve as calculated?

A It would reduce the amount, I have --

Q It would be less in place?

A It would be less in place. Now, this is the total, we are talking about now, of course, about total oil in the reservoir as compared to our earlier discussion about oil in place per acre. Now, from this information, we earlier

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determined oil in place per acre at 1500 to 2,000 barrels per acre. We have now determined total oil in the reservoir on the order of twenty to ninety million barrels. If, for example, the true amount of oil in place is forty million barrels and there is 2,000 barrels per acre, this means our reservoir in Southwest Puerto Chiquito will cover something like 20,000 acres and this is the amount of area that is being drained by the well and which is affecting the pressures in the wells in the interference test.

Now, this is, of course, a substantial area, 20,000 acres, and is far greater than the area which has been, in which we have so far drilled wells.

Q All right, Mr. Greer, do you have any reason to believe that, that irrespective the fact you have made that calculation on an area on wells encompassed within four sections, do you have reason to believe it's correct for a much larger area?

A Yes, sir, I do.

(Whereupon, an off the record discussion was held.)

A The calculation of the total area of the reservoir was made from information from wells within the participating area in Canada Ojetos Unit, this area I am pointing to on the map. Now, 20,000 acres would be an area on the order of a township, something maybe as big as this. Now, we have just --

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we are just in the process of completing a well here which is some two miles away from the nearest well which we would use to compute the size of the reservoir and this well was given a fracture treatment, oh, two or three weeks ago. Following the fracture treatment, the pressures are declining in the well and they have now declined to a point below the virgin pressure in the area. In other words, it indicates to me that this well has been drained by the others and, of course, supports the fact the pool covers a substantially greater area than where wells are currently drilled.

Q What is the name of that well?

A This is the O-33 in Section 33, 26 North, Range 1 West.

Q What is the nearest producing well to it?

A About two miles, which is the, oh, the L-11. Approximately the same distance away is a very small well, the A-16 in Section 16 of 25 North, Range 1 West, but A-16 only produces thirty to forty barrels a day and I doubt that that well had much influence in reducing the reservior pressure in the area two miles north of it; the thousand, approximately a thousand barrels per day production in this area and the participating area has had an influence.

Q Now, to come back to when I first started to introduce this point. This actually is further effective interference test from a practical standpoint, is it not?

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A Yes.

Q And it shows that the production down there is in effect in communication with that well?

A Yes. The difference in this type of a test is that we have not positively shown that the reduction in pressure results from opening and closing wells such as we have done here. The pressure is lower and it's, -- I would assume that the reason it's lower than the original pressure is because oil has been pulled from around that area by the producing wells.

Q You don't have a concomitant variation, right, you don't have a variation before and after but it is a sound assumption here, is it not, in your opinion, that the reservoir pressure there was the same, initially?

A That is true, but --

Q And if you make that, then it's an interference test, right?

A Yes, sir, but in contrast to this and where we have a definite pressure change resulting from something we have done down here we would, for instance, shut these wells in and then watch this pressure rise. Now, at this point in time with a lot of the oil below the bubble point it takes a longer time for this part of a test to be effective.

Q That would be in the range of 10,000 feet across

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there, would it not? And if that is correct, it would show drainage -- it would show that one well would drain more than 6,000 barrels that we were talking about earlier -- 6,000 acres that we were talking about earlier?

A Yes, sir.

Q Has this information been plotted on -- tabulated?

A Yes, sir. That is the next two sheets following the graph we just looked at under Section "B". This shows the pressures as they are falling off in this well and then the graph following those sheets is the plot of it and here again we have plotted the pressure decline against time on a log scale which incidentally we have not done any work on this but it would appear to me that it follows the typical straight line relation of pressure against log time and we feel that perhaps we can in the future use this type of information in further analysing our reservoir perhaps to permeability and that sort of thing. We can see here the original reservoir pressure was 1620 pounds. The pressure has already declined now in this well two miles away from the nearest producer. On November 11th it was some, nearly a hundred pounds less than the original pressure and still declining and it is our plan to leave this well shut in and determine just where the pressure finally levels off, and of course the reason for this is that it will give us a clue as to the average permeability

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between the present producing wells and this well.

From the reaction of its fracture treatment, I feel that it will be a small well and it's important for us to know if this is going to be something characteristic in this area or if again we are still in the area of a fracture system of high permeability which characterizes the rest of this reservoir.

Q Has this well ever produced?

A No, sir, this well has never produced.

Q What effect does this have on your knowledge and information with regard to the areal extent of the reservoir?

A Well, it confirms that the reservoir, the reservoir covers an area substantially greater than that in which we had our information and computed the size of the reservoir.

Q The next sheet then is headed "Estimation of Area of Low Permeability."

A Yes, sir. This has to do with the area around the P-11 which although it's one of our better wells, it's actually completed in an area, oh, I would judge something on the order of 1,000 to 2,000 acres. It's hard to determine exactly how big this area is, but it's possible to compute the size of it, an area which has a transmissibility on the order of one darce feet.

Q This is the one that you referred to earlier and

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explained with regard to it when you calculated your oil, barrels of oil in place per acre?

A This is correct. It's in an area which is about, has a transmissibility about one-fifth as much as the average of the reservoir. Now, this incidentally is still a pretty high transmissibility. The well, if opened up, probably could produce on the order of 1,000 barrels a day if we had some way of getting the oil out, practical. It has produced over 300,000 barrels of oil despite the fact that it has permeability or transmissibility only one-fifth of what I estimate the reservoir average to be.

Q Anything further with regard to Exhibit "P".

A No, sir.

Q I believe "Q" is still a part of your total oil in place, Section "Q"?

A Yes, sir, Section "Q" has to do with Northeast Puerto Chiquito, an estimation of total oil in place in that area. The first plat under "Q" is the plat of the area in which we have made the calculation. Following that is a statistical record of the production from that particular -- of wells in that particular area. The last sheet before the graph is a summary of some of the pressures in the -- taken in the P-19 well within this particular area. Then the first graph is a plot of this statistical information. Now, here again we have

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the typical break in the pressure production curve as we experience change in compressibility when pressures go below the bubble point. It initially, pressure dropped rather rapidly and then it leveled off. At this point in time it's on the order of eight to ten thousand barrels per pound.

Now from this information we can compute just as we have before, although we have not included it here, it appeared to us that we had about as many exhibits as we needed, on the order of six to ten million barrels in place in this particular area.

Q You're talking about the area encompassed in the --

A In this particular area here which I will point to on the map. Now, here again the amount of this oil that is recoverable, of course, is going to depend on a number of things, one of course is how successful we are in shutting in high gas-oil ratio wells at the top of the structure. We have already shut in --

Q Is it four?

A We have already shut in four wells because of high gas-oil ratios. Now, when we say "high" I am speaking now in terms of about 2,000 cubic feet per barrel which of course ordinarily not considered high.

In my opinion, this area we need to shut wells in at about that point, and of course we hope as a result to increase

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the recovery we might otherwise have. Also in time we hope to unitize the entire area and perhaps inject either gas or water.

Q How do you increase the ultimate recovery of oil by shutting in your high gas-oil ratio wells?

A We maintain the pressure in the remaining oil at a higher point. The viscosity stays lower and we have more efficient recovery.

Q Well, with the drainage you have you can produce all the oil under those wells that are shut in?

A Oh, yes, sir.

Q And gain greater efficienty because you conserve the reservoir interest?

A This is true. In other words, we can, by properly producing the field we can recover more oil on wide spacing than we could if we opened all the wells up on close spacing.

Q Was the reverse of this situation, or in other words, do we have an exhibit or an instance of where this was not done and was created in Cha-Cha and Totah-Gallup?

A Yes, sir. We attempted to water flood Cha-Cha, Southeast Cha-Cha Gallup at a time when it was too late to be effective. If we had drilled that field on a wider spacing it's possible we could have had more effective results of the water flood.

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Q In that pool if it had been possible to shut in the higher gas-oil ratio wells, would the result have been greater recovery of the oil in place than what was actually realized?

A Well, we need to be very careful about exactly what I say here. As far as the primary recovery is concerned, I think there would have been no difference whether the pool produced at a high rate or not. As to the possibilities of secondary recovery measures, there could have been a difference and this is the, I think the important feature.

Q Is there anything further before we leave this graph?

A I just want -- no, nothing before we leave the graph.

Q Then your next sheet in Section "Q" --

A This just is a sketch which shows a possible, one possible method in which we might have a water well which is updip from a producing oil well in communication with it and also which points out the hazard or another of the indeterminate factors in computing oil in place in Northeast Puerto Chiquito.

We know that we have a situation somewhat like this shown on the sketch, but the total amount of water is difficult to determine. All we can say is that we have six to ten million barrels of oil in place, less whatever amount of water could be in that area effective. It's a very indeterminate thing.

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Q I believe this morning when you were going through the details with regard to the interference test conducted in the northeast area, you said that you had information that you were taking pressures in water wells.

A This is true.

Q And this is an indication of how that pressure still reads on the oil reservoir?

A This is true. We, we do get some benefit from these wells in helping us to know what the pressure is, although they are completed in a water zone in the reservoir.

Q And this graph shows how water can occur both updip and downdip from oil in the same pool?

A Well, we have shown here how water can occur updip and gas can occur downdip from other producing oil wells.

Q Could the situation you have indicated here in which has been observed here, occur from faulting?

A Yes, sir.

Q Anything further with regard to Exhibit "Q" or total oil in place in Northeast Puerto Chiquito?

A No, sir.

Q That brings us, then, to "Part-Nine Data Relative to Efficiency of Drainage." Now, we have, I believe, by your interference tests proven possibly and irrevocably that you do have communication and that you do have drainage. Do you

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know of anything with regard to the efficiency of this drainage?

A Yes, sir. We can make certain conclusions from the tests that we have made regarding efficiency.

Q Tell us about those.

A The first sheet under Section "R" is "A Schedule of Information Taken in the Spring of 1965, Concerning Productivity Index Test in the Canada Ojetos L-11." This information is plotted in the graph next following and the important thing here is we have simply a straight line relation between producing pressure and production rate which, of course, is something that is a well-known physical principle of production in sand reservoirs and, of course, we feel that it should be in fractured shale and, of course, here we deomonstrate that it is.

Now, the important thing here is that the amount of oil that a well will produce, then, at any particular period of time will be dependent upon the amount of pressure drop available, or on the other hand, if we produce a well at a certain rate, a certain pressure drop will result. For instance, if we pull the pressure down in this particular well at the rate of 100 pounds, it will produce 240 barrels a day. If we produce it at 400 barrels a day the pressure will drop 200 pounds. Now, this gives us a clue as to what

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will happen later on as pressure declines and permeability of the oil drops off and how we can compute efficiency.

We might move to the next graph, then, as to one way in which we can compare efficiency, and what we would like to look at now is the comparative efficiency of recovery for different well spacing patterns. Now, the first graph shows the ranges of relative permeability of fractured formations as is reported in the literature. It's an extremely wide range and I think it's, as a result it's not very helpful in determining recoverable oil, but it does give us the extremes with which we might be dealing and we can treat the extremes and then know that our calculations will be within these limits.

Now, from the relative permeability of fractured formations and using the fluid sample analysis which we have, I have computed three different --

Q You are now on the graph that is headed "Calculated Production History for the Following Conditions"?

A I am just getting ready --

Q Just coming to it?

A Just coming to it. I am just -- I have computed three types of pressure production history which might result. These are the next three graphs. And at this particular time for simplicity and calculation, we used 1600

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pounds as a saturation pressure rather than 1520 which will have no particular bearing in this calculation. What I would like to point out is, for example, on the first graph which shows its ultimate recovery, is five and seven-tenths per cent of the oil in place. This is for the minimum recovery curve of relative permeability zero per cent connate water. Now, we note on the right-hand side of the curve that for the last 200 pounds, or for the 200 pound drop in pressure from, say 400 pounds to approximately 200 pounds, that there may be, oh, four per cent of the ultimate recovery is obtained during that 200 pound pressure drop or about two per cent of the recovery per 100 pounds drop in reservoir pressure.

In other words, if a well reached its economic limit at 400 pounds, it would recover, say ninety-seven per cent as much oil as one which can produce clear on down to 200 pounds.

Now, this is the clue that we have as to difference in efficiency on different spacings because we have, if everything else is the same, a well -- wells on water spacing will have a higher pressure drop from the reservoir limit to the well bore. And this higher pressure at abandonment, then, represents oil in place which is not recovered on the closer spacing. Now, we can put a figure on the approximate range or the limits that we are speaking of, for instance, on the second graph which is for fifty per cent connate water, the ultimate

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recovery is about twelve per cent of the oil in place and here we have a slower drop in pressure and a slightly higher amount of oil is left in place under these conditions. This is about seven per cent per 100 pounds.

The next graph is for the maximum relative permeability curve. Ultimate recovery here is forty-one per cent of the oil in place if the connate water is zero per cent and here again we have the lower right-hand curve of the bottom hole pressure, indicates approximately seven per cent per 100 pounds is the amount of oil that is recovered within that period of time or during that part of the production history.

And I would like to skip the next graph, we have it out of place, and go to the one that is marked "Producing Pressure Differential at Abandonment, Southwest Puerto Chiquito." Now, we have shown here the producing pressure differential which will result for transmissibility of one darce foot and five darce feet against well spacing from 40 acres per well to 320 acres per well. Now, I believe from our interference tests that the transmissibility is on the order of five darce feet. The lowest that we have in the local area around the P-11 of 1,000 to 2,000 acres is about one darce foot. Now, --

Q Mr. Greer, you referred to darce feet here and usually you engineers at these hearings are talking about millidarcies, aren't you?

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A Oh, yes.

Q So we are really talking about a thousand millidarcies when you say a darce?

A Yes, sir. The --

Q Which shows very great permeability in this fractured shale?

A Yes, sir. The permeabilities are so high just from a standpoint of calculation it's easier to use numbers from one to ten than from 1,000 to 10,000. But what we are talking about here, of course, is 1,000 millidarcy feet and 5,000 millidarcy feet. Now, we can see then that the producing pressure differential when a field is abandoned, for instance, for 320 acre spacing as compared to 40 acre spacing, if we have five darce feet this pressure scale that is on the right-hand side is on the order of two and three-tenths pounds. In other words, the reservoir of pressure on 320 acre spacing will be two and three-tenths pounds higher at abandonment than if the field were drilled on 40 acre spacing, assuming all conditions to be exactly the same in the two respective spacing patterns.

Now, if the transmissibility is one darce foot or one thousand millidarcy feet, we will have a higher producing pressure differential and we will -- there will be correspondingly a greater amount of oil left in the reservoir

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on the wide spacing as compared to the narrow spacing.

Now, we can put some actual numbers on these figures because we saw earlier that the range that we can expect from the extremes of relative permeability that we can anticipate in fractured shale is two per cent per hundred pounds on the one side and seven per cent per hundred pounds on the other. Now, if we have a 2.3 pound differential as would be indicated by five darce feet for 40 acre spacing as compared to 320 for the seven per cent per hundred pounds difference in ultimate recovery would mean fifteen- hundredths of one per cent more oil will be left in the reservoir on 320 acre spacing as compared to 40 acre spacing.

If on the other hand, the relative permeability characteristics are such that it is two per cent per hundred pounds, then the amount of oil left in place would be five-hundredths of one per cent. Now, these are extremely small numbers.

Now, if the permeability is less which the smallest we have measured, as for instance in the P-11, the producing differential then on 40 acre spacing as compared to 320, is 11.6 pounds, this gives us then two-tenths of one per cent to eight-tenths of one per cent. Now, this, I think, is the maximum amount of oil that could be left in place in wide spacing as compared, by wide -- I mean 320 acres, as compared

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to 40 acres, if all other conditions were equal. But these figures, the important thing as I see it in this pool is that these figures are quite small as compared to the practical aspects of producing the pool. For instance, by improving our fracture techniques we can recover oil, additional oil that could be several times this amount. In other words, proper fracturing of wells on 320 acre spacing could give us far more oil than improper fracturing techniques on 40 acres.

Now, I stated earlier that from our interference tests we have determined that a well on 6,000 acre spacing could drain the area under one of these other wells better than the well itself. I would like to refer to that again, if I might.

Q I wish you would go into it. If it shocks the Commission as much as it shocked me, they will be quite surprised.

A It's relatively simple to determine from our interference test how this can occur. The particular interference test within Southwest Puerto Chiquito, we are speaking of the effect of the L-11, on a well, the A-23, some 8,900 feet away which is a drainage -- which would be equivalent to a drainage area of some 6,000 acres. Now, the statement that I made was that this well, the L-11, can drain this area better, more efficiently than the well itself. Now, we can arrive at that and see how this is true by this preceding graph which

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shows producing pressure differential, Southwest Puerto Chiquito. The L-11, for instance, produces at a lower producing pressure differential than the P-11. Now, on this particular plot, because I had more information on the P-11 than the L-11, I have shown it here. The P-11 has approximately a 310 pound pressure drop from static to produce some 500 barrels of oil per day. This is shown by the point marked by P-11 on this graph. Now, the well that I referred to, the A-23, which is being drained by the well 9,000 feet away, better than the well itself can do, has a capacity on the order of 100 barrels a day with a 1500 pound pressure differential.

Now, we know that as the pressure declines the productivity in the A-23 will decline. For example, if right now when it has 1500 pounds it will produce about 100 barrels a day. Now, when the pressure drops, let's say to 300 pounds, one-fifth as much pressure as we now have, the well would have approximately one-fifth of the producing capacity which it presently has, namely 20 barrels a day if the permeability to oil were to stay the same. Now, we know, of course, that when we get to these lower pressures that the permeability to oil will decline. Now, this will be a function not of the well but of the reservoir, so for instance, when the reservoir pressure has declined to 300 pounds there will be 300 pounds available to produce oil into the A-23, there will be 300 pounds

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available to produce oil into the L-11 and the P-11. Now, at that point, we know that the productivity, then, of the A-23 will be number one. We can take one-fifth of its present 1500 pounds and we will be down to 20 barrels a day if it had the same permeability to oil which it now has. Now, we know that it will have probably about one-fifth of the relative permeability to oil at 300 pounds as at 1500. Now, this will be true for both the L-11 and the P-11, so we will not be able to produce 20 barrels a day out of the A-23; we will be able to produce about 4 barrels a day which will be below its economic limit.

We will have to shut it in. We will shut that well in when the reservoir pressure, then, is on the order of 300 pounds. Now, at the same time, the P-11, we can see from this graph, with 300 pounds of reservoir pressure, it will produce 500 barrels a day if the permeability to oil is the same, but it will have the same reduction, of course, as the other well, namely one-fifth, so it will be able to produce not 500 barrels a day but 100 barrels a day. So this means that when we abandon the A-23 when it is no longer able to produce oil at an economic rate, the P-11, a mile and a half away, will still be pulling oil out from under that well and producing its oil more efficiently. It will pull oil out from under the A-23 after it's plugged and abandoned.

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Q Then actually, the A-23 is an unnecessarily drilled well?

A This is true. Now, the only reason that wells such as this need to be drilled is that they would help us get the oil out a little bit faster. Not more efficiently, but faster, and not very much faster since it's a small well.

Q Mr. Greer, going back -- excuse me.

A I might -- I would just like to add one thing.

Q Yes.

A I just want to point out that these, these things, the capacities of the wells which are dependent primarily on our completion techniques are far more important considerations as to ultimate recovery from the pool than well spacing. Under the type reservoir that we have ultimate recovery is practically independent of well spacing. It just doesn't make -- it's not going to make much difference whether we have one well on 160 acres, one well on 40 acres or one well on 1,000 acres as far as total oil recovered from the pool would be under solution gas drive methods.

Now, there are other factors which, of course, lead us to believe that we will recover more oil on wide spacing, but these are the ones, the factors that we consider at this point.

Q On the first graph on this "R" I notice on your graph line you have the letters PI equal 2.4 BOPD over PSI, and I

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don't believe you covered that. Would you explain what is meant by that?

A I see. Well, of course, the engineers are all familiar with this. This is simply an expression of productivity index in terms of barrels per day per pound. If the particular well produced 240 barrels with a 100 pound drawdown, it would be 2.4 barrels per day per pound. We refer to that as productivity index.

Q Mr. Greer, coming back to the major premise, if I understand you, you are saying that actually in your opinion you can recover and will recover more oil out of this reservoir if you have 320 acre spacing than if you had the standard 40 or even if you had the 160 acres that was given on the first temporary allowable?

A Yes, sir. There are two reasons for this. One, of course, that if we can make a profit which we can at 320 acres and we cannot at 160, then we are more inclined to spend some money improving our fracturing techniques as completion methods and perhaps we can, and have, we have improved our completion techniques without doubt, and of course there is room, we feel, for further improvement and we can determine that because we now know from our interference tests that we have a fracture system of high transmissibility. We have yet to complete a well which has reached the maximum productivity which would be,

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which is possible from this transmissibility. In other words, we have been able to reach into that fracture system with our treatments and get in some instances pretty good wells. We have not yet been able to reach the maximum.

Q Well, if I understand what you said, then even your very best wells and some of them you have indicated would make more than 1,000 a day if you could handle it, were not real good wells without treatment?

A Well, this is true, whereas in Boulder, good wells were produced natural, are completed natural. We have yet to complete one in Southwest Puerto Chiquito that's a commercial well without some form of artificial stimulation.

Q Is this artificial stimulation a costly process?

A Yes, sir, it is. The costs in improving our techniques, unfortunately, we have found that the improvement is almost a direct relation to the cost.

Q Well, could this be accomplished on narrow spacing?

A No, sir. We couldn't afford to do it.

Q This is your point, that it far more than offsets the very small amount of oil that is not recovered?

A Right.

Q If I understood you, the range of what is left in for 320 acre spacing over the 40 acre, and I think we need to go back over it, is only fifteen-hundredths of one per cent to

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five-tenths of one per cent on one situation and two-tenths of one per cent to eight-tenths of one per cent on the other. In other words, the larger factor of oil that will not be recovered because of wide spacing is less than one per cent?

A That is true. Your figures are correct, except where you said fifteen-hundredths to five-tenths. It's really fifteen-hundredths decreasing to five-hundredths.

Q Well, you shocked me so much with some of these figures that I go the wrong direction. It's insignificant, is it not?

A It is, yes, sir.

MR. PORTER: Let's take a break and have about a ten minute recess.

(Whereupon, a short recess was taken.)

MR. PORTER: The hearing will come to order, please.

Q (By Mr. Verity) Mr. Greer, I believe you had just finished your testimony with regard to data relative to efficiency of drainage and this brings us to Part 10, which is a comparison of characteristics of fractured shale reservoirs with sand reservoirs. In our opening statement we promised to show the Commission a working model that would give some, I think, dramatic comparisons between these two reservoirs. But in a word, if you will, before we start our exhibit, will you tell us what is the comparison with regard

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to reserve and production characteristics?

A Yes, sir. This is best shown by looking at one of our exhibits under Section "S". The first part of Section "S" is a core analysis from one of the sandy streaks, I might say the sandiest streak that we have found in any of our cores from which it can be seen that there is no possibility of a sandstone type reservoir in this area. This was all of the sand that we have found in our core, I think four feet of silty sandstone or sandy shale. There is nothing there of any help as far as producing oil is concerned.

Q We have referred to matrix porosity and if I understand it, you're saying, except for the fractures, there is none in our fractured shale where you are dealing?

A Yes, sir.

Q And appointed out by this.

A This is our thought. Then the next graph shows the relation of porosity to permeability for sandstone and for one type of a fracture system in which the fractures are parallel with the direction of flow. We can see from this graph, for instance, that for this type of a fracture system there is roughly, oh, from ten to a hundred times as much porosity for any given permeability that is shown. Now, we can't say that this is exactly the way the fracture system in

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a reservoir is because there will also be fractures normal or perpendicular to the direction of flow and they may be of various sizes and such which could raise the yellow area somewhat on the graph.

Even so, I just can't visualize a fracture system which would have a porosity greater than something on the order of one-tenth to one-fiftieth of that of sandstone for the same permeability and accordingly the same producing characteristics. In other words, if we had a sand reservoir and a fractured shale reservoir in which wells in both reservoirs produce at the same rate initially, you would just normally anticipate only a tenth or twentieth as much oil in the fractured reservoir as in the sand reservoir.

Q In other words, there is actually ten to fifty times more space for the oil to occupy in the holes in the sand than there is in the fractures in the shale?

A That's right. Also we've shown on this particular graph, while we have it, the red line is the approximate area that I -- or indicates the approximate area on this graph on which I believe the characteristics of Southwest Puerto Chiquito are indicated. In other words, we can compute the relation of permeability to porosity and it will be somewhere along that red line or perhaps a little bit less than that, perhaps slightly to the left. The figures in, that says

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H equals 3 for Pie H equals three-tenths is the feet of pay thickness which would fit the circumstances that we have in Southwest Puerto Chiquito. For instance, if there were a porosity as high as ten per cent, then it would take three feet of pay to give us the oil in place that is in Southwest Puerto Chiquito. This would be getting up comparable to a sand. We feel that we don't, do not have this, that probably the pay zones are about, as we looked at earlier in the exhibit, on the order of twenty to forty feet in thickness which would put us down in the area around where the H equals 30 on red figures on this graph which is on the order of one per cent porosity and 200 millidarcies.

It's my thought that somewhere in this range is, represents the true property in Southwest Puerto Chiquito.

Q Now, Mr. Greer, although sandstones and matrix porosity reservoirs contain much more oil in place and in the pore space, how do they compare when it comes to permeabilities and the resulting rate of flow and the amount of initial production that comes from the two reservoirs?

A Well, it's possible they would have two reservoirs at the same rate of production, substantially less oil in place in the shale reservoirs than the sand.

Q And have them make the same amount of oil initially?

A The same amount, say in barrels per day, you open

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the wells up in the fractured shale reservoir they might make 1,000 barrels a day. Those in the sand reservoir, if they make 1,000 barrels a day, you would just not anticipate, then, that the fractured shale reservoir would have anywhere near as much oil as the sand.

Q Have you caused two working models to be made that will demonstrate and illustrate these drastic differences between the fractured shale reservoir such as we have here and the matrix porosity reservoir such as the common sand type reservoir?

A Yes, sir. We have two little models, the one that has sand in it, has sand, I believe, ten to forty mesh sand, porosity probably on the order of thirty-five to forty per cent which is probably twice as much --

Q The one on the left?

A -- as an ordinary sand reservoir. The little fractured reservoir we have is made out of a block of plastic with fractures cut in it and also fracture spaces between the plastic and the glass. Pore space in the fracture reservoir models is probably on the order of three or four per cent which is probably two or three times as high as the true porosity in a fractured reservoir such as we are producing in Southwest Puerto Chiquito. In other words, both models probably have porosities approximately twice as high as you would ordinarily

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suspect.

Q But they are in relation to one another?

A Right. They are about --

Q I noticed that these are at a distinct slope from your sample reservoir from one end to the other. Was this done for a particular reason?

A Oh, just simply that we have a steep dipping formation in Southwest Puerto Chiquito.

Q It approximates the same condition?

A Well, it illustrates the slope.

Q Or illustrates the same condition?

A It illustrates a sloping formation.

Q Anything further before we start the operation of these?

A Only that the initial production rates from each of our two sample reservoirs will be roughly the same, I think five to ten seconds for the first tank of oil in each, and we anticipate that the fractured reservoir will not produce as much oil as the sand reservoir.

MR. CAMPBELL: If it does, you are in trouble.

THE WITNESS: If it does, you've made a mistake.

MR. VERITY: If so, the lawyer cuts his throat. Are you ready, then, to start these?

A Yes, sir, I'm ready.

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MR. VERITY: We are starting our sand reservoir first.

MR. UTZ: Is this saturated or unsaturated?

MR. VERITY: Can we start this?

THE WITNESS: I don't know whether Virgil can handle it by himself or not.

MR. VERITY: You notice we started the sand reservoir slightly first and at this juncture I believe, will you take it up from there, Mr. Greer? I believe we are stopped here.

A Well, of course the sand reservoir started producing first and, of course, it's still producing. The fractured shale reservoir, just like we saw on the graph this morning, for Southeast Cha-Cha where you have a high permeability produces kind of like a flashing fan and is gone and the sand reservoir keeps on producing. Even so, they both had the same, approximately the same initial production rate. We might say it's 1,000 barrels a day or a tank of oil a day, however you want to compare it

CROSS EXAMINATION

BY MR. NUTTER:

Q Was the original oil in place the same in those two reservoirs?

A The two reservoirs have approximately the same gross reservoir space. Then the pore volume is about thirty-five to

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forty per cent in the sand reservoir which is probably twice the normal sand reservoir. The fractured one has, I believe, two to four per cent -- three to four per cent porosity.

Q So you would have eight times as much oil in the sand reservoir as you did in the shale reservoir, anyway?

A Oh, true, true, and this is the whole situation we are faced with.

Q But the initial production rates were the same?

A But the initial production rates were approximately the same. Now, I suspect that our recovery efficiency in the fractured reservoir here is somewhat higher than we have in the field. The water seems to leave that plastic quite dry and there is not much oil left in our fractured reservoir so I'm sure that our recovery per cent is considerably higher there than in the sand. I think in the sand we put, we recovered about half of the water that we put in the model, whereas in the fractured reservoir we covered about ninety per cent of it.

Q Now, this is an expanding gas cap with all the atmospheres pushing down on it?

A Yes, sir. I guess it could be so stated.

REDIRECT EXAMINATION

BY MR. VERITY:

Q Mr. Greer, I believe you have one operator in this

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pool, Dr. Sam G. Dunn, is that correct?

A Yes, sir.

Q Have you received a letter from him recently in the past few months with regard to his experience in the area concerning production and spacing?

A Yes, sir. I wrote Dr. Dunn several months ago asking if he had engineering data regarding anything that would be helpful concerning spacing in the pool and he responded to it.

Q You received a letter back from him?

A Yes, sir.

Q Is this the letter that you got back from Dr. Dunn?

A Yes, this is a copy of it.

MR. VERITY: With the Commission's permission, I think it would be well and we would like to read this letter. For your information, Dr. Dunn is a very prominent medical doctor and a fellow of the American College of Surgeons from Lubbock, Texas, who also has been, as well as a good doctor, very successful in the oil industry and has extensive production in West Texas, and I think in Southeast New Mexico, and he is learning in Northeastern New Mexico, and I would like to read his letter to Mr. Greer.

"Dear Mr. Greer: In answer to your inquiry relative to running an electric log on the Puerto Chiquito Unit Number 20, will say that I have had so much unshirted hell on that

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lease that I am pretty well disgusted with the whole deal. As a last resort, I am sending a reverse circulator rig up there to see if we can bypass the tools that we have lost in the hole which could not be fished out. As for getting the Gravey Unit outside of the Puerto Chiquito Pool, we'll say that in a way I believe you may be right about the wells being too close together.

"Before the unit was formed I had already drilled the Number 2 Gravey and there is definitely a connection between the Number 2 and the Number 1 because when I am pumping one of them, the other one goes down, which shows they are both dipping in the same pool of oil.

"We plan to go up on top of the hill to the orthodox location for the next well, if I drill another one, that would meet the requirements of the Puerto Chiquito Unit as I am afraid if I drill where I have already spent a lot of money making a location, and was prevented from drilling by the unit rules, that I might be going into the same pool again. Everyone tells me that you know more about the oil in place in that area than anyone else and I value your opinion very highly relative to this.

"If it is necessary to run a log on this deal, then I will probably go in with you before we finally abandon it. The USGS has required so many sacks of cement placed at so

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many different levels that it is going to be quite expensive to plug and abandon. Since I have already spent over $20,000 on that hole, I am somewhat adverse to spending any more than I have to, as you can readily see."

And he concludes with this: "As you no doubt know, I bought the Boulder Unit from Mobile in the Jicarilla Indian Reservation and I plan to work some of the wells over to see if we can raise their production somewhat. It seems, however, that the production in the whole area is like a quarter horse in that they will run like hell for a quarter of a mile, then fold up in the stretch, which, of course, is a lot different from the San Andres production in this area."

MR. VERITY: We offer it in evidence and we think without the benefit of seeing our models, Dr. Dunn has learned what we understand is a costly result. Will you mark that, please, as Exhibit 6?

(Whereupon, Applicant's Exhibit Number 6 was marked for identification.)

Q Anything further, Mr. Greer, with regard to the models?

A No, sir. I believe it's pretty evident that the sand model has produced more oil than the fractured shale without even counting the tanks of oil down there.

Q Anything further concerning Section "S"?

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A No, sir.

Q I believe that brings us, then, to Part II, which is "Data Relative to Oil and Gas Lease Ownership and the Position of Lease Owners Regarding Application for 320 Acre Spacing in the West Puerto Chiquito." Are you familiar with the land ownership situation or the lease ownership situation in this area?

A Yes, sir.

Q Have you plotted it in Section "T" or do you have a map that shows it in Section "T"?

A Yes, sir. The first plat in Section "T" which has yellow coloring on it, is an oil and gas lease ownership map in Puerto Chiquito Pool according to information which we have been able to obtain.

Q And what does the part that is marked in yellow represent and indicate?

A The part that is in yellow, leases operated by Benson-Montén and Greer Drilling Corp., in which the Benson-Montén-Greer group has fifty per cent interest or more.

Q And this is owned by those that we said we represented at the time of this hearing?

A Yes, sir.

Q What is the white on this?

A The white is other owners.

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Q Now, turning in Section "T" to the next map, will you tell us what that shows?

A This shows position of lease owners respecting our application here today in, for West Puerto Chiquito which is our, concerns the temporary order for 320 acre spacing. The area colored in pink is, indicates leases whose owners favor our application. The green are leases owned by people who we have not received a response from our, as to whether they approve it or not. And that in yellow is unleased land. There are two corrections which should be noted that have changed since this was prepared. The two quarter sections in green in the bottom right-hand corner, we have now contacted the owner and he approves our application. And the two 40 acre tracts about the middle of the map in Section 26 North, 1 West, I believe, have now been leased and we have not contacted the owner of those two 40 acre tracts.

Q And actually, I notice in the graph you have got a wide place here for those again. Are there any against it at all?

A Not that we know of.

Q Do you have anything further on this point?

A No, sir.

Q Mr. Greer, I believe that concludes this exhibit and I believe that you have made reference to Exhibits 4 and 5 as

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you have gone along with presenting certain data. Do you have anything further with regard to Exhibits 4 and 5?

A No, sir.

Q In light of the conclusions or the observations and studies and conclusions that you have made, do you have a recommendation to make to the Commission with regard to spacing and allowable?

A Yes, sir.

Q Well, first, I believe we covered it, but let's start first with regard to separation of the present Puerto Chiquito Pool into two pools and then with regard to spacing allowables.

A Yes. We recommend that the present pool be divided into the east and west portions that we have indicated earlier. Permanent 160 acre spacing in the east portion, temporary 320 acre spacing in the west portion and we have not stated it before, but we believe that the allowables should be in direct proportion in one area as compared to the other. We would suggest four 40 acre allowables for the East Puerto Chiquito and eight standard 40 acre allowables for West Puerto Chiquito with no recognition for the depth characteristics -- depth factor.

Q How long a temporary order for 320 acres do you think would be proper and is necessary?

A We are asking for three years.

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Q Now, you say that you think the 160 acres should be made permanent in the east?

A Yes, sir.

Q As a matter of fact, is the drainage up there greater than the 160 acres?

A Yes. Our test shows a minimum of 600 acres drainage.

Q And would it support 320 acre spacing?

A Oh, I think it would support 320 acre spacing, yes, sir.

Q But it's a little bit difficult to undrill the wells that are drilled there, is this correct?

A Yes, sir. I think it would be impractical to suggest 320 acre spacing on the east.

Q Is there another very critical economic differentiation why 160 acre spacing up there can be, why the applicants can live with that whereas they couldn't in the west part?

A Yes, sir. As we will show in a few minutes, we can make a profit at 160 acre spacing in East Puerto Chiquito whereas we cannot in the west Puerto Chiquito.

RECROSS EXAMINATION

BY MR. CAMPBELL:

Q Mr. Greer, do you think the well could produce 560 barrels a day without causing waste?

A Yes, sir.

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Q You don't think it would damage the reservoir?

A No, sir. We have two examples of that. One well has produced some 330,000 barrels of oil which is equivalent to about seven wells in the Boulder Pool drilled on eighty acres produced to abandonment, and that well and another well which has produced 200 -- over 200,000 barrels of oil are still producing at maximum solution gas drive efficiency. By that, I mean the gas-oil ratio is still the same as the solution ratio.

REDIRECT EXAMINATION

BY MR. VERITY:

Q Turning, referring to Exhibit 5 which is the gray exhibit, have you collected certain information in this exhibit?

A Yes, sir.

Q Will you go over, briefly, the outline, the index and outline of the information?

A Yes, sir. The, in Part 1 we have data relative to economics in Northeast Puerto Chiquito. Part 2 is economics in Southwest Puerto Chiquito. Part 3 is miscellaneous and we should note under miscellaneous Section "C", we have indicated that there are two sheets and that is a typographical error. There is just one sheet. We probably should change the official exhibit.

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Q Turning, then, to Part 1 in Section "A", will you explain it to us?

A In Section "A" we just show the present value to the working interest per barrel for oil in Northeast Puerto Chiquito which incidentally now is higher than it was three years ago because pipe line has been built into the area and as a result, the wellhead price of oil is higher than it was at our hearing three years ago.

Q This was the Yavas Pipe Line that was stated at the last hearing that 160 acres would make possible, that has been built?

A This pipe line has been built and the price of oil is now higher than it was.

Q And the next sheet in Section "A"?

A The next sheet shows the economics for 40 acre spacing, 80 acre spacing and 160 acre spacing. Now, this compares with our exhibits covering this same thing in our previous hearing in that previously we estimated 500 barrels per acre in Northeast Puerto Chiquito. We are now estimating 700 barrels per acre. With this additional recovery, plus the higher price of oil, we now have a higher profit indicated than we showed three years ago. There will be a slight profit on 80 acre spacing and a profit of about $80,000 on 160 acre spacing.

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Q That's $80,000 to the well?

A Yes, sir. Now, we show there that --

Q That is out of an average well cost of how much?

A Of $65,000. Now, that, of course, is just the well cost of a producing well. It does not take into account dry hole cost, and the dry hole cost experience in this area has been quite high.

Q So actually, even on your producing well you are only about, get your money back about double, a little more than double, if I understand it?

A This is true, and if we take into account the dry hole, we will receive less than two to one on our investment.

Q Anything else on Section "A"?

A No, sir.

Q Then turn into Section "B". Will you explain that, please?

A Section "B", the first schedule under Section "B" is just a statistical summary of our actual experience of cost of drilling wells in West Puerto Chiquito. Every well that has been drilled in West Puerto Chiquito has been drilled by our company and these are the costs that are now recorded on our books for these wells. And out of these nine wells, we have seven producers. So the average cost per completed producer shown on the last line on this page is $236,900,

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extemely expensive well for this depth.

RECROSS EXAMINATION

BY MR. CAMPBELL:

Q You have in that an average of your well that you had so much trouble with, don't you?

A Right. Yes, sir.

Q Do you think with the experience you have had, it's going to cost you this much to drill additional wells there?

A We had hoped before, in fact, we had estimated at our hearing three years ago that although we had experienced in high cost that we could reduce them in the future and actually our costs have gone up rather than down. The one well that we had the fire in, we hoped would be the last one and, of course, in August of this year we had another well with a downhole fire and it's cost will possibly exceed the other one when we finally get through with it.

REDIRECT EXAMINATION

BY MR. VERITY:

Q You have your next page on Section "B"?

A The next page shows the present value of oil to the working interest at the wellhead, which again, as compared to our same information three years ago, we have experienced an increase in price due to the pipe line in the area.

Q And your next page, "Economics of Development as

Depended on Well Spacing."

A This next page gives our present estimate of the basis in which we now estimate the cost of the future well shown under Item "A"; the average cost of the first nine wells was $184,000. Estimated future cost of similar wells, we hope we can do for a little less, $175,000. Then Item "C" is the cost differential which will apply if we drill wells on closer spacing and we have quite an unusual situation there with respect to location cost on denser spacing because they are, this part of the pool is in the Santa Fe National Forest.

Q I believe you went into that fully at the last hearing, did you not?

A Yes, sir.

Q If you can drill fewer wells, you can actually drill them cheaper because the location is a lot cheaper, you can make a couple of locations a section cheaper than you can make four?

A That is true, and then that is shown on the next shcedule. For instance, the total cost per well is shown on about the third line from the bottom on 30 acre spacing, $225,000; eighty acres, 240,000; 160, 245,000; and on 320, $175,000. The primary difference in cost there is the cost of moving out of the canyon floor up on the sides of the canyon if we can go to the wider spacing. Now, this is just a happenstance

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of the topography in that particular area. Now, this shows --

Q Then you have a bottom line there, "Profit or Loss Per Well." What does that show?

A Well, that shows on 40 acres, now we have estimated here the same as we did three years ago, 500 acres per well. I failed -- 500 barrels per acre, and I failed to point out earlier that we have arrived at that this time from our direct calculation of oil in place of 1500 to 2,000 barrels per care, and then using the analogy with Boulder of one-third to one-sixth of the oil in place being recoverable. This gives us something like 250 barrels per acre to 700 barrels per acre as being the range in which, I think, the recoverable oil per acre would be. 500 barrels per acre is the average and that is the basis for this estimate.

Q Then on 40 acres you have 189,800; on 80, 169.06 and even on the 160 acres, you still would have a loss of $104,200?

A Yes, sir. Only on 320 acres can we anticipate a profit and even then, it's not going to be as large a profit as is desirable or even necessary.

Q And it's less than one to one for cost, is it not?

A This is true. And I probably should point out at this time that the only reason we feel now we can live with 320 acres per well is that we believe that we will be able to

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institute gas injection secondary recovery measures and increase our recovery in this fashion which we can do on the wide spacing but cannot do economically on the narrow spacing of 160 acre spacing.

Q Why can you do it on the wider?

A The same situation as existed in Southeast Cha-Cha, if we drill wells too close together and produce the wells at rates which are, give us an economic rate of return, reasonable economic rate of return, we will deplete the reservoir too fast to effectively subject it to secondary recovery measures and pressure maintenance.

Q Anything further on Section "B"?

A No, sir.

Q Then turning to Section "C", first page, will you explain that?

A Section "C" is just a schedule which shows the amount of production which has been delayed as a result of our interference test in Southwest Puerto Chiquito. We show the allowable if the interference test had not been run, actual production resulting under test conditions and the amount of production that we are currently losing or being delayed as the result of the test.

As can be seen from the schedule, from the last few months, we are losing only a small amount currently. Our

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biggest losses were, of course, while the wells were shut in and producing only one or two barrels -- or one or two wells.

Q And going to "D".

A "D" is a duplicate of one exhibit we had at the hearing three years ago which indicates the amount of damage to the forest lands as dependent on well spacing and which results from the figures we just looked at earlier. On 320 acres, there will be two per cent as much damage to the forest as on 40 acre spacing.

Q Now, in your opinion, will the spacing in Puerto Chiquito have an affect on the economy of New Mexico and particularly on the amount of money that is returned to the various Governmental agencies -- Governmental divisions of both Federal and State Government?

A Yes, sir. Even though it's primarily Federal lands in Southwest Puerto Chiquito, the income from these lands will have an affect on income or revenue to the State of New Mexico.

Q Have you set this information out on Exhibit "E"?

A Yes, sir.

Q Will you explain it in detail?

A Exhibit "E" shows the amount of revenue which will accrue to the United States, the State of New Mexico and Rio Arriba County for each ten million barrels of oil produced from Southwest Puerto Chiquito which is primarily Federal

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lands, that's the current value of oil to wellhead. The reason we have included this exhibit is that I feel that from information we have, that at this time there is a good possibility in Southwest Puerto Chiquito of a reservoir of approximately forty million barrels of oil in place. If we can, by primary methods, recover a sixth to a third, say perhaps a fourth of it, we may recover, oh, eight or ten million barrels by primary methods.

If we could successfully institute gas injection if the reservoir would be susceptible to it, we might double that recovery, we might produce an additional eight or ten million barrels of oil by secondary recovery methods.

Now, the point of this is that although I don't know that the reservoir will respond to pressure maintenance methods, I think it's possible, in fact I think it's probable that it would, but it can only be done on wide spacing. If we attempt to secondary recovery on 160 acre spacing, we will just have exactly the same thing that has happened in other pools, the pressure drops too fast, the gas comes out of solution, the permeability to oil declines and you have nothing really but a solution gas dry mechanism.

Q Mr. Greer, have you already been in conversation and communication with the USGS with regard to approval of the pressure maintenance during the year 1967?

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A Yes, sir. We have had tentative approval from the USGS to institute pressure maintenance in our plan of development for the year 1967 rather than drill any additional well.

Q We would, of course, also have to apply for permission to this Commission before we could do this?

A Oh, yes.

Q Now, will institution of the pressure maintenance give you information, further information about the pool and how to proceed with it?

A Yes, sir. If it responds --

Q How to proceed with development?

A Yes, sir. If it responds to pressure maintenance, of course, this means one thing. If it does not, this means another.

Q Although most of these leases are Federal Government leases, I notice you've got the accrual to the State of New Mexico?

A Yes, sir.

Q Do they -- out of that twelve and a half per cent royalty, does part of that go to the State?

A Yes, sir. Three-eighths of the royalty goes to the State of New Mexico, five-eighths remains with the Federal Government.

Q And then when you calculate the other matters to the State, if I read these figures, you've got almost $2,000,000 additional to the Federal Government two and a half million into the State and a little over a quarter of a million dollars to Rio Arriba County?

A Yes, sir. Yes, sir, these amounts of money, I believe, are possible in addition to that these agencies might receive this additional amount of money if the secondary recovery measures are successful.

Q This is in addition --

A To climbing --

Q -- to savings to the operator?

A Oh, yes, sir. Of course, the operators, of course, will have an additional income too. The point there which I would like to make here is although we can't say that the pressure maintenance will be successful, we can definitely say that it is impossible on 160 acre spacing.

Q Then, Mr. Greer, in light of particularly Sections "B" and "C", it's actually economically impossible to develop this pool on 160 acres, is it not?

A Yes, sir. It's economically impossible to develop --

Q There would not be an income return on that many wells?

A No, sir. You could not recover as much money from

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drilling wells, from producing wells as it costs to drill them.

Q And in addition to this, certainly no one would be stimulated to look for another pool?

A No, sir.

Q Mr. Greer, you have recommended temporary 320 acre spacing. Are you possibly familiar with what some of the provinces in Canada have done with regard to recognizing the principle that we have presented here today toward granting wide spacing on production of oil?

A Yes, sir. I am generally familiar with some of the spacing regulations.

Q Do you have properties in Canada?

A Yes, sir.

Q Tell us what have the Canadian Conservation Commission recognized in this regard?

A Well, at our hearing three years ago we put in some information in this respect and I would not repeat that, but in addition to that, since our 1963 hearing, Alberta has gone and made quite a study and has adopted a new plan and they permit now up to two and one-quarter sections per well, per oil well spacing in Alberta.

Q Do you have anything else that you think would be helpful to the Commission?

A No, sir. I have one other thing. I noticed another

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typographical error, we should correct one of the exhibits. Exhibit 3 in the Index Page 4 under Item 5 at the top where it says "Twelve sheets," it should be nine sheets.

Q That is under "O", Section "O", Item 5?

A Under "N", Item 5.

Q Yes. Should be how many sheets?

A I believe it should be nine sheets instead of twelve.

Q Anything further?

A No, sir.

MR. VERITY: We offer Exhibits 3, 4 and 5 and also Exhibit 6 in evidence.

MR. PORTER: Is this Exhibit 6 your economic picture?

MR. VERITY: No, I am sorry, Your Honor. Exhibit 6 was the real masterpiece we had from Dr. Dunn. Exhibit 4 was the blue-covered document that we made various references to as containing data that was collected from time to time.

MR. PORTER: I have that, but Exhibit 5, this economic picture that you presented.

MR. VERITY: That's Exhibit 5, Your Honor. It's in the gray folder.

MR. PORTER: We have one here, Attachments "A", "B" and "C" to the methods of interpretation of pressure.

MR. GREER: That was Exhibit 2.

MR. PORTER: That's Exhibit 2?

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MR. GREER: Yes, sir.

(Whereupon, an off the record discussion was held.)

MR. VERITY: That's all of this witness. You may have him for cross.

MR. PORTER: Without objection the exhibits will be admitted into the record.

RECROSS EXAMINATION

BY MR. PORTER:

Q Mr. Greer, you have recommended that the temporary rules remain in effect, that the temporary rules be made permanent for the east side of this area for which you are recommending the 160 acres. Now on the west you are recommending 320 acres and for a temporary period of three years?

A Yes, sir.

Q Would you like to have the same rules except for the proration unit for the west that are now in effect in the east pool?

A I think so, until we are ready for permanent order I believe it would be proper to keep them the same.

Q What about well location?

A Well, of course, it would be helpful if we had a little more leeway, but I understand the policy that the Commission has had in the past in spacing the wells so that

if ever they want to change the pattern that it can be done. We can live with the rules the way they are. We, of course, have to ask for an unorthodox exception on an unorthodox location once in awhile, but that's not a too cumbersome a procedure.

Q All right. Now, you definitely want to limit one, each 320 acres to one well?

A Yes, sir, absolutely.

Q And the only way that you could be granted a second well would be after notice of hearing?

A Yes, sir. Only after notice of hearing. This is the way we would request it.

MR. PORTER: Does anyone else have a question of the witness? Mr. Utz.

FURTHER CROSS EXAMINATION

BY MR. UTZ:

Q Would the location and participation be due to the topography?

A Yes, sir.

MR. PORTER: No one has a question. Mr. Nutter.

FURTHER CROSS EXAMINATION

BY MR. NUTTER:

Q Mr. Greer, this whole case is based on, or apparently all of the drainage in this case is based on the fractures

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due to the natural fractures or fractures which you create by the well stimulation techniques out there?

A Yes, sir.

Q As far as the natural fractures are concerned, is there any evidence that these fractures are oriented in any particular direction?

A I can't say that there is definite orientation of fractures so far. Despite all of the work that we have done, it's pretty hard to say. In Northeast Puerto Chiquito there may be a little better permeability or more communication evident north and south rather than east and west which is more or less what we would anticipate from a general, contours of the producing formation. In Southwest Puerto Chiquito, I thought, for instance, from our interference test that perhaps we may have directional permeability between the A-14 and the L-11, but when we put the L-11 on production it didn't materialize so if there is any direction permeability then it's quite small, I believe.

Q Now, what is the name of this uplift on the east side, is that the Monument uplift there?

A Yes, sir.

Q Now, when that thing -- now, this well was presumably laid down as a relatively flat, in a relatively flat plain, was it not?

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A This is what I would presume, yes, sir.

Q And then the uplift came after that. Wouldn't you suspect that this uplift and the faulting running north and south, that the main vein of the fractures would probably be in a north-south direction also?

A Yes, sir, that's what we had thought earlier.

Q And it's possible that maybe a well would drain an area of 6,000 acres long but it would be in a north-south direction and maybe not east and west, is that possible?

A It would be possible. Of course, the results of our interference test do not indicate that we have that sort of a situation. As you may recall, we computed the oil in place at one day, two days, three days, and so on down. If we had substantial directional permeability, then it would have shown up in this part of the test. We might have a little directional permeability, but I think it would be inconsequential in this respect.

Q Now, also I missed your explanation of what caused the pressure decline in that well which was a dry hole there in Section 6 of the Northeast Puerto Chiquito area which is on the west side of the fault and I don't believe that there are any producing wells out there on that side of the fault, are there?

A Yes, sir, I believe I indicated earlier that we are

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not sure how long that fault is or how effective it is other than I feel we have a zone of faulting and that each fault probably restricts the communication somewhat and we do not have as good communication with the well in Section 6, for instance, as we do with the well in Section 19, or as good of communication, for instance, as we have had in Southwest Puerto Chiquito. So it's my thought that this restriction is probably caused by an area of faulting and so although it's on the west side of the fault, we do not have complete separation.

Now, it's possible that the communication goes around the fault if it's not a long one.

Q Are these faults evident on the surface out there?

A Some faults are evident on the surface.

Q Is that one that you figured you out with that Well F-30, is that fault evident on the surface?

A Well, we think so. It's just a little bit hard to say for sure, you know where one starts on the surface and ends in the ground, but there is a pronounced fault in that general area.

Q Mr. Greer, a normal provision in many of the pools that the Commission has issued has been the statement that "Nothing herein and contained shall be construed as prohibiting the drilling of a second well on this 80 acre unit," or

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something along those lines. What is the objection to the permitting of a drilling of a second well on a 160 acre unit and a 320 unit if the allowable is proportional for the amount of acreage that is dedicated to the well?

A Well, our objection to that now is the same as it was three years ago and that is, that although we will have the allowable proportional, in other words, this is what we would like to have, the allowable proportional to the spacing, the chances are pretty good that the wells will not all make the allowable and so, for instance, at this time the average productivity in Southwest Puerto Chiquito, I guess, would be two or three hundred barrels per well per day. Now, if we have an allowable of the eight normal allowables, we will have an allowable in excess of 500 barrels a day. One or two of the wells will make it; most of them will not.

So when you reach this point that wells are producing at capacity, then you can put, say two wells on a section and take twice as much oil out of it as one well on a section or on a spacing unit. In other words, let's say that the capacities of the wells were 250 barrels a day each and the allowable is 500 barrels a day. On one section we would have two wells, 320 acres each, and they will recover, they will produce 400 barrels a day from that section.

If you drill four wells adjoining them in the next

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section, they will take 800 barrels a day out of the reservoir so that people who drill on wide spacing, then, will suffer drainage to the wells that's drilled on a more dense pattern.

Q You're thinking only in terms of marginal wells where the allowables would not be in proportion to the acreage?

A This is true.

Q Top allowable wells will always be in directional proportion.

A Right. If they would always be top allowable wells, then we would have no problem. Other people could drill for whatever they wanted to and we would drill for what we wanted to, but at some point in any well's life, it reaches a capacity production and it starts earlier in some and later in others.

And, of course, we have one other objection. I shouldn't say we don't have any objections, we do have another objection. If another operator drills on a more dense pattern, even though they are taking the same amount of oil per acre as we are, chances are that we are going to get into a jam regarding pressure maintenance and secondary recovery measures that we wish to avoid.

Q I realize why one of those exhibits there, that most of the acreage in this area was colored yellow so I don't anticipate that this problem will come up very often, but it did come up in the last three years, so I just wondered what

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the real basis for it was. I was recalling that at your other hearing you testified it was something to do with capacity of the proposed pipe line, along those lines, the objection to the second well being drilled on the unit.

A Right. This is still true. If we try to produce too fact, why, of course, we cannot run it through a pipe line which is of reasonable size for the total amount of oil, so this means, then, either you pay a higher price to the pipe line company to build an unnecessary pipe line just like drilling unnecessary wells, we didn't have an unnecessary pipe line, or in the alternative we have to truck the additional oil, which of course is at a higher cost.

Q Of course, if that man drills those marginal wells on his property and had to drill more than one well on the proration unit and you had a good well over there on 320 acres, according to your testimony, there with that A-14 and that other well, you are going to drain his oil out anyway?

A Yes, sir. If we could just be assured that the other people would get small wells, why, that would be fine. We would have no objection.

MR. NUTTER: I believe that's all.

FURTHER CROSS EXAMINATION

BY MR. PORTER:

Q Mr. Greer, in September, I believe there was a

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temporary order entered in this case extending the provisions of the existing order. Do you know when that order expires?

A Well, the first --

MR. PORTER: Mr. Cooley.

MR. COOLEY: I believe the Commission's order and the Commission's decision were both continued until such time as the Commission entered its order as a result of this hearing.

MR. PORTER: I have forgotten whether it was a definite period of time.

MR. HATCH: Until further order of the Commision.

MR. PORTER: I see. Are there any further questions of Mr. Greer? You may be excused.

(Whereupon, the witness was excused.)

MR. PORTER: Do you have any other witness?

MR. VERITY: With that, we rest, Your Honor. There are no more witnesses and no more evidence. I believe that's all we have. I think there are some others here and I would like to make just the very briefest summation.

MR. PORTER: We will allow you to do that after we have determined whether there is any more testimony to be presented. Does anyone else desire to present testimony in this case? Would you like to make your statement now, Mr. Verity?

MR. VERITY: No. I would like to include, Your Honor,--

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MR. PORTER: Mr. Boyd, do you want to go ahead and make the statement?

MR. BOYD: Ben Boyd, El Paso Natural Gas Company. I have a very brief statement. El Paso Natural Gas Company is not an active operator in Puerto Chiquito Mancos oil pool, but is the owner of certain interests in Federal oil gas leases. These leases are within the boundary of the pool as presently defined by the New Mexico Oil Conservation Commission. El Paso Natural has no objection to the application of Benson-Montin-Greer Drilling Corporation for the establishment of the pool boundary and pool rules of the Puerto Chiquito Mancos as has been represented by the applicant at this hearing.

MR. PORTER: Does anyone else desire to make a statement? Mr. Cooley.

MR. COOLEY: I would like to make a statement for Plateau, Inc., the other client that I represent. They also own fifty per cent interest in certain leases in this area in the West Puerto Chiquito Pool and have instructed me to advise this Commission that they fully support the application of Benson-Montin and Greer Drilling Corporation.

MR. PORTER: Thank you. Does anyone else have a statement? Mr. Hatch, I believe the Commission has received a number of communications. Would you make reference to those at this time, please?

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MR. HATCH: I have a number of communications in support of the application. These communications were from Bert's Royalty Company, Reeding and Bates Production Company, Dale-Reeve, Inc., Charles B. Gonzales, M.A.S.T. Company, Pan-American, Ernie Hanson, Atlas Mineral, Skelly Oil, and Noel Reynolds. I also had communication from J. M. McLaughlin which he says no objections, and from Humble Oil offering no objections to the application. And that is all the communications I have.

MR. PORTER: If I recall the previous case, Mr. Greer, the Forest Service also supported the application. Did they tell you their standing?

MR. GREER: No, sir. We were just afraid we had so much testimony we wouldn't have room for it.

MR. PORTER: Mr. Verity, you may proceed with your summation.

MR. VERITY: Your Honor, in addition to those read, I believe we got copies of communication from both Humble and Mobile Oil, also and in case they didn't get through I wonder if I could offer these, for I believe they support our application, also.

MR. PORTER: They will be placed in file with the other correspondence.

MR. VERITY: I don't care to take but just a briefest

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moment at this juncture in behalf of the applicant and myself. I do sincerely appreciate the attention that the Commission has given and the Commission staff to what I realize is very technical and voluminous data. I think it is a credit to my client and the applicant that they have collected the amount of data that they have.

I think that this has kept faith with the Commission's granting of temporary allowables and transfer of allowables and we believe that it's for the good of the State as well as the good of the industry and particularly the good of the applicant as well as the royalty owners and others in the area.

I want to call your attention to this fact and that is, not forget it, that Shell pointed out that they need this oil and that they can use as much production as we have, that they are in favor of anything conservation-wise that increases the amount of oil, and particularly that they, that this oil is going to support this Cineza Plant which is up in, I believe it's Gallup.

We think that we have demonstrated, and at least the applicant's lawyers have been impressed, with the information that we have and the detail with which the applicant has gone into engineering principles to establish drainages, reservoir characteristics, the amount of area that can be drained and the efficiency of drainage and all other aspects of this. We

believe that it will definitely promote the good of the industry and the good of the State of New Mexico, Federal Government, Rio Arriba County and everyone in the area and that no one will be hurt or disturbed by the granting of this application. We earnestly and sincerely submit it and humbly request that the Commission grant our application.

And we call your attention to the fact that you can always drill a well that hasn't been drilled. You can always come later, and last time I think Humble and their attorney pointed out that although you may make a three-year temporary order, this order can be interrupted at any time and any person or the Commission on its own application can call the matter for further hearing and say "We want to hear it now, and we think now that you should infield," but if you have infield a well like up in northeast or in Cha-Cha and other areas, you sure can't undrill it.

MR. PORTER: It sounds pretty much like the Humble attorney.

MR. CAMPBELL: I think the record ought to show that we had any drilled wells.

MR. PORTER: Anything further to be offered in this case? The Commission will take the case under advisement.

MR. VERITY: I want Your Honor to be sure that we are requesting on the temporary 320 spacing an opportunity to

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continue interference tests.

MR. PORTER: That's right.

(Whereupon, the hearing was concluded.)

STATE OF NEW MEXICO)
) ss
COUNTY OF BERNALILLO)

I, JERRY POTTS, Notary Public in and for the County of Bernalillo, State of New Mexico, do hereby certify that the foregoing and attached transcript of hearing was reported by me in stenotype and that the same was reduced to typewritten transcript under my personal supervision and contains a true and correct record of said proceedings, to the best of my knowledge, skill and ability.

Jerry Potts
NOTARY PUBLIC

My Commission Expires:

July 10, 1970

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BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
December 17, 1969

EXAMINER HEARING

IN THE MATTER OF: Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320-acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico.	CASE NO. 3455

BEFORE: Daniel S. Nutter, Examiner.

TRANSCRIPT OF HEARING



MR. NUTTER: Case 3455, reopened. Continued from the November 5, 1969 Examiner Hearing.

MR. HATCH: In the matter of Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320-acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, for a period of three years.

MR. COOLEY: William J. Cooley, Farmington, appearing on behalf of the Applicant. We have one witness to be sworn in this case.

(Witness sworn.)

(Whereupon, Applicant's Exhibits 1 through 4 were marked for identification.)

ALBERT R. GREER,

called as a witness, having been first duly sworn, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. COOLEY:

Q State your name and place of residence, please.

A Albert R. Greer, Farmington.

Q By whom are you employed?

A Benson, Martin & Greer Drilling Corporation.

Q Are you the same Albert R. Greer who previously testified in connection with this case?

A Yes, sir.

MR. COOLEY: Are the witness' qualifications acceptable to the Examiner?

MR. NUTTER: They are.

Q (By Mr. Cooley) Mr. Greer, at the hearing three years ago, concerning this matter where temporary rules were ultimately established by the Commission, you gave testimony with respect to certain communication tests and other data which you had assembled which led you to believe that there was excellent communication in this pool, the west part of Chiquita, West Mancos Oil Pool, as well as the data with respect to the oil in place and the capability of one well to drain certain areas in this pool.

Have you developed any further information since that time in connection with these points?

A Yes, sir. We have.

Q First, I call your attention to what has been marked as Exhibit 1 in this case. It's the green pamphlet, and ask you if the plat shown under Section A correctly reflects the status of the pool at this time with respect to wells under various statuses of these wells?

A Yes, sir. This plat under Section A of Exhibit 1 shows an outline of boundaries of the west part of Chiquita Pool, boundary of the Quinata-Jitos unit within the pool, the status

of wells which are currently drilled or being drilled within the pool.

Q Would you briefly explain the color symbols?

A Yes. The color blue indicates wells currently producing or capable of production. The triangular wells colored green are observation wells, and the one well with the yellow square is the gas injection well. The wells with the red coloring indicate wells currently drilling or not complete.

Q Moving on, directing your attention to Section B of Exhibit 1, would you explain briefly the significance of this data?

A Yes, sir. This shows bottom hole pressure data taken in an observation well. This particular well has been shut in practically its entire life; several years.

Q This is the A-23?

A This is the A-23, located in Section 23, and marked on the plat under Section A. Up until 1969, while the reservoir was undergoing depletion without gas injection, the rate of decline of the fluid level in this particular well gave us an excellent indication of the rate of change of pressure within the reservoir, and we depended primarily upon the fluid levels in this well, but occasionally, we would measure the pressure to determine that the fluid levels did

actually reflect the change in pressure in the reservoir.

Q Mr. Greer, what relationship between fluid level drop or rise is there in pressure drop or rise?

A Well, the oil has a density of approximately one-third of a pound per square inch per foot, as can be seen in the last column on the right of this particular page. And, as a result, then, one foot or three feet of oil is roughly equivalent to one pound per square inch.

Now, after we commenced gas injection in August of 1968, after a period of some six or eight months after that, gas began moving toward the observation well, and, as a result, we have a little gas working its way into the oil column in this observation well, lightening the column. And, as a result, the fluid levels now do not represent as accurately as they did before changes in reservoir pressure.

Accordingly, we have to take pressure more often now, about once a month, rather than once a year, which we did prior to commencing gas injection.

Q Mowing on to the next figure under Exhibit B, would you explain to the Examiner the import of this information with respect to the Quinata-Jitos Unit E-10 well.

A Yes, sir. We have found that as the pressure in the reservoir declines, and we drill new wells, that the new wells encounter not a virgin reservoir pressure, but the depleted

pressure as represented by pressures in the other wells. In this particular instance, at the time the F-10 well was completed, which is in Section 10 of 25 North, Range 1 West, shown on the plat under Section D; wells colored in blue. The well was completed in the summer of 1967, given the sand fract treatment July 19, 1967, and within about twenty days after that, the pressure remaining from the sand fract treatment had declined to a rate of approximately two-thirds of a pound per day.

The bottom hole pressure was taken on August 9, at which time the pressure was still declining. This pressure is shown on the schedule under Section B, 1609 pounds as measured at a depth of 6900 feet in this well, which corrected back to the datum to which we have applied all the pressures, so far, that's been reported to the Commission in this pool, to datum of plus 1195 would be 1374 pounds.

The observation well, which was the A-23, had a datum pressure at that time of 1365 pounds. So, this well, at the end of some twenty days after fract treatment, had a pressure within about nine pounds of equalization with the pressure in the observation well. And this pressure was some 250 pounds less than virgin reservoir pressure.

Q And the distance between these two wells?

A Is approximately two and a half miles.

Q If you would move on, then, please, to the last

figure under Section B, and explain the significance of the information there with respect to the Quinata-Jitos unit A-22 well?

A This is the same type of information as we just saw regarding the E-10 well. This particular well, A-22, is only approximately one mile from the observation well, as shown by the plat. This well was given a sand fract treatment during the completion process on September 20, 1968. Within ten days, the pressure decline following the fract treatment had stopped and the well's pressure was essentially equalized with the reservoir pressure in that area, which we measured, then, on October 15, 1968, to be 1486.6 pounds at 6750 feet.

Correcting this back to the datum of plus 1195 is a pressure of 1302.6 pounds. Now, at that time, the pressure in the observation well, as indicated under Roman Numberal II, the figures under that line, and on this page, show 1329 pounds. Now, at this particular time, the gas injection had just been commenced. There was an interference effect as a result of this in the observation well, and also, an interference effect in A-22.

The difference in this interference effect we calculate to be twenty-seven pounds. Accordingly, under Roman Numberal IV on this page, we show the comparative pressure, then, in the A-23 observation well, had there been no effect of interference

from gas injection would be 1302 pounds, which compares back with the 1302.6 pounds, which is actually measured in the well. This indicates almost complete equalization of pressures between the new well and that shown on the observation well.

And these pressures are some three hundred pounds below the virgin pressure of the reservoir.

Q The pressures reflected in this last tabulation, with respect to the A-22 well, were taken at a later date than those on the E-10 and the previous exhibit, were they not?

A This is true. The reservoir declined in pressure approximately some seventy pounds, and, as a result, then, when the A-22 well was drilled in 1968, it had a pressure, approximately seventy pounds less than when the E-10 well was drilled a year earlier.

Q Briefly, then, what is your conclusion with respect to the pressure information that you have discussed here under Section B?

A It's my interpretation that these new wells have encountered depleted reservoir pressures and, as a result, the communication between the wells which were producing and draining the oil out from under these tracts is extremely good.

Q This is a strong indication of pressure communication between all the wells tested?

A Yes, sir.

Q Moving, then, to Section C of Exhibit 1. Would you explain, please, the significance of the first plat and graph shown thereon?

A The plat under Section C shows the relative locations of the subject well. We will discuss under this part of the exhibit, which is the L-27, located in Section 27 of 26 North, 1 West. And the same observation well we've been referring to in Section 23 some five miles to the south. I believe these wells are actually separated a distance of approximately four and three-fourths miles.

Well 27 was drilled this summer, 1969, was given a sand fract treatment October 2, and we're still watching the decline in pressure following the sand fract treatment in an effort to determine the degree of depletion in this area, and, as an aid in determining the transmissibility of the general area of the well.

The first graph under this Section C shows the rate at which the fluid level is declining in this well. This can be seen from this graph; after approximately five days, the fluid level was declining at the rate of some forty feet per day, and after sixty days, the rate of decline of fluid level was some three feet per day.

Q Moving, then, to the next graph under Section C. What is the significance of this?

A The next graph shows a plat of the actual fluid levels in this well, following the sand fract treatment, and comparing these fluid levels with equivalent fluid levels which would have existed in the well, had it been drilled at a time when virgin reservoir pressure existed in the area in which the well was drilled. This particular pressure of 1620 pounds, the virgin reservoir pressure would have had an equivalent fluid level in this well of approximately 1760 feet.

And that's shown by the upper horizontal dashed line on this graph. Bottom hole pressure was actually measured in this well at about seven days following the sand fract treatment, at a time when the fluid level was at 1805 feet. The result of this pressure measurement is shown on the graph. It was 1920 pounds at 17200 feet, which adjusted to our plus 1195 datum, would be 1635 pounds.

The fluid level which represents datum pressure of the observation well at this time is shown by the lower horizontal dashed line, which is 1325 pounds or its equivalent fluid level would be about 2675 feet. Now, we can see from this plot that the pressure in the vicinity of this L-27 well has declined at least two hundred pounds below the virgin pressure and, of course, if the pressure decline continues as is indicated on this graph, in another couple of hundred days, it will be equalized with the pressure in the observation well

some five miles away. Now, we'll probably have determined the information we need to know in less than the additional two to three hundred days required for equalization, and we presume that we will put the well on production sooner than that.

I might say we have two purposes in determining the pressure in this area. One, of course, is communication with the other wells, and information for this particular hearing, and in addition, we are interested in knowing the approximate transmissibility of that area, and whether it would be worthwhile to extend our gas injection facilities to the north part of the unit to include this and other wells to the north.

Q Proceed, then, Mr. Greer, to Section D of Exhibit 1. Would you explain the significance of the first graph?

A The first graph under Section D is a plot of production in fluid level decline in the observation well. Production is for all of the wells in the participating area in the Quintana-Jitos Unit, and is a continuation of the same type of information we presented at the 1966 spacing hearing.

And one thing of interest is the fact that we were maintaining the production rate at approximately one thousand barrels per day, which is substantially less than the producing ability of the wells.

And, of course, our reason for this is that we want-

ed to commence gas injection with the highest possible reservoir pressure. As a result, we restricted the production rates from the producing wells until this could be accomplished. Another thing of interest is the leveling of the rate of fall of the fluid level in the observation well in mid-July of this year, 1967, and this leveling of fluid level was caused by the sand fracture treatment in the E-10 well, which we just reviewed a few minutes ago.

Injecting the fract volume into the reservoir some two and a half miles away, in one well, caused a change in the reaction of the fluid level in the observation well. The E-10 well was put on production in the latter part of August, as shown by the heavy bar at the bottom of the graph, and by the difference in the production rates shown from all the wells in the participating area.

The upper production rate line reflects total production from all wells. The lower line is production from all wells except the E-10, and as can be shown on this graph, although the E-10 well had a capacity to produce of several thousand barrels per day, we restricted its production to a couple of hundred barrels per day, and reduced production from some of the other wells in order not to exceed our approximately one thousand barrels per day, previously established rate at which we wanted to produce the wells in this area.

Q This is a self-imposed rate?

A Yes, sir.

Q Would you proceed, then, to the graph of production of 1968, the next graph?

A 1968 is a continuation of the same information shown on the previous graph. Very important here is the reaction of the fluid level in the observation well, and its bottom hole pressure, which is also shown on this graph, as a result of the commencement of gas injections in August of 1968. Injection was commenced August 9, and the reaction was first observed in significant fluid level changes in about eight or ten days.

The amount of gas injected as shown by the upper line of the graph, and there is a scale that shows the amount. It was approximately eight hundred MCF per day, which was equivalent to approximately fifteen hundred barrels per day in reservoir space.

Q Was it on this graph that the A-22 was completed?

A Yes, sir. We referred to A-22 a little earlier. Its pressure communication with the main reservoir. The upper bar on the bottom part of the graph, the upper horizontal bar in November shows when the A-22 was put on production. This well is also capable of producing at rates of a thousand barrels per day, or higher. But, again, because of our desire to maintain the production rate as low as economically feasible,

after we put this well on production and tested it, we reduced the unit production rate to about a thousand barrels per day.

Q Finally, under Section D, would you explain the significance of the 1969 production graph?

A Yes, sir. We have, again, the same information as was shown for the year 1968, and we believe by February of 1969, that the transient pressure increases resulting from the gas injection had definitely reached a steady state condition and that the reservoir was in condition to commence and increase in production rate.

As a result, in February of '69, we increased the production rate to approximately fifteen hundred barrels per day. In May, June, and July of this year, gas reached the first down dip well from the injection well, and as a result, as we continued to produce this well, the fluid level, bottom hole pressure, declined until the well was shut in in July of this year.

The well I'm referring to is the A-14, and it's shown on the plat under Section A of this Exhibit 1. Since July, the pressures have been equalized. Our injection rate is approximately equal to the withdrawal rate of about fifteen hundred barrels per day. This is the approximate capacity of the compressors at this time.

In November of this year, we've added one more compressor, and we propose now to increase our production rate to somewhere between fifteen hundred and two thousand barrels per day.

Q Do the result of production history characteristics during the periods July, August, September, and October of 1969 give you any indication as to the effectiveness of your gas injection pressure maintenance project?

A Yes, sir. These injection volumes calculate to be a reservoir displacement of approximately fifteen hundred barrels per day, and the fact that with the withdrawal rate of fifteen hundred barrels per day, and injection rate, which we calculate to be equivalent to fifteen hundred barrels per day of reservoir space.

Under these conditions, and we find the pressure in the oil zone that is, the area below the gas-oil contact to be stabilized. This means that we have exactly the same effect we had hoped with our gas injection; namely, with pressure maintenance. We're maintaining the pressure, keeping the viscosity low, the other reservoir characteristics good, and as a result, we anticipate a high ultimate recovery.

Q Moving, finally, to Exhibit E, or Section E of Exhibit 1. Do the producing gas-oil ratios and tested gas-oil ratios tend to confirm the information that is just

testified to, with respect to the effectiveness of pressure maintenance?

A Well, yes, sir. But, particularly this Section E is evidence of the method in which we have produced the reservoir in that we have -- in that all of the oil we produced to date has been at a gas-oil ratio equal to the dissolved gas-oil ratio or less.

In order to preserve the reservoir pressure and receive the maximum benefit from gas injection, of course, it's necessary to produce the wells at minimum gas-oil ratios, and this we've done. This is an example under Section E of the gas-oil ratio history of one well, and we've shown the details of the calculations arriving at the gas-oil ratio here, simply because, with the gas-oil ratio as low as it is, some four hundred to five hundred cubic feet per barrel, it's a little difficult to get an exact measured gas-oil ratio.

As can be shown here, the fourth column from the right, the separator gas-oil ratio during the period shown on the first sheet of the tables of figures runs from three hundred to four hundred cubic feet per barrel, with a separator pressure of forty pounds, as shown on this page. There is still dissolved in the oil or still in solution in the oil, sixty-five cubic feet per barrel, which carries over to the stock tank.

So, when we measure three hundred to four hundred cubic

feet per barrel, this separator is actually a produced ratio of some four hundred fifty feet per barrel. As shown on the second page of these tabulations, when we installed our gas gathering system, and went to a higher separator pressure of 185 pounds, the gas in solution carrying over to the stock tank is approximately 110 cubic feet per barrel, and so, gas delivered from the well into the gathering system and which of course, is the -- gives us the gas figures which we ordinarily report our gas-oil ratios to the Commission and the other courses is, of course, only a part of the gas since some of it is still dissolved and the oil carries over to the stock tank.

It becomes significant when we are dealing with ratios as low as we are here. As a matter of fact, we found in addition to the gas which is still in solution in oil that's produced in the reservoir from the reservoir in a particular instance of this well, which is produced with a hydraulic bottom hole pump. Apparently, some of the gas mixes with the power oil and it also carries over and this is particularly important in cold weather.

We found that as much as a half to two-thirds of the total gas produced will carry over to the stock tank in cold weather from this particular well. This gas-oil ratio inform-

ation is summarized on the last graph on this exhibit. We show in this graph the lower dashed line is the separator gas-oil ratio. The total produced gas-oil ratio, as we have calculated it and shown on the previous sheets, is the upper solid line. The shaded area represents our estimate of the true trend of the gas-oil ratio from this well, or of the oil produced from this well.

Now, the dips, the low marks, we can see are primarily where gas-oil ratios are measured in cold months, and the high points are where they were measured in the warmer months, which simply reflects the amounts of gas, additional amount held in solution as mentioned awhile ago. Also, on this graph, we show the pressure at the structural datum at which this well was completed, along with the bubble point pressure of 1520 pounds, and this can be seen from this graph.

The well was produced at or above the bubble point until shortly before gas injection was commenced in 1960. And at the present time, the pressure at the structural datum of this well is still slightly above the bubble point. Now, this is the highest well, structurally, of our main recovery wells and our pressure maintenance project, and it's our plan to maintain the pressure at or near the bubble point in these main recovery wells, which we have succeeded in doing here.

It's possible that the gas-oil ratios actually

declining in this particular well, as indicated by the information here. This well, as well as the other main producers in this pool, are draining very large areas and it's possible that oil we're producing from this well is moving from a mile or two up dip, and, as a result, the dissolved gas at the lower pressures higher up did.

It is less, of course, than that dissolved at the bubble point, and it's possible that this is the reason that gas-oil ratio appears to be declining in this well.

Q Mr. Greer, directing your attention to figure Number 1-8, under Appendix 1 of Exhibit 2.

A Under Appendix 1 of Exhibit 2, figure 1-8 is a reproduction of a part of one of the graphs under Section D of Exhibit 1, which shows the effect of gas injection on the observation well, A-23, when pressure maintenance was commenced in August of 1968.

Q What conclusions can you reach with respect to interference as shown by that graph?

A From the interference resulting from the gas injection in a nearby well, and the distance is approximately thirty-seven hundred feet from the injection well to the observation well. The gas injection rate is equivalent to a reservoir displacement volume of approximately fifteen hundred barrels per day, and from this information, we can

calculate the transmissibility of the area in which these wells are located and the amount of oil in placement per acre.

Q Are these calculations done directly or by trial and error?

A In this particular instance, because of the reservoir conditions, we couldn't make the direct calculations which we had with a similar test, and recorded to the Commission in 1966 on two other wells. It was necessary to calculate by trial and error the using different assumed values of transmissibility and oil in place, and fit the calculated curves with the actual curve.

This is shown on Figure 1-9, the next page. Examples shown here are for an assumed volume of oil in place of sixteen hundred barrels per acre. Transmissibilities of one Darcie feet, 1.8 Darcie feet, and four Darcie feet, and, as can be seen from this graph, there is a substantial difference in curves, not only from the time at which initial interference is first noted, but for forty to fifty days shown on this graph.

There is no question in my mind that a transmissibility of 1.8 Darcie feet at 1600 barrels per acre represent the physical reservoir characteristics in the area of this particular test. Also, if we assume different volumes of oil in place; for instance, if we vary the amount from 1600 barrels per acre to eleven or twelve hundred barrels per

acre, or as high as two thousand barrels per acre, we also find displacements of curves about the same magnitude as shown for the differences in transmissibilities shown on this graph.

In other words, we feel that as a result of this particular test, the calculations which it permits, that the determination of sixteen hundred barrels per acre of stock tank oil is a reasonably accurate figure. I believe it would be within twenty percent of the true value of oil in place.

Now, of course, at this time, since the pressure was below the bubble point, there was some free gas, undoubtedly in the general area of this test. Transmissibilities are accordingly less than they would have been with no free gas, or had no free gas evolved from the oil. Accordingly, I would estimate that the initial transmissibility would be something greater than the 1.8 Darcie feet indicated at the time this test was taken.

That figure I would estimate to be between 2.5 to 3.5 Darcie feet.

Q Directing your attention next, Mr. Greer, to Figure 1-16, just following this.

A 1-16 is the last figure under Appendix 1.

Q Was this in essence a transmissibility composite of the producing areas of the West Chiquita-Mancos Oil Pool?

A Yes, sir. We have measured transmissibilities over large areas of this particular part of the pool by three separate tests. One was an interference test in 1965, and reported to the Commission at the hearing in 1966. That is an estimate of 6.5 Darcie feet, which is shown here, the values of five to ten Darcie feet, and that's the area colored in blue.

Q The entire area, the entire square?

A The test we just referred to, resulting from gas injection of 2.5 to 3.5 Darcie feet, I believe, is the result of reservoir conditions in the area shown by the diagonal cross-hatching in which the diagonals slant from lower left to upper right.

MR. NUTTER: Or are these southwest?

A Affirmative. We ran one other interference or one other transmissibility test, which we'll not go into details right now. The rules are shown in that Appendix 1, the method of calculation. It shows ten to twelve Darcie feet, and that's represented by the diagonal cross-hatching northwest to southeast, which, incidentally, the two tests covering the smaller areas, one of two and a half to three and a half Darcie feet, the other, ten to twelve Darcie feet.

We would assume the average, then, of transmissibility represented by these two areas would be somewhere between five

and ten Darcie feet, which is, of course, what was measured by the first test which we think covered the entire area.

Q Well, then, concluding from all of the information which you have on interference in this pool, and transmissibilities, oil in place, and other data which has now been made available to you, is it still your conclusion that one well will drain well in excess of 320 acres in this pool?

A Yes, sir. I think we might take time to look at one well. Its actual production in the area, or the, approximately the area that it's drained.

Q It should be Figure 4-1 under Appendix 4.

A Yes, sir. Under this Exhibit 2, Appendix 4, Figure 4-1, we show the relations of oil recovery in terms of percent of oil in place at the bubble point pressure. Two, pressure at any one time. The subject well I would like to discuss at this time is the L-11, completed in Section 11 of 25 North, One West. This well, under virgin reservoir conditions, would have had a reservoir pressure at its structural datum of about eighteen hundred pounds.

At the time, it was -- at the time gas injection was commenced in August of 1968, its pressure had declined to about fifteen hundred pounds. We saw the rate of decline on the gas-oil ratio graph for this well a few minutes ago. This well, at the time gas injection was commenced in August of

1968, it had produced approximately four hundred and seventy thousand barrels of oil. The nearest comparative pool to this one is the Boulder Pool. The average recovery from -- average ultimate recovery from wells in the Boulder Pool was approximately sixty thousand barrels per well, and this pool was developed on eighty-acre spacing, so we can see that this particular well, at the time gas injection had commenced, had produced an amount of oil equivalent to approximately eight of the wells in the Boulder Pool.

And it was not, of course, completed. As a matter of fact, we can see from this graph Figure 4-1, that after having produced all this oil, the reservoir had been depleted at its structural datum, only 1.5 percent of the oil in place. Now, we can't, of course, use this to forecast ulti-mate recovery from the well, but it is a very definite indicator of the extremely large areas that these wells are draining.

It has to be in terms of tens of thousands of acres of these wells.

Q Moving now, Mr. Greer, to Figure 5 under the main figures The first tab on Exhibit 2 indicates figures, and Figure 5 under that section, I direct your attention to. Mr. Greer, before we proceed further, would you explain to the Examiner, in your opinion, as to the reservoir drive mechan-

ism that is available in the west part Chiquita-Mancos Oil Pool?

A Yes, sir. There is no water drive. The producing mechanism can be only solution gas drive or gravity drainage, or solution gas drive with some help from gravity drainage, and with the particular reservoir characteristics of this pool, it's entirely possible to produce the reservoir in a reasonable length of time by restricting the production to the gravity drainage rate available.

And in so doing, to recover from five to ten times as much oil as we would if we produced strictly under a solution gas drive.

Q Well, in other words, the operator of this pool has a choice of two different drainage mechanisms from which to choose? I mean, two of them from which to choose?

A Yes, sir.

Q The solution gas mechanism being highly inefficient, comparatively speaking, and the gravity drainage mechanism being something on the order of five to ten times more efficient than the solution gas?

A This is true. This fractured shale reservoir has an extremely poor solution gas drive recovery. We'll not go into it, but as shown by the information on this Exhibit 2,

the solution gas drive recovery would be on the order of six percent of the oil in place. And there is no way, solution gas drive is, of course, not rate sensitive. There is no way by adjusting rates of production or any other physical means, to increase that recovery beyond six percent.

Q You say the solution gas drive mechanism is not rate sensitive? Is the gravity drainage system any different?

A Gravity drainage mechanism is sensitive. I would not say that the reservoir is rate sensitive, but, of course, the mechanism, the gravity drainage mechanism is sensitive and if we greatly exceed, or, as a matter of fact, we don't have to exceed it greatly, if we just exceed the reservoir gravity drainage ability just a little bit, we immediately move into all of the cycles of dissolved gas drive, which result in rapid depletion of pressure and low ultimate recovery.

Q To recap, then, if the operator exceeds the gravity drainage rate, then it initiates or institutes a mixture between that and the solution gas drive mechanism?

A This is true.

Q And to whatever extent they are mixed, it is less than -- the ultimate recovery would be less than the optimum expected from pure gravity drainage?

A This is true.

Q What are some of the factors that impede gravity drainage?

A Well, of course, it's necessary to have some dip of the formation. In this particular instance, the dip varies from two hundred feet to four hundred feet per mile, and with the high transmissibilities which we just reviewed, it's possible to have gravity drainage rates as high as a thousand barrels per day per linear mile, which we have shown how to calculate, and which are represented on this Figure 5.

Q You say a given number of barrels per linear mile. Is that per linear mile along the strike?

A Yes, sir, per linear mile along the strike, and, unfortunately, under the gravity drainage, there is only one gravity drainage rate available for any given length, the reservoir section down dip.

Q Any variety of length down dip; isn't that correct?

A Yes, sir. For instance, if the rate is a thousand barrels per day, per linear mile, and the reservoir has a length down dip of one mile, it's a thousand barrels per day. If the reservoir is two or three or four miles in length down dip, and you have two or three or four times as much oil in place, you still have only the one one thousand barrels per day per linear mile along the strike of gravity drainage?

Q Just because of the physical principle of the

mechanism?

A Yes, sir.

Q And to repeat my question a moment ago, what are some of the factors that will impede efficient gravity drainage?

A Well, of course, the most important factor is rate of production. Once you've seen the gravity drainage rate, you move into the solution gas drive depletion mechanism and you soon have the reservoir in such condition that it's impossible to recover substantial or significant amounts of oil by gravity drainage.

Q Well, isn't the presence of free gas on the reservoir the result of moving into the solution gas phase?

A This would be one result; yes, sir.

Q And then, directing your attention to Figure 5 under the tab called "Figures," on Exhibit 2, would you briefly explain the significance of this?

A Yes, sir. This figure is calculated for a condition of a formation dip of four hundred feet per mile, and the oil properties of the west part of Chiquita, and we can see, for example, that for the value of transmissibility of four to five Darcie feet, which, I believe, exists in the upper part of the reservoir, where the dip is this four hundred feet per mile, that we would have a gravity drainage rate on the

order of seven to eight hundred barrels per day, per linear mile. Now, it just happens that in the part of the reservoir where the dip is only two hundred feet per mile, we have ten to twelve Darcie feet, and we can also estimate that by taking the value which it shows for a dip of four hundred feet per mile and dividing by two, and we arrive at the same general order of magnitude of eight hundred to a thousand barrels per day per linear mile, is the gravity drainage ability of part of the reservoir where the dip is only two hundred feet per mile.

Q Then, to conclude from that, it's your opinion that quite by coincidence of nature, that the inverse relationship of transmissibility in proportion to the reservoir, as respects the change in dip of one compensation to the other, and you have about the same gravity drainage rate through the down dip portion of the reservoir?

A That's true.

Q Moving on to Figure 6, would you briefly discuss it?

A I would like to add just a little bit about this gravity drainage rate. These are the maximum gravity drainage rates available. There are factors which can cause the gravity drainage rate to be somewhat less than this, but

there is probably nothing that can increase it, so we can view the figures, or the amounts calculated from this figure, to be the very maximum.

Now, particularly under pressure maintenance, the relative permeability characteristics enter into the time at which the gas front reaches any particular point in the reservoir, and the stage of depletion of are behind it. Our calculations indicate that if we produce under pressure maintenance of the rate approximately three-fourths of that indicated here, that we will have a very efficient movement of gas down dip.

The gas front will not be seriously ahead of the main ultimate recovery from the reservoir. In other words, when the gas front reaches some particular point, the recovery of oil behind that point could be as much as eighty percent of the ultimate recovery from that portion of the reservoir.

Q As this gas front proceeds down dip, you will progressively shut in the wells that are intersected by this movement of the gas front, will you not?

A This is true, and, as a matter of fact, we have shifted most of our production to the down dip wells already. And, actually, we are using up dip wells more as observation wells. There is really no benefit in distributing the

production over the wells. Any wells that can produce at the gravity drainage rate is below the gas oil contact,and is a suitable well to recovery oil.

Q You have already shut in one well, which you consider to have been by-passed by the gas mileage?

A Yes, sir.

Q Now, then, to conclude this testimony with respect to gravity drainage, would you move to Figure 10 of the same section under Figures of Exhibit 2?

A Yes, sir. This shows, Figure 10 shows our estimate of the approximate time which would be required to produce a section of the reservoir which is one mile in width along the strike, four miles in length along the dip, which approximates the conditions in the west part of Chiquita for the conditions of transmissibility, and oil in place, which we found in this reservoir.

If the reservoir were produced at its gravity drainage rate, without gas injection, without pressure maintenance, its gravity drainage rate would decrease with time as the pressure drops, and the viscosity of the oil increases as free gas evolves and moves to the gas cap. There will be a restriction, of course, to the oil movement, and will cause the rates to drop somewhat. We would estimate that the field could be depleted in about thirteen years by adhering

strictly to gravity drainage rates available.

Q Would you consider this period of time to be within economic time, from the operator's standpoint?

A Yes, sir. This is a reasonable length of time in which produced the pool, and it would not be costly, would not be too costly, to restrict the production to this rate, providing, of course, there are not too many wells.

Q If we were to compare this with a hypothetical pool, with a sand, rather than a fractured shale, and other characteristics being identical, would this same comment carry forward?

A No, sir. There are really very few pools in which the gravity drainage mechanism can be utilized to its maximum efficiency, which you can use here in the west part of the Chiquita. And, of course, the reason for it is that as we indicated in 1966 hearing for the transmissibilities, which are exhibited by fractured reservoir, if we compare transmissibilities of those magnitudes with transmissibilities of sand reservoirs of about the same magnitude, we would expect the sand reservoir to contain from ten to fifty times as much oil in place, per acre.

Q How would this affect the economic time with which to recover that oil, through strictly gravity drainage rates?

A For example, if we had a sand pool, with, say, a

hundred millidarcies permeability, and the same transmissibility as we have here, we would have fifty feet of sand thickness, and we would have roughly fifty times as much oil in place. This means, again, as we discussed it a little earlier, the gravity drainage rate, however, despite the fact that there was fifty times as much oil in place, the gravity drainage rate in terms of barrels per day per linear mile would be the same as we have here.

This means, then, to deplete such a pool by gravity drainage would require fifty times as long, or approximately seven hundred years to produce a sand pool the same physical dimensions of this one, same transmissibility, if it were a sand, rather than the fractured shale.

Q Is this the reason why gravity drainage has not been considered as an effective economic method, or mechanism in most pools throughout the country and the world?

A This is true. There are very few pools which have been utilized to its maximum efficiency.

Q Moving, then, to Figure 11, Mr. Greer. Would you briefly outline the significance of this exhibit?

A Yes, sir. Figure 11 shows the detriment to ultimate recovery which will result if the wells are drilled to a density greater than two hundred twenty acres per well. And

wells are produced at rates which will give income permitting them to retire their cost within a reasonable length of time.

We can see, for example, that under eighty-acre spacing, the second line at the bottom of the graph, there would be thirty-two wells per linear mile along the strike of a reservoir section, which is one mile wide and four miles down the dip. To produce at an economic rate, the first rate which we find, moving horizontally to the right across the schedule, would be one hundred twenty barrels per day, which for these thirty-two wells, if they move up from that point on the graph, we find to be thirty-eight hundred barrels per day total production. Thirty-eight hundred barrels per day per linear mile along the strike, and for that production rate, we would estimate an ultimate recovery of about seven percent of oil in place.

Q In that particular situation, there would be virtually no effect -- beneficial effect -- to solution gas?

A This is true. For eighty-acre spacing, or anything greater than that is, for instance, forty acres. Now, if we restrict a number of wells, one well to three hundred twenty acres, we find, moving across, horizontally, to one hundred twenty barrels per day production rate, which would then be nine hundred sixty barrels per day total. We might realize an ultimate recovery of forty percent of oil in place.

To reach the maximum, sixty-five percent of oil, sixty-five percent of oil in place, we would have to have density of approximately one well to six hundred forty acres. As indicated on this graph, at which we are producing six hundred forty barrels per day per linear mile, along the strike, and of course, if we have a well spacing of one well to three hundred twenty acres, it's probable that our actual average drill in density of the pool would not exceed one well to six hundred forty acres.

Q Do you have any further comments with respect to this?

A No, sir.

Q Directing your attention, then, Mr. Greer, to Exhibit 3. Would you explain the economic effect upon the royalty owners of the leases in this area of the west part of the Chiquita-Mancos Oil Pool, as a result of various types of well density?

A Yes, sir. This schedule shows for various well densities in the left-hand column, the ultimate recovery in terms of percent of oil in place, which we just reviewed, from a previous graph. The total ultimate recovery, then, in terms of thousands of barrels for a sixteen square mile productive tract of the reservoir, which is four miles long, the strike, and four miles down dip.

The assumption is made in preparation of this Exhibit 3, of course, that if the wells are drilled to the density shown, they would be produced at rates which would return their cost within a reasonable length of time, which is something on the order of a hundred barrels per day.

We can see, for instance, that on forty-acre spacing, New Mexico would receive in royalties and severance tax and sales tax about two hundred fifty to two thousand dollars for each sixteen-square mile tract. If, however, the pool was developed on a density of six hundred forty acres or greater, rather than receiving only two hundred fifty thousand dollars from this tract, it would receive from the same tract of land some two million, seven hundred thousand dollars.

Q Mr. Greer, you have referred numerous times in your testimony to -- with respect to this facet of the case, to a production rate which would return to the operator the cost of the well and a reasonable return of its money. What is the average cost of a well in this pool, in this particular area?

A The average cost is between a hundred seventy-five thousand to two hundred thousand dollars.

Q And would there be any reason to believe that wells drilled on forties or eighties or one hundred sixties

would cost any less?

A They might cost slightly less if the operator would use smaller sand fracture treatments. This is balanced, however, by the fact that the drilling, the cost of preparing the location, would be greatly increased because on such close density, it would be necessary to have locations on the sides of the mountains. This is in a Federal forest.

So that the overall cost would probably be the same for any density.

Q And has the Forest Service taken a position with respect to this type of dense drilling in the forest?

A Yes, sir. There is no question but drilling to densities of greater than one well of three hundred twenty acres would cause considerable destruction to the forest and would have an adverse effect on its beauty. At a previous hearing, of course, the Forest Service was represented and made this statement. From our standpoint, I can say from our point of view, that it is a beautiful forest, and we do everything we can to preserve it.

And it would be a serious tragedy to drill unnecessary wells and mar the beauty of the forest.

Q Mr. Greer, in conclusion, with respect to your testimony of the subject of utilization of the gravity drain-

age mechanism, as opposed to the solution gas drive mechanism, I take it that it is your opinion that not only will there be as much oil recovered on the three hundred twenty-acre spacing, but, based upon this information, a great deal more than would be recovered on forty-acre spacing, or anything else less than a hundred twenty?

A This is true. The fewer the wells, the greater will be the ultimate recovery.

Q Mr. Greer, do you have any recommendations with respect to the particular wording of any order the Commission might enter in this case, particular with respect to the permissibility of drilling more than one well on three hundred twenty-acres?

A Yes, sir. We feel that it is absolutely essential that no more than one well be allowed for the three hundred twenty-acre tract, and by this, we mean that we should not permit, say, two wells to be drilled on a half section, and each well receive a reduced allowable.

It is essential that only one well be drilled on each half section. In this case, following Case Number 3455 in 1966, in the order which was issued, it is necessary to have correspondence with the Commission regarding strict interpretation of this particular provision.

Q Is that Order R-2565-B?

A Yes, sir. So, accordingly, we would suggest language changes which we have shown on Exhibit 4 to clarify this particular point.

Q Briefly, that is simply to refer to these three hundred twenty-acre units as spacing units and make it clear that not more than one well could be drilled on each unit?

A Yes, sir. And in the event a proration unit of less than three hundred twenty acres is established, it would be necessary to have a notice and hearing before such could be done.

Q Do you have anything further to add in this case?

A No, sir.

Q No further questions. We move for the admission of -- Mr. Greer, are these exhibits, with the exception of Exhibit 4, prepared by you or under your supervision?

A Yes, sir.

Q And Exhibit 4, are the alterations and changes in R-2565-B your suggestions with respect to this order?

A Yes, sir.

MR. COOLEY: We move for the admission of Exhibits 1, 2, 3, and 4.

MR. NUTTER: Applicant's Exhibits 1 through 4 will be admitted into evidence.

MR. COOLEY: That's all our questions, Mr. Examiner.

(Whereupon, Applicant's Exhibits 1 through 4 were admitted into evidence.)

CROSS EXAMINATION

BY MR. NUTTER:

Q Mr. Greer, just briefly, to summarize your testimony, I think, if you turn to Section D of the Exhibit 1, we have a long pull-out there. Now, we have fluid levels depicted here for well Number A-23, and the fluid levels are continually and constantly down in the well --

A Yes, sir.

Q As the wells in the pool are being produced?

A Yes, sir.

Q Until here in mid-July, we suddenly have a leveling off of the fluid levels in Well Number A-23.

A Yes, sir.

Q And this was at the time that well Number E-10 was drilled and fracted; is this correct?

A Yes, sir. The well was fracted on July 19.

Q And that's just about the exact date that that the fluid level declined, leveled off?

A Yes, sir. Perhaps --

Q Then, the fluid levels remained rather constant for a period of maybe two or three weeks, then, they started declining again. And referring to the bottom part of the

Exhibit 2, it would appear that that's when Well Number E-10 was put on production?

A This is true.

Q Now, how far is Well Number E-10 from A-23?

A Approximately two and a half miles.

Q Now, if we turn to the next pull-out, we see the fluid levels in Well Number A-23 are again declined until about the 9th of August.

A Yes, sir.

Q And what was the significance of that date?

A That's when we commenced gas injection.

Q And what well is the gas injection into, Mr. Greer?

A The gas is being injected in our K-13, which is in Section 13.

Q And how far away from Well Number 18 would that be?

A Thirty-seven hundred feet away.

Q So, the fluid levels remained rather constant in that well for maybe ten or twelve days, and then started increasing, so this would have been the effect of the gas going into the well, which is about three-fourths of a mile away?

A Yes, sir.

Q Now, the next pull-out, you had some changes in

fluid level there. Would you repeat the significance of these changes, please?

A Yes, sir. In January and February, the rising fluid level there, we believe, is primarily the result of gas moving into the well bore of the observation well and lightening the oil column. And this was proven when a pressure was measured in March -- that's 26th or 27th, I believe. This confirmed that the density of the oil had changed enough to just about make up the difference in the fluid level.

Q Well, now, Mr. Greer, is this when the gas went up the structure and started back down towards A-23?

A Yes, sir. My feeling is that as we commenced gas injection, probably a little bubble moved from the injection well to all directions for a short distance, and then, since we were producing at a rate less than the gravity drainage ability of the reservoir, then there was gravity segregation and most of the gas, I believe moved up. As a matter of fact, we have seen an occasion in our part of sub-dip well, which is now shut in in Section 18, that gas actually did move up dip to it.

At the same time, I believe the gas was spreading probably horizontally along the strike and probably down dip somewhat. And after some five or six or seven months, then,

it reached, or part of it, perhaps, through maybe a high capacity channel, or reached to this well. And I think it's possible that gas is probably moving in, fingering, in a sense, out ahead of the main gas oil contact. It's my belief that that's what happened in the observation well.

Q But do you feel that you do have gas in the observation well at this time, and it has lightened the fluid column with the subsequent rise of the fluid level?

A Yes, sir.

Q Then, to the very beginning of your testimony, Mr. Greer, I believe it was over in Section B -- yes. On your interference tests, or your decrease in pressure, converging reservoir pressure, it would appear that the pressure was down when you completed the Well Number E-10, as compared with the observation well A-23?

A Yes, sir.

Q Then, again, this is approximately two and a half miles apart?

A Yes, sir.

Q As depicted by the plat there; and then you had another test for Well Number A-22?

A Yes, sir.

Q And how far is A-22; that's about a mile away?

A Yes, sir. It's a little over a mile.

Q So these interference tests, plus these variations in the fluid levels on the observation well, when the E-10 was drilled and fracted and the gas injection was started, would all appear to indicate that you do have communication across this reservoir, at least in the range of three hundred twenty-acre spacing draining pattern?

A Yes, sir. At least.

Q Now, on this Exhibit Number 4.

A Yes, sir. I might interrupt, if I may, to say that undoubtedly the Commission and its staff could choose more appropriate language than we have here. I believe, however, what is shown on Exhibit 4 would indicate the intent that we are seeking.

Q In other words, your Rule Number Two here, you're requiring a standard spacing unit of three hundred twenty acre spacing, and you would propose that no non-standard unit would be approved without a hearing?

A Yes, sir.

MR. COOLEY: And it would be understood that not more than one well could be drilled on a spacing unit, if that needs to be made specific, then we would urgently propose that it be done. In this connection, we would request and express findings that in order to prevent waste

and assure maximum ultimate recovery from the oil from the west part of the Chiquita-Mancos Oil Pool, that not more than one well be drilled, that the pool not be drilled to a density greater than one well per three hundred twenty acres.

Q (By Mr. Nutter) As the pool is defined at the present time, by the Commission, you have the Quinata-Jitos unit which is operated by the Applicant, covering a good portion of the pool as defined, but there are some wells to the north of the Quinata-Jitos unit which are outside of the unit but in the pool. Are those operated by the Applicant?

A One of the wells -- the producing well shown in the area to which you refer is operated by the Applicant.

Q That would be the D-21?

A The D-21; yes, sir. The offsetting well colored in red, which we understand has not yet been completed, was drilled by Doug Florence, and that well and the four section tract, the lease on which it's located, is owned by other people.

Q That would be Sections 17, 18, 19, and 20?

A I believe they're Sections 19, 20, 29, and 30.

Q Oh, I see. You do operate the Quinata-Jitos; is this true?

A Yes, sir. I believe we own the rest of the acreage in the area.

Q So, for the present at least, all of the producing wells in the pool are operated by them?

A Yes, sir. As a matter of fact, we think we, in two or three months, we'll probably own these two.

Q All right. Are there any further questions of Mr. Greer? You may be excused.

Do you have anything further, Mr. Cooley?

MR. COOLEY: No, Mr. Examiner.

MR. NUTTER: Does anyone have anything they wish to offer in Case 3455, reopened?

MR. KENDRICK: Yes, I would like him to explain how he would have, on these specific provisions, have well locations while your plat in Section A here, you show Sections 25 through 30 have Township 27 North, One West, to be short sections which cannot be subdivided on an equal three hundred twenty-acre tract. Would you make some provision for those in your rules for rigid spacing patterns, please?

I suggest that this could be explained at a later date, if the Commission's staff, if this is not objectionable to the Examiner.

THE WITNESS: It was my thoughts that those tracts were primarily greater than three hundred twenty acres, and certainly, we will have no objection to a well being drilled

on a tract that has shown three hundred twenty acres allowed to it.

MR. NUTTER: Do you know what the acreage is?

THE WITNESS: Approximately four hundred is the figure that I recall. It might be, since that's probably the only place where this occurs in this pool, it might be well just to write it into the order, that we could make one spacing unit out of those partial sections.

MR. NUTTER: I doubt if that's within the call of this particular hearing, Mr. Greer. It would probably have to be taken up at a later hearing, as a separate piece.

Does that answer your question, Mr. Kendrick?

MR. KENDRICK: Yes.

MR. NUTTER: Are there further questions of Mr. Greer? You may be excused.

Do you have anything further?

MR. COOLEY: No.

MR. NUTTER: Does anyone have anything they wish to offer in Case Number 3455? If there is nothing, I'll call Case 4257.

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STATE OF NEW MEXICO))
)
COUNTY OF BERNALILLO)

I, DAVID BINGHAM, Court Reporter in and for the County of Bernalillo, State of New Mexico, do hereby certify that the foregoing and attached Transcript of Hearing before the New Mexico Oil Conservation Commission was reported by me; and that the same is a true and correct record of the said proceedings to the best of my knowledge, skill, and ability.

David Bingham
COURT REPORTER

I do hereby certify that the foregoing is a complete record of the proceedings in the Examiner hearing of Case No. 3965, heard by me on 12/69, 1969.

Examiner
New Mexico Oil Conservation Commission

RECORD OF FLUID LEVELS

INTERFERENCE TESTS

PUERTO CHIQUITO POOL

November 16, 1966

BEFORE THE
OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
Exhibit No. 7
Case No. 3455

RECORD OF FLUID LEVELS

SOUTHWEST PUERTO CHIQUITO (NIOBRARA-GREENHORN PARTICIPATING AREA:

A. CAÑADA OJITOS UNIT NO. L-11

B. CAÑADA OJITOS UNIT NO. A-14

C. CAÑADA OJITOS UNIT NO. A-23

NORTHEAST PUERTO CHIQUITO

D. JICARILLA 237 NO. P-19

E. JICARILLA 237 NO. P-20

F. PUERTO CHIQUITO UNIT NO. F-6

FLUID LEVEL MEASUREMENTS
CANADA OJITOS UNIT L-11

(1) DATE	(2) TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEV.	(5) REMARKS
1965				
June 7		1582		
9	9:00 AM	1569		
	3:45 PM	1566		
10	8:00 AM	1564		
11	7:00 AM	1561	Wallace	
12	7:00 AM	1557	Steele	
	6:00 PM	1555	"	
13	6:30 AM	1553	"	
	6:00 PM	1551	"	
14	6:30 AM	1549	"	
	2:10 PM	1548	Lee	
	6:00 PM	1547	Steele	
15	6:45 AM	1545	"	
	6:00 PM	1543	"	
16	6:30 AM	1542	"	
	7:00 PM	1541	"	
17	6:30 AM	1539	"	Changed Line
	5:30 PM	1538	"	
18	6:30 AM	1537	"	
	6:00 PM	1536	"	
19	6:45 AM	1535	"	
	3:00 PM	1535	Lee	
20	6:30 AM	1534	Steele	
	6:45 PM	1533	"	
21	6:30 AM	1532	"	
	4:00 PM	1530	"	Changed Line
22	6:30 AM	1529	"	
	6:30 PM	1527	"	
23	6:30 AM	1526	"	
	4:40 PM	1526	Lee	
	6:00 PM	1526	Steele	
24	6:30 AM	1525	Steele	
	4:40 PM	1526	Lee	Changed Block
	6:30 PM	1523	Steele	
25	6:15 AM	1522	"	
	5:30 PM	1521	"	
26	6:30 AM	1520	"	
	4:30 PM	1519	"	
27	6:45 AM	1518	"	
	5:00 PM	1518	"	
28	6:45 AM	1518	"	
	5:15 PM	1517	"	

(1)		(2)	(3)	(4)	(5)
June	29	6:30 AM	1516	Steele	
		5:45 PM	1516	Wallace	
	30	6:30 AM	1515	"	
		6:10 PM	1513	"	
July	1	6:30 AM	1513	"	
	2	6:45 AM	1513	"	
		6:10 PM	1513	"	
	3	6:30 AM	1513	"	
		5:40 PM	1511	"	
	4	7:25 AM	1510	"	
		6:00 PM	1509	"	
	5	7:30 AM	1508	"	
		5:30 PM	1508	"	
	6	6:45 AM	1507	"	
		6:35 PM	1506	"	
	7	6:30 AM	1505	"	
		6:45 PM	1505	"	
	8	7:00 AM	1505	"	
		5:00 PM	1506	Lee	After Pulling Line and running BHP
	9	7:00 AM	1504'6"	Wallace	
		5:35 PM	1504'6"	"	
	10	6:45 AM	1504	"	
		6:15 PM	1503'6"	"	
	11	6:15 AM	1503'6"	"	
		5:30 PM	1503'6"	"	
	12	6:35 AM	1502'6"	"	
		6:30 PM	1502	"	
	13	7:00 AM	1501'6"	"	
		5:20 PM	1501'6"	"	
	14	7:05 AM	1501	"	
		5:50 PM	1500'6"	"	
	15	7:10 AM	1500	"	
		6:00 PM	1499	Steele	
	16	6:15 AM	1499	"	
		6:30 PM	1498	"	
	17	6:30 AM	1498	"	
		6:00 PM	1497	"	
	18	6:30 AM	1497	"	
		5:00 PM	1496	"	
	19	7:15 AM	1496	Wallace	
		6:35 PM	1495'6"	"	
	20	7:25 AM	1495	"	
		5:45 PM	1494'6"	"	
	21	7:00 AM	1494	"	
		1:30 PM	1494	Lee	
		6:00 PM	1493	Wallace	
	22	7:05 AM	1493	"	
		5:45 PM	1493	Steele	
		5:50 PM	1493	Lee	

(1)		(2)	(3)	(4)	(5)
July	23	6:45 AM	1492	Steele	
		6:00 PM	1491	"	
	24	6:00 AM	1493	"	
		Noon	1493	Wallace	
		5:30 PM	1494	"	
	25	6:30 AM	1496	"	
		Noon	1496	"	
		6:45 PM	1496	"	
	26	10:00 AM	1494'6"	"	
		6:35 PM	1494	"	
	27	7:00 AM	1493'6"	"	
		5:40 PM	1493	"	
	28	7:05 AM	1492'6"	"	
	29	6:40 AM	1491	"	
		5:30 PM	1491	"	
	30	7:45 AM	1490	"	
		6:00 PM	1490	Steele	
	31	6:00 AM	1489	"	
		6:15 PM	1489	"	
August	1	6:45 AM	1488	Wallace	
		6:00 PM			Road Impassable
	2	6:35 AM	1488	"	
		6:00 PM	1488	"	
	3	7:35 AM	1487	"	
		6:50 PM	1487	"	
	4	7:10 AM	1486	"	
		6:10 PM	1487'6"	"	
	5	6:35 AM	1490	"	
		5:35 PM	1492	Steele	
	6	6:45 AM	1494	"	
		6:00 PM	1496	"	
	7	6:30 AM	1498	"	
		5:30 PM	1500	"	
	8	6:30 AM	1501	Wallace	
		6:10 PM	1503	"	
	9	7:10 AM	1505	"	
		6:20 PM	1506'6"	"	
	10	6:35 AM	1508	"	
		7:35 PM	1509	"	
	11	7:25 AM	1510	"	
		6:15 PM	1512	"	
	12	6:15 AM	1512	"	
		6:05 PM	1513	Steele	
	13	6:45 AM	1514	"	
		5:45 PM	1515	"	
	14	6:00 AM	1515	"	
		5:45 AM	1516	"	
	15	6:00 AM	1516'6"	Wallace	
		5:55 PM	1518	"	
	16	7:25 AM	1519	"	
		6:15 PM	1520	"	
	17	7:25 AM	1521	"	

(1)		(2)	(3)	(4)	(5)
August	17	6:25 PM	1521'6"	Wallace	
	18	7:30 AM	1522	"	
		6:30 PM	1522	"	
	19	6:15 AM	1523		
		6:34 PM	1523	Steele	
	20	6:45 AM	1524	"	
		6:30 PM	1525	"	
	21	6:15 AM	1525	"	
		5:30 PM	1526	"	
	22	6:20 AM	1526		
		5:55 PM	1527	Wallace	
	23	7:10 AM	1528	"	
		6:20 PM	1529	"	
	24	7:25 AM	1530	"	
		8:25 PM	1531	"	
	25	7:15 AM	1531	"	
		6:20 PM	1533	"	
	26	7:40 AM	1533		
		6:45 PM	1533	Steele	
	27	6:15 AM	1533	"	
		5:45 PM	1533	"	
	28	6:45 AM	1534	"	
		6:10 AM	1534'6"	"	
	29	7:00 AM	1535		
		5:50 PM	1535'6"	Wallace	
	30	7:05 AM	1536	"	
		5:45 PM	1536	"	
	31	6:45 AM	1537	"	
		5:00 PM	1537'6"	"	
Sept.	1	7:25 AM	1538		Wellhead off
		PM			
	2	8:45 AM	1538'6"	"	

FLUID LEVEL MEASUREMENTS
CANADA CJITOS UNIT A-14

(1) DATE		(2) TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEV.	(5) REMARKS
1965					
April	15	3:45 PM	1690		
	16	7:00 AM	1637		
	17	7:00 AM	1636		
		6:00 PM	1635		
	18	7:00 AM	1635		
		6:00 PM	1636		
	19	7:00 AM	1636		Bailing
		7:00 PM	1635		Bailing
	20	7:00 AM	1634		Bailing
		6:00 PM	1639		
	21	7:00 AM	1633		
		5:00 PM	1658		Bailing
	22	7:00 AM	1633		Pressured up with Butane 12#
	23	7:00 AM	1628		
		11:15 AM	1629		
		12:15 PM	1637		
		12:45 PM	1643		
		1:00 PM	1645		
		1:30 PM	1648		
		2:00 PM	1650		
		2:30 PM	1653		
		3:00 PM	1655		Released Pressure
		4:00 PM	1659		
		5:30 PM	1649		
		6:00 PM	1646		
		6:15 PM	1644		
	24	7:00 AM	1628		
		6:00 PM	1625		
	25	7:00 AM	1625		
		6:30 PM	1625		
	26	7:30 AM	1624	Wallace	
		4:00 PM	1621	Lee	
	27	7:30 AM	1624	Steele	
		6:30 PM	1619	"	
	28	7:00 AM	1615	"	
		6:30 PM	1611	"	
	29	7:00 AM	1607	"	
		5:00 PM	1605	"	
	30	7:00 AM	1603	"	
		5:00 PM	1600	"	

(1)		(2)	(3)	(4)	(5)
May	1	7:00 AM	1597	Steele	
		5:30 PM	1595	"	
	2	7:00 AM	1593		
		5:30 PM	1591	Wallace	
	3	7:00 AM	1589	"	
		5:30 PM	1587	"	
	4	7:00 AM	1586	"	
		6:30 PM	1584	"	
	5	7:00 AM	1581		
		6:00 PM	1583	Lee	
	6	7:30 AM	1581	Wallace	
		7:00 PM	1582	Steele	
	7	7:00 AM	1583	"	
		4:00 PM	1584	"	
	8	7:30 AM	1585		
		7:00 PM	1585	Wallace	
	9	7:00 AM	1585	"	
		5:30 PM	1585	"	
	10	7:00 AM	1584	"	
		5:30 PM	1585	"	
	11	7:00 AM	1585	"	
		5:30 PM	1585	"	
	12	7:15 AM	1585	"	
	13	6:30 AM	1586		
	14	7:00 AM	1586	Steele	
	15	8:00 AM	1586	"	
	16	6:30 AM	1587	Wallace	
		5:00 PM	1587	"	
	17	7:00 AM	1587		
	20	6:00 PM	1585	Lee	
	21	7:00 AM	1584	Steele	
	22	9:00 AM	1584	Lee	
		4:00 PM	1584	Lee	
	23	7:30 AM	1585	Wallace	
		6:15 PM	1585	"	
	24	7:35 AM	1585	"	
		5:30 PM	1586	"	
	25	7:00 AM	1587		
		9:00 AM	1588	Lee	
		7:00 PM	1587	Wallace	
	26	6:30 AM	1588	"	
		5:45 PM	1588		
	27	7:00 AM	1590	Steele	
	28	7:00 AM	1589	"	
		4:00 PM	1589	Lee	
	29	7:00 AM	1590	Steele	
	30	7:00 PM	1591	"	
	31	7:00 AM	1592	Wallace	
		8:30 AM	1593	Lee	
		7:00 PM	1592	Wallace	
June	1	6:45 AM	1593	"	
		8:00 AM	1594	Lee	
		6:15 PM	1593	Wallace	

(1)		(2)	(3)	(4) (5)
May	1	7:00 AM	1597	Steele
		5:30 PM	1595	"
	2	7:00 AM	1593	
		5:30 PM	1591	Wallace
	3	7:00 AM	1589	"
		5:30 PM	1587	"
	4	7:00 AM	1586	"
		6:30 PM	1584	"
	5	7:00 AM	1581	
		6:00 PM	1583	Lee
	6	7:30 AM	1581	Wallace
		7:00 PM	1582	Steele
	7	7:00 AM	1583	"
		4:00 PM	1584	"
	8	7:30 AM	1585	
		7:00 PM	1585	Wallace
	9	7:00 AM	1585	"
		5:30 PM	1585	"
	10	7:00 AM	1584	"
		5:30 PM	1585	"
	11	7:00 AM	1585	"
		5:30 PM	1585	"
	12	7:15 AM	1585	"
	13	6:30 AM	1586	
	14	7:00 AM	1586	Steele
	15	8:00 AM	1586	"
	16	6:30 AM	1587	Wallace
		5:00 PM	1587	"
	17	7:00 AM	1587	
	20	6:00 PM	1585	Lee
	21	7:00 AM	1584	Steele
	22	9:00 AM	1584	Lee
		4:00 PM	1584	Lee
	23	7:30 AM	1585	Wallace
		6:15 PM	1585	"
	24	7:35 AM	1585	"
		5:30 PM	1586	"
	25	7:00 AM	1587	
		9:00 AM	1588	Lee
		7:00 PM	1587	Wallace
	26	6:30 AM	1588	"
		5:45 PM	1588	
	27	7:00 AM	1590	Steele
	28	7:00 AM	1589	"
		4:00 PM	1589	Lee
	29	7:00 AM	1590	Steele
	30	7:00 PM	1591	"
	31	7:00 AM	1592	Wallace
		8:30 AM	1593	Lee
		7:00 PM	1592	Wallace
June	1	6:45 AM	1593	"
		8:00 AM	1594	Lee
		6:15 PM	1593	Wallace

(1)		(2)	(3)	(4)	(5)
June	2	8:00 AM	1594	Wallace	
		6:15 PM	1594	"	
	3	7:45 AM	1595		
		7:00 PM	1596	Steele	
	4	7:30 AM	1596	Lee	
	5	7:00 AM	1596	Steele	
	6	7:30 AM	1597		
		5:30 PM	1597	Wallace	
	7	7:15 PM	1598	"	
		5:45 PM	1598	"	
	9	8:00 AM	1595	"	
		3:45 PM	1593	"	
	10	8:00 AM	1589	"	
	11	6:45 AM	1586		
	12	7:00 AM	1581	Steele	
		6:00 PM	1579	"	
	13	6:45 AM	1577	"	
		6:00 PM	1575	"	
	14	6:45 AM	1572		
		2:00 PM	1570	Lee	
		6:00 PM	1570	Steele	
	15	6:30 AM	1568	"	
		6:00 PM	1566	"	
	16	6:45 AM	1565	"	Changed Line
	17	5:30 PM	1556		
	18	6:45 AM	1555	Steele	
		.30 PM	1552	"	Changed Line
	19	6:45 AM	1554		
		3:00 PM	1553	Lee	
	20	6:45 AM	1552	Steele	
		6:30 PM	1551	"	
	21	6:30 AM	1550		Changed Line
		4:30 PM	1549=1548 (old)(new)		
	22	6:45 AM	1546	Steele	
		6:30 PM	1545	"	
	23	6:45 AM	1544		
		4:00 PM	1542	Lee	
		6:15 PM	1543	Steele	
	24	6:45 AM	1542		
		4:50 PM	1542	Lee	
		6:30 PM	1541	Steele	
	25	6:30 AM	1540	"	
		4:00 PM	1539	"	
	26	6:30 AM	1538	"	
		4:00 PM	1537	"	
	27	6:30 AM	1536	"	
		5:15 PM	1535	"	
	28	6:30 AM	1534	"	
		6:00 PM	1533	"	
	29	6:30 AM	1532		
		6:00 PM	1532	Wallace	
	30	6:15 AM	1532	"	

(1)		(2)	(3)	(4)	(5)
June	30	6:15 PM	1529	Steele	
July	1	6:30 AM	1530	Wallace	
		6:25 PM	1529	"	
	2	7:00 AM	1528	"	
		6:25 PM	1429	"	
	3	6:10 AM	1528	"	
		5:50 PM	1528	"	
	4	7:15 AM	1527	"	
		6:15 PM	1526	"	
	5	7:00 AM	1525	"	
		6:00 PM	1523'6"	"	
	6	6:30 AM	1522	"	
		6:25 PM	1521	"	
	7	6:00 AM	1520	"	
		6:30 PM	1519'6"	"	
	8	6:40 AM	1519'6"	"	
		7:15 PM	1519	Lee	Pulled line and ran BHP
	9	7:15 AM	1518'6"	Wallace	
		5:20 PM	1518	"	
	10	6:30 AM	1518	"	
		5:30 PM	1517'6"	"	
	11	6:40 AM	1517	"	
		5:15 PM	1516'6"	"	
	12	6:30 AM	1516	"	
		6:15 PM	1515'6"	"	
	13	6:30 AM	1515'6"	"	
		5:10 PM	1515	"	
	14	6:50 AM	1514	"	
		5:40 PM	1513	"	
	15	7:00 AM	1513	"	
		6:00 PM	1512	Steele	
	16	6:30 AM	1512	"	
		6:15 PM	1511	"	
	17	6:15 AM	1510	"	
		6:15 PM	1510	"	
	18	6:45 AM	1509	"	
		5:15 PM	1508	"	
	19	7:10 AM	1508	Wallace	
		6:30 PM	1508	"	
	20	7:20 AM	1507'6"	"	
		6:45 PM	1507	"	
	21	6:45 AM	1506'6"	"	
		1:35 PM	1506	Lee	
		6:15 PM	1506	Wallace	
	22	6:55 AM	1505'6"	"	
		5:45 PM	1505	Steele	
		6:00 PM	1505	Lee	
	23	6:30 AM	1505	Steele	
		6:00 PM	1504	"	
	24	6:15 AM	1505		
		Noon	1505	Wallace	

(1)	(2)	(3)	(4)	(5)
July 24	6:25 PM	1505	Wallace	
25	7:30 AM	1506	"	
	Noon	1507	"	
	6:00 PM			High water in wash. Location inaccessible
26	6:20 PM	1506	Wallace	
27	6:40 AM	1505'6"	"	
	6:50 PM	1505	"	
28	6:55 AM	1504	"	
29	6:00 AM	1503'6"	"	
	5:50 PM	1502'6"	"	
30	7:00 AM	1501	"	
	6:15 PM	1501	Steele	
31	6:00 AM	1500	"	
	6:15 PM	1500	"	
August 1	6:45 AM	1499	Wallace	
	6:00 PM			Road Impassable
2	5:30 AM	1498	"	
	5:45 PM	1498	"	
3	7:15 AM	1497	"	
	6:40 PM	1497	"	
4	7:30 AM	1496'5"	"	
	6:00 PM	1497	"	
5	6:45 AM	1501	"	
	5:30 PM	1502	Steele	
6	7:00 AM	1504	"	
	5:45 PM	1506	"	
7	6:30 AM	1508	"	
	5:15 PM	1510	"	
8	6:30 AM	1512	Wallace	
	5:45 PM	1514	"	
9	7:30 AM	1516	"	
	5:50 PM	1517'6"	"	
10	6:45 AM	1519	"	
	6:40 PM	1521	"	
11	6:50 AM	1522	"	
	5:50 PM	1523	"	
12	7:00 AM	1524'6"	"	
	6:30 PM	1525	Steele	
13	7:00 AM	1526	"	
	6:10 PM	1527	"	
14	6:30 AM	1528	"	
	6:15 PM	1529	"	
15	6:15 AM	1530	Wallace	
	5:45 PM	1531'6"	"	
16	6:55 AM	1532	"	
	5:50 PM	1533	"	
17	6:55 AM	1533'6"	"	
	6:50 PM	1535	"	
18	6:55 AM	1536	"	
	6:35 PM	1537	"	
19	6:25 AM	1538	"	
	7:00 PM	1539	Steele	

(1)		(2)	(3)	(4)	(5)
August	20	7:00 AM	1539	Steele	
		6:45 PM	1540	"	
	21	6:45 AM	1540	"	
		4:45 PM	1541	"	
	22	6:10 AM	1541	"	
		6:20 PM	1542	Wallace	
	23	6:20 AM	1543	"	
		5:55 PM	1544	"	
	24	7:15 AM	1545	"	
		8:55 PM	1546	"	
	25	7:45 AM	1546'6"	"	
		6:55 PM	1546	"	
	26	8:05 AM	1546'6"	"	
		6:25 PM	1546	Steele	
	27	6:15 AM	1546	"	
		6:00 PM	1547	"	
	28	6:45 AM	1548	"	
		6:45 PM	1548	"	
	29	7:20 AM	1549	"	
		6:30 PM	1550	Wallace	
	30	7:15 AM	1551	"	
		6:10 PM	1551	"	
	31	6:55 AM	1551'6"	"	
		5:45 PM	1552	"	
Sept.	1	7:35 AM	1552'6"	"	
		6:10 PM	1553	"	
	2	6:45 AM	1553'6"	"	
		5:50 PM	1554	Steele	
	3	6:15 AM	1554	"	
		7:15 PM	1553	"	
	4	6:45 AM	1555	"	
		6:15 PM	1558	"	
	5	7:00 AM	1563	"	
		6:25 PM	1566	Wallace	
	6	7:15 AM	1570	"	
		6:30 PM	1573'6"	"	
	7	6:55 AM	1574'6"	"	
		5:40 PM	1573'6"	"	
	8	7:10 AM	1572'6"	"	
		5:50 PM	1572	"	
	9	7:15 AM	1572	"	
		6:15 PM	1573	"	
	10	6:30 AM	1572	Steele	
		6:00 PM	1572	"	
	11	6:45 AM	1571	"	
		5:30 PM	1572	"	
	12	7:15 AM	1572	"	
		5:15 PM	1572	Wallace	
	13	6:25 AM	1572	"	
		6:35 PM	1572	"	
	14	7:30 AM	1572'6"	"	
		5:00 PM	1572'6"	Greer & Stoabs	
	15	6:45 AM	1572	Wallace	
		11:55 AM	1571'6"	"	

(1)		(2)	(3)	(4)	(5)
Sept.	15	6:10 PM	1571'6"	Wallace	
	16	7:20 AM	1571'6"	"	
		12:10 PM	1571'6"	"	
		5:10 PM	1571'6"	"	
	17	7:10 AM	1571'6"	Steele	
		12:00 Noon	1571'6"	"	
		5:40 PM	1572	"	
	18	7:15 AM	1572	"	
		6:10 PM	1572	"	
	19	6:20 AM	1572	"	
		5:40 PM	1572	Wallace	
	20				Roads impassable -Rain
	21				Freezing Counter Readings unreliable
	22				" "
		12:00 Noon			Pulled block - found counter 5' of
		6:15 PM	1573	Wallace	
	23	6:50 AM	1573	Steele	
		5:45 PM	1573	"	
	24	6:50 AM	1573	"	
		6:20 PM	1574	"	
	25	6:50 AM	1578	"	
		5:20 PM	1581	"	
	26	7:40 AM	1584	"	
		5:45 PM	1586	Wallace	
	27	7:20 AM	1589	"	
		6:10 PM	1591	"	
	28	6:50 PM	1593	"	
		6:10 PM	1595	"	
	29	7:40 AM	1597	"	
		6:10 PM	1598	"	
	30	7:10 AM	1600	"	
		5:10 PM	1602	Steele	
October	1	6:45 AM	1604	"	
		5:45 PM	1606	"	
	2	7:45 AM	1608	"	
		6:15 PM	1608	"	
	3	7:15 AM	1609	"	
		6:20 PM	1610	Wallace	
	4	6:35 AM	1612	"	
		6:15 PM	1613	"	
	5	6:50 AM	1614	"	
		6:20 PM	1615	"	
	6	7:00 AM	1615'6"	"	
		5:10 PM	1616'6"	"	
	7	7:10 AM	1617	Steele	
		5;20 PM	1618	"	
	8	6:30 AM	1619	"	
		6:00 PM	1620	"	
	9	6:50 AM	1621	"	
		5:40 PM	1622	"	

(1)	(2)	(3)	(4)	(5)
October 10	6:50 AM	1623	Steele	
	12:45 PM	1624	Wallace	
	5:45 PM	1624'6"	"	
11	6:55 AM	1625	"	
	2:30 PM	1625'6"	"	
	6:30 PM	1626	"	
12	6:50 AM	1626'6"	"	
	6:00 PM	1627	"	
13	6:55 AM	1628	"	
	6:05 PM	1629	"	
14	7:00 AM	1630	"	Re-set 2' difference
	6:30 PM	1630		
15	7:05 AM	1630	Steele	
	5:30 PM	1631	"	
16	6:30 AM	1631'6"	"	
	5:30 PM	1632	"	
17	6:30 AM	1632		
	5:35 PM	1632'6"	Wallace	
18	7:45 AM	1634	"	
	5:10 PM	1635	"	
19	6:55 AM	1636	"	
	5:15 PM	1637	"	
20	6:55 AM	1638	"	
	5:50 PM	1639	"	
21	7:25 AM	1640		
	6:05 PM	1641	Steele	
22	7:15 AM	1641	"	
	6:00 PM	1641	"	
23	7:15 AM	1642	"	
	5:35 PM	1643	"	
24	7:25 AM	1644		
	4:50 PM	1645	Wallace	
25	7:25 AM	1646	"	
	5:25 PM	1646'6"	"	
26	6:55 AM	1647	"	
	5:10 PM	1648	"	
27	7:15 AM	1648'6"	"	
	5:10 PM	1649'6"	"	
28	6:55 AM	1650		
	5:15 PM	1650'6"	Steele	
29	7:15 AM	1651	"	
	7:10 AM	1652	"	
30	7:10 AM	1652	"	
	5:40 PM	1652'6"	"	
31	7:45 AM	1653		
	5:10 PM	1654	Wallace	
Nov. 1	7:10 AM	1654	"	
	5:20 PM	1655	"	
2	7:20 AM	1656	"	
	5:10 PM	1657	"	
3	7:10 AM	1657'6"	"	
	5:10 PM	1658	"	
4	7:10 AM	1658'6"	"	
	5:10 PM	1659	Steele	
5	8:15 AM	1659'6"	"	

(1)	(2)	(3)	(4)	(5)
November	5 5:00 PM	1659'6"	Steele	
	6 7:15 AM	1660	"	
	5:30 PM	1660	"	
	7 7:20 AM	1661		
	5:10 PM	1662	Wallace	
	8 7:15 AM	1662'6"	"	
	3:00 PM	1663'6"	"	

FLUID LEVEL MEASUREMENTS
CANADA OJITOS UNIT A-23

(1) DATE	(2) TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEV.	(5) REMARKS
1965				
June 17	7:15 AM	1575	Steele	
	3:00 PM	1546	"	Ran BHP
	6:00 PM	1543	"	
18	7:00 AM	1533		
	2:45 PM	1531	Lee	
19	6:45 AM	1529	Steele	
	3:20 PM	1528	Lee	
20	6:45 AM	1527	Steele	
	6:30 PM	1526	"	
21	6:45 AM	1525	"	
	4:30 PM	1524	"	
22	6:45 AM	1522	"	
	6:30 PM	1521	"	
23	6:45 AM	1521		
	4:55 PM	1520	Lee	
	6:00 PM	1520	Steele	
24	6:45 AM	1519	"	
	4:55 PM	1520	Lee	
	6:45 PM	1518	Steele	
25	6:45 AM	1517	"	
	4:30 PM	1517	"	
26	6:45 AM	1516	"	
	5:00 PM	1515	"	
27	6:45 AM	1514	"	
	5:15 PM	1513	"	
28	6:45 AM	1513	"	
	5:30 PM	1513	"	
29	6:45 AM	1513	"	
	6:00 PM	1512	Wallace	
30	6:45 AM	1512	"	
	6:05 PM	1512	"	
July 1	6:45 AM	1512	"	
	6:15 PM	1510	"	
2	7:10 AM	1509	"	
	6:20 PM	1509	"	
3	6:30 AM	1509	"	
	6:00 PM	1508	"	
4	7:00 AM	1508	"	
	6:25 PM	1507	"	
5	7:30 AM	1505'6"	"	
	6:05 PM	1502'6"	"	
6	7:00 AM	1502		

(1)		(2)	(3)	(4)	(5)
July	6	6:15 PM	1501	Wallace	
	7	6:40 AM	1500'6"	"	
		6:40 PM	1499'6"	"	
	8	7:25 AM	1499'6"	"	
		8:20 PM	1498	Lee	After pulling line and running BHP
	9	7:00 AM	1497'6"	Wallace	
		5:50 PM	1497	"	
	10	7:10 AM	1497	"	
		5:30 PM	1496'6"	"	
	11	7:40 AM	1495'6"	"	
		5:00 PM	1495'6"	"	
	12	6:15 AM	1495'6"	"	
		6:00 PM	1494'6"	"	
	13	6:30 AM	1494	"	
		5:00 PM	1493'6"	"	
	14	6:40 AM	1493	"	
		6:10 PM	1492'6"	"	
	15	6:50 AM	1492'	"	
		6:30 PM	1491	Steele	
	16	6:30 AM	1491	"	
		6:30 PM	1490	"	
	17	6:30 AM	1489	"	
		6:30 PM	1489	"	
	18	6:45 AM	1488	"	
		5:25 PM	1487	"	
	19	7:00 AM	1487	Wallace	
		6:50 PM	1487	"	
	20	7:00 AM	1486	"	
		6:45 PM	1486	"	
	21	6:30 AM	1485	"	
		1:40 PM	1484	Lee	
		6:10 PM	1484'6"	Wallace	
	22	6:45 AM	1484	"	
		5:30 PM	1483	Steele	
		6:10 PM	1483	Lee	
	23	6:30 AM	1483	Steele	
		5:30 PM	1483	"	
	24	6:15 AM	1483	"	
		12:00 Noon	1483	Wallace	
		6:15 PM	1483	"	
	25	7:30 AM	1483	"	
		Noon	1483	"	
		6:30 PM	1483	"	Roads Impassable
	26	6:00 PM	1482'6"	"	
	27	6:30 AM	1482	"	
		6:00 PM	1481'6"	"	
	28	6:45 AM	1481	"	Road Washed out
	29	6:00 PM	1479'6"	"	

(1)		(2)	(3)	(4)	(5)
July	30	6:50 AM	1479	Wallace	
		6:30 PM	1478	Steele	
	31	6:30 AM	1478	"	
		6:00 PM	1477		
August	1	6:30 AM	1477	Wallace	Road Impassable
		6:00 PM			
	2	5:30 AM	1476	Wallace	
		6:15 PM	1476	"	
	3	7:00 AM	1476	"	
		6:30 PM	1475'6"	"	
	4	7:30 AM	1475	"	
		6:30 PM	1475'6"	"	
	5	6:50 AM	1476		
		5:30 PM	1476	Steele	
	6	7:00 AM	1477	"	
		6:15 PM	1477'6"	"	
	7	6:45 AM	1478	"	
		6:15 PM	1478		
	8	6:45 AM	1479	Wallace	
		6:25 PM	1479	"	
	9	7:35 AM	1478'6"	"	
		6:35 PM	1479'6"	"	
	10	7:05 AM	1480	"	
		6:50 PM	1480'6"	"	
	11	7:40 AM	1481	"	
		6:00 PM	1481	"	
	12	7:10 AM	1481"6"	"	
		6:35 PM	1482	Steele	
	13	6:05 AM	1482	"	
		6:15 PM	1483	"	
	14	6:45 AM	1483	"	
		6:20 PM	1484		
	15	6:45 AM	1484	Wallace	
		5:50 PM	1485	"	
	16	6:45 AM	1485'6"	"	
		5:40 PM	1486	"	
	17	6:45 AM	1487	"	
		6:00 PM	1487	"	
	18	6:45 AM	1487'6"	"	
		6:45 PM	1488	"	
	19	6:30 AM	1488'6"		
		7:10 PM	1489	Steele	
	20	7:15 AM	1489	"	
		7:00 PM	1490	"	
	21	6:45 AM	1490	"	
		6:00 PM	1491	"	
	22	6:00 AM	1492		
		6:25 PM	1492	Wallace	
	23	7:30 AM	1492'6"	"	
		6:35 PM	1493		

(1)	(2)	(3)	(4)	(5)
August 24	7:05 AM	1494	Wallace	
	8:50 PM	1494'6"	"	
25	7:50 AM	1495	"	
26	8:20 AM	1496	"	
	6:20 PM	1496	"	
27	6:00 AM	1496	Steele	
	6:15 AM	1497	"	
28	6:30 AM	1497	"	
	6:20 PM	1498	"	
29	6:45 AM	1498	"	
	6:30 PM	1498'6"	Wallace	
30	7:25 AM	1499	"	
	6:00 PM	1499'6"	"	
31	AM			No reading- wire line unit on Bolack #2
	5:35 PM	1500	Wallace	
Sept 1	7:45 AM	1500'6"	"	
	6:20 PM	1501	"	
2	6:35 AM	1501	"	
	5:30 PM	1501	Steele	
3	6:45 AM	1501	"	
	7:30 PM	1501	"	
4	6:45 AM	1503	"	
	6:20 PM	1504	"	
5	7:00 AM	1505	"	
	6:35 PM	1506	Wallace	
6	7:25 AM	1507	"	
	6:45 PM	1508	"	
7	6:45 AM	1509	"	
	5:50 PM	1510	"	
8	7:20 AM	1510	"	
	PM			Road Impassable- Rain
9	7:25 AM	1512	Wallace	
	6:30 PM	1512	"	
10	6:45 AM	1513	Steele	
	5:45 PM	1513	"	
11	7:00 AM	1514	"	
	5:45 PM	1514'6"	"	
12	7:35 AM	1515	Steele	
	5:35 PM	1516	Wallace	
13	7:45 AM	1516'6"	"	
	5:30 PM	1517	"	
14	7:40 AM	1517'6"	"	
15	7:20 AM	1517	Wallace	
	11:45 AM	1517	"	
	6:20 PM	1517'6"	"	
16	7:30 AM	1518	"	
	11:45 AM	1518	"	
	5:20 PM	1518	"	
17	7:15 AM	1518	Steele	

(1)		(2)	(3)	(4)	(5)
Sept	17	11:45 AM	1518	Steele	
		5:30 PM	1518	"	
	18	6:45 AM	1518	"	
		6:20 PM	1518	"	
	19	6:15 AM	1518'6"	"	
		5:20 PM	1518	Wallace	Counter Frozen
					Reading No Good
	20				" "
	21				" "
	22	7:40 AM	1518	Wallace	
		6:20 PM	1518	"	
	23	6:45 AM	1518	Steele	
		5:30 PM	1519	"	
	24	6:45 AM	1519	"	
		6:15 PM	1520	"	
	25	6:45 AM	1521	"	
		5:15 PM	1522	"	
	26	7:15 AM	1524		
		5:50 PM	1524	Wallace	
	27	7:30 AM	1525	"	
		6:15 PM	1525'6"	"	
	28	6:40 AM	1526		"
		6:15 PM	1527	Wallace	
	29	7:45 AM	1528	"	
		6:15 PM	1530	"	
	30	7:05 AM	1531		
		5:00 PM	1532	Steele	
October	1	7:40 AM	1533	"	
		5:30 PM	1534'6"	"	
	2	7:50 AM	1536	"	
		6:15 PM	1537	"	
	3	7:15 AM	1538		
		6:20 PM	1539	Wallace	
	4	6:35 AM	1540	"	
		6:15 PM	1541	"	
	5	6:50 AM	1542	"	
		6:30 PM	1543	"	
	6	6:55 AM	1544	"	
		5:00 PM	1545		
	7	7:00 AM	1546	Steele	
		5:10 PM	1547	"	
	8	6:15 AM	1548	"	
		5:45 PM	1549	"	
	9	6:55 AM	1550	"	
		5:45 PM	1551	"	
	10	6:45 AM	1552		
		1:00 PM	1553	Wallace	
		6:00 PM	1553'6"	"	
	11	6:50 AM	1554	"	
		2:20 PM	1554'6"	"	

(1)	(2)	(3)	(4)	(5)
October 11	6:40 PM	1555	Wallace	
12	6:45 AM	1555'6"	"	
	6:10 PM	1556	"	
13	6:50 AM	1557	"	
	4:00 PM	1558	"	
14	6:55 AM	1559	"	
	5:35	1557		Re-set - 2' difference
15	7:00 AM	1557	Steele	
	5:15 PM	1559	"	
16	6:25 AM	1560	"	
	5:35 PM	1560	"	
17	6:35 AM	1561		
	5:45 PM	1562	Wallace	
18	7:30 AM	1562	"	
19	6:45 AM	1564	"	
	5:25 PM	1564'6"	"	
20	6:50 AM	1565	"	
	6:00 PM	1565'6"	"	
21	7:20 AM	1566		
	6:00 PM	1567	Steele	
22	7:00 AM	1568	"	
	6:10 PM	1568'6"	"	
23	7:00 AM	1569	"	
	5:45 PM	1569'6"	"	
24	7:15 AM	1570		
	4:45 PM	1571	Wallace	
25	7:15 AM	1572	"	
	5:35 PM	1573	"	
26	6:50 AM	1574	"	
	5:35 PM	1575	"	
27	7:10 AM	1576	"	
	5:15 PM	1576'6"	"	
28	6:50 AM	1577		
	5:55 PM	1577'6"	Steele	
29	7:00 AM	1578	"	
	5:30 PM	1579	"	
30	7:00 AM	1580	"	
	5:00 PM	1581		
31	8:00 AM	1582	Steele	
	5:15 PM	1583	Wallace	
November 1	7:00 AM	1483'6"	"	
	5:30 PM	1584	"	
2	7:15 AM	1584'6"	"	
	5:20 PM	1585	"	
3	7:00 AM	1585'6"	"	
	5:20 PM	1586	"	
4	7:00 AM	1587		
	5:20 PM	1587'6"	Steele	

(1)		(2)	(3)	(4)	(5)
Nov.	5	7:00 AM	1588	Steele	
		5:15 PM	1589	"	
	6	7:10 AM	1589	"	
		5:20 PM	1590	"	
	7	7:10 AM	1590'6"	"	
		5:20 PM	1591	Wallace	
	8	7:00 AM	1591'6"	"	
		5:45 PM	1592'6"	"	
	9	7:20 AM	1593	"	
		5:30 PM	1594	"	
	10	7:00 AM	1594'6"	"	
		4:45 PM	1595	"	
	11	7:10 AM	1595'6"	"	
		5:15 PM	1596	Steele	
	12	7:15 AM	1597	"	
		5:30 PM	1598	"	
	13	7:00 AM	1600	"	
		5:15 PM	1601	"	
	14	7:00 AM	1602	"	
		5:30 PM	1603	Wallace	
	15	7:30 AM	1604	"	
		5:10 PM	1604'6"	"	
	16	7:00 AM	1605	"	
		4:30 PM	1605	"	
	17	7:15 AM	1605	"	
		5:15 PM	1605	"	
	18	7:20 AM	1605'6"	"	
		4:30 PM	1605	"	
	19	7:15 AM	1605	Steele	
		5:15 PM	1605'6"	"	
	20	7:00 AM	1606	"	
		5:10 PM	1606'6"	"	
	21	7:15 AM	1607	"	
		5:20 PM	1608	Wallace	
	22	7:00 AM	1609	"	
		5:20 PM	1610	"	
	23	7:15 AM	1611	"	
		5:15 PM	1612	"	
	24	7:15 AM	1613	"	
		4:35 PM	1614	"	
	25	7:00 AM	1614'6"	"	
		4:45 PM	1615	Steele	
	26	7:15 AM	1615'6"	"	
		4:45 PM	1616	"	
	27	7:15 AM	1617	"	
		4:30 PM	1618'6"	"	
	28	8:40 AM	1619'6"	"	
		4:45 PM	1621	Wallace	
	29	7:10 AM	1622	"	
		5:15 PM	1624	"	
	30	7:05 AM	1625'6"	"	

(1)	(2)	(3)	(4)	(5)
December 1	7:15 AM	1628	Wallace	
	4:45 PM	1628'6"	"	
2	8:40 AM	1630	"	
	5:00 PM	1631		
3	7:15 AM	1632	Steele	
	4:30 PM	1633	"	
4	7:15 AM	1634	"	
	2:00 PM	1634'6"	"	
5	2:30 PM	1637	"	
6	8:00 AM	1638	"	
7	8:00 AM	1640	"	
	4:30 PM	1641'6"	"	
8	8:00 AM	1642	"	
	5:10 PM	1642'6"	"	
9	7:30 AM	1643	"	
	4:00 PM	1644	"	
10	8:00 AM	1645		
	5:15 PM	1646	Wallace	
11	7:00 AM	1647'6"	"	
	5:30 PM	1648	"	
12	7:20 AM	1649	"	
	5:20 PM	1649'6"	"	
13	7:00 AM	1650'6"	"	
	5:20 PM	1651	"	
14	7:00 AM	1652	"	
	5:00 PM	1652'6"	"	
15	7:00 AM	1653	"	
	5:00 PM	1654	"	
16	7:25 AM	1655		
	4:30 PM	1655'6"	Steele	
17	7:00 AM	1656	"	
	5:00 PM	1657	"	
18	7:15 AM	1658	"	
	5:00 PM	1659	"	
19	7:15 AM	1660	"	
	4:15 PM	1660'6"	"	
20	7:00 AM	1661	"	
	5:00 PM	1662	"	
21	7:15 AM	1663		
	5:10 PM	1663	Wallace	
22	7:25 AM	1664	"	
	5:00 PM	1665	"	
23	8:00 AM	1666		
	5:00 PM	1666'6"	Steele	
24	7:15 AM	1667'6"	"	
	4:30 PM	1668		
25	7:30 AM	1669	Wallace	
	4:00 PM	1669'6"	"	
26	8:00 AM	1670'6"	"	
	3:50 PM	1671		

(1)		(2)	(3)	(4)	(5)
Dec.	27	7:25 AM	1672	Wallace	
		5:00 PM	1672'6"	"	
	28	7:15 AM	1673'6"	"	
		3:45 PM	1674	"	
	29	7:45 AM	1675		
		4:00 PM	1675'6"	Steele	
	30	7:35 AM	1676'6"	"	
		4:45 PM	1676'6"	"	
	31	7:45 AM	1677	"	
		4:00 PM	1677'6"		
1966					
January	1	7:15 AM	1678	Steele	
		4:00 PM	1678	"	
	2	8:00 AM	1679		
		4:00 PM	1679'6"	Wallace	
	3	7:45 AM	1680'6"	"	
		4:50 PM	1681	"	
	4	7:25 AM	1682	"	
		4:00 PM	1682'6"	"	
	5	7:40 AM	1683'6"	"	
		4:00 PM	1684	"	
	6	7:45 AM	1685	"	
		5:00 PM	1685'6"	"	
	7	8:30 AM	1686	Steele	
		4:45 PM	1686'6"	"	
	8	7:45 AM	1687	"	
		4:45 PM	1687'6"	"	
	9	7:45 AM	1688		
		4:50 PM	1689	Wallace	
	10	7:30 AM	1690	"	
		5:20 PM	1690'6"	"	
	11	7:15 AM	1691'6"	"	
		5:05 PM	1692	"	
	12	7:30 AM	1693	"	
		4:50 PM	1693'6"	"	
	13	7:50 AM	1694		
		5:15 PM	1694'6"	Steele	
	14	7:45 AM	1695	"	
		5:50 PM	1695'6"	"	
	15	7:45 AM	1696	"	
		5:15 PM	1696'6"	"	
	16	7:45 AM	1697		
		4:00 PM	1698	Wallace	
	17	7:00 AM	1699	"	
		5:10 PM	1699'6"	"	
	18	7:00 AM	1700'6"	"	
		5:10 PM	1701	"	
	19	7:00 AM	1702		

(1)	(2)	(3)	(4)	(5)
January 19	5:15 PM	1702'6"	Wallace	
20	7:15 AM	1603'6"	"	
	5:15 PM	1704	Steele	
21	7:00 AM	1704'6"	"	
	5:00 PM	1705	"	
22	8:15 AM	1705'6"	"	
	5:15 PM	1706	"	
23	7:15 AM	1706'6"	"	
	5:35PM	1707	Wallace	
24	7:20 AM	1707'6"	"	
	5:10 PM	1708	"	
25	7:30 AM	1709	"	
	4:30 PM	1709'6"	"	
26	7:10 AM	1710	"	
	5:15 PM	1709'6"	"	
27	7:45 AM	1710	"	
	5:00 PM	1710	"	
28	7:30 AM	1710'6"	"	
	5:00 PM	1710'6"	Steele	
29	7:30 AM	1711	"	
	5:00 PM	1711	"	
30	7:45 AM	1711'6"	"	
	4:15 PM	1712	Wallace	
31	7:30 AM	1712'6"	"	
	4:30 PM	1713	"	
February 1	7:15 AM	1713'6"	"	
	5:20 PM	1713'6"	"	
2	7:15 AM	1714	"	
	5:25 PM	1714'6"	"	
3	7:45 AM	1715		
	5:15 PM	1715	Steele	
4	7:45 AM	1715'6"	"	
	5:00 PM	1715'6"	"	
5	7:30 AM	1716	"	
	5:00 PM	1716	"	
6	7:15 AM	1716		
	5:15 PM	1717	Wallace	
7	7:15 AM	1718	"	
	5:15 PM	1718'6"	"	
8	7:15 AM	1719	"	
	5:15 PM	1719'6"	"	
9	"		"	
			"	
10	7:30 AM	1720'6"		
	5:00 PM	1720'6"	Steele	
11	7:15 AM	1721	"	
	4:15 PM	1721	"	
12	7:15 AM	1721'6"	"	
	5:00 PM	1722	"	
13	7:30 AM	1722'6"	"	
	5:30 PM	1723	Wallace	
14	7:30 AM	1723'6"	"	

(1)		(2)	(3)	(4)	(5)
Feb.	14	5:30 PM	1724	Wallace	
	15	7:15 AM	1724'6"	"	
		5:15 PM	1725'6"	"	Rezeroed
	16	7:10 AM	1726	"	
		5:05 PM	1726	"	
	17	7:30 AM	1726'6"	"	
		5:00 PM	1726'6"	"	
	18	7:30 AM	1727	Steele	
		5:00 PM	1727	"	
	19	7:30 AM	1727'6"	"	
		5:00 PM	1727'6"	"	
	20	7:30 AM	1728	"	
		5:00 PM	1728'6"	Wallace	
	21	7:15 AM	1729	"	
		6:30 PM	1729	"	
	22	7:00 AM	1729'6"	"	
		5:00 PM	1730	"	
	23	7:00 AM	1730	"	
		5:00 PM	1730	"	
	24	7:30 AM	1730'6"	"	
		5:00 PM	1730'6"	Steele	
	25	7:30 AM	1730'6"	"	
		5:00 PM	1730'6"	"	
	26	7:30 AM	1731	"	
		5:00 PM	1731	"	
	27	7:30 AM	1731		
		5:15 PM	1731'6"	Wallace	
	28	7:30 AM	1732	"	
		5:30 PM	1731	"	
March	1	7:30 AM	1727	Wallace	Fluid levels unreliable. Heavy spring thaw flooded location and surface water entered well bore
		5:00 PM	1727'6"	"	
	2	9:10 AM	1728	"	
		5:00 PM	1728	"	
	3	7:30 AM	1728	"	
		4:15 PM	1729	"	
	4	7:30 AM	1729'6"	"	
		4:45 PM	1730'6"	Steele	
	5	8:00 AM	1731	"	
		5:00 PM	1731'6"	"	
	6	8:00 AM	1732		
		5:00 PM	1732'6"	Wallace	
	7	9:50 AM	1725'6"	"	
		5:20 PM	1717	"	
	8	6:30 AM	1720	"	
	9	8:15 AM	1724	"	
	10	7:20 AM	1727	"	
	17	7:00 AM	1738		
	18	9:00 AM	1737	Steele	
	19	7:00 AM	1739	"	
	20	7:00 AM	1740	"	

(1)		(2)	(3)	(4)	(5)
March	21	7:00 AM	1741	Wallace	March 25 through 28 bailed well off bottom. Recovered 51 gallons water and 245 gallons oil. Commencing March 27 fluid level measurements considered reliable.
	22	7:00 AM	1742'6"	"	
	23	7:00 AM	1743'6"	"	
	27	6:50 AM	1773	Steele	
		5:50 PM	1764	"	
	28	6:50 AM	1757	Wallace	
		5:30 PM	1785	"	
	29	6:45 AM	1762	"	
		5:25 PM	1756	"	
	30	6:45 AM	1752	"	
		5:20 PM	1752	"	
	31	6:50 AM	1752	"	
		5:45 PM	1752	"	
April	1	6:50 AM	1752	Steele	
		6:00 PM	1752	"	
	2	6:30 AM	1751'6"	"	
		6:45 PM	1751'6"	"	
	3	6:45 AM	1751'6"	"	
		4:70 PM	1752'6"	"	
	4	6:45 AM	1753	Wallace	
		5:00 PM	1753	"	
	5	6:45 AM	1753	"	
		5:15 PM	1753	"	
	6	7:00 AM	1753	"	
		5:00 PM	1753	"	
	7	7:30 AM	1753	"	
		5:45 PM	1753	"	
	8	6:45 AM	1752 '6"	Steele	
		5:45 PM	1752'6"	"	
	9	6:45 AM	1752	"	
		5:45 PM	1752	"	
	10	6:45 AM	1752	"	
		5:40 PM	1751'6"	"	
	11	6:30 AM	1751	Wallace	
		5:30 PM	1751	"	
	12	10:30 AM	1750'6"	"	
		6:15 PM	1751	"	
	13	6:30 AM	1751'6"	"	
		5:15 PM	1751	"	
	14	7:00 AM	1750'6"	"	
		5:45 PM	1750'6"	Steele	
	15	6:45 AM	1751	"	
		6:00 PM	1751	"	
	16	6:15 AM	1751'6"	"	
		6:00 PM	1751'6"	Wallace	
	17	6:45 AM	1751'6"	"	
		6:15 PM	1752	"	
	18	6:45 AM	1752'6"	"	
		6:00 PM	1752'6"	"	
	19	6:30 AM	1752'6"	"	
		6:00 PM	1753		

(1)		(2)	(3)	(4)	(5)
April	20	6:30 AM	1753	Wallace	
		6:00 PM	1753	"	
	21	7:00 AM	1753'6"	"	
		5:00 PM	1753'6"	Steele	
	22	6:45 AM	1753'6"	Steele	
		5:30 PM	1754	"	
	23	6:45 AM	1754	"	
		5:45 PM	1754	"	
	24	6:45 AM	1754'6"	"	
		5:00 PM	1754'6"	Wallace	
	25	6:30 AM	1755	"	
		5:00 PM	1755	"	
	26	6:30 AM	1756	"	
		6:30 PM	1756	"	
	27	6:30 AM	1756'6"	"	
		6:15 PM	1756'6"	"	
	28	6:45 AM	1757	"	
		4:30 PM	1757'6"	"	
	29	6:45 AM	1757'6"	Steele	
		4:30 PM	1758	"	
	30	6:45 AM	1758	"	
		5:00 PM	1758	"	
May	1	5:30 PM	1759'6"	"	
	2	6:30 AM	1760	Wallace	Zeroed Line
		2:00 PM	1760'6"	Stoabs	
	3	6:30 AM	1761'6"	Wallace	
		6:00 PM	1761'6"	"	
	4	6:30 AM	1762	"	
		5:45 PM	1762'6"	"	
	5	6:40 AM	1762'6"	"	
		5:30 PM	1763	"	
	6	6:45 AM	1763	Steele	
		5:45 PM	1763	"	
	7	6:45 AM	1763'6"	"	
		5:45 PM	1763'6"	"	
	8	6:45 AM	1764	"	
		5:15 PM	1764'6"	"	
	9	6:30 AM	1765'6"	Wallace	
		5:15 PM	1766	"	
	10	6:30 AM	1766'6"	"	
		6:15 PM	1766'6"	"	
	11	6:20 AM	1767	"	
		6:15 PM	1767	"	
	12	6:45 AM	1767'6"	"	
		6:15 PM	1767'6"	Steele	
	13	6:45 AM	1767'6"	"	
		6:30 PM	1768	"	
	14	6:45 AM	1768	"	
		5:45 PM	1768	"	
	15	6:45 AM	1769		
		5:30 PM	1769'6"	Wallace	
	16	6:30 AM			

Canada Ojitos Unit A-23

(1)		(2)	(3)	(4)	(5)
May	16	5:30 PM	1770	Wallace	
	17	6:30 AM	1770'6"	"	
		5:30 PM	1770'6"	"	
	18	6:30 AM	1771	"	
		5:40 PM	1771	"	
	19	6:30 AM	1771'6"	"	
		5:30 PM	1771'6"	"	
	20	6:45 AM	1772	Steele	
		5:45 PM	1772	"	
	21	6:45 AM	1772	"	
		5:45 PM	1772'6"	"	
	22	6:45 AM	1772'6"	"	
		5:30 PM	1773	"	
	23	6:15 AM	1773'6"	Wallace	
		6:00 PM	1773'6"	"	
	24	6:10 AM	1774	"	
		6:00 PM	1774	"	
	25	6:20 AM	1774	"	
		5:00 PM	1774'6"	"	
	26	6:10 AM	1774'6"	"	
		4:00 PM	1774'6"	"	
	27	6:45 AM	1774'6"	Steele	
		5:45 PM	1774'6"	"	
	28	6:45 AM	1774'6"	"	
		5:45 PM	1774'6"	"	
	29	6:45 AM	1775	"	
		5:15 PM	1775'6"	"	
	30	6:30 AM	1776'6"	Wallace	
		6:00 PM	1777	"	
	31	6:20 AM	1777'6"	"	
		6:00 PM	1777'6"	"	
June	1	6:15 AM	1777'6"	"	
		5:45 PM	1777'6"	"	
	2	6:10 AM	1778	"	
		6:10 PM	1778	"	
	3	6:45 AM	1778	Steele	
		6:00 PM	1778	"	
	4	6:45 AM	1778'6"	"	
		6:15 PM	1778'6"	Wallace	
	5	6:45 AM	1778'6"	"	
		6:15 PM	1779	"	
	6	6:20 AM	1779'6"	"	
		6:30 PM	1780	"	
	7	6:20 AM	1680'6"	"	
		6:00 PM	1680'6"	"	
	8	6:30 AM	1781	"	
		6:10 PM	1781	"	
	9	6:10 AM	1781'6"	"	
		5:20 PM	1781	"	
	10	6:20 AM	1781'6"	Steele	
		6:10 PM	1781'6"	"	

Fluid Level Measurements - Page 15
Canada Ojitos Unit A-23

(1)		(2)	(3)	(4)	(5)
June	11	6:30 AM	1781'6"	Steele	
		6:15 PM	1782	"	
	12	6:20 AM	1782	"	
		6:10 PM	1782'6"	"	
	13	7:15 AM	1783'6"	Wallace	
		5:50 PM	1783'6"	"	
	14	6:00 AM	1784	"	
		5:50 PM	1784'6"	"	
	15	6:45 AM	1784'6"	Steele	
		6:10 PM	1784'6"	"	
	16	6:10 AM	1784'6"	"	
		6:10 PM	1785	"	
	17	6:10 AM	1785	"	
		6:10 PM	1785	"	
	18	6:00 AM	1785	"	
		6:10 PM	1785'6"	"	
	19	6:00 AM	1785'6"	"	
		5:40 PM	1785'6"	"	
	20	6:15 AM	1787	Wallace	
		6:20 PM	1787'6"	"	
	21	7:00 AM	1788	"	
		5:30 PM	1788	"	
	22	7:00 AM	1788	Steele	
		6:10 PM	1788'6"	"	
	23	6:20 AM	1788'6"	"	
		5:40 PM	1789	"	
	24	6:30 AM	1789	"	
		6:10 PM	1789	"	
	25	6:20 AM	1789'6"	"	
		4:40 PM	1789'6"	"	
	26	6:10 AM	1790	"	
		4:40 PM	1790	"	
	27	6:30 AM	1790'6"	Wallace	
		6:15 PM	1791	"	
	28	6:30 AM	1791'6"	"	
		4:50 PM	1791'6"	"	
	29	6:15 AM	1792	Steele	
		6:00 PM	1792	"	
	30	6:10 AM	1792'6"	"	
		6:00 PM	1792'6"	"	
July	1	6:25 AM	1792'6"	"	
		6:00 PM	1793	"	
	2	6:10 AM	1793	"	
		6:10 PM	1793	"	
	3	6:00 AM	1793'6"	"	
		4:30 PM	1793'6"	"	
	4	6:00 AM	1794	Wallace	
		6:30 PM	1794	"	
	5	6:00 AM	1794	"	
		6:30 PM	1794'6"	"	
	6	7:00 AM	1794'6"	"	
		6:30 PM	1795	"	
	7	6:20 AM	1795	"	
		4:45 PM	1795	"	

(1)		(2)	(3)	(4)	(5)
July	8	7:00 AM	1795	Steele	
		5:30 PM	1795	"	
	9	5:55 AM	1795'6"	"	
		4:50 PM	1795'6"	"	
	10	6:45 AM	1796	"	
		6:25 PM	1796	"	
	11	6:20 AM	1796'6"	Wallace	
		7:00 PM	1796'6"	"	
	12	11:30 AM	1797	"	
		7:00 PM	1797	"	
	13	6:30 AM	1797'6"	"	
		6:45 PM	1797'6"	"	
	14	6:15 AM	1797'6"	"	
		4:15 PM	1797'6"	"	
	15	7:00 AM	1798	Steele	
		6:00 PM	1798	"	
	16	6:10 AM	1798	"	
		4:15 PM	1798'6"	"	
	17	6:20 AM	1798'6"	Wallace	
		5:25 PM	1798'6"	"	
	18	6:20 AM	1798'6"	"	
		5:20 PM	1798'6"	"	
	19	6:15 AM	1799	"	
		6:15 PM	1799	"	
	20				Road to location Impassable
		6:00 PM	1799'6"	Wallace	
	21	AM			Road Impassable
	22				Road Impassable
		5:30 PM	1800	Steele	
	23	5:30 AM	1800	"	
		4:30 PM	1800	"	
	24	7:00 AM	1800'6"	Wallace	
		5:15 PM	1800'6"	"	
	25	6:30 AM	1801	"	
		6:00 PM	1801	"	
	26	6:30 AM	1801'6"	"	
		6:30 PM	1801'6"	"	
	27	7:00 AM	1801'6"	"	
		5:30 PM	1802	"	
	28	7:00 AM	1802	"	
		6:45 PM	1802	Steele	
	29	6:30 AM	1802'6"	"	
	30	6:45 PM	1803	"	
	31	6:00 AM	1803	"	
		6:45 PM	1803	Wallace	
August	1	6:45 AM	1803'6"	"	
		7:00 PM	1803'6"	"	
	2	7:00 AM	1904'	"	
		6:00 PM	1804	"	
	3				Road Impassable
	6	6:30 PM	1806	Steele	
	7	3:00 PM	1806	"	

(1)		(2)	(3)	(4)	(5)
August	8	6:45 AM	1806'6"	Wallace	
		6:30 PM	1807	"	
	9	6:15 AM	1807	"	
		6:00 PM	1807	"	
	10	7:20 AM	1807	"	
		6:45 PM	1807	"	
	11	6:00 AM	1807'6"	"	
		7:10 PM	1807'6"	Steele	
	12	5:45 AM	1807'6"	"	
		7:20 PM	1808	"	
	13	5:50 AM	1808	"	
		7:00 PM	1808	"	
	14	6:00 AM	1808'6"	"	
		6:30 PM	1808'6"	Wallace	
	15	6:30 AM	1808'6"	"	
		6:00 PM	1808'6"	"	
	16	7:00 AM	1808'6"	"	
		6:45 PM	1808'6"	"	
	17	6:30 AM	1808'6"	"	
		5:30 PM	1808'6"	"	
	18	6:35 AM	1808'6"	"	
		6:35 PM	1808'6"	"	
	19	6:40 AM	1808'6"	"	
		6:15 PM	1808'6"	"	
	20	6:45 AM	1808'6"	"	
		6:00 PM	1808'6"	"	
	21	6:45 AM	1808'6"	"	
		6:15 PM	1808'6"	"	
	22	6:10 AM	1808'6"	"	
		4:30 PM	1808'6"	"	
	23	6:45 AM	1808'6"	"	
		4:40 PM	1808'6"	"	
	24	8:30 AM	1808'6"	Steele	
		5:45 PM	1808'6"	"	
	25	7:00 AM	1809	"	
		6:45 PM	1809	"	
	26	6:45 AM	1809	"	
		5:45 PM	1809	"	
	27	6:45 AM	1809	"	
		6:45 PM	1809	"	
	28	6:45 AM	1809'6"	"	
		5:00 PM	1809'6"	"	
	29	6:30 AM	1809'6"	Wallace	
		5:30 PM	1809'6"	"	
	30	6:30 AM	1809'6"	"	
		3:00 PM	1810	"	
	31	8:15 AM	1811'6"	"	Rezeroed Line
		6:00 PM	1811'6"	"	
September	1	7:00 AM	1812	"	
		6:45 PM	1812'6"	Steele	
	2	6:45 AM	1813	"	
		6:45 PM	1813	"	

(1)	(2)	(3)	(4)	(5)
September 3	6:45 AM	1813'6"	Steele	
	5:45 PM	1813'6"	"	
4	6:45 AM	1814	"	
	5:45 PM	1814		
5	6:30 AM	1814	Wallace	
	6:15 PM	1814	"	
6	6:30 AM	1814'6"	"	
	5:15 PM	1814'6"	"	
7	6:30 AM	1814'6"	"	
	5:30 PM	1815	"	
8	6:45 AM	1815'6"	"	
	6:15 PM	1815'6"	Steele	
9	6:45 AM	1816	"	
	6:45 PM	1816	"	
10	6:45 AM	1816'6"	"	
	6:30 PM	1816'6"	"	
11	6:45 AM	1817	"	
	5:00 PM	1817'6"	"	
12	6:45 AM	1817'6"	Wallace	
	5:45 PM	1817'6"	"	
13	6:45 AM	1818	"	
	5:50 PM	1818	"	
14	6:45 AM	1818'6"	"	
	5:30 PM	1818'6"	"	
15	6:45 AM	1819	Wallace	
	6:45 PM	1819	Steele	
16	6:45 AM	1819	"	
	6:00 PM	1819'6"	"	
17	7:00 AM	1819'6"	"	
	6:15 PM	1820	"	
18	6:45 AM	1820	"	
	5:00 PM	1820'6"	Wallace	
19	6:45 AM	1821	"	
	5:30 PM	1821'6"	"	
20	6:34 AM	1821'6"	"	
	5:45 PM	1822	"	
21	6:45 AM	1822'6"	"	
	5:10 PM	1823	"	
22	7:00 AM	1823	Wallace	
	5:30 PM	1823	"	
23	7:00 AM	1823'6"	Steele	
	6:45 PM	1823'6"	"	
24	6:45 AM	1823'6"	"	
	7:00 PM	1824	"	
25	6:45 AM	1824'6"	"	
	6:00 PM	1825		
26	6:45 AM	1825'6"	Wallace	
	5:40 PM	1825'6"	"	
27	6:45 AM	1826	"	
	6:45 PM	1826	"	
28	6:45 AM	1826'6"	"	
	5:45 PM	1826'6"	"	

(1)	(2)	(3)	(4)	(5)
September 3	6:45 AM	1813'6"	Steele	
	5:45 PM	1813'6"	"	
4	6:45 AM	1814	"	
	5:45 PM	1814		
5	6:30 AM	1814	Wallace	
	6:15 PM	1814	"	
6	6:30 AM	1814'6"	"	
	5:15 PM	1814'6"	"	
7	6:30 AM	1814'6"	"	
	5:30 PM	1815	"	
8	6:45 AM	1815'6"	"	
	6:15 PM	1815'6"	Steele	
9	6:45 AM	1816	"	
	6:45 PM	1816	"	
10	6:45 AM	1816'6"	"	
	6:30 PM	1816'6"	"	
11	6:45 AM	1817	"	
	5:00 PM	1817'6"	"	
12	6:45 AM	1817'6"	Wallace	
	5:45 PM	1817'6"	"	
13	6:45 AM	1818	"	
	5:50 PM	1818	"	
14	6:45 AM	1818'6"	"	
	5:30 PM	1818'6"	"	
15	6:45 AM	1819	Wallace	
	6:45 PM	1819	Steele	
16	6:45 AM	1819	"	
	6:00 PM	1819'6"	"	
17	7:00 AM	1819'6"	"	
	6:15 PM	1820	"	
18	6:45 AM	1820		
	5:00 PM	1820'6"	Wallace	
19	6:45 AM	1821	"	
	5:30 PM	1821'6"	"	
20	6:34 AM	1821'6"	"	
	5:45 PM	1822	"	
21	6:45 AM	1822'6"	"	
	5:10 PM	1823		
22	7:00 AM	1823	Wallace	
	5:30 PM	1823	"	
23	7:00 AM	1823'6"	Steele	
	6:45 PM	1823'6"	"	
24	6:45 AM	1823'6"	"	
	7:00 PM	1824	"	
25	6:45 AM	1824'6"	"	
	6:00 PM	1825	"	
26	6:45 AM	1825'6"	Wallace	
	5:40 PM	1825'6"	"	
27	6:45 AM	1826	"	
	6:45 PM	1826	"	
28	6:45 AM	1826'6"	"	
	5:45 PM	1826'6"	"	

(1)		(2)	(3)	(4)	(5)
Sept.	29	7:10 AM	1827	Wallace	
		5:15 PM	1827	Steele	
	30	8:15 AM	1827'6"	"	
		5:45 PM	1827'6"	"	
October	1	6:45 AM	1828	"	
		5:45 PM	1828	"	
	2	7:00 AM	1828	"	
		5:30 PM	1828'6"	"	
	3	6:45 AM	1829'6"	Wallace	
	4	7:00 AM	1830	"	
		6:00 PM	1830	"	
	5	6:50 AM	1830'6"	"	
		5:30 PM	1830'6"	"	
	6	7:15 AM	1831	"	
		5:45 PM	1831	Steele	
	7	8:00 AM	1831'6"	"	
		5:45 PM	1832	"	
	8	8:00 AM	1832	"	
		6:00 PM	1832'6"	"	
	9	8:15 AM	1832'6"	"	
		6:00 PM	1833	"	
	10	6:50 AM	1833	Wallace	
		5:00 PM	1833	"	
	11	7:00 AM	1833'6"	"	
		6:00 PM	1833'6"	"	
	12	6:45 AM	1834	"	
		5:30 PM	1834	"	
	13	6:45 AM	1834'6"	"	
		6:00 PM	1834'6"	Steele	
	14	8:00 AM	1835	"	
		5:45 PM	1835	"	
	15	8:00 AM	1835'6"	"	
		6:00 PM	1835'6"	"	
	16	8:15 AM	1836	"	
		5:45 PM	1836	"	
	17	6:40 AM	1836'6"	Wallace	
		5:45 PM	1836'6"	"	
	18	7:00 AM	1837	"	
		4:30 PM	1837	"	
	19	7:00 AM	1837'6"	"	
		5:10 PM	1837'6"	"	
	20	7:30 AM	1838	"	
		6:00 PM	1838	Steele	
	21	8:20 AM	1838'6"	"	
		6:00 PM	1839	"	
	22	8:15 AM	1839	"	
		6:00 PM	1839'6"	"	
	23	8:30 AM	1840	"	
		5:50 PM	1840	Wallace	
	24	6:45 AM	1840	"	
		5:45 PM	1840'6"	"	
	25	7:15 AM	1840'6"	"	

(1)	(2)	(3)	(4)	(5)
October 25	5:35 PM	1840'6"	Wallace	
26	7:00 AM	1841	"	
	5:45 PM	1841	"	
27	7:15 AM	1841'6"	Steele	
	6:00 PM	1841'6"	"	
28	8:15 AM	1842	"	
	5:45 PM	1842	"	
29	7:00 AM	1842'6"	"	
	5:45 PM	1842'6"	"	
30	8:30 AM	1842'6"	"	
	5:00 PM	1843		
31	6:30 AM	1843'6"	Wallace	
	4:50 PM	1843'6"	"	
November 1	6:45 AM	1844		

FLUID LEVEL MEASUREMENTS
JICARILLA 237 P-19

(1) DATE	(2) TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEV.	(5) REMARKS
1966				
February 22	11:00 AM	1452	Wallace	
23	Noon	1450	"	
24	9:00 AM	1449	Steele	
25	10:00 AM	1448	"	
26	10:00 AM	1448'6"	"	
27	10:00 AM	1449	"	
28	10:00 AM	1449	Wallace	
March 1	10:30 AM	1449	"	All wells Shut in 10:30 AM
2	6:30 AM	1446	"	
3	9:10 AM	1437	"	
	5:30 PM	1434	Steele	
4	7:45 AM	1431	"	
	4:00 PM	1429	"	
5	7:00 AM	1426	"	
	5:45 PM	1423	"	
6	7:00 AM	1420	"	
7	6:45 AM	1416'6"	Wallace	
8	8:30 AM	1415'6"	"	
9	10:00 AM	1412	"	
10	10:00 AM	1408	"	
11	7:30 AM	1412	Steele	
12	7:45 AM	1418	"	
13	7:00 AM	1422	"	
14	9:20 AM	1427	Wallace	
15	8:30 AM	1423'6"	"	
16	Noon	1423'6"	Steele	
17	7:30 AM	1426	"	
18	7:00 AM	1428'6"	"	
19	9:30 AM	1430	"	
20	10:30 AM	1432	"	
21	10:30 AM	1433	Wallace	
22	10:30 AM	1430'6"	"	
23	Noon	1423'6"	"	
24	9:30 AM	1421	Steele	
25	3:30 PM	1425	"	
26	10:00 AM	1429	"	
27	11:00 AM	1431	"	
28	10:50 AM	1433	Wallace	
29	9:15 AM	1431	York	
30	10:10 AM	1428	Wallace	
31	9:00 AM	1426	Steele	

(1)		(2)	(3)	(4)	(5)
April	1	10:00 AM	1425	Steele	
	2	10:00 AM	1424'6"	"	
	3	10:00 AM	1424'6"	"	
	4	9:30 AM	1424'6"	Wallace	
	5	9:45 AM	1421	"	
	6	12:30 PM	1415	"	
	7	9:30 AM	1415	"	
	8	9:30 AM	1417		
	9	10:00 AM	1418	Steele	
	10	9:30 AM	1418	"	
	11	9:15 AM	1418	Wallace	
	12	6:45 AM	1416'6"	"	
	13	10:00 AM	1411	Steele	
	14	9:00 AM	1412	"	
	15	10:00 AM	1415	"	
	16	10:15 AM	1416	Wallace	
	17	9:30 AM	1415	"	
	18	10:00 AM	1416	"	
	19	9:30 AM	1417	"	
	20	Noon	1418		
	21	11:30 AM	1419	Bud	
	22	7:45 AM	1418'6"	"	
	23	8:15 AM	1418'6"	Steele	
	24	9:45 AM	1419	"	
	25	6:45 PM	1419	Wallace	
	26	10:10 AM	1418	"	
	27	Noon	1412	"	
	28	8:30 AM	1414	Templeman	
	29	10:00 AM	1413	Steele	
	30	7:30 AM	1422	"	
May	1	7:45 AM	1425	"	
	2	11:00 AM	1428'6"	Wallace	
	3	11:30 AM	1429'6"	"	
	4	11:00 AM	1431	"	
	5	9:45 AM	1432'6"	"	
	6	11:00 AM	1434	Steele	
	7	10:31 AM	1435	"	
	8	10:10 AM	1436	"	
	9	10:45 AM	1431'6"	Wallace	
	10	Noon	1426	"	
	11	9:45 AM	1426'6"	"	
	12	9:45 AM	1429		
	13	10:30 AM	1432	Steele	
	14	11:00 AM	1434	"	
	15	10:00 AM	1431	"	
	16	10:15 AM	1425'6"	Wallace	
	17	10:20 AM	1424'6"	"	
	18	9:30 AM	1424	Steele	
	19	Noon	1431	"	
	20	10:00 AM	1434	"	
	21	10:00 AM	1435	"	
	22	9:40 AM	1437	"	
	23	10:00 AM	1439'6"	Wallace	
	24	10:45 AM	1440	"	

(1)		(2)	(3)	(4)	(5)
	25	10:00 AM	1440	Steele	
	26	8:00 AM	1441	"	
	27	8:45 AM	1439	"	
	28	9:30 AM	1437	"	
	29	10:00 AM	1439	"	
	30	10:00 AM	1440	Wallace	
	31	9:45 AM	1441	"	
June	1	Noon	1443	"	Rezored
	2	11:30 AM	1444	"	
	3	9:45 AM	1445	Steele	
	4	9:00 AM	1445'6"	Wallace	
	5	9:00 AM	1445'6"	"	
	6	11:00 AM	1446	"	
	7	11:45 AM	1446'6"	"	
	8	9:40 AM	1447	"	
	9	10:30 AM	1448	"	
	10	9:45 AM	1448'6"	Steele	
	11	10:15 AM	1448'6"	"	
	12	12:30 PM	1449	"	
	13	10:00 AM	1450	Wallace	
	14	10:00 AM	1449'6"	"	
	15	10:00 AM	1450'6"	Steele	
	16	10:30 AM	1450	"	
	17	10:20 AM	1448	"	
	18	8:30 AM	1441	"	
	19	10:15 AM	1435	Wallace	
	20	10:15 AM	1429'6"	"	
	21	10:30 AM	1425	"	
	22	11:00 AM	1421	Steele	
	23	10:00 AM	1418	"	
	24	9:10 AM	1415'6"	"	
	25	9:50 AM	1413	"	
	26	9:00 AM	1411	"	
	27	12:30 PM	1408'6"	Wallace	
	28	9:00 AM	1412	"	
	29	9:15 AM	1419	Steele	
		4:30 PM	1420'6"	"	
	30	8:40 AM	1424	"	
July	1	9:30 AM	1428	"	
		6:30 PM	1429	"	
	2	8:30 AM	1431	"	
	3	9:00 AM	1433	"	
	4	10:45 AM	1435	Wallace	
	5	10:30 AM	1436'6"	"	
	6	10:45 AM	1438'6"	"	
	7	11:00 AM	1439'6"	"	
	8	10:00 AM	1441	Steele	
	9	9:00 AM	1442	"	
	10	8:45 AM	1440	"	
	11	Noon	1439'6"	Wallace	
	12	10:00 AM	1441	"	
	13	11:00 AM	1442'6"	"	
	14	10:00 AM	1444	"	
	15	9:30 AM	1445'6"	Steele	
	16	9:30 AM	1446'6"	"	

(1)		(2)	(3)	(4)	(5)
	17	10:00 AM	1447'6"	Wallace	
	18	10:00 AM	1448	"	
	19	10:00 AM	1448'6"	"	
	20	10:00 AM	1449	"	
	21	Noon	1450	Steele	
	22	10:30 AM	1450	"	
	23	9:30 AM	1450'6"	Wallace	
	24	10:15 AM	1451	"	
	25	11:00 AM	1449'6"	"	
	26	10:00 AM	1439'6"	Steele	
	27	11:00 AM	1437'6"	Stoabs	
		2:00 PM	1437'6"	Steele	
		6:00 PM	1435'6"	"	
	28	8:45 AM	1436	"	
	29	9:45 AM	1437	"	
	30	11:00 AM	1438	"	
	31	9:00 AM	1439	Wallace	
August	1	1:00 PM	1440	"	
	2	10:45 AM	1443	Steele	
	3	10:30 AM	1445'6"	"	
	4	8:30 AM	1447	"	
	5	10:00 AM	1449'6"	"	
	6	9:00 AM	1450'6"	"	
	7	9:15 AM	1452'6"	Wallace	
	8	10:00 AM	1464'6"	"	
	9	2:15 PM	1456	Steele	
	10	10:45 AM	1457'6"	"	
	11	9:00 AM	1459	"	
	12	1:00 PM	1460	"	
	13	9:00 AM	1461	"	
	14	9:30 AM	1462'6"	Wallace	
	15	10:00 AM	1463'6"	"	
	16	10:15 AM	1464	"	
	17	10:40 AM	1466	Steele	
	18	11:30 AM	1467	Wallace	
	19	1:15 PM	1468	Steele	
	20	11:30 AM	1469'6"	"	
	21	11:00 AM	1471	Wallace	
	22	Noon	1472'6"	"	
	23	11:35 AM	1474	Steele	
	24	12:15 PM	1475	"	
	25	10:00 AM	1475'6"	"	
	26	9:30 AM	1477	"	
	27	10:00 AM	1478	"	
	28	9:20 AM	1478'6"	Wallace	
	29	11:00 AM	1479'6"	"	Rezeroed line
	30	1:00 PM	1481	"	
	31	11:00 AM	1481	Steele	
Sept.	1	8:45 AM	1482	"	
	2	9:40 AM	1483	"	
	3	10:30 AM	1483'6"	"	
	4	10:00 AM			

(1)		(2)	(3)	(4)	(5)
	5	11:00 AM	1484	Wallace	
	6	11:35 AM	1485	"	
	7	11:30 AM	1486	"	
	8	10:30 AM	1485	Steele	
	9	10:00 AM	1483	"	
	10	10:30 AM	1482	Wallace	
	11	9:00 AM	1481'6"	"	
	12	9:30 AM	1481'6"	"	
	13	10:45 AM	1481'6"	"	
	14	11:30 AM	1480'6"	"	
	15	8:15 AM	1481	Steele	
	16	Noon	1482'6"	"	
	17	10:30 AM	1484	"	
	18	10:00 AM	1486	"	
	19	11:15 AM	1487'6"	Wallace	
	20	10:35 AM	1488'6"	"	
	21	9:20 AM	1490	"	
	22	9:00 AM	1489'6"	Steele	
	23	10:40 AM	1488'6"	"	
	24	10:30 AM	1488'6"	"	
	25	9:50 AM	1490	"	
	26	9:10 AM	1490'6"	Wallace	
	27	10:30 AM	1492	"	
	28	9:00 AM	1494	Steele	
	29	8:45 AM	1495	"	
	30	10:15 AM	1496	"	
Oct.	1	8:45 AM	1497	"	
	2	9:45 AM	1497'6"	"	
	3	10:30 AM	1498	Wallace	
	4	10:30 AM	1498'6"	"	
	5	12:30 PM	1499'6"	"	
	6	9:00 AM	1500'6"	Steele	
	7	10:30 AM	1501	"	
	8	10:00 AM	1499	"	
	9	10:00 AM	1496	"	
	10	12:10 PM	1495'6"	Wallace	
	11	11:00 AM	1497'6"	"	
	12	10:15 AM	1498'6"	Steele	
	13	11:10 AM	1500	"	
	14	10:10 AM	1501	"	
	15	10:00 AM	1502	"	
	16	10:05 AM	1502'6"	"	
	17	10:40 AM	1503'6"	Wallace	
	18	10:55 AM	1504'6"	"	
	19	11:15 AM	1506	"	
	20	10:45 AM	1506	Steele	
	21	10:15 AM	1506	"	
	22	11:15 AM	1506	"	
	23	10:45 AM	1507	"	
	24	11:30 AM	1507'6"	Wallace	
	25	1:40 PM	1508	Steele	
	26	10:00 AM	1508	"	
	27	8:45 AM	1508'6"	"	

(1)		(2)	(3)	(4)	(5)
	28	11:00 AM	1508'6"	Steele	
	29	11:30 AM	1509	"	
	30	10:30 AM	1509'6"	"	
	31	11:30 AM	1509'6"	Wallace	
Nov.	1	Noon	1509'6"	"	
	2	10:05 AM	1510	Steele	
	3	9:00 AM	1510	"	
	4	Noon	1510	"	
	5	9:30 AM	1510'6"	"	
	6	11:45 AM	1510'6"	"	
	7	11:45 AM	1511	Wallace	
	8	10:35 AM	1511	"	

FLUID LEVEL MEASUREMENTS
JICARILLA #237, #P-20

(1) DATE	(2) TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEVEL	(5) REMARKS
1965				
June 21		1228		Wire Line Unit #2 RanBHP
July 9		1240		Wire Line Unit #2 Ran BHP
August 5		1259		Wire Line Unit #2 RanBHP
August 11		1267		Wire Line Unit #2 Ran BHP to 2358
August 16		1272		
August 17		1273		
August 18		1274		
August 19		1274		
August 21		1275		
August 23	10:00 A.M.	1277		
August 24	10:00 A.M.	1278		
August 25	1:00 P.M.	1278		
August 27	11:00 A.M.	1279		
August 28	11:00 A.M.	1280		
August 29	10:00 A.M.	1280		
August 30	11:30 A.M.	1280		Wallace
August 31	9:30 A.M.	1281		Wallace
September 1	8:00 A.M.	1281		Steele
September 2	11:00 A.M.	1282		Steele
September 3	11:00 A.M.	1283		Steele
September 4	10:00 A.M.	1284		Steele
September 5	10:00 A.M.	1285		Steele
September 6	10:30 A.M.	1284		Wallace
September 7	11:00 A.M.	1285		Wallace
September 9	10:00 A.M.	1285		Wallace
September 10	9:00 A.M.	1286		Steele
October 27	11:00 A.M.	1309		Wallace
October 28	11:15 A.M.	1310		Wallace
October 29	10:00 A.M.	1311		Steele
November 1	10:30 A.M.	1310		Wallace
November 2	10:30 A.M.	1311		Wallace
November 4	9:15 A.M.	1311		Wallace
November 5	10:00 A.M.	1313		Steele
November 7	10:30 A.M.	1313'6"		Steele
November 8	10:30 A.M.	1313		Wallace
November 9	11:00 P.M.	1314		Wallace
November 10	10:30 A.M.	1313		Wallace
November 11	8:30 A.M.	1313		Steele
November 12	11:00 A.M.	1313		Steele
November 13	10:30 A.M.	1313		Steele
November 14	10:30 A.M.	1313'6"		Steele
November 15	10:30 A.M.	1313		Wallace

(1)	(2)	(3)	(4)	(5)
Nov. 16	2:30 P.M.	1313	Wallace	
Nov. 17	10:00 A.M.	1313'6"	Steele	
Nov. 18	10:30 A.M.	1313'6"	Steele	
Nov. 19	10:30 A.M.	1313'6"	Steele	
Nov. 20	1:00 P.M.	1314'6"	Steele	
Nov. 21	10:30 A.M.	1315	Steele	
Nov. 22	11:30 A.M.	1315'6"	Wallace	
Nov. 23	11:15 A.M.	1317'6"	Wallace	
Nov. 24	11:00 A.M.	1317'6"	Wallace	
Nov. 25	11:00 A.M.	1318	Steele	
Nov. 26	10:30 A.M.	1318	Steele	
Nov. 27	10:00 A.M.	1318	Steele	
Nov. 28				No reading.
Nov. 29	10:30 A.M.	1318	Wallace	
Nov. 30	3:00 P.M.	1318'6"	Wallace	
Dec. 1				No reading.
Dec. 2				No reading.
Dec. 3	10:30 A.M.	1318	Steele	
Dec. 4	9:30 A.M.	1318'6"	Steele	
Dec. 5	10:00 A.M.	1319	Steele	
Dec. 6	10:30 A.M.	1319	Steele	
Dec. 7	10:00 A.M.	1317'6"	Steele	
Dec. 8	1:00 P.M.	1318	Steele	
Dec. 9	2:00 P.M.	1316	Steele	
Dec. 10				No reading
Dec. 11	12:00 NOON	1316'6"	Wallace	
Dec. 12	1:30 P.M.	1316	Wallace	
Dec. 13	10:00 A.M.	1315	Wallace	
Dec. 14	11:00 A.M.	1316	Wallace	
Dec. 15				No reading.
Dec. 16	9:30 A.M.	1317	Steele	
Dec. 17	11:00 A.M.	1317'6"	Steele	
Dec. 18				No reading.
Dec. 19	11:00 A.M.	1318	Steele	
Dec. 20				No reading.
Dec. 21	11:00 A.M.	1318	Steele	
Dec. 22	1:30 P.M.	1317	Steele	
Dec. 23	10:30 A.M.	1318	Steele	
Dec. 24	11:00 A.M.	1317	Steele	
Dec. 25	10:30 A.M.	1318	Wallace	
Dec. 26				No reading.
Dec. 27	12:00 NOON	1317	Wallace	
Dec. 28	11:30 A.M.	1318'6"	Wallace	
Dec. 29				No reading.
Dec. 30	10:00 A.M.	1319	Steele	
Dec. 31				No reading.

(1)	(2)	(3)	(4)	(5)
1966				
January 1	10:30 A.M.	1318	Steele	
January 4	2:30 P.M.	1319	Wallace	
January 5	1:00 P.M.	1318	Steele	
January 6	12:00 NOON	1318'6"	Steele	
January 7	11:00 A.M.	1318'6"	Steele	
January 8	1:00 P.M.	1319	Steele	
January 9	1:00 P.M.	1319	Steele	
January 10	11:00 A.M.	1320	Wallace	
January 11	10:30 A.M.	1320	Wallace	
January 12				No reading.
January 13	11:00 A M.	1320	Steele	
January 14	10:30 A.M.	1320	Steele	
January 15	11:00 A.M.	1320	Steele	
January 16				No reading.
January 17	2:00 P.M.	1322	Wallace	
January 18	11:00 A.M.	1322	Wallace	
January 19	12:00 NOON	1323	Walace	
Janaury 20	11:00 A.M.	1323	Steele	
January 24	11:00 A.M.	1324	Wallace	
January 25	11:30 A.M.	1324	Wallace	
January 26				No reading.
January 27				No reading.
January 28				No reading.
January 29				No reading.
January 30	1:30 P.M.	1326	Steele	
January 31	12:00 NOON	1326	Wallace	
February 1	12:00 NOON	1326	Wallace	
February 2				No reading.
February 3	10:00 A.M.	1325'6"	Steele	
February 4	11:30 A.M.	1325'6"	Steele	
February 7	3:15 P.M.	1325	Wallace	
February 10	10:00 A.M.	1326	Steele	
February 12	10:00 A.M.	1325'6"	Steele	
February 14	11:20 A.M.	1320	Wallace	
February 15	9:30 A.M.	1318'6"	Stoabs	Rezeroed wire line unit.
February 16	11:00 A.M.	1317	Steele	
February 17	10:00 A.M.	1317'6"	Steele	
February 18	11:00 A.M.	1317'6"	Steele	
February 21	1:00 P.M.	1317	Wallace	
February 22	11:30 A.M.	1317	Wallace	
February 23	11:30 A.M.	1318	Wallace	
February 24	8:30 A.M.	1318	Steele	
February 25	11:00 A.M.	1318	Steele	
February 26	9:30 A.M.	1318	Steele	
February 27	9:30 A.M.	1318	Steele	
February 28	11:00 A.M.	1318	Wallace	
March 1	11:10 A.M.	1318	Wallace	
March 2	6:45 A.M.	1317	Wallace	
March 3	6:00 P.M.	1318'6"	Steele	
March 4	8:00 A.M.	1318'6"	Steele	

(1)	(2)	(3)	(4)	(5)
March 4	4:15 P.M.	1319	Steele	
March 5	7:15 A.M.	1319	Steele	
	5:30 P.M.	1319'6"	Steele	
March 6	7:15 A.M.	1320	Steele	
March 7	7:00 A.M.	1319'6"	Wallace	
March 8				No reading.
March 11	8:00 A.M.	1320	Steele	
March 12	8:00 A.M.	1320	Steele	
March 13	7:45 A.M.	1320	Steele	
March 14	11:30 A.M.	1323	Walace	
March 15	7:40 A.M.	1322	Wallace	
March 16	1:00 P.M.	1322	Steele	
March 17	7:30 A.M.	1322	Steele	
March 18	6:30 A.M.	1322'6"	Steele	
March 19	10:00 A.M.	1323	Steele	
March 20	10:30 A.M.	1323'6"	Steele	
March 22	12:00 NOON	1324'6"	Wallace	
March 24	9:15 A.M.	1324'6"	Steele	
March 25	4:00 P.M.	1325	Steele	
March 26	10:30 A.M.	1325	Steele	
March 27	1:30 P.M.	1326	Steele	
March 28	11:45 A.M.	1326	Wallace	
March 30	11:00 A.M.	1327	Walace	
March 31	8:45 A.M.	1327	Steele	
April 1	9:30 A.M.	1328	Steele	
April 2	9:30 A.M.	1328	Steele	
April 3	9:45 A.M.	1328	Steele	
April 4	11:30 A.M.	1328'6"	Wallace	
April 5	10:45 A.M.	1328'6"	Wallace	
April 6	10:00 A.M.	1329	Wallace	
April 7	10:00 A.M.	1329	Wallace	
April 8	9:45 A.M.	1329'6"	Steele	
April 9	10:30 A.M.	1329'6"	Steele	
April 10	8:30 A.M.	1330	Steele	
April 11	9:40 A.M.	1330'6"	Wallace	
April 12	7:30 A.M.	1330'6"	Wallace	
April 13	9:00 A.M.	1331	Steele	
April 14	8:00 A.M.	1331'6"	Steele	
April 15	10:30 A.M.	1331'6"	Steele	
April 16	9:45 A.M.	1332	Wallace	
April 17	10:00 A.M.	1332	Wallace	
April 18	10:30 A.M.	1333	Wallace	
April 19	10:15 A.M.	1333	Wallace	
April 20	12:30 P.M.	1333'6"	Wallace	
April 21	12:00 NOON	1334	Bud	
April 22	8:15 A.M.	1333'6"	Bud	
April 23	7:30 A.M.	1334	Steele	
April 24	9:30 A.M.	1334	Steele	
April 25				No reading.
April 26	11:00 A.M.	1335	Wallace	
April 27	12:50 P.M.	1335	Wallace	

(1)	(2)	(3)	(4)	(5)
April 28	7:30 A.M.	1334		
April 29	10:30 A.M.	1333	Steele	
April 30	7:15 A.M.	1335	Steele	
May 1	8:00 A.M.	1336	Steele	
May 2	11:30 A.M.	1337	Wallace	
May 3	12:30 P.M.	1337	Wallace	
May 4	1:00 P.M.	1337	Wallace	
May 6	10:45 A.M.	1337	Steele	
May 7	10:15 A.M.	1337	Steele	
May 8	9:45 A.M.	1337	Steele	
May 9	11:00 A.M.	1336	Wallace	
May 10	12:30 P.M.	1337	Wallace	
May 11	11:00 A.M.	1337	Wallace	
May 12	10:30 A.M.	1338	Wallace	
May 13	10:00 A.M.	1339	Steele	
May 14	10:15 A.M.	1339	Steele	
May 15	9:30 A.M.	1339	Steele	
May 16	11:00 A.M.	1340	Wallace	
May 17	11:30 A.M.	1340	Wallace	
May 18	9:00 A.M.	1340'6"	Steele	
May 19	1:00 P.M.	1341	Steele	
May 20	9:30 A.M.	1341	Steele	
May 21	9:45 A.M.	1341	Steele	
May 22	9:30 A.M.	1341'6"	Steele	
May 23	10:45 A.M.	1341'6"	Wallace	
May 24	9:30 A.M.	1342	Wallace	
May 25	10:45 A.M.	1342	Steele	
May 26	9:00 A.M.	1342	Steele	
May 27	9:00 A.M.	1342'6"	Steele	
May 28	9:15 A.M.	1342'6"	Steele	
May 29	9:15 A.M.	1342'6"	Steele	
May 30	11:00 A.M.	1344	Wallace	
May 31	10:30 A.M.	1344	Wallace	
June 1	12:40 P.M.	1344'6"	Wallace	
June 2	12:00 NOON	1344'6"	Wallace	
June 3	10:15 A.M.	1344'6"	Steele	
June 4				No reading
June 5	9:35 A.M.	1344'6"	Wallace	
June 6	11:30 A.M.	1345	Wallace	
June 7	12:30 P.M.	1345'6"	Wallace	
June 8	10:15 A.M.	1345'6"	Wallace	
June 9	11:00 A.M.	1346	Wallace	
June 10	10:15 A. M.	1346	Steele	
June 11	11:00 A.M.	1346'6"	Steele	
June 12	11:00 A.M.	1347	Wallace	
June 13	11:00 A.M.	1347	Wallace	
June 14	10:00 A.M.	1348	Wallace	

(1)	(2)	(3)	(4)	(5)
June 15	10:30 A.M.	1348	Steele	
June 16	11:00 A.M.	1348	Steele	
June 17	9:30 A.M.	1348	Steele	
June 18	8:40 A.M.	1349	Steele	
June 19	9:30 A.M.	1350	Wallace	
June 20	10:30 A.M.	1349'6"	Wallace	
June 21	11:30 A.M.	1350	Steele	
June 22	10:30 A.M.	1350	Steele	
June 23	9:45 A.M.	1349	Steele	
June 24	9:15 A.M.	1349	Steele	
June 25	9:40 A.M.	1348'6"	Steele	
June 26	9:15 A.M.	1348'6"	Wallace	
June 28	9:30 A.M.	1348	Steele	
June 29	9:20 A.M.	1348	Steele	
June 30	9:20 A.M.	1347'6"	Steele	
July 1	10:00 A.M.	1347'6"	Steele	
July 2	10:00 A.M.	1347'6"	Steele	
July 3	9:30 A.M.	1348	Wallace	
July 4	11:15 A.M.	1348	Wallace	
July 5	10:50 A.M.	1348	Wallace	
July 6	11:10 A.M.	1348'6"	Wallace	
July 7	10:45 A.M.	1348'6"	Steele	
July 8	10:45 A.M.	1348'6"	Steele	
July 9	9:30 A.M.	1349	Steele	
July 10	9:50 A.M.	1349	Wallace	
July 11	12:30 P.M.	1349	Wallace	
July 12	9:30 A.M.	1349	Wallace	
July 13	1:00 P. M.	1350	Steele	
July 15	11:00 A.M.	1350	Wallace	
July 17	11:10 A.M.	1351	Wallace	
July 18	12:00 Noon	1351	Wallace	
July 19	10:30 A.M.	1352	Wallace	
July 20	11:00 A.M.	1352	Wallace	
July 21	12:45 P.m.	1352'6"	Steele	
July 23	10:00 A.M.	1353	Wallace	
July 24	11:00 A.M.	1353'6"	Wallace	
July 25	12:00 NOON	1353'6"	Wallace	
July 26	11:50 A.M.	1354	Steele	
July 28	9:15 A.M.	1354'6"	Steele	
July 31	10:00 A.M.	1355	Wallace	
August 1	1:30 P.M.	1355'6"	Wallace	
August 2	11:30 A.M.	1356'6"	Steele	
August 4	9:00 A.M.	1357	Steele	
August 6	9:30 A.M.	1357'6"	Wallace	
August 8	10:30 A.M.	1359'6"	Wallace	
August 9	1:55 P.M.	1360'6"	Steele	
August 10	11:00 A.M.	1360'6"		

(1)	(2)	(3)	(4)	(5)
August 13	9:30 A.M.	1361	Steele	
August 15	10:35 A.M.	1361'6"	Wallace	
August 16	9:40 A.M.	1363'6"	Wallace	
August 17	11:35 A.M.	1362'6"	Wallace	
August 19	2:00 P.M.	1363	Wallace	
August 20	11:45 A.M.	1363'6"	Steele	
August 21	10:30 A.M.	1364	Steele	
August 22	11:15 A.M.	1364	Wallace	
August 23	11:45 A.M.	1364'6"	Wallace	
August 24	12:00 NOON	1365	Steele	
August 25	10:30 A.M.	1365	Steele	
August 26	10:00 A.M.	1365'6"	Steele	
August 27	11:00 A.M.	1365'6"	Steele	
August 28	10:00 A.M.	1365'6"	Steele	
August 29	10:00 A.M.	1366	Wallace	
August 30	1:30 P.M.	1367	Wallace	
August 31	11:30 A.M.	1367'6"	Wallace	
September 1	9:15 A.M.	1367'6"	Steele	
September 2	10:00 A.M.	1368	Steele	
September 3	9:45 A.M.	1368	Steele	
September 4	9:35 A.M.	1368'6"	Steele	
September 5	10:20 A.M.	1370	Wallace	
September 6	10:45 A.M.	1370	Wallace	
September 7	11:00 A.M.	1370'6"	Wallace	
September 8	11:00 A.M.	1370'6"	Steele	
September 9	9:30 A.M.	1370'6"	Steele	
September 10	9:15 A.M.	1371	Wallace	
September 11	9:45 A.M.	1371	Wallace	
September 12	10:25 A.M.	1370'6"	Wallace	
September 13	11:30 A.M.	1370'6"	Wallace	
September 14	10:55 A.M.	1370'6"	Wallace	
September 15	8:45 A.M.	1370'6"	Steele	
September 16	12:15 P.M.	1371	Steele	
September 17	11:00 A.M.	1371	Steele	
September 18	10:30 A.M.	1371	Steele	
September 19	10:30 A.M.	1371	Wallace	
September 20	11:00 A.M.	1371'6"	Wallace	
September 21	9:00 A.M.	1371	Wallace	
September 22	9:30 A.M.	1371	Steele	
September 23	11:10 A.M.	1371'6"	Steele	
September 24	11:00 A.M.	1371'6"	Steele	
September 25	10:15 A.M.	1371'6"	Steele	
September 26	10:00 A.M.	1372	Wallace	
September 27	11:15 A.M.	1372 '6"	Wallace	
September 28	8:45 A.M.	1372'6"	Steele	
September 29		1372'6"	Steele	
September 30	11:00 A.M.	1372'6"	Steele	
October 1	10:00 A.M.	1373	Steele	
October 2	10:00 A.M.	1374	Wallace	
October 3	11:05 A.M.	1375	Wallace	
October 4	11:40 A.M.			

(1)	(2)	(3)	(4)	(5)
October 5	11:15 A.M.	1375	Wallace	
October 6	9:30 A.M.	1375	Steele	
October 7	11:00 A.M.	1375	Steele	
October 8	10:30 A.M.	1375'6"	Steele	
October 9	11:00 A.M.	1375'6"	Steele	
October 10	12:50 P.M.	1377	Wallace	
October 11	12:00 NOON	1377	Wallace	
October 12	9:25 A.M.	1377'6"	Steele	
October 13	11:45 A.M.	1378	Steele	
October 14	10:45 A.M.	1378	Steele	
October 15	10:00 A.M.	1378'6"	Steele	
October 16	10:30 A.M.	1378'6"	Steele	
October 17	11:10 A.M.	1379	Wallace	
October 18	11:30 A.M.	1380	Wallace	
October 19	10:00 A.M.	1380	Wallace	
October 20	9:30 A.M.	1380'6"	Steele	
October 21	11:00 A.M.	1380'6"	Steele	
October 22	12:00 NOON	1380'6"	Steele	
October 23	11:20 A.M.	1381	Steele	
October 24	2:00 P.M.	1381'6"	Wallace	
October 25	2:30 P.M.	1382	Wallace	
October 26	9:45 A.M.	1382	Steele	
October 27	9:45 A.M.	1382	Steele	
October 28	11:45 A.M.	1382'6"	Steele	
October 29	12:00 NOON	1382'6"	Steele	
October 30	11:00 A.M.	1383	Steele	
October 31	12:30 P.M.	1383	Wallace	

FLUID LEVEL MEASUREMENTS
PUERTO CHIQUITO UNIT #F-6

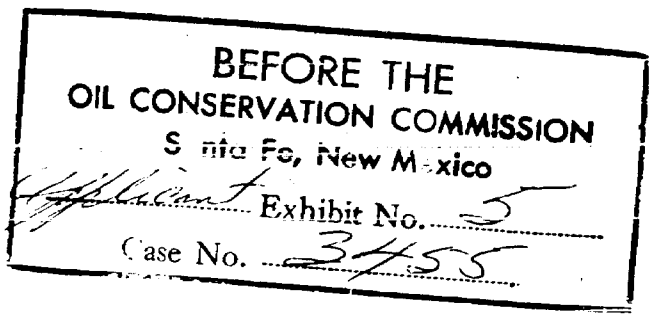
DATE	TIME MEASURED	(3) FLUID LEVEL (FEET FROM SURFACE)	(4) PERSON MEASURING FLUID LEVEL	(5) REMARKS
1965				
August 13		1405	Lee	
November 19		1414	Lee	
1966				
February 15		1424	Stoabs	Wire Line Unit #2 Oil in hole.
May 12		1439	Stoabs	Ran BHP.
May 13		1439	Steele	
May 14	9:45 A.M.	1439	Steele	
May 15	9:15 A.M.	1439	Steele	
May 16	10:00 A.M.	1439	Steele	
May 20	11:00 A.M.	1439'6"	Steele	
May 22	10:30 A.M.	1440	Steele	
May 24	12:15 P.M.	1442	Wallace	
May 26	7:10 A.M.	1442	Steele	
May 28	8:45 A.M.	1442	Steele	
May 31	11:00 A.M.	1442	Wallace	
June 1	11:00 A.M.	1443	Wallace	
June 3	11:00 A.M.	1443	Steele	
June 5	11:00 A.M.	1443	Wallace	
June 7	2:30 P.M.	1444	Wallace	
June 9	11:45 A.M.	1445	Wallace	
June 11	9:30 A.M.	1445	Wallace	
June 13	12:30 P.M.	1445'6"	Wallace	
June 15	11:00 A.M.	1445'6"	Steele	
June 16	11:00 A.M.	1445'6"	Steele	
June 18	8:15 A.M.	1445'6"	Steele	
June 20	11:30 A.M.	1446'6"	Wallace	
June 22	11:15 A.M.	1446	Steele	
June 24	9:00 A.M.	1446	Steele	
June 26	8:45 A.M.	1446	Steele	
June 29	10:30 A.M.	1446'6"	Steele	
July 1	9:00 A.M.	1446'6"	Steele	
July 3	8:45 A.M.	1447	Steele	
July 5	12:30 P.M.	1447'6"	Wallace	
July 7	10:00 A.M.	1448	Wallace	
July 9	9:50 A.M.	1448	Steele	
July 10	9:45 A.M.	1448'6"	Steele	
July 12	10:40 A.M.	1449	Wallace	
July 13	12:30 P.M.	1449'6"	Wallace	
July 15	11:30 A.M.	1449	Steele	
July 17	9:40 A.M.	1449'6"	Wallace	

(1)	(2)	(3)	(4)	(5)
July 18	12:30 P.M.	1449'6"	Wallace	
July 20	1:00 P.M.	1450'6"	Wallace	
July 24	11:45 A.M.	1450'6"	Wallace	
July 26	12:15 P.M.	1450	Wallace	
July 28	7:30 A.M.	1450'6"	Steele	
July 31	9:15 A.M.	1451	Steele	
August 2	12:30 P.M.	1451'6"	Wallace	
August 4	8:15 A.M.	1451'6"	Steele	
August 6	9:30 A.M.	1452	Steele	
August 8	4:30 P.M.	1452	Wallace	
August 10	10:00 A.M.	1452'6"	Steele	
August 13	8:30 A.M.	1453	Steele	
August 14	11:45 A.M.	1453'6"	Steele	
August 16	11:45 A.M.	1453'6"	Wallace	
August 20	10:50 A.M.	¼ 54'6"	Steele	
August 23	12:45 P.M.	1454'6"	Wallace	
August 25	9:30 A.M.	1454'6"	Steele	
August 27	9:15 A.M.	1454'6"	Steele	
August 29	9:30 A.M.	1455'6"	Wallace	
August 31	12:30 P.M.	1455'6"	Wallace	Rezeroed line.
September 1	9:30 A.M.	1456	Steele	
September 2	9:50 A.M.	1456	Steele	
September 4	9:15 A.M.	1456	Steele	
September 6	10:00 A.M.	1457	Wallace	
September 8	9:45 A.M.	1457	Steele	
September 10	9:15 A.M.	1457	Wallace	
September 12	11:15 A.M.	1458'6"	Wallace	
September 14	2:30 P.M.	1458	Wallace	
September 16	12:30 P.M.	1458'6"	Steele	
September 18	9:20 A.M.	1458'6"	Steele	
September 20	12:30 P.M.	1459	Wallace	
September 22	8:15 A.M.	1459	Steele	
September 24	9:00 A.M.	1459	Steele	
September 26	9:00 A.M.	1459'6"	Wallace	
September 28	10:00 A.M.	1460	Steele	
September 30	9:00 A.M.	1460	Steele	
October 2	9:15 A.M.	1460	Steele	
October 4	12.50 P.M.	1461	Wallace	
October 6	8:00 A.M.	1461	Steele	
October 8	11:00 A.M.	1461'6"	Steele	
October 10	1:25 P.M.	1461'6"	Wallace	
October 12	11:00 A.M.	1462	Steele	
October 14	9:30 A.M.	1462	Steele	
October 16	9:35 A.M.	1462'6"	Steele	
October 18	10:20 A.M.	1464	Wallace	
October 20	9:15 A.M.	1464	Steele	
October 22	10:50 A.M.	1464'6"	Steele	
October 24	10:45 A.M.	1465	Wallace	

(1)	(2)	(3)	(4)	(5)
October 26	10:45 A.M.	1465	Steele	
October 28	11:15 A.M.	1465'6"	Steele	
October 30	9:30 A.M.	1465'6"	Steele	

BENSON-MONTIN-GREER DRILLING CORP.
EXHIBITS IN CASE 3455
BEFORE THE
NEW MEXICO OIL CONSERVATION
COMMISSION
NOVEMBER 16, 1966

DATA RELATIVE TO ECONOMICS



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SECTION C: AMOUNT OF PRODUCTION DELAYED BECAUSE OF INTERFERENCE TESTS CONDUCTED IN SOUTHWEST PUERTO CHIQUITO (2 SHEETS)

SECTION D: SCHEDULE SHOWING COMPARATIVE COST OF CONSTRUCTION AND RESULTING DAMAGE TO FOREST LANDS AS FUNCTION OF WELL SPACING

SECTION E: REVENUE ACCRUING TO THE UNITED STATES, THE STATE OF NEW MEXICO AND RIO ARRIBA COUNTY FOR EACH TEN MILLION BARRELS OF OIL PRODUCED FROM SOUTHWEST PUERTO CHIQUITO, FEDERAL LANDS

[redacted]

CURRENT NET VALUE OF OIL TO WORKING INTEREST
FROM WELLS ON LEASES IN WHICH
BENSON-MONTIN-GREER OWNS AN INTEREST
IN NORTHEAST PUERTO CHIQUITO
(BEFORE OPERATING EXPENSE)

Posted price of 40° oil		$2.80
Less gravity penalty (for 33° oil)	.14	
Less transportation differential (25¢ to Apache Junction + 5¢)	.30	
Value after adjustment for gravity and transportation		$2.36
Less royalty, overriding royalty and taxes	.80	
NET VALUE TO WORKING INTEREST BEFORE OPERATING EXPENSE		$1.56

ECONOMICS OF DEVELOPMENT DEPENDENT ON WELL SPACING FOR 3000' WELLS, PUERTO CHIQUITO AREA

PER BARREL REVENUE:

Net value of oil per barrel to working interest before operating expense	$1.56
Less operating expense	.25
PER BARREL REVENUE	$1.31

	WELL SPACING - ACRES PER WELL		
	40	80	160
Gross oil production at 700 barrels per acre	28,000 bbl.	56,000 bbl.	112,000 bbl.
Revenue to working interest	$36,680	$73,360	$146,720
Drilling Cost	65,000	65,000	65,000
PROFIT or (LOSS)	$ (28,320)	$8.360	$81,720

PROFIT FIGURE DOES NOT INCLUDE AN ALLOWANCE FOR DRY HOLES, LEASEHOLD COST, INTEREST ON INVESTMENT OR INCOME TAXES.

[redacted]

WELL COSTS WEST PUERTO CHIQUITO MANCOS
FOR
COMPLETED WELLS OPERATED BY BENSON-MONTIN-GREER DRILLING CORP.

WELL	TOTAL
Canada Ojitos A-14	$ 275,767.28[1]
Canada Ojitos A-16	157,205.07
Canada Ojitos A-23	200,961.39[2]
Canada Ojitos B-18	150,282.18
Canada Ojitos C-2	146,086.57
Canada Ojitos K-13	175,624.68
Canada Ojitos L-11	162,892.02[3]
Canada Ojitos P-11	168,896.88
Jicarilla 200 D-21	220,598.90
	$ 1,658,314.97

1. Costs above average because of down hole fire and subsequent directional drilling of portion of hole.

2. Costs above average because of drilling and testing the Greenhorn and Dakota formations.

3. Includes approximately $15,000.00 coring and testing.

Leasehold, operating and $70,000.00 Engineering and testing costs not included in above figures.

Total expenditure on above wells $1,658.314.97.

Average cost per producer (7producers out of 9 wells) is $236,902.14.

CURRENT NET VALUE OF OIL TO WORKING INTEREST FROM WELLS ON LEASES IN WHICH BENSON-MONTIN-GREER OWNS AN INTEREST IN SOUTHWEST PUERTO CHIQUITO (BEFORE OPERATING EXPENSE)

Posted price of 40° oil		$2.80
Less gravity penalty (for 39° oil)	.02	
Less transportation differential (25¢ to Apache Junction + 5¢)	.30	
Value after adjustment for gravity and transportation		$2.48
Less royalty and taxes	.47	
NET VALUE TO WORKING INTEREST BEFORE OPERATING EXPENSE		$2.01

ECONOMICS OF DEVELOPMENT AS DEPENDENT ON WELL SPACING FOR WELLS IN THAT PART OF THE PUERTO CHIQUITO POOL WHICH ARE DRILLED IN THE SANTA FE NATIONAL FOREST * ENCOUNTERING "ZONE A" OF NIOBRARA AT AVERAGE DATUM OF + 500 FEET SEA LEVEL REFERENCE

I. BASIS OF DRILLING AND COMPLETION COST ESTIMATE:

(a) Average cost of first nine wells drilled from canyon floor to top of Zone A at ± 6500' — $184,222

(b) Estimated future cost of similar wells drilled from canyon floor — $175,000

(c) Estimated cost differential per foot for increased depths if necessary to build locations at higher elevations on mountainsides:

1. Rotary rig cost	$ 7.00
2. Trucking costs	5.00
3. Mud and water (probably will experience loss of circulation)	35.00
4. Intermediate casing (7-5/8") and tubing	4.00
	$51.00

(Use $50.00 for estimate)

II. PER BARREL REVENUE:

Net value of oil per barrel to working interest before operating expense	$2.01
Less operating expense	.25
Per barrel revenue	$1.76

* South part of West Puerto Chiquito

SUMMARY OF ECONOMICS AS DEPENDENT ON WELL SPACING
FOR WELLS IN THAT PART OF THE PUERTO CHIQUITO POOL
WHICH ARE DRILLED IN THE SANTA FE NATIONAL FOREST

	WELL SPACING - ACRES PER WELL			
	40	80	160	320
Gross production at 500 barrels per acre	20,000 bbl.	40,000 bbl.	80,000 bbl.	160,000 bbl.
Revenue to working interest	$35,200	$70,400	$140,800	$281,600
Drilling and completion cost:				
(a) Basic cost of 6500' well located in canyon floor	165,000	165,000	165,000	165,000
(b) Road and location costs	30,000	35,000	30,000	10,000
(c) Depth differential cost: 160 acres - 1000' 80 acres - 800' 40 acres - 600'	30,000	40,000	50,000	0
TOTAL COST PER WELL	$225,000	$240,000	$245,000	$175,000
PROFIT or (LOSS) per well	(189,800)	(169,600)	(104,200)	$106,600

PROFIT FIGURE DOES NOT INCLUDE ALLOWANCE FOR DRY HOLES, LEASEHOLD COST, INTEREST ON INVESTMENT OR INCOME TAXES

[redacted]

AMOUNT OF PRODUCTION DELAYED BECAUSE OF INTERFERENCE TEST CONDUCTED IN SOUTHWEST PUERTO CHIQUITO MAY 1965 THROUGH SEPTEMBER 1966 (NIOBRARA PARTICIPATING AREA - CANADA OJITOS UNIT)

YEAR & MONTH	PROBABLE PARTICIPATING AREA ALLOWABLE IF INTERFERENCE TEST HAD NOT BEEN RUN (BBLS) (1)	ACTUAL PRODUCTION RESULTING UNDER TEST CONDITIONS (BBLS) (2)	DIFFERENCE COLUMN (2) MINUS COLUMN (1) OVER OR UNDER ( ) (BBLS) (3)	CUMULATIVE DIFFERENCE UNDER ( ) (BBLS) (4)
1965				
May	33,232	15,492	(17,740)	(17,740)
June	32,160	3,020	(29,140)	(46,880)
July	33,232	413	(32,819)	(79,699)
August	33,232	13,067	(20,165)	(99,864)
September	32,160	18,718	(13,442)	(113,306)
October	33,232	28,221	(5,011)	(118,317)
November	32,160	28,070	(4,090)	(122,407)
December	32,232	34,489	2,257	(120,150)
1966				
January	32,232	33,407	1,175	(118,975)
February	30,016	27,013	(3,003)	(121,978)
March	32,232	32,243	11	(121,967)
April	32,160	26,263	(5,897)	(127,864)
May	33,232	29,219	(4,013)	(131,877)
June	32,160	29,564	(2,596)	(134,473)
July	33,232	27,430	(5,802)	(140,275)
August	33,232	24,585	(8,647)	(148,922)
September	28,200	27,975	(225)	(149,147)

[redacted]

ESTIMATE OF COMPARATIVE COST OF CONSTRUCTION OF ROADS AND LOCATIONS AND RESULTING DAMAGE TO FOREST LANDS SANTA FE NATIONAL FOREST AS FUNCTION OF WELL SPACING

	WELL SPACING - ACRES PER WELL			
	320	160	80	40
Estimated per well cost of roads and location	$10,000	$10,000 1st well $50,000 2nd well	$10,000 1st well $50,000 2nd well $40,000 3rd well $40,000 4th well	$35,000 1st to 4th $25,000 5th to 8th
Average	$10,000	$30,000	$35,000	$30,000
Total cost per 640-acre section	$20,000	$120,000	$200,000	$480,000
Road and location costs per section as percent of cost of 40-acre development	4.1%	25%	58%	100%
Comparative damage to forest lands	2%	25%	58%	100%

ESTIMATE DOES NOT INCLUDE PRICE PAID TO FOREST FOR TREES DESTROYED. THIS COST IS BASED ON A BOARD-FOOT BASIS AND IT IS ASSUMED THAT MOST OF THIS COST CAN BE RECOVERED BY SELLING THE TIMBER TO LUMBER MILLS.

REVENUE ACCRUING TO THE UNITED STATES,
THE STATE OF NEW MEXICO AND RIO ARRIBA COUNTY
FOR EACH TEN MILLION BARRELS OF OIL PRODUCED FROM
SOUTHWEST PUERTO CHIQUITO (FEDERAL LANDS)

CURRENT WELLHEAD VALUE $2.48 FOR 39° API

SOURCE	AMOUNT ACCRUING TO UNITED STATES	NEW MEXICO	RIO ARRIBA COUNTY
12½% ROYALTY	$1,937,500	$1,162,500	
2.55% NEW MEXICO SALES TAX ON WELLHEAD SALES		632,400	
2.5% SEVERANCE TAX		620,000	
3% NEW MEXICO SALES TAX ON PIPELINE TRANSPORTATION CHARGE OF 30¢/BBL		90,000	
AD VALOREM TAX		92,380	$279,620
T O T A L	$1,937,500	$2,597,280	$279,620

NOTE: (1) AD VALOREM TAX RATE ESTIMATED TO BE AVERAGE .030

(2) CONSERVATION TAX EXCLUDED FROM ABOVE FIGURES

dearnley-meier

SPECIALIZING IN: DEPOSITIONS, HEARINGS, STATEMENTS, EXPERT TESTIMONY, DAILY COPY, CONVENTIONS

1120 SIMMS BLDG. • P. O. BOX 1092 • PHONE 243-6691 • ALBUQUERQUE, NEW MEXICO

BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
November 5, 1969

EXAMINER HEARING

IN THE MATTER OF:

Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320 acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico for a period of three years.

Case No. 3455

BEFORE: Elvis A. Utz, Examiner

TRANSCRIPT OF HEARING

MR. UTZ: Case 3455.

MR. HATCH: Case 3455 reopened. In the matter of Case No. 3455 being reopened pursuant to the provisions of Order No. R-2565-B, which order, among other things, established 320-acre spacing units for the West Puerto Chiquito-Mancos Oil Pool, Rio Arriba County, New Mexico, for a period of three years.

The applicant has requested that the case be continued for at least thirty days. The next Examiner Hearing that would closely come to that period, would be one set for December 17. The time on that Examiner Hearing is 10:00 A.M., December 17, 1969.

MR. UTZ: Case 3455 will be continued to Examiner Hearing the 17th of December. This Hearing will be on the same day as a regular state-wide Hearing; will be called at 10:00 o'clock, December 17th.

STATE OF NEW MEXICO)
) ss
COUNTY OF BERNALILLO)

I, Wayne Flores, Court Reporter in and for the County of Bernalillo, State of New Mexico, do hereby certify that the foregoing and attached Transcript of Hearing before the New Mexico Oil Conservation Commission was reported by me; and that the same is a true and correct record of the said proceedings, to the best of my knowledge, skill and ability.

Wayne Flores
Court Reporter

I do hereby certify that the foregoing is a complete record of the proceedings in the Examiner hearing of Case No. 3455, heard by me on Dec. 5, 1962.

Examiner
New Mexico Oil Conservation Commission

dearnley-meier
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METHODS OF INTERPRETATION OF PRESSURE BEHAVIOR IN THE OIL PRODUCING FRACTURED SHALE RESERVOIRS OF THE PUERTO CHIQUITO POOL RIO ARRIBA COUNTY, NEW MEXICO

November 1, 1966

BEFORE THE
OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
Exhibit No. 1
Case No. 3455

NOVEMBER 10, 1966 EDITION

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METHODS OF INTERPRETATION OF PRESSURE BEHAVIOR IN THE OIL PRODUCING FRACTURED SHALE RESERVOIRS OF THE PUERTO CHIQUITO POOL

I. INTRODUCTION

This paper presents some of the engineering concepts used by Benson-Montin-Greer Drilling Corp. personnel in the interpretation of the pressure-production histories and interference tests of wells producing from oil reservoirs in the Niobrara Member of the Mancos Shale Formation in the Puerto Chiquito Pool, Rio Arriba County, New Mexico. Benson-Montin-Greer Drilling Corp., as operator of a substantial proportion of the oil and gas leases in the Puerto Chiquito Pool, has made application to the New Mexico Oil Conservation Commission regarding spacing of wells in this pool, and also, as operator of the federal units within the Puerto Chiquito Pool, currently makes recommendations to the U.S.G.S. relative to development of these units and sizes of participating areas. Most of these matters which will be ruled on by the New Mexico Oil Conservation Commission and the U.S.G.S. are dependent upon engineering and geological facts, and interpretations of these facts. The purpose of this paper is to provide material to the New Mexico Oil Conservation Commission and the U.S.G.S. engineers to assist them in study of the engineering data supplied by Benson-Montin-Greer Drilling Corp.

Early analysis of well costs in the Puerto Chiquito Pool and analogy with other fractured shale reservoirs indicated that this pool could be economically developed only on well spacing patterns considered wide by standards of other New Mexico fields.

This analogy was helpful in initiating development in Puerto Chiquito, but analogy has its limitations, and direct determination of physical reservoir properties was considered desirable. These properties, however, cannot be determined in Puerto Chiquito by ordinary methods of coring and logging, since the producing reservoirs are fractured shales. The only means available by which some of these properties may be estimated is analysis of pressure-production data and interference tests.

It is possible, for example, from properly conducted interference tests, to determine oil in place per acre, and where a high degree of communication exists, total oil in place and areal extent of a reservoir can also be approximated from data developed from the first few wells completed in it. Use of interference tests in Puerto Chiquito for quantitative determination of oil in place per acre, however, requires that the tests be conducted on a reservoir-wide basis, because of the high degree of communication existing. Such information, then, can only be obtained for reasonable costs by planned interference tests and transfer of allowables under special Oil Conservation Commission orders. Accordingly, upon application of Benson-Montin-Greer Drilling Corp., the New Mexico Oil Conservation Commission in September, 1963, granted a three-year temporary order respecting field rules and permitting production and interference tests to be conducted, in order to better evaluate the reservoir conditions in the Puerto Chiquito Pool.

Benson-Montin-Greer Drilling Corp., on behalf of the owners of leases it operates, has, in the time allotted, made a

good faith and determined effort to develop reliable data from well tests and to provide methods of interpretation of the data accumulated. Interference tests of the type necessary to provide the data required are costly. Approximately $70,000.00 has been spent in the Puerto Chiquito Pool conducting tests and developing engineering data, and an additional $300,000.00 of delayed income has resulted. Commission orders have permitted transfer and make up of allowable, so that income not be delayed or lost, providing the transfer wells are capable of producing the total allowable. Despite this provision, however, it was recognized prior to commencement of tests that allowable would be lost. Nevertheless the tests were conducted. These facts are mentioned only to point up the importance which the well owners attach to the engineering data provided by the tests.

The full value of the data developed by tests, however, cannot be realized unless it is properly interpreted and analyzed. Accordingly the applicable technical literature has been carefully reviewed, and Benson-Montin-Greer Drilling Corp. personnel have made a serious attempt to develop methods of interpretation of the data obtained in testing the Puerto Chiquito wells, which methods are set out herein. Some of the methods are general and will apply to any reservoir of uniform properties. Some of the analyses apply only to the Puerto Chiquito reservoirs, or to reservoirs of similar properties, and must not be considered generally applicable. It is recognized that no two oil-producing reservoirs are exactly alike, and these differences in characteristics require that the reservoirs be individually analyzed.

Methods set out in this paper utilize only existing principles of physical behavior of reservoir rocks and fluids. No new theories are presented. However, some of the methods of application of these principles have not been generally used or published in the technical literature. These are therefore set out in detail so that the New Mexico Oil Conservation Commission and U.S.G.S. engineers can more readily study the methods and verify their applicability.

This paper is forwarded prior to the 1966 Puerto Chiquito Pool spacing hearing, in order that these agencies know in advance the methods of interpretation which Benson-Montin-Greer Drilling Corp. personnel will use in presenting its case. It is hoped that this will allow time to verify the methods, or if not, to prepare queries for witnesses to clarify any methods or procedures that are not self-evident.

II. GENERAL DISCUSSION

As pointed out in the introduction, it was recognized at the 1963 Puerto Chiquito spacing hearing that interference tests would be desirable to make direct determination of some of the reservoir properties and to establish the conditions which were presumed by analogy to exist. Since the 1963 hearing there have emerged three specific reasons making quantitative analysis of the interference tests even more important, particularly as applied to conditions in Southwest Puerto Chiquito. These three specific reasons follow.

First, during the first year of the three-year temporary spacing order, before enough wells were drilled in Southwest Puerto Chiquito to conduct interference tests of the type desired, interference was observed during completion of new wells. The degree of communication evident was surprising, if not alarming. It appeared probable that a fracture system existed in the reservoir with a transmissibility which was higher than would be anticipated from the producing ability of the completed wells. Under such conditions it is obvious that well spacing will have a negligible effect on efficiency of recovery of oil in place by the solution gas drive mechanism. It is recognized, however, that communication and efficiency of recovery alone do not completely satisfy the criteria to establish optimum well spacing. It is also necessary to determine that the wells can produce the recoverable oil in a reasonable length of time. The time for a well to deplete its allotted drainage area is dependent, among other things, upon the amount of recoverable oil under this drainage

area. Determination of this volume of oil implies knowledge of oil in place per unit area (as for instance barrels per acre). In order to establish, then, that the recoverable oil under any spacing pattern can be produced in a reasonable length of time, we need first to establish the oil in place per acre. Accordingly, for this specific reason, quantitative analysis of interference tests became important to confirm the probable range of values of oil in place per acre.

Second, from information available at the 1963 spacing hearing it appeared that the entire Puerto Chiquito area was underlain by one common source of supply. The effect, if any, of permeability restrictions throughout the pool, and whether these barriers would be significant in preventing migration from one area to another during the producing life of the pool, was unknown. Accordingly, to protect correlative rights in the event of communication throughout the entire area, a uniform allowable was requested for both the shallow and deep parts of the pool, so that orderly development and protection of correlative rights might ensue. This was granted by the Commission at the 1963 hearing, and established by temporary order. During development under the temporary order, information has been obtained which establishes the production in Southwest Puerto Chiquito to be from a reservoir separate from production in the east part of the pool. Accordingly it now seems appropriate to divide the area into two pools with a north-south dividing line, and this is one of the provisions requested by Benson-Montin-Greer Drilling Corp. in its application for the 1966 spacing hearing covering this pool. If the area be divided in this fashion, it is noted that in the east part of the

pool production has been established over the greater part of its length, and at one part across its breadth. In the west portion, however, production has been established only in the southwest part. This, then, points up the question as to how large an area should be covered by the West Puerto Chiquito Pool spacing order. Since an approximation of the areal extent of the reservoir in communication with the producing wells in Southwest Puerto Chiquito can be made if a quantitative approximation can be determined as to the total oil in place in the reservoir and the oil in place per acre, it becomes desirable to determine these values from pressure-production data and interference tests.

Third, from geological inference of the information presented in the 1963 hearing, it was believed that the Puerto Chiquito area covered a rather large reservoir. Production data and interference tests since that time confirm this. The reservoir in communication with the producing wells in Southwest Puerto Chiquito alone probably contains a volume of oil measured in terms of tens of millions of barrels. This is a large enough reservoir to consider secondary recovery or pressure maintenance measures. Whether such measures have any chance of success in such a reservoir as is found in Puerto Chiquito, however, requires determination of some of the physical properties which might be obtained from interference tests. For this reason, then, quantitative analysis of interference tests is desirable.

In addition to the above reasons, it is important to make a direct determination of oil in place per acre to support the estimates of recovery made by analogy with the most comparative

field known (Boulder-Mancos). By this analogy, per-acre recoveries in Southwest Puerto Chiquito by solution gas drive should be less than that resulting in Boulder, because of the greater amount of gas in solution and higher shrinkage. Even so, when one realizes that a single well in Southwest Puerto Chiquito has already produced as much oil as seven average Boulder wells on 80-acre spacing produced to depletion, and this well is still capable of producing high rates at maximum solution gas drive efficiency (i.e., the produced gas-oil ratio is still at the dissolved gas-in-solution ratio), and that any reasonable projection of future production suggests that the better wells in Southwest Puerto Chiquito are each capable of producing as much oil as all twenty-four wells in the Boulder Pool, the importance of confirmation of the presumed effective drainage area determined by analogy is evident.

Direct determination of the physical reservoir properties controlling oil in place per acre and total oil in place in the reservoir have been made from analysis of interference tests and production data for Southwest Puerto Chiquito. Examples of type of calculations which will be used to determine these quantities for Puerto Chiquito are given in this paper. One example of calculation of total oil in place is given for the Boulder-Mancos Pool.

Since the Boulder Pool is now practically depleted and it is analogous in some respects to the reservoirs of the Puerto Chiquito Pool, information as to Boulder's production behavior is helpful in analyzing conditions in the Puerto Chiquito Pool.

Interpretation, however, of pressure data from all of these fractured shale reservoirs (Boulder included) on the east side of the San Juan Basin is complicated in comparison with many oil producing reservoirs. These complicating factors which involve both analysis by analogy and direct analysis should be recognized. They are as follows:

1. The producing formation dips steeply in each of the known reservoirs, and actual reservoir pressures vary substantially from up-dip to down-dip limits.

2. Each of the three presently defined reservoirs, Boulder Mancos, Southwest Puerto Chiquito (Cañada Ojitos Unit Niobrara Participating Area), and Northeast Puerto Chiquito, during at least some part of its producing history has contained both undersaturated oil and saturated oil. The Boulder reservoir also contained free gas in communication with the oil at the time of discovery. Estimates of total oil in place in a reservoir determined from pressure-production data require a knowledge of the compressibility of the fluids, and because of the widely varying compressibilities of saturated oil, undersaturated oil and free gas, an accurate determination of oil in place from pressure decline can only be made if the proportion of the reservoir occupied by each of these fluids is known. Since it is impossible in Puerto Chiquito to determine these saturations exactly, estimates of oil in place must be qualified by recognition of the probable range of values which apply to each fluid saturation.

3. Calculations of total oil in place from pressure decline, for the condition in which undersaturated oil occupies

a large part of the reservoir, require an accurate determination of the compressibility of the reservoir rock. No information is now available from any known sources as to compressibility of fractured shale formations. The estimates must then recognize the uncertainty of this factor and its effect on the computed reservoir volume.

4. The portion of the reservoir which is occupied by mobile water is also difficult to determine. Some of the wells in the Boulder Pool produce a substantial amount of water, and in Northeast Puerto Chiquito one well has been completed relatively high up-dip on the structure which produces one hundred percent water, but which also is in pressure communication with offset wells producing oil with low water cuts, and several hundred feet up-dip from wells producing clean oil.

The above described complicating factors are recognized in the interpretation of data by assigning ranges of probable values for the affected quantities and making graphical presentations of the computed results. In this fashion the magnitude of the effects of each of the uncertainties of these factors is clearly evident, and a better understanding of interpretations results.

III. COMPRESSIBILITIES OF THE RESERVOIR ROCKS AND FLUIDS

Both determination of total oil in place in a reservoir from pressure decline and oil in place per unit area from interference tests require a knowedge of the effective compressibility of the system under consideration. This total system compressibility is best approximated by summing the individual effects of components of the system. These components, aside from the rock itself, are the following fluids: Free gas, saturated oil, undersaturated oil, connate water and mobile water within the hydrocarbon portion of the reservoir, and bottom water or aquifer. These fluids are represented schematically on Figure 1, in which they are arranged as they might occur in a reservoir by gravitational segregation. Depending upon the amount the pressure has declined below the bubble point, the saturated oil part of the reservoir will also probably contain free gas dispersed within it.

Discussions of the compressibilities of the rocks and fluids and manner of determining their values are set out below in Paragraphs Nos. 1 through 5. Paragraph No. 6 shows the method in which these individual compressibilities are used to determine effective compressibility of a system. Paragraph No. 7 identifies some of the compressibilities with the terms of one of Muskat's equations for calculating solution gas drive production histories. Attachments A, B and C to this paper are reservoir fluid analyses from wells in the subject reservoirs and from which some of the data relative to compressibilities was obtained.

All compressibilities used in this paper are defined by the equation:

$$C = \frac{\Delta V}{V \Delta P} \qquad (1)$$

where P is in pounds per square inch. For consistency and to more readily show the relative values of the compressibilities of the various components, all compressibilities in this paper are expressed in terms of 10^{-6} .

1. COMPRESSIBILITY OF FREE GAS:

Free gas is the most compressible fluid we deal with. This compressibility can be accurately determined. Since its effect on the total system, however, depends on its saturation (fraction of pore space occupied) this total effect can be only as accurate as the saturation is known.

The method of calculating compressibility of free gas used in this paper is from the equation (1,2,3)*

$$C_g = \frac{1}{P} - \frac{1}{Z}\frac{dz}{dp} \qquad (2)$$

where C_g = gas compressibility, psi^{-1}

Z = gas deviation factor

P = pressure, psia

Gas deviation factors (Z) were available from the Boulder and Southwest Puerto Chiquito reservoir fluid analyses. For Northeast Puerto Chiquito they were estimated from gas gravity and reservoir temperature. These deviation factors for the subject reservoirs are shown on Figure 2. The resulting compressibilities are shown on Figure 3. It is interesting to note that although

* All references are given at end of appendix

an appreciable difference exists in the absolute values of the deviation factors for Boulder and Southwest Puerto Chiquito, the value dz/dp over the range of pressures currently of interest is nearly the same, and consequently the free gas compressibilities for these two reservoirs are, for practical purposes, identical (for the same pressures).

2. COMPRESSIBILITY OF UNDERSATURATED OIL:

The value for the undersaturated oil is readily determined by laboratory analysis, providing of course a proper sample has been obtained. There are methods available in the technical literature for calculating the value of the compressibility of undersaturated oil if the solution gas-oil ratio, temperature, pressure and gravity of the oil are known. The error from either laboratory measurement or computed value will be relatively small. In the instance of Boulder, Northeast Puerto Chiquito and Southwest Puerto Chiquito, laboratory analyses of bottom hole samples are available. These compressibilities vary only slightly with pressure. The figures are provided directly in the fluid sample analyses in Attachments A, B and C to this paper. Values range from about 6 x 10-6 for Northeast Puerto Chiquito to about 10 x 10-6 for Southwest Puerto Chiquito. These figures are considered quite reliable. However, the same situation exists here as for free gas, in that the effect of this compressibility on the overall system compressibility is also a function of its saturation (fraction of res rvoir pore space it occupies).

With respect to the part of the reservoir occupied by

undersaturated oil, it is noted that each of the reservoirs from which have been obtained data with respect to saturation pressures of oil indicate that this saturation pressure was near the original pressure in the structurally high part of the reservoir, and that early in the life of production pressures in this part of the reservoir dropped below the bubble point, while at the same time a substantial amount of oil down-dip existed at pressures above the bubble point. Because of the long vertical column of oil, a significant part of the producing history of each of these reservoirs occurs at times when it contains both saturated oil and undersaturated oil. This must be taken into account in any interpretation of pressure behavior, as the reservoir will accordingly have a history of pressure versus cumulative production different from that of a typical reservoir in which there is a comparatively small vertical column of oil.

3. COMPRESSIBILITY OF SATURATED OIL:

In contrast to undersaturated oil, compressibility of saturated oil is quite dependent on pressure. Ordinarily fluid studies provide this compressibility for one set of conditions. If compressibilities at other conditions are required, the values may be obtained by calculation if certain other data are known. Values of compressibilities of saturated oil used in this paper result from the following relation:[4,5,6]

$$C_{os} = \frac{-1}{B}\frac{dB}{dP} + \frac{G}{B}\frac{dR}{dP} \qquad (3)$$

where C_{os} = compressibility of saturated oil, psi^{-1}

B = Oil Formation Volume factor, reservoir volume/ stock tank volume

P = Pressure, psi

R = Solution gas-oil ratio, standard cubic feet per barrel

G = Gas formation volume factor, reservoir barrels per standard cubic foot

Formation volume factors (B, above) for the three reservoirs, Boulder, Southwest Puerto Chiquito and Northeast Puerto Chiquito, taken from the attached fluid studies are shown on Figure 4. Gas in solution values (R, above) from the same sources are shown on Figure 5. Values of G were calculated using the deviation factors of Figure 2. The resulting compressibilities are shown on Figure 6.

Here again, the effect of the saturated oil compressibility on the overall system compressibility is partly dependent on its saturation (fraction of pore space occupied).

4. COMPRESSIBILITY OF FORMATION WATER:

Most of the literature on material balance equations show compressibilities of formation water to be relatively small. Even water which contains dissolved gas has compressibilities on the order of 3 to 4 x 10^{-6}. Muskat (7) indicates that strict accounting of the effect of connate water requires that it be treated the same as saturated oil. Ramey (6) has given numerical values to connate water compressibilities by recognizing this, in that it will have a different compressibility when pressures are lowered below its "bubble point" pressure. Compressibility of saturated water has been calculated by the method shown by Ramey, and is set out on Figure No. 7. These are the values used for connate water and mobile water for pressures

below its bubble point. For pressures higher than the bubble point values were determined by the method shown by Dodson and Standing [8].

5. COMPRESSIBILITY OF RESERVOIR ROCK:

No information has been developed regarding formation compressibility of fractured shales. Values used by Benson-Montin-Greer Drilling Corp. personnel are estimated from information in the technical literature of compressibilities of sandstones and limestones.

Laboratory measurements of formation compressibility have been made by Hall [9] and Fatt [10].

Hall investigated sandstone and limestone formations with a porosity range from 2 to 26 percent, using an overburden pressure of 3,000# and reservoir pressures of zero to 1,500#. From this work Hall developed a correlation between porosity and compressibility.

Fatt measured compressibilities of sandstones with porosities varying from 10 to 15 percent, and in a net overburden pressure range of zero to 12,000#. Fatt found a correlation between compressibility and net overburden pressure, but no relation of compressibility to porosity.

Figure No. 8 shows the approximate results of Hall's work and Fatt's work. Also shown on the graph is the range of compressibilities used by Benson-Montin-Greer Drilling Corp. in estimating compressibilities of reservoir systems in the Puerto Chiquito Pool.

It is believed that the Niobrara fractured shale reservoirs have a low porosity, on the order of 2 to 4 percent,

and that, all other factors being equal, one intuitively expects shale to be more compressible than sandstone or limestone. For this reason minimum values for the Puerto Chiquito reservoir formation compressibilities were assumed to be somewhat higher than would be determined from Hall's work for 2 percent porosity. Using this as a base, values were estimated for different overburden pressure ranges by paralleling the trend indicated by Fatt's work. Maximum values were arbitrarily estimated at about twice the maximum (for each overburden pressure) shown by Fatt's work.

Because information as to compressibility of fractured shale formations is so indefinite, calculations involving formation compressibilities were made using both the minimum and maximum values indicated on Figure No. 8, in order that results be obtained covering the assumed range of compressibilities of fractured shale.

Formation compressibility is, of course, a significant component when total system compressibility is small, such as for periods when substantially all of the oil is undersaturated and there is little or no free gas. After pressures have dropped below the bubble point throughout the reservoir, formation compressibility will be of little significance and can often be totally disregarded. In Southwest Puerto Chiquito, for example, the range of compressibility shown on Figure No. 8 will yield a two-to-one difference (100 percent) for oil in place using the maximum and minimum formation compressibilities indicated if the reservoir contains only undersaturated oil. On the other hand, only 10 percent difference in value of computed oil in place results if the oil is below the bubble point.

6. EFFECTIVE COMPRESSIBILITY OF RESERVOIR:

Many forms of material balance equations have been developed. The form which will be used herein derives from the method shown by Craft and Hawkins [11] and which utilizes "effective compressibility" as it applies to one of the components (oil) forming the total system compressibility.

"Effective" compressibility of the oil saturated part of pore volume of some reservoir systems can be approximated as:

$$C_e \equiv \frac{S_o C_o + S_w C_w + C_f}{S_o} \qquad (4)$$

where C_e = "Effective" total system compressibility for oil

C_o = Compressibility of oil

C_w = Compressibility of water

C_f = Formation compressibility

S_o = Fraction of pore space occupied by oil

S_w = Fraction of pore space occupied by water

Equation (4) applies to undersaturated oil. It is obvious, however, that this equation can be expanded to include saturated oil and free gas as follows:

$$C_e \equiv \frac{S_{ou} C_{ou} + S_{os} C_{os} + S_g C_g + S_w C_w + C_f}{S_{ou} + S_{os}} \qquad (5)$$

where the symbols, in addition to those shown above, represent:

C_{ou} = Compressibility of undersaturated oil

C_{os} = Compressibility of saturated oil

C_g = Compressibility of free gas

S_{ou} = Fraction of pore space occupied by undersaturated oil

S_{os} = Fraction of pore space occupied by saturated oil

S_g = Fraction of pore space occupied by free gas

It is also apparent that compressibility effects of mobile water or a limited aquifer can be treated in the same fashion by expanding Equation (5). One must, of course, select the proper factors to fit the circumstances. It will apply if the effective compressibility is to be used to compute total oil in place in the reservoir, and static pressures are available for the entire oil reservoir, aquifer and gas cap. Equation (5) can be used to determine total oil in place from rate of decline of pressures in observation wells while the reservoir is being produced, if conditions are such that the initial pressure transients have passed throughout and pressures are declining at a uniform rate in the oil reservoir, gas cap and aquifer. If, however, unsteady state conditions exist, then the situation must be treated in a fashion to recognize this.

For calculation of oil in place per unit area, the compressibility must be for the area affected during the time of the test, which ordinarily will not extend into an aquifer or gas cap, and these compressibilities will not form a part of the system compressibility under consideration.

As to compressibility of connate water, no information is available as to its "bubble point". Since it is possible that the reason that the Puerto Chiquito reservoirs contained undersaturated oil on discovery is because of subsidence of the formations, causing otherwise saturated oil to

become subject to higher pressures and hence undersaturated, the same may apply to the connate water. Accordingly, for any particular calculation, compressibility of connate water has been determined by assuming the same fraction of total connate water to be undersaturated as the fraction of total oil is assumed to be undersaturated.

7. USE OF COMPRESSIBILITIES FOR PURPOSES OTHER THAN DETERMINATION OF OIL IN PLACE

Although most of the calculations of total oil in place in the reservoir have been made using formulas which are approximate rather than exact, it is of course possible to use the compressibilities of Paragraphs 1 through 5 for use in equations which take the factors into account exactly.

Also, for calculating production histories, if one uses Muskat's [12] method involving, among other equations, the following:

$$\left(1+\frac{\mu_o}{\mu_g}\psi\right)\frac{dp_o}{dp} = p_o\lambda(p) + (1-p_o-p_w)\varepsilon(p) + p_o\eta(p)\psi \qquad (6)$$

it is noted that two of the above terms are numerically equal to terms calculated in determining compressibilities, and can be used in the graphical integration of Equation (6). These are:

ε in Equation (6) is equal to gas compressibility, Equation (2), Page 12 of this paper, and given directly on Figure No. 3.

λ in Equation (6) is the same as the second term $\frac{G\ dr}{B\ dp}$ of Equation (3) of this paper.

IV. CALCULATION OF TOTAL OIL IN PLACE IN A DRAINAGE AREA FROM DECLINE IN STATIC PRESSURES

A simplified material balance type of calculation has been used to estimate total reservoir oil in place. This is:

$$N = \frac{N_p}{C_e \ \Delta P} \qquad (7)$$

where N = Total stock tank barrels of oil in place in the drainage area

N_p = Stock tank barrels of oil produced during reservoir pressure decline ΔP (in psi)

C_e = "Effective" total system compressibility for oil

This equation results from that of Craft and Hawkins (13) after dropping the formation volume factor term. This equation is not intended to be an exact solution, rather it is recognized as yielding approximate results. Its accuracy is, however, adequate for the purposes used. Errors resulting from its inexact nature will be small compared with the uncertainties of the effective compressibilities which must be used.

Although approximation of total oil in place can be made using this equation in conjunction with effective compressibilities as defined in Section III of this paper for time periods when part or all of the reservoir is below the bubble point, it should only be used before critical gas saturation is reached. For obvious reasons, when pressures are below this point and produced gas-oil ratios exceed the solution ratio, conventional material balance methods should be used.

Ramey (6) has shown how two-phase compressibilities can be determined for pressures below the bubble point and above

critical gas saturation. This method was not used in calculations of Puerto Chiquito reservoirs, however, because of the uncertainty of initial free gas saturation, and accordingly the necessity to include such a term.

V. COMPARISON OF RESERVOIR CHARACTERISTICS OF FRACTURED SHALE RESERVOIRS WITH SANDSTONE RESERVOIRS

It is believed that the reservoirs in the Puerto Chiquito Pool consist of fractured shales and that the fractures not only form the flow channels by which oil is brought to the well bores, but actually form the reservoir void space itself. Accordingly, the permeability and resulting transmissibility of the formation is high with respect to the pore volume, when compared with sandstone or intergranular limestone reservoirs. This is illustrated graphically on Figure No. 9, which shows the relation of porosity to permeability for sandstones and the relation of porosity to permeability for a type of fracture system in which the fractures are parallel to the direction of flow.

The information regarding sandstone porosities and permeabilities is from the work of Bulnes and Fitting [14]. About 93 percent of the approximately 2,200 samples investigated by Bulner and Fitting fall within the range indicated on Figure 9.

The relation of porosity to permeability for systems of parallel fractures of equal width was computed from the equation shown by Muskat [15] for permeability for a fracture, which, after converting to fracture width, w, in inches is:

$$K = 5.36 \times 10^{7} w^{2} \text{ darcys} \qquad (8)$$

and recognizing the law of parallel flow.

It is to be expected, of course, that not all fractures in a fractured shale reservoir will be parallel to the direction of flow, and accordingly porosity for a given permeability can be expected to be somewhat higher than that

indicated on Figure No. 9. Even so, it is hard to visualize a fracture system with ten to fifty fractures per foot which will contain a pore volume greater than one-tenth to one-fiftieth of that for a sandstone with similar permeability. Accordingly, per-acre oil in place in a fractured shale reservoir is anticipated to be substantially less than for a sandstone reservoir with wells of comparable producing abilities.

This feature of fractured shales, in that permeability is relatively high compared to porosity, in addition to the difference in per-acre oil in place for similar producing abilities of wells when compared with sandstones, is a significant property which causes these fractured shales to have a relatively higher degree of communication through a reservoir. This relation, permeability to porosity, can be expressed as a ratio:

$$\frac{K}{\phi} \qquad (9)$$

where K = permeability, darcys

ϕ = porosity, fraction

In this paper, because of the high permeabilities in Puerto Chiquito, the equations are expressed in darcys, rather than the customarily used dimension of millidarcys. Values of $\frac{K}{\phi}$ (darcys) are indicated on Figure No. 8 for values of $\frac{K}{\phi}$ in multiples of ten.

It is helpful, in studying the high degrees of communication found in fractured shales, to compare values of the diffusivity constant for these fractured shales to those

normally to be expected from sandstones. The diffusivity constant determines the time of the transient period of pressure disturbances in a reservoir resulting from the withdrawal of fluid. Muskat [16] describes this constant as being the analog of the diffusivity in heat conduction or diffusion systems. In this paper the diffusivity constant is given the symbol η and for dimensions of the units used in this paper it has the following value:

$$\eta = \frac{6.328K}{\phi C \mu} \qquad (10)$$

where K = Permeability, darcys

ϕ = Porosity, fraction

C = Compressibility, $\Delta V/V/psi$

μ = Viscosity, centipoises

It should be noted here that the product of

$$C\phi = C_e\phi_{hc} \qquad (11)$$

where C = Total system compressibility

ϕ = 100 percent porosity

C_e = "Effective" porosity (referred to oil phase)

ϕ_{hc} = Effective porosity of the oil phase
= $\phi (1 - S_w - S_g)$

Consequently, in computing the diffusivity constant one may use either of the terms of equation (11) in equation (10).

With the diffusivity constant having the dimensions of Equation (10), it can be used in the time transient equations that follow, where distance is measured in feet and time is measured in days.

Using Figure No. 9 to determine the range of values of $\frac{K}{\phi}$ for sandstones of 10, 100 and 1,000 millidarcys, and computing the diffusivity constant from Equation (10), data is developed from which Figure No. 10 can be constructed, showing values of the diffusivity constant as a function of $\frac{K}{\phi}$ and $C\mu$.

Also shown in Figure No. 10 for comparison with sandstones is the apparent range of values of $\frac{K}{\phi}$ for the Southwest Puerto Chiquito reservoir. The diffusivity constant for Southwest Puerto Chiquito is accordingly indicated to be in the order of 5×10^6 to 1×10^7.

We now have a means for comparing the order of magnitude of time of transient periods of pressure behavior for sandstones of given permeabilities with fractured shales.

For example, Muskat [17] has shown the time required to establish steady state conditions can be approximated from the elements of the diffusivity constant. In the dimensions of the units used in this paper this relation is:

$$t \equiv \frac{r_f^2}{4\eta} \qquad (12)$$

where t = time to establish steady state conditions, days

r_f = drainage distance, feet

η = diffusivity constant

In the instance of a circular drainage area, the approximation indicated above becomes exact, if r_f is the radius.

It is also interesting to note that the time t of Equation (11) is also the time required for a shut-in well in

a closed reservoir to reach static conditions. This is apparent from Perrine's [17] work. Perrine shows that at a value of dimensionless time, $\overline{t}$, of .25, a shut-in well in a closed reservoir will reach static conditions. Using dimensions of units of this paper, Perrine's dimensionless time may be expressed as

$$\overline{t} = \frac{\eta t}{r^2} \qquad (13)$$

where the symbols have meanings previously set out in this paper. Accordingly, for a value of $\overline{t} = .25$, Equation (13) becomes identical with Equation (12).

The time indicated by Equation (12) to establish steady state conditions is set out on Figure No. 11 as a function of drainage radius and diffusivity constant.

Using Figures No. 10 and No. 11 one may approximate the times required to reach steady state conditions or the drainage radius over which steady state conditions might be reached in a given time period. For example, a well producing from a low pressure 10 millidarcy sandstone reservoir at pressure below the bubble point would have (from Figure No. 10) a diffusivity constant approximating 1,000, and in ten days steady state conditions could be established over a drainage radius of 200 feet. A well producing from a 100 millidarcy sandstone reservoir containing undersaturated oil and other compressibilities comparable to Southwest Puerto Chiquito could in ten days establish steady state conditions over a drainage radius approximating 3,000 feet. In Southwest Puerto Chiquito the comparable drainage radius is about 15,000 feet.

This high value of the diffusivity constant for fractured shales can be useful in determining average reservoir pressures from observation wells. It creates difficulty, however, in determining some of the reservoir properties customarily obtained from pressure build-up tests, as for instance transmissibility (Kh). Miller, Dyes and Hutchinson [18] and Perrine [17] have shown that for a shut-in well in a closed reservoir the pressure will cease to be a function of $\log_{10}$ time at a dimensionless time value of .03. Determination, then, of the time (t_x) prior to which data must be obtained in order to calculate Kh from a pressure build-up test can be determined by substituting .03 for $\bar{t}$ in Equation (13), from which the following relation results:

$$t_x = \frac{r_f^2}{33.3\eta} \qquad (14)$$

This relation is shown graphically on Figure No. 12. This indicates, for example, that for a diffusivity constant of 5×10^6 (order of magnitude of Southwest Puerto Chiquito) only the first two or three hours of pressure build-up data (0.1 day) can be used to determine Kh if the drainage radius is 4,000 feet. Since the first few hours of pressure build-up may be influenced by "after production", it is obvious that use of pressure build-up data in Southwest Puerto Chiquito to determine Kh is possible only on a reservoir-wide basis, and even then, boundary effects must be recognized as possibly influencing the pressures.

To assist in comparing drainage radius with drainage area, Figure No. 13 is provided, which shows circular drainage area as a function of drainage radius.

VI. CALCULATION OF TOTAL OIL IN PLACE IN A DRAINAGE AREA DETERMINED FROM RATE OF PRESSURE DECLINE UNDER PRODUCING CONDITIONS

The relatively high values of the diffusivity constant for the reservoirs in the Puerto Chiquito and Boulder Pools cause these reservoirs to be particularly adaptable to methods of determining rate of pressure decline from a few observation wells while the reservoir is in a producing condition. Muskat has shown that the interference effects of wells producing from a common reservoir are cumulative. Accordingly it is evident that where a high degree of communication exists (high value of the diffusivity constant) the rate of decline in reservoir pressure can be determined from a few observation wells.

In order that the pressure decline in any particular observation well be representative of the overall rate of reservoir pressure decline, it is necessary that the wells be produced at reasonably constant rates, and that each well have been produced long enough that its interference effects throughout the reservoir will be in the time period following its initial pressure transient (i.e., each well produced as long as the time required to establish steady state conditions). Under such conditions, if the reservoir is closed, steady state conditions will not of course prevail. The pressure, however, will decline at uniform rate (i.e. in pounds/day). At any one time the individual observation wells may have rather widely varying absolute pressures when compared with each other. These pressures will differ because of the different degrees of interference caused by producing wells. The rate of decline,

however, will be the same in all the observation wells.

Information on the Boulder Field is used to illustrate this manner of estimating total oil in place in a reservoir. It is believed that average transmissibility of the Boulder Reservoir is fairly high. Individual well values cover a wide range from about 200 millidarcy feet to as high as the 47,000 millidarcy feet reported by Standard of Texas for one of its wells at the Commission hearing regarding spacing for the Boulder Pool. Such high values are of course difficult to measure with accuracy; even so, it is obvious that the transmissibility is quite high in many of the wells, and it is reasonable to presume that the range of the overall average transmissibility for the Boulder reservoir could be as high as 1 to 10 darcy feet (1,000 to 10,000 millidarcy feet). It appears that the Boulder Pool will ultimately produce approximately 700 barrels per acre, and if the recovery factor is on the order of one-sixth to one-third of the oil in place it suggests an initial oil in place per acre of two to four thousand barrels. This gives a range of $\frac{K}{\phi_{hc}}$ of 1.5 to 30 darcys. With a system compressibility of 20×10^{-6} to 50×10^{-6} for undersaturated oil and with a viscosity of 3 centipoises, a range for the product of $C\mu$ of 60 to 150×10^{-6} is indicated. This means a value for the diffusivity constant η of 4×10^{4} to 4×10^{6} (from Equation (10) or Figure No. 10 of this paper).

Initial pressures measured in Mobil's 12-14 and 23-14 wells in the north part of the pool during early development of the reservoir can be used within limits to approximate

the total volume of oil in the reservoir. These wells are located some three miles from the southern limits of the field, and it can be seen from Figure No. 11 of this paper that for this distance a diffusivity constant of 1×10^6 would permit steady-state conditions to be established over this distance in about forty days. This value of the diffusivity constant is within the range described above. There is now no way to determine that the average diffusivity constant in Boulder was at that time this high, but for the purpose of illustrating the method of computing total oil in place in a reservoir it will be assumed here that the diffusivity was this high, and that accordingly pressure decline in these test wells represented the rate of pressure decline of the entire reservoir.

The pressure-production history of the Boulder Pool is shown here as Figure No. 14. From this it can be seen that the initial pressure decline versus cumulative production for the period from first production to October 1, 1962, approximated 1,200 barrels per pound. With this information, and using the assumed compressibilities and saturations shown, the graph of Figure No. 15 was constructed (applying Equation (7), Page 21 of this paper). The presentation is made in this fashion because of the indefinite values of the saturations and compressibilities. The chief indeterminate factors of course are the percent of the reservoir which is occupied by undersaturated oil as opposed to saturated oil, and the amount of free gas in the reservoir. Even so, by using a reasonable range for these saturations, which for this time period would appear to be on the order of 7/10ths to 9/10ths of reservoir occupied by undersaturated

oil and something less than 5 percent being occupied by free gas, the total volume of oil in the Boulder reservoir appears to have minimum and maximum values of 3½ and 15 million barrels respectively. Although the center of the colored range in the shaded area of Figure No. 15 suggests a reservoir of 5 to 8 million barrels, the inherent uncertainties connected with fractured shale reservoir analysis make it impossible to definitely determine (from information available at the date 10-1-62) that the limits could be drawn closer together.

During the period from October 1, 1962, to May 1, 1963, Standard of Texas conducted interference tests on some of its wells, and information on these pressures plotted against total field production is shown by the upper solid line on Figure No. 14. The latter part of this curve from about January 1, 1963, to May 1, 1963, is during a time when the greater part of the reservoir would be saturated oil rather than under-saturated oil, and accordingly the rate of pressure decline has decreased. For this time interval it appears to be on the order of 3,000 barrels per pound. With this information, and the fact that the reservoir now contains mostly saturated oil, the same type of calculation can be made as for Figure No. 15 to yield the curves set out on Figure No. 16. The information now shows a more definitive range of figures for the oil in place. It can be seen from this Figure No. 16 that the range would be 4½ to 9 million barrels. Now the center of the shaded area in the range of assumed saturations suggests oil in place on the order of 5 to 6 million barrels. During the period from October, 1962, to May, 1963, production from the field was rather constant,

and as can be seen from Figure No. 11 a value of the diffusivity constant could be as low as 5×10^5 and data from Standard of Texas' observation wells could be representative of pressure decline in the entire reservoir, allowing the last 100 days of 1962 for the reservoir rate of pressure decline to adjust to a uniform value. Whether the interference effects of all wells had at that time passed their initial pressure transients is not known. Also, as for the case above, it is impossible now to tell. It is interesting to note, however, that the computation of oil in place by this method, assuming field-wide communication, yields a value which is of the proper order of magnitude. assuming that the recovery factor in Boulder will be on the order of one-sixth to one-third of the oil in place.

Perhaps it should be noted here that in Southwest Puerto Chiquito, tests have indicated a diffusivity constant greater than 5×10^6 and communication has been established by interference tests over distances measured in miles. Accordingly, during times when pressures are above the bubble point, the question as to whether data from observation wells in Southwest Puerto Chiquito is representative of reservoir-wide pressures is eliminated, and the method of determining total volume of reservoir oil in place by the method set out in this section can be applied to Southwest Puerto Chiquito with complete confidence that this necessary condition has been satisfied (in that rate of pressure decline in an observation well is representative of rate of pressure decline for the overall reservoir). *

* Excepted from this statement, of course, would be any part of the reservoir that is semi-isolated by permeability restrictions.

Also, for times when pressures are below the bubble point in local areas around producing wells and operating pressures in these wells are declining at a fasterrate (as dictated by the consequently changing relative permeability values in this local area), pressure data from observation wells may still be representative of overall reservoir pressure decline if pressures in these observation wells are still above the bubble point, and they are properly located with respect to the producing area and the main part of the reservoir. Whether the changing compressibilities in the local areas under these conditions will materially affect any particular calculation will depend in part on the magnitude of the difference in the pressure decline of the producing wells as compared to observation wells, and the relative volume of the subject affected area as compared to the overall reservoir volume. Only the pertinent facts of each case can determine if these factors will be significant and must be recognized.

In general, however, estimation of total oil in place in a reservoir by the above described method has many advantages over methods which require the reservoir to be in a static condition. As a matter of fact, few reservoirs are ever totally shut in and pressures allowed to reach static. Ordinary "key well" static pressure surveys, and methods of calculation of oil in place using this data, are subject to the same limitations above described, whether or not formally recognized in the calculation.

One important feature of the procedure herein used, in which rate of decline of pressure in an observation well is

considered to represent rate of decline in the entire reservoir, should be noted. This is, for pressures above the bubble point, or for pressures below the bubble point if relative permeability changes and resulting effects of compressibility changes can be disregarded, the often-required (in reservoir calculations) stipulation that reservoir properties be reasonably uniform is eliminated. For constant production rates, the rate of reservoir pressure decline following the initial transient period will be independent of local conditions of porosity, pay thickness and permeability. Extreme variation in these properties from one part of a reservoir to another will have no effect on an observation well. An observation well in one part of the reservoir will have the same rate of decline in pressure as a well in another part of the reservoir. Accordingly, if more than one observation well is used, and it is desired to average the results obtained, the data averaged should be rate of decline (in barrels/day or barrels/psi) rather than attempting to obtain absolute pressures at a given datum and averaging these pressures.

It is accordingly apparent that if a well-connected fracture system exists over a reservoir, which condition is believed to obtain in the Puerto Chiquito reservoirs, time required for the initial transient period to pass after putting wells on production will be more dependent on the diffusivity constant of the overall system than on the time required for a well locally to "stabilize" with the system. By methods shown above it can be determined that a well completed in a local area of low permeability, for example 500 acres with a value of Kh =

300 millidarcy feet and 2,000 barrels per acre of stock tank oil in place, will have reached a point equivalent to steady state condition in four or five days. (This example is for Southwest Puerto Chiquito conditions of oil viscosity, compressibility and pressures above the bubble point). Its effects from this time on would be a function of the overall system diffusivity constant. Accordingly, the effects of this well's production on the overall reservoir pressure, despite the fact it is completed in a "tight" part of the reservoir, might be accurately measured by an observation well two or three miles away within a few days after putting the well on production.

VII. ESTIMATION OF TOTAL OIL IN PLACE IN A DRAINAGE AREA FROM SINGLE COMPLETE PRESSURE BUILD-UP TEST

Methods have been shown in the technical literature whereby one may estimate the stabilized build-up pressure of a shut-in well in a closed reservoir from information obtained during an incomplete pressure build-up, if the approximate volume and geometry of the reservoir are known. It is accordingly possible, using the same principles, to determine total oil in place in the drainage area if a complete pressure build-up curve is available and the shape of the reservoir is known. The manipulation of the equations to solve for oil in place rather than for pressure is not complicated. However, for clarification one method is shown in the appendix (Part I). This is for use with the Perrine [17] method of using the data of Miller, Dyes and Hutchinson [18].

This method is illustrated using the build-up curves of Figure No. 17, which are for a well with the conditions indicated on Plate I of this figure. These build-up curves result for a well in a closed reservoir with a drainage radius of 27,650 feet, which has been produced for a period of time greater than that required to establish steady state condition before shutting in. This build-up curve assumes the well to be closed in at the reservoir, which of course ordinarily will not be the case. Rather, the pressure will build up more slowly than is indicated on Figure No. 17 until the effect of "after production" has ceased, at which time the actual build-up curve will coincide with the one shown on this Figure.

Procedure for use of this method to determine oil in place would be first to plot the pressure difference from the complete static build-up pressure against $\frac{\Delta t}{t + \Delta t}$ in the conventional semi-log plot, as shown in Plate II of Figure No. 17, in order to determine that we are dealing with a well in a closed reservoir rather than one affected by essentially infinite conditions (which would result if the well had produced for a time too short to equal that required to establish steady state conditions). If essentially infinite conditions exist, extrapolation of the build-up curve will show zero pressure difference from static at a point at which the quantity $\frac{\Delta t}{t + \Delta t}$ equals 1. If, however, the zero pressure difference from static occurs at a point substantially less than 1, or if a significant curvature appears in the upper part of the build-up plot, then it can be assumed that some form of boundary condition is affecting the pressure build-up. Oil in place in the drainage area can then be calculated.

Next, determine the slope, m, of the build-up curve from the plot of pressure difference from static against time on the log to base ten scale. For Plate I of Figure No. 17 this is 15 pounds per cycle. Then, determine the value of the dimensionless pressure difference, $\overline{\Delta P}$, from Figure No. 18 of this paper (after Perrine[17]) using the following relation:

$$\overline{\Delta P} = \frac{1.151(P_{ws} - P_t)}{m} \qquad (15)$$

The symbols are identified on Figure No. 18. Any point can be chosen along the build-up curve, as for example in Plate I of Figure No. 17, 3.7 pounds at 10 days. Substituting this value

in Equation 15 above yields a value for $\overline{\Delta P}$ of .28. Referring now to Figure No. 18, the equivalent dimensionless time $\overline{t}$ is .075.

Finally, the total volume of stock tank oil in the drainage area can then be computed from the following equation:

$$N = \frac{qt}{1.74\ m\ C_e\ \overline{t}} \qquad (16)$$

in which N = Total stock tank oil in place in the drainage area, barrels

q = Stabilized production rate prior to shutting in, barrels per day

m = Slope of the build-up plot in pounds per cycle

C_e = Effective hydrocarbon pore space compressibility as defined earlier in this paper

$\overline{t}$ = Dimensionless time determined from Figure No. 18 corresponding to the real time t in days at which $\overline{\Delta P}$ is determined as above.

Substituting the values shown on Plate I and as determined above into this equation yields the following:

$$N = \frac{(500)(10)}{(1.74)(15)(25\times10^{-6})(.075)}$$

$$= 102 \times 10^6 \text{ barrels stock tank oil}$$

The result, 102 million barrels, compares with the correct volume of 100 million barrels, the difference being the result of not reading the values from the curves exactly.

If in the above example the reservoir had been one in which constant pressure was maintained at the drainage radius, a value for $\overline{t}$ (Curve B of Figure No. 18) would have been .26 and the volume of oil in place in the drainage area would have

been 40 million barrels rather than 100 million barrels.

The obvious limitations of this method are the same that apply to extrapolation of static pressure from a partial build-up curve. Reservoir properties must be fairly uniform throughout the drainage area, and the drainage area for use of Equation (16) needs to be approximately circular in shape. Significant variation in these factors will of course cause significant variation in the computed result. If, for example, the well is located in a large reservoir but the area around the well is of substantially lower permeability than the rest of the reservoir, the result will show a smaller reservoir than actually exists. In this instance, however, the volume of the area of low permeability may be approximated from the assumption of the conditions of constant pressure being maintained at the boundary. Such a determination has been used in Southwest Puerto Chiquito to approximate the size of a local area of low permeability in a large reservoir.

It is noted here that because of the high value of the diffusivity constant in Southwest Puerto Chiquito, extrapolation of build-up pressure curves cannot accurately be accomplished without a knowledge of the geometry of reservoir boundaries. Matthews, Brons and Hazebroek [19] have shown that the geometrical shape of boundaries has a significant effect on the pressure build-up of wells in closed reservoirs. Little is now known of the geometry of the boundaries in Southwest Puerto Chiquito. Consequently for this reservoir any extrapolation of build-up pressures has been by comparison rather than computation by customary methods.

VIII. DETERMINATION OF OIL IN PLACE PER UNIT AREA FROM INITIAL PRESSURE TRANSIENTS

Part I - Preliminary Discussion

If the areal extent of a reservoir is known, it is of course a simple matter to determine the oil in place per unit area (i.e. barrels per acre) after one has first determined the total oil in the reservoir by one of the previously discussed methods. In the instance of Southwest Puerto Chiquito, however, the areal extent of the reservoir currently being produced is unknown, and this method cannot be used. Also, as stated in the introduction, data from cores and logs are of little use in Southwest Puerto Chiquito for estimating reservoir volumes. The only direct method of estimating pore volumes for these reservoirs is by analysis of the initial pressure transients which result when a well commences producing.

Muskat has shown that a well put to production at a constant rate in a reservoir in which conditions are stabilized and pressure above the bubble point will cause pressure disturbances throughout the reservoir. Pressure distributions for finite reservoirs can usually be considered in two phases with respect to the length of time the well has produced. These are an initial transient phase, which ordinarily is of relatively short duration, followed by a period of "steady-state" behavior (or period of uniform rate of pressure decline, depending on the boundary conditions).

During the second phase the pressure distribution for a given uniform rate of production from a reservoir of uniform thickness is dependent only on the drainage radii, permeability

and viscosity (and formation volume factor). For a reservoir with constant pressure maintained at its boundary, pressures throughout the reservoir will stabilize. For a closed reservoir the pressures throughout the reservoir will decline at a rate dependent on the total reservoir volume and its compressibility; the pressure distribution at any one time, however, will be dependent on the same factors (though in different relation to each other) as for the reservoir with constant pressure maintained at its boundary.

On the other hand, pressure distribution during the initial transient phase is dependent, in addition to the controlling factors of the second phase, on porosity and system compressibility. Accordingly, if proper pressure data can be obtained during the initial transient period, and all of the reservoir properties but one are known, it can be computed from the governing equations. If two or more properties are unknown, their relation may be determined.

Since in Southwest Puerto Chiquito no information is available as to any of the three factors, porosity, permeability or pay thickness, the transient flow equations are used to determine the relation of permeability to porosity ($\frac{K}{\phi}$). Then from customary methods (or by the modification described later in this paper) the transmissibility (Kh) is determined. Dividing Kh by $\frac{K}{\phi}$ one obtains the product ϕh, which defines unit pore volume. If system compressibility for the 100 percent pore volume is used, the result will be total reservoir pore volume. If "effective" oil phase compressibility is used, the result will be effective "hydrocarbon" (oil) volume. In this instance, $\phi_{nc}h$ will

result from solution of the equation. Since there are 7,758 barrels in an acre-foot, this unit pore volume can be expressed in terms of barrels per acre as follows:

$$\text{Barrels/acre} = 7{,}758 \times \phi_{hc} h$$

The time during which the initial pressure distributions are of a transitory nature, as defined by Muskat, is given by Equation 12 (Page 26) of this paper. All determinations of per acre oil in place from interference tests in Southwest Puerto Chiquito have been confined to this time period. Calculations are made by using the exponential integral solution of the diffusivity equation, in which the producing well is represented by a methematical "sink" or point in an infinite reservoir. Muskat [20] has indicated "suitable synthesis" of this equation to be the simplest way to construct solutions for compressible liquid systems. Horner [12] has stated that for the application of his report, the error caused by considering the well radius to be a point was negligible. As used in the methods of calculation that follow, it is believed the same negligible effect of this condition also obtains.

Although only the one equation is used in calculations of oil in place per unit area, it is of interest to study the similarities (and differences) of pressure behavior of a well as affected by boundary conditions of its reservoir. Generally, there are three different types of boundary condition which might apply. These are conditions of (1) boundary at infinite distance, (2) constant pressure maintained at boundary, (3) reservoir closed at the boundary.

Examples of these are given by Figure No. 19, which

shows pressure decline for a well with reservoir properties described on Plate I of this figure and for conditions of infinite reservoir and for reservoirs with certain finite boundaries. Conditions of both constant pressure at the boundary and closed boundary are shown. It is apparent from this figure that the boundaries have little effect on the example well until the time required to establish steady-state conditions is reached (between 32 and 33 days for the example conditions).

The pressure distributions for the different times and conditions indicated can be described by the following equations:

(a) Pressure distribution for the infinite reservoir:

This relation is as follows:

$$P_e - P = \frac{q \mu B}{14.16 Kh} \quad Ei \left[\frac{-r^2}{4\eta t} \right] \qquad (17)$$

where P_e = Pressure at radius r from producing well (pressure in psi and r in feet)

q = Constant production rate, barrels per day of stock tank oil

μ = Reservoir viscosity, centipoises

B = Formation volume factor

K = Permeability, darcys

h = Pay thickness, feet

Ei Exponential integral

η = Diffusivity constant as earlier defined in this paper

t = Time in days

For the infinite reservoir case the transient period is considered infinite and the pressure distribution will be governed by this equation throughout any time interval considered.

(b) Reservoir with pressure maintained constant at its boundary:

Prior to the time t defined in the first paragraph above, the pressure distribution approximates the infinite case described next above. After 32.7 days, if pressure is maintained constant at the reservoir boundary, the reservoir will be in a steady-state condition, for which Muskat [22] gives the pressure distribution as follows:

$$P_e - P = \frac{q\,\mu\,B}{3.076\,Kn} \log_{10} \frac{r_e}{r} \qquad (18)$$

where r_e = the circular drainage radius of the field boundary in feet

and other symbols have the same meaning as above.

(c) Closed Reservoir:

The exact pressure distribution for a well producing from a closed reservoir is given by Muskat [23], which defines the pressure distribution both during and after initial transient. Use of this equation is difficult and tedious. Horner [21], however, has given a relatively simple approximation which can be expressed as follows:

$$P_e - P = \frac{q\,\mu\,B}{14.16\,Kh}\left\{ Ei\left[\frac{-r^2}{4\eta t}\right] - Y\left[\frac{r_f^2}{4\eta t}\right]\right\} \qquad (19)$$

where r_f = Field radius in feet

Y = A function defined by Horner, the value of which is shown in his paper.

Hurst and Guerrero [24] have developed an adjustment for Horner's approximation to improve its accuracy. After the time which is equivalent to that required to establish steady-state conditions for a reservoir which has constant pressure at its boundary, the

pressures in a closed reservoir will from that time forward decline at a uniform rate in terms of pounds per day. Although clearly not a steady-state condition as found for a reservoir with constant pressure at its boundary, it is a condition of constant rate of pressure decline, and it is sometimes referred to as a steady-state decline. During this period in which the pressures are declining uniformly throughout the reservoir, pressure distribution at any one time is given by the following equation [25]:

$$P - P_w = \frac{q\,\mu\,B}{7.08\,Kh}\left(2.303\,\log_{10}\frac{r}{r_w} - \frac{r^2}{2r_e^2} + \frac{r_w^2}{2r_e^2}\right) \quad (20)$$

where P_w = Pressure in the producing well in psi

r_w = Effective drainage radius of the producing well in feet.

P = Pressure, psi, at radius r, feet

The other symbols have the same values as above.

It can be seen from figure No. 19 that the pressure distribution during the transient period can be rather closely approximated for any of the three boundary conditions with the relatively simple exponential integral formula for the infinite case. The amount of this deviation will of course vary with reservoir conditions. For Southwest Puerto Chiquito, with reservoir properties in the order of magnitude shown in the example, it is believed the unadjusted exponential integral formula will apply to the situations for which it has been used.

VIII. DETERMINATION OF OIL IN PLACE PER UNIT AREA FROM INITIAL PRESSURE TRANSIENTS

Part 2 - Calculation of per acre oil in place from initial pressure transient of a single well

It is possible, mathematically speaking, to calculate per acre oil in place from the transient pressure behavior of a single well. From a practical standpoint, because of the large influence of local conditions about the well bore (as for instance insufficient perforations in the casing through the producing section) it is seldom that such a calculation can be made with acceptable accuracy.

Example of this type calculation is useful, however, to illustrate the application of Equation (17) to calculation of per acre oil in place.

Equation (17) may also be written

$$P_e - P = \frac{m}{2.30} \quad Ei\left[\frac{-r^2}{4nt}\right] \qquad (21)$$

where m = slope of plot of pressure versus time on $\log_{10}$ scale

$$m = \frac{q\ u\ B}{6.15\ Kh} \qquad (22)$$

and symbols have the meanings shown on Figure No. 18.

Per acre oil in place for the well shown in Figure No. 19 is accomplished as follows:

First, determine the slope m to be 15 psi/cycle from Plate II of Figure 19.

Next, select a pressure drop for any time during which infinite ' conditions exist (period for which pressure drop is straight line function of time on $\log_{10}$ scale) which is any

time up to 32 days, as shown on Plate II of Figure No. 19, and substitute these values in Equation (21). It is here assumed that no independent knowledge of the properties, permeability, porosity or pay thickness, is known, but that oil viscosity of .65 centipoises is available and FVF = 1.28 and that effective compressibility (C_e) is 25×10^{-6}/psi.

Assuming that a pressure drop of 122 psi is read from Figure No. 19 at a time of 10 days, and substituting in Equation (21), one obtains (for a well bore radius of 1 foot):

$$\frac{P_e - P}{m} \times 2.30 = \frac{(122)(230)}{15} = Ei\left[\frac{-6.44 \times 10^{-8}}{K/\phi_{hc}}\right]$$

Next, from tables or calculation determine that the number whose exponential integral is 18.7 is -4.28×10^{-9} so that

$$4.28 \times 10^{-9} = \frac{6.44 \times 10^{-8}}{K/\phi_{hc}}$$

from which $\frac{K}{\phi_{hc}} = 15$ darcys

Kh is determined from the slope m, and other known factors by use of Equation (22) to be 4.5 darcy feet.

Dividing Kh by $\frac{K}{\phi_{hc}}$ yields $\phi_{hc}h$, which is $\frac{4.5}{15} = .3$ feet

The per acre volume of hydrocarbon pore space is accordingly

$$(.3)(7758) = 2{,}320 \text{ barrels}$$

Stock tank oil in place is determined by dividing by the formation volume factor of 1.28, which indicates approximately

1,800 barrels/acre.

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Part 3 - Calculation of per acre oil in place from interference tests during initial pressure transient period - Driscoll's method

Use of interference test wells to measure transient pressure behavior of a reservoir avoids the problem of local non-uniformity which attaches to the single well calculation. Under certain conditions a great deal of non-uniformity of properties near the producing well can exist, and oil in place still be accurately determined from pressures measured in adjoining wells. Ordinarily pressures in the shut-in test wells can also be measured more accurately, and the important factor, pressure drop, can be measured with a very high degree of accuracy in these wells if conditions are such that the pressure decline can be measured by drop in fluid levels.

An excellent paper on use of interference tests to calculate per acre oil in place has been written by Driscoll (26). Driscoll's subject is well treated, and no comment is offered here regarding method of calculation, other than to note that estimates of oil in place can be made through use of dimensionless time and dimensionless pressure drop, read from the graphs of his article. Such a method is of course only as accurate as the numbers can be estimated from the graph. This, however, is accurate enough for many purposes, and it has the advantage of avoiding the necessity of manipulating the Ei equation.

Driscoll's Figure 9 is reproduced here as Figure No. 20. For the use made of the data given thereon as it has been

applied to calculations of Southwest Puerto Chiquito interference tests and for the dimensions of units used in this paper, the following are noted:

$$t_D = \frac{6.328\ Kt}{\phi\ c\ \mu\ r^2} = \frac{\eta\ t}{r^2} \qquad (23)$$

$$\Delta P_D = \frac{(P_e - P_w)\ 14.16\ Kh}{q\ \mu\ B} \qquad (24)$$

where t_D = Dimensionless time

ΔP_D = Dimensionless pressure drop

K = Permeability, darcys

t = Producing time, days

ϕ = Porosity, fraction

μ = Viscosity, centipoises

r = Distance from producing well to interference test well, feet

η = Diffusivity constant, Equation (10) Page 25 of this paper

$P_e - P_w$ = Pressure drop, psi

h = Pay thickness, feet

q = Production rate, BOPD

B = Formation volume factor, reservoir barrels per stock tank barrel

For calculations of per-acre oil in place in Southwest Puerto Chiquito where the three quantities permeability, porosity and pay thickness, are unknown, it is convenient to rewrite Equation (23) as

$$\frac{K}{\phi} = \frac{c\ \mu\ r^2\ t_D}{6.328\ t} \qquad (25)$$

Also, by rearranging terms of Equation (22) and substituting in Equation (24), we may express ΔP_D as follows:

$$\Delta P_D = \frac{2.30\ (P_e - P_w)}{m} \qquad (26)$$

Use of Driscoll's method is now illustrated with reference to Plate I of Figure No. 21, on which is shown interference effects at various distances resulting from the production of the well whose initial pressure history is given on Figure No. 19.

It is assumed that the effective compressibility, 25×10^{-6} psi, and viscosity, .65 centipoises, are known, and it is desired to calculate per acre oil in place.

First: From pressure build-up data of the wells (i.e., from Figure No. 17, which is for a well in the example reservoir) determine slope m to be 15 psi/cycle.

Next: Select an interference pressure drop in one of the wells during the time infinite conditions exist (prior to 32.7 days for the example situation), as for example 14 psi at 10 days for the observation well located 4,000 feet from the producer.

Now determine ΔP_D from Equation (26) as follows:

$$\Delta P_D = \frac{(2.30)(14)}{15} = 2.15$$

From this value of ΔP_D and Figure No. 20 (for $r_F/r_{AB} = \infty$) determine the corresponding dimensionless time, t_D, which is 3.4

Next determine $\frac{K}{\phi}$ from Equation (25).

$$\frac{K}{\phi} = \frac{(25 \times 10^{-6})(4000)^2(.65)(3.4)}{(6.328)(10)}$$

$$\frac{K}{\phi} = 14$$

Determine Kh from Equation (22)

Kh - 4.5 darcys

As before, øh is then determined by dividing Kh by $\frac{K}{\phi}$.

This gives $\frac{4.5}{14}$ = .32 feet

Since effective compressibility was used, the result is a measure of hydrocarbon pore space. Stock tank oil in place is determined by multiplying by 7758 and dividing by the FVF (1.28)

Per acre stock tank oil in place is accordingly:

1,950 bbl/acre

which compares with the correct amount, 1,818 bbl/acre, the difference being the error resulting from reading of dimensionless time directly from Figure No. 20.

VIII. DETERMINATION OF OIL IN PLACE PER UNIT AREA FROM INITIAL PRESSURE TRANSIENTS

Part 4 - Additional notes regarding calculation of oil in place from interference tests during initial transient period:

A. Determination of transmissibility from interference test data

B. Confirmation of assumption that infinite conditions exist

C. Effect of one near boundary

D. Effect of large fracture treatment on producing well.

Interference tests were conducted on wells in Southwest Puerto Chiquito at a time when the reservoir pressure was above the bubble point throughout all, or substantially all, of the known reservoir. This fact, plus other data from the interference tests, indicates the reservoir diffusivity constant at that time to be of a high value. Under these conditions it becomes critical to the validity of the assumptions to confirm that infinite conditions of pressure behavior existed during the transient period involved. Also under these conditions effect of boundaries is more likely to occur than for a reservoir with a low diffusivity constant. In addition, even though it is to be expected that pressure declines in the observation wells will be the result of a considerable degree of averaging of influences, such that this data may be representative of certain of the properties of a large portion of the reservoir, before this information can be converted to oil in place per acre it is necessary also to rely heavily on the value of transmissibility (Kh), which is ordinarily determined from tests conducted on individual wells.

Since it is believed that the individual wells so far completed in Southwest Puerto Chiquito are influenced by conditions locally (locally here may mean in terms of hundreds of acres) and because of the reasons stated earlier making it difficult to determine Kh from pressure build-up tests in a reservoir with a diffusivity constant as high as found here, it becomes apparent that it would be highly desirable to determine the value of an average reservoir transmissibility as might be measured by data from the interference test itself, rather than from independent information developed from individual tests.

Further, since large fracture treatments are used to stimulate production, it becomes of interest to explore the possible effect of these large fracture treatments as they might influence the calculations made with the transient flow equations, particularly in view of the fact that the Ei formula assumes the producing well to be of infinitesimally small radius.

These matters have been studied and procedures developed to generally confirm that the assumptions are met within reasonable limits, and that the resulting calculations can have an acceptable degree of accuracy. Discussion as to each of the four above identified matters follows.

A. Determination of transmissibility from interference test data:

By the same type of analysis that Horner [21] and others have used to show that Kh can be determined from the slope of a semi-log plot of pressure build-up against time for an individual well, it can be demonstrated that under certain conditions the interference drop in an observation well is a straight

line function of log time, and that Kh can similarly be determined from its slope. It is apparent from inspection of the Ei Equation (17), Page 44 of this paper, that from the time at which the exponential integral of the term $\frac{r^2}{4\eta t}$ becomes logarithmic until reservoir boundary conditions have an effect, the pressure drop in an interference well will be a straight line function of log time. Although exponential integrals of a number are not strictly logarithmic unless the number has a value less than two hundredths, a very nearly straight line logarithmic relation exists for values of $\frac{r^2}{4\eta t}$ which are 0.1 or less. This value of the exponential integral term in Equation (17) above ordinarily will be less than 1/10th when applied to a producing well within a few minutes after it has been put on production. As to interference test wells located some distance from the producing well, this time will be large enough to have a significant meaning. The times involved are of course directly dependent on the subject reservoir conditions, and no general statement can be made encompassing all situations. For wells and conditions in Southwest Puerto Chiquito the magnitude of this time is in the order of days.

This is illustrated by Plate II of Figure No. 21, on which are plotted the same pressure interference curves as for the wells in Plate I of Figure No. 21. For the period in which $\frac{r^2}{4\eta t}$ is less than one-tenth, the subject curves of Plate II are shown as solid lines. This indicates that for a shut-in observation well 2,000 feet from the producing well, pressures measured during the time period from 1 day to about 30 days will be valid for use in computing Kh. For the well 4,000 feet away

from the producing well the time period from the seventh to about the thirtieth day can be used. For wells 8,000 feet and beyond, the value of $\frac{r^2}{4\eta t}$ does not become less than one-tenth before boundary conditions begin to have an effect, and accordingly cannot be used to determine Kh.

From information of pressure drop in the proper wells taken during valid time periods (as identified next above) Kh can be determined in the conventional manner by use of Equation (22), Page 47. This calculation is given on Plate II of Figure No. 21.

Determination of Kh in this fashion is considered to be representative of a large segment of the reservoir; in fact, it provides the key to successful application of the method of calculating oil in place from transient pressure behavior for fractured shale reservoirs. Accordingly, despite the statement above that the mathematical implications establishing the substance of this subsection are evident from inspection of the Ei equation, the conclusions are so vital to the principle of calculation used that a formal derivation is included in the Appendix (Part II).

B. Confirmation of assumption that infinite conditions exist:

Driscoll [26] shows methods of determining whether infinite conditions may be expected when certain boundary conditions are known. One also may estimate from the diffusivity constant times during which infinite conditions exist. In general, it appears that nearly all of the transient period (from first production to time required to establish steady-state conditions)

may be used to compute $\frac{K}{\phi}$ if Kh is known. Determination of Kh, of course, is limited to the times described above (Section VIII, Part 4 - A).

This is in contrast to the transient period of pressure build-up of a shut-in well, in which only a small part of the time may be available for calculation of Kh. For instance, it takes the example producing well shown on Figure 21 32.6 days to reach a time equivalent to steady state conditions when first placed on production, and most of this time is useable for analysis: the observation well 2,000 feet away, for example, will yield valid data to determine Kh for practically all of this time. On the other hand, if the example producing well is shut in, only the first four days of information are available to compute Kh, despite the fact it takes the same 32.6 days to build up to stabilization. (Shown on Figure No. 17).

That boundary conditions have only a small effect on pressures measured in interference wells until the time required for steady-state conditions is reached (for a closed reservoir) is indicated by calculations of pressure distribution within a reservoir by Horner's[21] approximation. Hurst and Guerrero [24] have given an adjustment for the Horner approximation to improve its accuracy. This serves to reduce the effect of the pressure difference shown by Horner from the simple Ei solution. Horner shows an example for one condition of ratio of field boundary radius to well bore radius in which his approximate method results in errors of only a few percent. Hurst and Guerrero found no difference in their adjustment to Horner's approximation for different ratios of field radius to well radius. Hurst and Guerrero

also indicate that for high permeabilities (such as are found in Southwest Puerto Chiquito) the error is small.

It is probable, however, that either of the methods yield results of sufficient accuracy that we can be assured, for reservoir properties in Southwest Puerto Chiquito, that essentially infinite conditions will exist for the greater part of the transient period. Magnitude of differences in the straight Ei solution and Horner's approximation for the example wells of Figure No. 21 at 20 days after initiating production are .8 percent, 1.2 percent and 2.3 percent for the 2,000 foot, 4,000 foot and 8,000 foot wells respectively. It is accordingly concluded that the greater part of the transient period can be used for analysis, and that the Ei solution will apply during this time, even for a closed reservoir.

Two additional practical guides are useful in defining the transient period. One is to determine if pressures in the observation wells are straight line functions of log time for the periods in which $\frac{r^2}{4nt}$ is less than .1. A second is through rate of pressure decline. When rate of pressure decline becomes uniform it can be assumed that the wells are in the time period beyond that required to establish steady-state conditions. As for the example wells, Figure No. 21, Plate I, after 32 days the pressure is declining in each well at the rate of .2 pound per day, and it will be noted that the pressures plotted versus time on the coordinate scale are a straight line. If total size of the reservoir (oil in place) is available, then the rate of pressure decline can be anticipated through use of Equation (7), Page 21. In the example shown on Figure No. 21, the closed reservoir

encompasses a volume of stock tank oil of 100 million barrels. For this volume, and for the compressibility of 25×10^{-6}, Equation (7) shows that the pressure drop will be 2,500 barrels per pound in the period of uniform rate of pressure decline following the initial transient pressure period. The test well is assumed, for Figure No. 21, to be producing 500 barrels per day, which means that the pressure will then decline at the rate of .2 pound per day.

It is interesting to note from Plates I and II of Figure No. 21 that during the transient period the pressure declines in the nearby observation wells show curves when plotted on coordinate scales (Plate I), and for the same time period (after $\frac{r^2}{4\eta t}$ is less than one-tenth) the data yields straight lines in a plot of pressure versus log time (Plate II). Conversely, after the time required to establish steady-state conditions is reached, the plots of data for all wells of pressure versus time result in parallel straight lines on coordinate scales (Plate I) whereas on the pressure versus log time plot (Plate II) the data yields curved lines.

C. Effect of one near boundary:

If a straight line field boundary passes very near to either the producing well or the shut-in well, and the other boundaries are remote, the effect on the pressure of the shut-in well will be that it will drop almost exactly twice as fast as if there were no boundary present. * For the period of time following the time at which $\frac{r^2}{4\eta t}$ is less than one-tenth until the

* This is evident from application of the "method of images" as described by Muskat, Horner et al

remaining field boundaries exercise their influence on the pressure decline, the pressure drop will be a straight line function of log time (for reasons shown in Appendix, Part II). The resulting slope, however, will be twice that which would result if there were no boundaries near the subject wells. It is therefore apparent that for this condition the slope m and the total pressure drop in the interference well will be directly proportional.

Accordingly, if Kh (or m) is determined by the method shown above (Section VIII, Part 4 - A), although the correct value of Kh will not be obtained, substitution of this "apparent" Kh or m in the Ei equation will yield a true value of $\frac{K}{\phi}$.

This results despite the fact that the near boundary has caused the pressure to decline in the shut-in well at twice its rate if no boundary were present. It will, of course, be necessary, in determining ϕh, to divide the **true** $\frac{K}{\phi}$ into the true value of Kh. The true value of Kh in this instance would be twice that of the "apparent" Kh.

D. Effect of large fracture treatment on producing well:

As stated earlier in this paper, because of well stimulation practices in Southwest Puerto Chiquito it is of interest to study the resulting effects on the transient pressure behavior of a shut-in observation well during an interference test if the producing well had been subject to a large hydraulic fracture treatment.

Muskat [27] has determined a solution to the

diffusivity equation which can be applied to a specific example of this situation. He has also given numerical evaluation of this solution for dimensionless time values up to 20. This graphical evaluation is reproduced here as Figure No. 21, on which the values of the coordinates are expressed by dimensions of properties as used in this paper.

Our determination of the effect of a fracture treatment is made for an extreme example in which it is assumed that the treatment results in a circular-horizontal fracture of 2,000 feet radius. The fracture is assumed to be of infinitely high permeability and of infinitesimal thickness. An observation well at the periphery of the fracture will then have pressure corresponding to the "internal field boundary" pressure of a system whose pressure behavior can be described by the data of Figure No. 22.

The resulting pressures during the transient period are shown on Figure No. 23 for a reservoir with properties as indicated thereon. Also shown is the pressure behavior which would result if the producing well had an infinitesimally small radius (Ei solution).

If per acre oil in place were calculated from Curve B of this figure, the result would be an error of about two to one in value of computed oil in place for the area outside of the fracture radius. It is thus seen that large fracture treatments should not invalidate the procedures. It is not known just how large an area is fractured during a well fracture treatment; however, it is probably measured in terms of hundreds of feet, rather than thousands, and the resulting effect on interference tests accordingly would be relatively small.

Perhaps of greater significance than effect of fracture treatment, as can be inferred from Figure No. 23, is the maximum effect of long individual fractures. If, for example, a 4,000 foot vertical fracture originating in the observation well extended through the producing well and beyond for 2,000 feet, and the rest of the reservoir were of properties shown on Figure No. 23, the resulting pressure behavior of the observation well would necessarily lie between the two curves of Figure No. 23. Accordingly, such a situation would result in an error in calculated oil in place which could be expected to be much less than a two to one ratio. (From data at 10 days).

The above examples, of course, only apply to a reservoir with properties as indicated. No implication is here made that effect of large fractures can be disregarded in all reservoirs.

Summary of Section VIII:

There are, of course, limitations and qualifying conditions to the procedures outlined in this Section VIII. These are enumerated as follows:

1. As indicated by Driscoll, where high permeabilities exist, as are found in Southwest Puerto Chiquito, the pressure drops which will result during the significant transient period will be small, and they are difficult to measure by conventional methods. Southwest Puerto Chiquito pressure drops on the order of 10 pounds occurred during the transient period used for calculations. This pressure difference was observed through changes in fluid levels in the wells, which fluid levels were obtained with an accuracy approximating one half foot, which is

on the order of one-sixth pound. Measurement error, then, in the differential pressure drops used is on the order of two to five percent of the pressure drops considered for calculations, which is believed to be of acceptable accuracy.

2. Interpretation of data is of course simplified if prior to the starting of the subject producing well, the reservoir is in either a static condition, or effects of the other producing wells are such that their initial transients have passed, and the reservoir is essentially undergoing a predictable pressure change in terms of pounds per day, so that the effect of the production of the subject test well can be determined. If this is not the case, methods such as those indicated by Driscoll can of course be used to estimate the effects of the subject producing test well.

3. Discussions in this section are intended to apply to reservoirs that have a constant compressibility during the time under consideration, such as undersaturated oil above the bubble point. Since transient flow theory has apparently been successfully applied to saturated reservoirs in pressure build-up considerations, it is also possible that the herein-outlined procedures could be successfully applied to reservoirs producing at pressures below the bubble point, if proper consideration be taken of the effect of the changing compressibility. Accordingly, it would appear that for high permeabilities and small pressure changes this procedure might successfully be extended to these conditions of pressures below the bubble point.

4. It would seem, particularly in view of Part 4 - D of Section VIII herein, that a considerable degree of non-uniformity can exist throughout the reservoir and

such an interference test still yield reasonably accurate results for the average value of oil in place per acre. Muskat has shown that in many instances a high degree of anisotropy of formation properties will have relatively small influence in pressure behavior. Driscoll explains how the pressures in the shut-in observation well reflect the weighted average value of properties for continually increasing distances from the producing well as the value of dimensionless time increases. Among other things, Driscoll states that for certain conditions "in this time range a good quantitative answer for ϕh, and thus pore volume in the vicinity of the observation well, can be obtained even with a considerable degree of random areal anisotropy". The one type of non-uniformity which could, of course, invalidate a test is the condition of a large local area of substantially different properties from the average of the reservoir. If the subject producing well is located in such an area, the interference drops measured in the other wells will not be representative of average conditions. In this instance, the rate of decline of pressure drop in the producing well would be at a greater rate than in the adjoining wells. Accordingly, for interference tests in pools such as Southwest Puerto Chiquito, it appears essential that for data from an interference test to be considered for computation of per acre oil in place the following condition should be satisfied:

> After such time as the value of $\frac{r^2}{4\eta t}$ is one-tenth or less for the subject observation well, its pressure decline in terms of pounds per day should be approximately the same as that for the producing well.

It would appear that this condition would not have to be rigorously met, but if, during the time interval defined above, the producing well has a substantially greater pressure drop than the subject observation well, it is indicative that factors affecting the two wells are so greatly different that the assumption of "uniform conditions" is not met, and accordingly the calculations will not apply.

5. The foregoing procedure for calculating oil in place per acre implies fluid flow in the subject reservoirs is radial and obeys Darcy's law. It is believed that the latter requirement is met in most fracture systems, inasmuch as the flow in any one fracture is so governed. As to the first requirement, for flow to be essentially radial in a fractured shale reservoir, the linear dimensions of the individual interconnecting fractures must be small with respect to the gross size of the drainage area. If individual fractures are long with respect to the drainage radius, or the fractures have a particularly high degree of orientation, such that the permeability is several times greater in one direction than in another, strictly radial flow conditions may not prevail. In the instance of Southwest Puerto Chiquito, in which Benson-Montin-Greer Drilling Corp. has developed interference test data which is believed to be useful for quantitative analysis, it is believed that the gross area of the flow system being measured is of the order of tens of thousands of acres, and that the corresponding drainage radii are long with respect to the length of individual fractures, and accordingly essentially radial flow conditions existed during the interference tests. It is therefore believed that the Southwest

Puerto Chiquito reservoir can be expected to follow essentially Darcy's law and radial flow, and analyses based upon these two principles should be valid, at least for determining the proper order of magnitude of physical properties, such as volume of oil in place per unit area.

IX. ESTIMATION OF AREAL EXTENT OF RESERVOIR

If degree of communication is high, as indicated for Southwest Puerto Chiquito, and total reservoir volume can be estimated and per-acre oil in place determined by the procedures outlined herein, it is then possible to approximate the areal extent of the reservoir by dividing the total reservoir volume by the volume per acre. Certain of the limitations which restrict the accuracy of determination of total oil in place, as for example the presence of unknown free gas (i.e., gas cap), will to the same degree affect calculation of the area of the reservoir.

It is interesting to note, however, that calculation of areal extent of a reservoir may be made to a higher degree of accuracy than either the total reservoir volume or the per-acre oil in place (assuming that volume per acre determined is average for the reservoir). This is because some of the factors affecting compressibility similarly enter into calculation of oil in place per acre and total reservoir volume. The resulting calculation is accordingly independent of these factors.

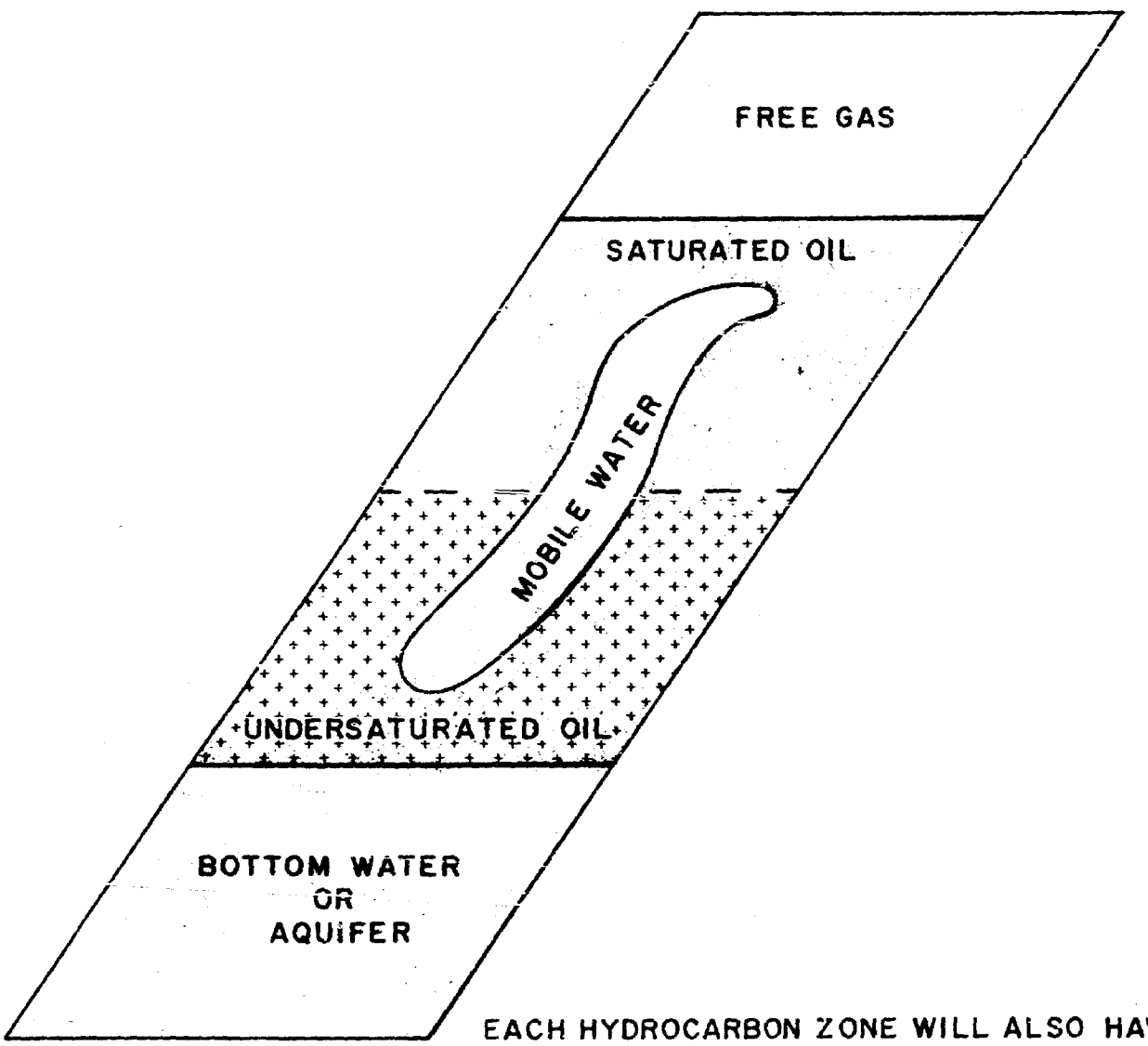
An example of this is the effect of the indeterminate value of compressibility in a fractured shale formation. As applied to Southwest Puerto Chiquito, this factor can introduce a difference of total oil in place in the reservoir on the order of two to one for the limits of formation compressibility (herein shown in Figure No. 8) used for calculation of oil in place for the condition in which the reservoir contains under-saturated oil. An error, then, of two to one could exist from

this factor alone in determining total oil in place, as for example if the true compressibility is twice that used in the calculation, the true value of oil in place will be one-half that calculated. By the same token, use of this factor in calculating oil in place per acre would also yield twice the true amount of oil in place per acre. Accordingly, when these two values are used to determine total area of the reservoir, the resulting area will be exactly determined insofar as effect of formation compressibility is concerned.

In view of the above, it is apparent that a reasonable order of magnitude of the size of the reservoir might be determined from the first few wells initially drilled in it, if a high degree of communication exists throughout the reservoir.

Albert R. Greer
November 1, 1966

SKETCH
SHOWING
COMPRESSIBLE
RESERVOIR FLUIDS



EACH HYDROCARBON ZONE WILL ALSO HAVE CONNATE WATER-ALL ZONES SUBJECT TO FORMATION COMPRESSIBILITY

Fig. No. 1

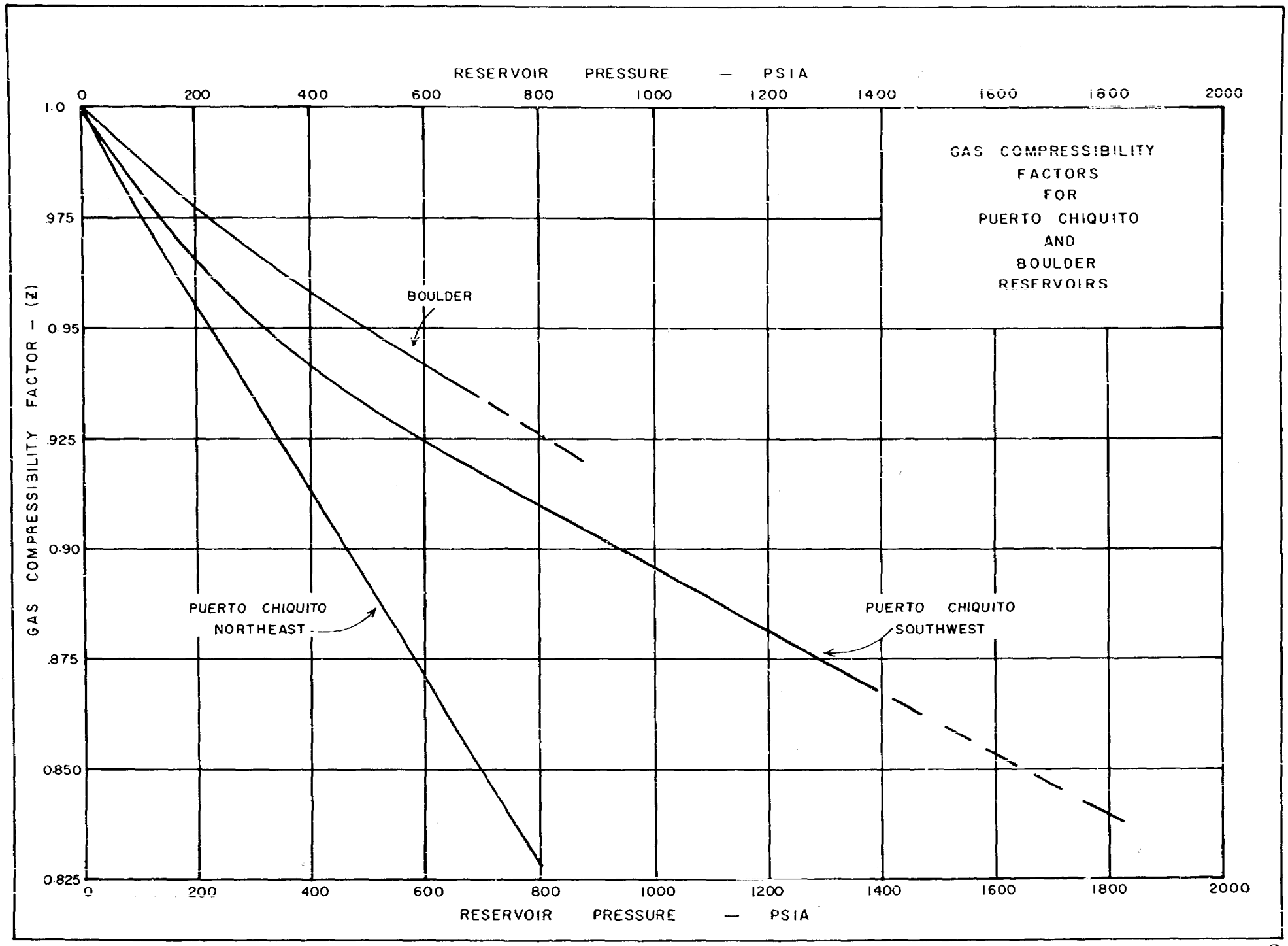

RESERVOIR PRESSURE — PSIA
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1.0
.975
0.95
.925
0.90
.875
0.850
0.825
GAS COMPRESSIBILITY FACTOR — (Z)
GAS COMPRESSIBILITY FACTORS FOR PUERTO CHIQUITO AND BOULDER RESERVOIRS
BOULDER
PUERTO CHIQUITO NORTHEAST
PUERTO CHIQUITO SOUTHWEST

Fig. No. 2

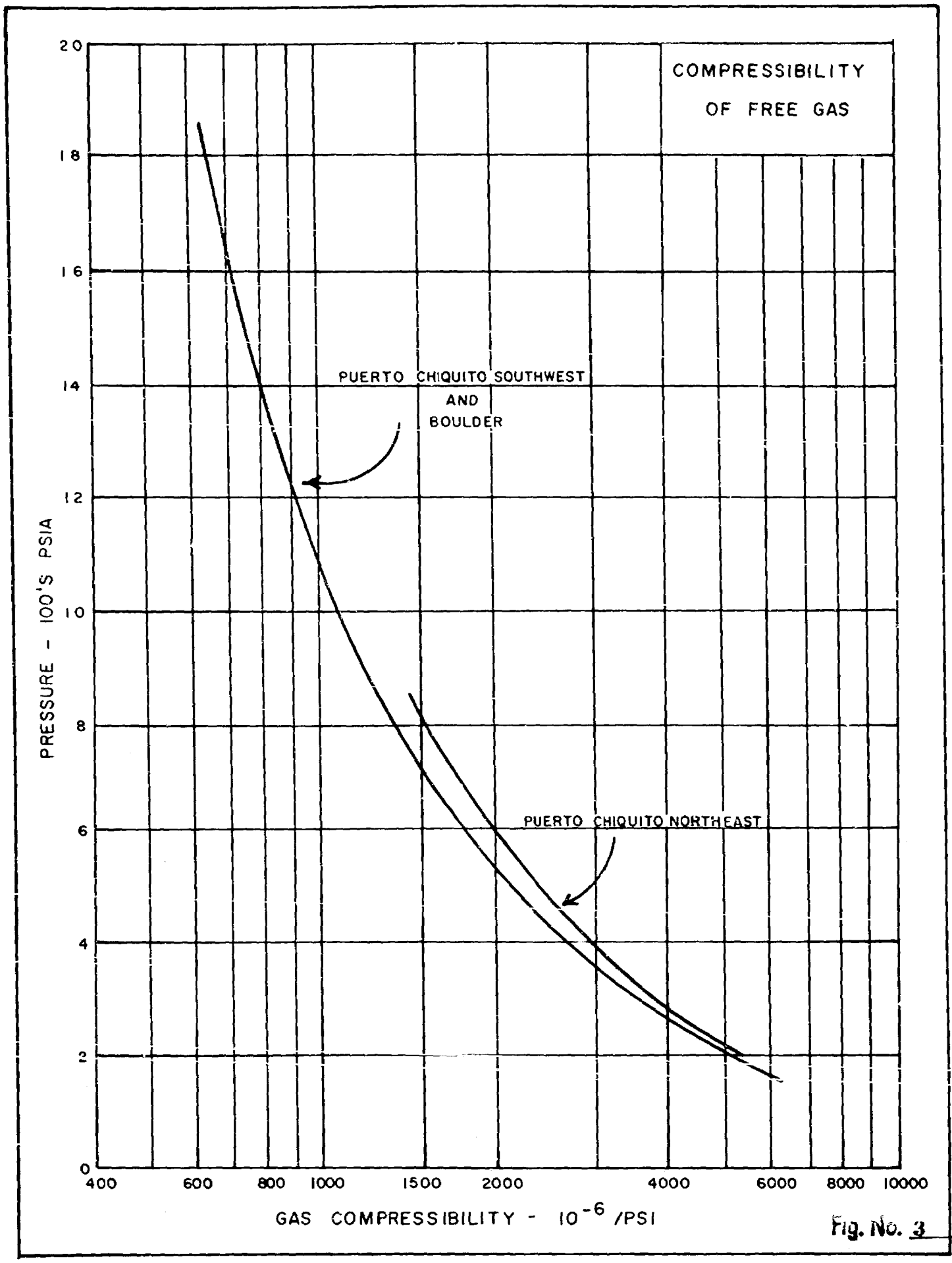

COMPRESSIBILITY
OF FREE GAS
PUERTO CHIQUITO SOUTHWEST
AND
BOULDER
PUERTO CHIQUITO NORTHEAST
PRESSURE - 100'S PSIA
GAS COMPRESSIBILITY - 10^{-6} /PSI
0
2
4
6
8
10
12
14
16
18
20
400
600
800
1000
1500
2000
4000
6000
8000
10000

Fig. No. 3

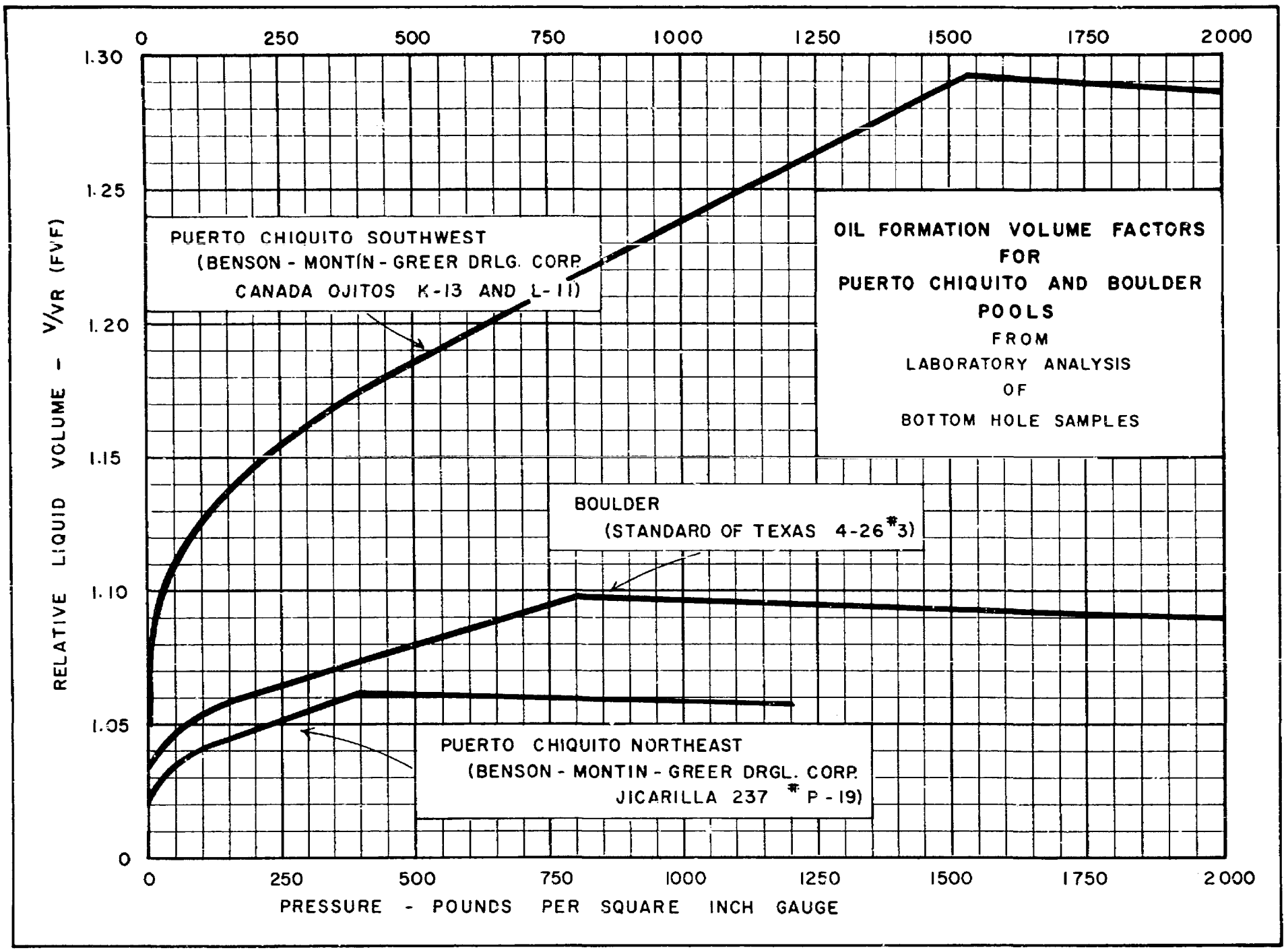

OIL FORMATION VOLUME FACTORS
FOR
PUERTO CHIQUITO AND BOULDER
POOLS
FROM
LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
PUERTO CHIQUITO SOUTHWEST
(BENSON - MONTIN - GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 *3)
PUERTO CHIQUITO NORTHEAST
(BENSON - MONTIN - GREER DRGL. CORP.
JICARILLA 237 * P-19)
RELATIVE LIQUID VOLUME - V/VR (FVF)
1.30
1.25
1.20
1.15
1.10
1.05
0
0
250
500
750
1000
1250
1500
1750
2000
PRESSURE - POUNDS PER SQUARE INCH GAUGE

Fig. No. 1

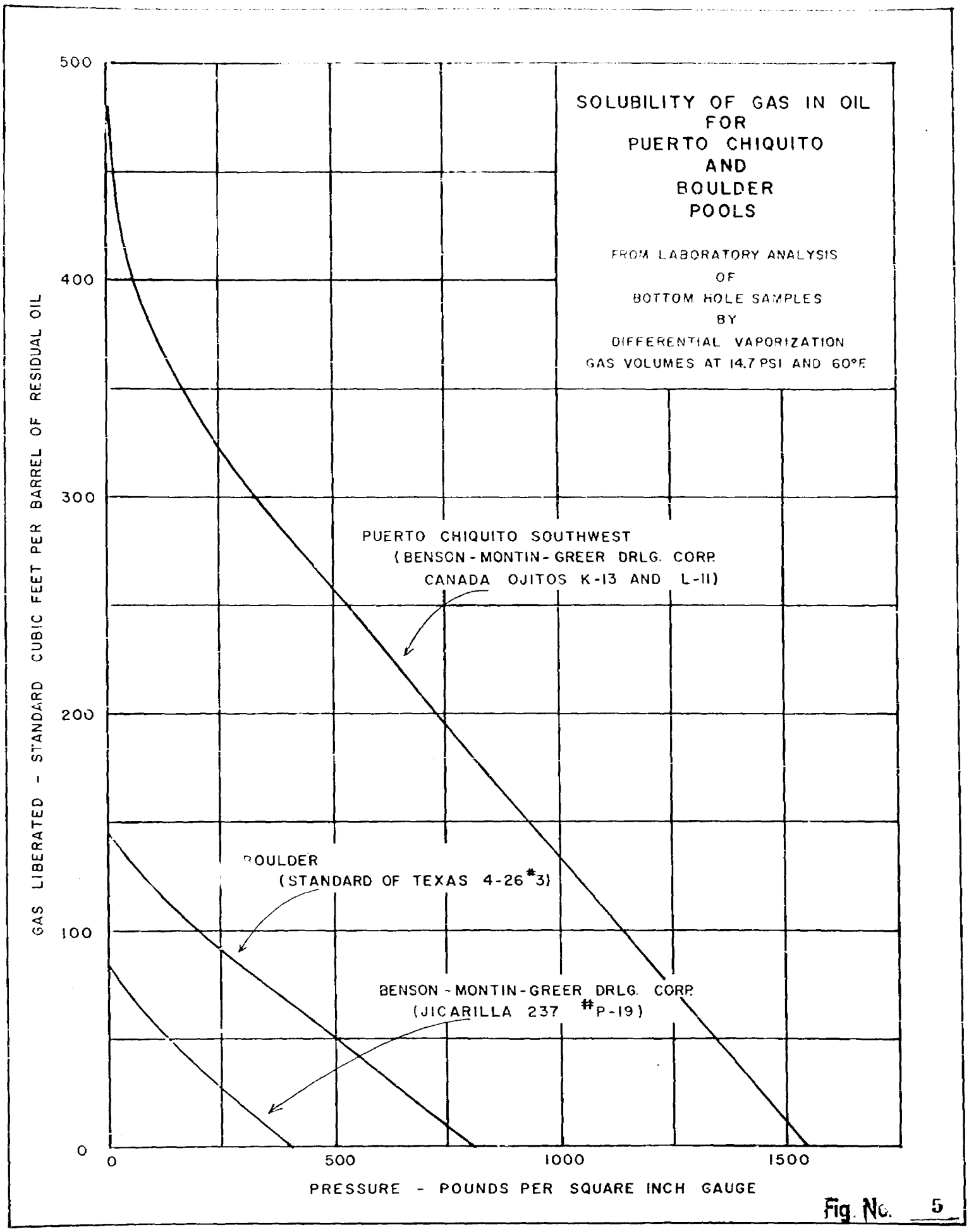

SOLUBILITY OF GAS IN OIL
FOR
PUERTO CHIQUITO
AND
BOULDER
POOLS
FROM LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
BY
DIFFERENTIAL VAPORIZATION
GAS VOLUMES AT 14.7 PSI AND 60°F
PUERTO CHIQUITO SOUTHWEST
(BENSON-MONTIN-GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
BENSON-MONTIN-GREER DRLG. CORP.
(JICARILLA 237 #P-19)
GAS LIBERATED - STANDARD CUBIC FEET PER BARREL OF RESIDUAL OIL
500
400
300
200
100
0
0
500
1000
1500
PRESSURE - POUNDS PER SQUARE INCH GAUGE

Fig. No. 5

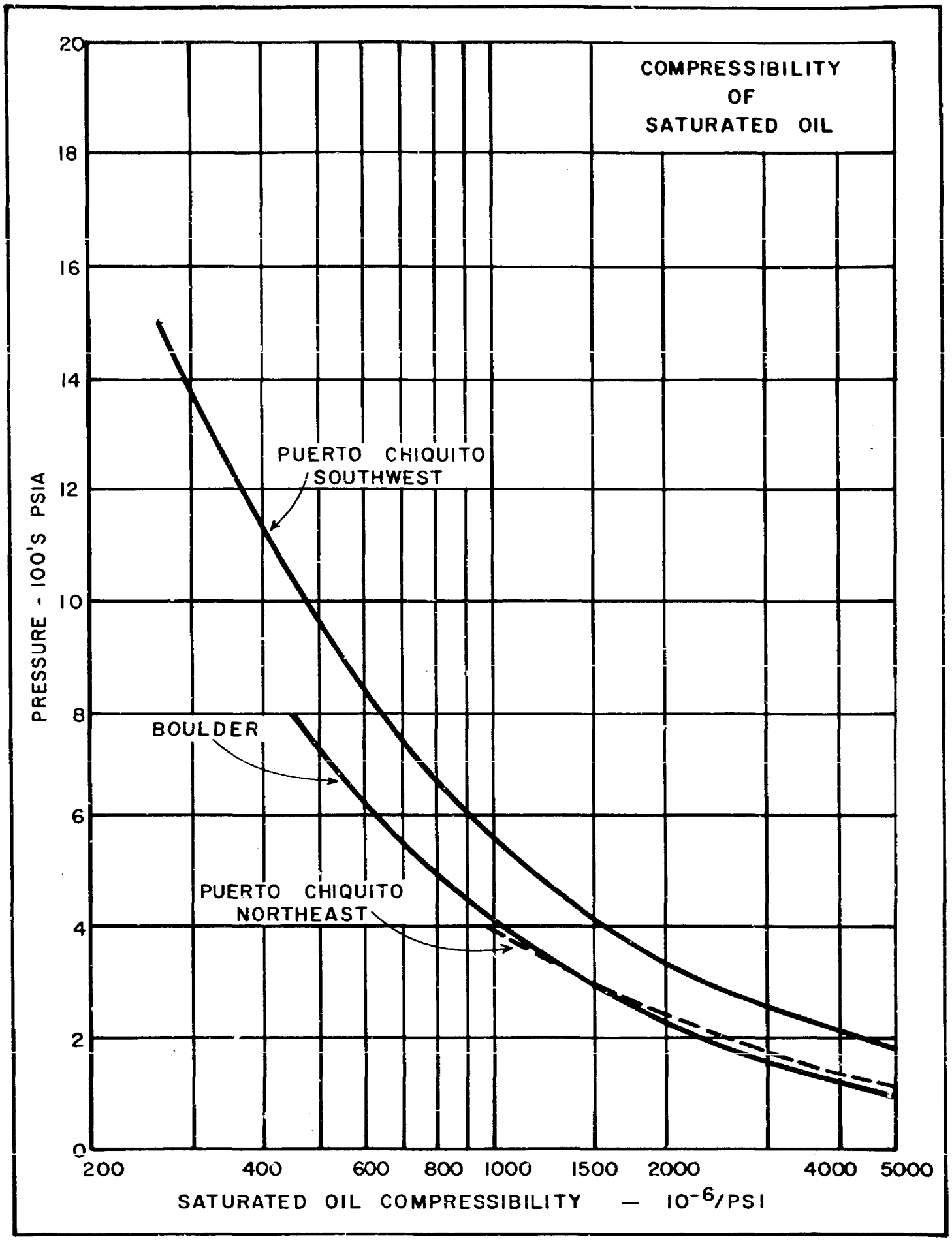

COMPRESSIBILITY
OF
SATURATED OIL
PUERTO CHIQUITO
SOUTHWEST
BOULDER
PUERTO CHIQUITO
NORTHEAST
PRESSURE - 100'S PSIA
20
18
16
14
12
10
8
6
4
2
0
200
400
600
800
1000
1500
2000
4000
5000
SATURATED OIL COMPRESSIBILITY — 10^{-6}/PSI

Fig. No. 6

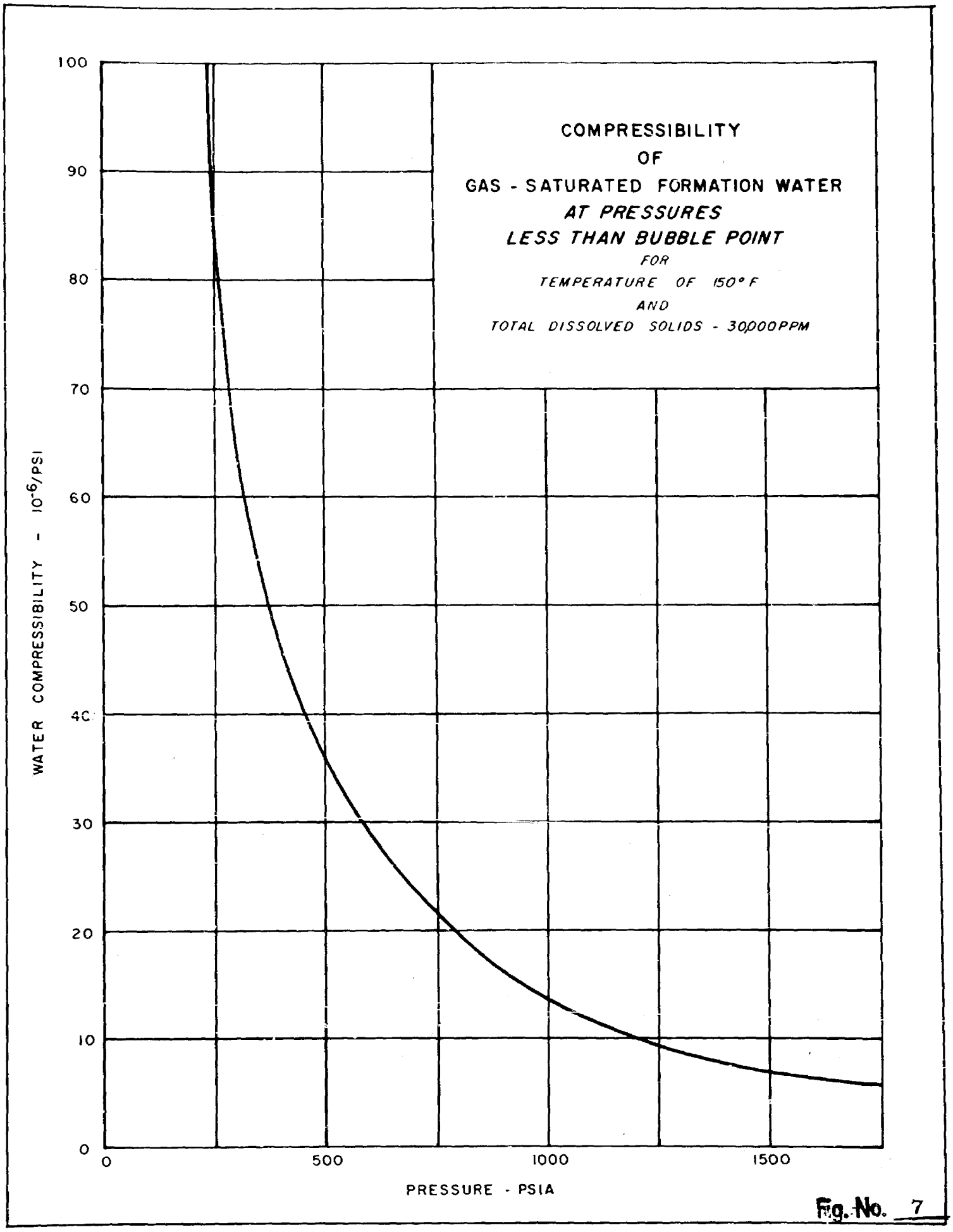

COMPRESSIBILITY
OF
GAS - SATURATED FORMATION WATER
AT PRESSURES
LESS THAN BUBBLE POINT
FOR
TEMPERATURE OF 150° F
AND
TOTAL DISSOLVED SOLIDS - 30,000PPM
WATER COMPRESSIBILITY - 10⁻⁶/PSI
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
PRESSURE - PSIA

Fig. No. 7

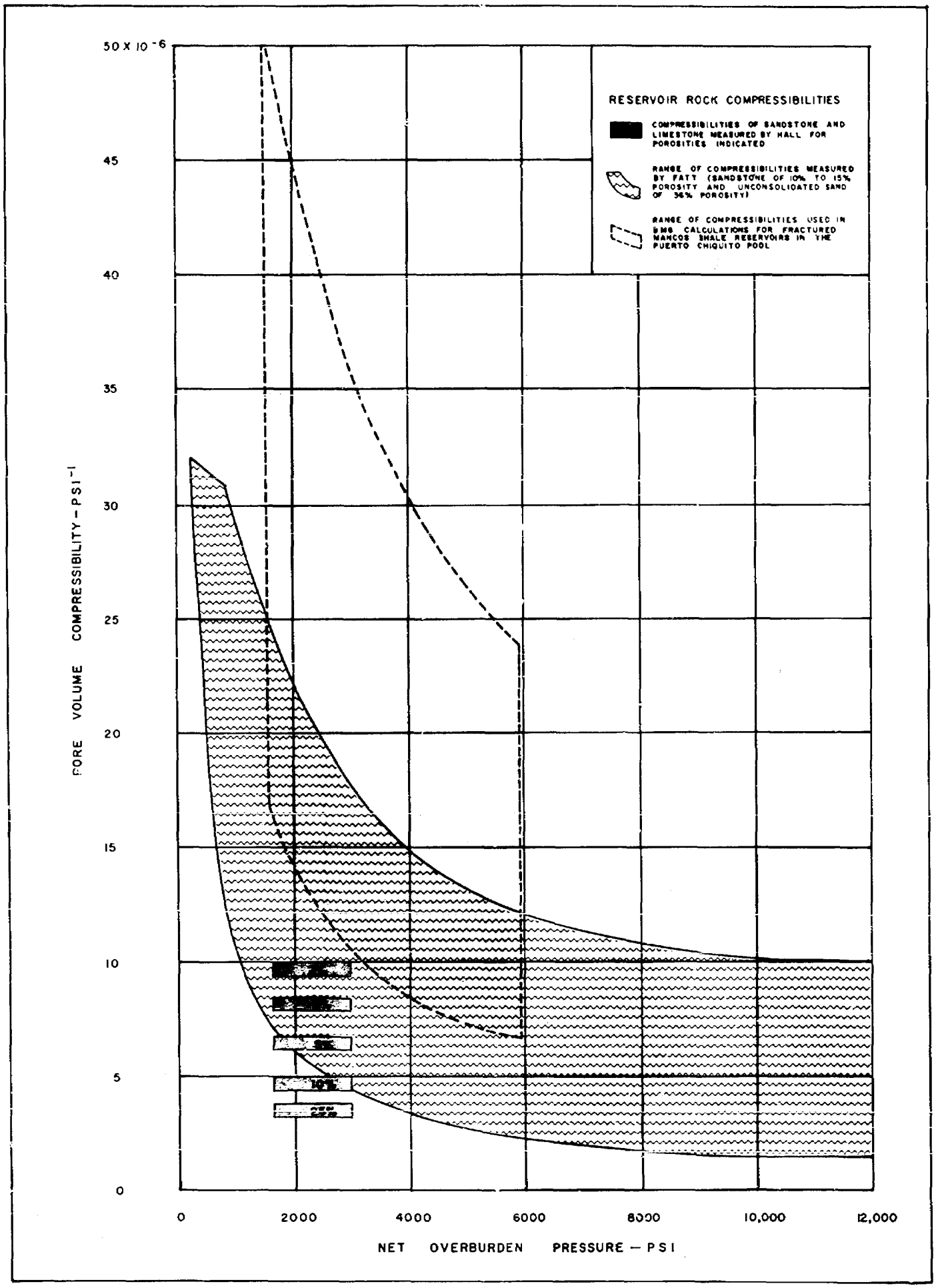

RESERVOIR ROCK COMPRESSIBILITIES
COMPRESSIBILITIES OF SANDSTONE AND LIMESTONE MEASURED BY HALL FOR POROSITIES INDICATED
RANGE OF COMPRESSIBILITIES MEASURED BY FATT (SANDSTONE OF 10% TO 15% POROSITY AND UNCONSOLIDATED SAND OF 36% POROSITY)
RANGE OF COMPRESSIBILITIES USED IN S.M.B. CALCULATIONS FOR FRACTURED MANCOS SHALE RESERVOIRS IN THE PUERTO CHIQUITO POOL
50 X 10⁻⁶
45
40
35
30
25
20
15
10
5
0
PORE VOLUME COMPRESSIBILITY – PSI⁻¹
0
2000
4000
6000
8000
10,000
12,000
NET OVERBURDEN PRESSURE – PSI

Fig. No. 8

VALUES OF K/φ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

FRACTURES PARALLEL TO DIRECTION OF FLOW

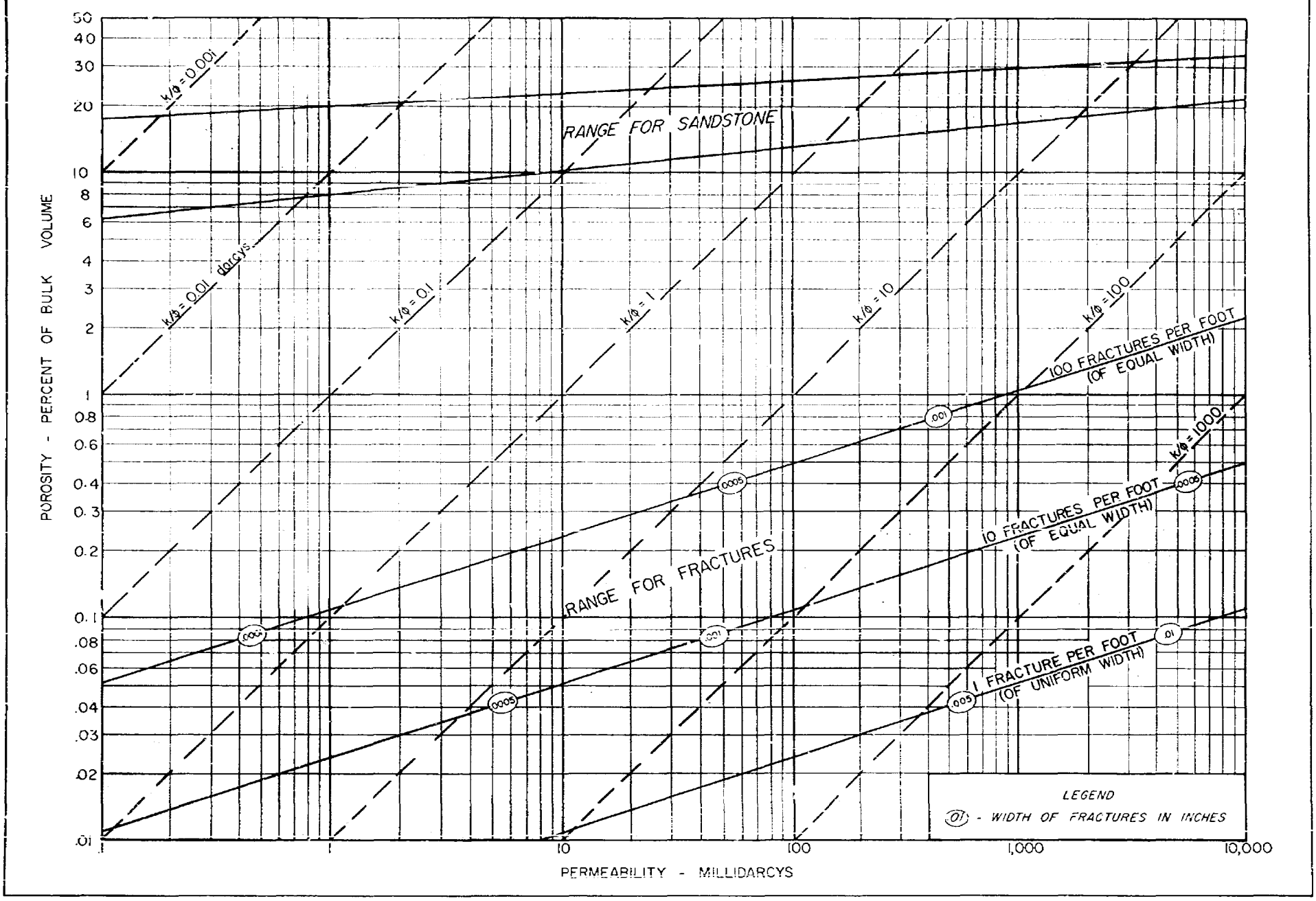
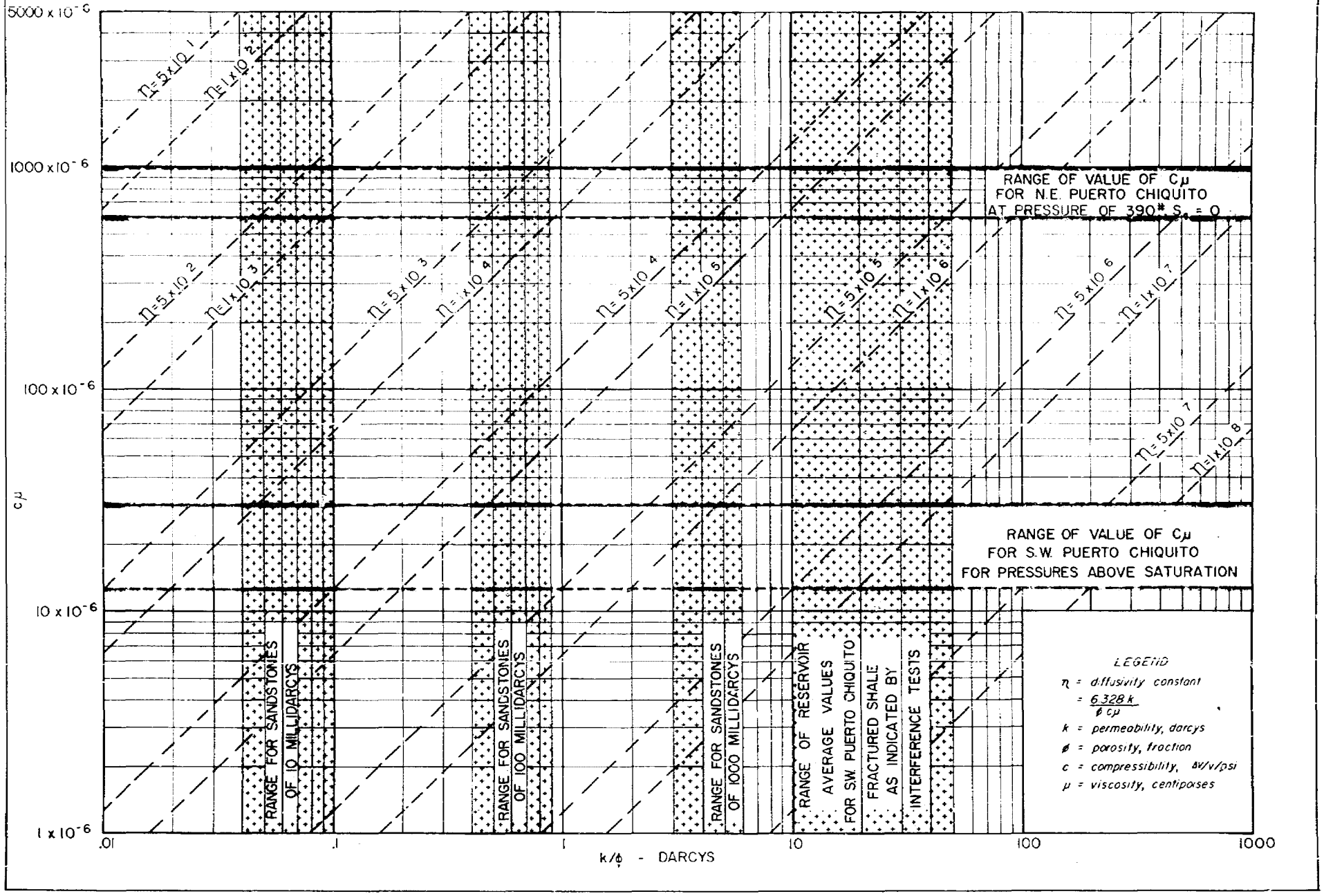


Fig. No. 9

VALUE OF DIFFUSIVITY CONSTANT AS FUNCTION OF K/ϕ VS. $c\mu$



TIME REQUIRED TO ESTABLISH STEADY-STATE CONDITIONS FOR CIRCULAR DRAINAGE AREAS OF UNIFORM PROPERTIES

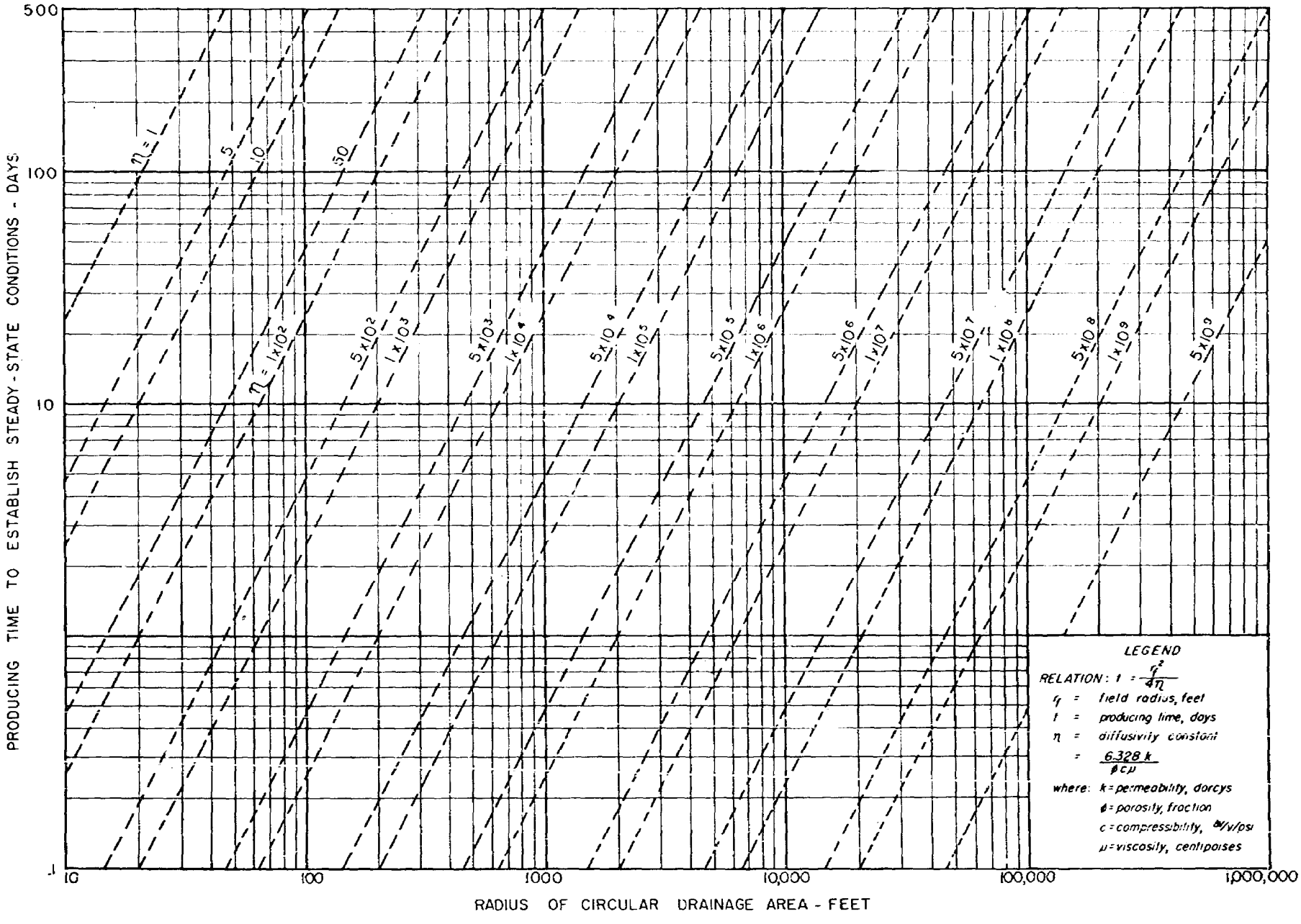
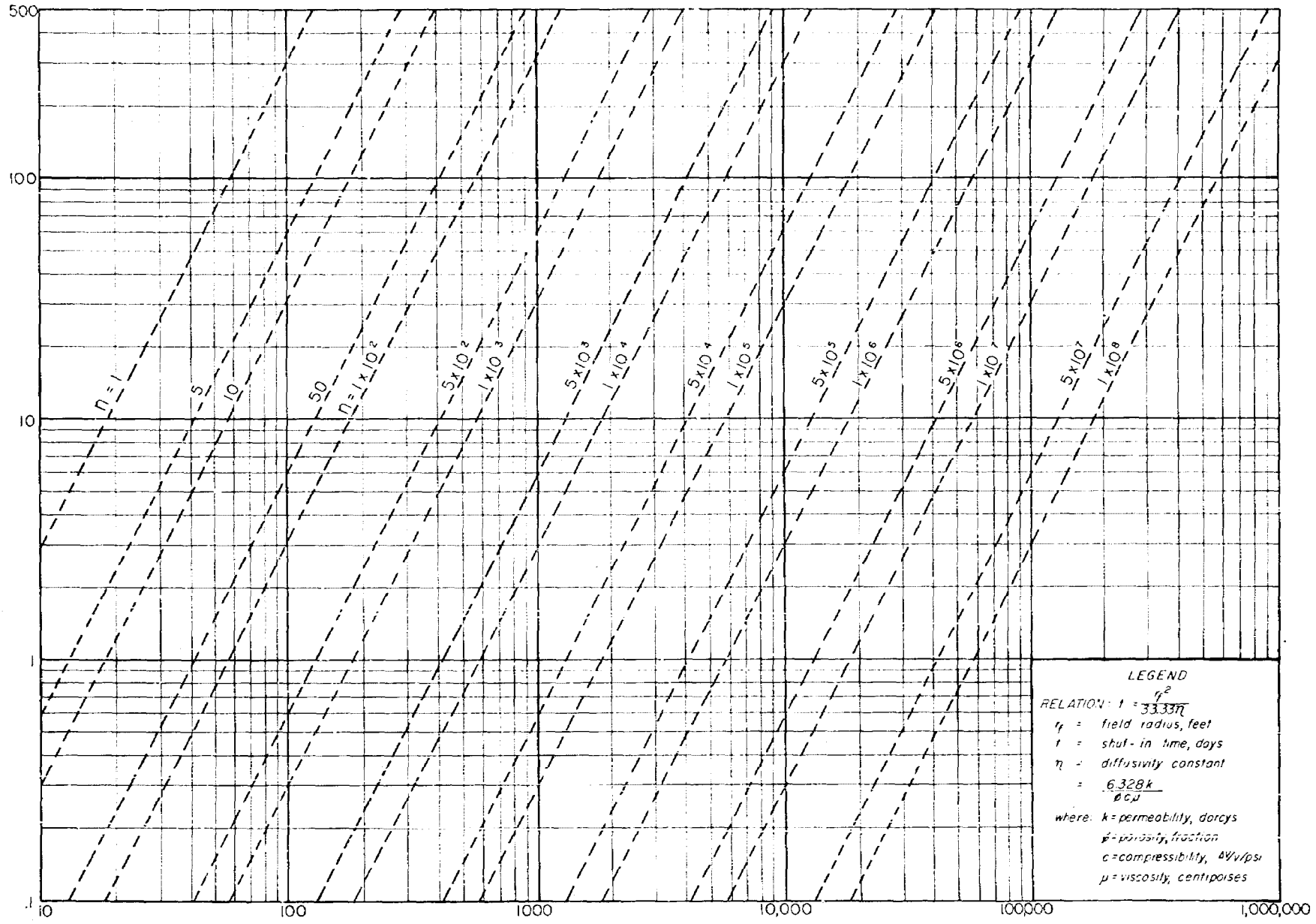


Fig. No. 11

TIME AT WHICH PRESSURE BUILD-UP OF SHUT-IN WELL CEASES TO BE A STRAIGHT LINE FUNCTION OF LOG TIME DUE TO EFFECT OF BOUNDARY CONDITIONS

FOR WELL IN CLOSED CIRCULAR DRAINAGE AREA OF UNIFORM PROPERTIES

DETERMINED BY TIME AT WHICH $T_D = .03$ AFTER FERRNE, API DRILLING AND PRODUCTION PRACTICE 1956 AND MILLER, DYES AND HUTCHINSON, JR. PET. TR. '50



SHUT-IN TIME - DAYS

RADIUS OF CIRCULAR DRAINAGE AREA - FEET

Fig. No. 12

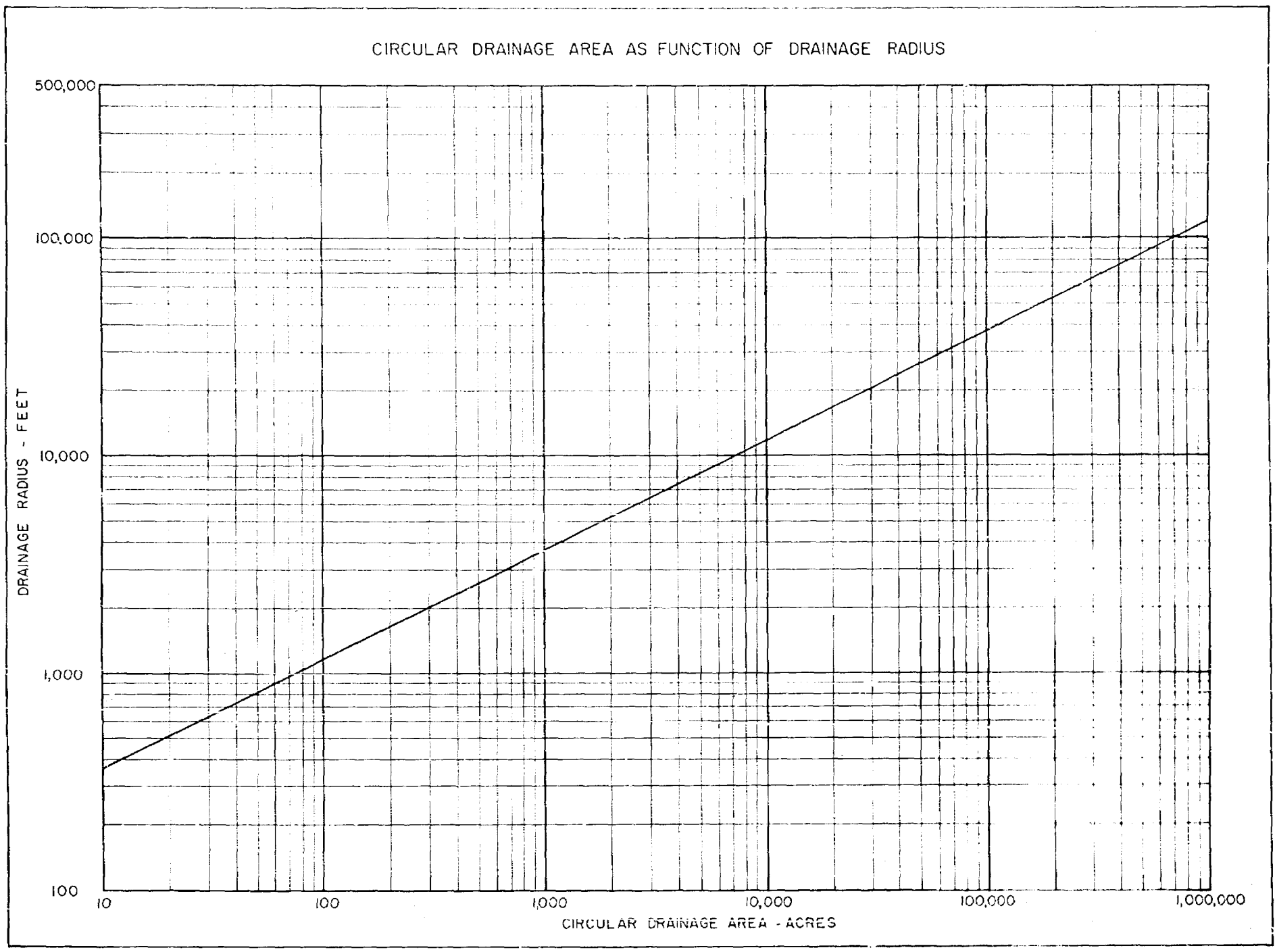

CIRCULAR DRAINAGE AREA AS FUNCTION OF DRAINAGE RADIUS
500,000
100,000
10,000
1,000
100
DRAINAGE RADIUS - FEET
10
100
1,000
10,000
100,000
1,000,000
CIRCULAR DRAINAGE AREA - ACRES

Fig. No. 13

PRESSURE PRODUCTION HISTORY

BOULDER MANCOS POOL

RIO ARRIBA COUNTY

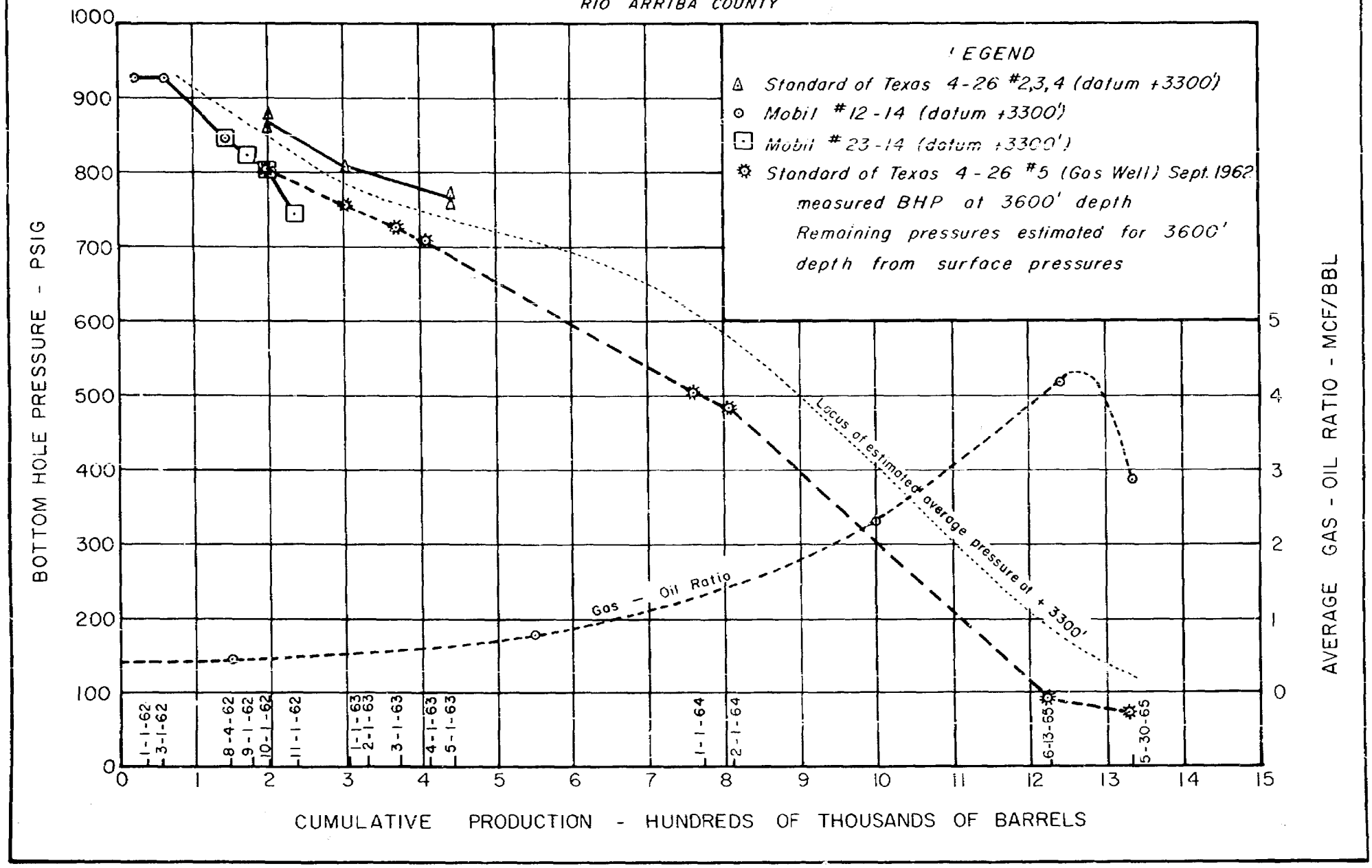


Fig. No. 14

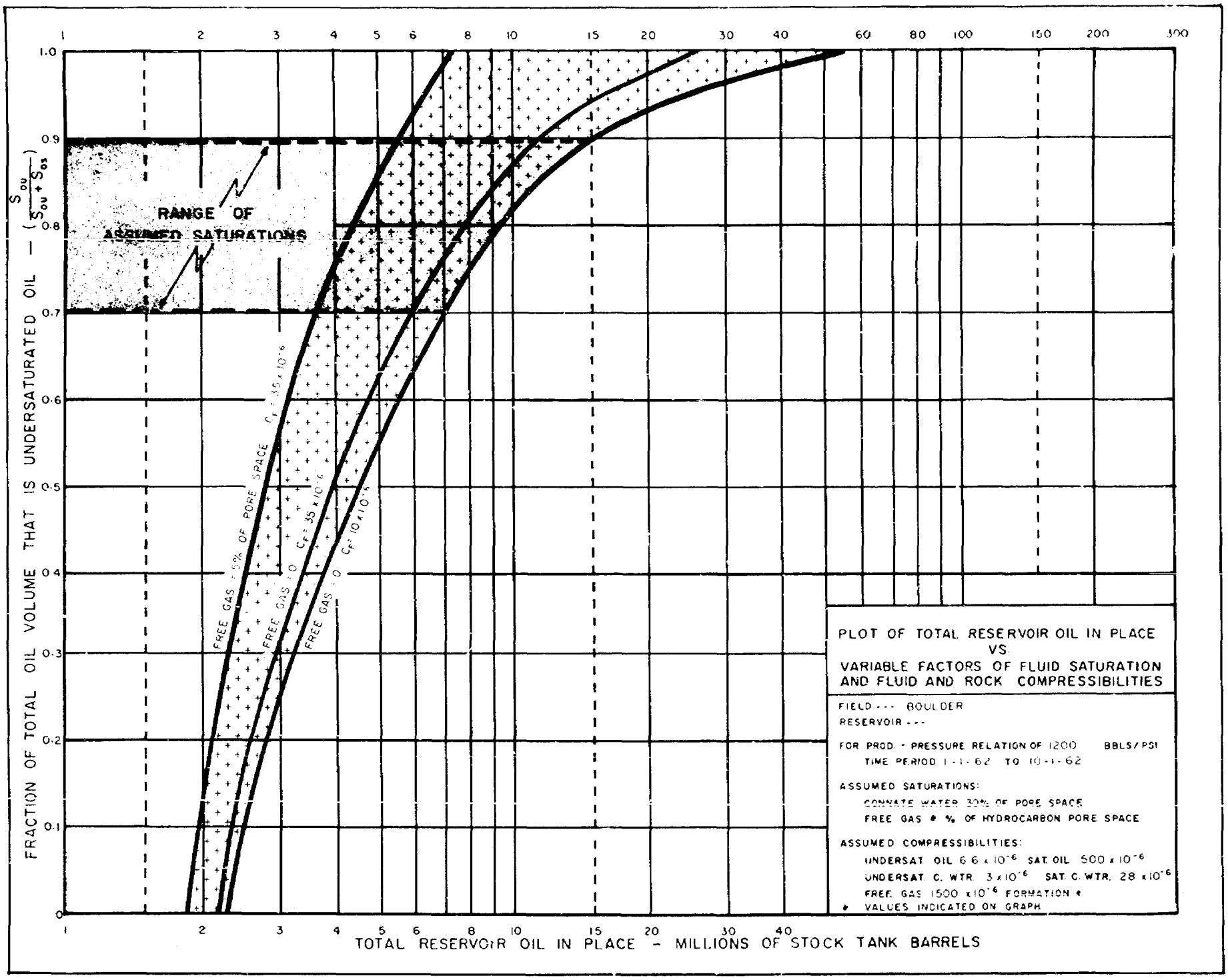

1
2
3
4
5
6
8
10
15
20
30
40
60
80
100
150
200
300
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\frac{S_{ou}}{S_{ou}+S_{os}}$
FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL —
RANGE OF ASSUMED SATURATIONS
FREE GAS = 5% OF PORE SPACE $C_f = 35 \times 10^{-6}$
FREE GAS = 0 $C_f = 35 \times 10^{-6}$
FREE GAS = 0 $C_f = 10 \times 10^{-6}$
TOTAL RESERVOIR OIL IN PLACE - MILLIONS OF STOCK TANK BARRELS
PLOT OF TOTAL RESERVOIR OIL IN PLACE
VS.
VARIABLE FACTORS OF FLUID SATURATION
AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- BOULDER
RESERVOIR ---
FOR PROD. - PRESSURE RELATION OF 1200 BBLS/PSI
TIME PERIOD 1-1-62 TO 10-1-62
ASSUMED SATURATIONS:
CONNATE WATER 30% OF PORE SPACE
FREE GAS # % OF HYDROCARBON PORE SPACE
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 6.6×10^{-6} SAT. OIL 500×10^{-6}
UNDERSAT. C. WTR. 3×10^{-6} SAT. C. WTR. 28×10^{-6}
FREE GAS 1500×10^{-6} FORMATION #
VALUES INDICATED ON GRAPH

Fig. No. 15

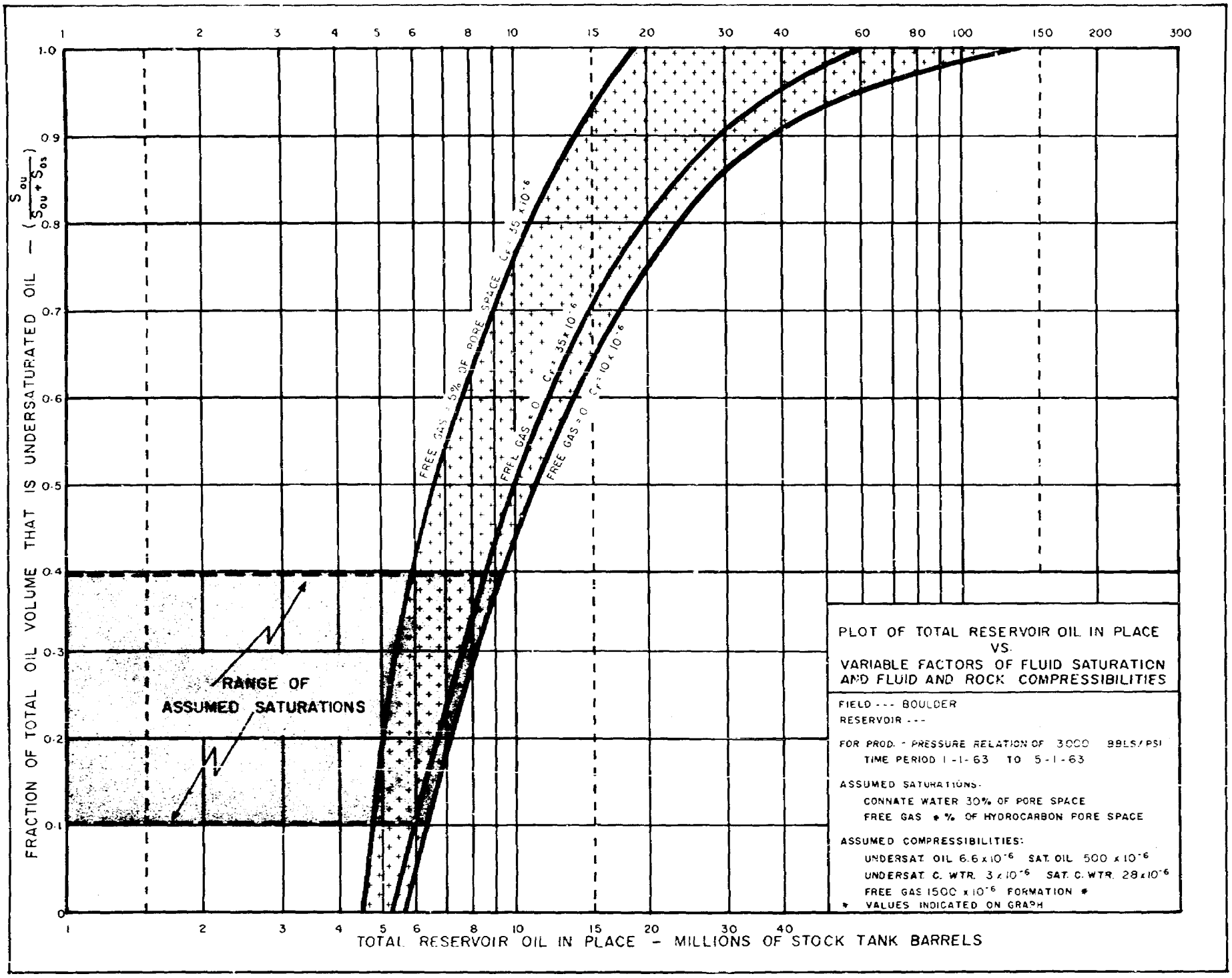
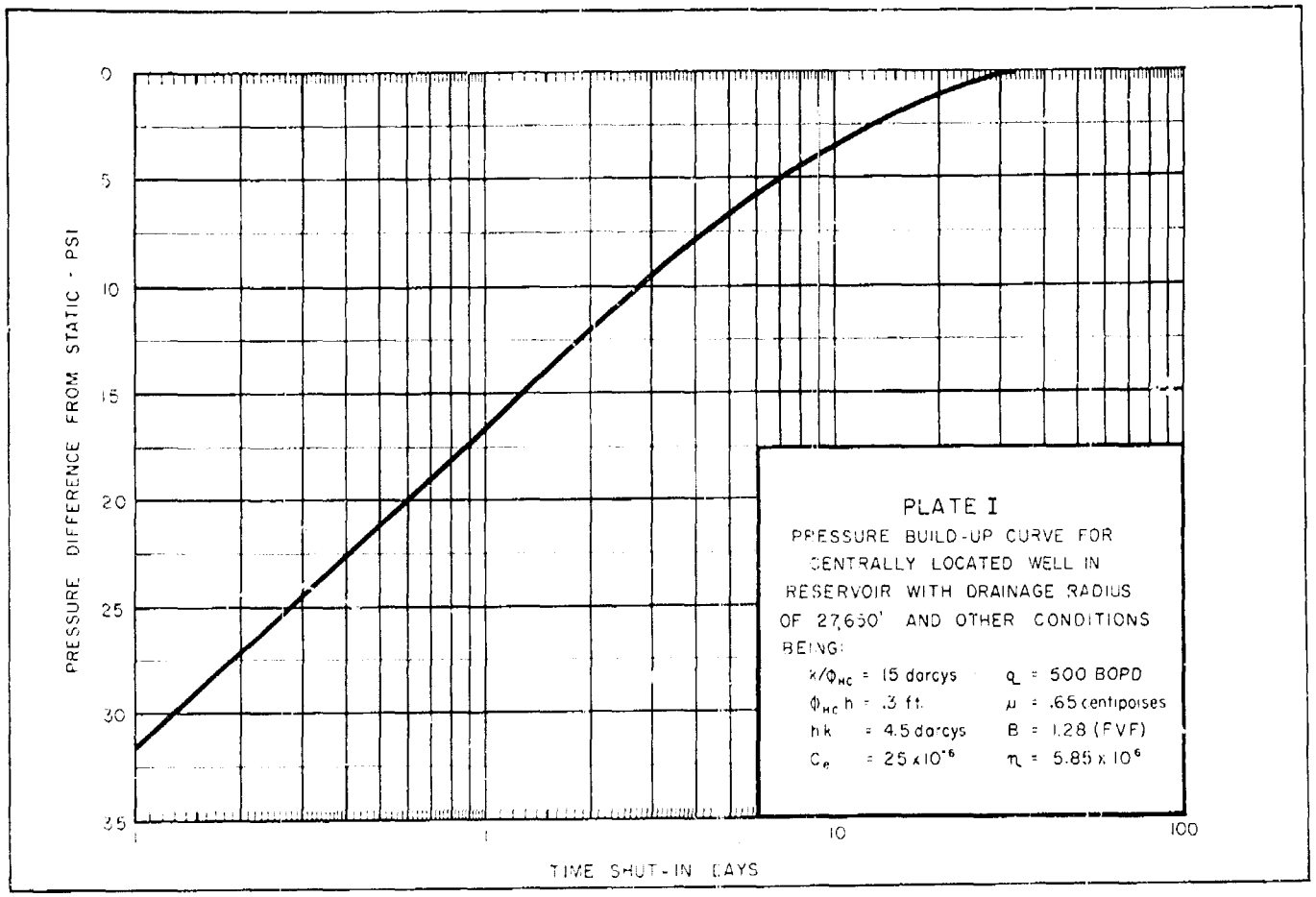

1
2
3
4
5
6
8
10
15
20
30
40
60
80
100
150
200
300
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL — $\left(\frac{S_{ou}}{S_{ou}+S_{os}}\right)$
FREE GAS = 5% OF PORE SPACE Cf = 35 x 10⁻⁶
FREE GAS = 0 Cf = 35 x 10⁻⁶
FREE GAS = 0 Cf = 10 x 10⁻⁶
RANGE OF ASSUMED SATURATIONS
TOTAL RESERVOIR OIL IN PLACE — MILLIONS OF STOCK TANK BARRELS
PLOT OF TOTAL RESERVOIR OIL IN PLACE
VS.
VARIABLE FACTORS OF FLUID SATURATION AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- BOULDER
RESERVOIR ---
FOR PROD. - PRESSURE RELATION OF 3000 BBLS/PSI
TIME PERIOD 1-1-63 TO 5-1-63
ASSUMED SATURATIONS-
CONNATE WATER 30% OF PORE SPACE
FREE GAS * % OF HYDROCARBON PORE SPACE
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 6.6 x 10⁻⁶ SAT. OIL 500 x 10⁻⁶
UNDERSAT. C. WTR. 3 x 10⁻⁶ SAT. C. WTR. 28 x 10⁻⁶
FREE GAS 1500 x 10⁻⁶ FORMATION *
* VALUES INDICATED ON GRAPH

Fig. No. 16


PRESSURE DIFFERENCE FROM STATIC - PSI
0
5
10
15
20
25
30
35
1
10
100
TIME SHUT-IN DAYS
PLATE I
PRESSURE BUILD-UP CURVE FOR CENTRALLY LOCATED WELL IN RESERVOIR WITH DRAINAGE RADIUS OF 27,650' AND OTHER CONDITIONS BEING:
k/ϕ_{HC} = 15 darcys
$\phi_{HC} h$ = .3 ft.
hk = 4.5 darcys
C_e = 25×10^{-6}
q_L = 500 BOPD
μ = .65 centipoises
B = 1.28 (FVF)
π = 5.85×10^6

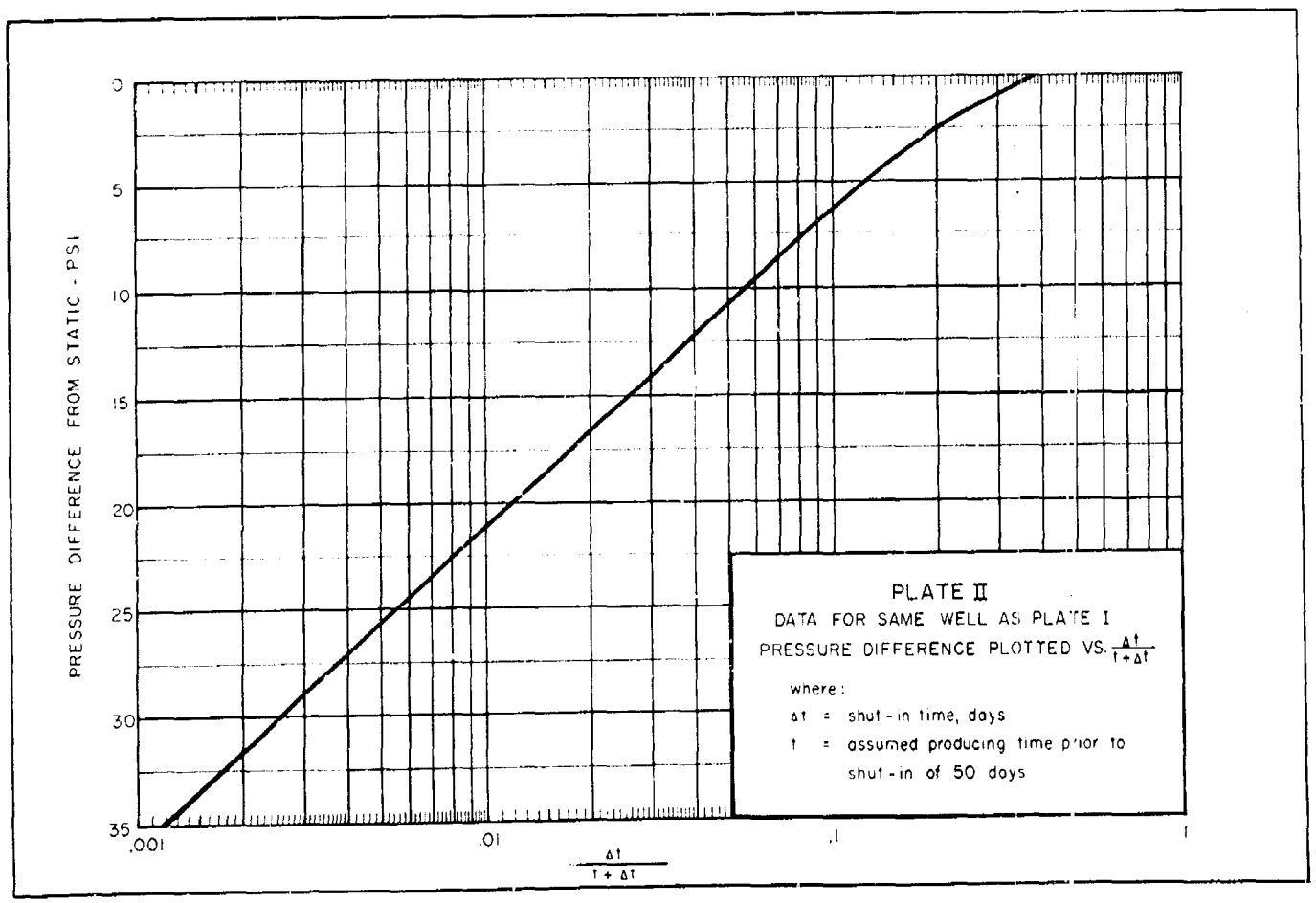
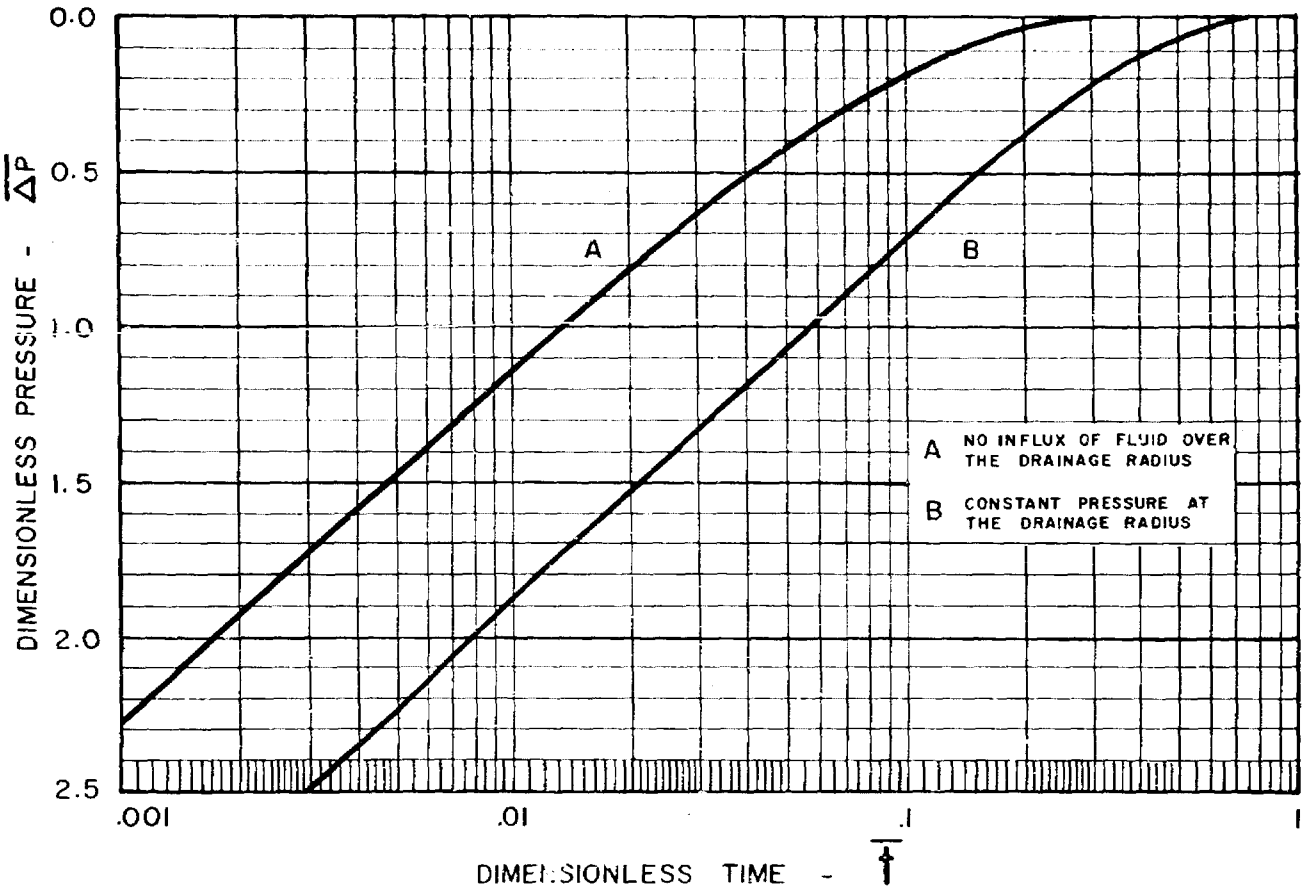

PRESSURE DIFFERENCE FROM STATIC - PSI
0
5
10
15
20
25
30
35
.001
.01
.1
1
$\frac{\Delta t}{t + \Delta t}$
PLATE II
DATA FOR SAME WELL AS PLATE I
PRESSURE DIFFERENCE PLOTTED VS. $\frac{\Delta t}{t + \Delta t}$
where:
Δt = shut-in time, days
t = assumed producing time prior to shut-in of 50 days

Fig. No. 17

PRESSURE - BUILD-UP CURVE FOR CIRCULAR RESERVOIR OF UNIFORM PROPERTIES IN TERMS OF DIMENSIONLESS PRESSURE AND TIME VARIABLES

AFTER PERRINE, API DRILLING AND PRODUCTION PRACTICE, 1956
AND
MILLER, DYES AND HUTCHINSON, AIME, 1950, VOL. 189



$$\overline{t} = \frac{6.328\, k_o t}{\phi c \mu r_e^2} = \frac{\eta t}{r_e^2} \qquad \eta = \frac{6.328\, k_o}{\phi c \mu}$$

where:

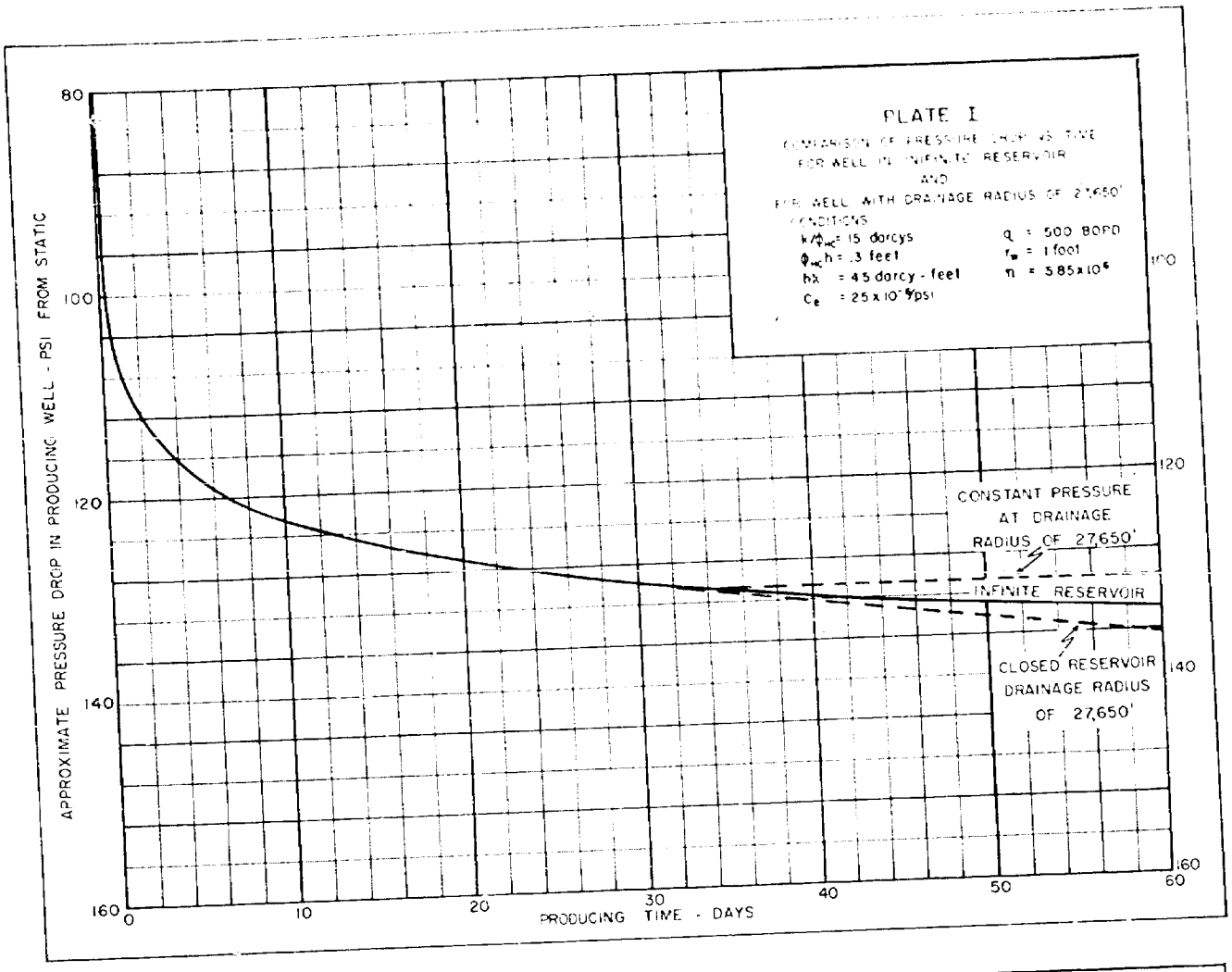
$\overline{t}$ = dimensionless time
k_o = permeability to oil, darcys
t = shut-in time, days
ϕ = porosity, fraction
c = system compressibility, $\Delta V/V$/psi
μ = reservoir oil viscosity, centipoises
r_e = drainage radius, feet

$$\overline{\Delta p} = \frac{7.08\, k_o h\, (P_{ws} - P_t)}{q \mu B} = \frac{1.151\,(P_{ws} - P_t)}{m}$$

where:

Δp = dimensionless pressure difference
k_o = permeability to oil, darcys
h = pay thickness, feet
q = stabilized production rate prior to shut-in, BOPD
μ = reservoir oil viscosity, centipoises
B = formation volume factor, reservoir barrels per stock tank barrel
P_{ws} = static well pressure, psi
P_t = well pressure at time t, after shut-in, psi
$m = \frac{q \mu B}{6.151\, k_o h}$ = slope of plot of pressure vs. $\log_{10}$ time, psi/cycle

Fig. No. 18


PLATE I
COMPARISON OF PRESSURE DROP VS TIME
FOR WELL IN INFINITE RESERVOIR
AND
FOR WELL WITH DRAINAGE RADIUS OF 27,650'
CONDITIONS
k/ϕ_{mc} = 15 darcys
$\phi_{mc}h$ = .3 feet
hk = 45 darcy - feet
C_e = 2.5 x 10⁻⁶/psi
q = 500 BOPD
r_w = 1 foot
n = 5.85 x 10⁶
APPROXIMATE PRESSURE DROP IN PRODUCING WELL - PSI FROM STATIC
PRODUCING TIME - DAYS
CONSTANT PRESSURE AT DRAINAGE RADIUS OF 27,650'
INFINITE RESERVOIR
CLOSED RESERVOIR DRAINAGE RADIUS OF 27,650'
80
100
120
140
160
0
10
20
30
40
50
60

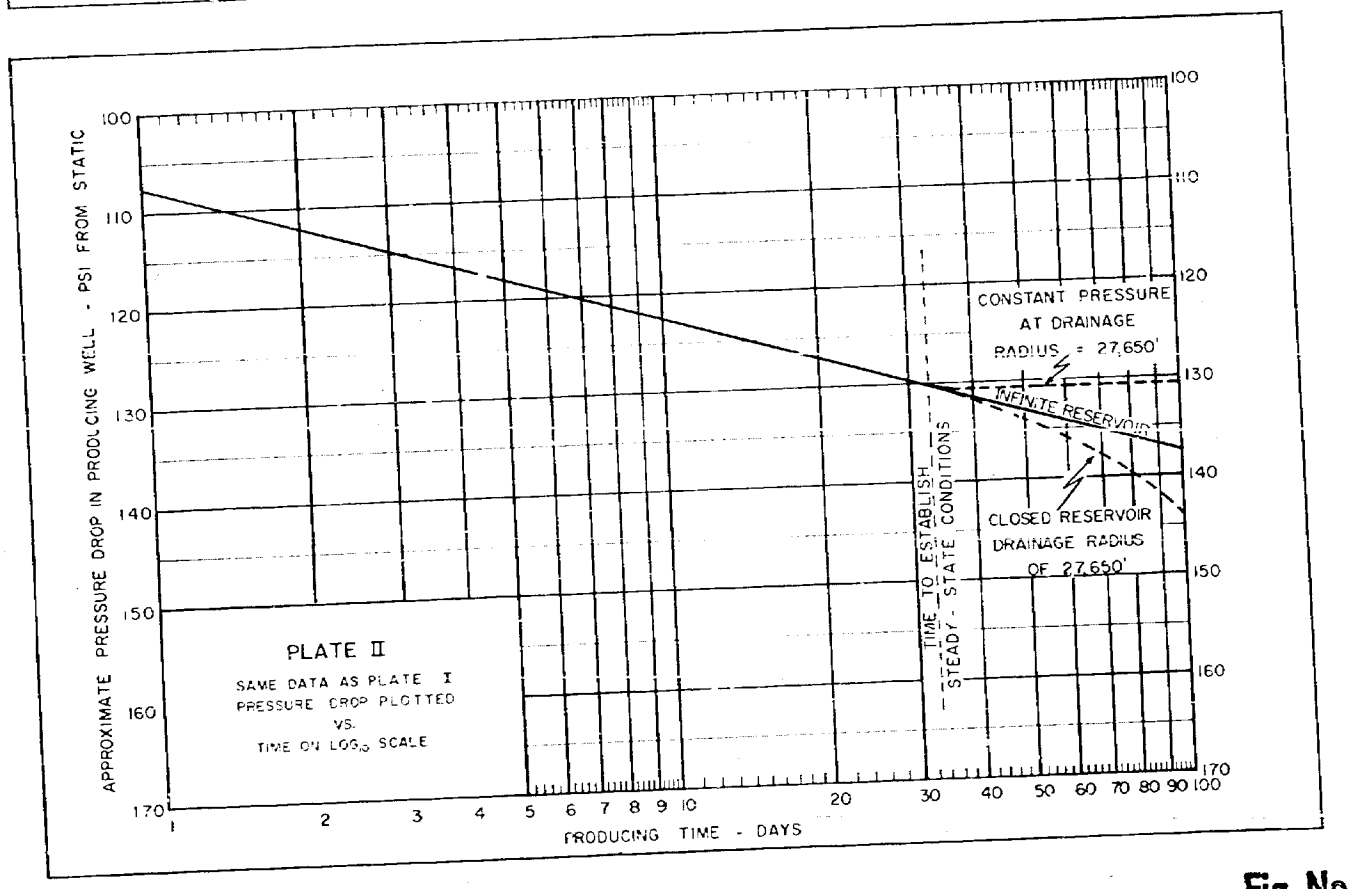

PLATE II
SAME DATA AS PLATE I
PRESSURE DROP PLOTTED
VS.
TIME ON LOG_{10} SCALE
APPROXIMATE PRESSURE DROP IN PRODUCING WELL - PSI FROM STATIC
PRODUCING TIME - DAYS
TIME TO ESTABLISH STEADY - STATE CONDITIONS
CONSTANT PRESSURE AT DRAINAGE RADIUS = 27,650'
INFINITE RESERVOIR
CLOSED RESERVOIR DRAINAGE RADIUS OF 27,650'
100
110
120
130
140
150
160
170
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100

Fig. No. 19

DIMENSIONLESS PRESSURE DROP AT OBSERVATION WELL 'B'
DUE TO PRODUCTION OF CENTRALLY LOCATED WELL 'A'
IN A SYMMETRICALLY BOUNDED RESERVOIR

AFTER DRISCOLL, TRANS. AIME, 1963, VOL.228, 1127

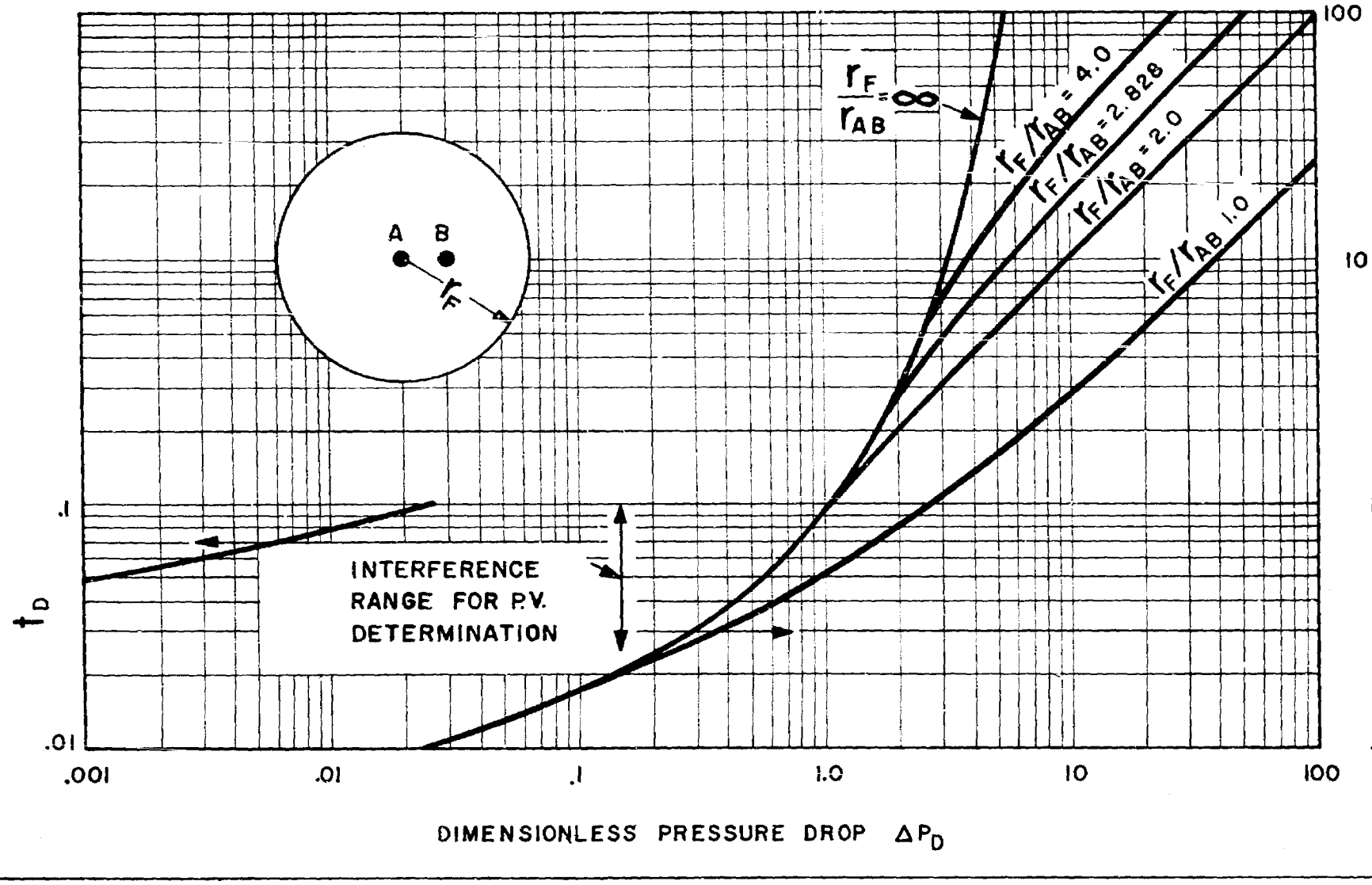
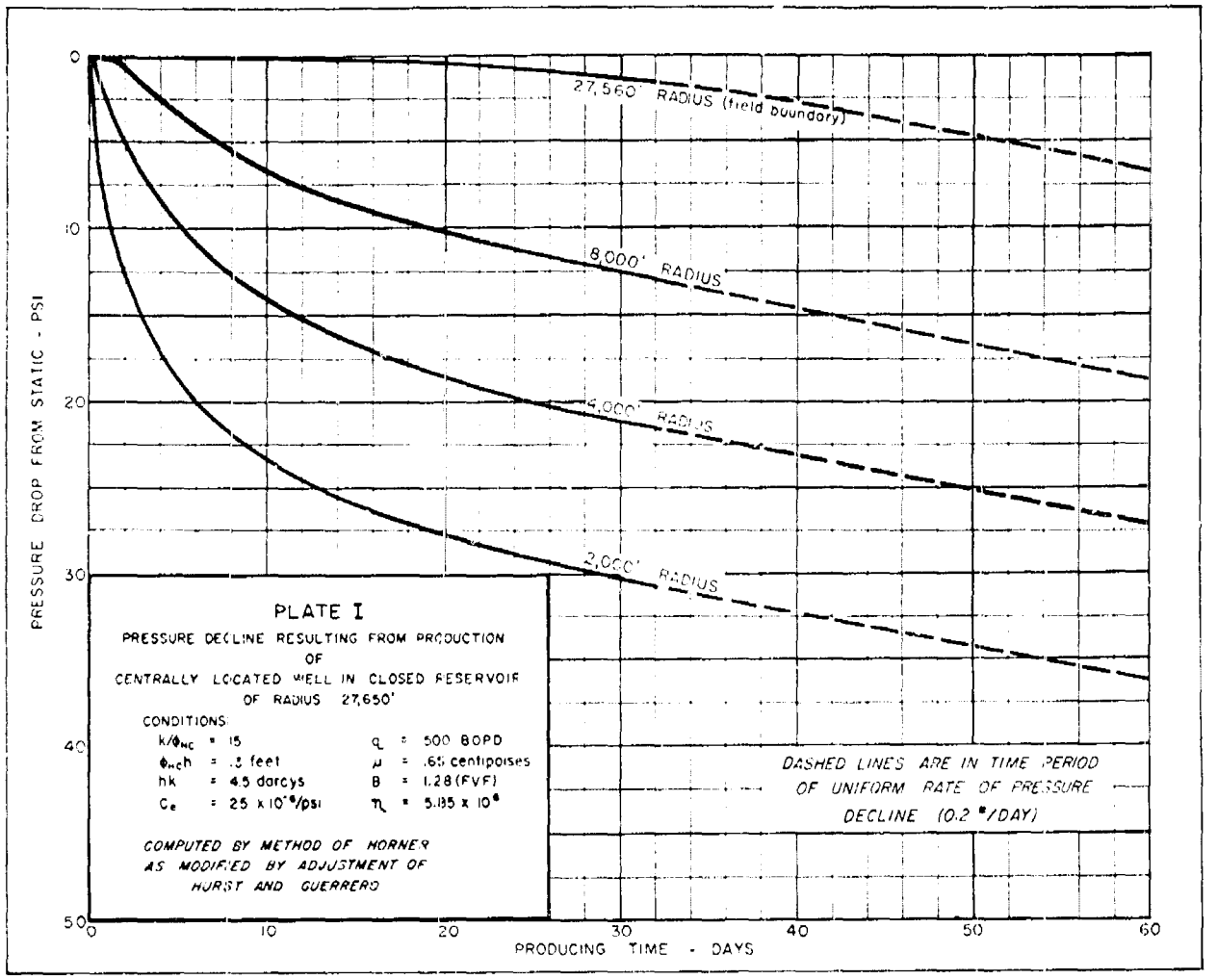


Fig. No. 20


PRESSURE DROP FROM STATIC - PSI
0
10
20
30
40
50
0
10
20
30
40
50
60
PRODUCING TIME - DAYS
27,560' RADIUS (field boundary)
8,000' RADIUS
4,000' RADIUS
2,000' RADIUS
PLATE I
PRESSURE DECLINE RESULTING FROM PRODUCTION
OF
CENTRALLY LOCATED WELL IN CLOSED RESERVOIR
OF RADIUS 27,650'
CONDITIONS:
k/φμc = 15
φμch = .3 feet
hk = 4.5 darcys
Ce = 25 x 10⁻⁶/psi
q = 500 BOPD
μ = .65 centipoises
B = 1.28 (FVF)
η = 5.185 x 10⁴
COMPUTED BY METHOD OF HORNER
AS MODIFIED BY ADJUSTMENT OF
HURST AND GUERRERO
DASHED LINES ARE IN TIME PERIOD
OF UNIFORM RATE OF PRESSURE
DECLINE (0.2 #/DAY)

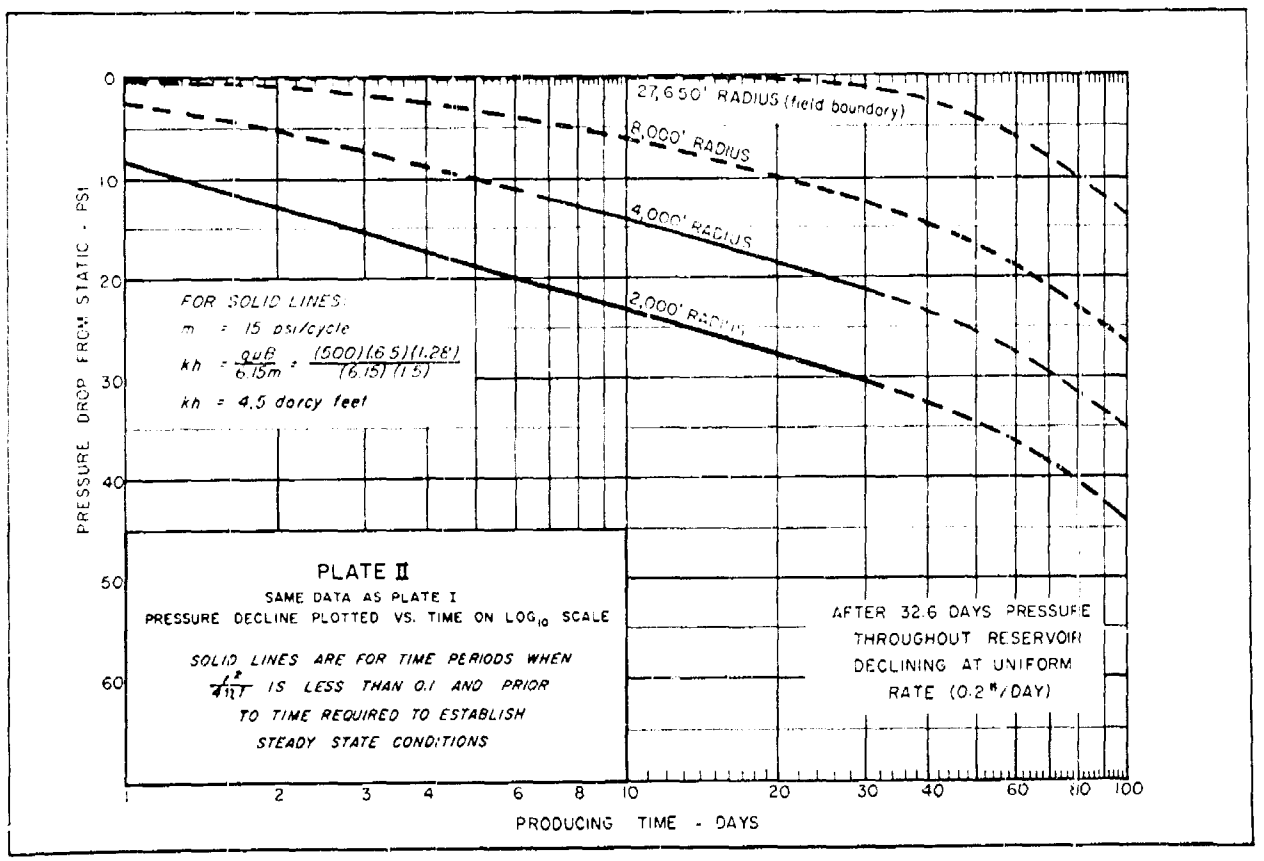
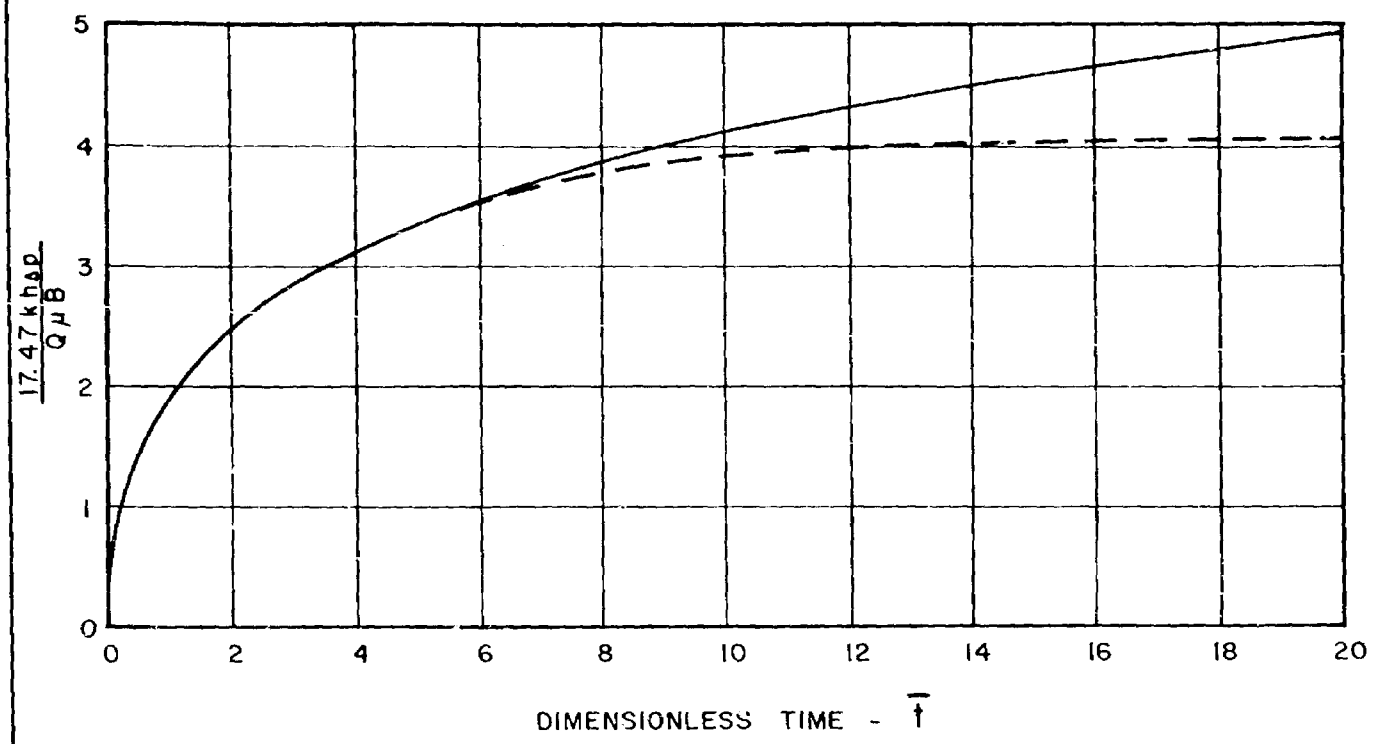

PRESSURE DROP FROM STATIC - PSI
0
10
20
30
40
50
60
1
2
3
4
6
8
10
20
30
40
60
80
100
PRODUCING TIME - DAYS
27,650' RADIUS (field boundary)
8,000' RADIUS
4,000' RADIUS
2,000' RADIUS
FOR SOLID LINES:
m = 15 psi/cycle
kh = qμB/6.15m = (500)(.65)(1.28)/(6.15)(15)
kh = 4.5 darcy feet
PLATE II
SAME DATA AS PLATE I
PRESSURE DECLINE PLOTTED VS. TIME ON LOG10 SCALE
SOLID LINES ARE FOR TIME PERIODS WHEN
kt/φμcr² IS LESS THAN 0.1 AND PRIOR
TO TIME REQUIRED TO ESTABLISH
STEADY STATE CONDITIONS
AFTER 32.6 DAYS PRESSURE
THROUGHOUT RESERVOIR
DECLINING AT UNIFORM
RATE (0.2 #/DAY)

Fig. No. 21

PRESSURE DECLINE AT THE INTERNAL BOUNDARY OF LARGE RESERVOIRS SUBJECT TO CONSTANT WITHDRAWAL RATE

AFTER MUSKAT, PHYSICAL PRINCIPLES OF OIL PRODUCTION, 543



$$\bar{t} = \frac{6.328\,kt}{\phi c \mu\, r_f^2} = \frac{\eta t}{r_f^2} \qquad \eta = \frac{6.328k}{\phi c \mu}$$

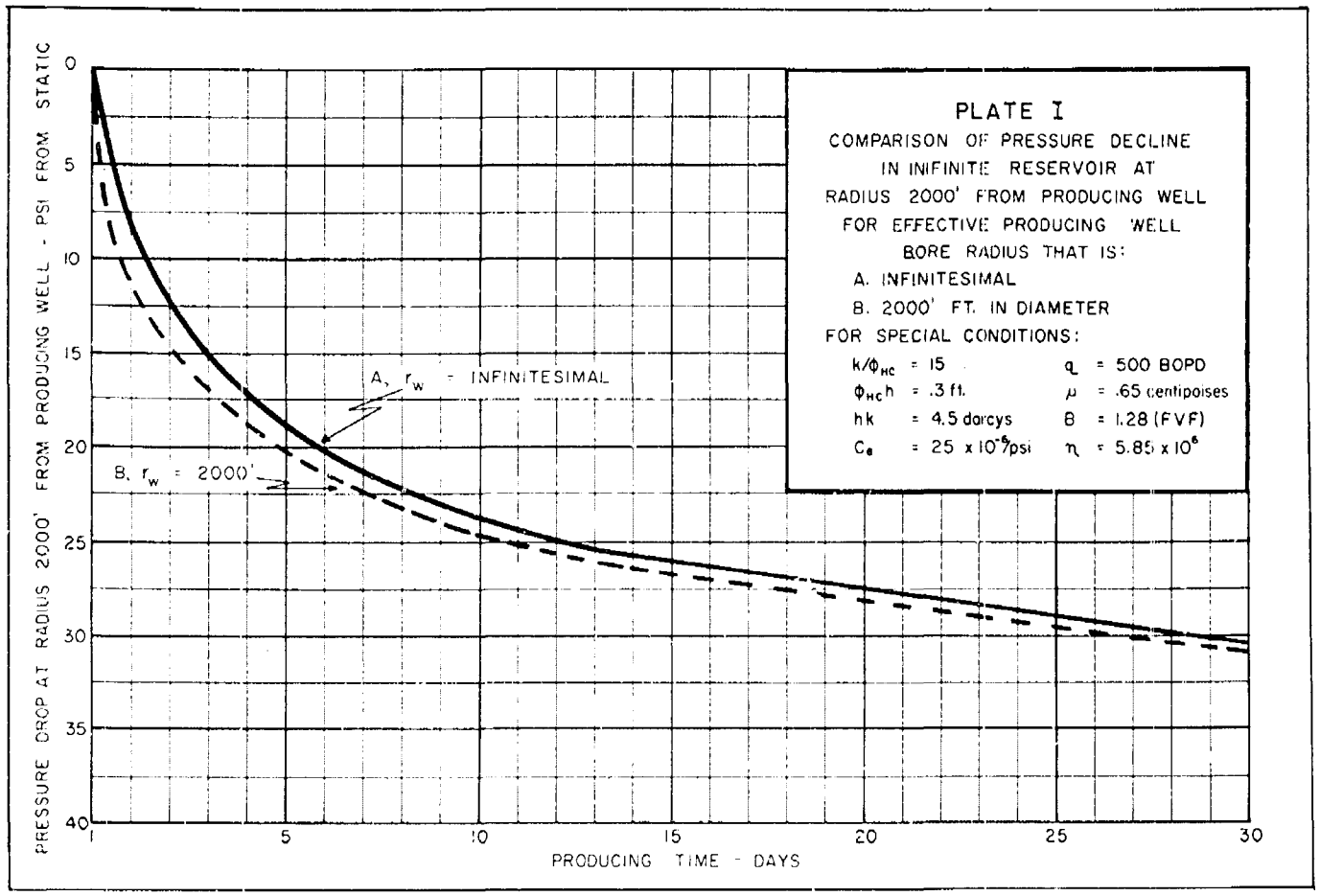
where:

$\bar{t}$ = dimensionless time
k = permeability, darcys
t = producing time, days
ϕ = porosity, fraction
c = system compressibility, $\Delta v/v/psi$
μ = viscosity, centipoises
r_f = internal boundary radius, feet
Q = constant withdrawal rate, bbls/day
μ = viscosity, centipoises
B = formation volume factor, reservoir bbls per surface barrel

ΔP = pressure drop from static at time t, at internal boundary

SOLID CURVE REFERS TO AN INFINITE RESERVOIR
DASHED CURVE APPLIES TO A FINITE RESERVOIR WITH THE PRESSURE KEPT FIXED AT AN EXTERNAL RADIUS THAT IS 6.3 TIMES r_f

Fig. No. 22


PRESSURE DROP AT RADIUS 2000' FROM PRODUCING WELL - PSI FROM STATIC
0
5
10
15
20
25
30
35
40
A, r_w = INFINITESIMAL
B, r_w = 2000'
1
5
10
15
20
25
30
PRODUCING TIME - DAYS
PLATE I
COMPARISON OF PRESSURE DECLINE IN INIFINITE RESERVOIR AT RADIUS 2000' FROM PRODUCING WELL FOR EFFECTIVE PRODUCING WELL BORE RADIUS THAT IS:
A. INFINITESIMAL
B. 2000' FT. IN DIAMETER
FOR SPECIAL CONDITIONS:
k/ϕ_{HC} = 15
$\phi_{HC}h$ = .3 ft.
hk = 4.5 darcys
C_e = 25 x 10^{-6}/psi
q = 500 BOPD
μ = .65 centipoises
B = 1.28 (FVF)
η = 5.85 x 10^6

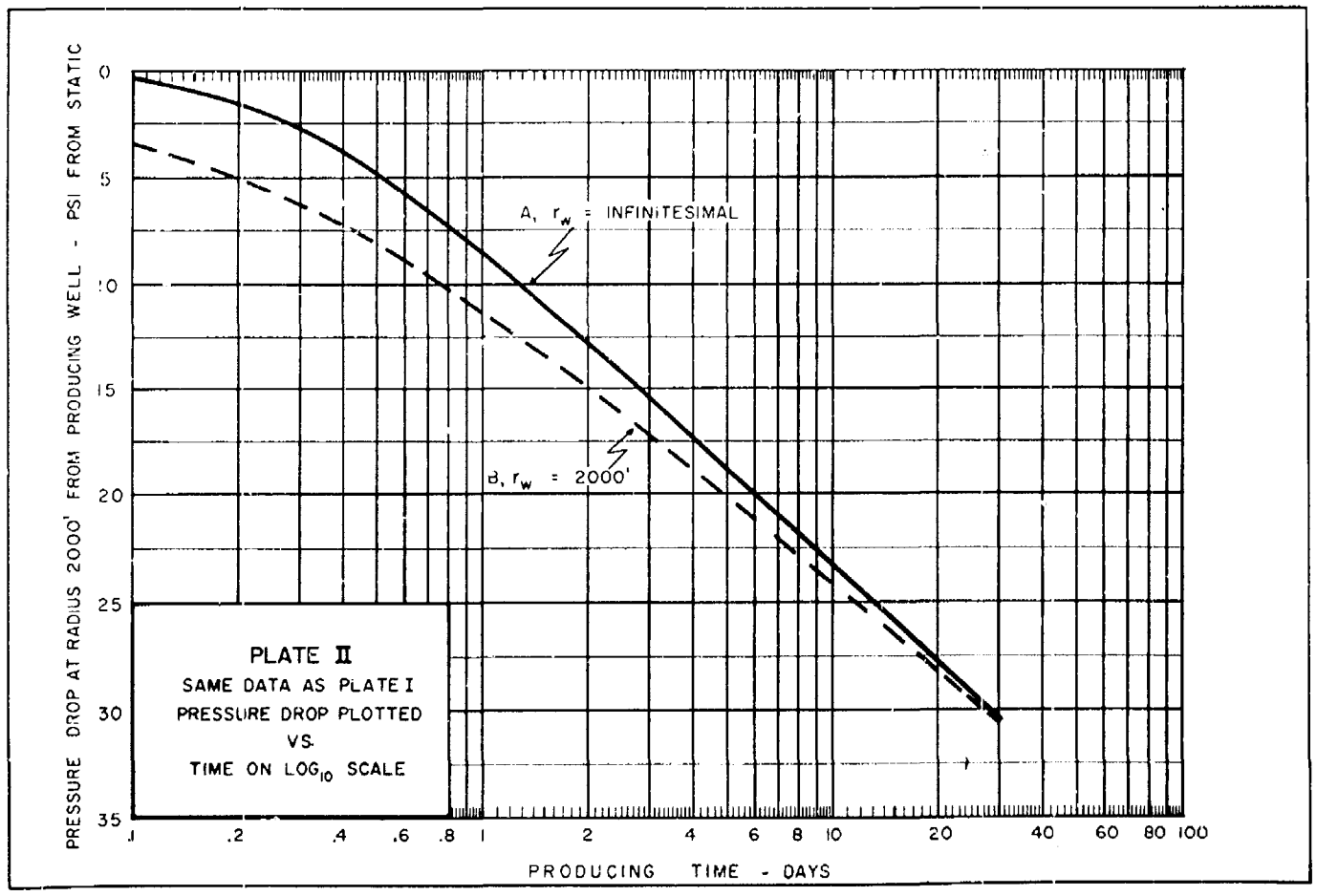
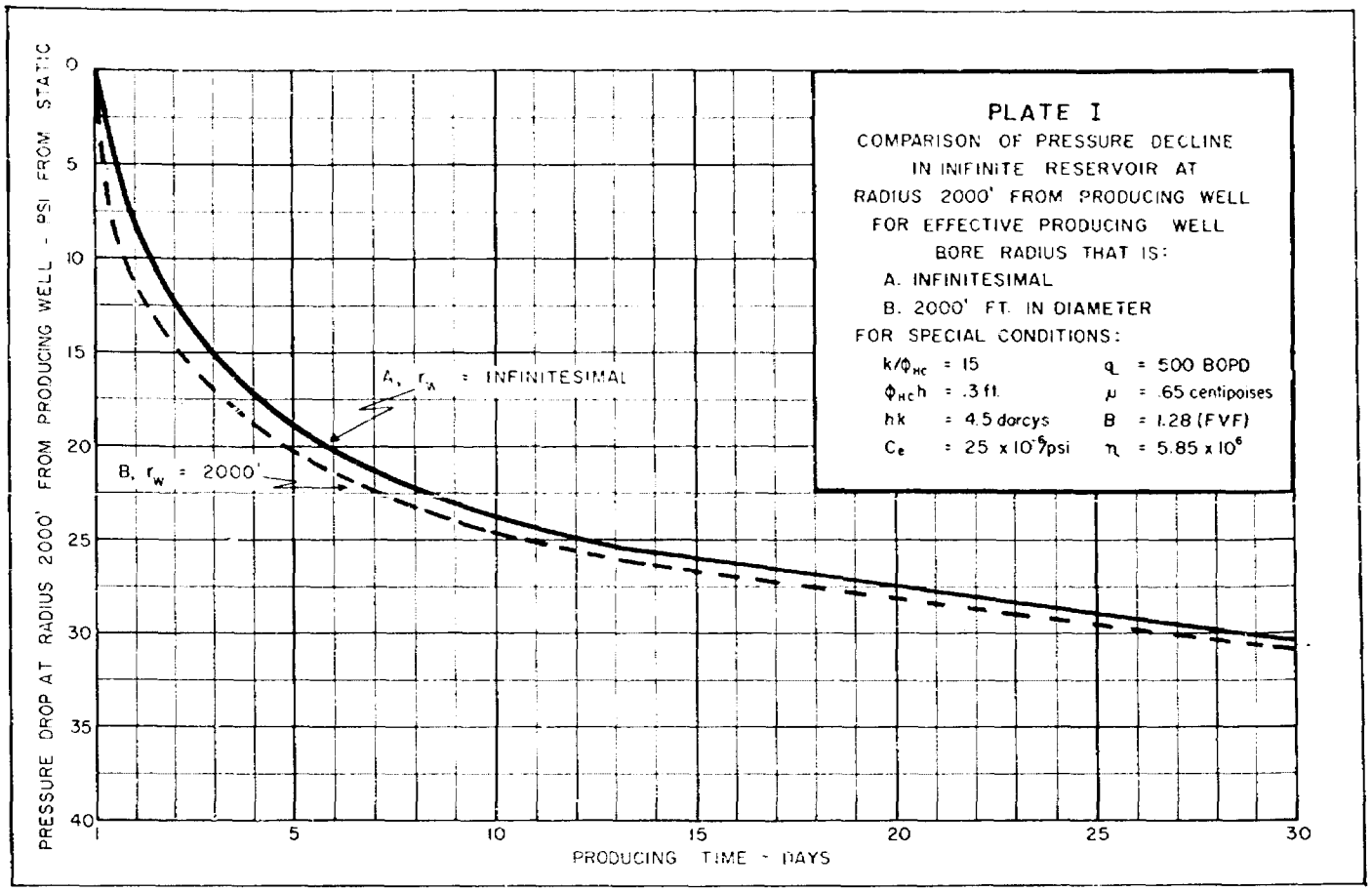

PRESSURE DROP AT RADIUS 2000' FROM PRODUCING WELL - PSI FROM STATIC
0
5
10
15
20
25
30
35
A, r_w = INFINITESIMAL
B, r_w = 2000'
.1
.2
.4
.6
.8
1
2
4
6
8
10
20
40
60
80
100
PRODUCING TIME - DAYS
PLATE II
SAME DATA AS PLATE I
PRESSURE DROP PLOTTED
VS.
TIME ON LOG_{10} SCALE

Fig. No. 23


PLATE I
COMPARISON OF PRESSURE DECLINE IN INIFINITE RESERVOIR AT RADIUS 2000' FROM PRODUCING WELL FOR EFFECTIVE PRODUCING WELL BORE RADIUS THAT IS:
A. INFINITESIMAL
B. 2000' FT. IN DIAMETER
FOR SPECIAL CONDITIONS:
k/ϕ_{Hc} = 15
$\phi_{Hc}h$ = .3 ft.
hk = 4.5 darcys
C_e = 25 x 10^{-6}/psi
q = 500 BOPD
μ = .65 centipoises
B = 1.28 (FVF)
η = 5.85 x 10^6
A, r_w = INFINITESIMAL
B, r_w = 2000'
PRESSURE DROP AT RADIUS 2000' FROM PRODUCING WELL - PSI FROM STATIC
PRODUCING TIME - DAYS
0
5
10
15
20
25
30
35
40
1
5
10
15
20
25
30

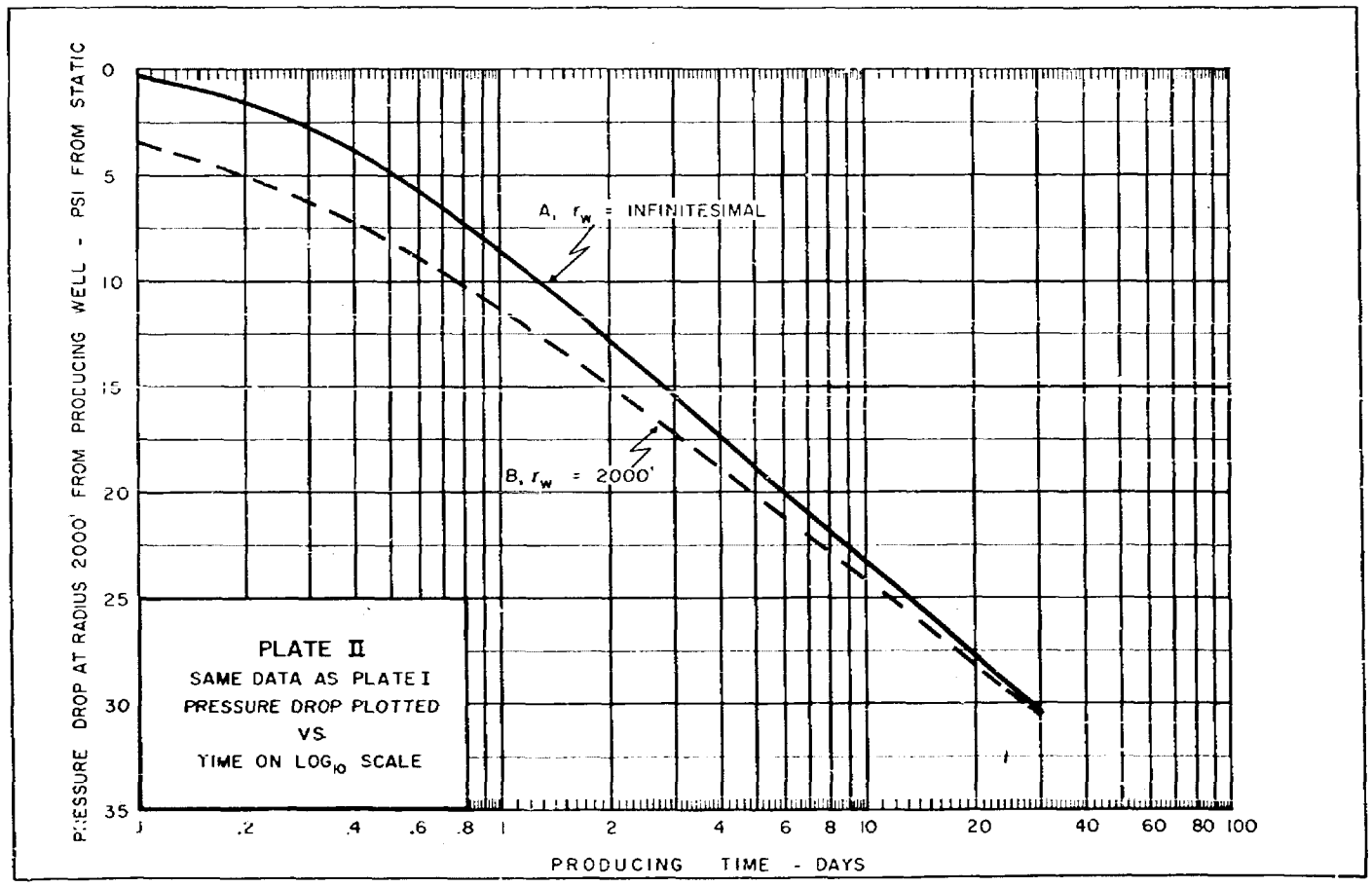

PLATE II
SAME DATA AS PLATE I
PRESSURE DROP PLOTTED
VS
TIME ON LOG_{10} SCALE
A, r_w = INFINITESIMAL
B, r_w = 2000'
PRESSURE DROP AT RADIUS 2000' FROM PRODUCING WELL - PSI FROM STATIC
PRODUCING TIME - DAYS
0
5
10
15
20
25
30
35
.1
.2
.4
.6
.8
1
2
4
6
8
10
20
40
60
80
100

Fig. No. 23

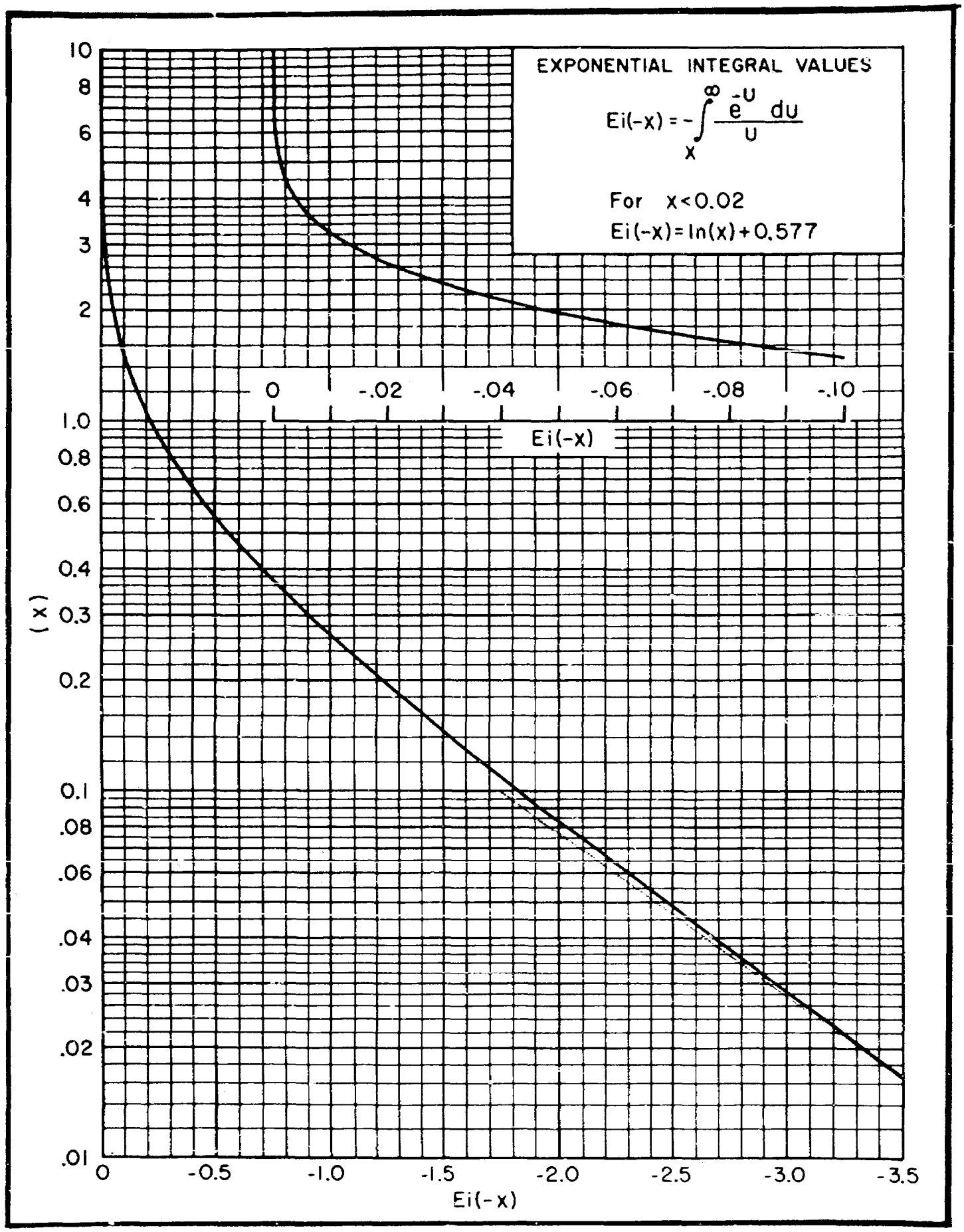

EXPONENTIAL INTEGRAL VALUES
$Ei(-x) = -\int_x^\infty \frac{e^{-u}}{u}\,du$
For x<0.02
Ei(-x)=ln(x)+0.577
10
8
6
4
3
2
1.0
0.8
0.6
0.4
0.3
0.2
0.1
.08
.06
.04
.03
.02
.01
(x)
0
-.02
-.04
-.06
-.08
-.10
Ei(-x)
0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
Ei(-x)

Fig. No. 24

[redacted]

APPENDIX

PART I

ESTIMATION OF TOTAL OIL IN PLACE IN A DRAINAGE AREA FROM SINGLE COMPLETE PRESSURE BUILD-UP TEST

The method shown here for estimating total oil in place in a drainage area is for a closed, circular reservoir of uniform properties and with the well centrally located. It is presumed this type method could similarly be developed for different geometrical configurations (i.e., from pressure build-up method shown by Matthews, Brons and Hazebroek [19]), if the geometry is known and properly accounted for.

Using Perrine's [17] method (after Miller, Dyes and Hutchinson [18]) and symbols and dimensions of units of this paper (given on Figure No. 18) dimensionless time can be expressed:

$$\bar{t} = \frac{6.328\ Kt}{\phi\ c\ \mu\ r_e^2} \qquad \text{(A-1)}$$

which becomes, by multiplying through by pay thickness, h, in feet:

$$\bar{t} = \frac{6.328\ Kh\ t}{C\mu\ (\phi\ h\ r_e^2)} \qquad \text{(A-2)}$$

Since $$C\phi = C_e\phi_{hc} \qquad \text{(A-3)}$$

where ϕ_{hc} = effective porosity of the oil phase hydrocarbon = $\phi(1 - S_w - S_g)$

we may write $$\bar{t} = \frac{6.328\ Kh\ t}{C_e\mu(\phi_{hc}r_e^2)} \qquad \text{(A-4)}$$

If N represents total stock tank oil in place in the circular drainage area, we may write:

$$N = \frac{\pi r_e^2 h \phi_{hc}}{5.615\ B} \qquad \text{(A-5)}$$

Rearranging terms and substituting Equation (A-5) into Equation (A-4)

we obtain $$N = \frac{3.54\ Kh\ t}{C_e\ \mu\ B\ \overline{t}} \qquad \text{(A-6)}$$

Recognize that $$Kh = \frac{q\ \mu\ B}{6.15m} \qquad \text{(A-7)}$$

and rearranging terms and substituting in Equation (A-6) we obtain

$$N = \frac{q\ t}{1.74m\ C_e\ \overline{t}} \qquad \text{(A-8)}$$

$\overline{t}$ for any real time t is obtained from $\overline{\Delta P}$ determined from Perrine's equation (and from Figure No. 18)

$$\overline{\Delta P} = \frac{1.151\ (P_{ws} - P_t)}{m}$$

after choosing $P_{ws} - P_t$ at the same real time, t, from the complete pressure build-up curve.

Total oil in place in the drainage area can then be calculated by Equation (A-8).

APPENDIX

PART II

DETERMINATION OF TRANSMISSIBILITY (Kh) FROM TRANSIENT PRESSURE BEHAVIOR OF INTERFERENCE TEST WELLS

As shown by Craft and Hawkins (1959, Page 319), the Ei equation expressed in symbols and units of dimensions of this paper and for times when $\frac{r^2}{4nt}$ is less than .02 may be written:

$$P_e - P_w = \frac{q \mu B}{14.16 Kh} \ln \left(\frac{14.22 Kt}{c \phi \mu r^2} \right) \qquad (A\text{-}10)$$

where r is the distance from the producing well to the shut-in observation well.

Changing to logarithms to base 10,

$$P_e - P_w = \frac{q \mu B}{6.15 Kh} \log_{10} \left(\frac{14.22 Kt}{c \phi \mu r^2} \right) \qquad (A\text{-}11)$$

which may also be written:

$$P_e - P_w = \frac{q \mu B}{6.15 Kh} \log t + \text{constant} \qquad (A\text{-}12)$$

which is of the form:

$$y = m x + b$$

the equation of a straight line, if time be expressed as a logarithm to base 10.

The coefficient of log t will be the slope, m, which is

$$m = \frac{q \mu B}{6.15 Kh} \quad \#/\text{cycle} \qquad (A\text{-}13)$$

from which transmissibility is determined to be

$$Kh = \frac{q \mu B}{6.15 m} \quad \text{(darcy feet)} \qquad (A\text{-}14)$$

Although the above relation will be strictly true only for times when $\frac{r^2}{4\eta t}$ is less than .02, the deviation will not be great for times when $\frac{r^2}{4\eta t}$ is between .02 and .1, as indicated on Figure No. 24.

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[redacted]

Use of Well Interference and Build-Up Data for Early Quantitative Determination of Reserves, Permeability and Water Influx

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ABSTRACT

A method is given for checking pore volume reserve estimates and transient water influx factors utilizing early well performance. Principal applications are based on the observation that there is a convenient transient time-range in terms of well spacing in which observed pressure drop will give a good indication of fluid in-place. Primary quantity determined is a porosity-feet value applicable in the vicinity of an observation well. Checks on porosity or net pay thickness and permeability values also are obtained. These are particularly valuable in improving quality of interpretive factors entering into pore-volume reserve determinations for larger fields. In smaller fields, direct determination of total field reserves and approximate location of boundaries may be made in some cases.

Well interference and production data plus a build-up curve on the observation well are needed. The build-up curve may be taken at any time. Field applications are given. The method can be applied with the completion of the second well on a new discovery or to older reservoirs by major changes in withdrawal rates from a local area. Appropriate test length permits results to be obtained with equal accuracy on widely spaced wells. Criteria for optimizing test conditions are given. Provision is made for various boundary and well effects including incomplete observation well build-up.

INTRODUCTION

Due to low quality data, initial pore volume reserve and water influx estimates may often vary by a factor of two or more from results obtained at a later date. Unfortunately, by conventional methods, more reliable answers from performance usually are not available until after most significant economic decisions have been made. Furthermore, in older reservoirs, uncertainties may still exist as to original oil-in-place, recovery factors and residual oil saturations due to incomplete or inaccurate performance data.

This paper outlines situations and appropriate arrangements of basic transient theory whereby well interference data can be utilized to improve the quality of estimates under certain conditions. In addition to production data on offset producers, key information required is a measured pressure drop at an observation well, corrected for any incomplete build-up due to previous production, plus a formation capacity value derived from a conventional pressure build-up plot on the observation well.

The method, as outlined, is strictly applicable only to a horizontal single-layered system of uniform rock characteristics containing a homogeneous fluid of low and constant compressibility. However, under the set of test conditions devised, requirements can usually be relaxed so that it should be applicable to most low permeability gas, water and undersaturated oil reservoirs. This is an area where more reliable information is certainly needed.

BASIC CONSIDERATIONS

A, B, C and F as subscripts or in the text refer to producing Well A, observation Well B, a more remote producing Well C and field boundary F. Combinations such as AB refer to distances and dimensionless times in terms of distances between these points, while single letters refer to distances and dimensionless times in terms of the wellbore or field radius. Equations covering definitions of quantities and complex situations are given in the Appendix. Key equations in practical units are given in Table 2.

Transient Pressure Behavior

Fig. 1 illustrates pressure drop at Point B with time due to initiation of a constant rate of withdrawal from Point A. This is shown as Δp_{D_B} vs $t_{D_{AB}}$ since a quantitative under-

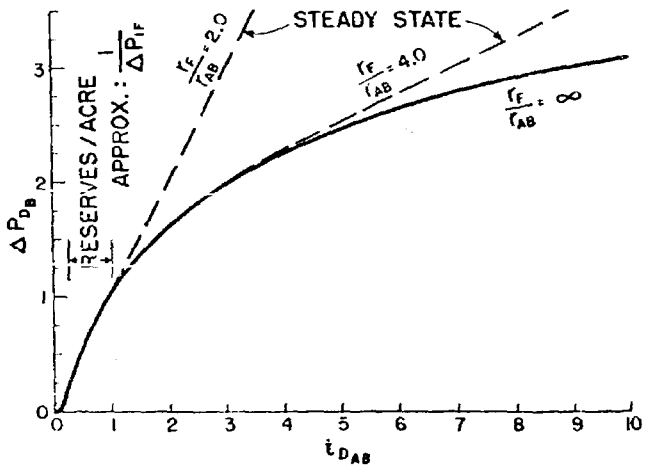


FIG. 1— DIMENSIONLESS PRESSURE DROP WITH TIME AT POINT B DUE TO INITIATION OF A CONSTANT WITHDRAWAL RATE FROM POINT A.

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standing of the amount of pressure drop with time appears lost with the usual semi-logarithmic plot.

While a pressure transient moves with the speed of sound in the particular media, it is so attenuated with distance that it will not begin to be physically measureable at an observation point until a $t_{D_{AB}}$ of 0.0625 to 0.1 is approached. Thus, the observed pressure drop (1) is negligible at small values of dimensionless time, (2) rapidly builds up over a subsequent time range and (3) tends to flatten out at increasing values of dimensionless time. Further increases in total pressure drop become a logarithmic function of time at dimensionless time values greater than about 25 for the infinite reservoir case. Where a boundary is encountered, the pressure-drop curve will diverge and subsequently increase at the appropriate steady-state decline rate. This divergence to steady-state will occur over a dimensionless time range of about 0.1 in terms of the nearest boundary to 0.4 in terms of the most remote boundary.

At a producing well, initial transient phases are passed almost instantaneously and pressure decline is very rapid. It then slows down until, at steady-state conditions or very large times for the infinite case, rate of pressure decline will be identical with that at a more remote observation point.

Use of Pressure Transients for Reserve Determinations

The real problem in transient theory application for reserve determination is to devise a suitable combination of theory and test conditions so that necessary data can be quantitatively obtained in the field. It is not generally realized that, if nearest boundaries are at least twice the distance AB from the producing well, a nearly linear relationship exists between ϕh and, thus, reserves per acre and the reciprocal of the observed pressure drop in the range $t_{D_{AB}}$ equal 0.25 to 1. Actually a relatively simple quantitative relationship exists between ϕh and observed pressure drop throughout the transient range.

In terms of the producing wellbore radius, the dimensionless time range of 0.25 to 1 is passed in a matter of seconds. However, in terms of well spacing, this is usually a conveniently measured time of hours, days or months. Differences in total pressure drop exist both at producing and observation wells for a constant formation capacity but differing porosity-feet values. However, at a producing well these normally will be completely obscured by skin effects.

The decline rate at the producing well, as indicated by Park Jones[13] and L. G. Jones,[14] is independent of skin effects and can be used in reserve determinations. This approach is sensitive to pressure measurement accuracy and minor variations in flow rate. However, in a one well system, this and subsequent build-up data are the only approaches that can be taken.

Eq. 29 of Ref. 13 gives a transient approach for determining a quantity equivalent to ϕh for gas reservoirs using an observation well. In addition to using decline rate, the required condition that the well spacing be treated as a point-sink severely limits quantitative application in this form to effectively infinite reservoirs at a $t_{D_{AB}} \geq 25$. Thus, while subject to some relaxation, boundaries or other producing wells theoretically would have to be on the order of 20 to 30 times the well spacing distance removed to eliminate influence on decline rate. Furthermore, permeabilities must be of high magnitude to allow reasonable test length.

[13]References given at end of paper.

At an observation well, pressures may be determined with maximum accuracy and are independent of skin effects and minor rate variations. Furthermore, with the method presented in this paper, total pressure drop is normally employed rather than decline rate, while required test length is moderate. Fig. 2 schematically illustrates the situation. By the time a $t_{D_{AB}}$ of 1 is reached, pressure drop at the observation well will be about 1/16 of the producing well drawdown if the condition ratio is 1, or 1/8 if the producing well condition ratio is 2. This latter value is commonly observed on stimulated wells in the lower permeability range. As indicated, the observed pressure drop at Well B can be influenced by incomplete build-up from prior production. Where significant, effects of boundaries or other producing wells on observed pressure drop should be included.

THEORETICAL BACKGROUND

Pressure drop with time at any point in an infinite reservoir due to a constant withdrawal rate at Point A is given by the well known point-source solution of the diffusivity equation:

$$\Delta p_{t r_B} = \frac{q_s}{4\pi}\left(\frac{u\mathrm{B}}{kh}\right)_{fB}\left[-E_i(-X)\right]_{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where $-E_i(-X)$ is the exponential integral function available in tables from various sources.[9] The function is shown by Fig. 1 and more fully by the infinite case on Fig. 9. Knowing q, u, B observing Δp_n, and obtaining kh or kh/u of the interwell area from a conventional pressure build-up test, preferably on the observation well, this equation may be solved for the exponential integral.

Knowing $-E_i(-X)_{AB}$ the value X can then be determined. Now X in turn is a function of the dimensionless time:

$$t_D = \frac{kt}{\phi u c r^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$X = \frac{1}{4t_D} = \frac{\phi u c r^2}{4kt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This may also be written including h in both numerator and denominator and at desired conditions as:

$$X_{AB} = \left(\frac{\phi h u c}{4kh}\right)_B \cdot \frac{r_{AB}^2}{t_A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now knowing X, u, c, r, kh and t, Eq. 4 may be solved for ϕh:

$$(\phi h)_B = 4t_A\left(\frac{X}{r^2}\right)_{AB}\left(\frac{kh}{uc}\right)_B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Assuming that either porosity or net pay thickness is known within reasonable limits, the other can be determined:

$$h_B = \left(\frac{\phi h}{\phi}\right)_B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

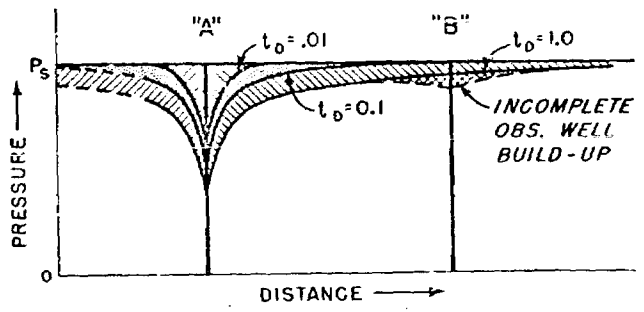


FIG. 2—SCHEMATIC OF PRESSURE PROFILE WITH DISTANCE AS FUNCTION OF WELL A PRODUCING TIME.

or

$$\phi_B = \left(\frac{\phi h}{h}\right)_B \quad \ldots \quad (6b)$$

Consequently the interwell permeability is also determined:

$$k_B = \left[\frac{(kh)_{BU}}{h}\right]_B \quad \ldots \quad (7)$$

Assuming that either ϕ or h is known may appear to lead to indeterminancy. However, in real situations, ϕ and h are both known within certain limits. The value of further breakdown of ϕh is in being able to refine the value of the factor known with the least degree of accuracy. In larger fields, one or more tests of this type when compared to log, core or other information on the observation wells can thus be used to refine criteria for porosity or net pay picks for the entire reservoir.

INCOMPLETE OBSERVATION WELL BUILD-UP

Amount of incomplete well build-up is obtained by superimposing an equal negative producing rate on Eq. 1. At dimensionless times greater than 25 to 100, which occur rapidly in terms of wellbore geometry, the log approximation applies and

$$\Delta p_{INC\ BU_B} = \left(\frac{q\mu B}{4\pi kh}\right)_B \cdot \left[\ln \frac{t+\theta}{\theta}\right]_B \quad \ldots \quad (8)$$

Now with incomplete build-up the interference pressure drop becomes:

$$\Delta p_{IF_B} = \Delta p_{OBS_B} - \Delta p_{INC\ BU_B}, \quad \ldots \quad (9)$$

or under what would be a common case under field conditions:

$$\Delta p_{IF_B} = \Delta p_{OBS} - \left(\frac{q\mu B}{4\pi kh}\right)_B \left[\ln\left(\frac{t+\theta}{\theta}\right)\right]_B \quad \ldots \quad (10)$$

WATER INFLUX APPLICATIONS

FULLERTON CLEARFORK UNIT

The location of water supply wells for one large West Texas waterflood in early 1960 is shown by Fig. 3. Using factors developed from pressure build-up and interference tests in a conventional material balance with van Everdingen and Hurst's water influx term,[3,6] and using an iterative procedure to balance pressure drop required for needed influx and remaining available pressure drop to produce the water from wells in the steady-state core, it was possible to conclusively demonstrate that the Santa Rosa was an inadequate source of water supply. Consequently, action to develop a supplementary supply was expedited.

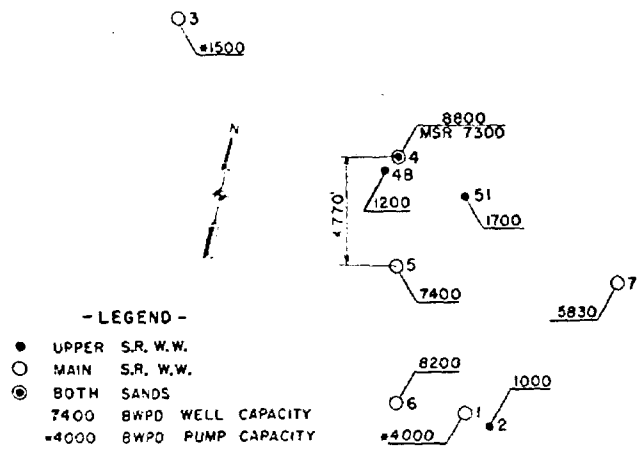


FIG. 3—FULLERTON CLEARFORK UNIT SANTA ROSA WATER WELLS AS OF EARLY 1960.

The main Santa Rosa water sand occurs at a depth of approximately 1,200 ft in the Fullerton area and has a gross sand thickness of about 230 ft. An upper sand at about 850 ft has a net sand thickness of 40 to 80 ft. Nearest supply outcrops are some 50 miles away in New Mexico, and calculations indicate that 20 years would be required for transients to effectively reach the outcrop; some 80 years before steady-state conditions would be approached.

Interpretation of Interference Tests

To properly interpret interference tests, previous production history is important. The original three supply wells had been on production supplying pilot waterfloods for about four years. Consequently, in the vicinity of Well Nos. 4, 5 and 7, pressure had reached a psuedo-stabilized condition. Calculations indicated that actual pressure decline at Well Nos. 4 and 5 would be about 1/2 ft/month due to this old semi-stabilized production. New wells were all initially completed in the main sand and subsequently tested one at a time.

Well No. 4 was pumped 56 days at maximum well capacity. Final rate was 7,300 BWPD. Three days later production was commenced from Well No. 5. Fig. 4 shows the pressure build-up curve obtained on Well No. 4 as affected by initiation of production from Well No. 5. Since this is an infinite reservoir case, the amount of interference can be read directly as the difference between the projected straight line build-up and the observed build-up. The following sample calculations, using the 25-day interference drop of 19.5 ft of fluid head, illustrate the basic technique.

Sample Calculation of ϕh, h, k and Water-in-Place

Given: $\Delta_{IF_B} = 19.5 \text{ ft} \times 0.434 = 8.45 \text{ psi}$; $\phi = 0.23$

$t = 25$ days; $\mu_o = 0.7$ cp

$kh_B = 24{,}200$ md-ft by build-up; $c_o = 9.3 \times 10^{-6}$ PV/PV/psi

$q_A = 7{,}400$ BWPD; $B_W = 1.0$

$r_{AB} = 4{,}770$ ft

Using Eq. 1 in oilfield units:

$$E_i(-X) = 8.45 \times \frac{24{,}200}{70.6 \times 7{,}400 \times 0.7 \times 1} = 0.5589$$

$$X = 0.591 .$$

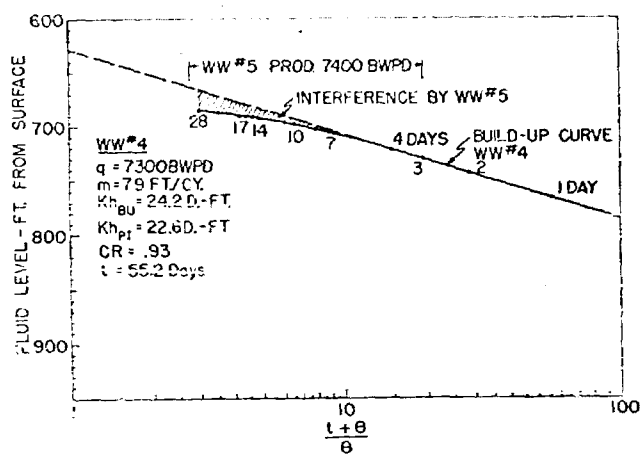


FIG. 4—BUILD-UP CURVE SANTA ROSA WATER WELL NO. 4, FULLERTON CLEARFORK FIELD SHOWING INTERFERENCE DUE TO PRODUCTION WATER WELL NO. 5.

Using Eq. 5 in oilfield units:

$$\phi h = \frac{0.025312 \times 25 \times 0.501 \times 24{,}200}{4{,}770^2 \times 0.7 \times 9.3 \times 10^{-6}} = 51.8 \text{ por-ft.}$$

Then by Eqs. 6 and 7:

$$h = \frac{51.8}{0.23} = 225 \text{ ft}$$

$$k = \frac{24{,}200}{225} = 107.5 \text{ md}$$

$$\text{Water-in-Place} = 7{,}758 \frac{\phi h \, S_w}{B_w} = \frac{7{,}758 \times 51.8 \times 1}{1}$$

$$= 401{,}900 \text{ bbl/acre.}$$

This basic approach is directly applicable in many cases, particularly to gas wells or water supply wells which have been shut-in long enough after initial tests pending market negotiations or connection so that essentially static pressure has been reached. Where static pressure is not available, the amount of interference drop usually can be arrived at by other means. This includes the method used in arriving at interference drop for the sample calculation. In other situations, a value of static pressure of desired accuracy to determine total interference drop can be obtained from an extrapolated build-up curve taken on the discovery, observation, or other well prior to the time the projected static pressure would be significantly affected by depletion or interference.

Verification of Compressibility Value

One point clouding the validity of predictions was the possibility that a dispersed free-gas saturation existed in the Santa Rosa. This possibility was based on production of some nitrogen gas with the water and the occurrence of air flows in drilling the underlying Yates formation. The presence of even a small, dispersed free-gas saturation would have changed the compressibility by at least 10- to 20-fold and on this basis it could be shown that an adequate supply was obtainable.

Fig. 5 shows observed vs calculated pressure-drop at two old, nearby Upper Santa Rosa water supply wells after Well No. 4 was perforated and placed on production from the upper sand. The points closely fit the case for no free-gas saturation and, due to wide differences, completely rule out the possibility of a free-gas saturation of even 1 or 2 per cent being present. Similar conclusions were applicable to interference test results in the main sand. Measured volumes of 12 to 50 Mcf/D also bracketed indicated production of about 30 Mcf/D based on the solubility of air in water of about 4 Mcf/bbl.

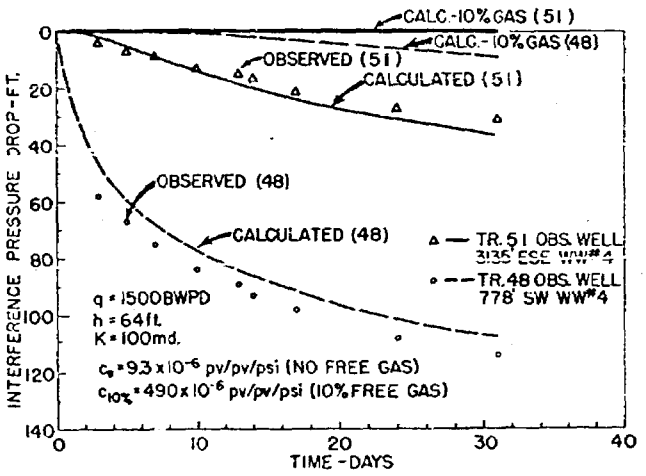


FIG. 5—CALCULATED VS OBSERVED PRESSURE DROP IN UPPER SANTA ROSA OBSERVATION WELLS.

Rock Compressibility Modification

Normally rock compressibility is a minor component of total compressibility; however, in water reservoirs it can furnish the greater component of effective compressibility. Therefore, an approximate adjustment was made for differences in overburden pressures.[4,5] In the following equation, c_r' is the adjusted effective rock compressibility in PV/PV/psi, c_r and c_{rc} are the effective rock compressibility and the compaction component as given by Hall, and p is the average net overburden pressure in psi in the range of interest:

$$c_r' = (c_r - c_{rc}) + c_{rc}\left(\frac{2{,}250}{p}\right)^{2.3} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

This gave a total adjusted effective rock and water compressibility of 9.3×10^{-6} PV/PV/psi for a 900-psi net overburden pressure, or 37 per cent more than the unadjusted number. For an oil reservoir under a comparable situation, the correction would have been more on the order of 10 per cent.

Subsequent Results

Using a combined rock and water compressibility, which the interference tests had shown to be applicable, plus values of ϕh, h and k obtained in the manner previously indicated, it was possible to make performance predictions for various development cases with considerable confidence. Values also were compatible with available log, core and production data.

An additional one-point interference check with data available when additional wells were drilled, and most wells placed on production to supply the initial injection line early in 1961, indicated a pore volume of about 80 per cent of the average value obtained from the initial interference tests. Actual Santa Rosa performance during the 1½ years since it was placed on production has closely followed predictions for the given development case.

OTHER WATER SUPPLY APPLICATIONS

Similar applications of interference data have been made to the Santa Rosa in the Foster-South Cowden area and to the El Capitan Reef in the Hendrick area of West Texas-New Mexico. In the Hendrick area it was possible to firm up basic factors sufficiently to state with confidence that this would be an adequate long-term water supply for a number of major West Texas floods. While examples cited refer to water supply, it is obvious that early predictions of water influx in a conventional oilfield situation often could be greatly improved as to their quantitative accuracy by similar use of well interference data.

GAS FIELD APPLICATION

Fig. 6 shows results of an application to a low permeability gas well employing limited data as frequently occurs in field situations. A conventional build-up curve was not available for kh determination and the observed interference pressures covered a dimensionless time range only slightly exceeding 0.45 to 0.5.

In this case, the observation Well B produced some 8.3 MMcf at completion on several shortly dispersed tests at a rate of 4.8 MMcf/D for an equivalent producing time t of 1.729 days. Fourteen days later an accurate shut-in pressure was obtained prior to a three-hour potential test.

This pressure indicated a difference, in terms of bottom-hole pressure, of 11.7 psi below the maximum shut-in pressure observed after the potential test.

Nearby offset-producing Well A over one-half mile away had been producing for 200 days at close to a constant rate of 2.1 MMcf/D at time of the potential test on Well B. Pressure difference measurements on Well B were accurate to less than 1 psi and Sonolog shots down both tubing and casing annulus indicated that Well B was free of condensate to below the end of the tubing string.

METHOD OF ANALYSIS

The observed pressure build-up between the time prior to potential test and the maximum observed pressure 28 days later would equal (1) the amount of pressure build-up between the time of potential and the maximum observed pressure due to production at completion, (2) minus the amount of incomplete build-up due to the potential test and (3) minus the amount of interference decline over the 28-day period. This can be expressed as:

$$\Delta p_{BU\ 200-228} = m_1\left(\log\frac{t_1+O_1}{O_1} - \log\frac{t+O_2}{O_2}\right) - m_2\left(\log\frac{t_2+O_3}{O_3}\right) - \Delta p_{IF_{200-228}} \quad . \quad . \quad (12)$$

Since m_2 was known to be 0.9188 m_1 based on the difference in flow rates, and the interference decline could be approximated from the actual 7.8-psi decline during the subsequent observed 28- to 65-day period, a nearly correct value of m_1 could be obtained as:

$$m_1 = \frac{(\Delta p_{BU} + \Delta p_{IF})_{200-228}}{\left(\log\frac{t_1+O_1}{O_1} - \log\frac{t_1+O_2}{O_2}\right) - 0.9188\log\left(\frac{t_2+O_3}{O_3}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Knowing the slope m_1, the producing rate at completion and other necessary values, the kh could then be determined in terms of the average pressure in the area of interest:

$$(kh)_{BU_B} = 818.5\left(\frac{quTz}{m_1 p_a}\right)_B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The kh values were then split by values of h which would bracket the possible actual values of k and h. Calculated values of Δp_{ONS} were then determined for various points over the range of interest for the corresponding permeability values and a ϕ of 10 per cent by substituting

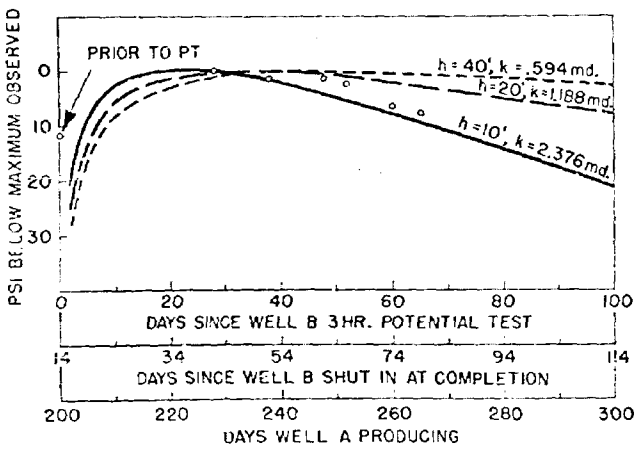


FIG. 6—CALCULATED VS OBSERVED PRESSURE DROP AT GAS WELL B DUE TO COMBINED EFFECTS OF INCOMPLETE PRESSURE BUILD-UP OF GAS WELL B AND INTERFERENCE BY OFFSET PRODUCING GAS WELL A.

TABLE 1—PARAMETERS USED FOR OIL WELL EXAMPLE

k = 10 md, 2.5 md	h = 10 ft, 40 ft
ϕ = 0.153	S_w = 0.15
c_e = 11.7 × 10^{-6} PV/PV/psi	P_i = 2215 psia
μ = 1.73 cp	B_o = 1.245
T = 570 °R	AB = 1,320 ft (40 Acre Spac.)
CR = 2	r_w = 0.25 ft
kh = 100 md-ft	r_e = 660 ft
q_o = 122.2 BOPD	

Eqs. 1 and 8 in gas units into Eq. 9. The calculated slope of the build-up curve was partially a function of the interference drop in this case, where a conventional build-up curve was not available. Consequently, a second iteration was necessary to give an essentially perfect fit. Value of kh of 23.756 md-ft by this second iteration was some 10 per cent lower than the first approximation. For the 10-ft pay thickness, the value of permeability was high enough so that some slight effects of more remote producing wells would have been felt and these were included to give a total Δp_{IF} and calculated Δp_{ONS} for this case by superposition.

Since the initial static pressure was not accurately known, the combined effects of incomplete pressure build-up and interference decline were plotted for each case relative to the minimum calculated pressure drop. These are the results shown by Fig. 6. As may be noted, observed values fall within the 10- to 20-ft envelope with individual points indicating values of 12 to 16 ft, or an average of 14 ft. In reviewing other data available, the alternate interpretation of 17.5 ft of net pay with a porosity of 8 per cent and permeability of 1.584 md was believed to be most applicable.

If Well B had been completed and shutin before production from Well A had been commenced, a total pressure drop of about 60 psi would have been observed. Under this more ideal condition and with a conventional build-up curve, the straight-forward and simple approach of directly employing Eqs. 1, 5, 6 and 7 could have been used.

OIL FIELD APPLICATION

This calculated example demonstrates some additional factors involved in practical application. Assumed values are given by Table 1. The interwell area was considered to be above the bubble point; and the formation capacity as measured by an observation well build-up test was considered to be 100 md-ft. Two basic cases were calculated: (1) a 40-ft case for which average permeability was

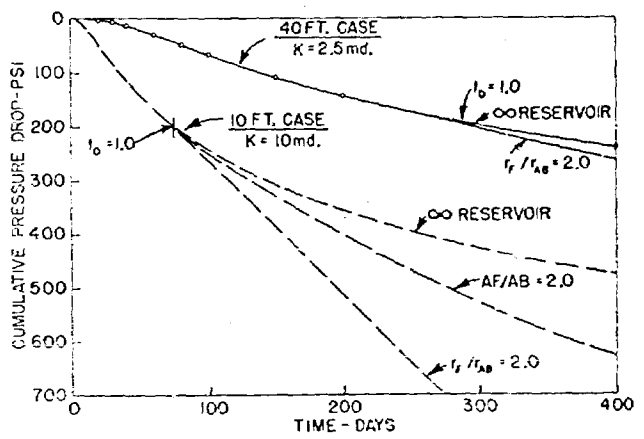


FIG. 7—PRESSURE DROP WITH TIME AT OBSERVATION WELL B DUE TO PRODUCING OIL WELL A; DIFFERENT THICKNESS AND BOUNDARY CONDITIONS BUT CONSTANT kh OF 100 MD-FT.

2.5 md, and (2) a 10-ft case for which average permeability was 10 md.

Fig. 7 shows the results for the condition of an infinite reservoir and boundary conditions r_F/r_{AB} and AF/AB equal to 2. At time 80 days which corresponds to a t_{DAB} of 0.276 for the 40-ft case and 1.104 for the 10-ft case, the observed pressure drop was 48 and 209 psi respectively for the 4:1 difference in oil-in-place.

To illustrate the effects of incomplete build-up, a variation of the 40-ft case was prepared where Well B was completed 60 days after the discovery well. Fig. 8 shows the observed pressure, assuming Well B was not produced, produced 3 days, or produced 30 days after completion. As may be seen, the amount of incomplete build-up and the magnitude of correction needed varies with amount of prior production. In a bounded reservoir the amount of incomplete build-up due to prior production will finally approach a maximum at a dimensionless prior producing time in excess of 0.25 for Well B in terms of r_e or r_F depending on applicable boundary conditions. This would correspond to a time of 290 days for the given example for a r_F/r_{AB} distance of 2 from Well B to the field boundary.

To minimize build-up correction and obtain maximum accuracy, it would be desirable to hold production at completion of Well B to a minimum. A three-day test would be more than ample to run a subsequent build-up for kh. The method of refining kh values with short-term varying-rate flow tests recently developed by Odeh and Selig[15] would appear applicable in many instances. The pressure build-up test also could be run after the interference test providing reasonable estimates of kh and k were available for control purposes.

OTHER APPLICATIONS

UNDERSATURATION

Due to necessary drawdowns during bottomhole sampling operations, uncertainty often exists as to whether an oil reservoir was initially saturated or undersaturated, clouding interpretation of early performance data. In view of the marked change in compressibility of 10 to 30-fold, which occurs upon crossing the bubble point, interference tests can be used to determine whether undersaturation exists in the interwell area.

OLDER RESERVOIRS

While the well interference method is primarily an early application method, it can be applied to new development or production in older areas. The Fullerton water supply is an example where other transients had reached a pseudo-stabilized state. Similarly, increasing withdrawals by several fold by appropriate transfers of allowable or new development will often allow establishment of a new transient condition of sufficient magnitude to allow determination of ϕh, ϕ or h, and k in older reservoirs.

SATURATION DETERMINATIONS

Theoretically, with appropriate modifications for multiphase flow, interference tests could be used in oil reservoirs below the bubble point. One application would be to "back calculate" gas saturation in reservoirs in an advanced state of depletion. However, following a sharp change upon crossing the bubble point, further changes in total compressibility as a function of saturation are relatively moderate. Thus, normally other factors will not be known with sufficient accuracy to allow calculation of relative saturation data. In waterfloods, interference tests could be used to determine when all free gas had gone back into solution in an area between the injection and observation well and thus indirectly be used to help determine gas saturation prior to flooding, conformance, sweep efficiency, etc.

FURTHER POINTS IN APPLICATION

BOUNDED RESERVOIRS

Reservoirs are not infinite, and both amount of interference drop and incomplete observation well build-up can be affected by field boundaries or more remote producing wells. Therefore, it is important to know when these effects are significant and how to compensate for each.

Fig. 9 gives dimensionless pressure drop at observation Well B for various ratios of r_F/r_{AB} vs t_D and can be used to correct for known boundary effects with a centrally located producing well. Fig. 10 gives the "fault" solution for interference decline for the case of Well B being on line with and closer to the immediate boundary with other boundaries remote. Fig. 10 solutions also approximately correspond to the effects of a second producing well at a distance (2AF-AB) from the observation well providing formation and fluid properties are comparable.

The *rate* of interference decline at Well B due to production of Well A in a bounded reservoir begins to be affected at dimensionless time values greater than 0.0625 in terms of distance to the nearest reservoir boundary. However, boundaries do not significantly affect the *total*

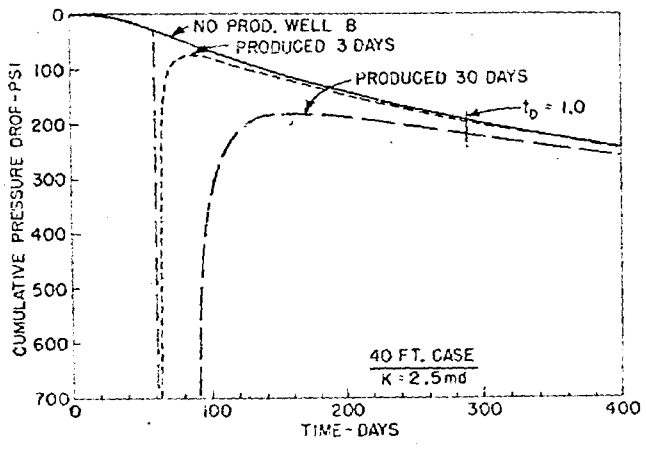


FIG. 8—CALCULATED PRESSURE DROP AT WELL B DUE TO PRODUCING OIL WELL A PLUS EFFECTS OF PRIOR PRODUCTION OF OIL WELL B.

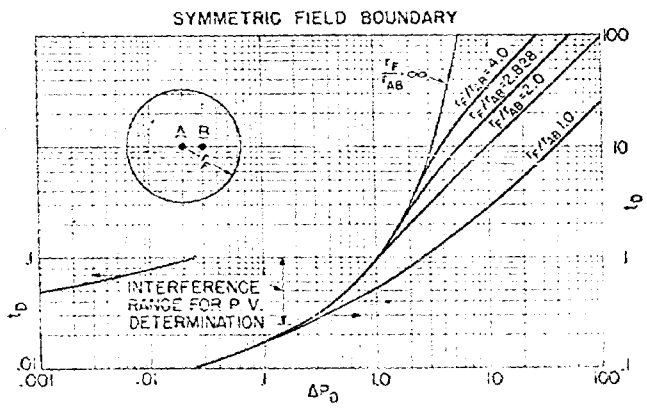


FIG. 9—DIMENSIONLESS PRESSURE DROP AT OBSERVATION WELL B DUE TO PRODUCTION OF CENTRALLY LOCATED WELL A IN A BOUNDED RESERVOIR.

interference drop at Well B until the dimensionless time, in terms of the nearest reservoir boundary, reaches 0.25. Practically speaking, this means that, where dimensionless time values of one are not exceeded during an interference test in terms of distance AB, effects of a field boundary greater than 2AB from the producing well can be neglected. At t_D equal to 1 and r_s/r_{AB} equal 2, the actual deviation is 2¼ per cent, which would cause an error in pore volume determination of about 3 per cent. Conversely, with interference tests of sufficient duration, approximate determination of field boundaries can be made, and in small reservoirs total field reserves obtained from the steady-state decline rate. Required test length will be essentially the same as that developed by Ref. 14. ($t_{DF} > 0.37$).

Where t is small and distance to a boundary is greater than 2AB, the infinite solutions for incomplete observation well build-up can be used with negligible error. This is true since a close numeric approximation of the amount of incomplete build-up at a given shut-in time is needed, rather than the actual static pressure at Well B. This latter value is being continuously modified by increasing interference pressure drop. Thus, various solutions given in the literature applicable to assumed steady-state boundaries between wells, while appropriate in arriving at average reservoir pressures for each well's approximate steady-state drainage area for material balance purposes, are not applicable here. It is also useful to realize that for a bounded case, amount of incomplete observation well build-up at large shut-in times will always be less than indicated by Eq. 8.

Equations for the effects of boundaries on both observed interference pressure drop and incomplete observation well build-up with time for either a centrally located well or the fault solution are given in the Appendix. Numeric solutions are not readily available for other geometric shapes although they can be obtained by the method of images. In the occasional complex case where this would be pertinent, this limitation can usually be circumvented in practice with a little ingenuity including "sketching in" a curve between initial effects indicated by using the "fault" solution with the closest boundary and an end-point value indicated by the circular solution of equivalent area.

GAS RESERVOIRS

Since drawdown during interference testing is small, the incompressible liquid case can be used with negligible error. The correct pressure to be used in determining interference pressure drop is essentially the pressure in the area of interest. Use of this pressure is in lieu of the average between the producing well and the static reservoir pressure used in the steady state radial flow equation.

Formation capacity should be determined in the conventional manner for gas wells by plotting p_θ^2 vs log $(t + \theta)/\theta$. The amount of incomplete build-up at a given shut-in time θ can be obtained for the infinite case by dividing the applicable $(p_s^2 - p_\theta^2)_a$ by $(p_s + p_\theta)_a$ or:

$$(\Delta p_{INC\ BUD})_B = \frac{(p_s^2 - p_\theta^2)_a}{(p_s + p_\theta)_a} \quad \ldots\ldots\ (15)$$

Similar modifications can be made for the bounded reservoir cases.

INITIAL PRESSURE UNKNOWN

The situation can be handled in which actual static pressure at the observation well prior to the initiation of the interference test is not determinable and observed pressure is available only over some subsequent range. One method is to take the measured interference drop over a given range, correct it for any incomplete build-up and solve Eq. 1 for $\Delta[-E_i(-X)]$. For the given ratio t_2/t_1 of producing well time intervals, a solution can then be obtained for X_2. This may be done from an exponential integral table by observing values of $\Delta[-E_i(-X)]$ at the appropriate ratio X_1/X_2 until an interpolated match for $\Delta[-E_i(-X)]$ is found determining X_2.

The best method for maximum resolution with limited data is that of assuming a given ϕ and three values of h. This in turn determines certain k values. Three sets of pressure drops can then be calculated. Comparison of these with observed points will then allow determination of ϕh with maximum accuracy by giving weight to all available points.

DETERMINING DEGREE OF INCOMPLETE BUILD-UP AND NECESSARY TEST LENGTH WITH LIMITED DATA

A build-up curve may not be available for determining if essentially static pressure has been reached and provide control as to desirable test length. In this case, an approximate formation capacity can be developed from flow test data at completion or from subsequent tests using a modified form of the radial flow equation. For a bounded reservoir this is

$$kh = \frac{qu\mathrm{B}\,(\ln r_e/r_w - 3/4)}{2\pi\,(p_e - p_w)\cdot CR\cdot q_t/q_{ss}} \quad \ldots\ldots\ (16)$$

In this equation, CR is the condition ratio of the well

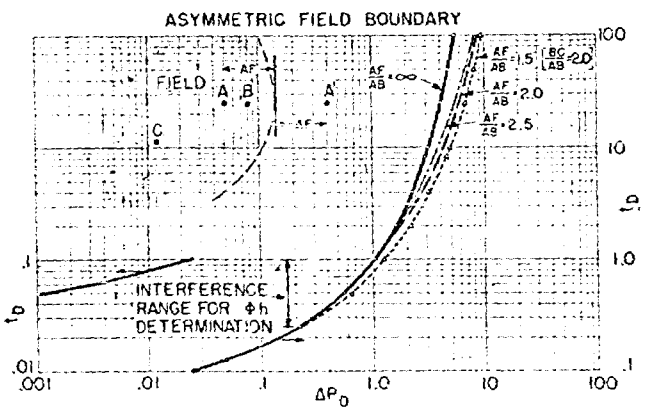


FIG. 10—DIMENSIONLESS PRESSURE DROP AT OBSERVATION WELL B LOCATED BETWEEN WELL A AND IMMEDIATE FIELD BOUNDARY WITH OTHERS REMOTE OR APPROXIMATE EFFECT OF SECOND PRODUCING WELL C AT DISTANCE BA' OR (2AF-AB) FROM WELL B.

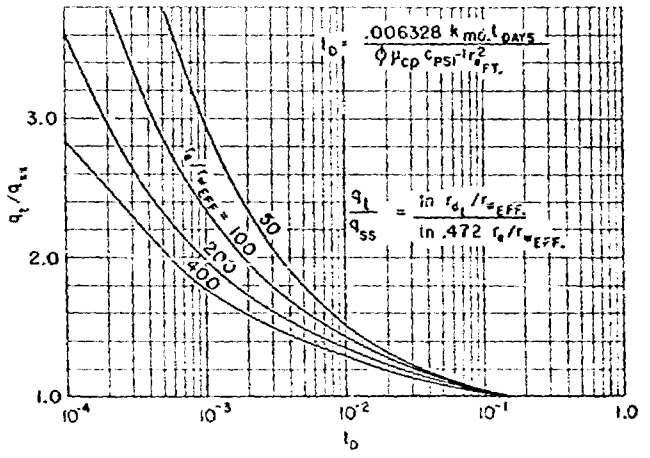


FIG. 11—RATIO ACTUAL TO STEADY-STATE FLOW RATE FOR BOUNDED RESERVOIR WITH CONSTANT PRESSURE DRAWDOWN: $(p_e - p_w)$ FOR OIL, $(p_e^2 - p_w^2)$ FOR GAS.

which usually ranges from 1 in wells of high formation capacity to in excess of 2 for low permeability acidized or fractured wells. Values of CR can be considerably less than one; however, there are few wells of this type left with current industry practices.

Values of q_t/q_{ss} vs dimensionless time are shown by Fig. 11. The equation used in deriving this correlation from the work of Aronofsky and Jenkins[6] is shown on the figure. The correlation has been found to be quite good at values of dimensionless time greater than 10^{-2}. At values of t_D less than 10^{-2}, the correlation should be used with caution as the validity of equating a fracture to an equivalent wellbore radius becomes increasingly dubious at low values of dimensionless time.

The initial value of t_D can be obtained using a k obtained by dividing a first approximation of kh by the best estimate of net pay and other appropriate values. In any event, using a kh derived in this manner or from core data and appropriate values of t, O, q, u and B, the magnitude of the amount of incomplete build-up at the observation well at any given shut-in time after completion or other tests can be determined by Eq. 8. Where indicated, several successive trials can be made to arrive at best values of kh, k, t_D and p_i. Required test length, usually to a $t_{D_{AB}}$ of about 1, can be determined by substituting desired dimensionless time length and other necessary values in Eq. 2.

LIMITATIONS

1. Well interference is not usually applicable to oil reservoirs where the interwell area is below the bubble point.

2. Equations employed assume a constant producing rate. Results for cumulative interference drop are not sensitive to minor variations from the average producing rate. Major shifts in producing rate or allowance for shut-in periods of significant duration should, of course, be made by superposition.

3. In reservoirs of high formation capacities and consequent low producing well drawdown, the interference method does not appear applicable due to limitations of field measurement accuracy with conventional testing equipment. In borderline situations, the interference drop can often be increased by suitably locating the observation well between a group of producers and by increasing withdrawal rates from the local area.

4. In reservoirs with marked anisotropy in rock or fluid properties, the use of the kh and interference drop at the observation well is not rigorous. Although a transient can "see" a distance about four times the distance obtained by solving the dimensionless-time equation (Eq. 2), it cannot effectively feel, in the total pressure drop, variations in properties further than 2 AB at a t_D of 1. Thus, at a t_D of 1 the weighted average properties being measured would be on the order of 1.5 AB or less. Similarly, at a t_D of 0.25 the weighted average properties would be those on the order of 0.75 AB. Therefore, in this time range a good quantitative answer for ϕh and thus pore volume in the vicinity of the observation well can be obtained even with a considerable degree of random areal anisotropy.

5. Double porosity systems should have little effect on interference drop. This is true due to times involved unless this type anisotropy is present to a very marked degree.

6. Reservoirs with a marked degree of directional permeability orientation or multiple reservoirs of different average permeability characteristics producing into a common wellbore present serious limitations. Under the latter condition, values obtained for ϕh will tend to be less than actual values.

CONCLUSIONS

1. The well interference approach outlined is applicable to both small and large reservoirs and provides a means of using early performance data to check and improve the quantitative accuracy of pore volume reserve estimates and individual values of ϕ or h and k in water, gas and undersaturated oil reservoirs of low to moderate permeability.

2. Total field reserves can be directly determined in smaller reservoirs subject to essentially the same time requirements as one-well methods.

3. Field boundaries beyond 2AB or wells beyond 3AB will have no appreciable effect on observed pressure drop and thus, ϕh determination in the dimensionless time range of 0.25 to 1, provided that for other wells, producing times, rates and other data are comparable.

4. From an observed pressure drop standpoint, ϕh determinations can be made with the same accuracy on widely spaced wells as on those with closer spacing; the only difference is that required observation time is greater.

5. The amount of interference drop due to production of a single producing well will normally be 1/8 to 1/16 the drawdown at the single producing well at a dimensionless time of 1; this can be increased by suitably locating the observation well among a group of producers and by judicious transfer of allowables.

6. Allowance can usually be made for effects of symmetric and asymmetric field boundaries, incomplete build-up, changes in producing rates and other producing wells.

NOMENCLATURE

CR = Condition ratio = kh_{PI}/kh_{BU}
$_{BU}$ = Build-up or by build-up test
$_{INC\ BU}$ = Incomplete build-up
$_{OBS}$ = Observed
$_{PI}$ = By production test
$_{\theta}$ = Shut-in time
$_{ss}$ = Steady-state

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TABLE 2—EQUATIONS IN PRACTICAL UNITS

EQ	OIL	GAS	REMARKS
(1)	$\Delta p_{IF_B} = 70.6\, q_A \left(\frac{\mu\beta}{kh}\right)_B \left[E_i(-X)\right]_{AB}$	$\Delta p_{IF_B} = 355.4 q_A \left(\frac{\mu T z}{khp/\theta}\right)_B \left[-E_i(X)\right]_{AB}$	Interference drop at observation Well B in ∞ reservoir
(1-A)	$-E_i(-X)_{AB} = \frac{.014.6}{q_A}\left(\frac{kh\Delta p_{IF}}{\mu\beta}\right)_B$	$-E_i(-X)_{AB} = \frac{.002814}{q_A}\left(\frac{kh\Delta p_{IF}}{\mu\beta}\right)_B$	$-E_i(-X)_{AB}$ in ∞ reservoir
(2)	$t_D = .006328\ \frac{kt}{\phi\mu c r^2}$	$t_D = .006328\ \frac{kt}{\phi\mu c_e r^2}$	Dimensionless time
(3)	$X_{AB} = 39.505\ \left(\frac{\phi\mu c}{k}\right)_B \cdot \frac{r_{AB}^2}{t_A}$	$X_{AB} = 39.505\ \left(\frac{\phi\mu c_e}{k}\right)_B \cdot \frac{r_{AB}^2}{t_A}$	$X = 1/4\, t_D$: X_{AB} in vicinity of Well B due to producing Well A
(5)	$(\phi h)_B = .025312\ t_A \left(\frac{X}{r^2}\right)_{AB} \left(\frac{kh}{\mu c}\right)_B$	$(\phi h)_B = .025312\ t_A \left(\frac{X}{r^2}\right)_{AB} \left(\frac{kh}{\mu c_e}\right)_B$	ϕh in vicinity of Well B
(6)	$h_B = \frac{(\phi h)_B}{\phi_B}$ or $\phi_B = \frac{(\phi h)_B}{h_B}$	$h_B = \frac{(\phi h)_B}{\phi_B}$ or $\phi_B = \frac{(\phi h)_B}{h_B}$	Net pay thickness or average pay porosity in vicinity of Well B
(7)	$k_B = \frac{(kh)_{BU_B}}{h_B}$	$k_B = \frac{(kh)_{BU_B}}{h_B}$	Average permeability in vicinity of Well B
(8)	$\Delta p_{INC\ BU_B} = 162.6 \left(\frac{q\mu\beta}{kh}\right)_B \left[\log \frac{t+\theta}{\theta}\right]_B$	$\Delta p_{INC\ BU_B} = 1637 \left[\frac{q\mu Tz}{kh(p_s + p_\theta)}\right]_B \left[\log \frac{t+\theta}{\theta}\right]_B$	Incomplete build-up at Well B due to prior production ∞ reservoir
(9)	$\Delta p_{IF_B} = \left[\Delta p_{OBS} - (9)\right]_B$	$\Delta p_{IF_B} = \left[\Delta p_{OBS} - (9)\right]_B$	Interference drop in ∞ reservoir with incomplete Well B build-up
	$(dp/dt)_{IF_B} = 70.6\ \frac{q_A}{t_A} \cdot \left(\frac{\mu\beta}{kh}\right) \cdot e^{-X_{AB}}$	$(dp/dt)_{IF_B} = 355.4\ \frac{q_A}{t_A} \cdot \left(\frac{\mu T z}{khp}\right)_B \cdot e^{-X_{AB}}$	Decline rate at Well B due to producing well A in ∞ reservoir
(14)	$(kh)_{BU} = 162.6\ \frac{q\mu\beta}{m}$	$(kh)_{BU} = 818.5\ \frac{q\mu Tz}{mp_o} = 1637\ \frac{q\mu Tz}{m'}$	kh from build-up curve. $m' = 2p_o m$ or m' equals slope of p_θ^2 vs. log $\frac{t+\theta}{\theta}$ $p_o = 1/2\,(p_s + p_\theta)$
(16)	$kh = 141.2\ \frac{q\mu\beta(\ln r_e/r_w - 3/4)}{(p_o - p_w)\cdot CR \cdot q_t/q_{ss}}$	$kh = 1421.6\ \frac{q\mu Tz(\ln r_e/r_w - 3/4)}{(p_o^2 - p_w^2)n \cdot CR \cdot q_t/q_{ss}}$	Formation capacity from production tests p_o = vol. wtd. avg.: $p_o \neq p_e$
(A-9)	$\Delta p_{IF_B} = 70.6 q_A \left(\frac{\mu\beta}{kh}\right)_B \left[E_i(-X)_{AB} + W(X)_F\right]$	$\Delta p_{IF_B} = 355.4\, q_A \left(\frac{\mu Tz}{khp}\right)_B \left[-E_i(X)_{AB} + W(X)_F\right]$	Interference drop at point B with time due to withdrawals at central point A in bounded circular reservoir
(A-10)	$\Delta p_{INC\ BU_B} = 70.6 \left(\frac{q\mu\beta}{kh}\right)_B \left\{\left(\ln \frac{t+\theta}{\theta}\right)_B + \left[W(X)_{t+\theta} - W(X)_\theta\right]_F\right\}$	$\Delta p_{INC\ BU_B} = 710.8 \left(\frac{q\mu zT}{kh}\right)_B \{\ \}$	Incomplete build-up with shut-in time at centrally located well in bounded circular reservoir
(A-11)	$\Delta p_{IF_B} = 70.6\, q_A \left(\frac{\mu\beta}{kh}\right)_B \left[-E_i(-X)_{AB} - E_i(-X)_{A'B}\right]$	$\Delta p_{IF_B} = 355.4\, q_A \left(\frac{\mu Tz}{khp}\right)_B \left[-E_i(-X)_{AB} - E_i(-X)_{A'B}\right]$	Interference drop with time at point B on line and between Well A and boundary with others remote
(A12)	$\Delta p_{INC\ BU_B} = 70.6 \left(\frac{q\mu\beta}{kh}\right)_B \left\{\left[\ln \frac{t+\theta}{\theta}\right]_B - \left[E_i(-X)_{t+\theta} - E_i(-X)_\theta\right]_{BB'}\right\}$	$\Delta p_{INC\ BU_B} = 710.8 \left(\frac{q\mu Tz}{kh}\right)_B \{\ \}$	Incomplete build-up with shut-in time at Well B due to producing Well B near one boundary with others remote
	$N = 7758\ \frac{\phi h(1-S_w)A}{\beta_o}$	$G = 1541\ \frac{\phi h(1-S_w)AP_L}{T_f\, z_i}$	Oil or gas in place
	$N = \frac{q_A}{c_e(dp/dt)_{ss}}$	$G = \frac{q_A}{c_e(dp/dt)_{ss}}$	Oil or gas in place from steady state decline rate

NOTE:

(1) $W(X) = Y(X) - L = E_i(-X) + \frac{e^{-X}}{X} - L$

(2) $-E_i(-X)$ in normal application is a positive quantity

(3) In equations for interference, rock and fluid properties of well B will normally apply with flow rate q_A

(4) For gas except at high pressures $c_e = c_g$

$c_g = \frac{1}{p} - \frac{dz}{zdp} = \frac{p}{z}$

OIL UNITS

q – BOPD	c – pv/pv/psi	p – psi	
μ – cp	r – ft	φ – fraction	
k – md	t – days	CR – dimensionless	
h – ft	θ – days	m – psi/log cy	
N – bbl	A – acres	β_o – dimensionless	

GAS UNITS

q – Mcf/D	c – pv/pv/psi	CR – dimensionless ratio	
μ – cp	t – days	m – psi/log cy	
k – md	θ – days	m' – psi^2/log cy = $m/2p_o$	
h – ft	p – psi	T – °R	
r – ft	φ – fraction	z – dimensionless	
G – Mcf	A – acres		

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APPENDIX

DEFINITION OF QUANTITIES

1. Dimensionless Pressure Drop

$$\Delta p_D = (p_e - p_w)\frac{4\pi kh}{qu\mathrm{B}} = 2p_{(t)} \text{ of Ref. 9} \quad . \quad . \quad (A\text{-}1)$$

2. Effective Compressibility

$$c_e = S_o c_o + S_g c_g + S_w c_w + c_r \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}2)$$

3. $-E_i(-X)$

$$-E_i(-X) = \int_X^\infty \frac{e^{-X}}{X}\,dX \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}3)$$

Note: $-E_i(-X)$ = positive quantity in normal use.

4. m

$$m = 2.303\frac{qu\mathrm{B}}{4\pi klt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}4)$$

5. Δp_{E_i}

$$\Delta p_{E_{i_B}} = -E_i(-X)_{AB} + E_i(-X)_F + \left(\frac{e^{-X}}{X}\right)_F \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}5)$$

6. L

$$L = \Delta p_{E_i} - \Delta p_D \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}6)$$

$L \approx \frac{1}{2}\, e^{-1/t_D}$ at $t_D > 1$

$L < \frac{1}{2}\, e^{-1/t_D}$ at $t_D < 1$

7. $Y(X)$

$$Y(X) = E_i(-X) + \frac{e^{-X}}{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}7)$$

8. $W(X)$

$$W(X) = Y(X) - L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}8)$$

SUPPLEMENTARY EQUATIONS

1. Interference Drop at an Observation Point With Time Due to Withdrawals at Central Point in Bounded Circular Reservoir

$$\Delta p_{Ir_B} = q_A\left(\frac{u\mathrm{B}}{4\pi kh}\right)_B\left[-E_i(-X)_{AB} + W(X)_F\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}9)$$

Hurst and Guerrero[7] give the correction factor L which is incorporated into $W(X)$ which makes the approximate Horner[4] solution numerically equal to the exact solution. As brought out by Hurst [10] and Mortada[11] for cases of non-uniform permeability and interference between oilfields, at large values of dimensionless time t_{D_A}, the properties at Field B apply in determining the pressure drop in the vicinity of Field B due to production of Field A. The same conclusions are applicable here and to the pressure to be used for compressibility and pressure drop in the gas field form of the equation.

2. Incomplete Build-up with Shut-In Time at a Centrally Located Well in Bounded Circular Reservoir

$$\Delta p_{Inc\,Bu_B} = \left(\frac{qu\mathrm{B}}{4\pi kh}\right)_B\left\{\left[\ln\frac{t+\Theta}{\Theta}\right] + \left[W(X)_{t+\Theta} - W(X)_\Theta\right]_F\right\} \quad . \quad . \quad . \quad (A\text{-}10)$$

3. Interference Drop With Time for an Observation Point On Line and Between Withdrawal Point and Boundary with Other Boundaries Remote

$$\Delta p_{Ir_B} = q_A\left(\frac{u\mathrm{B}}{4\pi kh}\right)_B\left[-E_i(-X)_{AB} - E_i(-X)_{BA'}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}11)$$

4. Incomplete Build-Up With Shut-In Time at Well Near One Boundary with Others Remote

$$\Delta p_{Inc\,Bu_B} = \left(\frac{qu\mathrm{B}}{4\pi kh}\right)_B\left[\ln\frac{t+\Theta}{\Theta}\right]_B + \left[-E_i(-X)_{t+\Theta} + E_i(-X)_\Theta\right]_{BB'} \quad . \quad (A\text{-}12)$$

CRITERION FOR OBSERVED PRESSURE DROP

Dimensionless pressure drop at Well A at large dimensionless times in terms of Well A and with normal range of r_e and r_w is:

$$\Delta p_{D_A} \approx \frac{2(\ln r_e/r_w - 3/4)}{CR} \approx \frac{16}{CR} \quad . \quad . \quad . \quad (A\text{-}13)$$

At $t_{D_{AB}} = 1$:

$$\Delta p_{D_B} \approx -E_i(-X) = 1.044 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}14)$$

Therefore at $t_{D_{AB}} = 1$:

$$\Delta p_B/\Delta p_A \approx (p_e - p_w)\cdot\frac{CR}{16} \quad . \quad . \quad . \quad . \quad (A\text{-}15)$$

Φh, h AND k WITH ALTERNATE Φ AND S_w VALUES

Given kh from build-up curve and ϕh, h and k determined for certain ϕ, S_w, S_g and S_o. Values of $(\phi h)'$, h', k' for alternate assumptions as to porosity and water saturation can be obtained as follows:

$$(\phi h)' = \frac{(\phi h)\,c_e(1 - S_w)}{(1 - S_w)'\,c'_e} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}16)$$

$$h' = \frac{(\phi h)'}{\phi'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}17)$$

$$k' = \frac{(kh)_{av}}{h'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A\text{-}18)$$

In gas reservoirs, effective compressibility is almost a direct function of the gas; and essentially hydrocarbon porosity-feet is determined with ϕh taking the necessary value to correspond to the water saturation employed. Similarly, in undersaturated oil reservoirs, effective compressibility is principally a function of the oil present; and changes in compressibility due to variations in assumed water saturation will have only a small effect on the hydrocarbon pore volume determined. ★★★

A

ATTACHMENTS A, B AND C TO
METHODS OF INTERPRETATION OF PRESSURE
BEHAVIOR IN THE OIL PRODUCING
FRACTURED SHALE RESERVOIRS OF
THE PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

November 1, 1966

BEFORE THE
OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
Exhibit No. 9
Case No. 3455

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

October 23, 1962

RESERVOIR FLUID DIVISION

Standard Oil Company of Texas
Drawer S
Monahans, Texas

Subject: Reservoir Fluid Study
Jicarilla 4-26 No. 3 Well
Boulder Mancos Field
Rio Arriba County, New Mexico
Our File Number: RFL 2301

Gentlemen:

Subsurface fluid samples were collected from the subject well by a representative of Core Laboratories, Inc. and submitted to our Dallas laboratory for use in a reservoir fluid study. The results of this study are presented on the following pages.

The saturation pressure of the fluid was measured to be 802 psig at the reservoir temperature of 141° F. The reservoir pressure at the sampling depth is 856 psig.

During differential pressure depletion the fluid evolved 147 standard cubic feet of gas per barrel of residual oil. The associated formation volume factor was measured to be 1.098 barrels of saturated fluid per barrel of residual oil. The viscosity of the fluid was measured under similar depletion conditions. It varied from a minimum of 3.03 centipoises at the saturation pressure to a maximum of 5.44 centipoises at atmospheric pressure.

It was a pleasure to perform this study for you. If you have any questions or if we may assist you further, please do not hesitate to contact us.

Very truly yours,

Core Laboratories, Inc.
Reservoir Fluid Division
P. L. Moses

A. C. Carnes, Jr.

A. C. Carnes, Jr.
Senior Engineer

ACC:dc

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Company Standard Oil Company of Texas Date Sampled October 4, 1962
Well Jicarilla 4-26 No. 3 County Rio Arriba
Field Boulder Mancos State New Mexico

FORMATION CHARACTERISTICS

Formation Name	Gallup
Date First Well Completed	August, 1960
Original Reservoir Pressure	867 PSIG @ 3880 Ft.
Original Produced Gas-Oil Ratio	167 SCF/Bbl
Production Rate	175 Bbl/Day
Separator Pressure and Temperature	PSIG, °F.
Oil Gravity at 60° F.	32.5 °API
Datum	Ft. Subsea
Original Gas Cap	

WELL CHARACTERISTICS

Elevation	7240 GL Ft.
Total Depth	4120 Ft.
Producing Interval	3820-4120 Ft.
Tubing Size and Depth	In. to Ft.
Productivity Index	Bbl/D/PSI @ Bbl/Day
Last Reservoir Pressure	867 PSIG @ 3880 Ft.
Date	October 4, 1962
Reservoir Temperature	139* °F. @ 3880 Ft.
Status of Well	Shut in 65 hours
Pressure Gauge	Amerada (DO)
Normal Production Rate	175 Bbl/Day
Gas-Oil Ratio	200 SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Base Pressure	15.025 PSIA
Well Making Water	None % Cut

SAMPLING CONDITIONS

Sampled at	3850 Ft.
Status of Well	Shut in 65 hours
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Tubing Pressure	4 PSIG
Casing Pressure	PSIG
Core Laboratories Engineer	NT
Type Sampler	Perco

REMARKS:

* Temperature extrapolated to mid-point of producing interval = 141° F.

CL-518

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301
Well Jicarilla 4-26 No. 3

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 802 PSIG @ 141 °F.
2. Thermal expansion of saturated oil @ 5000 PSI $= \frac{V \text{ @ } 141 \text{ °F}}{V \text{ @ } 76 \text{ °F}} =$ 1.02778
3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

   From 5000 PSI to 3500 PSI = 5.27×10^{-6}

   From 3500 PSI to 2000 PSI = 5.92×10^{-6}

   From 2000 PSI to 802 PSI = 6.63×10^{-6}
4. Specific volume at saturation pressure: ft³/lb 0.01959 @ 141 °F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Well Jicarilla 4-26 No. 3

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 141 °F., RELATIVE VOLUME OF OIL AND GAS, V/VSAT.	VISCOSITY OF OIL @ 141°F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 141 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
5010		4.52			
5000	0.9755				1.071
4505		4.33			
4500	0.9780				1.074
4000	0.9806	4.15			1.077
3500	0.9833	3.96			1.080
3010		3.75			
3000	0.9861				1.083
2510		3.60			
2500	0.9890				1.086
2005		3.42			
2000	0.9921				1.089
1505		3.26			
1500	0.9953				1.093
1400	0.9960				1.094
1300	0.9967				1.094
1200	0.9973				1.095
1100	0.9980				1.096
1015		3.10			
1000	0.9987				1.097
900	0.9994				1.097
802	1.0000	3.03	0	147	1.098
798	1.0016				
794	1.0032				
790	1.0062				
777	1.0139				
755		3.09			
751	1.0293				
712	1.0477				
698			19	128	1.092
663	1.0795				
655		3.20			
603	1.1268				

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Well Jicarilla 4-26 No. 3

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE Psi GAUGE	PRESSURE-VOLUME RELATION @ 141 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 141°F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 141 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
601			34	113	1.087
550		3.37			
538	1.1915				
499			50	97	1.081
473	1.2765				
455		3.52			
404	1.3966				
398			67	80	1.075
350		3.78			
342	1.5473				
300			83	64	1.069
276	1.7859				
250		4.06			
200	2.2504				
199			100	47	1.062
150		4.38			
138	3.0146				
98			119	28	1.055
50		4.82			
0		5.44	147	0	1.036
				@ 60° F.	= 1.000

Gravity of residual oil = 30.5° API @ 60° F.

V = Volume at given pressure
Vsat. = Volume at saturation pressure and the specified temperature.
VR = Residual oil volume at 14.7 PSI absolute and 60° F.

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File RFL 2301
Well Jicarilla 4-26 No. 3

Differential Pressure Depletion at 141° F.

Pressure PSIG	Oil Density Gms/Cc	Gas Gravity	Deviation Factor Z
802	0.8176		
698	0.8199	0.686	0.934
601	0.8218	0.687	0.940
499	0.8242	0.689	0.950
398	0.8265	0.699	0.958
300	0.8287	0.714	0.968
199	0.8314	0.743	0.979
98	0.8340	0.806	
0	0.8428	1.093	

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Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Well Jicarilla 4-26 No. 3

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

SEPARATOR PRESSURE, PSI GAUGE	SEPARATOR TEMPERATURE, ° F.	SEPARATOR GAS/OIL RATIO See Foot Note (1)	STOCK TANK GAS/OIL RATIO See Foot Note (1)	STOCK TANK GRAVITY, ° API @ 60° F.	SHRINKAGE FACTOR, $V_R/V_{SAT.}$ See Foot Note (2)	FORMATION VOLUME FACTOR, $V_{SAT.}/V_R$ See Foot Note (3)	SPECIFIC GRAVITY OF FLASHED GAS
0	74	155		30.5	0.9033	1.107	0.885
30	74	138	10	30.7	0.9102	1.099	
60	74	127	20	30.7	0.9099	1.099	
120	74	111	40	30.7	0.9074	1.102	

(1) Separator and Stock Tank Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stock tank oil @ 60° F.

(2) Shrinkage Factor: $V_R/V_{SAT.}$ is barrels of stock tank oil @ 60° F. per barrel of saturated oil @ 802 PSI gauge and 141 ° F.

(3) Formation Volume Factor: $V_{SAT.}/V_R$ is barrels of saturated oil @ 802 PSI gauge and 141 ° F. per barrel of stock tank oil @ 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Company Standard Oil Company of Texas Formation Gallup

Well Jicarilla 4-26 No. 3 County Rio Arriba

Field Boulder Mancos State New Mexico

HYDROCARBON ANALYSIS OF Reservoir Fluid SAMPLE

COMPONENT	WEIGHT PER CENT	MOL PER CENT	DENSITY @ 60° F. GRAMS PER CUBIC CENTIMETER	° API @ 60° F.	MOLECULAR WEIGHT
Hydrogen Sulfide					
Carbon Dioxide	0.33	1.50			
Nitrogen	0.04	0.26			
Methane	1.38	17.21			
Ethane	0.63	4.17			
Propane	0.22	0.97			
iso-Butane	0.10	0.35			
n-Butane	0.11	0.37			
iso-Pentane	0.31	0.86			
n-Pentane	0.45	1.25			
Hexanes	0.97	2.25			
Heptanes plus	95.46	70.81	0.8771	29.7	269
	100.00	100.00			

Core Laboratories, Inc.
Reservoir Fluid Division

A. C. Carnes, Jr.

A. C. Carnes, Jr.
Senior Engineer

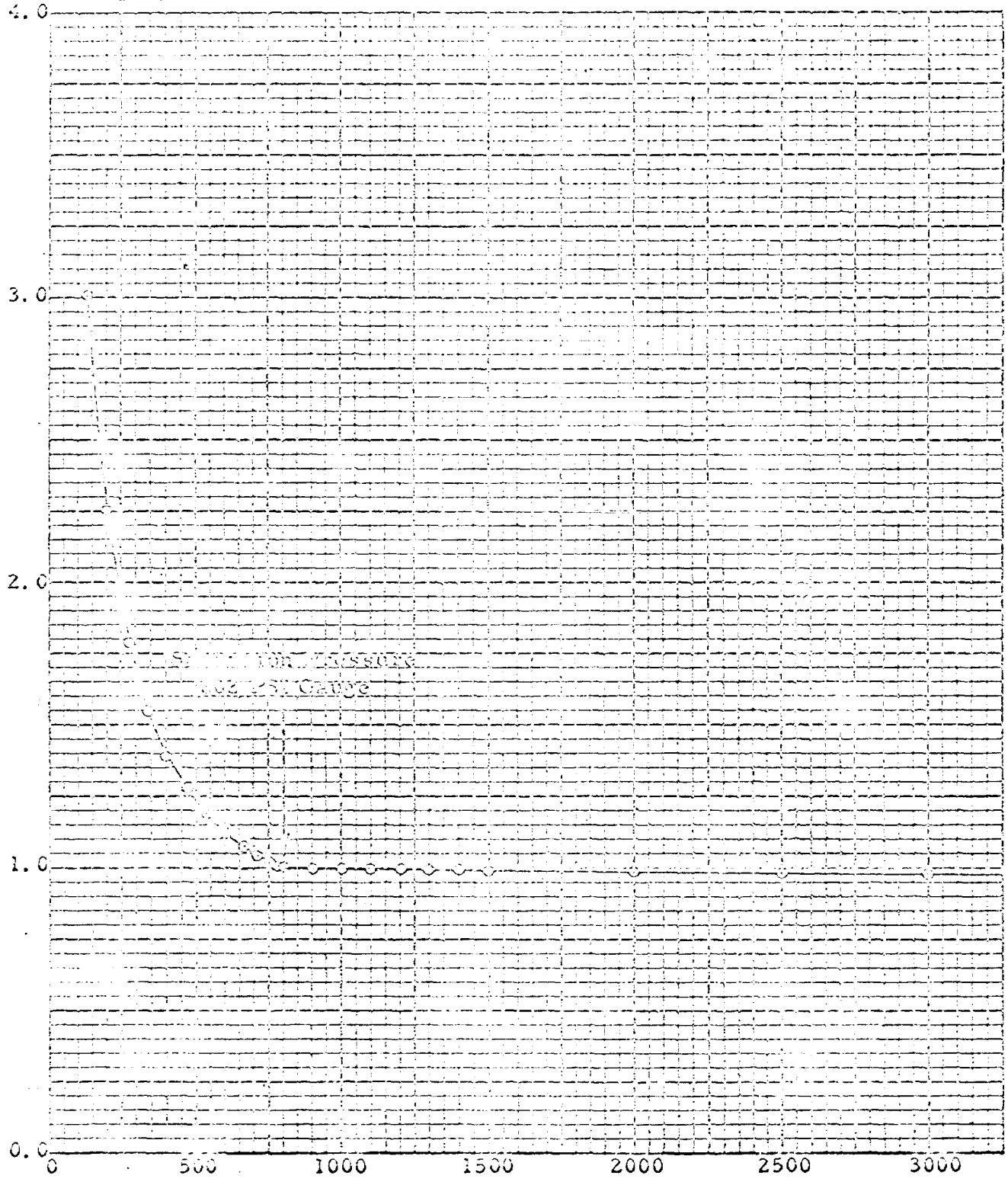
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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID

Company Standard Oil Co. of Texas — Formation Gallup
Well Jicarilla 4-26 No. 3 — County Rio Arriba
Field Boulder Mancos — State New Mexico

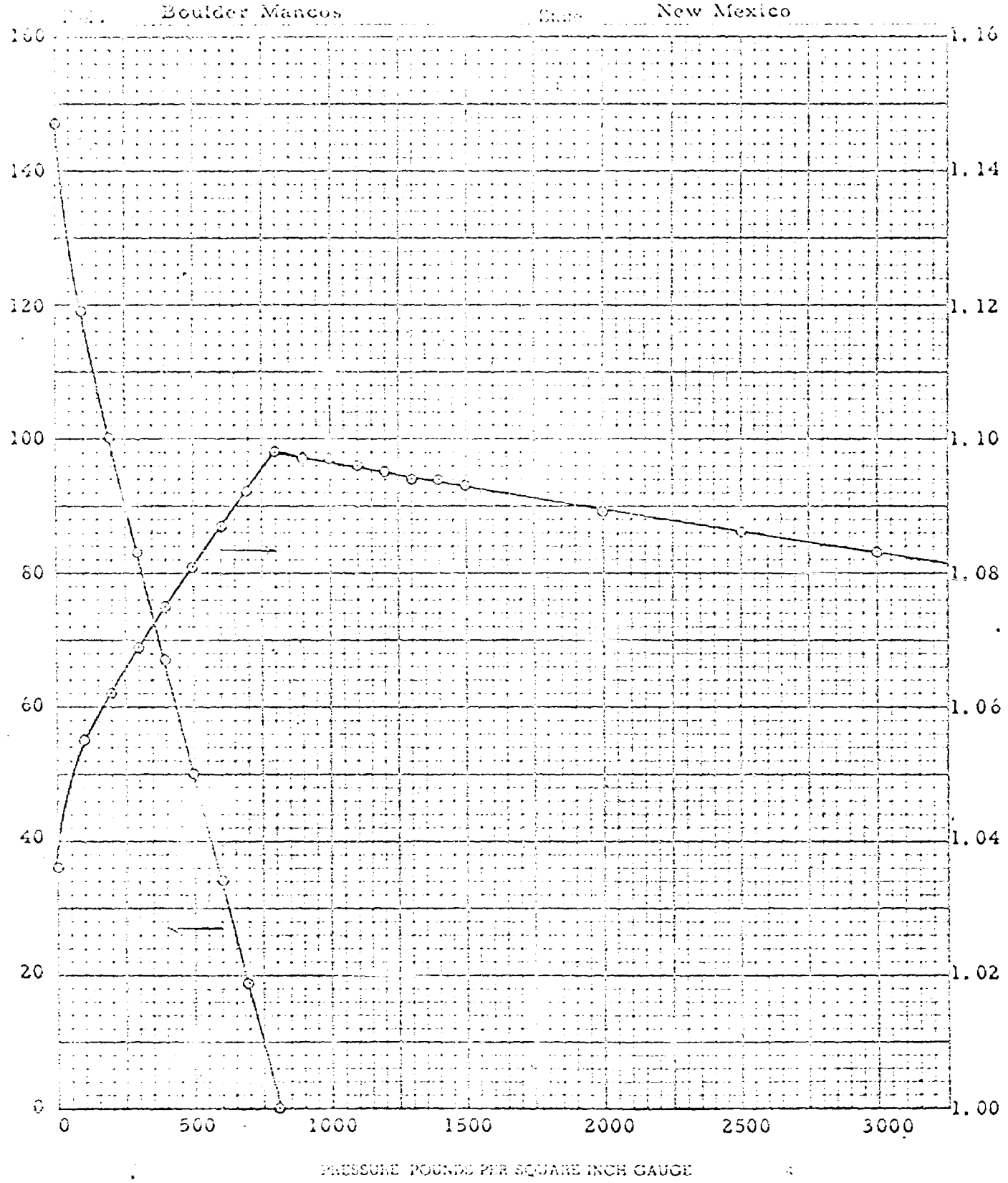


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Petroleum Reservoir Engineering
DALLAS, TEXAS

Page 9 of 11
File RFL 2301

EXPERIMENTAL VAPORIZATION AT RESERVOIR FLOW

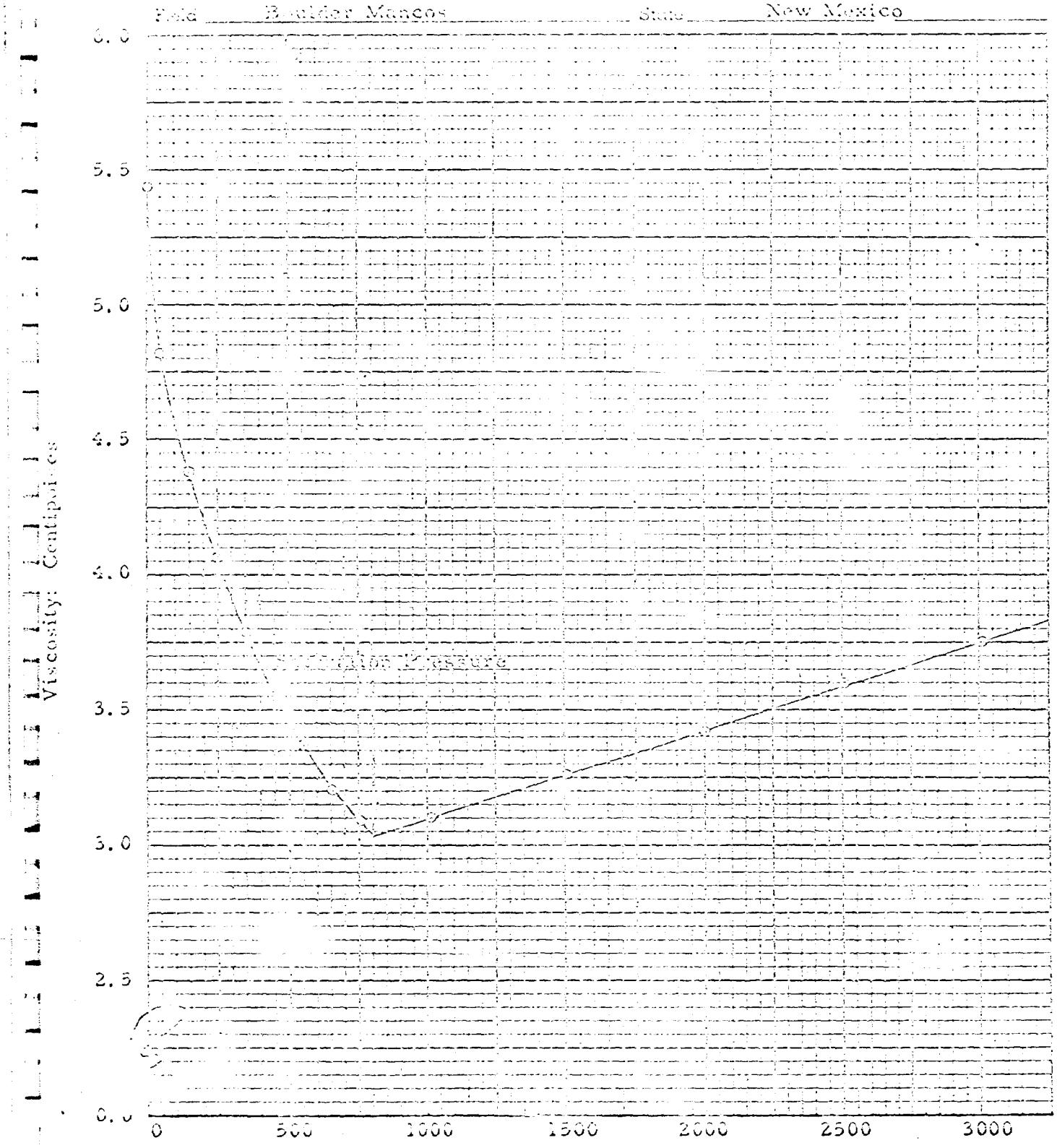
Company Standard Oil Co. of Texas
Well Jicarilla 4-26 No. 3
Field Boulder Mancos
Formation Gallup
County Rio Arriba
State New Mexico



CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Viscosity of Reservoir Fluid

Company Standard Oil Co. of Texas Formation Hallup
Well Ricarilla A-26 No. 3 County Rio Arriba
Field Boulder Mancos State New Mexico



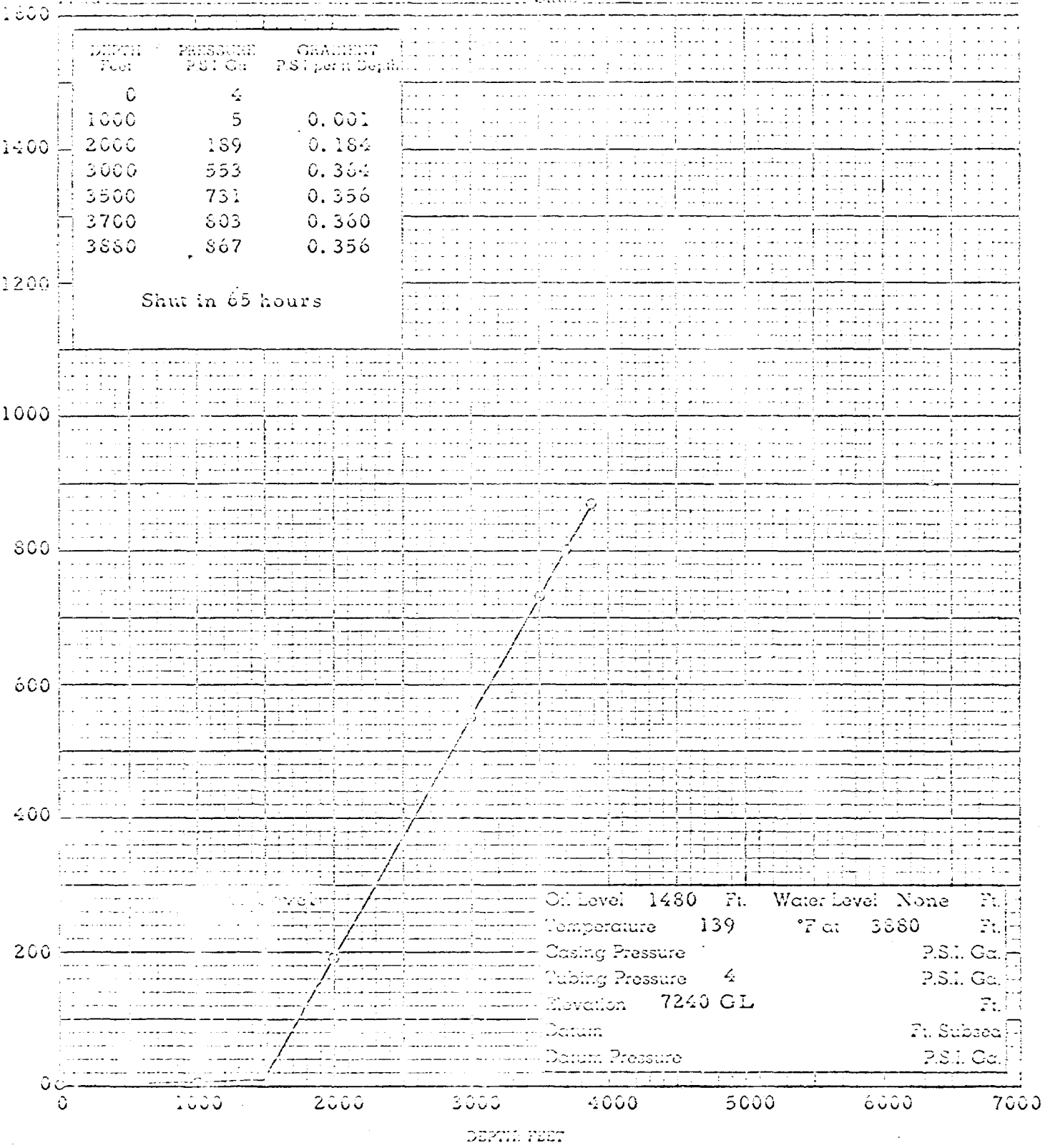
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2301

Company Standard Oil Co. of Texas Formation Gallup
Well Jicarilla 4-26 No. 3 County Rio Arriba
Field Boulder Mancos State New Mexico

DEPTH Feet	PRESSURE P.S.I. Ga.	GRADIENT P.S.I. per ft. Depth
0	4	
1000	5	0.001
2000	189	0.184
3000	553	0.364
3500	731	0.356
3700	803	0.360
3880	867	0.356

Shut in 65 hours



Oil Level 1480 Ft. Water Level None Ft.
Temperature 139 °F at 3880 Ft.
Casing Pressure P.S.I. Ga.
Tubing Pressure 4 P.S.I. Ga.
Elevation 7240 GL Ft.
Datum Ft. Subsea
Datum Pressure P.S.I. Ga.

B

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

November 8, 1963

RESERVOIR FLUID DIVISION

Benson-Montin-Greer Drilling Corporation
Petroleum Center
Farmington, New Mexico

Attention: Mr. Virgil Stoabs

Subject: Reservoir Fluid Study
Benson-Montin-Greer
Jicarilla No. P-19 Well
Puerto Chiquito Field
Rio Arriba County, New Mexico
Our File Number: RFL 2592

Gentlemen:

Subsurface fluid samples were collected from the Benson-Montin-Greer Jicarilla P-19 well. The results of fluid studies performed using these samples are transmitted to you on the following pages. One sample of fluid was collected from a depth of 2800 feet. This fluid had a saturation pressure of 511 psig at 118° F. This temperature was the measured temperature extrapolated to the lower perforations. Duplicate samples were collected at 2500 feet. The saturation pressure of one of the higher samples was measured to be 396 psig at 109° F.

A sample of the fluid from the higher horizon was subjected to differential pressure depletion conditions at 109° F. During this depletion 86 cubic feet of gas at 14.696 psia and 60° F. per barrel of residual oil were evolved. The accompanying formation volume factor was measured to be 1.062 barrels of saturated fluid per barrel of residual oil. Under similar depletion conditions the viscosity of the fluid varied from 3.17 centipoises at saturation pressure to 4.87 centipoises at atmospheric pressure.

Flash vaporization tests were performed at various pressures to determine the effect of separation pressure upon the produced fluid. The fluid was found to be essentially insensitive to changes in separation pressure with only slight benefit being realized by operation above atmospheric pressure.

It was a pleasure to cooperate with you in performing this study. Should you have any questions, please do not hesitate to contact us.

Very truly yours,

Core Laboratories, Inc.
Reservoir Fluid Division

P. L. Moses (PS)
P. L. Moses
Operations Supervisor

PLM:wm
7 cc. - Addressee

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Company Benson-Montin-Greer Drilling Corporation — Date Sampled October 9, 1963

Well B-M-G Jicarilla No. P-19 — County Rio Arriba

Field Puerto Chiquito — State New Mexico

FORMATION CHARACTERISTICS

Formation Name	Gallup
Date First Well Completed	, 1960
Original Reservoir Pressure	PSIG @ Ft.
Original Produced Gas-Oil Ratio	SCF/Bbl
Production Rate	Bbl/Day
Separator Pressure and Temperature	PSIG, °F.
Oil Gravity at 60° F.	°API
Datum	Ft. Subsea
Original Gas Cap	

WELL CHARACTERISTICS

Elevation	7051 KB Ft.
Total Depth	3130 Ft.
Producing Interval	2493-98; 2505-09; 2536-42; 2553-59; 2569; 3012-18 Ft.
Tubing Size and Depth	In. to Ft.
Productivity Index	Bbl/D/PSI @ Bbl/Day
Last Reservoir Pressure	616 PSIG @ 2800 Ft.
Date	October 9, 1963
Reservoir Temperature	114* °F. @ 2800 Ft.
Status of Well	Shut in 5 days
Pressure Gauge	Amerada
Normal Production Rate	Bbl/Day
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Base Pressure	15.025 PSIA
Well Making Water	% Cut

SAMPLING CONDITIONS

Sampled at	2500 and 2800 Ft.
Status of Well	Shut in 5 days
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Tubing Pressure	PSIG
Casing Pressure	PSIG
Core Laboratories Engineer	NT
Type Sampler	Perco

REMARKS:

* Temperature interpolated for 2500' sample = 109° F.
Temperature extrapolated for 2800' sample = 118° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 396 PSIG @ 109 °F.

2. Thermal expansion of saturated oil @ 3000 PSI $= \frac{\text{V @ 109 °F}}{\text{V @ 71.5 °F}} =$ 1.01712

3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

From 3000 PSI to 2000 PSI = 5.45×10^{-6}

From 2000 PSI to 1200 PSI = 5.75×10^{-6}

From 1200 PSI to 396 PSI = 6.32×10^{-6}

4. Specific volume at saturation pressure: ft^3/lb 0.01953 @ 109 °F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 109 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 109 °F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 109 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
3000	0.9849	4.25			1.046
2500	0.9875	4.03			1.049
2000	0.9903	3.83			1.052
1500	0.9932	3.63			1.055
1200	0.9949				1.057
1000	0.9962				1.058
980		3.44			
900	0.9968				1.059
800	0.9974				1.059
700	0.9980				1.060
680		3.32			
600	0.9987				1.061
580		3.26			
500	0.9993	3.22			1.061
396	1.0000	3.17	0	86	1.062
394	1.0022				
392	1.0041				
388	1.0080				
382	1.0158				
367	1.0351				
360		3.21			
352			8	78	1.060
345	1.0640				
320		3.26			
319	1.1026				
297			18	68	1.056
290	1.1605				
257	1.2377				
252			26	60	1.053
222	1.3439				
204			35	51	1.050
200		3.43			
190	1.4887				
160		3.50			

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

Reservoir Fluid SAMPLE PARTICULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 109 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 109°F., CENTIPOISES	DIFFERENTIAL VAPORIZATION @ 109 °F. GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	DIFFERENTIAL VAPORIZATION @ 109 °F. GAS/OIL RATIO LIBERATION PER BARREL OF RESIDUAL OIL	DIFFERENTIAL VAPORIZATION @ 109 °F. RELATIVE OIL VOLUME, V/VR
148	1.7399				
143			47	39	1.046
120		3.60			
112	2.1119				
97			57	29	1.043
80	2.6851	3.74			
45	3.6291				
40		3.89	70	16	1.037
0		4.87	86	0	1.022
				@ 60° F. =	1.000

Gravity of residual oil = 33.7° API @ 60° F.

Specific gravity of composite gas = 0.837

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

SEPARATOR PRESSURE, PSI GAUGE	SEPARATOR TEMPERATURE, ° F.	SEPARATOR GAS/OIL RATIO See Foot Note (1)	STOCK TANK GAS/OIL RATIO See Foot Note (1)	STOCK TANK GRAVITY, ° API @ 60° F.	SHRINKAGE FACTOR, $V_R/V_{SAT.}$ See Foot Note (2)	FORMATION VOLUME FACTOR, $V_{SAT.}/V_R$ See Foot Note (3)	SPECIFIC GRAVITY OF FLASHED GAS
				33.7	0.9346	1.070	0.957
0	76	94					
			7	33.8	0.9363	1.068	
15	77	85					
			14	34.0	0.9381	1.066	
35	80	77					
			24	34.0	0.9390	1.065	
75	77	66					

(1) Separator and Stock Tank Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stock tank oil @ 60° F.

(2) Shrinkage Factor: $V_R/V_{SAT.}$ is barrels of stock tank oil @ 60° F. per barrel of saturated oil @ 396 PSI gauge and 109 ° F.

(3) Formation Volume Factor: $V_{SAT.}/V_R$ is barrels of saturated oil @ 396 PSI gauge and 109 ° F. per barrel of stock tank oil @ 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Company Benson-Montin-Greer Drilling Corporation Formation Gallup

Well B-M-G Jicarilla P-19, Sampled at 2500 Ft. County Rio Arriba

Field Puerto Chiquito State New Mexico

HYDROCARBON ANALYSIS OF Reservoir Fluid SAMPLE

COMPONENT	WEIGHT PER CENT	MOL PER CENT	DENSITY @ 60° F. GRAMS PER CUBIC CENTIMETER	° API @ 60° F.	MOLECULAR WEIGHT
Hydrogen Sulfide					
Carbon Dioxide	0.25	1.12			
Nitrogen					
Methane	0.79	9.54			
Ethane	0.18	1.14			
Propane	0.48	2.11			
iso-Butane	0.19	0.62			
n-Butane	0.63	2.12			
iso-Pentane	0.18	0.47			
n-Pentane	1.02	2.75			
Hexanes	1.33	3.01			
Heptanes plus	94.95	77.12	0.8657	31.8	239
	100.00	100.00			

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Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2800 feet

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 511 PSIG @ 118 °F.
2. Thermal expansion of saturated oil @ 3000 PSI = $\frac{V \text{ @ } 118 \text{ °F}}{V \text{ @ } 76 \text{ °F}}$ = 1.01843
3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

From 3000 PSI to 2000 PS. = 5.65×10^{-6}

From 2000 PSI to 1200 PSI = 5.90×10^{-6}

From 1200 PSI to 511 PSI = 6.24×10^{-6}

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2800 feet

Pressure-Volume Relations of Reservoir Fluid at 118° F.

Pressure PSIG	Relative Volume V/Vs
3000	0.9854
2500	0.9881
2000	0.9910
1500	0.9938
1200	0.9957
1100	0.9963
1000	0.9968
900	0.9975
800	0.9982
700	0.9988
600	0.9994
511	1.0000
508	1.0023
505	1.0047
499	1.0102
487	1.0223
455	1.0465
419	1.0829
380	1.1313
334	1.2041
291	1.3012
246	1.4347
207	1.6047
167	1.8477
122	2.3144
79	3.1884

Core Laboratories, Inc.
Reservoir Fluid Division

P L Moses (PC)

P. L. Moses
Operations Supervisor

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page 9 of 13
File RAP-3392

RELATIVE VOLUME RELATIONS OF RESERVOIR FLUID

Dennon-Monta-Grace

Company Del Mar Corporation Formation Glorieta

Well D-M-G Pic Wells No. P-19, 2500 Ft. County Rio Arriba

Field Puerto Chiquito State New Mexico

4.0
3.0
2.0
1.0
0.0

Saturation Pressure
396 PSIG at 73°F

0 200 400 600 800 1000 1200

PRESSURE: POUNDS PER SQUARE INCH GAUGE

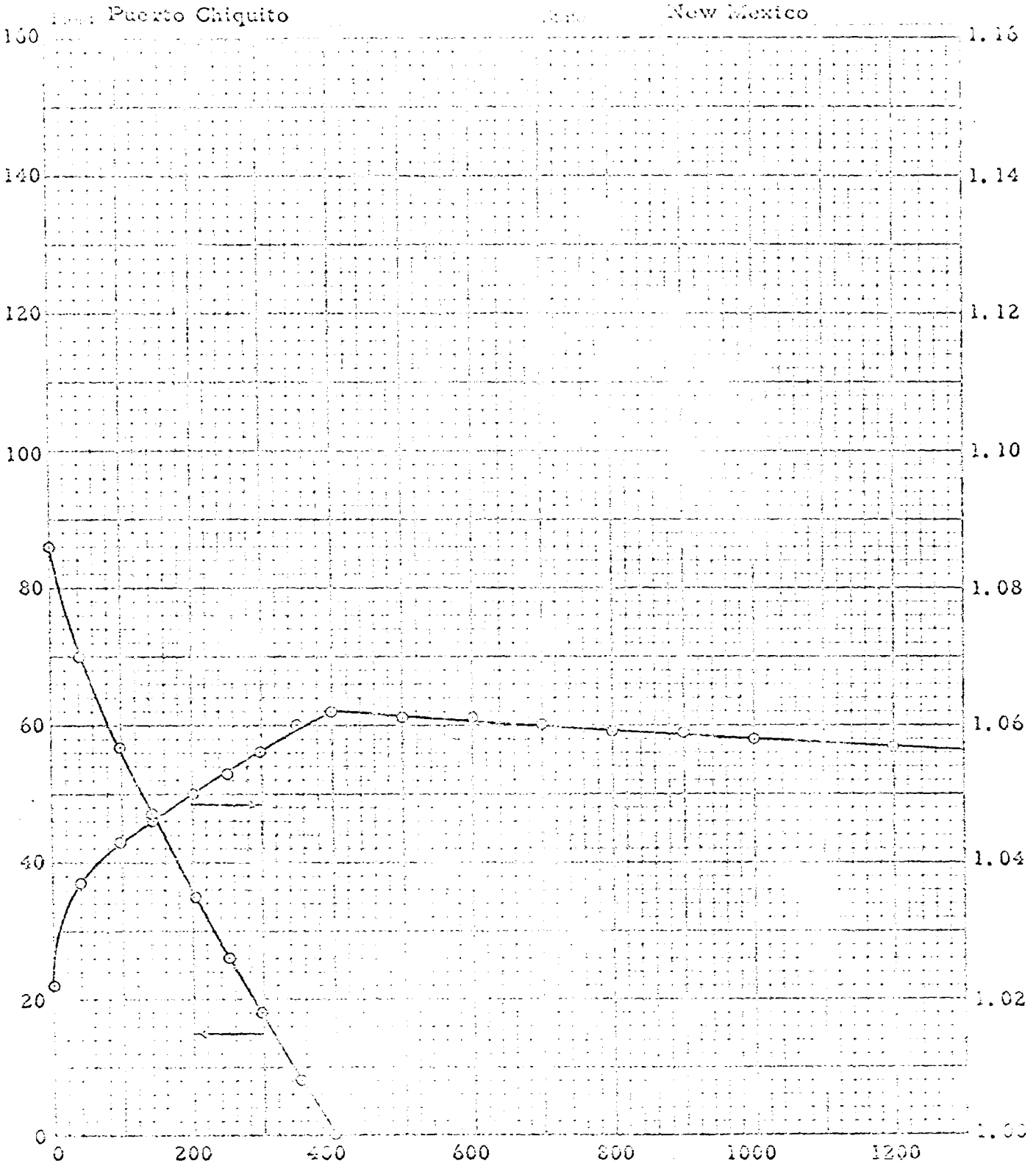
RELATIVE VOLUME V/Vs

CORE LABORATORIES, INC.
DALLAS, TEXAS

Page 10 of 12
File RFL 2592

Dawson-Montin-Greer
Drilling Corporation
B-M-G Jicarilla No. P-19, 2500 Ft.
Puerto Chiquito

Gallup
Rio Arriba
New Mexico

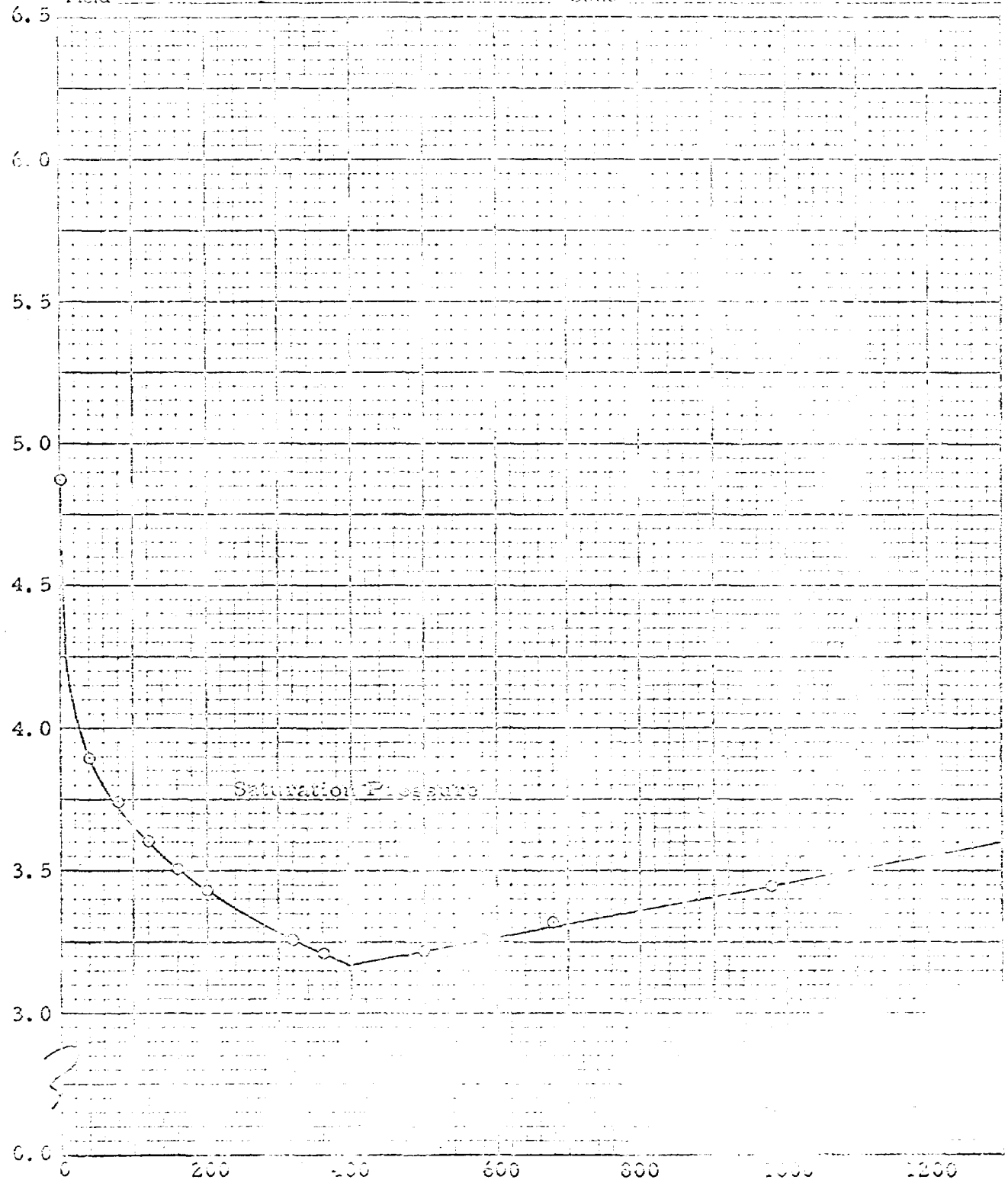


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Petroleum Reservoir Engineering
DALLAS, TEXAS

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VISCOSITY OF RESERVOIR FLUID

Company Denson-Monsin-Gr[illegible] Drilling Corporation Formation [illegible]
Well B-M-G Jicarilla No. P-19, 2500 Ft. County Rio Arriba
Field Puerto Chiquito State New Mexico



CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page [illegible]
File [illegible]

Company Benson-Montin-Greer Drilling Corporation
Well B-M-G Jicarilla No. P-19
Field Puerto Chiquito

Formation [illegible]
County Rio Arriba
State New Mexico

DEPTH Feet KB	PRESSURE P.S.I. Ga.	GRADIENT P.S.I. per ft. Depth
0		
1000	nil	
1500	149	0.298
1800	255	0.353
2100	364	0.363
2400	472	0.360
2600	543	0.355
2800	616	0.365
2927	664	0.378

Shut in 5 days

Oil Level

Oil Level 1092 Ft. Water Level Ft.
Temperature 114 °F at 2800 Ft.
Casing Pressure P.S.I. Ga.
Tubing Pressure P.S.I. Ga.
Elevation [illegible] K.B.
Datum Ft. Subsea
Datum [illegible] P.S.I. Ga.

PRESSURE POUNDS PER SQUARE INCH GAUGE

0 100 200 300 400 500 600 700 800

0 500 1000 1500 2000 2500 3000 3500

DEPTH FEET

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

November 8, 1963

RESERVOIR FLUID DIVISION

Benson-Montin-Greer Drilling Corporation
Petroleum Center
Farmington, New Mexico

Attention: Mr. Virgil Stoabs

Subject: Reservoir Fluid Study
Benson-Montin-Greer
Jicarilla No. P-19 Well
Puerto Chiquito Field
Rio Arriba County, New Mexico
Our File Number: RFL 2592

Gentlemen:

Subsurface fluid samples were collected from the Benson-Montin-Greer Jicarilla P-19 well. The results of fluid studies performed using these samples are transmitted to you on the following pages. One sample of fluid was collected from a depth of 2800 feet. This fluid had a saturation pressure of 511 psig at 118° F. This temperature was the measured temperature extrapolated to the lower perforations. Duplicate samples were collected at 2500 feet. The saturation pressure of one of the higher samples was measured to be 396 psig at 109° F.

A sample of the fluid from the higher horizon was subjected to differential pressure depletion conditions at 109° F. During this depletion 86 cubic feet of gas at 14.696 psia and 60° F. per barrel of residual oil were evolved. The accompanying formation volume factor was measured to be 1.062 barrels of saturated fluid per barrel of residual oil. Under similar depletion conditions the viscosity of the fluid varied from 3.17 centipoises at saturation pressure to 4.87 centipoises at atmospheric pressure.

Flash vaporization tests were performed at various pressures to determine the effect of separation pressure upon the produced fluid. The fluid was found to be essentially insensitive to changes in separation pressure with only slight benefit being realized by operation above atmospheric pressure.

It was a pleasure to cooperate with you in performing this study. Should you have any questions, please do not hesitate to contact us.

Very truly yours,

Core Laboratories, Inc.
Reservoir Fluid Division

P L Moses (PB)
P. L. Moses
Operations Supervisor

PLM:wm
7 cc. - Addressee

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Company Benson-Montin-Greer Drilling Corporation
Date Sampled October 9, 1963
Well B-M-G Jicarilla No. P-19
County Rio Arriba
Field Puerto Chiquito
State New Mexico

FORMATION CHARACTERISTICS

Formation Name	Gallup
Date First Well Completed	, 1960
Original Reservoir Pressure	PSIG @ Ft.
Original Produced Gas-Oil Ratio	SCF/Bbl
Production Rate	Bbl/Day
Separator Pressure and Temperature	PSIG, °F.
Oil Gravity at 60° F.	°API
Datum	Ft. Subsea
Original Gas Cap	

WELL CHARACTERISTICS

Elevation	7051 KB Ft.
Total Depth	3130 Ft.
Producing Interval	2493-98; 2505-09; 2536-42; 2553-59; 2569; 3012-18 Ft.
Tubing Size and Depth	In. to Ft.
Productivity Index	Bbl/D/PSI @ Bbl/Day
Last Reservoir Pressure	616 PSIG @ 2800 Ft.
Date	October 9, 1963
Reservoir Temperature	114* °F. @ 2800 Ft.
Status of Well	Shut in 5 days
Pressure Gauge	Amerada
Normal Production Rate	Bbl/Day
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Base Pressure	15.025 PSIA
Well Making Water	% Cut

SAMPLING CONDITIONS

Sampled at	2500 and 2800 Ft.
Status of Well	Shut in 5 days
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Tubing Pressure	PSIG
Casing Pressure	PSIG
Core Laboratories Engineer	NT
Type Sampler	Perco

REMARKS:

* Temperature interpolated for 2500' sample = 109° F.
Temperature extrapolated for 2800' sample = 118° F.

CL-513

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 396 PSIG @ 109 °F.
2. Thermal expansion of saturated oil @ 3000 PSI $= \frac{V \text{ @ } 109\ ^\circ F}{V \text{ @ } 71.5\ ^\circ F} =$ 1.01712
3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

   From 3000 PSI to 2000 PSI = 5.45×10^{-6}

   From 2000 PSI to 1200 PSI = 5.75×10^{-6}

   From 1200 PSI to 396 PSI = 6.32×10^{-6}
4. Specific volume at saturation pressure: ft^3/lb 0.01953 @ 109 °F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 109 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 109 °F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 109 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
					1.046
3000	0.9849	4.25			1.049
2500	0.9875	4.03			1.052
2000	0.9903	3.83			1.055
1500	0.9932	3.63			1.057
1200	0.9949				1.058
1000	0.9962				
980		3.44			1.059
900	0.9968				1.059
800	0.9974				1.060
700	0.9980				
680		3.32			1.061
600	0.9987				
580		3.26			1.061
500	0.9993	3.22			
396	1.0000	3.17	0	86	1.062
394	1.0022				
392	1.0041				
388	1.0080				
382	1.0158				
367	1.0351				
360		3.21	8	78	1.060
352					
345	1.0640				
320		3.26			
319	1.1026		18	68	1.056
297					
290	1.1605				
257	1.2377		26	60	1.053
252					
222	1.3439		35	51	1.050
204					
200		3.43			
190	1.4887				
160		3.50			

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 109 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 109°F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 109 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
148	1.7399				
143			47	39	1.046
120		3.60			
112	2.1119				
97			57	29	1.043
80	2.6851	3.74			
45	3.6291				
40		3.89	70	16	1.037
0		4.87	86	0	1.022
				@ 60° F. =	1.000

Gravity of residual oil = 33.7° API @ 60° F.

Specific gravity of composite gas = 0.837

V = Volume at given pressure
Vsat. = Volume at saturation pressure and the specified temperature.
VR = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Well B-M-G Jicarilla No. P-19
Sampled at 2500 feet

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

SEPARATOR PRESSURE, PSI GAUGE	SEPARATOR TEMPERATURE, ° F.	SEPARATOR GAS/OIL RATIO See Foot Note (1)	STOCK TANK GAS/OIL RATIO See Foot Note (1)	STOCK TANK GRAVITY, ° API @ 60° F.	SHRINKAGE FACTOR, $V_R/V_{SAT.}$ See Foot Note (2)	FORMATION VOLUME FACTOR, $V_{SAT.}/V_R$ See Foot Note (3)	SPECIFIC GRAVITY OF FLASHED GAS
0	76	94		33.7	0.9346	1.070	0.957
15	77	85	7	33.8	0.9363	1.068	
35	80	77	14	34.0	0.9381	1.066	
75	77	66	24	34.0	0.9390	1.065	

(1) Separator and Stock Tank Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stock tank oil @ 60° F.

(2) Shrinkage Factor: $V_R/V_{SAT.}$ is barrels of stock tank oil @ 60° F. per barrel of saturated oil @ 396 PSI gauge and 109 ° F.

(3) Formation Volume Factor: $V_{SAT.}/V_R$ is barrels of saturated oil @ 396 PSI gauge and 109 ° F. per barrel of stock tank oil @ 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592

Company Benson-Montin-Greer Drilling Corporation Formation Gallup

Well B-M-G Jicarilla P-19, Sampled at 2500 Ft. County Rio Arriba

Field Puerto Chiquito State New Mexico

HYDROCARBON ANALYSIS OF Reservoir Fluid SAMPLE

COMPONENT	WEIGHT PER CENT	MOL PER CENT	DENSITY @ 60° F. GRAMS PER CUBIC CENTIMETER	° API @ 60° F.	MOLECULAR WEIGHT
Hydrogen Sulfide					
Carbon Dioxide	0.25	1.12			
Nitrogen					
Methane	0.79	9.54			
Ethane	0.18	1.14			
Propane	0.48	2.11			
iso-Butane	0.19	0.62			
n-Butane	0.63	2.12			
iso-Pentane	0.18	0.47			
n-Pentane	1.02	2.75			
Hexanes	1.33	3.01			
Heptanes plus	94.95	77.12	0.8657	31.8	239
	100.00	100.00			

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CL-516

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well B-M-G Jicarilla No. P-19
Sampled at 2800 feet

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 511 PSIG @ 118 °F.

2. Thermal expansion of saturated oil @ 3000 PSI = $\frac{V \text{ @ } 118\ ^\circ F}{V \text{ @ } 76\ ^\circ F}$ = 1.01843

3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

From 3000 PSI to 2000 PSI = 5.65×10^{-6}

From 2000 PSI to 1200 PSI = 5.90×10^{-6}

From 1200 PSI to 511 PSI = 6.24×10^{-6}

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2592
Well C-14-C Jicarilla No. P-19
Sampled at 2800 feet

Pressure-Volume Relations of Reservoir Fluid at 118° F.

Pressure PSIG	Relative Volume V/Vs
3000	0.9854
2500	0.9881
2000	0.9910
1500	0.9938
1200	0.9957
1100	0.9963
1000	0.9968
900	0.9975
800	0.9982
700	0.9988
600	0.9994
511	1.0000
508	1.0023
505	1.0047
499	1.0102
487	1.0223
455	1.0465
419	1.0829
380	1.1313
334	1.2041
291	1.3012
246	1.4347
207	1.6047
167	1.8477
122	2.3144
79	3.1884

Core Laboratories, Inc.
Reservoir [illegible] Division

P. L. Moses
Operations Supervisor

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

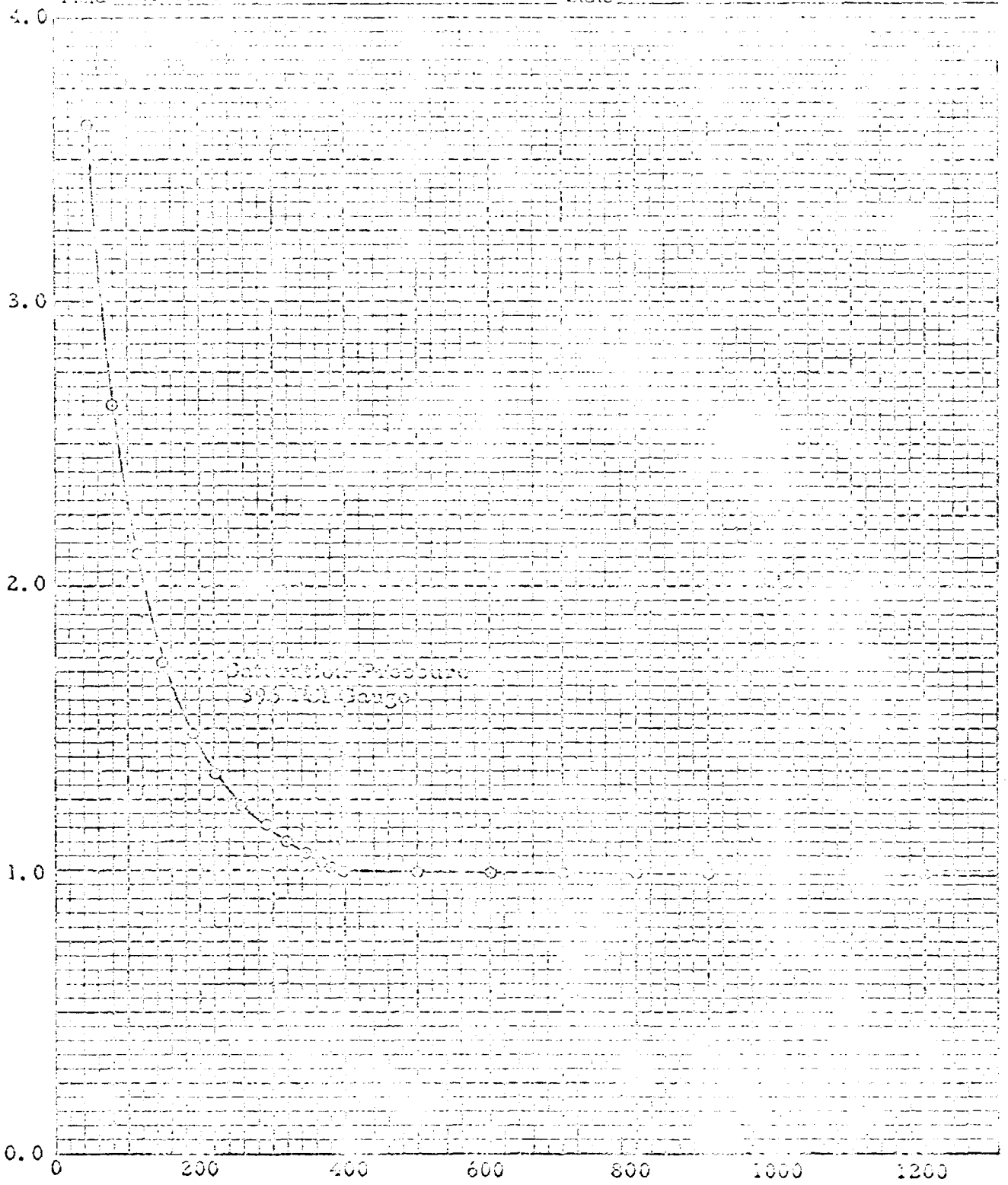
PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID

Denson-Monk-Greer

Company Drilling Corporation Formation [illegible]

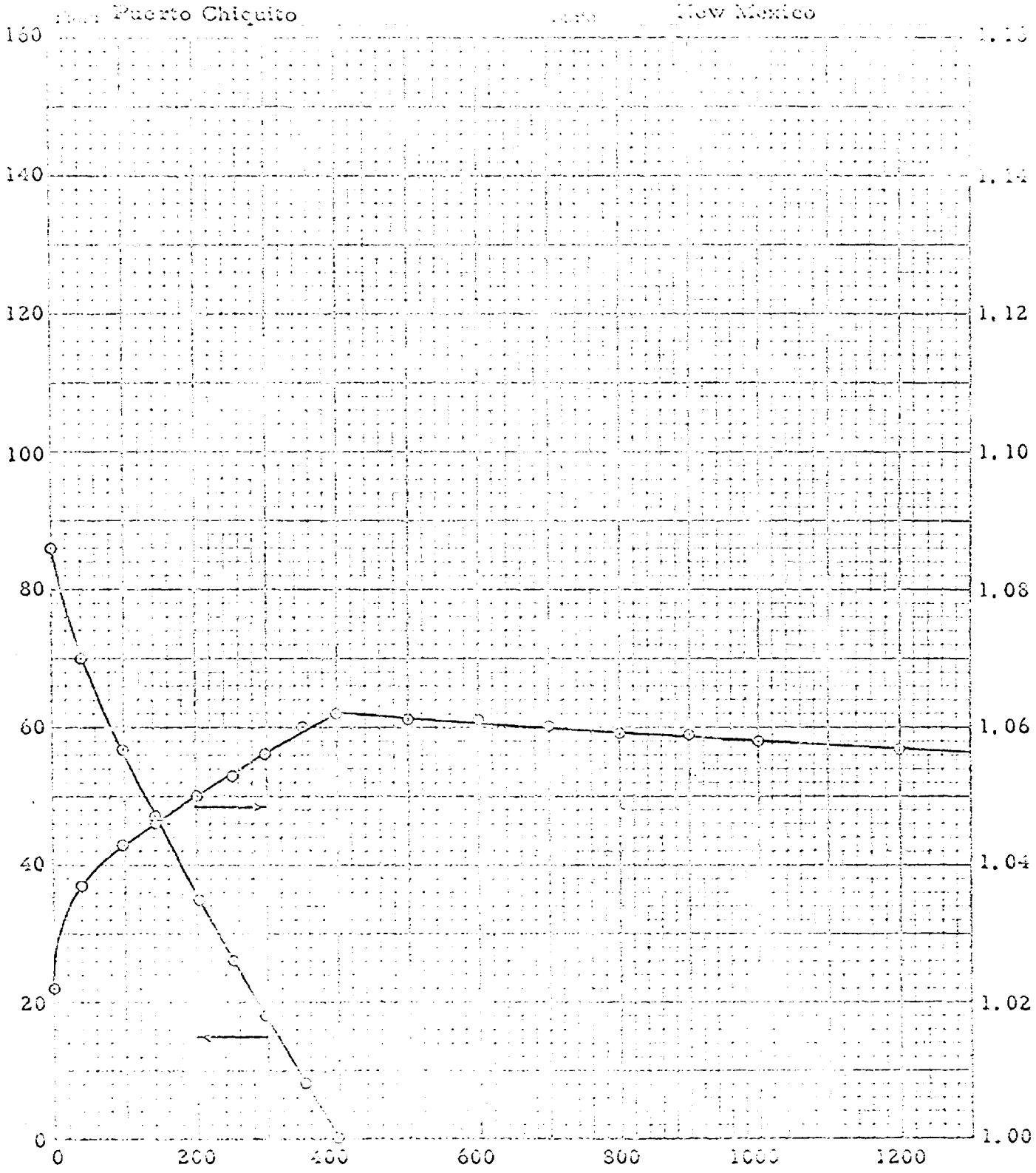
Well [illegible]-G Ricardo No. 2-19, 2500 Ft. County [illegible] Area

Field Pecos Chevron State [illegible]



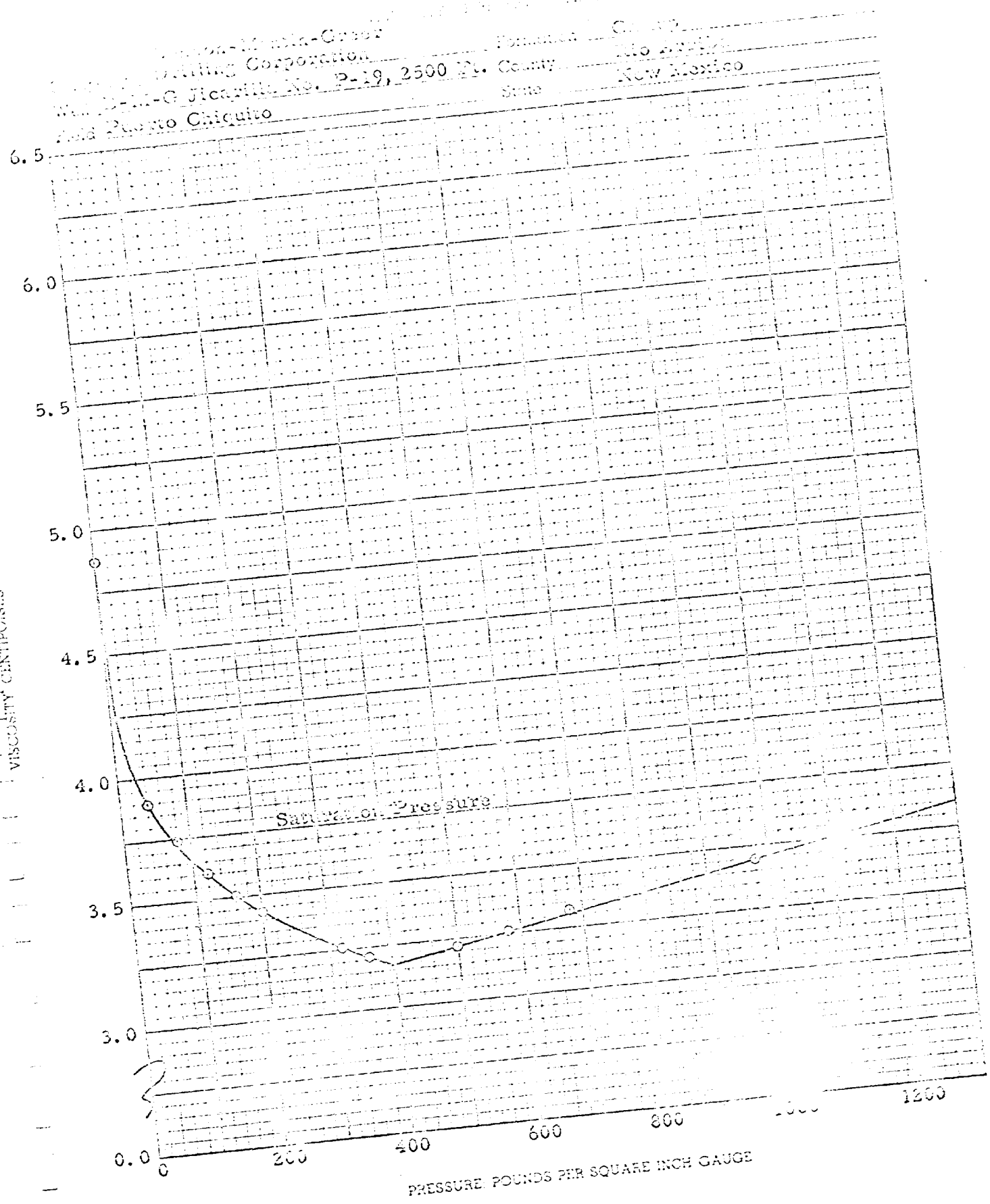
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Company: Benson-Montin-Greer Drilling Corporation
Formation: Gallup
Well: B-M-G Jicarilla No. P-19, 2500 Ft.
County: Rio Arriba
Field: Puerto Chiquito
State: New Mexico



Well Jicarilla No. B-19, 2500 Ft. County Rio Arriba

Field Puerto Chiquito State New Mexico



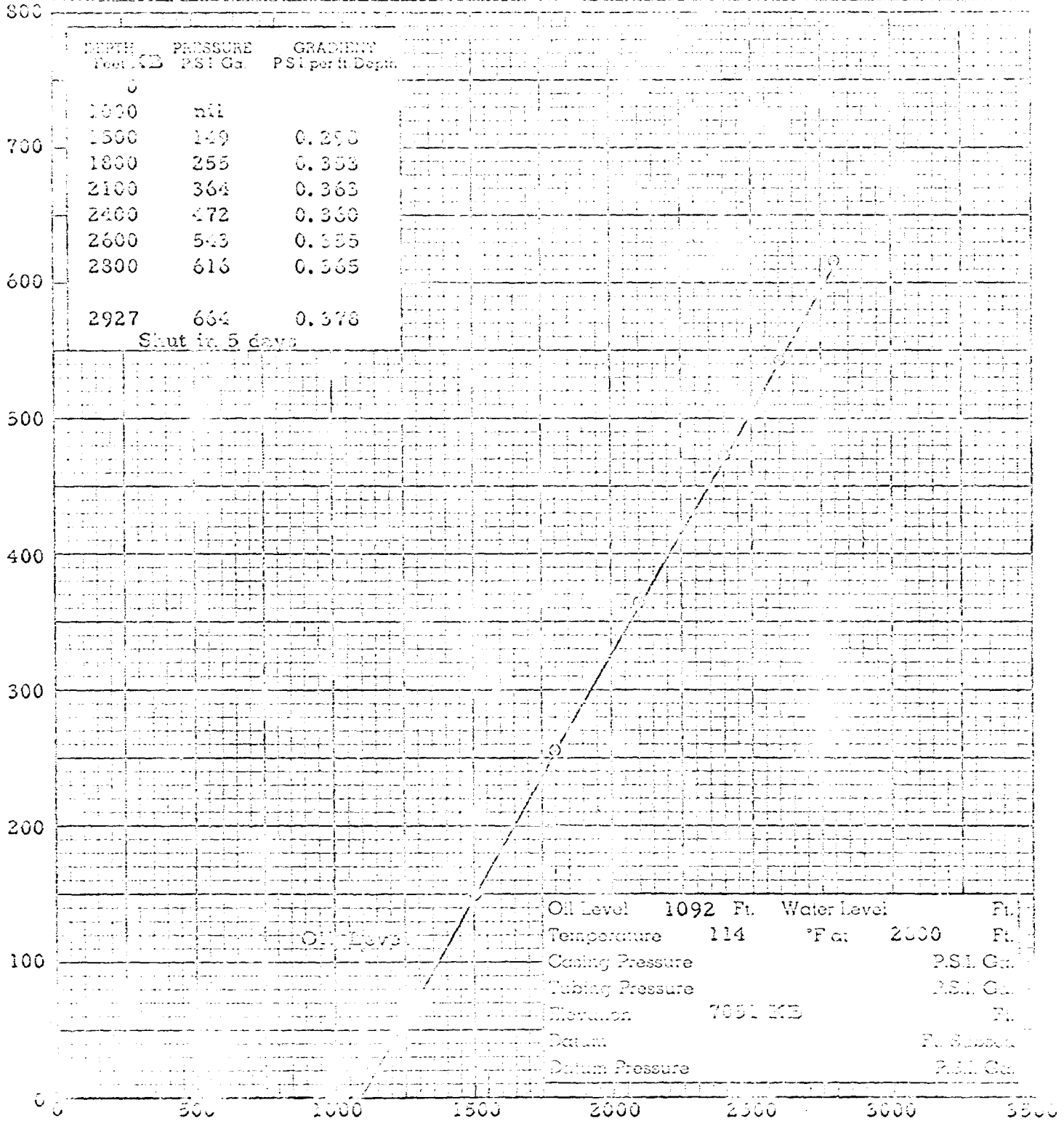
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page 12 of 12
File RFL-2592

Benson-Montin-Greer
Company Drilling Corporation Formation Glorieta
Well J-M-G Jicarilla No. P-19 County Rio Arriba
Field Ojo Caliente Extension State New Mexico

DEPTH Feet KB	PRESSURE PSI Ga.	GRADIENT PSI per ft. Depth
0		
1000	nil	
1500	149	0.298
1800	255	0.353
2100	364	0.363
2400	472	0.360
2600	543	0.355
2800	616	0.365
2927	664	0.378

Shut in 5 days



Oil Level 1092 Ft. Water Level Ft.
Temperature 114 °F at 2600 Ft.
Casing Pressure P.S.I. Ga.
Tubing Pressure P.S.I. Ga.
Elevation 7051 KB Ft.
Datum Ft. Subsea
Datum Pressure P.S.I. Ga.



CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

November 7, 1962

RESERVOIR FLUID DIVISION

Benson-Montin-Greer Drilling Corporation
158 Petroleum Center Building
Farmington, New Mexico

Attention: Mr. Virgil Stoabs

Subject: Reservoir Fluid Study
Bolack No. 2 Well
Wildcat
Rio Arriba County, New Mexico
Our File Number: RFL 2302

Gentlemen:

Subsurface fluid samples were collected from the subject well by a representative of Core Laboratories, Inc. on October 2, 1962, and transported to our Dallas laboratory, where they arrived on October 5, 1962. Presented in this report are the results of a reservoir fluid study performed using these samples.

The saturation pressure of the fluid was measured to be 1524 psig at the reservoir temperature of 152° F. The reservoir pressure at the sampling depth was measured to be 1631 psig.

During differential pressure depletion the fluid evolved 481 standard cubic feet of gas per barrel of residual oil. The associated formation volume factor was measured to be 1.292 barrels of saturated fluid per barrel of residual oil. Under similar depletion conditions the viscosity of the fluid varied from a minimum of 0.625 centipoise at the saturation pressure to a maximum of 1.750 centipoises at atmospheric pressure.

Separator tests were performed at four operating pressures and atmospheric temperature to determine the effect of changes in surface

separation pressure upon the produced fluid. These tests indicate that the optimum separator pressure is approximately 90 psig; however, near optimum recovery will be obtained at pressures as low as 40 psig.

It was a pleasure to perform this study for you. If you have any questions or if we may assist you further, please do not hesitate to contact us.

Very truly yours,

Core Laboratories, Inc.
Reservoir Fluid Division
P. L. Moses

A. C. Carnes, Jr.

A. C. Carnes, Jr.
Senior Engineer

ACC:dc
7 cc. - Addressee

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302

Company Benson-Montin-Greer Drilling Corporation — Date Sampled October 2, 1962
Well Bolack No. 2 — County Rio Arriba
Field Wildcat — State New Mexico

FORMATION CHARACTERISTICS

Formation Name	Gallup
Date First Well Completed	August 15, 1962
Original Reservoir Pressure	1631 PSIG @ 5957 Ft.
Original Produced Gas-Oil Ratio	SCF/Bbl
Production Rate	Bbl/Day
Separator Pressure and Temperature	PSIG, °F.
Oil Gravity at 60° F.	°API
Datum	Ft. Subsea
Original Gas Cap	

WELL CHARACTERISTICS

Elevation	7100 KB Ft.
Total Depth	6022 Ft.
Producing Interval	4900-6022 OH Ft.
Tubing Size and Depth	2-3/8 In. to 6003 Ft.
Productivity Index	Bbl/D/PSI @ Bbl/Day
Last Reservoir Pressure	1631 PSIG @ 5975 Ft.
Date	October 2, 1962
Reservoir Temperature	152 °F. @ 5975 Ft.
Status of Well	Shut in
Pressure Gauge	Amerada (DO)
Normal Production Rate	Bbl/Day
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Base Pressure	PSIA
Well Making Water	% Cut

SAMPLING CONDITIONS

Sampled at	5975 Ft.
Status of Well	Shut in
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Tubing Pressure	0 PSIG
Casing Pressure	PSIG
Core Laboratories Engineer	NT
Type Sampler	Perco

REMARKS:

CL-618

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302
Well Bolack No. 2

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 1524 PSIG @ 152 °F.

2. Thermal expansion of saturated oil @ 5000 PSI = $\frac{V\ @\ 152\ °F}{V\ @\ 73\ °F}$ = 1.04245

3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

From 5000 PSI to 3500 PSI = 7.92×10^{-6}

From 3500 PSI to 2500 PSI = 8.93×10^{-6}

From 2500 PSI to 1524 PSI = 10.34×10^{-6}

4. Specific volume at saturation pressure: ft^3/lb 0.02223 @ 152 °F.

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Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 152 °F., RELATIVE VOLUME OF OIL AND GAS, $V/V_{SAT.}$	VISCOSITY OF OIL @ 152 °F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 152 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/V_R
5000	0.9694	0.845			1.252
4500	0.9732	0.818			1.257
4005		0.787			
4000	0.9770				1.262
3500	0.9811	0.758			1.268
3000	0.9854	0.726			1.273
2505		0.691			
2500	0.9899				1.279
2100	0.9938				1.284
2000	0.9947	0.661			1.285
1900	0.9957				1.286
1800	0.9969				1.288
1700	0.9980	0.635			1.289
1600	0.9991				1.291
1524	1.0000	0.625	0	481	1.292
1516	1.0020				
1508	1.0041				
1483	1.0102				
1447	1.0204				
1400		0.631			
1381	1.0407				
1376			37	444	1.277
1299	1.0698				
1250		0.682			
1221			75	406	1.261
1201	1.1121				
1123			100	381	1.251
1100		0.720			
1090	1.1734				
971	1.2552				
968			139	342	1.235
950		0.760			
850	1.3679				
818			176	305	1.220

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302
Well Bolack No. 2

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 152 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 152 °F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 152 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/Vr
800		0.802			
728	1.5320				
669			213	268	1.204
650		0.858			
600	1.7783				
518			251	230	1.188
500		0.912			
469	2.1799				
365			290	191	1.170
354	2.7950				
350		0.977			
258	3.8098				
223			332	149	1.151
200		1.083			
112			371	110	1.130
0		1.750	481	0	1.044
				@ 60° F.	= 1.000

Gravity of residual oil = 38.6° API @ 60° F.

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302

Well Bolack No. 2

Differential Pressure Depletion at 152° F.

Pressure PSIG	Oil Density Gms/Cc	Gas Gravity	Deviation Factor Z
1524	0.7206		
1376	0.7246	0.693	0.869
1221	0.7290	0.694	0.879
1123	0.7319	0.696	0.886
968	0.7367	0.699	0.895
818	0.7413	0.708	0.909
669	0.7462	0.720	0.920
518	0.7512	0.739	0.932
365	0.7566	0.783	0.945
223	0.7627	0.856	0.965
112	0.7688	1.014	
0	0.7957	1.589	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302

Well Bolack No. 2

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

SEPARATOR PRESSURE, PSI GAUGE	SEPARATOR TEMPERATURE, ° F.	SEPARATOR GAS/OIL RATIO See Foot Note (1)	STOCK TANK GAS/OIL RATIO See Foot Note (1)	STOCK TANK GRAVITY, ° API @ 60° F.	SHRINKAGE FACTOR, $V_R/V_{SAT.}$ See Foot Note (2)	FORMATION VOLUME FACTOR, $V_{SAT.}/V_R$ See Foot Note (3)	SPECIFIC GRAVITY OF FLASHED GAS
0	79	503		38.4	0.7645	1.308	0.997
40	77	414	32	39.7	0.7924	1.262	
80	76	371	61	39.9	0.7994	1.251	
160	77	328	117	39.7	0.7930	1.261	

(1) Separator and Stock Tank Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stock tank oil @ 60° F.

(2) Shrinkage Factor: $V_R/V_{SAT.}$ is barrels of stock tank oil @ 60° F. per barrel of saturated oil @ 1524 PSI gauge and 152 ° F.

(3) Formation Volume Factor: $V_{SAT.}/V_R$ is barrels of saturated oil @ 1524 PSI gauge and 152 ° F. per barrel of stock tank oil @ 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 2302

Company Benson-Montin-Greer Drilling Corporation Formation Gallup

Well Bolack No. 2 County Rio Arriba

Field Wildcat State New Mexico

HYDROCARBON ANALYSIS OF Reservoir Fluid SAMPLE

COMPONENT	WEIGHT PER CENT	MOL PER CENT	DENSITY @ 60° F. GRAMS PER CUBIC CENTIMETER	° API @ 60° F.	MOLECULAR WEIGHT
Hydrogen Sulfide	0.05	0.14			
Carbon Dioxide	0.04	0.16			
Nitrogen	3.68	26.38			
Methane	1.70	6.48			
Ethane	2.45	6.39			
Propane	0.50	1.00			
iso-Butane	2.23	4.41			
n-Butane	1.16	1.86			
iso-Pentane	1.53	2.44			
n-Pentane	3.33	4.45			
Hexanes	83.33	46.29	0.8449	35.8	207
Heptanes plus	100.00	100.00			

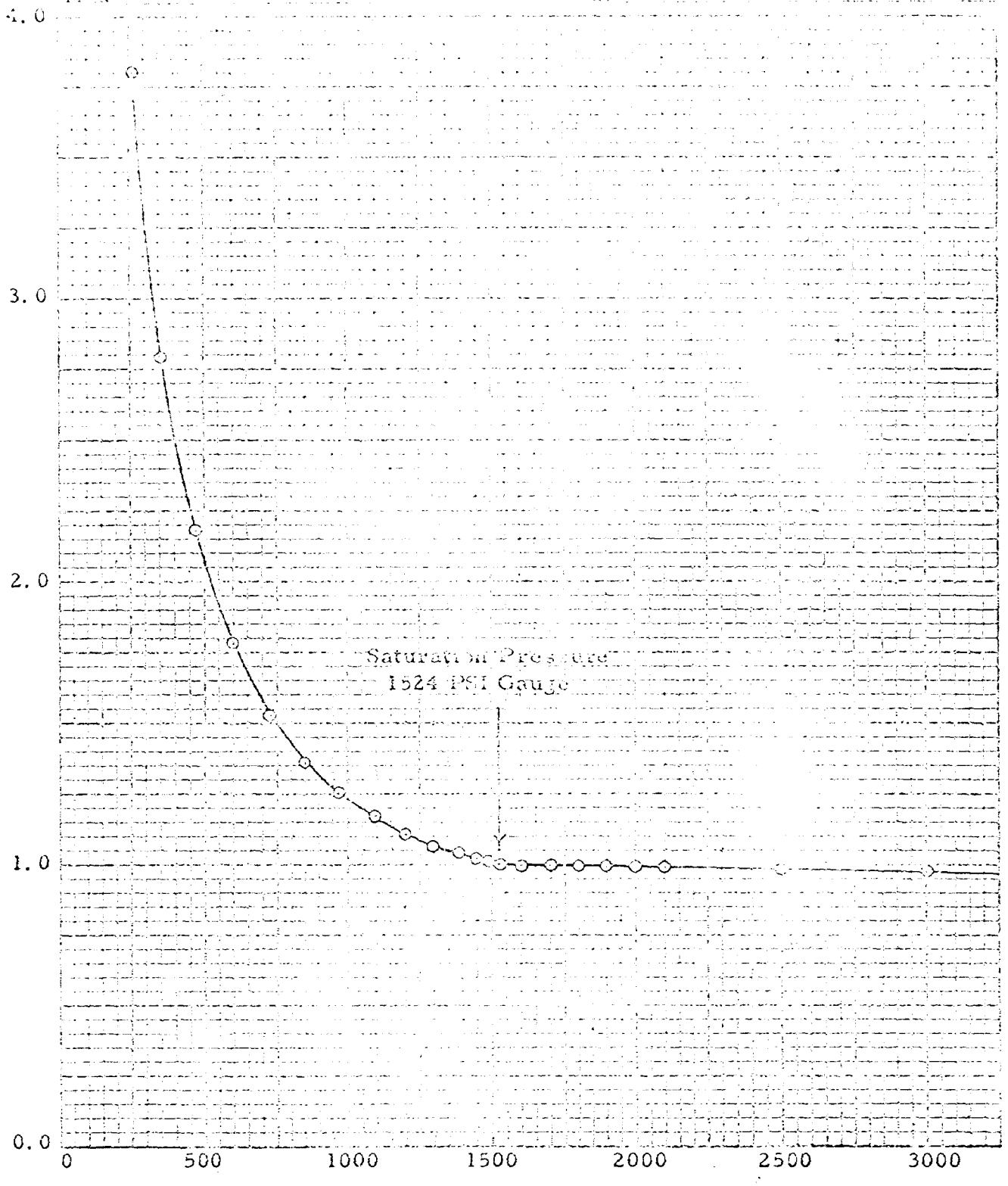
Core Laboratories, Inc.
Reservoir Fluid Division

A. C. Carnes, Jr.

A. C. Carnes, Jr.
Senior Engineer

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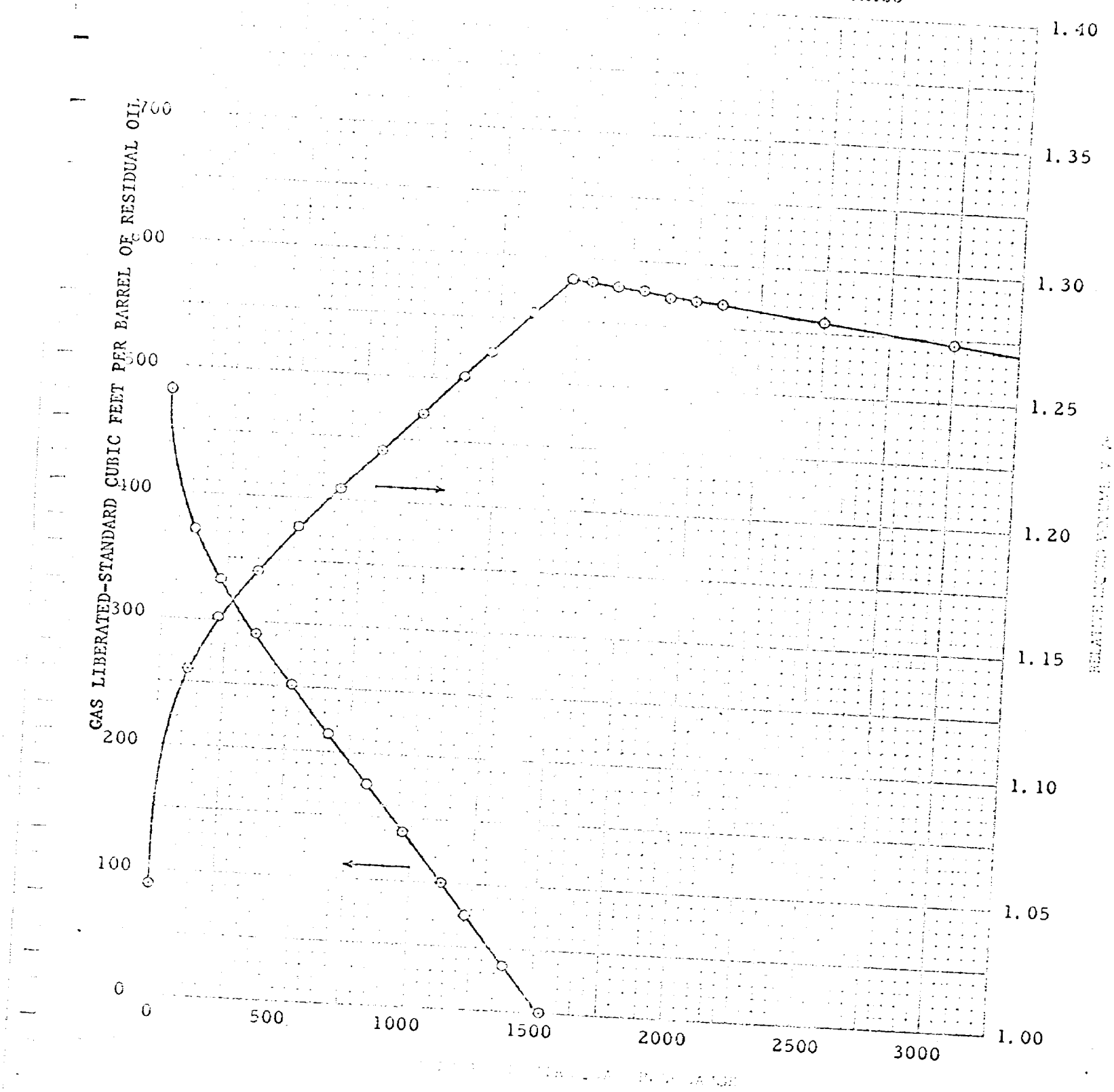
Ben-on-Mantin-Greer Drilling Corporation
Black No. 2
Wildcat
Gallup
Rio Arriba
New Mexico



9 11
RFL 2302

Benson-Montin-Greer
Drilling Corporation
Black No. 2
Wildcat

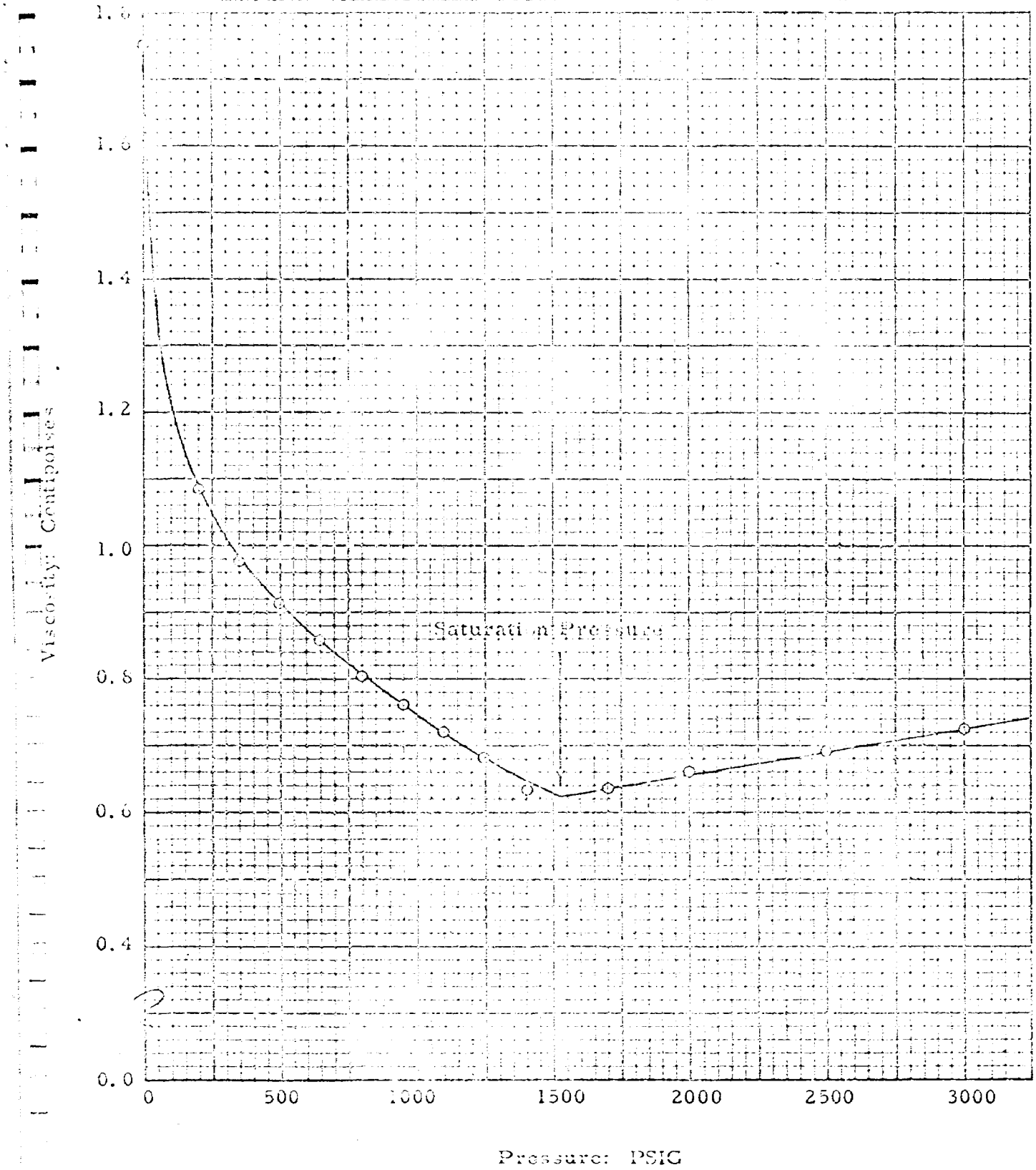
Gallup
Rio Arriba
New Mexico



CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Viscosity of Reservoir Fluid

Company: Beason-Montin-Greer Drilling Corporation
Well: Bolack No. 2
Field: Wildcat
Formation: Gallup
County: Rio Arriba
State: New Mexico



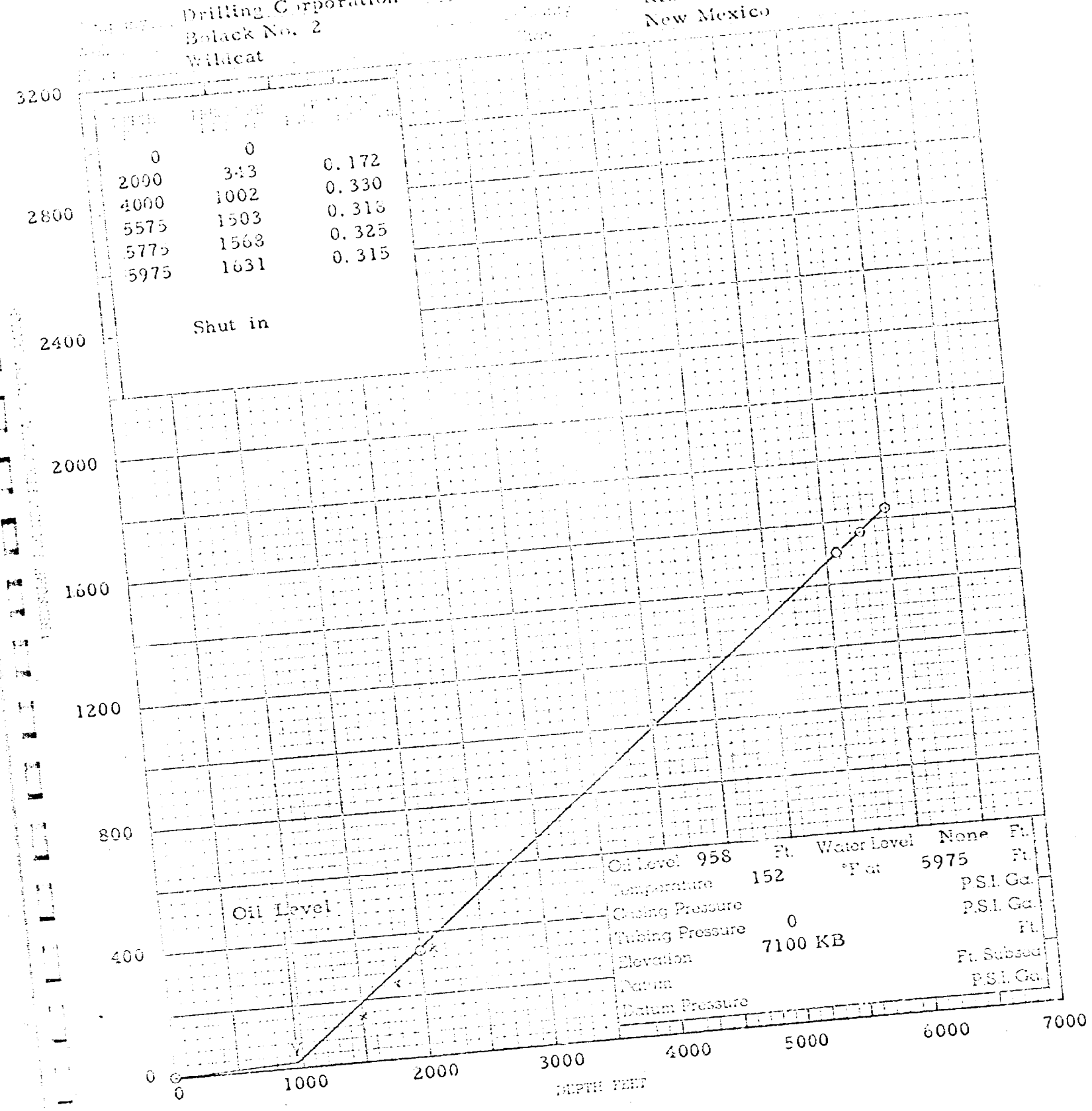
RFL 2302

Benson-Montin-Greer
Drilling Corporation
Bolack No. 2
Wildcat

Gallup
Rio Arriba
New Mexico

0	0	
2000	343	0.172
4000	1002	0.330
5575	1503	0.318
5775	1568	0.325
5975	1631	0.315

Shut in



Oil Level 958 Ft. Water Level None Ft.
Temperature 152 °F at 5975 Ft.
Casing Pressure P.S.I. Ga.
Tubing Pressure 0 P.S.I. Ga.
Elevation 7100 KB Ft.
Datum Ft. Subsea
Datum Pressure P.S.I. Ga.

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

July 27, 1965

RESERVOIR FLUID DIVISION

Benson-Montin-Greer Drilling Corporation
158 Petroleum Center Building
Farmington, New Mexico

Attention: Mr. Albert R. Greer

Subject: Reservoir Fluid Study
Bolack-Greer Inc.
Canada Ojitos Unit No. 12-11 Well
Puerto Chiquito Field
Rio Arriba County, New Mexico
Our File Number: RFL 3366

Gentlemen:

Subsurface fluid samples were collected from the subject well by a representative of Core Laboratories, Inc. and were delivered to our laboratory in Dallas for use in a reservoir fluid study. The results of this study are presented on the following pages.

The saturation pressure of the fluid was found to be 1519 psig at the reservoir temperature of 162° F. The associated formation volume factor was found to be 1.297 barrels of saturated fluid per barrel of residual oil. By differential pressure depletion the fluid evolved 478 standard cubic feet of gas per barrel of residual oil. Under similar depletion conditions the viscosity increased from a minimum of 0.625 centipoise at the saturation pressure to a maximum of 1.704 centipoises at atmospheric pressure. The saturation pressure of the fluid was measured at several different temperatures as you requested.

It has been a pleasure to perform this study for you. If you have any questions or if we may assist you further in any way, please do not hesitate to contact us.

Very truly yours,

Core Laboratories, Inc.
Reservoir Fluid Division

P. L. Moses (B)

P. L. Moses
Operations Supervisor

PLM:JB:bjm
7 cc. - Addressee

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Company Benson-Montin-Greer Drilling Corporation — Date Sampled July 1, 1965

Well Canada Ojitos Unit No. 12-11 — County Rio Arriba

Field Puerto Chiquito — State New Mexico

FORMATION CHARACTERISTICS

Formation Name	Nio Braro (Gallup)
Date First Well Completed	October, 1962
Original Reservoir Pressure	1631 PSIG @ 5957 Ft.
Original Produced Gas-Oil Ratio	SCF/Bbl
Production Rate	Bbl/Day
Separator Pressure and Temperature	PSIG, °F.
Oil Gravity at 60° F.	°API
Datum	Ft. Subsea
Original Gas Cap	

WELL CHARACTERISTICS

Elevation	7232 KB Ft.
Total Depth	6687 Ft.
Producing Interval	6648-6687 Ft.
Tubing Size and Depth	In. to Ft.
Productivity Index	Bbl/D/PSI @ Bbl/Day
Last Reservoir Pressure	1693 PSIG @ 6650 Ft.
Date	July 1, 1965
Reservoir Temperature	162 °F. @ 6650 Ft.
Status of Well	Shut in 27 days
Pressure Gauge	Amerada
Normal Production Rate	Bbl/Day
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Base Pressure	15.025 PSIA
Well Making Water	None % Cut

SAMPLING CONDITIONS

Sampled at	6650 KB Ft.
Status of Well	Shut in 27 days
Gas-Oil Ratio	SCF/Bbl
Separator Pressure and Temperature	PSIG, °F.
Tubing Pressure	0 PSIG
Casing Pressure	0 PSIG
Core Laboratories Engineer	NT
Type Sampler	Perco

REMARKS:

CL-818

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366
Well Canada Ojitos Unit
No. 12-11

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 1519 PSIG @ 162 °F.

2. Thermal expansion of saturated oil @ 5000 PSI $= \frac{V \text{ @ } 162 \text{ °F}}{V \text{ @ } 76 \text{ °F}} =$ 1.04528

3. Compressibility of saturated oil @ reservoir temperature: Vol/Vol/PSI:

From 5000 PSI to 3500 PSI = 8.24×10^{-6}

From 3500 PSI to 2500 PSI = 9.49×10^{-6}

From 2500 PSI to 1519 PSI = 10.68×10^{-6}

4. Specific volume at saturation pressure: ft^3/lb 0.02218 @ 162 °F.

5. Saturation pressure at various temperatures:

Temperature, °F.	Saturation Pressure, PSI BHS No. 1	BHS No. 2
76	1203	1204
110	1351	
152	1491	1492
162	1519	1519
172	1540	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Well Canada Ojitos Unit
No. 12-11

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 162 °F.. RELATIVE VOLUME OF OIL AND GAS, $V/V_{SAT.}$	VISCOSITY OF OIL @ 162 °F.. CENTIPOISES	DIFFERENTIAL LIBERATION @ 162 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/V_R
5000	0.9680	0.841			1.256
4500	0.9718				1.260
4000	0.9759	0.781			1.266
3500	0.9801	0.751			1.271
3000	0.9847	0.719			1.277
2500	0.9895	0.686			1.283
2300	0.9916				1.286
2100	0.9936				1.289
2000	0.9947	0.652			1.290
1900	0.9957				1.291
1800	0.9968				1.293
1700	0.9981				1.294
1600	0.9991				1.296
1519	1.0000	0.625	0	478	1.297
1508	1.0028				
1498	1.0054				
1481	1.0101				
1457	1.0162				
1429	1.0254				
1389			32	446	1.284
1369	1.0458				
1350		0.684			
1288	1.0766				
1259			65	413	1.270
1250		0.696			
1196	1.1174				
1129			96	382	1.257
1100		0.731			
1084	1.1789				
968	1.2610				
963			136	342	1.239
950		0.780			
858	1.3638				
812			173	305	1.224

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Well Canada Ojitos Unit
No. 12-11

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATION @ 162 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vsat.	VISCOSITY OF OIL @ 162°F., CENTIPOISES	DIFFERENTIAL LIBERATION @ 162 °F.		
			GAS/OIL RATIO LIBERATED PER BARREL OF RESIDUAL OIL	GAS/OIL RATIO IN SOLUTION PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR
800		0.835			
750	1.4975				
658			211	267	1.207
657	1.6518				
650		0.900			
566	1.8577				
519			246	232	1.192
500		0.980			
479	2.1482				
413	2.4573				
359			287	191	1.175
350	2.8694				
298	3.3145				
250	3.8813	1.161			
218			328	150	1.156
108			367	111	1.133
0		1.704	478	0	1.049
				@ 60° F.	= 1.000

Gravity of residual oil = 38.2° API @ 60° F.

V = Volume at given pressure
$V_{SAT.}$ = Volume at saturation pressure and the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Well Canada Ojitos Unit No. 12-11

Differential Pressure Depletion at 162° F.

Pressure PSIG	Oil Density Gms/Cc	Gas Gravity	Deviation Factor Z
1519	0.7223		
1389	0.7258	0.696	0.882
1259	0.7298	0.698	0.887
1129	0.7336	0.701	0.894
963	0.7389	0.709	0.902
812	0.7438	0.718	0.914
658	0.7487	0.731	0.929
519	0.7534	0.753	0.943
359	0.7589	0.791	0.958
218	0.7642	0.886	0.976
108	0.7716	1.067	
0	0.7939	1.702	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Well Canada Ojitos Unit
No. 12-11

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

SEPARATOR PRESSURE, PSI GAUGE	SEPARATOR TEMPERATURE, ° F.	SEPARATOR GAS/OIL RATIO See Foot Note (1)	STOCK TANK GAS/OIL RATIO See Foot Note (1)	STOCK TANK GRAVITY, ° API @ 60° F.	SHRINKAGE FACTOR, $V_R/V_{SAT.}$ See Foot Note (2)	FORMATION VOLUME FACTOR, $V_{SAT.}/V_R$ See Foot Note (3)	SPECIFIC GRAVITY OF FLASHED GAS
0	74	483		38.1	0.7639	1.309	0.986
40	74	386	27	39.6	0.7943	1.259	
80	74	354	55	39.6	0.7968	1.255	
160	74	300	110	39.4	0.7943	1.259	

(1) Separator and Stock Tank Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stock tank oil @ 60° F.

(2) Shrinkage Factor: $V_R/V_{SAT.}$ is barrels of stock tank oil @ 60° F. per barrel of saturated oil @ 1519 PSI gauge and 162 ° F.

(3) Formation Volume Factor: $V_{SAT.}/V_R$ is barrels of saturated oil @ 1519 PSI gauge and 162 ° F. per barrel of stock tank oil @ 60° F.

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Company Benson-Montin-Greer Drilling Corporation Formation Nio Braro (Gallup)

Well Canada Ojitos Unit No. 12-11 County Rio Arriba

Field Puerto Chiquito State New Mexico

HYDROCARBON ANALYSIS OF Reservoir Fluid SAMPLE

COMPONENT	MOL PER CENT	WEIGHT PER CENT	DENSITY @ 60° F. GRAMS PER CUBIC CENTIMETER	° API @ 60° F.	MOLECULAR WEIGHT
Hydrogen Suifide					
Carbon Dioxide	0.20	0.08			
Nitrogen	0.13	0.03			
Methane	26.36	3.65			
Ethane	6.86	1.78			
Propane	6.19	2.36			
iso-Butane	1.20	0.60			
n-Butane	4.29	2.15			
iso-Pentane	1.80	1.12			
n-Pentane	2.14	1.33			
Hexanes	4.49	3.34			
Heptanes plus	46.34	83.56	0.8474	35.3	209
	100.00	100.00			

Core Laboratories, Inc.
Reservoir Fluid Division

P. L. Moses (B)
P. L. Moses
Operations Supervisor

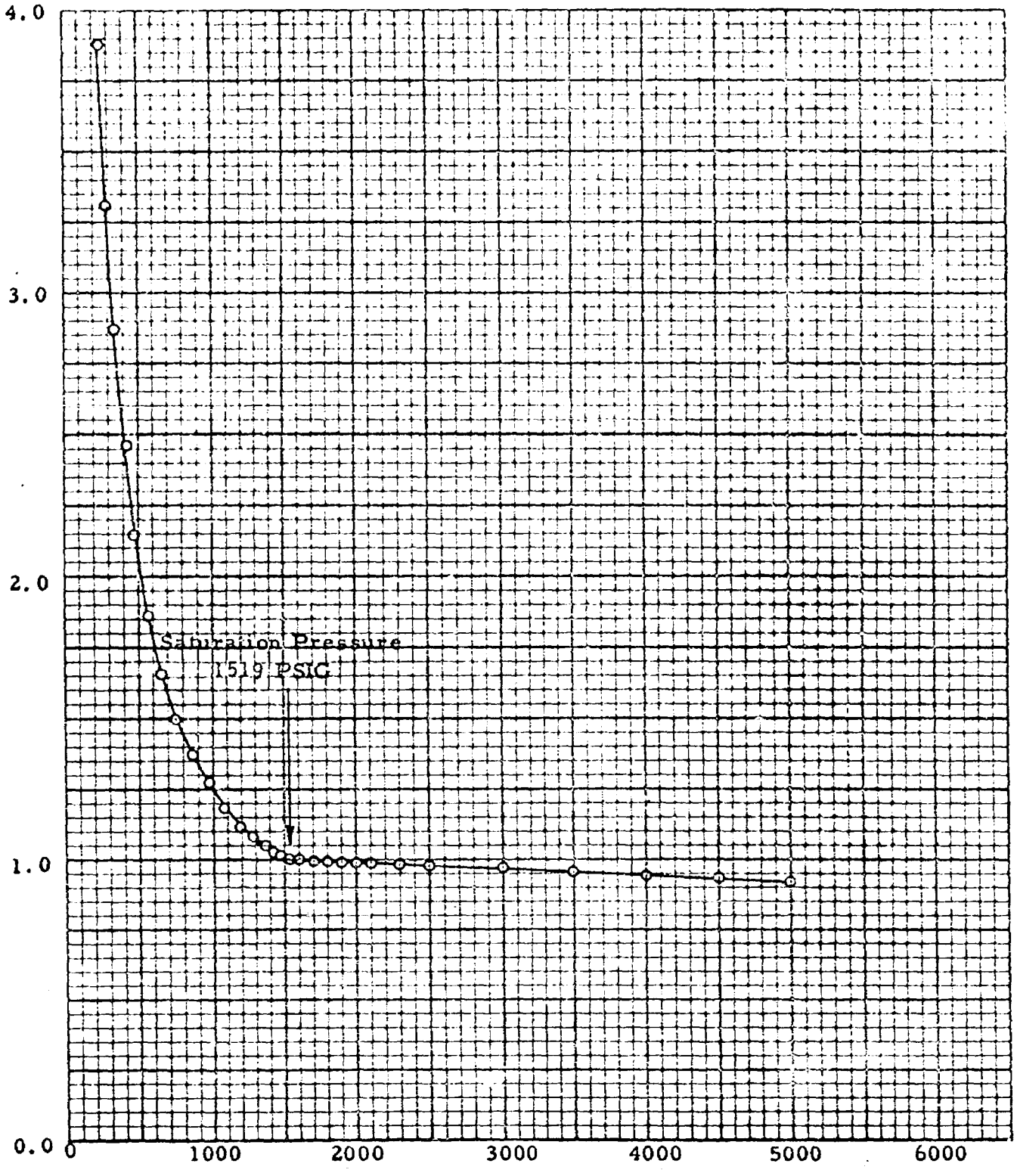
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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID

Company Benson-Montin-Greer Drilling Corporation
Formation Nio Braro (Gallup)
Well Canada Ojitos Unit No. 12-11
County Rio Arriba
Field Puerto Chiquito
State New Mexico

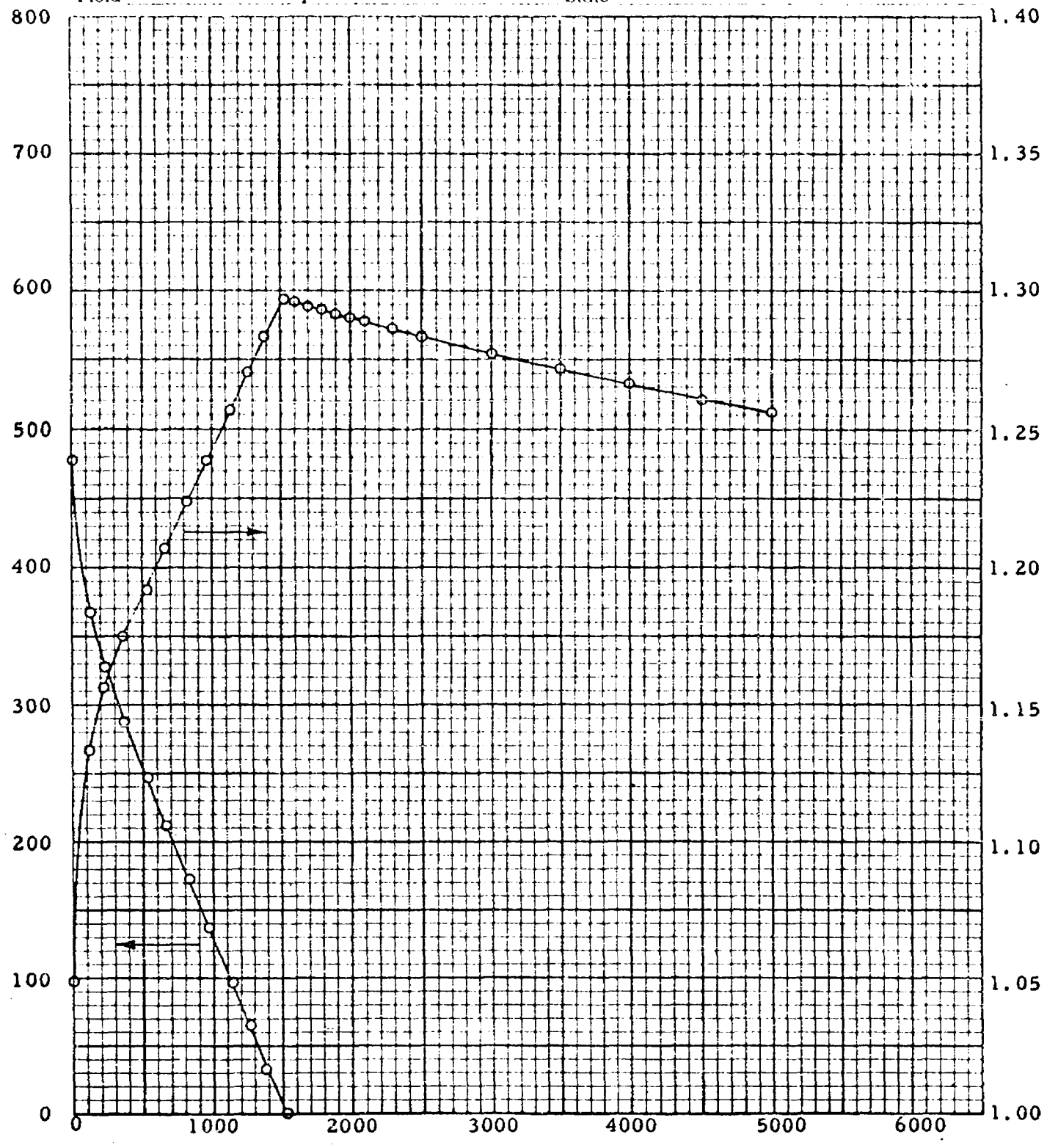


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

DIFFERENTIAL VAPORIZATION OF RESERVOIR FLUID

Company Benson-Montin-Greer Drilling Corporation
Well Canada Ojitos Unit No. 12-11
Field Puerto Chiquito
Formation Nio Braro (Gallup)
County Rio Arriba
State New Mexico

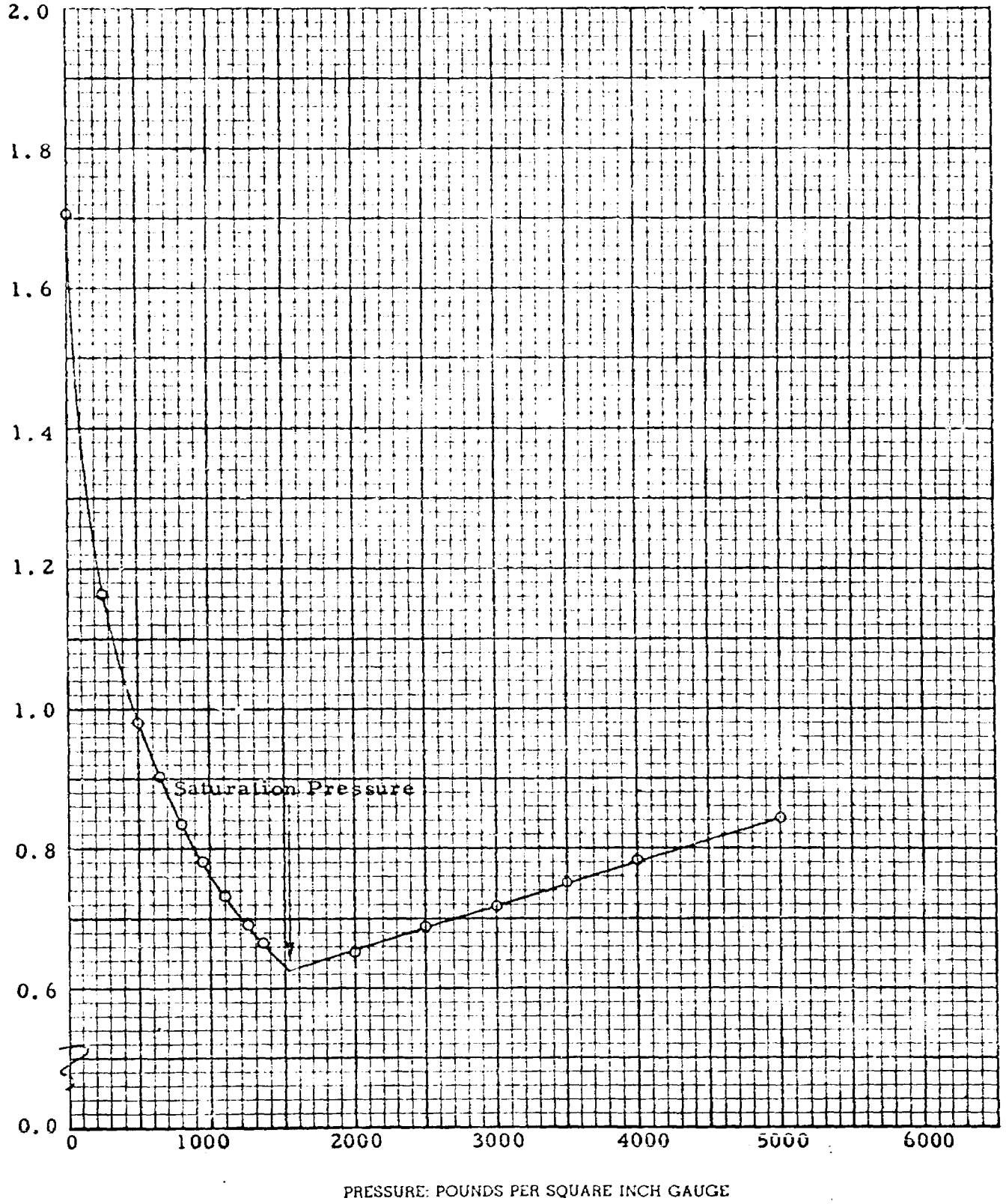


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

VISCOSITY OF RESERVOIR FLUID

Company Benson-Montin-Greer Drilling Corporation Formation Nio Braro (Gallup)
Well Canada Ojitos Unit No. 12-11 County Rio Arriba
Field Puerto Chiquito State New Mexico



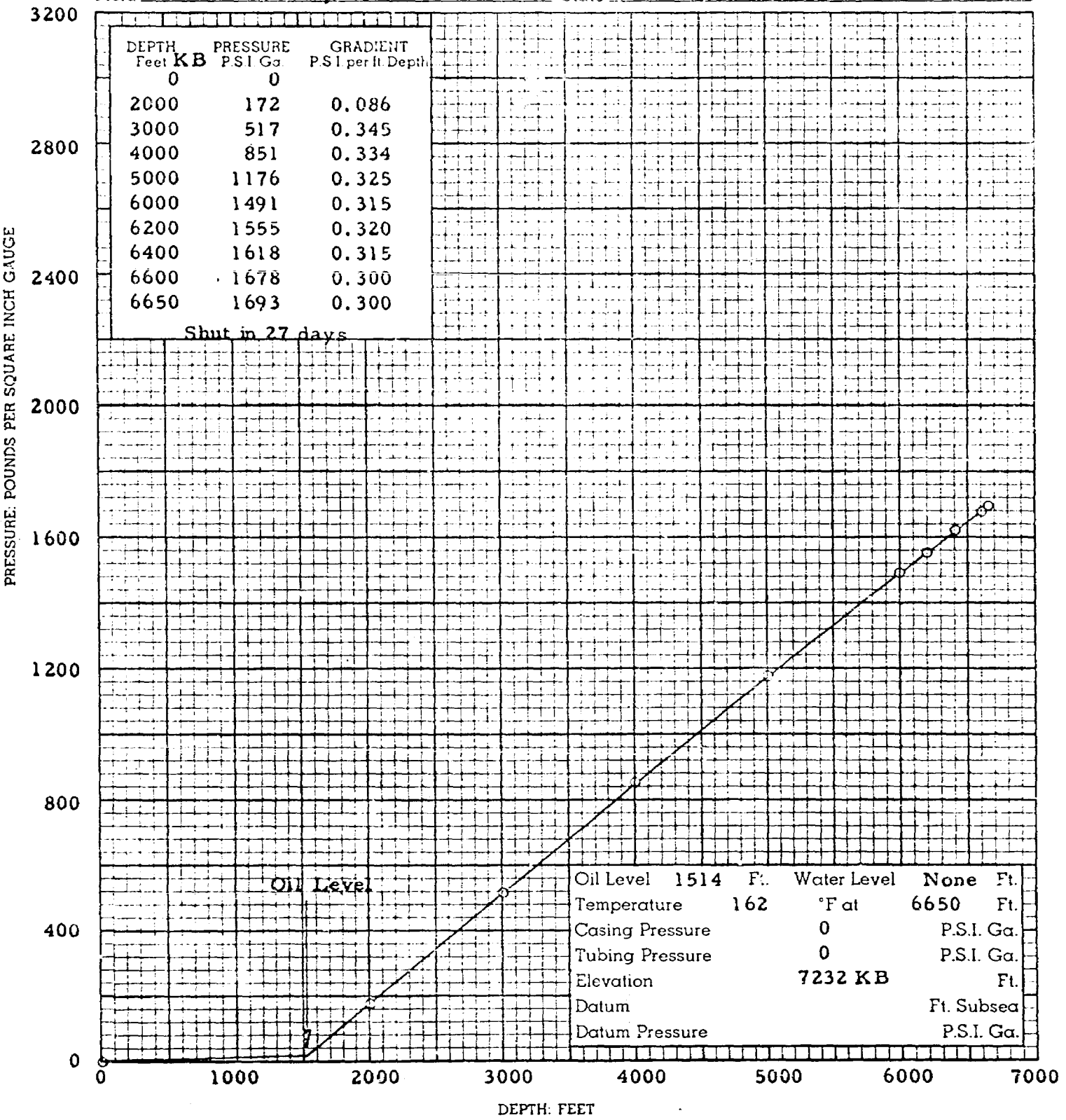
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 3366

Company Benson-Montin-Greer Drilling Corporation
Formation No Braro (Gallup)
Well Canada Ojitos Unit No. 12-11
County Rio Arriba
Field Puerto Chiquito
State New Mexico

DEPTH Feet KB	PRESSURE P.S.I. Ga.	GRADIENT P.S.I. per ft. Depth
0	0	
2000	172	0.086
3000	517	0.345
4000	851	0.334
5000	1176	0.325
6000	1491	0.315
6200	1555	0.320
6400	1618	0.315
6600	1678	0.300
6650	1693	0.300

Shut in 27 days



BENSON-MONTIN-GREER DRILLING CORP.

EXHIBITS IN CASE 3455

BEFORE THE

NEW MEXICO OIL CONSERVATION

COMMISSION

NOVEMBER 16, 1966

INDEX OF BENSON-MONTIN-GREER DRILLING CORP. EXHIBITS
IN CASE NO. 3455
BEFORE THE NEW MEXICO OIL CONSERVATION COMMISSION
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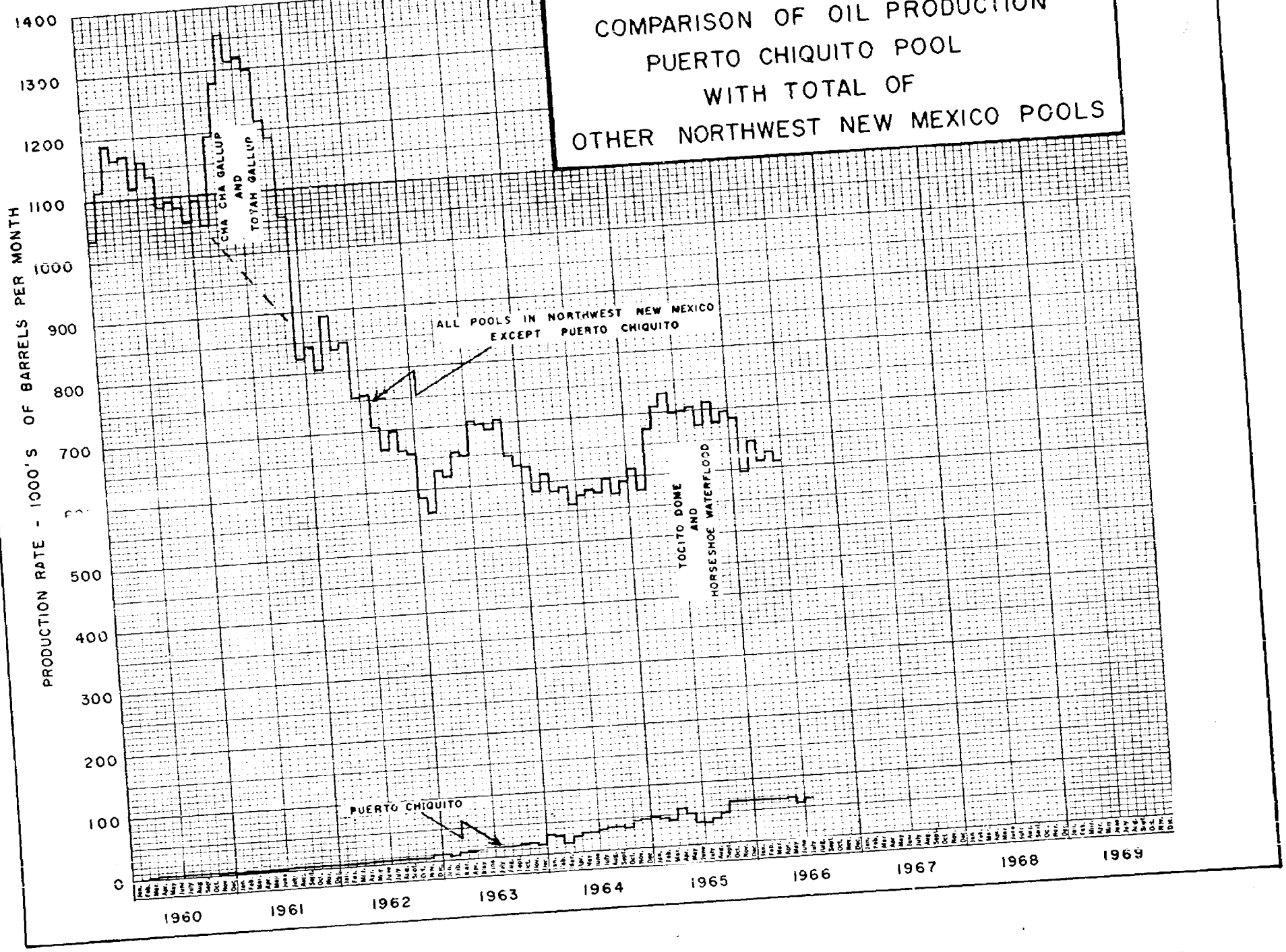
2. PLAT SHOWING POSITION OF LEASE OWNERS REGARDING APPLICATION OF BENSON-MONTIN-GREER DRILLING CORP. FOR 320-ACRE SPACING AND PROPOSED WEST PUERTO CHIQUITO POOL

[redacted]

[redacted]

[redacted]

COMPARISON OF OIL PRODUCTION PUERTO CHIQUITO POOL WITH TOTAL OF OTHER NORTHWEST NEW MEXICO POOLS



[redacted]

WELL NUMBERING NOMENCLATURE
FOR WELLS OPERATED BY
BENSON-MONTIN-GREER DRILLING CORP.
PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

November 1, 1966

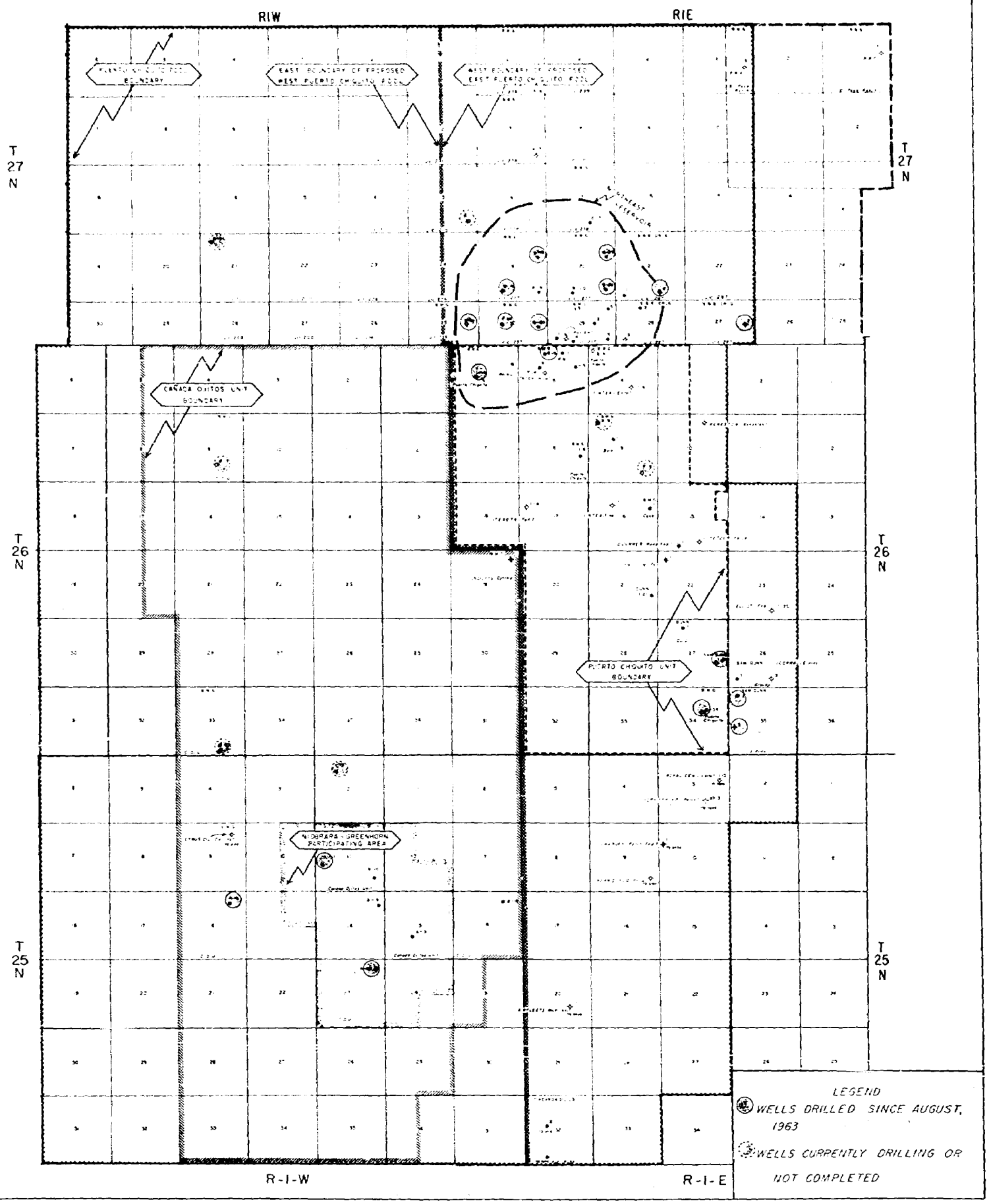
B-M-G PERMANENT DESIGNATION	B-M-G CURRENT SEQUENCE NUMBER	NMOCC UNIT DESIGNATION	SEQUENCE NO. APRIL 1964 TO JUNE 1965	SEQUENCE NO. AUGUST 1963
CAÑADA OJITOS UNIT				
O-9	1	O- 9-26-1W		Bolack #1
K-13	2	K-13-25-1W	13 11	Bolack #2
A-14	3	A-14-25-1W	14 1	Bolack A-14
P-11	4	P-11-25-1W	16	
B-18	5	B-18-25-1E	18 2	
L-11	6	L-11-25-1W	11 12	
A-23	7	A-23-25-1W	23 1	
A-16	8	A-16-25-1W		
C-2	9	C- 2-25-1W		
O-33	10	O-33-26-1W		
PUERTO CHIQUITO UNIT				
H-5	14	H- 5-26-1E	Intex 5-1	Intex 5-1
I-8	15	I- 8-26-1E	8 9	I-8
C-5	16	C- 5-26-1E	5 3	
D-9	17	D- 9-26-1E		
F-6	18	F- 6-26-1E		
D-4	19	D- 4-26-1E		

B-M-G PERMANENT DESIGNATION	B-M-G CURRENT SEQUENCE NUMBER	NMOCC UNIT DESIGNATION	SEQUENCE NO. APRIL 1964 TO JUNE 1965	SEQUENCE NO. AUGUST 1963
JICARILLA 237 LEASE				
L-29	1	L-29-27-1E	Betsy #1	Betsy #1
G-29	2	G-29-27-1E	Betsy #2	Betsy #2
C-29	3	C-29-27-1E	Betsy #3	Betsy #3
K-29	4	K-29-27-1E	Betsy #4	Betsy #4
A-29	5	A-29-27-1E	Betsy #5	Betsy #5
I-29	6	I-29-27-1E	Betsy #6	Betsy #6
N-20	7	N-20-27-1E	14	N-20
P-19	8	P-19-27-1E	16	P-19
H-30	9	H-30-27-1E	30 8	
H-20	10	H-20-27-1E	20 8	
P-20	11	P-20-27-1E	16	
H-19	12	H-19-27-1E	19 8	
F-30	13	F-30-27-1E		
N-19	14	N-19-27-1E		
JICARILLA 238 LEASE				
O-17	1	O-17-27-1E	17 15	O-17
BERNIE LEASE				
Bernie	1	H- 6-26-1E	Bayless Bernie #1	Bayless Bernie #1

[redacted]

PUERTO CHIQUITO POOL

RIO ARRIBA COUNTY, NEW MEXICO

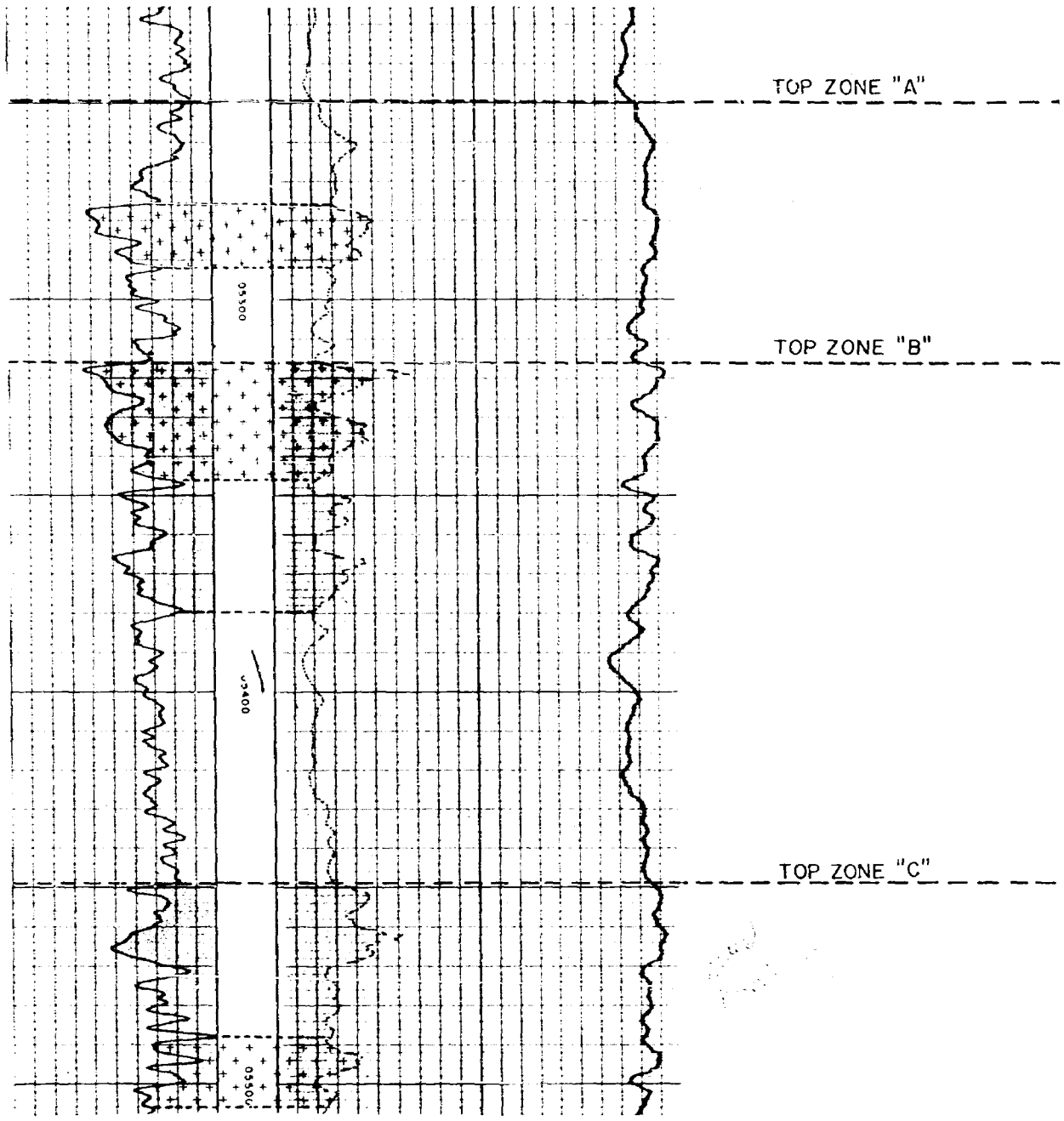


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IDENTIFICATION OF MAIN PRODUCING ZONES
NORTHEAST PUERTO CHIQUITO
AND
SOUTHWEST PUERTO CHIQUITO

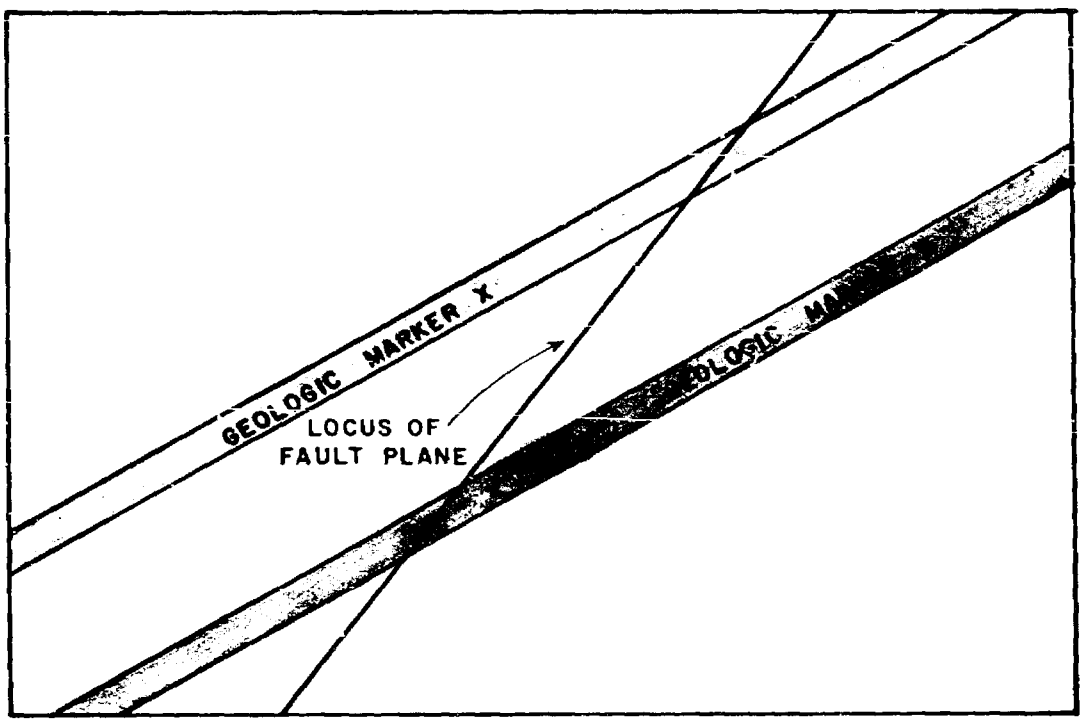
BENSON-MONTIN-GREER DRLG. CORP.

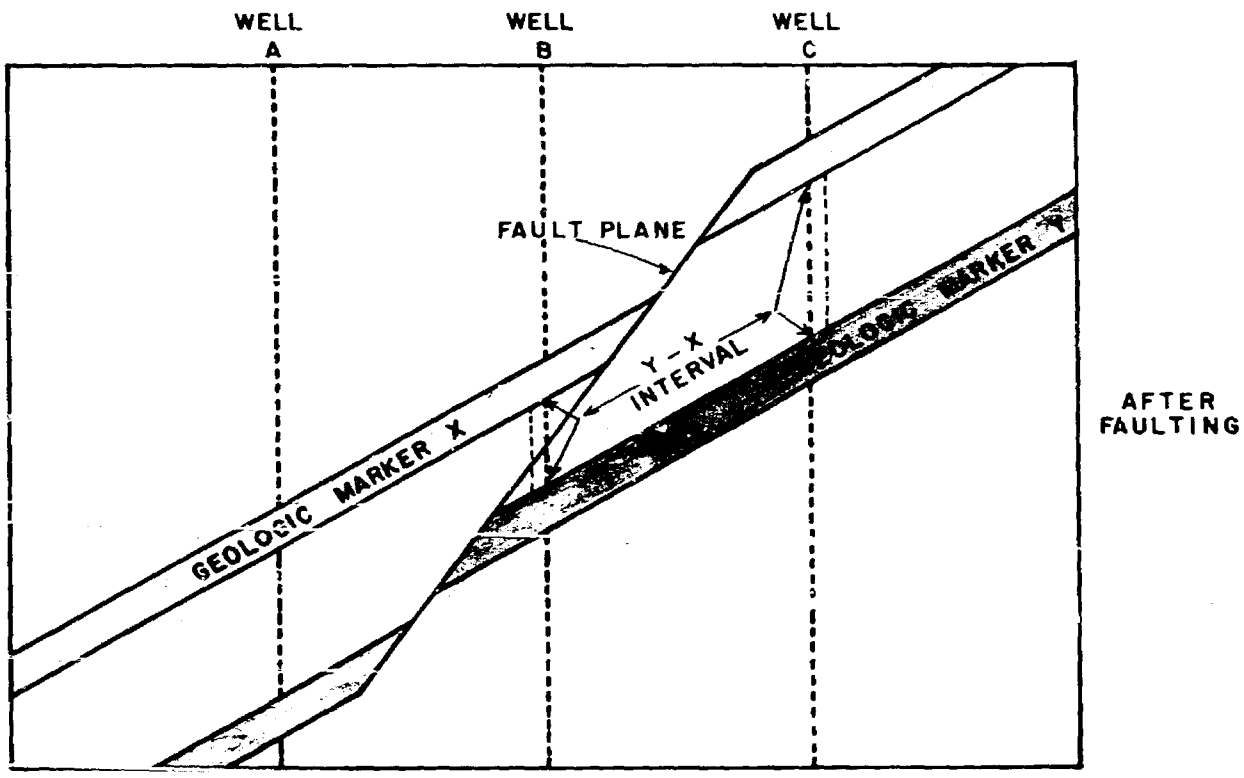
CAÑADA OJITOS UNIT NO. B-18



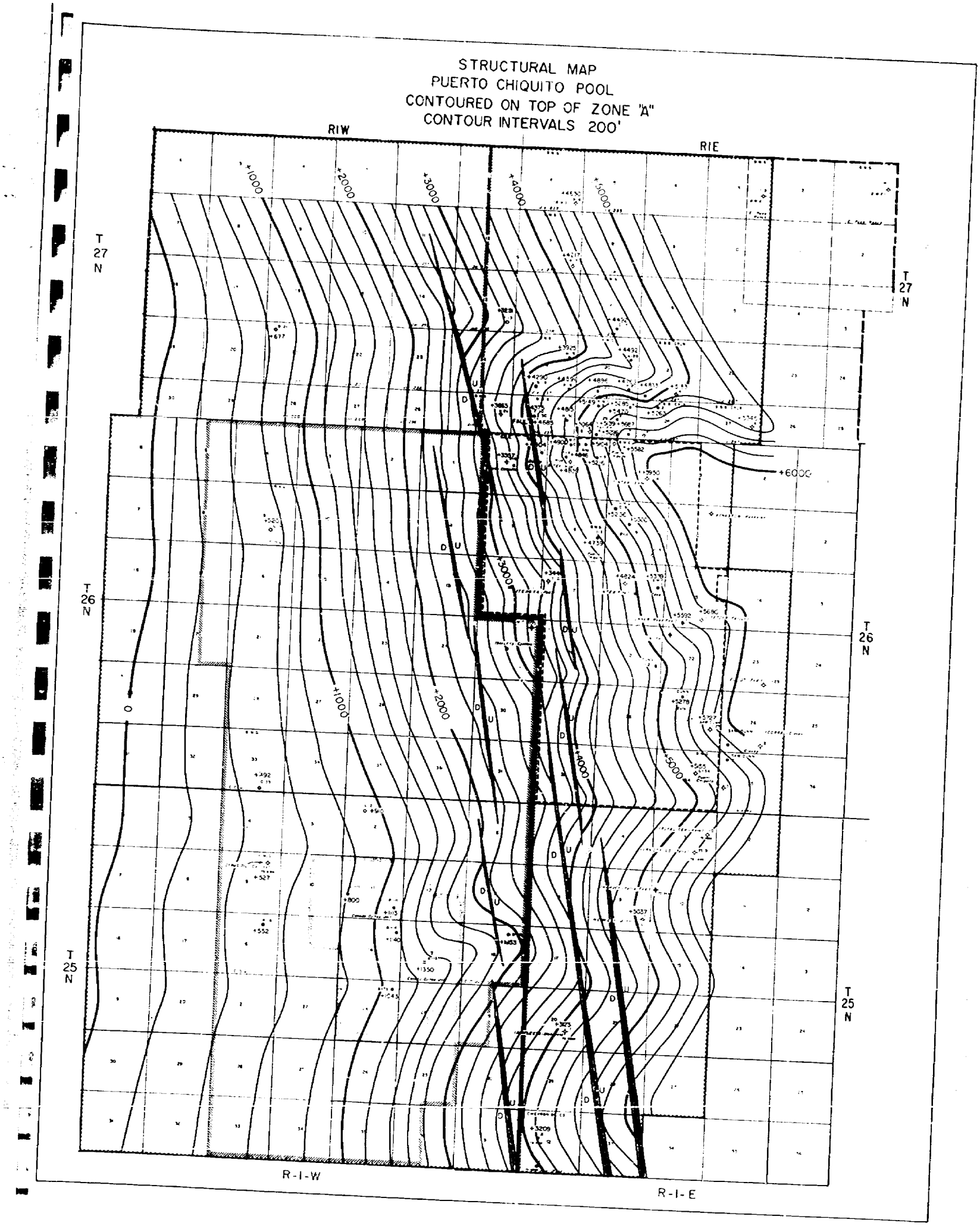
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SKETCH SHOWING
NORMAL FAULT

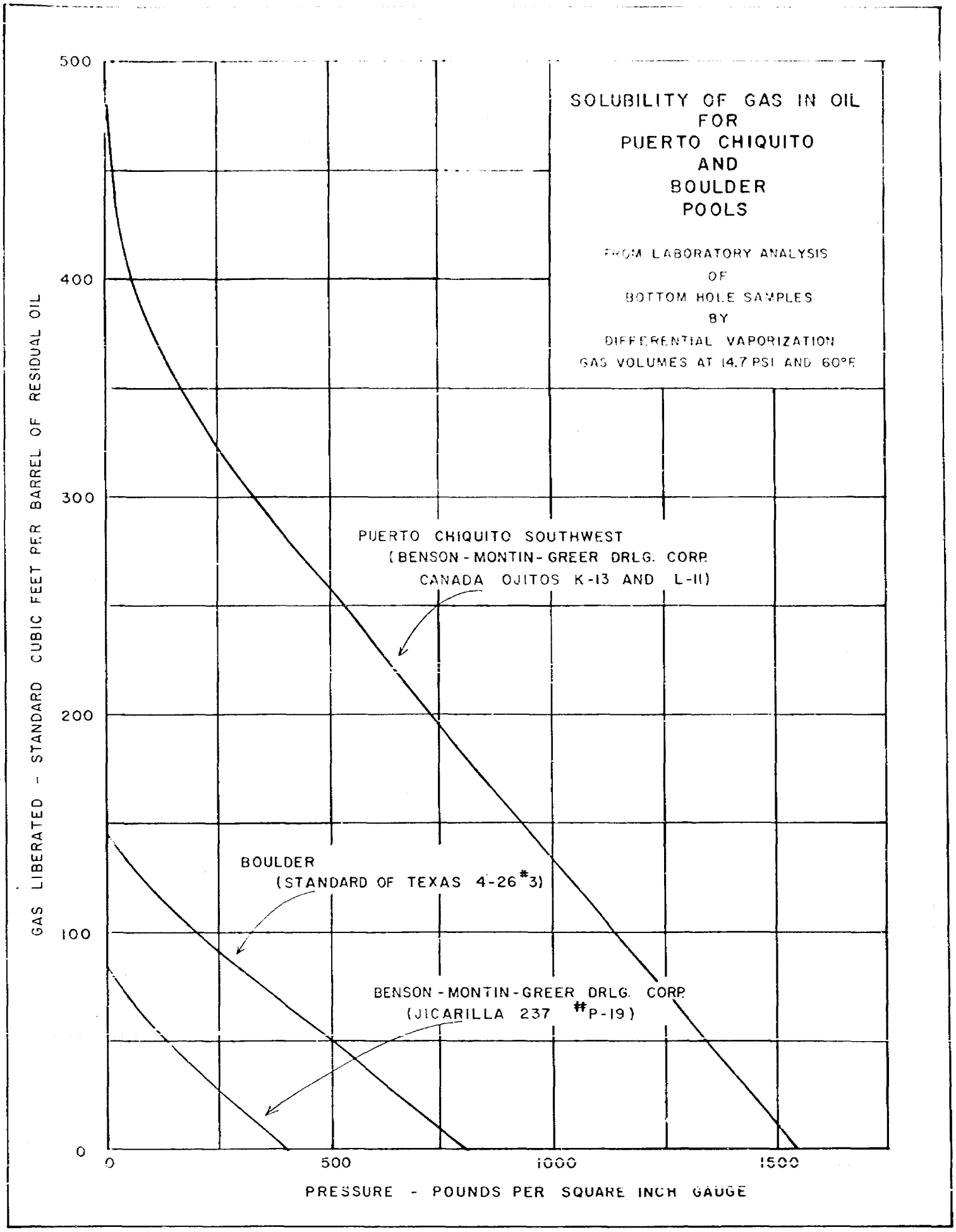


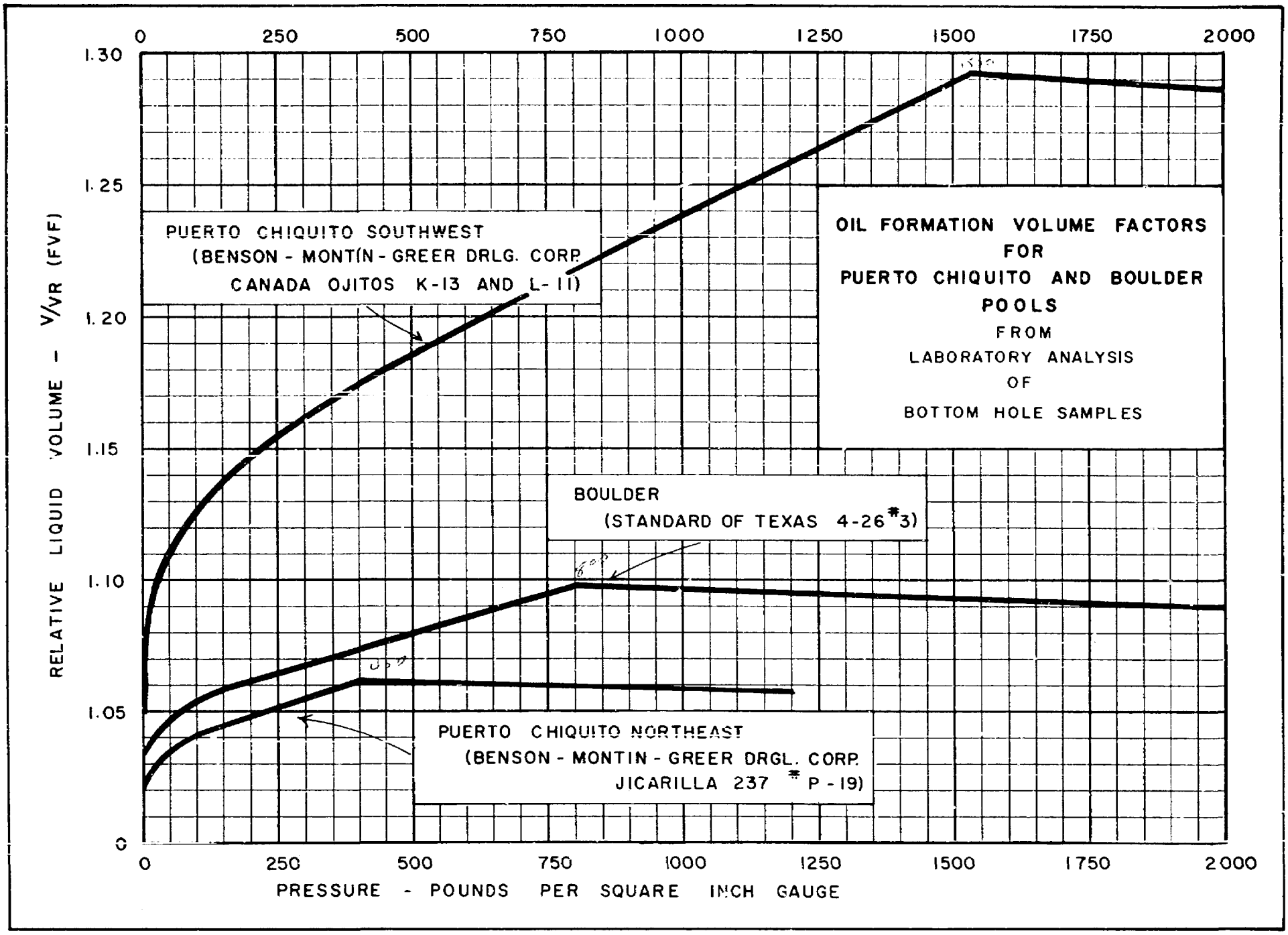


STRUCTURAL MAP
PUERTO CHIQUITO POOL
CONTOURED ON TOP OF ZONE 'A"
CONTOUR INTERVALS 200'



[redacted]


SOLUBILITY OF GAS IN OIL
FOR
PUERTO CHIQUITO
AND
BOULDER
POOLS
FROM LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
BY
DIFFERENTIAL VAPORIZATION
GAS VOLUMES AT 14.7 PSI AND 60°F
PUERTO CHIQUITO SOUTHWEST
(BENSON-MONTIN-GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
BENSON-MONTIN-GREER DRLG. CORP.
(JICARILLA 237 #P-19)
GAS LIBERATED - STANDARD CUBIC FEET PER BARREL OF RESIDUAL OIL
500
400
300
200
100
0
0
500
1000
1500
PRESSURE - POUNDS PER SQUARE INCH GAUGE


OIL FORMATION VOLUME FACTORS
FOR
PUERTO CHIQUITO AND BOULDER
POOLS
FROM
LABORATORY ANALYSIS
OF
BOTTOM HOLE SAMPLES
PUERTO CHIQUITO SOUTHWEST
(BENSON - MONTIN - GREER DRLG. CORP.
CANADA OJITOS K-13 AND L-11)
BOULDER
(STANDARD OF TEXAS 4-26 #3)
PUERTO CHIQUITO NORTHEAST
(BENSON - MONTIN - GREER DRGL. CORP.
JICARILLA 237 # P-19)
RELATIVE LIQUID VOLUME - V/VR (FVF)
PRESSURE - POUNDS PER SQUARE INCH GAUGE
0
250
500
750
1000
1250
1500
1750
2000
1.30
1.25
1.20
1.15
1.10
1.05
0

PLAT OF THE FOUR PHASES

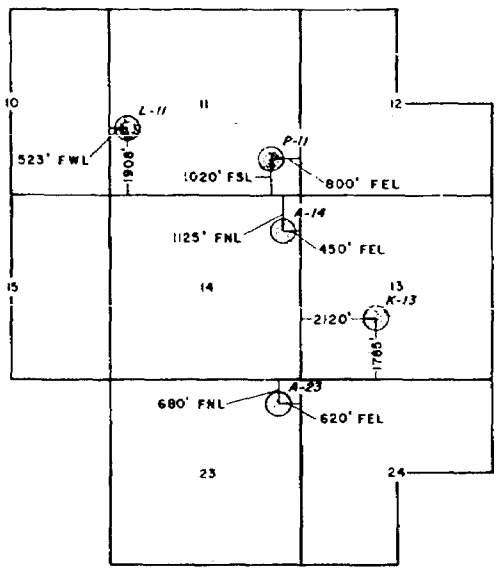
OF THE

1965 - 66 INTERFERENCE TEST

NIOBRARA - GREENHORN PARTICIPATING AREA

CANADA OJITOS UNIT

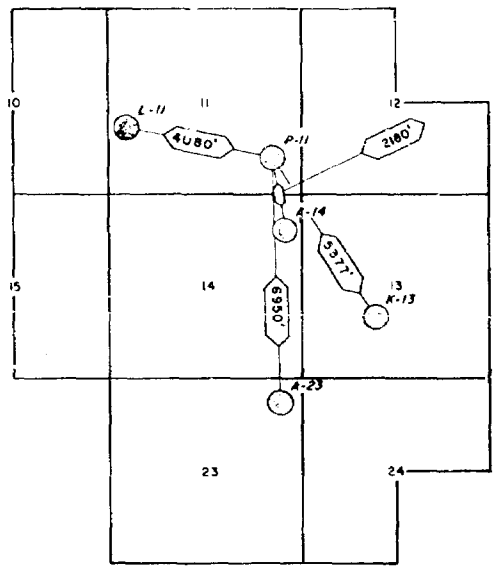
FOOTAGE LOCATIONS OF WELLS



ALL WELLS SHUT-IN

PHASE I

DISTANCES FROM P-11 TO SHUT-IN WELLS

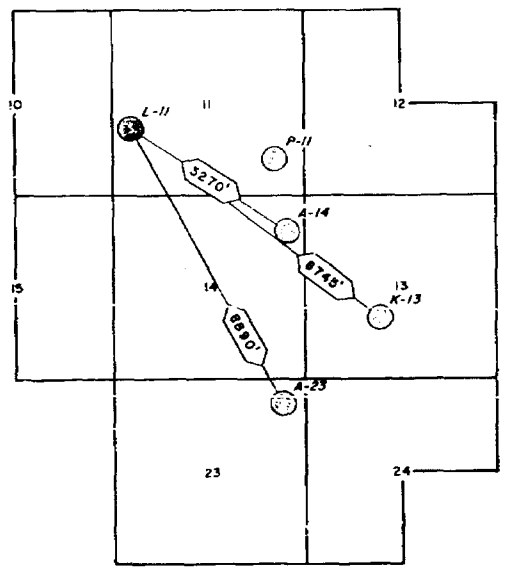


PRODUCING WELL

SHUT-IN WELL

PHASE II

DISTANCES FROM L-11 TO SHUT-IN WELLS

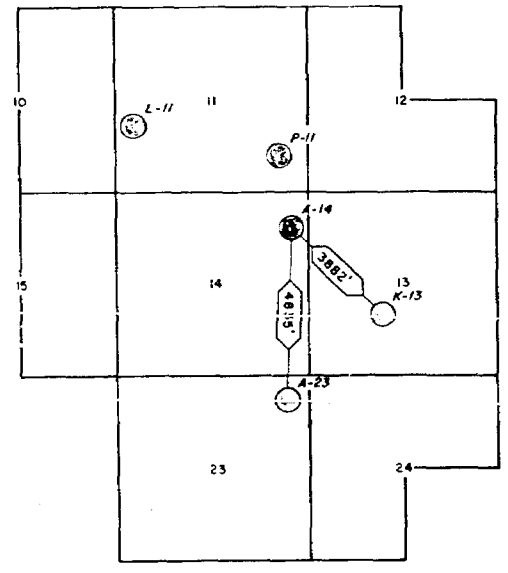


PRODUCING WELL

SHUT-IN WELL

PHASE III

DISTANCES FROM A-14 TO SHUT-IN WELLS



PRODUCING WELL

SHUT-IN WELL

PHASE IV

ADJUSTMENT OF SURVEY PRESSURES TO DATUM OF + 1195' CANADA OJITOS UNIT FOR 1965 AND 1966 SURVEYS

WELL	SURVEY DEPTH (FEET FROM RKB	ELEVATION GROUND	ELEVATION RKB	DEPTH CORRECTION FOR HOLE DEVIATION (FEET)	TRUE DEPTH OF SURVEY (FEET FROM RKB)	TRUE DATUM OF SURVEY DEPTH (FEET ABOVE SEA LEVEL)	ADJUSTMENT TO SURVEY PRESS. TO OBTAIN PRESS. AT DATUM OF + 1195' (PSIG)
K-13	5900	7088	7100	- 7	5893	+ 1207	+ 4
L-11	6600	7215	7227	- 2	6598	+ 629	- 177
A-14	6200	7125	7137	- 19	6181	+ 956	- 75
A-23	6300	7146	7158	- 4	6296	+ 862	- 104

NOTE: (1) ABOVE LISTED ELEVATIONS ARE FROM SPECIAL SURVEY OF GRADED GROUND LEVELS MADE IN JULY, 1965.

(2) RESERVOIR PRESSURE GRADIENT ASSUMED TO BE THAT OF UNDERSATURATED OIL AT PRESSURES OF 1520 TO 1800 PSIG (.312#/SQ.IN./FT).

(3) GRADIENT OF FLUID IN HOLE FROM SURVEY DEPTH TO PAY DEPTH ASSUMED TO BE .312#/SQ.IN./FT.

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT L-11
JUNE TO SEPT. 1965

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED			AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195'
	AMERADA #42	AMERADA #43	AVERAGE	
6- 7-65	1659.3		1659.3	1482.3
6- 8-65		1660.8	1660.8	1483.8
6-16-65		1670.3 *	1670.3 *	1493.3 *
6-26-65		1679.8 *	1679.8 *	1502.8 *
7- 5-65	1682.0 *		1682.0 *	1505.0 *
7- 8-65		1683.3 *	1683.3 *	1506.3 *
7-14-65	1686.8	1686.9	1686.8	1509.8
7-20-65	1685.6	1688.3	1686.5	1509.5
8-10-65	1685.8	1685.4	1685.6	1508.6
8-25-65	1677.7	1679.1	1678.1	1501.1
9- 2-65	1676.5	1675.5	1676.0	1499.0

* PRESSURES ESTIMATED FROM PRESSURE INCREASES OVER 6-8-65 PRESSURE BY COMPARISON OF PRESSURES ABOVE LINER. (PRESSURES FOR DEPTHS BELOW LINER TOP ON THESE DATES UNRELIABLE BECAUSE OF PRESSURE GAUGE STRIKING LINER TOP)

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT K-13
FEBRUARY, 1965 TO AUGUST, 1966

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED			AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195' (+ 4#)
	AMERADA #42	AMERADA #43	AVERAGE	
2-26-65	1474.0		1474.0	1478.0
3- 3-65	1479.4	1474.3	1476.9	1480.9
3- 8-65	1481.0	1477.6	1479.3	1483.3
3-11-65	1488.7 (Run 1) 1489.8 (Run 2)		1489.3	1493.3
3-18-65	1482.6 (Run 1) 1482.0 (Run 2)	1476.3 (Run 1) 1479.7 (Run 2)	1480.2	1484.2
3-23-65	1476.0	1469.1 (Run 1) 1471.4 (Run 2)	1472.6	1476.6
3-31-65	1467.9 (Run 1) 1467.9 (Run 2)	1461.3 (Run 1) 1460.4 (Run 2)	1464.4	1468.4
4- 9-65	1470.4 (Run 1) 1469.0 (Run 2)	1460.0 (Run 1) 1459.0 (Run 2)	1464.6	1468.6
4-16-65	1458.8 (Run 1) 1459.2 (Run 2)	1459.1 (Run 1) 1459.1 (Run 2)	1459.1	1463.1
4-19-65	1459.0		1459.0	1463.0
4-26-65	1460.4		1460.4	1464.4
5- 4-65	1468.5	1464.2	1466.4	1470.4
5-10-65		1470.2	1470.2	1474.2
5-21-65		1472.0	1472.0	1476.0
6- 7-65	1469.4	1474.1	1471.8	1475.8
6-17-65	1470.5	1475.0	1472.8	1476.8
6-25-65	1481.5	1482.7	1482.1	1486.1
7- 2-65	1487.2	1483.1	1485.1	1489.1
7- 5-65	1489.3	1486.7	1488.0	1492.0
7- 9-65	1490.3	1489.2	1489.7	1493.7

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED AMERADA #42	AMERADA #43	AVERAGE	AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195' (+ 4#)
7-14-65	1493.7	1491.1	1492.4	1496.4
7-20-65	1493.5	1493.0	1493.3	1497.3
8- 5-65	1499.5	1496.8	1498.2	1502.2
8-11-65	1494.7	1496.7	1495.7	1499.7
8-16-65	1492.1	1495.4	1493.8	1497.8
8-25-65	1490.2	1490.0	1490.1	1494.1
8-30-65		1487.1		
8-31-65	1490.4	1488.6	1488.7	1492.7
9-13-65	1483.5	1481.8	1482.7	1486.7
10- 1-65	1476.7	1474.5	1475.6	1479.6
10-15-65	1469.2	1471.6	1470.4	1474.4
10-26-65	1459.1	1460.6	1459.9	1463.9
11- 9-65	1462.7	1460.5	1461.6	1465.6
12- 5-65	1448.7	1447.4	1448.1	1452.1
12-21-65	1440.3	1435.9	1438.1	1442.1
2-14-66	1422.1	1420.6	1421.4	1425.4
3- 7-66	1417.3	1417.4	1417.4	1421.4
5-12-66	1403.6	1404.9	1404.2	1408.2
8-30-66	1389.6	1388.6	1389.1	1393.1

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED AMERADA #42	AMERADA #43	AVERAGE	AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195' (+ 4#)
7-14-65	1493.7	1491.1	1492.4	1496.4
7-20-65	1493.5	1493.0	1493.3	1497.3
8- 5-65	1499.5	1496.8	1498.2	1502.2
8-11-65	1494.7	1496.7	1495.7	1499.7
8-16-65	1492.1	1495.4	1493.8	1497.8
8-25-65	1490.2	1490.0	1490.1	1494.1
8-30-65				
8-31-65	1490.4	1487.1 1488.6	1488.7	1492.7
9-13-65	1483.5	1481.8	1482.7	1486.7
10- 1-65	1476.7	1474.5	1475.6	1479.6
10-15-65	1469.2	1471.6	1470.4	1474.4
10-26-65	1459.1	1460.6	1459.9	1463.9
11- 9-65	1462.7	1460.5	1461.6	1465.6
12- 5-65	1448.7	1447.4	1448.1	1452.1
12-21-65	1440.3	1435.9	1438.1	1442.1
2-14-66	1422.1	1420.6	1421.4	1425.4
3- 7-66	1417.3	1417.4	1417.4	1421.4
5-12-66	1403.6	1404.9	1404.2	1408.2
8-30-66	1389.6	1388.6	1389.1	1393.1

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT A-14
APRIL TO NOVEMBER, 1965

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED			AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195'
	AMERADA #42	AMERADA #43	AVERAGE	
4-16-65	1541.4		1541.4	1466.4
4-19-65	1540.9		1540.9	1465.9
4-26-65	1545.1		1545.1	1470.1
5- 4-65	1559.2	1557.5	1558.9	1483.9
5-10-65		1557.5	1557.5	1482.5
5-21-65		1558.2	1558.2	1483.2
6- 8-65		1556.3	1556.3	1481.3
6-16-65	1562.0		1562.0	1487.0
6-25-65	1574.9	1575.9	1575.4	1500.4
7- 8-65	1582.1		1582.1	1507.1
7-19-65	1585.4	1584.2	1584.8	1509.8
8-10-65	1578.3	1578.5	1578.4	1503.4
8-25-65	1569.9	1571.2	1570.6	1495.6
9-13-65	1566.4	1564.9	1565.7	1490.7
9-30-65	1555.3	1557.9	1556.6	1481.6
10-14-65	1547.6	1545.7	1546.7	1471.7
10-27-65	1539.0	1539.0	1539.0	1464.0
11- 8-65	1537.2	1536.9	1537.1	1462.1

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT A-23
JUNE, 1965 TO AUGUST, 1966

SURVEY DATE	PRESSURE (PSIG) AT 6300' (RKB) FOR PRESSURE GAUGE INDICATED			AVERAGE PRESSURE ADJUSTED TO DATUM OF + 1195'
	AMERADA #42	AMERADA #43	AVERAGE	
6-17-65		1585.8 (Run 1) 1587.5 (Run 2)	1596.7	1482.7
6-25-65		1598.7	1598.7	1494.7
7- 2-65	1600.4		1600.4	1496.4
7- 8-65		1606.0	1606.0	1502.0
7-19-65	1608.3	1607.3	1607.8	1503.8
8-11-65	1611.2	1609.4	1610.3	1506.3
8-27-65	1606.3	1604.9	1605.6	1501.6
9-13-65	1601.5	1600.2	1600.9	1496.9
9-29-65	1598.1	1597.4	1597.8	1493.8
10-14-65	1588.3	1585.9	1587.1	1483.1
10-26-65	1585.5	1583.9	1584.7	1480.7
11- 8-65	1580.8	1577.6	1579.2	1475.2
12- 5-65	1566.0	1569.9	1567.9	1463.9
12-21-65	1559.6	1559.0	1559.3	1455.3
2-15-66	1541.0	1542.6	1541.8	1437.8
5-13-66	1522.8	1524.1	1523.5	1419.5
8-30-66	1509.9	1510.2	1510.0	1406.0

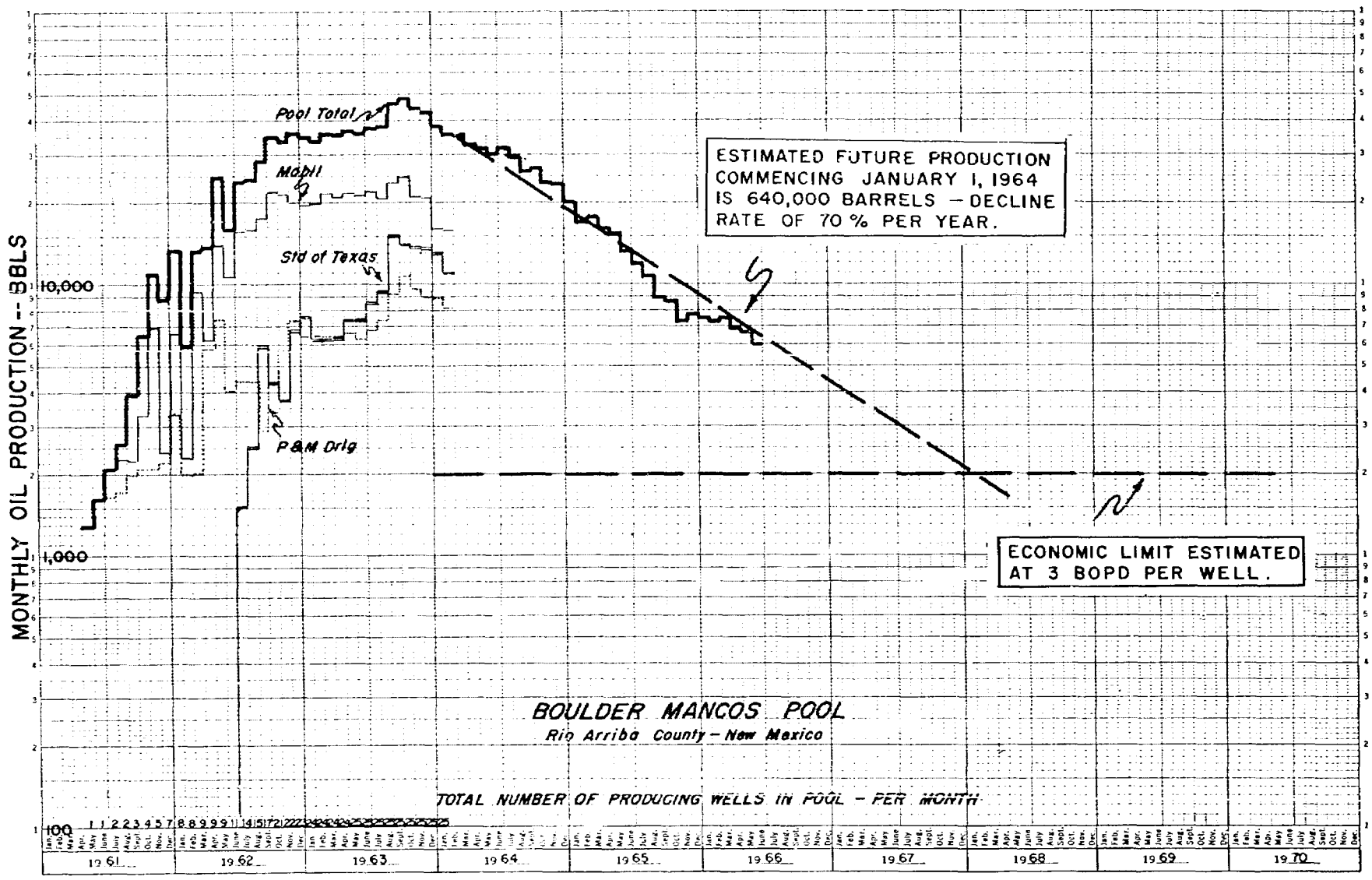
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5.6.9

BOTTOM HOLE PRESSURE SUMMARY
NORTHEAST PUERTO CHIQUITO RESERVOIR
JUNE, 1965 TO AUGUST, 1966

SURVEY DATE	PRESSURE (PSIG) PRESSURE GAUGE INDICATED AMERADA #42	AMERADA #43	AVERAGE
	JICARILLA 237 NO. P-20 AT 2300' (RKB)		
6-21-65		391.4	391.4
7-19-65		390.4	390.4
8- 5-65	379.4	381.0	380.2
8-11-65	377.7	380.1	378.9
10-27-65	362.8	364.0	363.4
2-15-66	359.5	360.8	360.2
5-13-66	352.0	352.7	352.4
8-31-66	335.9	340.2	338.1
	JICARILLA 237 NO. P-19 AT 2500' (RKB)		
3- 7-66	387.1	391.7	389.4
6- 1-66	376.7	381.0	378.9
6-25-66	384.7	391.1	388.9
8-31-66	362.3	367.9	365.1
	PUERTO CHIQUITO UNIT NO. F-6 AT 3800' (RKB)		
6-21-65	902.2		902.2
8-11-65	902.1	899.4	900.8
2-15-66	893.2	896.0	894.6
5-12-66	879.9	882.8	881.4
8-31-66	870.3	872.2	871.3

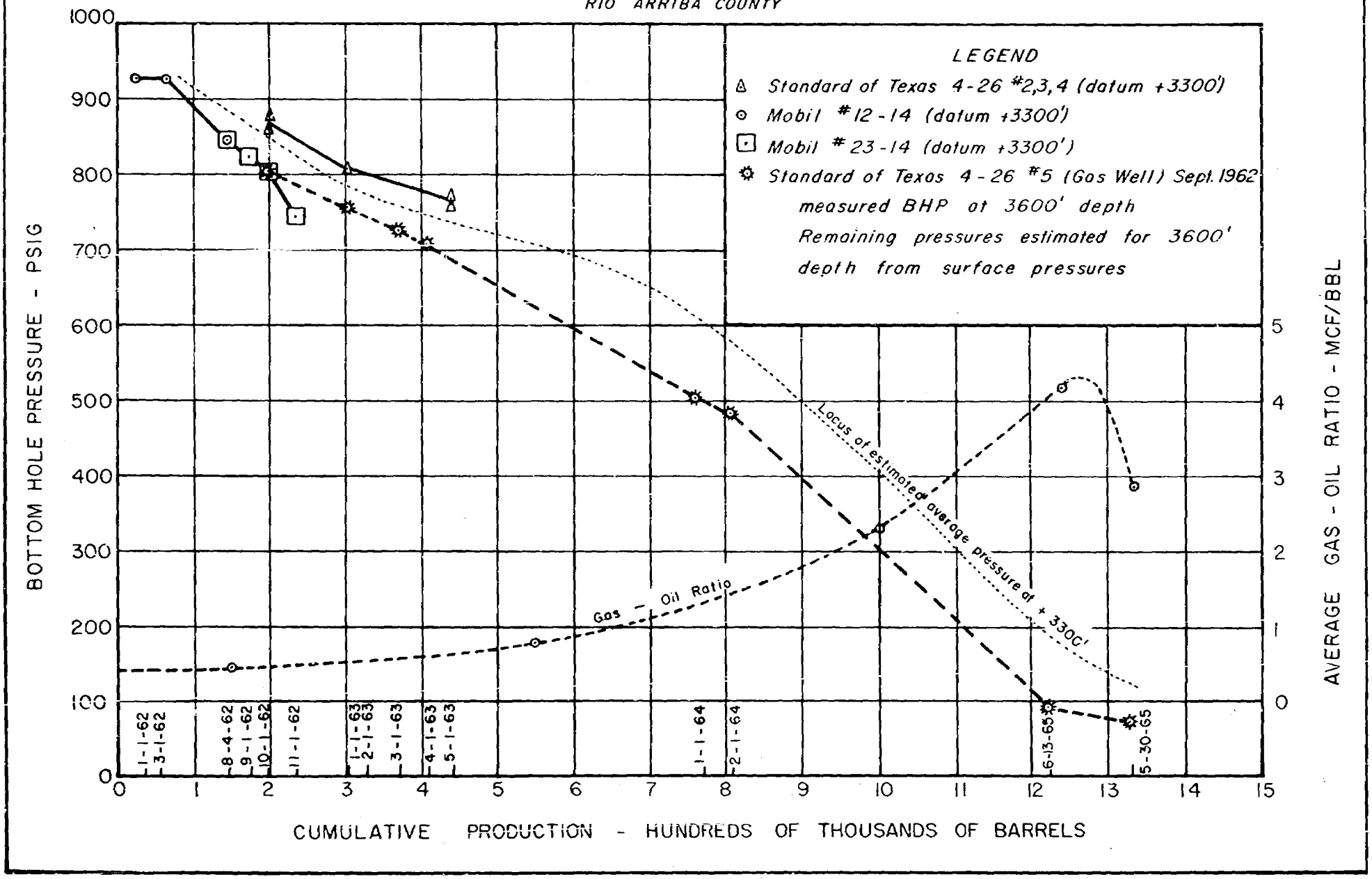
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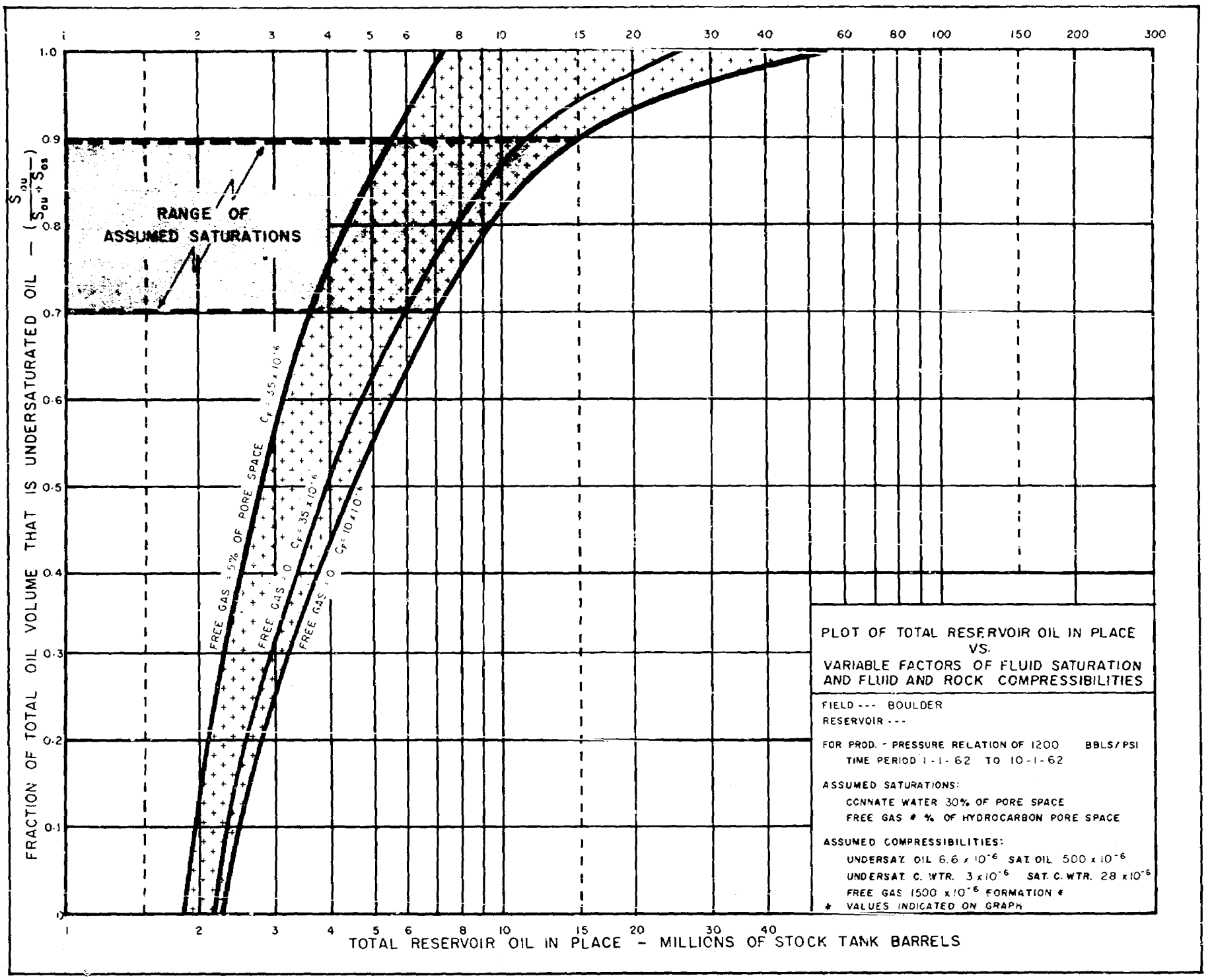

Pool Total
Mapl
Std of Texas
P&M Drlg
ESTIMATED FUTURE PRODUCTION COMMENCING JANUARY 1, 1964 IS 640,000 BARRELS – DECLINE RATE OF 70 % PER YEAR.
ECONOMIC LIMIT ESTIMATED AT 3 BOPD PER WELL.
MONTHLY OIL PRODUCTION -- BBLS
10,000
1,000
100
BOULDER MANCOS POOL
Rio Arriba County – New Mexico
TOTAL NUMBER OF PRODUCING WELLS IN POOL – PER MONTH
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970

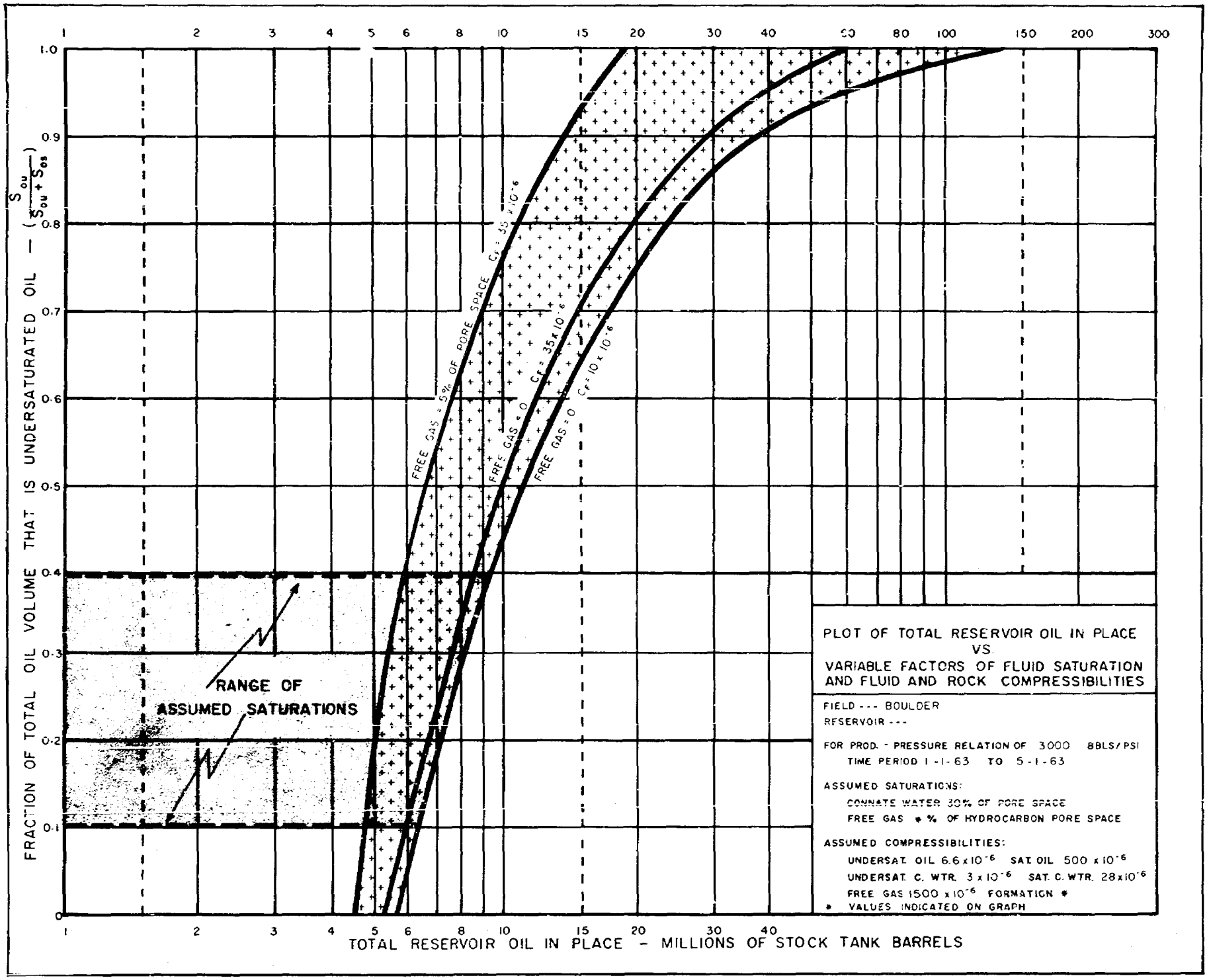
PRESSURE PRODUCTION HISTORY

BOULDER MANCOS POOL

RIO ARRIBA COUNTY




1
2
3
4
5
6
8
10
15
20
30
40
60
80
100
150
200
300
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$S_{ou}/(S_{ou}+S_{os})$
FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL —
RANGE OF ASSUMED SATURATIONS
FREE GAS = 5% OF PORE SPACE $C_F = 35 \times 10^{-6}$
FREE GAS = 0 $C_F = 35 \times 10^{-6}$
FREE GAS = 0 $C_F = 10 \times 10^{-6}$
TOTAL RESERVOIR OIL IN PLACE - MILLIONS OF STOCK TANK BARRELS
PLOT OF TOTAL RESERVOIR OIL IN PLACE
VS.
VARIABLE FACTORS OF FLUID SATURATION
AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- BOULDER
RESERVOIR ---
FOR PROD. - PRESSURE RELATION OF 1200 BBLS/PSI
TIME PERIOD 1-1-62 TO 10-1-62
ASSUMED SATURATIONS:
CONNATE WATER 30% OF PORE SPACE
FREE GAS # % OF HYDROCARBON PORE SPACE
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 6.6×10^{-6} SAT. OIL 500×10^{-6}
UNDERSAT. C. WTR. 3×10^{-6} SAT. C. WTR. 28×10^{-6}
FREE GAS 1500×10^{-6} FORMATION #
* VALUES INDICATED ON GRAPH


FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL — $(\frac{S_{ou}}{S_{ou}+S_{os}})$
TOTAL RESERVOIR OIL IN PLACE - MILLIONS OF STOCK TANK BARRELS
1
2
3
4
5
6
8
10
15
20
30
40
50
80
100
150
200
300
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FREE GAS = 5% OF PORE SPACE Cf = 35 x 10⁻⁶
FREE GAS = 0 Cf = 35 x 10⁻⁶
FREE GAS = 0 Cf = 10 x 10⁻⁶
RANGE OF ASSUMED SATURATIONS
PLOT OF TOTAL RESERVOIR OIL IN PLACE VS. VARIABLE FACTORS OF FLUID SATURATION AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- BOULDER
RESERVOIR ---
FOR PROD. - PRESSURE RELATION OF 3000 BBLS/PSI
TIME PERIOD 1-1-63 TO 5-1-63
ASSUMED SATURATIONS:
CONNATE WATER 30% OF PORE SPACE
FREE GAS * % OF HYDROCARBON PORE SPACE
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 6.6 x 10⁻⁶ SAT. OIL 500 x 10⁻⁶
UNDERSAT. C. WTR. 3 x 10⁻⁶ SAT. C. WTR. 28 x 10⁻⁶
FREE GAS 1500 x 10⁻⁶ FORMATION *
* VALUES INDICATED ON GRAPH

[redacted]

PER-ACRE OIL IN PLACE
CAÑADA OJITOS UNIT NIOBRARA PARTICIPATING AREA
DETERMINED FROM INTERFERENCE TEST
SEPTEMBER-OCTOBER, 1965
L-11 PRODUCING, A-14 OBSERVATION WELL

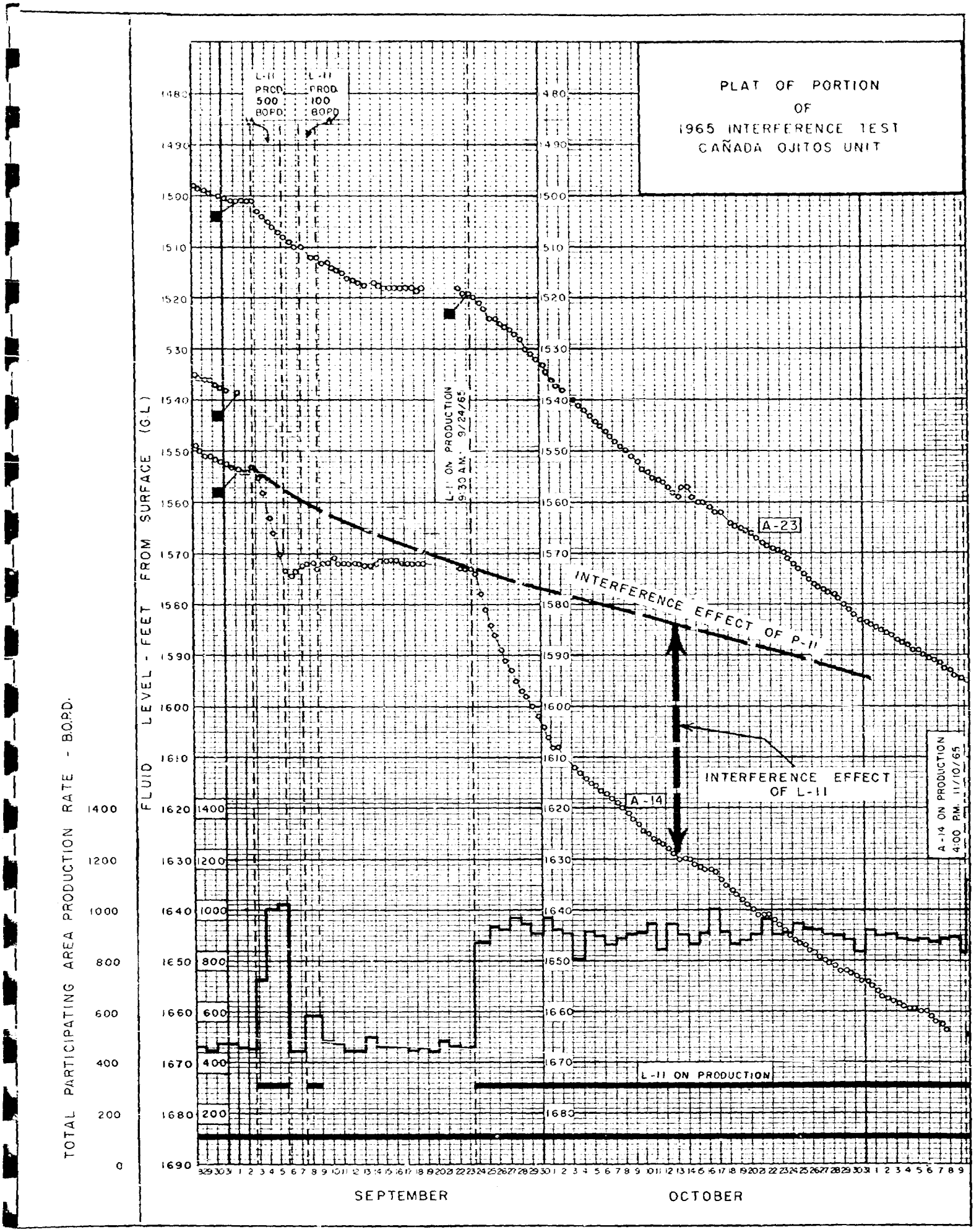
TIME AFTER START OF TEST AT WHICH INTERFERENCE PRESSURE DROP MEASURED	OIL IN PLACE (STOCK TANK BARRELS/ACRE FOR ASSUMED EFFECTIVE COMPRESSIBILITY INDICATED) For $C_e = 20 \times 10^{-6}$	For $C_e = 50 \times 10^{-6}$
1 day	2250	890
2 days	2520	1010
3 days	2670	1070
4 days	2740	1090
5 days	2660	1050
6 days	2600	1030
8 days	2520	1010
10 days	2460	980
12 days	2420	960
14 days	2440	970

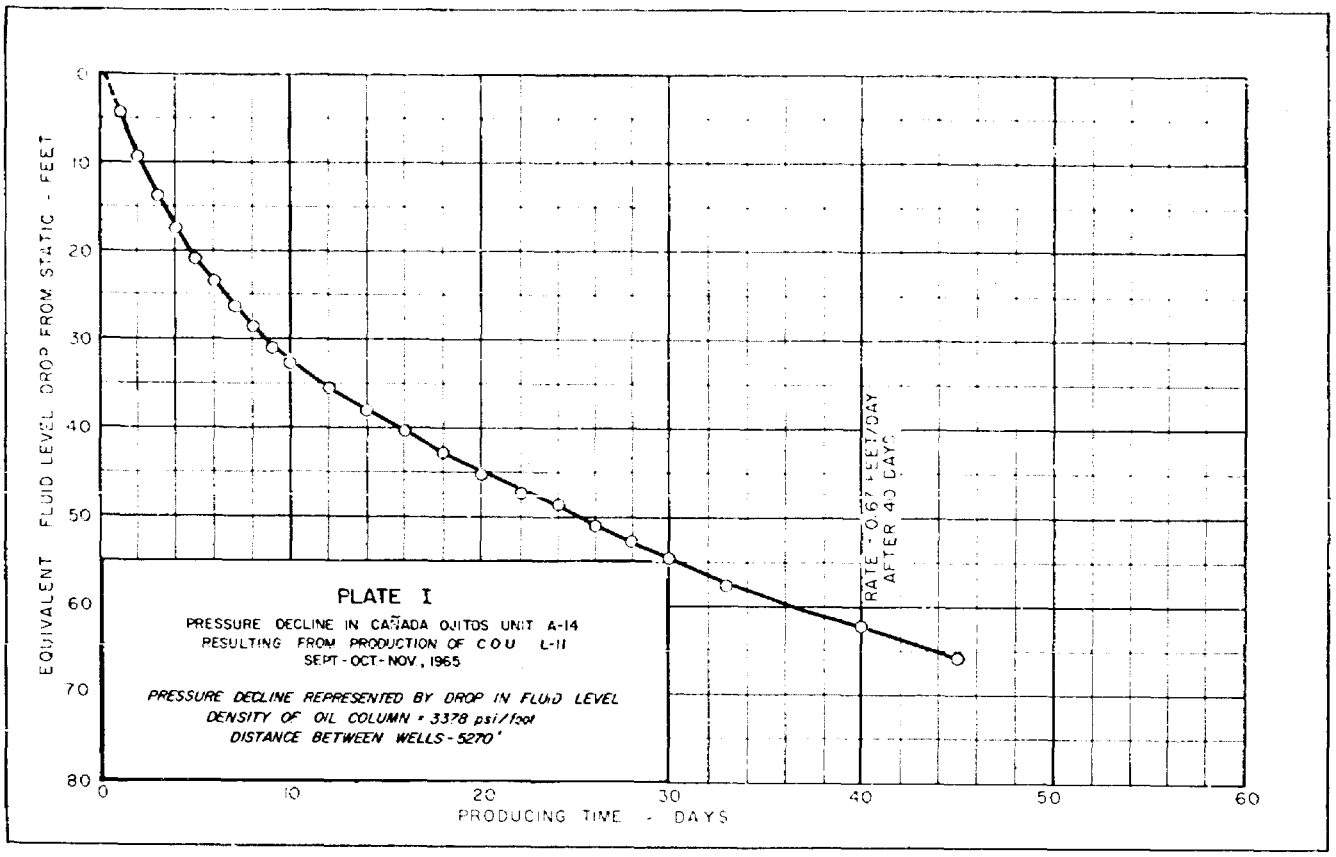
NOTE: (1) $C_e = 20 \times 10^{-6}$ results from assumed undersaturated compressibility of 10.5×10^{-6}, connate water 3.3×10^{-6}, formation compressibility of 6.7×10^{-6} and saturation as follows:

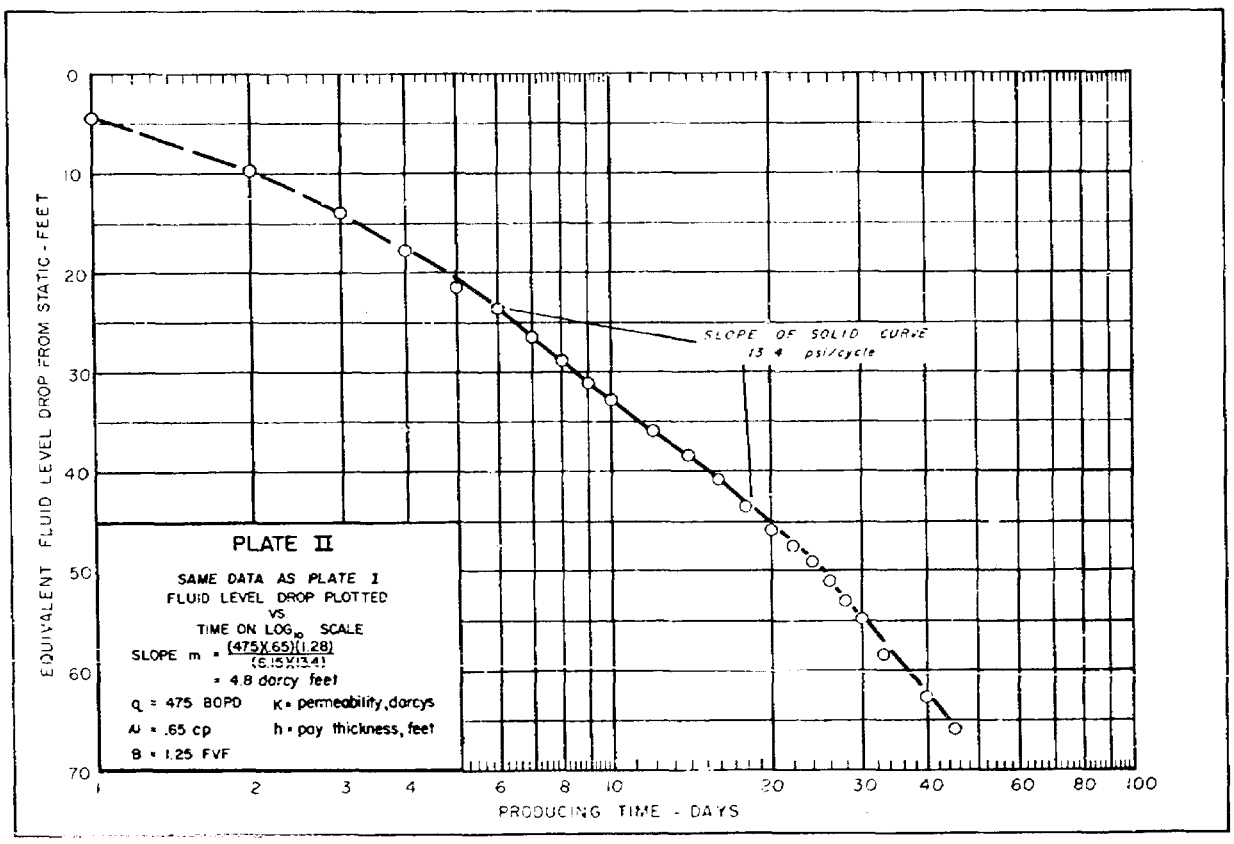
Undersaturated oil 75% of pore space
Saturated oil - 0
Connate water 25% of pore space

(2) $C_e = 50 \times 10^{-6}$ results from same values of fluid compressibilities but with formation compressibility of 23×10^{-6} and connate water saturation of 40% (assumed also no saturated oil in reservoir)

PLAT OF PORTION OF 1965 INTERFERENCE TEST CAÑADA OJITOS UNIT




EQUIVALENT FLUID LEVEL DROP FROM STATIC - FEET
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60
PRODUCING TIME - DAYS
RATE - 0.67 FEET/DAY
AFTER 40 DAYS
PLATE I
PRESSURE DECLINE IN CAÑADA OJITOS UNIT A-14
RESULTING FROM PRODUCTION OF C O U L-11
SEPT - OCT - NOV, 1965
PRESSURE DECLINE REPRESENTED BY DROP IN FLUID LEVEL
DENSITY OF OIL COLUMN = 3378 psi/1ooI
DISTANCE BETWEEN WELLS - 5270'


EQUIVALENT FLUID LEVEL DROP FROM STATIC - FEET
0
10
20
30
40
50
60
70
2
3
4
6
8
10
20
30
40
60
80
100
PRODUCING TIME - DAYS
SLOPE OF SOLID CURVE
13.4 psi/cycle
PLATE II
SAME DATA AS PLATE I
FLUID LEVEL DROP PLOTTED
VS.
TIME ON LOG$_{10}$ SCALE
SLOPE m = $\frac{(475)(.65)(1.28)}{(6.15)(13.4)}$
= 4.8 darcy feet
q = 475 BOPD
K = permeability, darcys
μ = .65 cp
h = pay thickness, feet
B = 1.25 FVF

INTERFERENCE EFFECT ON CAÑADA OJITOS UNIT NO. A-14
OF PRODUCING CANADA OJITOS UNIT NO. L-11
SEPTEMBER 25 TO NOVEMBER 8, 1965

DATE	TIME	DAYS L-11 PRODUCING	FLUID LEVEL IN A-14	PRESSURE DROP IN A-14			
				TOTAL EFFECT OF P-11 AND L-11 (FEET OF OIL COLUMN)	EFFECT OF P-11 ONLY (FEET OF OIL COLUMN)	EFFECT OF L-11 ONLY (FEET OF OIL COLUMN)	PSI
9-24-65	9:30 AM	0	1573				
9-25-65	"	1	1578.5	5.5	66	4.8	1.62
9-26-65	"	2	1584.2	11.2	1.31	9.9	3.35
9-27-65	"	3	1589.0	16.0	1.95	14.0	4.72
9-28-65	"	4	1593.1	20.1	2.58	17.5	5.81
9-29-65	"	5	1597.1	24.1	3.20	20.9	7.05
9-30-65	"	6	1600.5	27.5	3.81	23.7	8.00
10- 1-65	"	7	1603.8	30.8	4.41	26.4	8.81
10- 2-65	"	8	1606.8	33.8	5.00	28.8	9.72
10- 3-65	"	9	1609.5	36.5	5.58	30.9	10.45
10- 4-65	"	10	1611.9	38.9	6.15	32.8	11.0
10- 6-65	"	12	1616.0	43.0	7.26	35.7	12.1
10- 8-65	"	14	1619.5	46.5	8.33	38.2	12.9
10-10-65	"	16	1623.0	50.0	9.36	40.6	13.7
10-12-65	"	18	1626.5	53.5	10.42	43.2	14.6
10-14-65	"	20	1630.0	57.0	11.48	45.5	15.4

DATE	TIME	DAYS L-11 PRODUCING	FLUID LEVEL IN A-14	PRESSURE DROP IN A-14			
				TOTAL EFFECT OF P-11 AND L-11 (FEET OF OIL COLUMN)	EFFECT OF P-11 ONLY (FEET OF OIL COLUMN)	EFFECT OF L-11 ONLY (FEET OF OIL COLUMN)	PSI
10-16-65	9:30 AM	22	1632.7	59.7	12.54	47.2	15.9
10-18-65	"	24	1635.7	62.7	13.60	49.1	16.6
10-20-65	"	26	1638.6	65.6	14.66	50.9	17.2
10-22-65	"	28	1641.6	68.6	15.72	52.9	17.9
10-24-65	"	30	1644.6	71.6	16.78	54.8	18.5
10-27-65	"	33	1649.0	76.0	17.84	58.2	19.7
11- 3-65	"	40	1657.0	84.0	21.55	62.4	21.1
11- 8-65	"	45	1663.0	90.0	24.20	65.8	22.2

NOTE: (1) Assume effect of P-11 on A-14 to be 0.9 ft/day on September 1 and decreasing uniformly to .53 ft/day on October 10. (Steady state decline of 2,650 bbl/# = 900 bbl/ft. and 475/900 = .53 ft/day). Hence, effect on September 25 = .66 ft/day and on October 10 = .53 ft/day.

(2) Average pressure gradient of oil column in A-14 for this period is .3378#/sq.in/ft.

INTERFERENCE EFFECT ON CANADA OJITOS UNIT NO. A-14
OF PRODUCING CANADA OJITOS UNIT NO. L-11

$$\mu = .65 \text{ cp}$$

$$= (.485 \times 10^{-4})\left(\frac{K}{\phi_{mc}}\right)$$

for $c_t = 20 \times 10^{-6}$

$$= (.194 \times 10^{-4})\left(\frac{K}{\phi_{mc}}\right)$$

for $c_t = 50 \times 10^{-6}$

$$= \frac{-.113}{\left(\frac{K}{\phi_{mc}}\right)\Delta t}$$

for $c_t = 20 \times 10^{-6}$

$$= \frac{-.355}{\left(\frac{K}{\phi_{mc}}\right)\Delta t}$$

for $c_t = 50 \times 10^{-6}$

$$\Delta P = \frac{\Delta P}{5.83} \left[\frac{-n^2}{4\pi t} \right]$$

$$= \frac{\Delta P}{5.83} \left[\quad \right] \qquad \begin{aligned} \mu &= .975 \text{ centipoise} \\ c_t &= 1.45 \text{ cp} \\ B &= 1.28 \text{ RVF} \end{aligned}$$

$$m = 39.5 \times \mu \times c_t \times B = (39.5)(.338)\,\text{°F/cycle} = 13.7 \text{ °F/cycle}$$

$$\Delta P = \frac{13.7}{5.83} \Sigma \left[\quad \right]$$

$$\frac{\Delta P}{5.83} = \Sigma \left[\frac{-L^2}{4\pi t} \right]$$

Time (hrs)	ΔP (psi)	$\frac{\Delta P}{5.83}$	for $c_t = 20 \times 10^{-6}$ $\frac{-n^2}{4\pi t}$	[ ]	°F/psi	for $c_t = 50 \times 10^{-6}$ $\frac{-n^2}{4\pi t}$	[ ]	°F/psi
1	1.62	.28	-1.45 °F/psi	.85	16.5	-35.8 °F/psi	.85	42.1
2	3.35	.58	-7.15 °F/psi	.48	14.9	-17.9 °F/psi	.48	37.3
3	4.72	.81	-11.39 °F/psi	.34	14.0	-11.9 °F/psi	.34	35.0
4	5.51	1.00	-13.5 °F/psi	.26	13.8	-9.0 °F/psi	.26	34.5
5	7.1	1.22	-16.8 °F/psi	.20	14.3	-7.15 °F/psi	.20	35.8
6	8	1.37	-19.35 °F/psi	.165	14.4	-6.0 °F/psi	.165	36.4
8	9.7	1.66	-24.1 °F/psi	.12	14.4	-4.75 °F/psi	.12	37.4
10	11.0	1.89	-28.0 °F/psi	.093	15.3	-3.53 °F/psi	.093	38.5
12	12.1	2.08	-31.4 °F/psi	.076	15.6	-2.93 °F/psi	.076	39.2
14	12.1	2.22	-33.7 °F/psi	.066	15.4	-2.57 °F/psi	.066	38.8

(3) "Apparent" K_h = $\frac{\text{Total}}{\text{1.25 rule}}$

= $\frac{(4.25)(4.5)(1.25)}{(0.75)(3.5)}$

= 4.8 days/foot

(4) Design Term K_h = 1.3 × "Apparent" K_h

= (1.3)(4.8) = 6.2 days/foot

Because of possible boundary effects, since value from (3) is of lower [illegible] = (Maximum slope for beaching without for impermeable boundary would be 2:1)

(5) Stock Take on Beach = $\frac{\text{Vol}}{\text{Time}}$ × $\frac{1}{1.28}$ × 7758

For Given Interval Days	For $C_0 = 2 \times 10^{-4}$ $(\phi_{mc})(h)$	Maximum Diffusion	S.T.D. Diffusion	For $C_0 = 5 \times 10^{-4}$ $(\phi_{mc})(h)$	Maximum Diffusion	S.T.D. Diffusion
1 day	.37	2850	2350	.147	1140	590
2 "	.415	3220	2520	.166	1300	1010
3	.44	3420	2670	.177	1370	1070
4	.45	3500	2740	.180	1400	1090
5	.465	3600	2820	.193	1490	1150
6	.470	3650	2860	.190	1470	1140
8	.485	3760	2940	.194	1510	1170
10	.490	3800	2970	.196	1520	1180
12	.495	3840	3000	.198	1540	1190
14	.498	3870	3020	.199	1550	1200

DAILY PRODUCTION RATES
FOR
CANADA OJITOS UNIT #P-11 AND #L-11
DURING PART OF INTERFERENCE TEST
AUGUST 5 TO SEPTEMBER 15, 1965

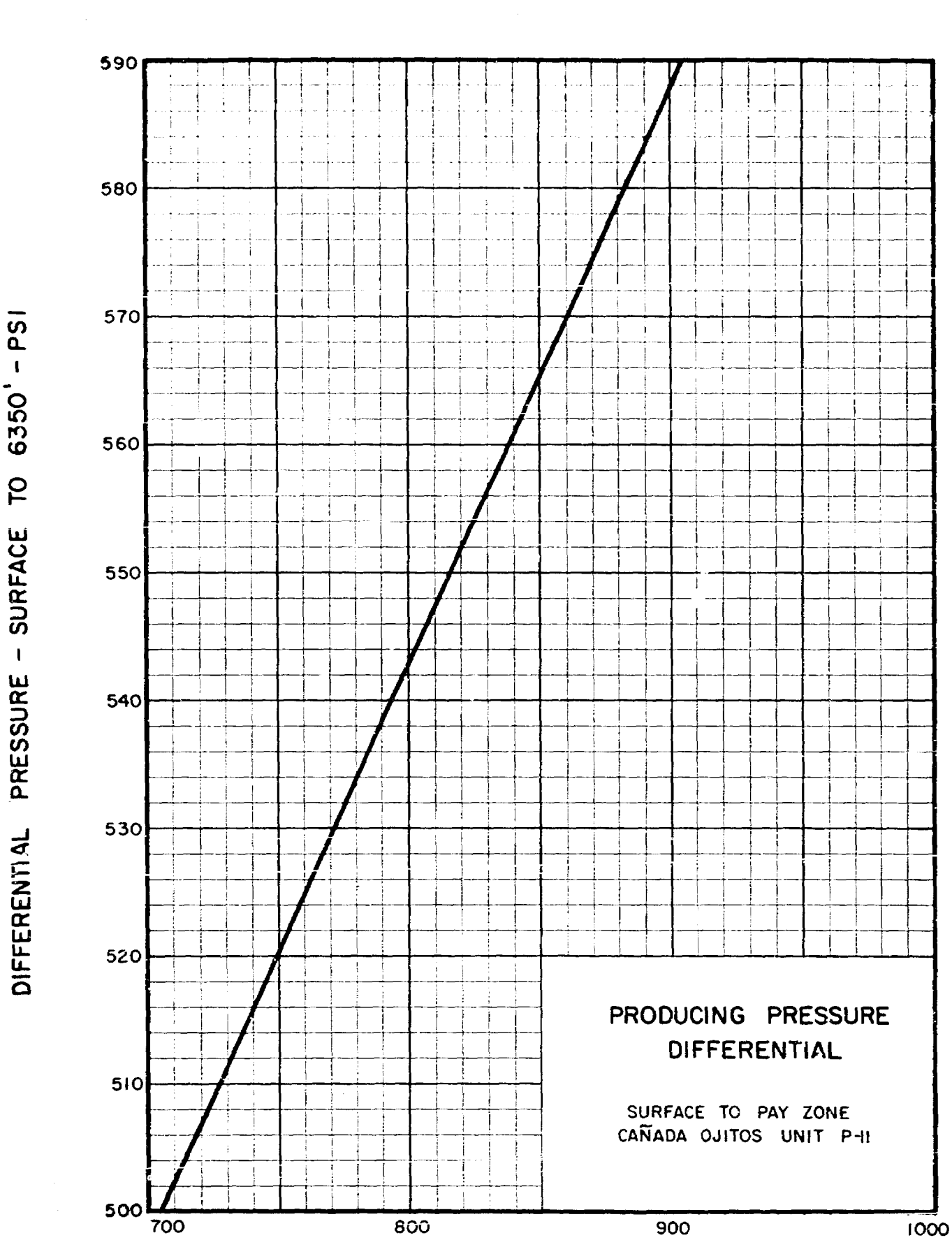
Production shown is 24-hour rate for period ending 7:00 A.M. on date indicated.

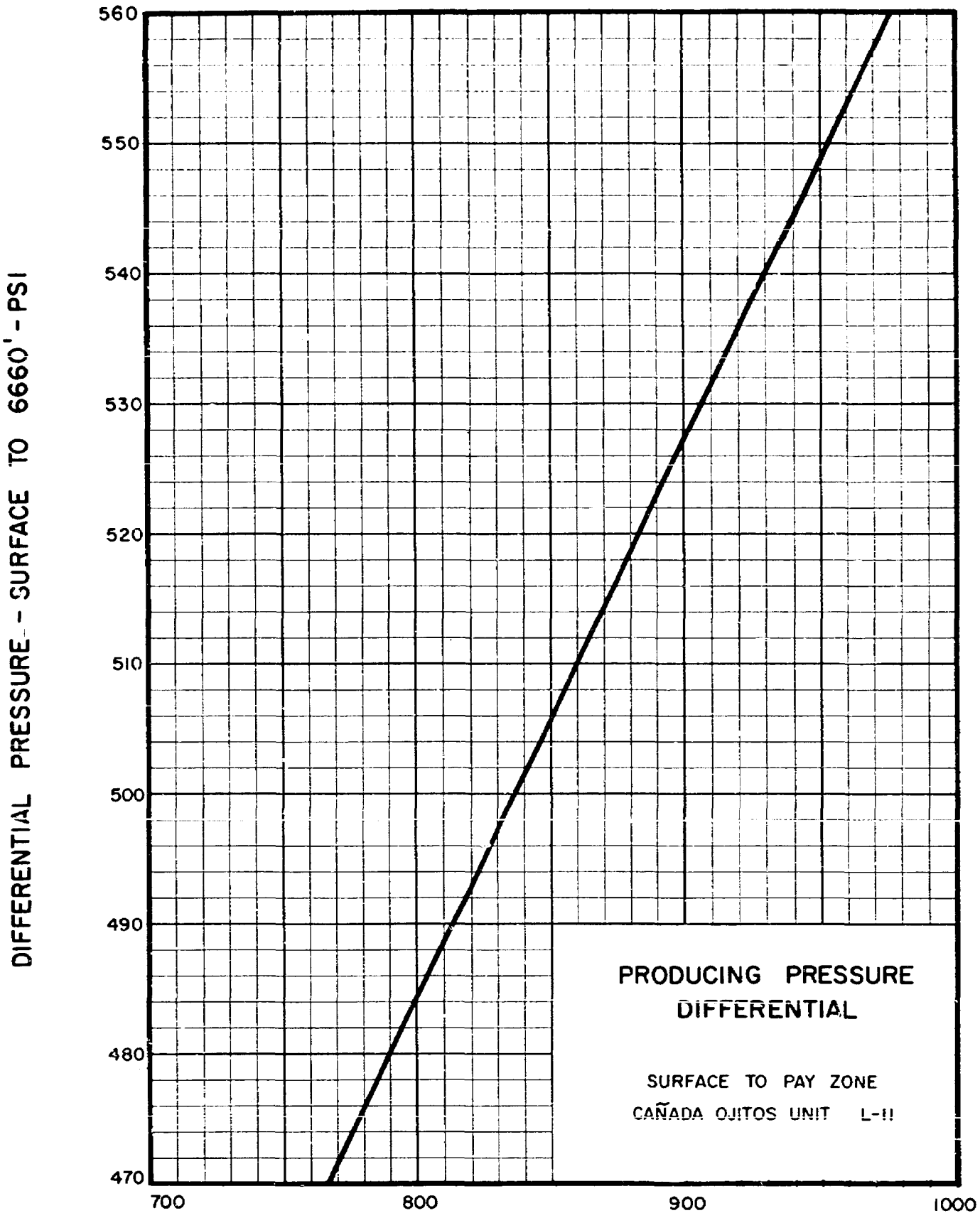
	P-11		L-11		TOTAL	
DATE	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)
8-5	410				410	
8-6	396				396	
8-7	498				498	
8-8	498				498	
8-9	487				487	
8-10	496	475			496	475
8-11	475				475	
8-12	476				476	
8-13	478				478	
8-14	486				486	
8-15	480	479			480	479
8-16	486				486	
8-17	476				476	
8-18	459				459	
8-19	456				456	
8-20	471	469			471	469
8-21	467				467	
8-22	463				463	
8-23	453				453	
8-24	481				481	
8-25	459	464			459	464
8-26	457				457	
8-27	477				477	
8-28	472				472	
8-29	462				462	
8-30	468				468	
8-31	479	469			479	469
9-1	464				464	
9-2	462				462	
9-3	469				469	
9-4	467		552		1019	
9-5	462	465	519	536	981	1001
9-6	466		559		1025	
9-7	452		549		1001	
9-8	466				466	
9-9	462		128		590	
9-10	453	460	75		528	
9-11	489				489	
9-12	448				448	
9-13	468				468	
9-14	480				480	
9-15	478	473			478	473

DAILY PRODUCTION RATES
FOR
CANADA OJITOS UNIT #P-11 AND #L-11
DURING PART OF INTERFERENCE TEST
SEPTEMBER 15 TO OCTOBER 20, 1965

Production shown is 24-hour rate for period ending 7:00 A.M. on date indicated.

	P-11		L-11		TOTAL	
DATE	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)	DAILY RATE (BOPD)	5-DAY AVERAGE (BOPD)
9-16	468				468	
9-17	466				466	
9-18	453				453	
9-19	470				470	
9-20	451	461			451	461
9-21	480				480	
9-22	469				469	
9-23	461				461	
9-24	462				462	
9-25	462	466	466		928	466
9-26	461		455		916	
9-27	465		491		956	
9-28	465		495		960	
9-29	445		507		952	
9-30	446	457	455	480	901	937
10-1	490		493		983	
10-2	450		475		925	
10-3	420		484		904	
10-4	365		455		820	
10-5	435	432	473	476	908	908
10-6	462		450		912	
10-7	406		450		856	
10-8	428		493		921	
10-9	437		472		909	
10-10	426	432	465	466	891	898
10-11	477		463		940	
10-12	390		457		847	
10-13	502		446		948	
10-14	452		445		897	
10-15	418	448	442	450	860	898
10-16	485		447		932	
10-17	481		520		1001	
10-18	449		440		889	
10-19	462		436		898	
10-20	438	462	425	454	863	916


DIFFERENTIAL PRESSURE - SURFACE TO 6350' - PSI
590
580
570
560
550
540
530
520
510
500
700
800
900
1000
PRODUCING PRESSURE
DIFFERENTIAL
SURFACE TO PAY ZONE
CAÑADA OJITOS UNIT P-11
SURFACE CASING PRESSURE - PSIG


DIFFERENTIAL PRESSURE - SURFACE TO 6660' - PSI
560
550
540
530
520
510
500
490
480
470
700
800
900
1000
PRODUCING PRESSURE
DIFFERENTIAL
SURFACE TO PAY ZONE
CAÑADA OJITOS UNIT L-11
SURFACE CASING PRESSURE - PSIG

RECORD OF OPERATING PRESSURES
CANADA OJITOS UNIT NO. P-11
FOR AUGUST, SEPTEMBER AND OCTOBER, 1965

DATE	DAYS ON PRODUCTION	DAILY AVERAGE PRESSURE FROM RECORDER (PSIG)	EST. AVG. TEMP.	PRESSURE CORRECTION DUE TO TEMP. (PSIG)	PRESSURE AFTER TEMP. CORRECTION (PSIG)	DIFF. PRESSURE SURFACE TO PAY ZONE (PSIG)	BOTTOM HOLE WORKING PRESSURE (PSIG)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
8- 5	1	920 to 870	59°	0	*	*	*
8- 6	2	866.6	58	0	867	573	1440
8- 7	3	844.3	59	0	844	563	1407
8- 8	4	832.0	58	0	832	557	1389
8- 9	5	824	59	0	824	554	1378
8-10	6	816.4	56	+ 1	817	550	1367
8-11	7	807.2	59	0	807	546	1353
8-12	8	801	58	0	801	543	1344
8-13	9	795.0	57	+ 1	795	540	1335
8-14	10	791.0	56	+ 1	792	539	1331
8-15	11	788.8	55	+ 1	790	538	1328
8-16	12	778	56	+ 1	779	533	1312
8-17	13	776.1	50	+ 2	778	532	1310
8-18	14	776.2	51	+ 2	778	532	1310
8-19	15	774.6	50	+ 2	777	532	1309
8-20	16	775.6	49	+ 2	778	532	1310
8-21	17	778.5	49	+ 2	781	534	1315
8-22	18	775.5	51	+ 2	778	532	1310
8-23	19	772.7	51	+ 2	775	531	1306
8-24	20	772.7	50	+ 2	775	531	1306
8-25	21	770.9	53	+ 1	772	530	1302
8-26	22	768	53	+ 1	769	529	1298
8-27	23	766.3	55	+ 1	767	528	1295
8-28	24	772.6	56	+ 1	774	531	1305

* Details recorded separately

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
8-29	25	772.5	43	+ 3	776	532	1308
8-30	26	770.6	43	+ 3	774	531	1305
8-31	27	769.4	45	+ 3	772	530	1302
9- 1	28	769.2	48	+ 2	771	529	1300
9- 2	29	765.0	47	+ 2	767	528	1295
9- 3	30	762.6	48	+ 2	765	527	1292
9- 4	31	762.3	51	+ 2	764	527	1291
9- 5	32	762.1	52	+ 1	763	526	1289
9- 6	33	760	54	+ 1	761	525	1286
9- 7	34	757.5	51	+ 2	760	525	1285
9- 8	35	755.3	47	+ 2	757	523	1280
9- 9	36	753.7	46	+ 2	756	523	1279
9-10	37	754.1	48	+ 2	756	523	1279
9-11	38	754.1	50	+ 2	756	523	1279
9-12	39	754.0	45	+ 3	757	523	1280
9-13	40	753.8	47	+ 2	756	523	1279
9-14	41	754.7	47	+ 2	757	523	1280
9-15	42	754.0	45	+ 3	757	523	1280
9-16	43	752.0	53	+ 1	753	521	1274
9-17	44	752.1	48	+ 2	754	522	1276
9-18	45	752.8	38	+ 4	757	523	1280
9-19	46	750.5	32	+ 5	756	523	1279
9-20	47	749.3	25	+ 6	755	522	1277
9-21	48	747.8	29	+ 5	753	521	1274
9-22	49	748.1	37	+ 4	752	521	1273
9-23	50	748.5	41	+ 3	752	521	1273
9-24	51	749.5	43	+ 3	753	521	1274
9-25	52	749.1	45	+ 3	752	521	1273
9-26	53	749.1	46	+ 2	751	520	1271
9-27	54	750.5	46	+ 2	753	521	1274
9-28	55	750.0	41	+ 3	753	521	1274
9-29	56	748.6	29	+ 5	754	522	1276
9-30	57	747.0	31	+ 5	752	521	1273

RECORD OF OPERATING PRESSURES
CANADA OJITOS UNIT NO. P-11

PAGE NO. 2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
10- 1	58	749.0	37	+ 4	753	521	1274
10- 2	59	747.5	40	+ 3	751	520	1271
10- 3	60	747.3	42	+ 3	750	520	1270
10- 4	61	746.5	42	+ 3	750	520	1270
10- 5	62	741.3	44	+ 3	744	517	1261
10- 6	63	742.3	43	+ 3	745	518	1263
10- 7	64	744.2	42	+ 3	747	519	1266
10- 8	65	744.9	41	+ 3	748	519	1267
10- 9	66	744.0	40	+ 3	747	519	1266
10-10	67						
10-11	68	747.0	44	+ 3	750	520	1270
10-12	69	742.1	40	+ 3	745	518	1263
10-13	70	740.2	42	+ 3	743	517	1260
10-14	71	743.7	40	+ 3	747	519	1266
10-15	72	736.8	39	+ 4	741	516	1257
10-16	73	743.3	28	+ 5	748	519	1267
10-17	74	743.9	18	+ 7	751	520	1271
10-18	75	740.6	22	+ 6	747	519	1266
10-19	76	738.7	28	+ 5	744	517	1261
10-20	77	738.7	31	+ 5	746	518	1264
10-21	78						
10-22	79	736.2	32	+ 5	741	516	1257
10-23	80	735.4	34	+ 4	739	515	1254
10-24	81	736.0	33	+ 5	741	516	1257
10-25	82	734.4	35	+ 4	738	514	1252
10-26	83	733.0	34	+ 4	737	514	1251
10-27	84	729.5	35	+ 4	734	513	1247
10-28	85	730.3	32	+ 5	735	513	1248
10-29	86	731.8	31	+ 5	737	514	1251
10-30	87						
10-31	88	733.7	35	+ 4	738	514	1252

RECORD OF OPERATING PRESSURES
CANADA OJITOS UNIT NO. P-11

PAGE NO. 3

RECORD OF OPERATING PRESSURES
CANADA OJITOS UNIT NO. L-11
FOR SEPTEMBER AND OCTOBER, 1965

DATE	DAYS ON PRODUCTION	DAILY AVERAGE PRESSURE FROM RECORDER (PSIG)	EST. AVG. TEMP.	PRESSURE CORRECTION DUE TO TEMP. (PSIG)	PRESSURE AFTER TEMP. CORRECTION (PSIG)	DIFF. PRESSURE SURFACE TO PAY ZONE (PSIG)	BOTTOM HOLE WORKING PRESSURE (PSIG)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
9-25	1	900.2	45°	+ 3	903	528	1431
9-26	2	910.5	46	+ 2	912	532	1444
9-27	3	903	46	+ 2	905	529	1434
9-28	4	902.5	41	+ 3	906	529	1435
9-29	5	907.6	29	+ 5	913	533	1446
9-30	6	904.0	31	+ 5	909	531	1440
10- 1	7	903.6	37	+ 4	908	530	1438
10- 2	8	904.7	40	+ 3	908	530	1438
10- 3	9	906.6	42	+ 3	910	531	1441
10- 4	10	910.7	42	+ 3	914	533	1447
10- 5	11	911.6	44	+ 3	915	533	1448
10- 6	12	917.3	43	+ 3	920	536	1456
10- 7	13	914.0	42	+ 3	917	534	1451
10- 8	14	914.4	41	+ 3	917	534	1451
10- 9	15	914.4	40	+ 3	917	534	1451
10-10	16	915.4	44	+ 3	918	535	1453
10-11	17	916.4	44	+ 3	919	535	1454
10-12	18	917.3	40	+ 3	920	536	1456
10-13	19	916.3	42	+ 3	919	535	1454
10-14	20	919.4	40	+ 3	922	536	1458
10-15	21	918.1	39	+ 4	922	536	1458
10-16	22	920.2	28	+ 5	927	539	1466
10-17	23	919.4	18	+ 6	925	538	1463
10-18	24	914.3	22	+ 7	921	536	1457
10-19	25	915.1	28	+ 5	920	536	1456
10-20	26	915.5	31	+ 5	921	536	1457

DETERMINATION OF ORIGINAL RESERVOIR PRESSURE
SOUTHWEST PUERTO CHIQUITO DATUM + 1195'

1. From Benson-Montin-Greer Drilling Corp. bottom hole pressure build-up on Canada Ojitos No. K-13 (Bolack No. 2) August and September, 1962, measured pressure 1635 psig at well depth of 5900'.

   Adjustment in measured pressure to correspond with Benson-Montin-Greer Drilling Corp. calibration equipment acquired in January, 1964: -19

   1635 - 19 = 1616 psig

2. This compares with pressure measured by Core Laboratories Inc. pressure bomb of 1608 psig at 5900'

3. For all subsequent pressures in Southwest Puerto Chiquito, calibration of pressure gauges made with Benson-Montin-Greer Drilling Corp. calibration equipment, and accordingly 1616psig used herein for pressure at 5900'.

4. Adjustment of 5900' well depth pressure to + 1195' datum = + 4 pounds (reference Section J, Item 2 herein).

5. Final adjusted pressure used is 1616 + 4 = 1620 psig at datum of + 1195' (above sea level).

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT NO. P-11
DECEMBER, 1963

PRESSURES MEASURED FOLLOWING HYDRAULIC SAND FRACTURE TREATMENT NOVEMBER 20, 1963, AND PRIOR TO PRODUCTION. LOST APPROXIMATELY 300 BARRELS OF OIL TO FORMATION WHILE CIRCULATING OUT SAND DECEMBER 9, 1963

DATE	PRESSURES AT 6000' (RKB) DEPTH FOR HUMBLE BOMB NO. 1260	1265	AVERAGE PRESSURE	REMARKS
12- 9-63	1616.7		1616.7	After taking pressure, circulated out sand. Lost 300 BO.
12-11-63	1591.7	1596.5	1594.1	
12-12-63	1585.9		1585.9	
12-14-63	1581.0	1581.1	1581.0	
12-17-63	1580.9	1581.7	1581.3	

Adjustment of survey pressure to datum pressure of + 1195'

1. Static pressure 1581.3 psig at 6000' RKB
2. Pressure at pay (6360' RKB) = 1581 + (360)(.363#/sq.in./ft) = 1712 psig
3. True elevation from July, 1965, special survey (7213' ground + 12') = 7225' RKB
4. True depth of 6360' = 6356' (loss of 4' due to hole deviation)
5. True datum of 6356' depth: $\begin{array}{r} 7225 \\ -6356 \\ \hline 869 \end{array}$
6. Adjustment to + 1195 datum: Datum difference 1195 - 869 = 326'

   1712 - (326 x .313#/sq.in./ft) = 1609

NOTE: (1) Reservoir pressure gradient assumed for pressures above bubble point (1520# to 1800#)

(2) Pressure gradient of oil in hole determined from bottom hole pressure surveys

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT NO. P-11
FEBRUARY, 1964

THE FOLLOWING DATUM PRESSURES WERE ESTIMATED FROM PRESSURES MEASURED AT 4730'. THE 4730' PRESSURES WERE TAKEN BY RUNNING BOTTOM HOLE PRESSURE BOMB ON KOBE PUMP ASSEMBLY. WELL SHUT IN 10:00 AM 2-21-64

DATE	DAYS SHUT IN	ESTIMATED PRESSURE AT DATUM OF + 1195'
2-22-64	1.3	1525
2-23-64	2.0	1528
	2.3	1536
2-24-64	3.1	1540
	3.3	1547
2-25-64	4.0 to 5.0	1551
2-26/28	5.0 to 7.0	1563
2-28/29	7.0 to 9.0	1575

BOTTOM HOLE PRESSURE SUMMARY
CANADA OJITOS UNIT NO. P-11
MARCH AND APRIL, 1964

DATE	DAYS SHUT IN	PRESSURES AT 6030' (RKB) DEPTH FOR HUMBLE BOMB NO. 1260	1265	AVERAGE PRESSURE	REMARKS
3- 7-64	15.25		1581.0	1581.0	Shut in 2-21-64 at 10:00 AM
3- 8-64	16.14		1582.5	1582.5	
3- 9-64	17.10		1581.0	1581.0	
3-11-64	19.04		1581.5	1581.5	
3-13-64	21.04		1581.3	1581.3	
3-16-64	24.13		1585.8	1585.8	
3-18-64	26.09		1591.0	1591.0	
3-20-64	28.04		1591.0	1591.0	
3-24-64	32.21		1591.5	1591.5	
3-27-64	35.13		1594.3	1594.3	
3-31-64	39.07		1595.2	1595.2	
4- 4-64	43.33	1598.7	1598.0	1598.0	
4- 8-64	47.33	1595.6	1597.8	1597.8	
4-14-64	53.3	1593.2		1593.2	
4-17-64	56.3	1595.1		1595.1	

SUMMARY OF BOTTOM HOLE PRESSURE SURVEY
BENSON-MONTIN-GREER #L-11 CANADA OJITOS UNIT
OCTOBER 1 TO OCTOBER 7, 1964

DATE	TIME	MEASURED PRESSURE	PRESSURE - 7 PSI	PRESS. DIF.	PRESS. DIFF. PER DAY	CALCULATED FLUID LEVEL ASSUMING FLUID LEVEL OF 1702 WITH PRESS. OF 1729
10-1	12:00 Noon	1755.6	1748.6			1643
10-2	4:00 PM	1747.5	1740.5	8	7	1668
10-3	3:00 PM	1747.0	1740.0	0.5	0.5	1669
10-4	1:00 PM	1744.1	1737.1	2.9	3.2	1678
10-5	3:00 PM	1742.3	1735.3	0.8	0.7	1683
10-7	12:00 Noon	1740.6	1733.6	1.7	0.9	1689

NOTES: (1) Pressures measured with B-M-G Humble bomb #1260, B-M-G wire line, S. J. Stanley, engineer.

(2) Pressures adjusted above as shown by subtracting 7 psi to conform to pressures measured 10-7-64 by S. J. Stanley with rented Amerada bomb.

SUMMARY OF BOTTOM HOLE PRESSURE SURVEY
BENSON-MONTIN-GREER #L-11 CANADA OJITOS UNIT
OCTOBER 14 TO OCTOBER 26, 1964

DATE	AVERAGE ADJUSTED PRESSURE
10-14	1728.1
10-15	1728.7
10-16	1732.8
10-17	1735.1
10-18	1730.3
10-19	1740.2
10-20	1739.4
10-21	1734.3
10-22	1738.0
10-23	1734.6
10-24	1737.8
10-26	1738.9

NOTES: (1) Pressures measured with B & R Amerada bomb and B & R wire lines.

(2) Bomb calibration with B-M-G deadweight tester.

(3) Pressures at each depth level adjusted for error in B & R wire line measuring device. This adjustment determined on October 26 by comparing fluid levels and pressures measured with B & R wire line and with new B-M-G wire line.

SCHEDULE OF FLUID LEVELS
TAKEN DURING BOTTOM HOLE PRESSURE SURVEY OF
BENSON-MONTIN-GREER #L-11 CANADA OJITOS UNIT
OCTOBER 7 TO OCTOBER 26, 1964

DATE	TIME	DEPTH FROM RKB	DEPTH FROM GROUND	OPERATOR	REMARKS
10- 7		1702	1690	S. J. Stanley	
10-10		1692	1680	R. E. Lee	
10-13	8:00 AM 2:00 PM	1697 1698	1685 1686	S. J. Stanley R. E. Lee	
10-14	12:00 Noon	1700	1688	R. E. Lee	
10-15	3:30 PM	1696	1684	R. E. Lee	
10-16	8:00 AM	1694	1682	R. E. Lee	
10-17	8:00 AM	1690	1678	R. E. Lee	
10-18	12:00 Noon	1685	1673	R. E. Lee	
10-19	1:00 PM	1680	1668	R. E. Lee	
10-20	8:00 AM	1678	1666	R. E. Lee	
10-21	1:00 PM 5:30 PM	1673 1672	1661 1660	R. E. Lee R. E. Lee	New veeder counter
10-22	9:00 AM 1:00 PM	1671	1659 (1665)	R. E. Lee R. E. Lee	B & R unit
10-23	12:00 Noon 12:00 Noon	1666	1654 (1661)	R. E. Lee R. E. Lee	B & R unit
10-24	3:45 PM	1662	1650	M. P. York	
10-26	9:00 AM 9:00 AM 11:00 AM	1660	1648 (1655) (1645)	R. E. Lee R. E. Lee R. E. Lee	B & R unit New line

BOTTOM HOLE PRESSURE SURVEY
CANADA OJITOS UNIT NO. L-11

OCTOBER, 1964

ADJUSTMENT OF SURVEY PRESSURE TO DATUM OF + 1195'

Static pressure from survey 1742 psig at survey depth 6600' (RKB)

1. Pressure at pay depth (6660') = 1742 + (60' x .325#/sq.in/ft)
   = 1761.5

2. True elevation (from July, 1965 special survey)
   7215 ground + 12' = 7225' RKB

3. True depth of 6660' is 6658' (2' correction for hole deviation).

4. True datum of true depth 6658'
   7227 - 6658 = + 569'

5. Datum difference = 1195 - 569 = 626'

6. DATUM PRESSURE = 1761.5 - (626 x .313) = 1565 psig

FLUID LEVEL BUILD UP DATA
FOR SHUT-IN PERIOD JUNE, JULY, AUGUST, 1965
CANADA OJITOS UNIT #L-11
SHUT-IN TIME DETERMINED
FROM
TIME P-11 SHUT IN
(12:00 Noon 6-8-65)

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
1965				
June 9	9:00 A.M.	1569	0.8	
	3:45 P.M.	1566	1.1	
June 10	8:00 A.M.	1564	1.8	
June 11	7:00 A.M.	1561	2.8	
June 12	7:00 A.M.	1557	3.8	
	6:00 P M.	1555	4.2	
June 13	6:30 A.M.	1553	4.8	
	6:00 P.M.	1551	5.2	
June 14	6:30 A.M.	1549	5.8	
	2:10 P.M.	1548	6.1	
	6:00 P.M.	1547	6.2	
June 15	6:45 A.M.	1545	6.8	
	6:00 P.M.	1543	7.2	
June 16	6:30 A.M.	1542	7.8	
	7:00 P.M.	1541	8.2	
June 17	6:30 A.M.	1539	8.8	Changed line.
	5:30 P.M.	1538	9.2	
June 18	6:30 A.M.	1537	9.8	
	6:00 P.M.	1536	10.2	
June 19	6:45 A.M.	1535	10.8	
	3:00 P.M.	1535	11.1	
June 20	6:30 A.M.	1534	11.8	
	6:45 P.M.	1533	12.2	
June 21	6:30 A.M.	1532	12.8	
	4:00 P.M.	1530	13.2	Changed line.
June 22	6:30 A.M.	1529	13.8	
	6:20 P.M.	1527	14.2	
June 23	6:30 A.M.	1526	14.8	
	4:40 P.M.	1526	15.2	
	6:00 P.M.	1526	15.2	
June 24	6:30 A.M.	1525	15.8	
	4:40 P.M.	1526	16.2	
	6:30 P.M.	1523	16.2	
June 25	6:15 A.M.	1522	16.8	
	5:30 P.M.	1521	17.2	
June 25	6:30 A.M.	1520	17.8	
	4:30 P.M.	1519	18.2	
June 27	6:45 A.M.	1518	18.8	
	5:oo P.M.	1518	19.2	
June 28	6:45 A.M.	1518	19.8	
	5:15 P.M.	1517	20.2	

FLUID LEVEL MEASUREMENTS - #L-11
PAGE #2

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
June 29	6:30 A.M.	1516	20.8	
	5:45 P.M.	1516	21.2	
June 30	6:30 A.M.	1515	21.8	
	6:10 P.M.	1513	22.2	
July 1	6:20 A.M.	1513	22.8	
July 2	6:45 A.M.	1513	23.8	
	6:10 P.M.	1513	24.2	
July 3	6:20 A.M.	1513	24.8	
	5:40 P.M.	1511	25.2	
July 4	7:25 A.M.	1510	25.8	
	6:oo P.M.	1509	26.2	
July 5	7:30 A.M.	1508	26.8	
	5:30 P.M.	1508	27.2	
July 6	6:45 A.M.	1507	27.8	
	6:35 P.M.	1506	28.2	
July 7	6:39 A.M.	1505	28.8	
	6:05 P.M.	1505	29.2	
July 8	7:00 A.M	1505	29.8	
	5:00 P.M.	1506	30.2	After V.S. pulled line and ran BHP
July 9	7:00 A.M.	1504	30.8	
	5:35 P.M.	1504	31.2	
July 10	6:43 A.M.	1504	31.8	
	6:15 P.M.	1503	32.2	
July 11	6:15 A.M.	1503	32.8	
	5:30 P.M.	1503	33.2	
July 12	6:35 A.M.	1502	33.8	
	6:30 P.M.	1502	34.2	
July 13	7:00 A.M.	1501	34.8	
	5:20 P.M.	1501	35.2	
July 14	7:05 A.M.	1501	35.8	
	5:50 P.M.	1500	36.2	
July 15	7:10 A.M.	1500	36.8	
	6:00 P.M.	1499	37.2	
July 16	6:15 A.M.	1499	37.8	
	6:30 P.M.	1498	38.2	
July 17	6:30 A.M.	1498	38.8	
	6:00 P.M.	1497	39.2	
July 18	6:30 A.M.	1497	39.8	
	5:00 P.M.	1496	40.2	
July 19	7:15 A.M.	1496	40.8	
	6:35 P.M.	1495	41.2	
July 20	7:25 A.M.	1495	41.8	
	5:45 P.M.	1494	42.2	
July 21	7:00 A.M.	1494	42.8	
	1:30 P.M.	1494	43.1	
	6:00 P.M.	1493	43.2	

FLUID LEVEL MEASUREMENTS - #L-11
PAGE #3

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
July 22	7:05 A.M.	1493	43.8	
	5:45 P.M.	1492	44.2	
July 23	6:45 A.M.	1492	44.8	
	6:00 P.M.	1491	45.2	
July 24	6:00 A.M.	1493	45.8	
	12:00 NOON	1493	46.0	
	5:30 P.M.	1494	46.2'	
July 25	6:30 A.M.	1496	46.8	
	12:00 NOON	1496	47.0	
	6:45 P.M.	1496	47.2	
July 26	10:00 A.M.	1494	47.9	
	6:35 P.M.	1494	48.2	
July 27	7:00 A.M.	1493	48.8	
	5:40 P.M.	1493	49.2	
July 28	7:05 A.M.	1492	49.8	
July 29	6:40 A.M.	1491	50.8	
	5:30 P.M.	1491	51.2	
July 30	7:45 A.M.	1490	51.8	
	6:00 P.M.	1490	52.2	
July 31	6:00 A.M.	1489	52.8	
	6:15 P.M.	1489	53.2	
August 1	6:45 A.M.	1488	53.8	
	6:00 P.M.			Road Impassable.
August 2	6:35 A.M	1488	54.8	
	6:00 P.M.	1488	55.2	
August 3	7:25 A.M.	1487	55.8	
	6:50 P.M.	1487	56.2	
August 4	7:10 A.M.	1486	56.8	

FLUID LEVEL BUILD UP DATA
FOR SHUT-IN PERIOD JUNE, JULY, AUGUST, 1965
CANADA OJITOS UNIT #A-14
SHUT-IN TIME DETERMINED
FROM
TIME P-11 SHUT IN
(12:00 Noon 6-8-65)

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
6-9-65	8:00 A.M.	1595	0.8	
	3:45 P.M.	1593	1.2	
6-10-65	8:00 A.M	1589	1.8	
6-11-65	6:45 A.M.	1586	2.8	
6-12-65	7:00 A.M.	1581	3.8	
	6:00 P.M.	1579	4.2	
6-13-65	6:45 A.M.	1577	4.8	
	6:00 P.M.	1575	5.2	
6-14-65	6:45 A.M.	1572	5.8	
	2:00 P.M.	1570	6.1	
	6:00 P.M.	1570	6.2	
6-15-65	6:30 A.M.	1568	6.8	
	6:00 P.M.	1566	7.2	
6-16-65	6:45 A.M.	1565	7.8	
6-17-65	5:30 P.M.	1556	9.2	Changed line.
6-18-65	6:45 A.M.	1555	9.8	
	5:30 P.M.	1552	10.2	
6-19-65	6:45 A.M.	1554	10.8	Changed line.
	3:00 P.M.	1553	11.1	
6-20-65	6:45 A.M.	1552	11.8	
	6:30 P.M.	1551	12.2	
6-21-65	6:30 A.M.	1550	12.8	
	4:30 P.M.	1549 = 1548 (old) (new)	13.2	Changed line.
6-22-65	6:45 A.M.	1546	13.8	
	6:30 P.M.	1545	14.2	
6-23-65	6:45 A.M.	1544	14.8	
	4:00 P.M.	1542	15.2	
	6:15 P.M.	1543	15.2	
6-24-65	6:45 A.M.	1542	15.8	
	4.50 P.M.	1542	16.2	
	6:30 P.M.	1541	16.2	
6-25-65	6:30 A.M.	1540	16.8	
	4:00 P.M.	1539	17.2	
6-26-65	6:30 A.M.	1538	17.8	
	4:00 P.M.	1537	18.2	
6-27-65	6:30 A.M.	1536	18.8	
	5:15 P.M.	1535	19.2	
6-28-65	6:30 A.M.	1534	19.8	
	6:00 P.M.	1533	20.2	

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
6-29-65	6:30 A.M.	1532	20.8	
	6:00 P.M.	1532	21.2	
6-30-65	6:15 A.M.	1532	21.8	
	6:15 P.M.	1529	22.2	
7-1-65	6:21 A.M.	1530	22.8	
	6:25 P.M.	1529	23.2	
7-2-65	7:00 A.M.	1528	23.8	
	6:25 P.M.	1529	24.2	
7-3-65	6:10 A.M.	1528	24.8	
	5.50 P.M.	1528	25.2	
7-4-65	7:15 A.M.	1527	25.8	
	6:15 P.M.	1526	26.2	
7-5-65	7:00 A.M.	1525	26.8	
	6:00 P.M.	1523	27.2	
7-6-65	6:30 A.M.	1522	27.8	
	6:25 P.M.	1521	28.2	
7-7-65	6:00 A.M.	1520	28.8	
	6:30 P.M.	1519	29.2	
7-8-65	6:40 A.M	1519	29.8	
	7:15 P.M.	1519	30.2	
7-9-65	7:15 A.M.	1518	30.8	
	5:20 P.M.	1518	31.2	
7-10-65	6:30 A.M.	1518	31.8	
	5:30 P.M.	1517	32.2	
7-11-65	6:40 A.M.	1517	32.8	
	5:15 P.M.	1516	33.2	
7-12-65	6:30 A.M.	1516	33.8	
	6:15 P.M.	1515	34.2	
7-13-65	6:30 A.M.	1515	34.8	
	5:10 P.M.	1515	35.2	
7-14-65	6:50 A.M.	1514	35.8	
	5.40 P.M.	1513	36.2	
7-15-65	7:00 A.M.	1513	36.8	
	6:00 P.M.	1512	37.2	
7-16-65	6:30 A.M.	1512	37.8	
	6:15 P.M.	1511	38.2	
7-17-65	6:15 A.M.	1510	38.8	
	6:15 P.M.	1510	39.2	
7-18-65	6:45 A.M.	1509	39.8	
	5:15 P.M.	1508	40.2	
7-19-65	7:10 A.M.	1508	40.8	
	6:30 P.M.	1508	41.2	
7-20-65	7:20 A.M.	1507	41.8	
	6:45 P.M.	1507	42.2	
7-21-65	6:45 A.M.	1506	42.8	
	1:35 P.M.	1506	43.1	
	6:15 P.M.	1506	43.2	
7-22-65	6:55 A.M.	1505	43.8	
	5:45 P.M.	1505	44.2	
7-23-65	6:30 A.M.	1505	44.8	
	6:00 P.M.	1504	45.2	

FLUID LEVEL MEASUREMENTS - #A-14
PAGE #2

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
7-24-65	6:15 A.M.	1505	45.8	
	Noon	15 05	46.0	
	6:25 P.M.	1505	46.2	
7-25-65	7:30 P.M.	1506	46.8	
	Noon	1507	47.0	
	6:00 P.M.			High water in wash, location inaccessible.
7-26-65	6:20 P.M.	1506	48.2	
7-27-65	6:40 A.M.	1505	48.8	
	6:50 P.M.	1505	49.2	
7-28-65	6:55 A.M.	1504	49.8	
7-29-65	6:00 A.M.	1503	50.8	
	5.50 P.M.	1502	51.2	
7-30-65	7:00 A.M.	1501	51.8	
	6:15 P.M.	1501	52.2	
7-31-65	6:00 A.M.	1500	52.8	
	6:15 P.M.	1500	53.2	
8-1-65	6:45 A.M.	1499	53.8	
	6:00 P.M.			Road impassable.
8-2-65	5:30 A.M.	1498	54.8	
	5:45 P.M.	1498	55.2	
8-3-65	7:15 A.M.	1497	55.8	
	6:40 P.M.	1497	56.2	
8-4-65	7:30 A.M.	1496	56.8	

FLUID LEVEL BUILD UP DATA
FOR SHUT-IN PERIOD JUNE, JULY, AUGUST, 1965
CANADA OJITOS UNIT #A-23
SHUT-IN TIME DETERMINED
FROM
TIME P-11 SHUT IN
(12:00 Noon 6-8-65)

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
1965				
June 17	7:15 A.M.	1575	8.8	
	3:00 P.M.	1546	9.1	
	6:00 P.M.	1543	9.2	
June 18	7:00 A.M.	1533	9.8	
	2:45 P.M.	1531	10.1	
June 19	6:45 A.M.	1529	10.8	
	3:20 P.M.	1528	11.1	
June 20	6:45 A.M.	1527	11.8	
	6:30 P.M.	1526	12.2	
June 21	6:45 A.M.	1525	12.8	
	4:30 P.M.	1524	13.2	
June 22	6:45 A.M.	1522	13.8	
	6:30 P.M.	1521	14.2	
June 23	6:45 A.M.	1521	14.8	
	4:55 P.M.	1520	15.2	
	6:00 P.M.	1520	15.2	
June 24	6:45 A.M.	1519	15.8	
	4:55 P.M.	1520	16.2	
	6:45 P.M.	1518	16.2	
June 25	6:45 A.M.	1517	16.8	
	4:30 P.M.	1517	17.2	
June 26	6:45 A.M.	1516	17.8	
	5:00 P.M.	1515	18.2	
June 27	6:45 A.M.	1514	18.8	
	5:15 P.M.	1513	19.2	
June 28	6:45 A.M.	1513	19.8	
	5:30 P.M.	1513	20.2	
June 29	6:45 a.M.	1513	20.8	
	6:00 P.M.	1512	21.2	
June 30	6:45 A.M.	1512	21.8	
	6:05 P.M.	1512	22.2	
July 1	6:45 A.M.	1512	22.8	
	6:15 P.M.	1510	23.2	
July 2	7:10 A.M.	1509	23.8	
	6:20 P.M.	1509	24.2	
July 3	6:30 A.M.	1509	24.8	
	6:00 P.M.	1508	25.2	
July 4	7:00 A.M.	1508	25.8	
	6:25 P.M.	1507	26.2	
July 5	7:30 A.M.	1505	26.8	
	6:05 P.M.	1502	27.2	
July 6	7:00 A.M.	1502	27.8	
	6:15 P.M.	1501	28.2	

FLUID LEVEL MEASUREMENTS - #A-23
PAGE #2

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
July 7	6:40 A.M.	1500	28.8	
	6:40 P.M.	1499	29.2	
July 8	7:25 A.M.	1499	29.8	
	8:20 P.M.	1498	30.3	After pulling line and running BHP
July 9	7:00 A.M.	1497	30.8	
	5:50 P.M.	1497	31.2	
July 10	7:10 A.M.	1497	31.8	
	5:30 P.M.	1496	32.2	
July 11	7:40 A.M.	1495	32.8	
	5:00 P.M.	1495	33.2	
July 12	6:15 A.M.	1495	33.8	
	6:00 P.M.	1494	34.2	
July 13	6:30 A.M.	1494	34.8	
	5:00 P.M.	1493	35.2	
July 14	6:40 A.M.	1493	35.8	
	6:10 P.M.	1492	36.2	
July 15	6:50 A.M.	1492	36.8	
	6:30 P.M.	1491	37.2	
July 16	6:30 A.M.	1491	37.8	
	6:30 P.M.	1490	38.2	
July 17	6:30 A.M.	1489	38.8	
	6:30 P.M.	1489	39.2	
July 18	6:45 A.M.	1488	39.8	
	5:25 P.M.	1487	40.2	
July 19	7:00 A.M.	1487	40.8	
	6:50 P.M.	1487	41.2	
July 20	7:00 A.M.	1486	41.8	
	6:45 P.M.	1486	42.2	
July 21	6:30 A.M.	1485	42.8	
	1:40 P.M.	1484	43.1	
	6:10 P.M.	1484	43.2	
July 22	6:45 A.M.	1484	43.8	
	5:30 P.M.	1483	44.2	
	6:10 P.M.	1483	44.2	
July 23	6:30 A.M.	1483	44.8	
	5:30 P.M.	1483	45.2	
July 24	6:15 A.M.	1483	45.8	
	12:00 NOON	1483	46.0	
	6:15 P.M.	1483	46.2	
July 25	7:30 A.M.	1483	46.8	
	12:00 NOON	1483	47.0	
	6:30 P.M.	1483	47.2	Roads Impassable.
July 26	6:00 P.M.	1482	48.2	
July 27	6:30 A.M.	1482	48.8	
	6:00 P.M.	1481	49.2	
July 28	6:45 A.M.	1481	49.8	
July 29				Road washed out.
	6:00 P.M.	1479	51.2	

FLUID LEVEL MEASUREMENTS - #A-23
PAGE #3

DATE	TIME	FLUID LEVEL (FT. FROM SURFACE)	TIME SHUT IN (DAYS)	REMARKS
July 30	6:50 A.M.	1479	51.8	
	6:30 P.M.	1478	52.2	
July 31	6:30 A.M.	1478	52.8	
	6:00 P.M.	1477	53.2	
August 1	6:30 A.M.	1477	53.8	
	6:00 P.M.			Road Impassable.
August 2	5:30 A.M.	1476	54.8	
	6:15 P.M.	1476	55.2	
August 3	7:00 A.M	1476	55.8	
	6:30 P.M.	1475	56.2	
August 4	7:30 A.M.	1475	56.8	

[redacted]

BOTTOM HOLE PRESSURE EQUILIBRIUM CURVE

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Cañada Ojitos P-11

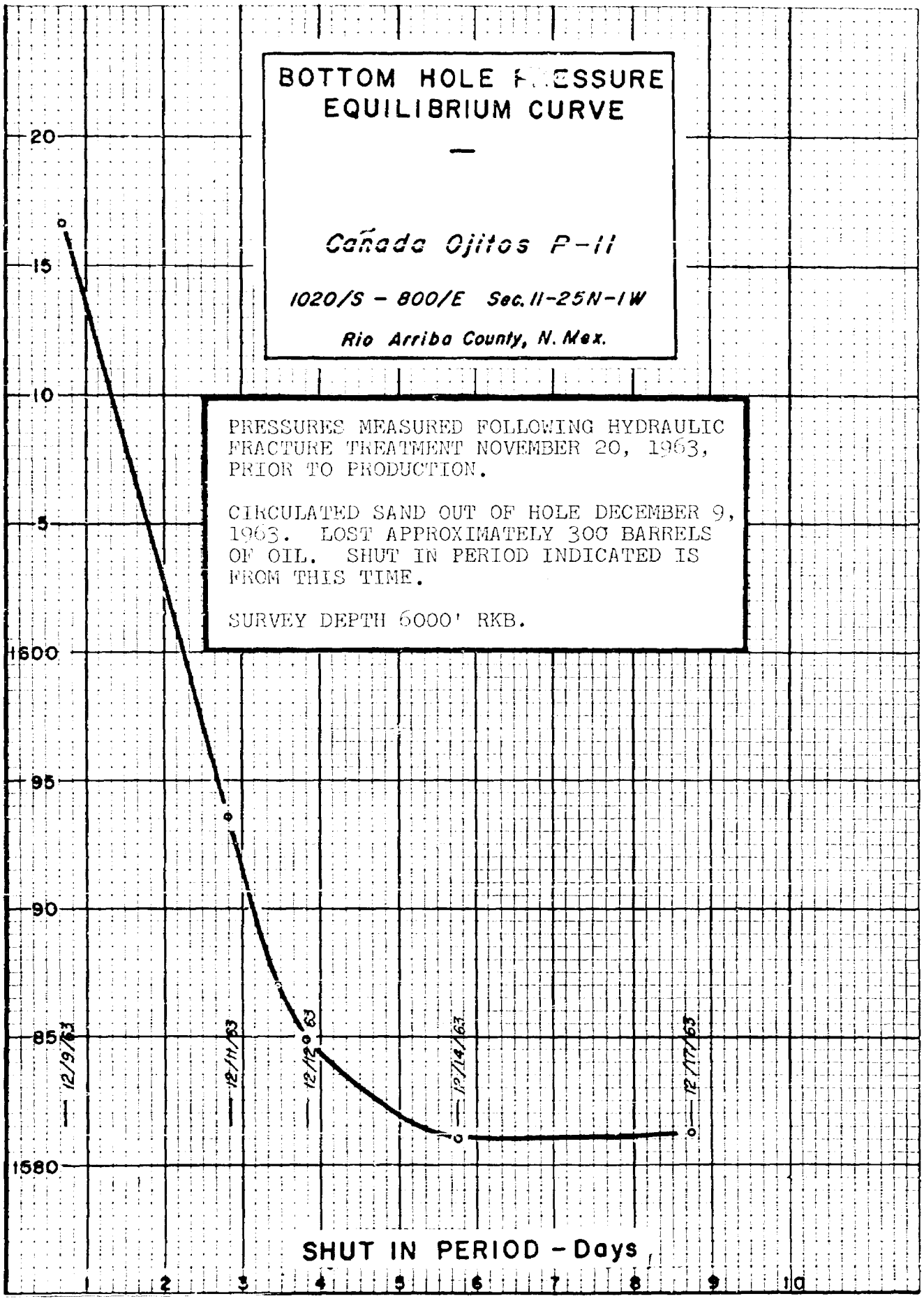
1020/S - 800/E Sec. 11-25N-1W

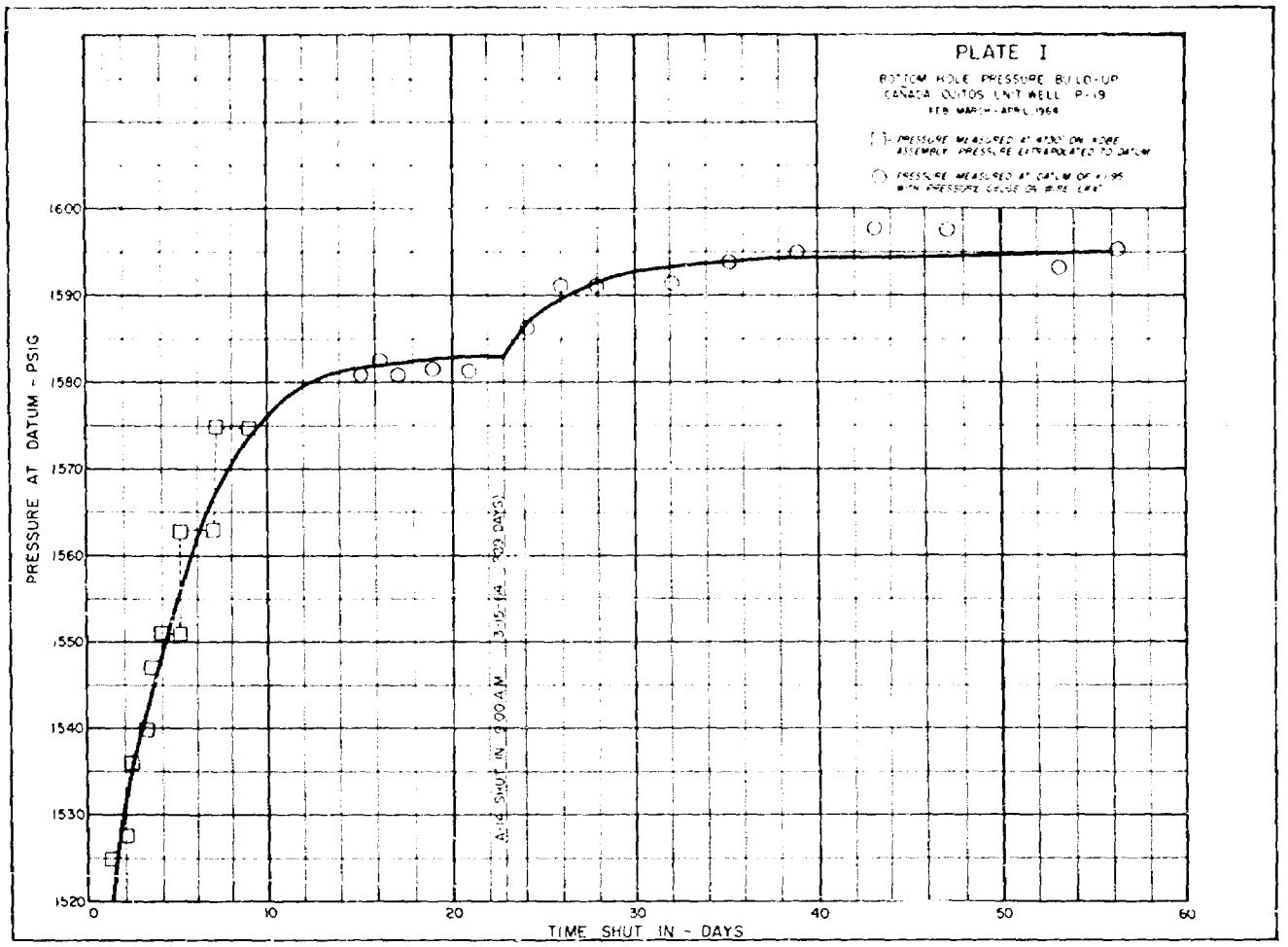
Rio Arriba County, N. Mex.

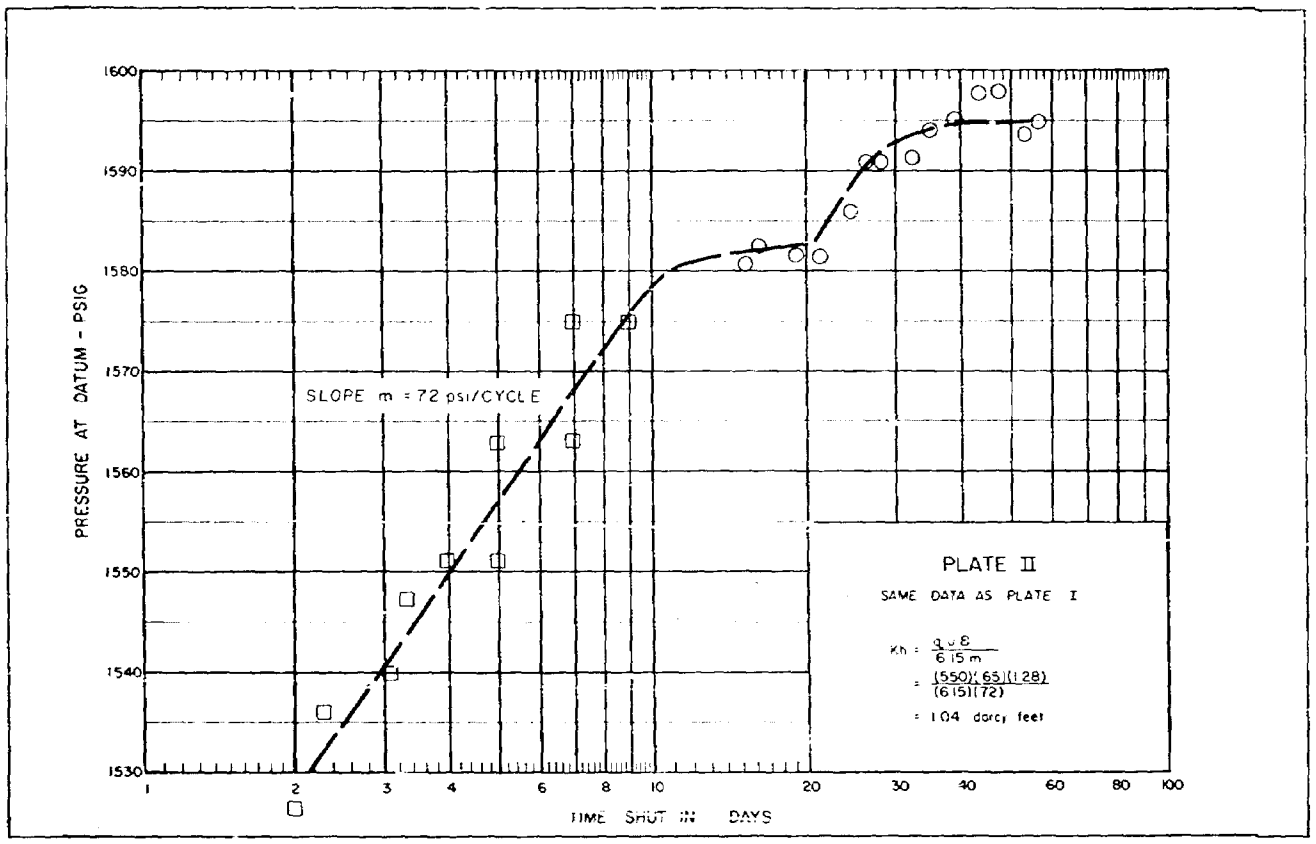
PRESSURES MEASURED FOLLOWING HYDRAULIC FRACTURE TREATMENT NOVEMBER 20, 1963, PRIOR TO PRODUCTION.

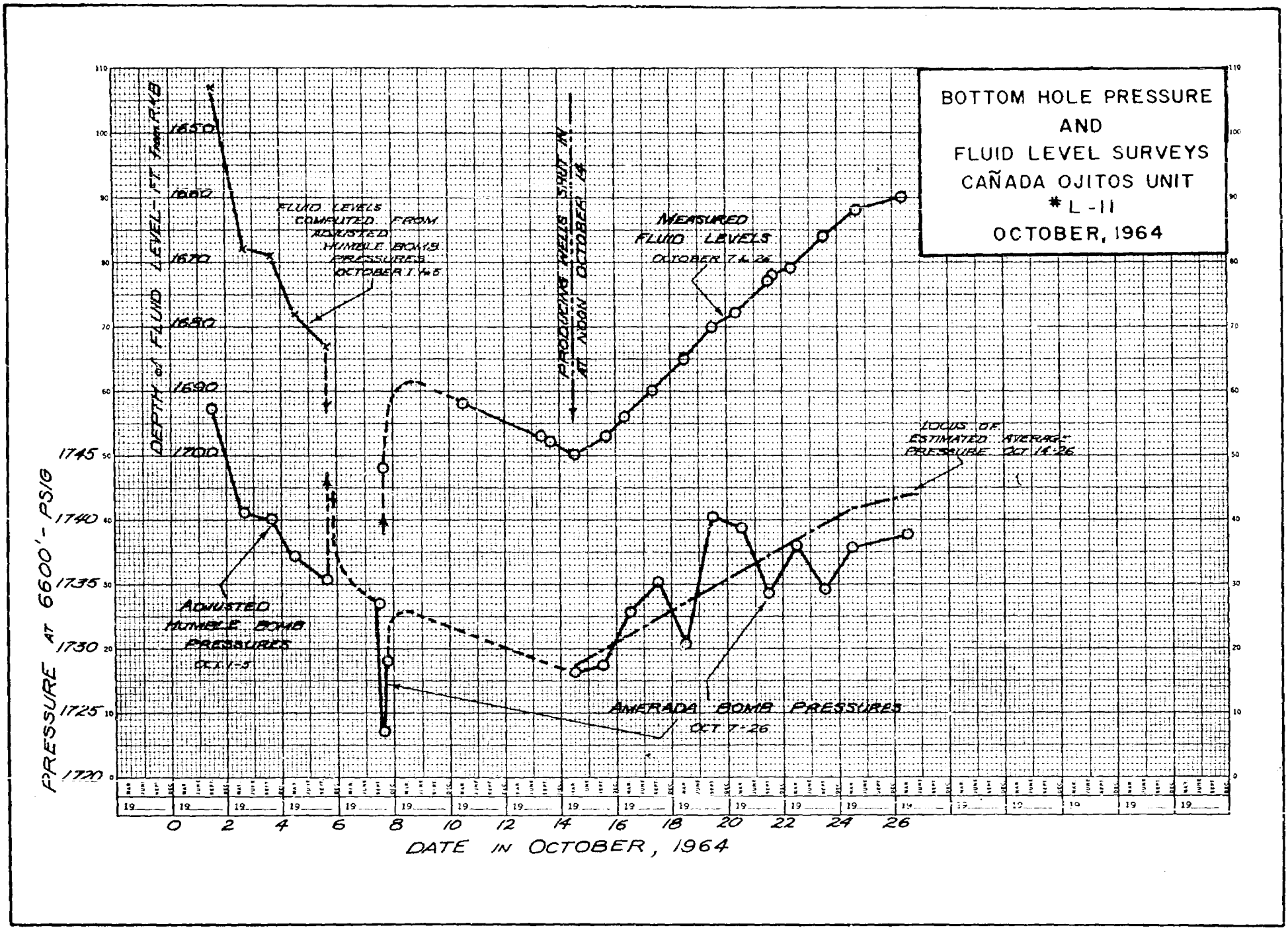
CIRCULATED SAND OUT OF HOLE DECEMBER 9, 1963. LOST APPROXIMATELY 300 BARRELS OF OIL. SHUT IN PERIOD INDICATED IS FROM THIS TIME.

SURVEY DEPTH 6000' RKB.

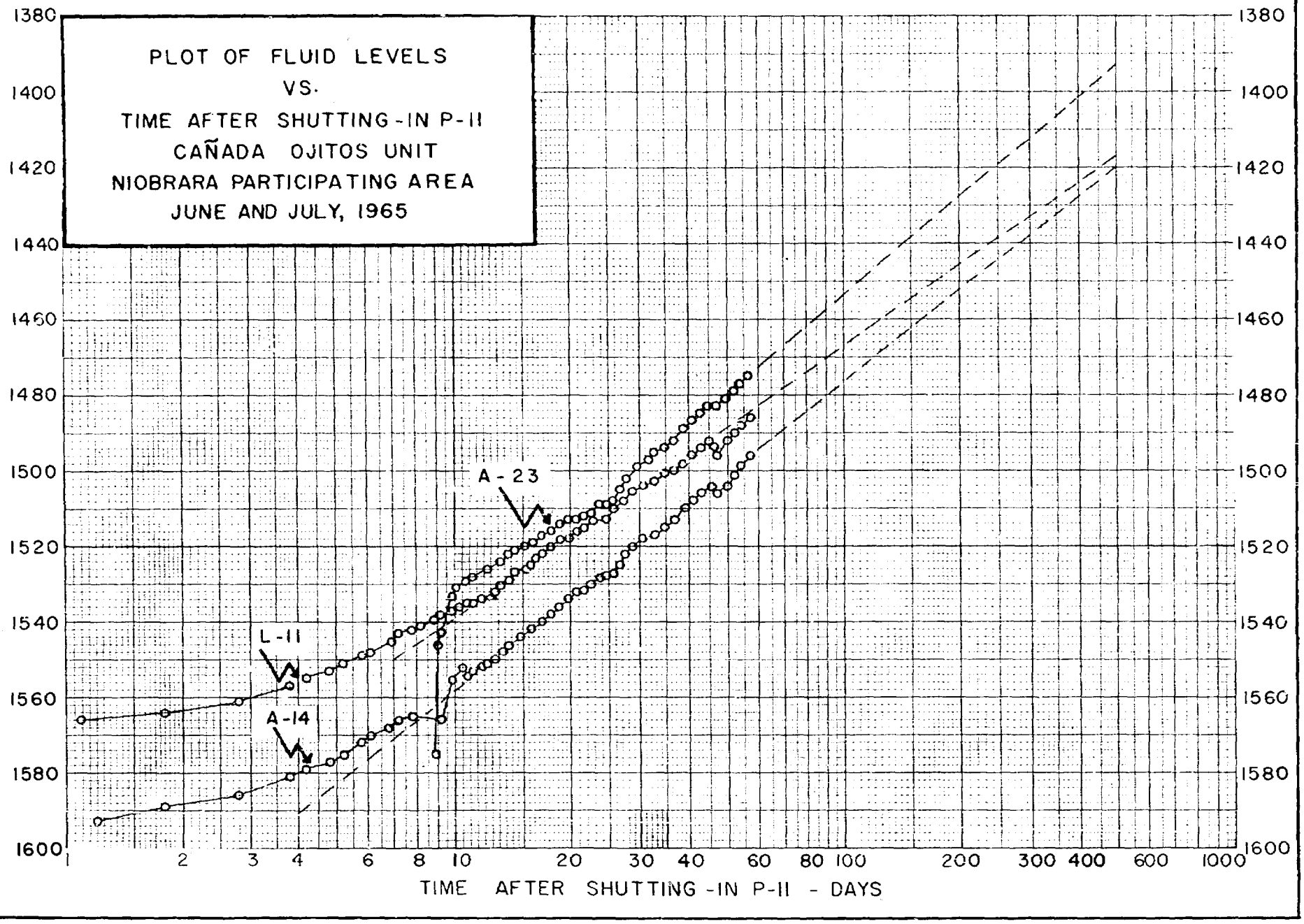



PLATE I
BOTTOM HOLE PRESSURE BUILD-UP
CANADA QUITOS UNIT WELL P-19
FEB MARCH - APRIL 1964
PRESSURE AT DATUM - PSIG
TIME SHUT IN - DAYS
1600
1590
1580
1570
1560
1550
1540
1530
1520
0
10
20
30
40
50
60


PRESSURE AT DATUM - PSIG
TIME SHUT IN - DAYS
SLOPE m = 72 psi/CYCLE
1600
1590
1580
1570
1560
1550
1540
1530
1
2
3
4
6
8
10
20
30
40
60
80
100
PLATE II
SAME DATA AS PLATE I
Kh = q μ β / 6.15 m
= (550)(.65)(1.28) / (6.15)(72)
= 1.04 darcy feet


BOTTOM HOLE PRESSURE
AND
FLUID LEVEL SURVEYS
CAÑADA OJITOS UNIT
* L - 11
OCTOBER, 1964
PRESSURE AT 6600'- PSIG
DEPTH of FLUID LEVEL - FT. from R.K.B.
1745
1740
1735
1730
1725
1720
1650
1670
1690
1700
FLUID LEVELS COMPUTED FROM ADJUSTED HUMBLE BOMB PRESSURES OCTOBER 1 to 6
PRODUCING WELLS SHUT IN AT NOON OCTOBER 14
MEASURED FLUID LEVELS OCTOBER 7 & 26
LOCUS OF ESTIMATED AVERAGE PRESSURE OCT 14-26
ADJUSTED HUMBLE BOMB PRESSURES OCT 1-5
AMERADA BOMB PRESSURES OCT 7-26
0 2 4 6 8 10 12 14 16 18 20 22 24 26
DATE IN OCTOBER, 1964

PLOT OF FLUID LEVELS
VS.
TIME AFTER SHUTTING-IN P-II
CAÑADA OJITOS UNIT
NIOBRARA PARTICIPATING AREA
JUNE AND JULY, 1965



CAÑADA OJITOS UNIT
NIOBRARA-GREENHORN PARTICIPATING AREA
OIL PRODUCTION BY WELLS BY MONTHS

	K-13	A-14	P-11	L-11	A-23	TOTAL	CUMULATIVE
1962							
December	689	737				1,426	
1963							
January	380	1,538				1,918	3,344
February	129	882				1,011	4,355
March	347	1,795				2,142	6,497
April	187	2,333				2,520	9,017
May	-	1,888				1,888	10,905
June	-	1,892				1,892	12,797
July	441	1,709				2,150	14,947
August	1,610	1,858				3,458	18,405
September	2,991	1,838				4,829	23,234
October	2,720	1,813				4,533	27,767
November	1,881	1,843				3,724	31,491
December	274	1,262				1,536	33,027
TOTAL FOR YEAR	10,960	20,641				31,601	
1964							
January	2,319	1,505	12,422			16,246	49,273
February	1,098	620	12,081			13,799	63,072
March	-	873	-			873	63,945
April	1,669	963	5,514			8,146	72,091
May	2,825	1,960	9,194			13,979	86,070
June	2,089	1,888	8,619			12,596	98,666
July	2,912	2,090	9,974			14,976	113,642
August	2,870	1,122	12,967			16,959	130,601
September	2,325	1,694	9,802			13,821	144,422
October	1,723	752	6,773			9,248	153,670
November	3,514	60	8,310	6,465		18,349	172,019
December	2,459	-	8,887	8,797		20,143	192,162
TOTAL FOR YEAR	25,803	13,527	104,543	15,262		159,135	

	K-13	A-14	P-11	L-11	A-23	TOTAL	CUMULATIVE
1965							
January	1,850	-	10,519	10,181		22,550	214,712
February	-	-	11,762	9,240		21,002	235,714
March	-	4,482	11,462	8,735		24,679	260,393
April	-	8,396	10,990	8,390	1,445	29,221	289,614
May	-	-	11,380	1,012	3,100	15,492	305,106
June	-	-	2,420	-	600	3,020	308,126
July	-	-	413	-	-	413	308,539
August	-	-	13,067	-	-	13,067	321,606
September	-	-	13,901	4,817	-	18,718	340,324
October	-	-	13,962	14,259	-	28,221	368,545
November	-	1,923	12,732	13,415	-	28,070	396,615
December	-	4,710	15,481	14,298	-	34,489	431,104
TOTAL FOR YEAR	1,850	19,511	128,089	84,347	5,145	238,942	
1966							
January	-	4,445	13,858	15,104	-	33,407	464,511
February	-	3,730	12,192	11,091	-	27,013	491,524
March	-	3,562	13,717	14,964	-	32,243	523,767
April	-	3,704	11,086	11,473	-	26,263	550,030
May	-	3,506	12,272	13,441	-	29,219	579,249
June	-	3,990	11,505	14,069	-	29,564	608,813
July	-	2,953	11,096	13,380	-	27,430	636,243
August	-	2,658	11,775	10,152	-	24,585	660,828
September	-	3,266	11,645	13,064	-	27,975	688,803

CAÑADA OJITOS UNIT - NIOBRARA GREENHORN PARTICIPATING AREA
OIL PRODUCTION BY WELLS BY MONTHS

[redacted]

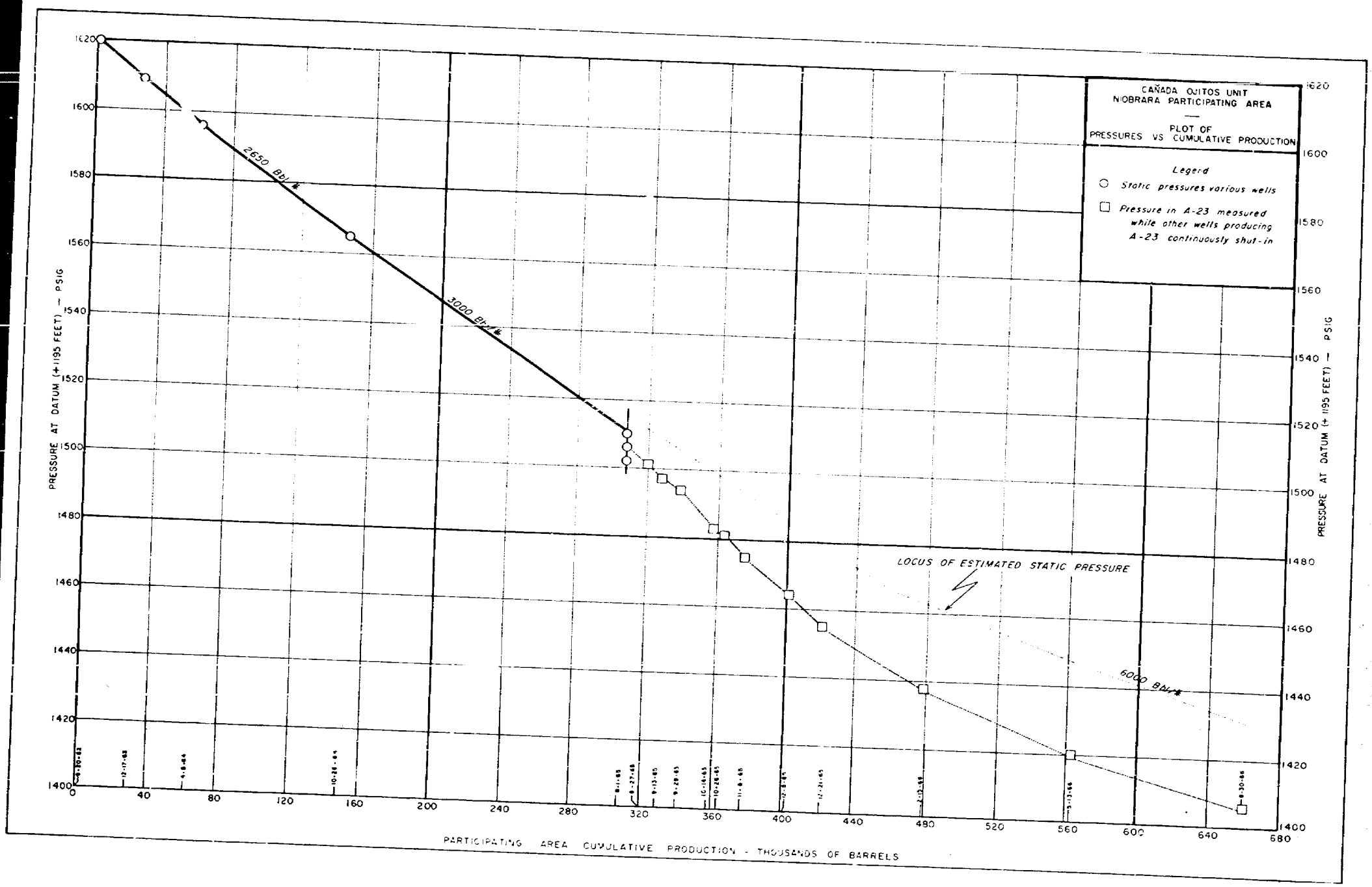
CAÑADA OJITOS UNIT
NIOBRARA-GREENHORN PARTICIPATING AREA

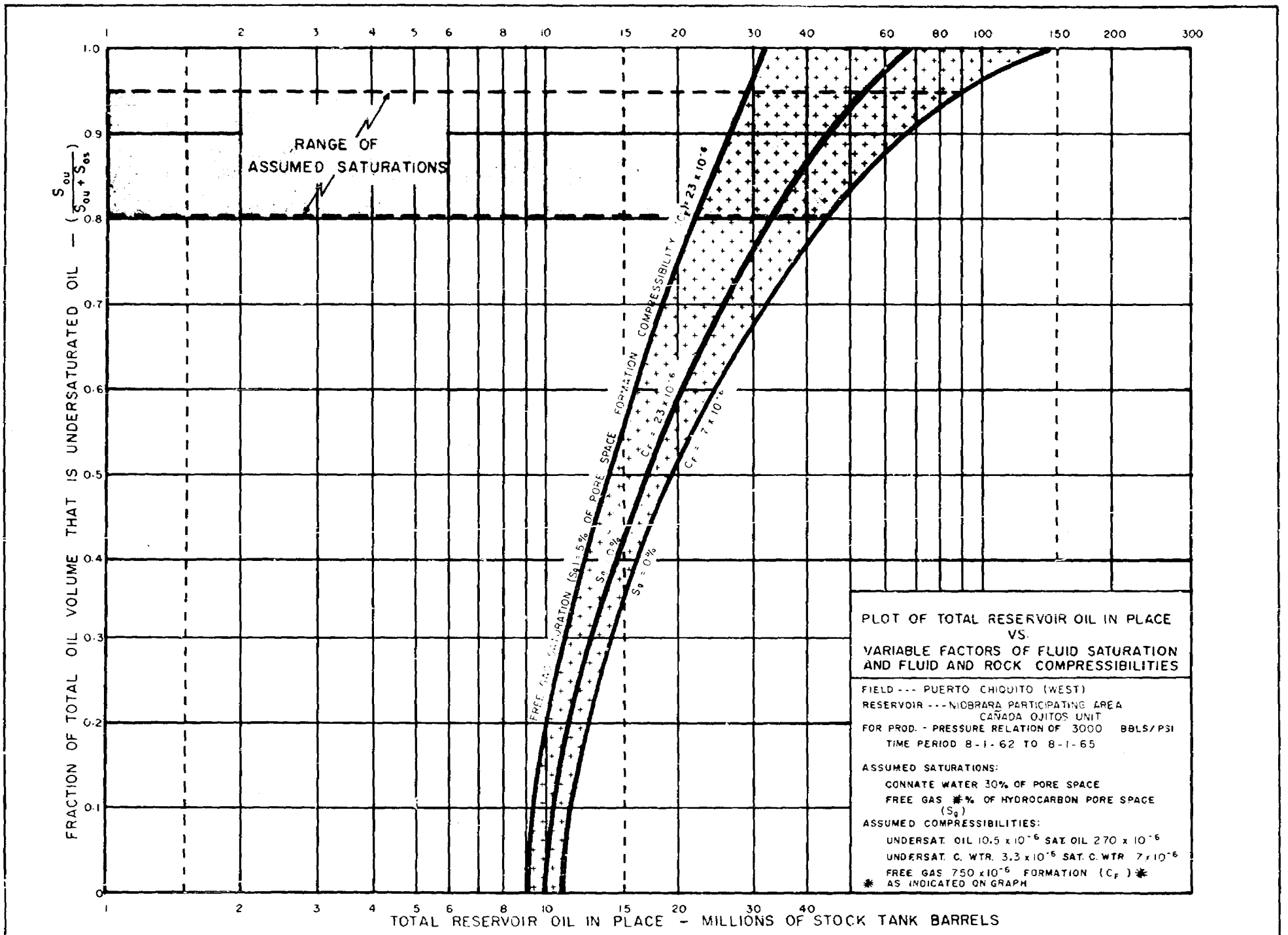
KEY WELL STATIC PRESSURES AND CUMULATIVE PRODUCTION

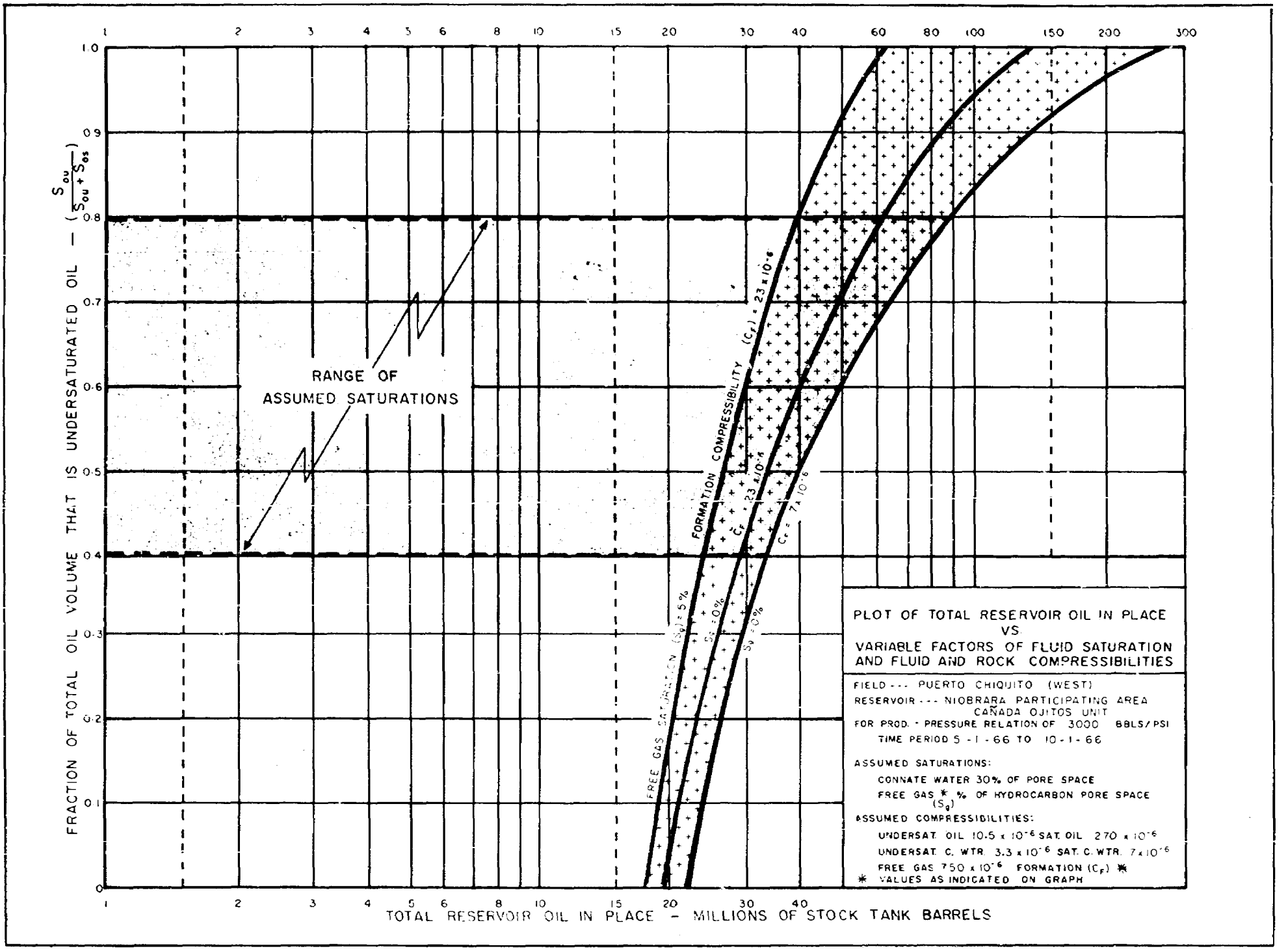
PRESSURES ADJUSTED TO DATUM OF + 1195' ABOVE SEA LEVEL

DATA FOR PERIOD FROM INCEPTION TO AUGUST, 1965

PRESSURE AT + 1195'	DATE	WELL	REMARKS	CUMULATIVE AREA PROD. (BBLS)
1620	9-20-62	K-13	S.I. 37 days	± 100
1609	12-17-63	P-11	After frac, prior to production	28,000
1596	4- 8-64	P-11	S.I. 47 days. Corrected pressure 1595 at uncorrected depth of 6030'	62,000
1565	10-26-64	L-11	After frac, prior to production. Producing wells S.I. 12 days	147,000
1510	7-19-65	A-14		308,000
1510	7-20-65	L-11		"
1502	8- 5-65	K-13		"
1506	8-11-65	A-23		"


CAÑADA OJITOS UNIT
NIOBRARA PARTICIPATING AREA
PLOT OF
PRESSURES VS CUMULATIVE PRODUCTION
Legend
Static pressures various wells
Pressure in A-23 measured while other wells producing A-23 continuously shut-in
2650 Bbl/A
3000 Bbl/A
6000 Bbl/A
LOCUS OF ESTIMATED STATIC PRESSURE
PRESSURE AT DATUM (+1195 FEET) — PSIG
PARTICIPATING AREA CUMULATIVE PRODUCTION - THOUSANDS OF BARRELS
1620
1600
1580
1560
1540
1520
1500
1480
1460
1440
1420
1400
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
640
680


RANGE OF ASSUMED SATURATIONS
FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL — $(\frac{S_{ou}}{S_{ou}+S_{os}})$
TOTAL RESERVOIR OIL IN PLACE - MILLIONS OF STOCK TANK BARRELS
FREE GAS SATURATION (S_g) = 5% OF PORE SPACE
S_g = 0%
S_g = 0%
S_g = 0%
FORMATION COMPRESSIBILITY C_f = 23 x 10⁻⁶
C_f = 23 x 10⁻⁶
C_f = 7 x 10⁻⁶
PLOT OF TOTAL RESERVOIR OIL IN PLACE
VS.
VARIABLE FACTORS OF FLUID SATURATION
AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- PUERTO CHIQUITO (WEST)
RESERVOIR ---NIOBRARA PARTICIPATING AREA
CAÑADA OJITOS UNIT
FOR PROD. - PRESSURE RELATION OF 3000 BBLS/PSI
TIME PERIOD 8-1-62 TO 8-1-65
ASSUMED SATURATIONS:
CONNATE WATER 30% OF PORE SPACE
FREE GAS *% OF HYDROCARBON PORE SPACE (S_g)
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 10.5 x 10⁻⁶ SAT. OIL 270 x 10⁻⁶
UNDERSAT. C. WTR. 3.3 x 10⁻⁶ SAT. C. WTR 7 x 10⁻⁶
FREE GAS 750 x 10⁻⁶ FORMATION (C_F) *
* AS INDICATED ON GRAPH


FRACTION OF TOTAL OIL VOLUME THAT IS UNDERSATURATED OIL — $(\frac{S_{ou}}{S_{ou}+S_{os}})$
TOTAL RESERVOIR OIL IN PLACE - MILLIONS OF STOCK TANK BARRELS
RANGE OF ASSUMED SATURATIONS
FORMATION COMPRESSIBILITY $(C_f) = 23 \times 10^{-6}$
$C_f = 23 \times 10^{-6}$
$C_f = 7 \times 10^{-6}$
FREE GAS SATURATION $(S_g) = 5\%$
$S_g = 10\%$
$S_g = 0\%$
PLOT OF TOTAL RESERVOIR OIL IN PLACE
VS
VARIABLE FACTORS OF FLUID SATURATION
AND FLUID AND ROCK COMPRESSIBILITIES
FIELD --- PUERTO CHIQUITO (WEST)
RESERVOIR --- NIOBRARA PARTICIPATING AREA
CAÑADA OJITOS UNIT
FOR PROD. - PRESSURE RELATION OF 3000 BBLS/PSI
TIME PERIOD 5 - 1 - 66 TO 10 - 1 - 66
ASSUMED SATURATIONS:
CONNATE WATER 30% OF PORE SPACE
FREE GAS * % OF HYDROCARBON PORE SPACE (S_g)
ASSUMED COMPRESSIBILITIES:
UNDERSAT. OIL 10.5 x 10^{-6} SAT. OIL 270 x 10^{-6}
UNDERSAT. C. WTR. 3.3 x 10^{-6} SAT. C. WTR. 7 x 10^{-6}
FREE GAS 750 x 10^{-6} FORMATION (C_F) *
* VALUES AS INDICATED ON GRAPH

PRESSURE FALL-OFF DATA
CANADA OJITOS UNIT NO. O-33
FOLLOWING HYDRAULIC FRACTURE TREATMENT
ON OCTOBER 27, 1966

(Treatment: 207,438 gallons oil, 190,000# sand)

DATE	TIME	DAYS AFTER TREAT-MENT	SURFACE PRESSURE (PSIG)	FLUID LEVEL (FEET FROM SURFACE G.L.)	LENGTH LIQUID COLUMN TO 7300' (RKB) DEPTH	PRESSURE DUE TO OIL COLUMN (PSIG)	TOTAL PRESSURE AT 7300' (RKB) (PSIG)	PRESSURE AT DATUM OF + 1195' (- 296 PSI) (PSIG)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
10-28-66	4:00 PM	1.0	380	0	7285	2593	2973	2677
	8:30 PM	1.2	320	0	7285	2593	2913	2617
10-29-66	6:00 AM	1.6	200	0	7285	2593	2793	2497
	4:30 PM	2.0	100	0	7285	2593	2693	2397
	9:00 PM	2.2	50	0	7285	2593	2643	2347
10-30-66	7:30 AM	2.6	0	133	7152	2545	2545	2249
10-31-66	9:30 AM	3.7	0	632	6653	2368	2368	2072
	4:00 PM	4.0	0	741	6544	2329	2329	2033
11- 1-66	8:00 AM	4.7	0	970	6315	2248	2248	1952
	1:45 PM	4.9	0	1049	6236	2219	2219	1923
11- 2-66	8:10 AM	5.7	0	1240	6045	2151	2151	1855
11- 3-66	8:00 AM	6.7	0	1438	5847	2081	2081	1785
11- 4-66	6:30 AM	7.6	0	1578	5707	2031	2031	1735
	6:00 PM	8.1	0	1731	5554	1977	1977	1681
11- 5-66	6:30 AM	8.6	0	1784	5501	1958	1958	1662
	3:00 PM	9.0	0	1836	5449	1939	1939	1643
11- 6-66	6:30 AM	9.6	0	1890	5395	1920	1920	1624
	5:30 PM	10.1	0	1926	5359	1907	1907	1611

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11- 7-66	7:00 AM	10.6	0	1969	5316	1892	1892	1596
	3:00 PM	11.0	0	1993	5292	1883	1883	1587
11- 8-66	8:00 AM	11.7	0	2043	5242	1866	1866	1570
11- 9-66	8:30 AM	12.7	0	2091	5194	1849	1849	1553
	3:00 PM	12.9	0	2102	5183	1845	1845 *	1549 *
	5:00 PM	13.0	0	2106	5179	1843	1843	1547
11-10-66	9:45 AM	13.7	0	2136	5149	1833	1833	1537
11-11-66	8:30 AM	14.7	0	2170	5115	1820	1820	1524

NOTE (1): ELEVATION = 7548 RKB
PAY DEPTH = 7300
DATUM OF PAY +248

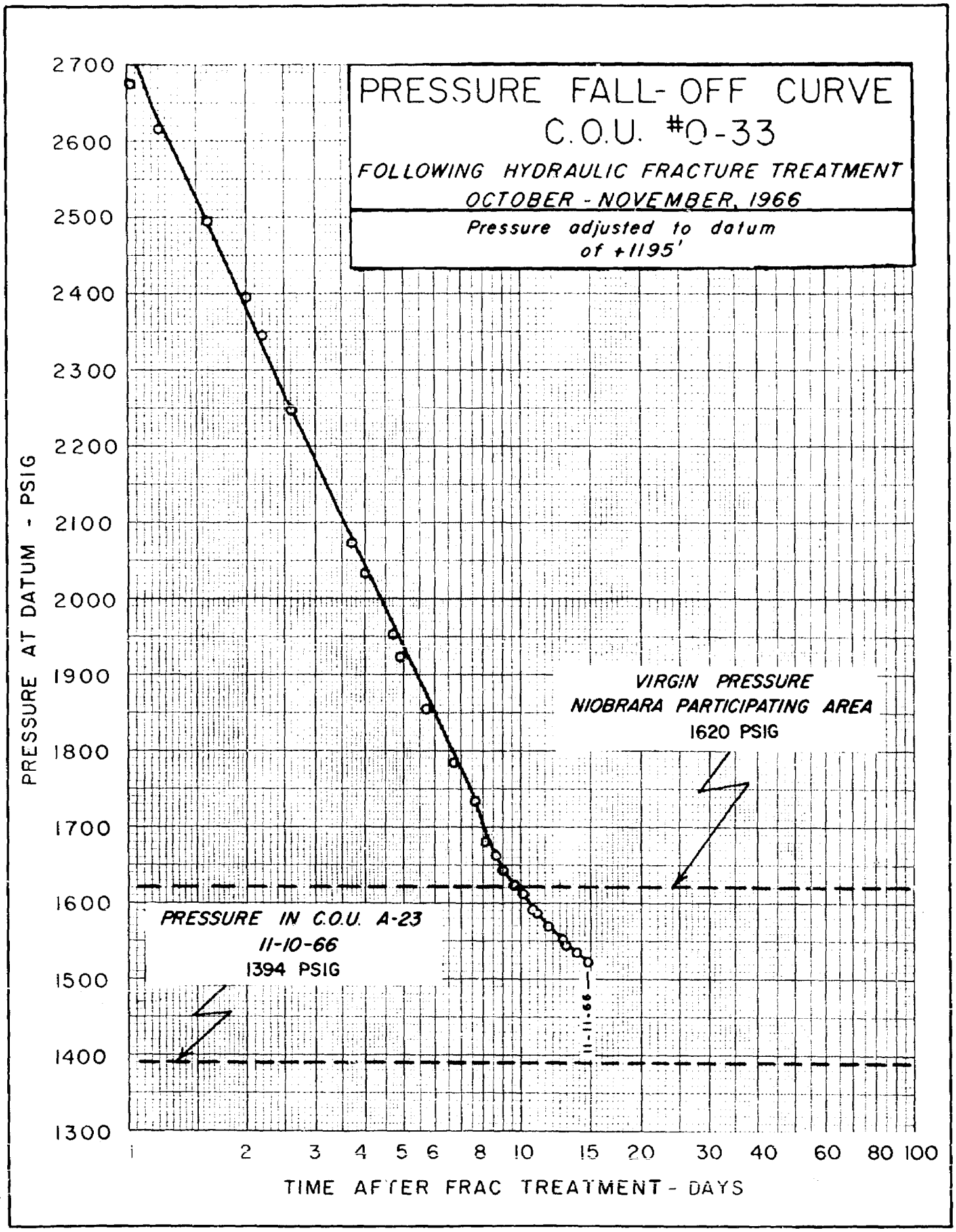
ADJUSTMENT TO + 1195 DATUM = (1195-248)(.312) = 296 psi

NOTE (2): GRADIENT PRESSURE OF OIL COLUMN = .3559#/sq.in./ft. DETERMINED FROM MEASURED BOTTOM HOLE PRESSURE ON 11-9-66

NOTE (3): RESERVOIR GRADIENT PRESSURE = .312#/sq.in./ft. (FROM FLUID SAMPLE ANALYSIS FOR PRESSURES 1520 psi TO 1800 psi).

* DETERMINED FROM MEASURED BOTTOM HOLE PRESSURE AT 7300' RKB.

PRESSURE FALL-OFF DATA
CANADA OJITOS UNIT NO. O-33


PRESSURE FALL-OFF CURVE
C.O.U. #0-33
FOLLOWING HYDRAULIC FRACTURE TREATMENT
OCTOBER - NOVEMBER, 1966
Pressure adjusted to datum of +1195'
VIRGIN PRESSURE
NIOBRARA PARTICIPATING AREA
1620 PSIG
PRESSURE IN C.O.U. A-23
11-10-66
1394 PSIG
11-11-66
PRESSURE AT DATUM - PSIG
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1
2
3
4
5
6
8
10
15
20
30
40
60
80
100
TIME AFTER FRAC TREATMENT - DAYS

ESTIMATION OF AREA OF LOW PERMEABILITY (AS COMPARED TO OVERALL RESERVOIR) IMMEDIATELY IN COMMUNICATION WITH CANADA OJITOS UNIT NO. P-11

$$N = \frac{q\ t}{1.74\ m\ C_e\ \bar{t}}$$

where N = total stock tank barrels in place

q = production rate, BOPD (550)

t = time, days

m = slope, psi/$\log_{10}$ cycle

C_e = effective compressibility $\Delta V/V/psi$ (estimated here to be 25×10^{-6})

$\bar{t}$ = dimensionless time for time t

$$\overline{\Delta P} = \frac{1.15\ (P_{ws} - P_t)}{m}$$

(Reference: Exhibit regarding methods of calculations)

1. ASSUMPTION: Pressure at 10 days is within 5 pounds of static pressure

$$\overline{\Delta P} = \frac{(1.15)(5)}{72} = .08$$

$\bar{t}$ for $\overline{P} = .08 = .47$ (from Perrine, constant pressure at boundary)

$$N = \frac{(550)(10)}{(1.74)(72)(25 \times 10^{-6})(.47)} = 3{,}700{,}000 \text{ barrels}$$

If oil in place is approximately 2,000 bbl/acre

Area of "low" permeability $= \frac{3{,}700{,}000}{2{,}000} = 1{,}800$ acres (approx.)

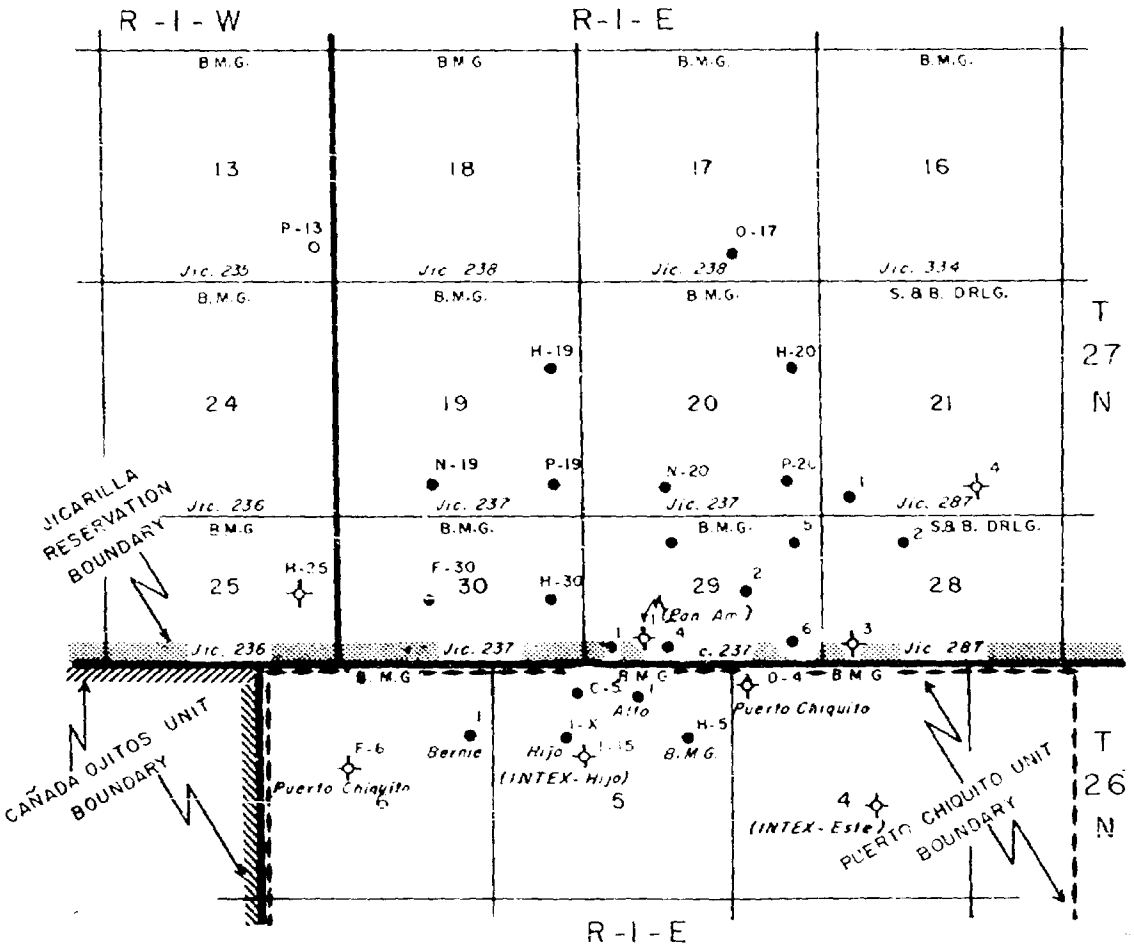
2. ASSUMPTION: Pressure at 10 days is within 10 pounds of static pressure

By same method as above

$N = 4{,}700{,}000$ barrels.

Area $= \pm$ 2,300 acres

PLOT OF PORTION
OF
NORTHEAST PUERTO CHIQUITO MANCOS POOL



NORTHEAST PUERTO CHIQUITO MANCOS POOL

1960	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
February	1	-0-	268	-0-	268
March	1	-0-	1863	-0-	2,131
April	1	-0-	1984	-0-	4,115
May	1	-0-	1929	-0-	6,044
June	1	-0-	2306	-0-	8,350
July	1	-0-	1175	-0-	9,525
August	1	-0-	2517	-0-	12,042
September	1	-0-	2117	-0-	14,159
October	1	-0-	2166	-0-	16,325
November	1	239	910	239	17,235
December	1	475	220	714	17,455

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1961	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	1	660	406	1,374	17,861
February	1	166	467	1,540	18,328
March	1	-0-	526	1,540	18,854
April	1	62	513	1,602	19,367
May	2	54	940	1,656	20,307
June	2	74	953	1,730	21,260
July	1	43	581	1,773	21,841
August	2	47	1148	1,820	22,989
September	2	45	910	1,865	23,899
October	2	42	1294	1,907	25,193
November	2	42	886	1,949	26,079
December	2	39	590	1,988	26,669

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1962	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	2	38	879	2,026	27,548
February	2	29	1222	2,055	28,770
March	3	47	1775	2,102	30,545
April	4	45	2045	2,147	32,590
May	5	44	2225	2,191	34,815
June	5	45	2507	2,236	37,322
July	5	180	2472	2,416	39,794
August	6	151	2655	2,567	42,449
September	4	142	2123	2,709	44,572
October	10	150	4181	2,859	48,753
November	9	99	3647	2,958	52,400
December	10	154	4365	3,112	56,765

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1963	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	10	154	5385	3,266	62,150
February	11	154	4870	3,420	67,020
March	10	145	5223	3,565	72,243
April	10	148	5772	3,713	78,015
May	13	145	6650	3,858	84,665
June	13	150	7225	4,008	91,890
July	14	155	8591	4,163	100,481
August	14	104	8619	4,267	109,100
September	14	124	7935	4,391	117,035
October	14	150	8213	4,541	125,248
November	14	135	8473	4,676	133,721
December	15	140	9243	4,816	142,964

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1964	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	15	150	8379	4,966	151,343
February	17	19	8001	4,985	159,344
March	17	110	10936	5,095	170,280
April	17	109	11284	5,204	181,564
May	17	27	11920	5,231	193,484
June	18	159	13154	5,390	206,638
July	17	240	14142	5,630	220,780
August	18	155	15537	5,785	236,317
September	19	150	16270	5,935	252,587
October	19	1974	19844	7,909	272,431
November	19	1560	22617	9,469	295,048
December	18	632	22955	10,101	318,003

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1965	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	18	81	22598	10,182	340,601
February	17	102	21213	10,284	361,814
March	17	159	14096	10,443	375,910
April	18	111	28309	10,554	404,219
May	18	116	31516	10,670	435,735
June	18	109	29362	10,779	465,097
July	18	114	30312	10,893	495,409
August	15	83	24484	10,976	519,893
September	15	123	28420	11,099	548,313
October	15	96	34755	11,195	583,068
November	14	96	33542	11,291	616,610
December	14	134	30517	11,425	647,127

NORTHEAST PUERTO CHIQUITO MANCOS POOL

1966	NUMBER OF WELLS	BARRELS OF WATER	BARRELS OF OIL	CUMULATIVE WATER	CUMULATIVE OIL
January	14	4332	29417	15,757	676,544
February	14	5715	34667	21,472	711,211
March	13	4371	28415	25,843	739,626
April	13	5294	34579	31,137	774,205
May	13	4535	30690	35,672	804,895
June	13	3122	20648	38,794	825,543

PRESSURE - PRODUCTION DATA
NORTHEAST PUERTO CHIQUITO RESERVOIR
PRESSURE DATA FOR BENSON-MONTIN-GREER DRILLING CORP.
JICARILLA 237 NO. P-19

DATE	PRESSURE	DEPTH	PRESSURE AT DATUM + 4900'	CUMULATIVE BARRELS OF OIL PRODUCED FROM NORTHEAST PUERTO CHIQUITO
7-30-63	378	2100 (Gd)	393	100,500
10-24-63	370	2100 (Gd)	385	125,200
6- 9-64	363	2100 (Gd)	378	197,000
3- 7-66	389	2500 (RKB)	263	711,000
6- 1-66	379	2500 (RKB)	253	805,000
6-25-66	389	2500 (RKB)	263	820,000

PLOT OF PRODUCTION
NORTHEAST PUERTO CHIQUITO RESERVOIR
VS
PRESSURE IN P-19 WELL
DATUM +4900'

PRESSURE AT DATUM (+1900 FEET) - PSIG

450
425
400
375
350
325
300
275
250
225
200

0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850

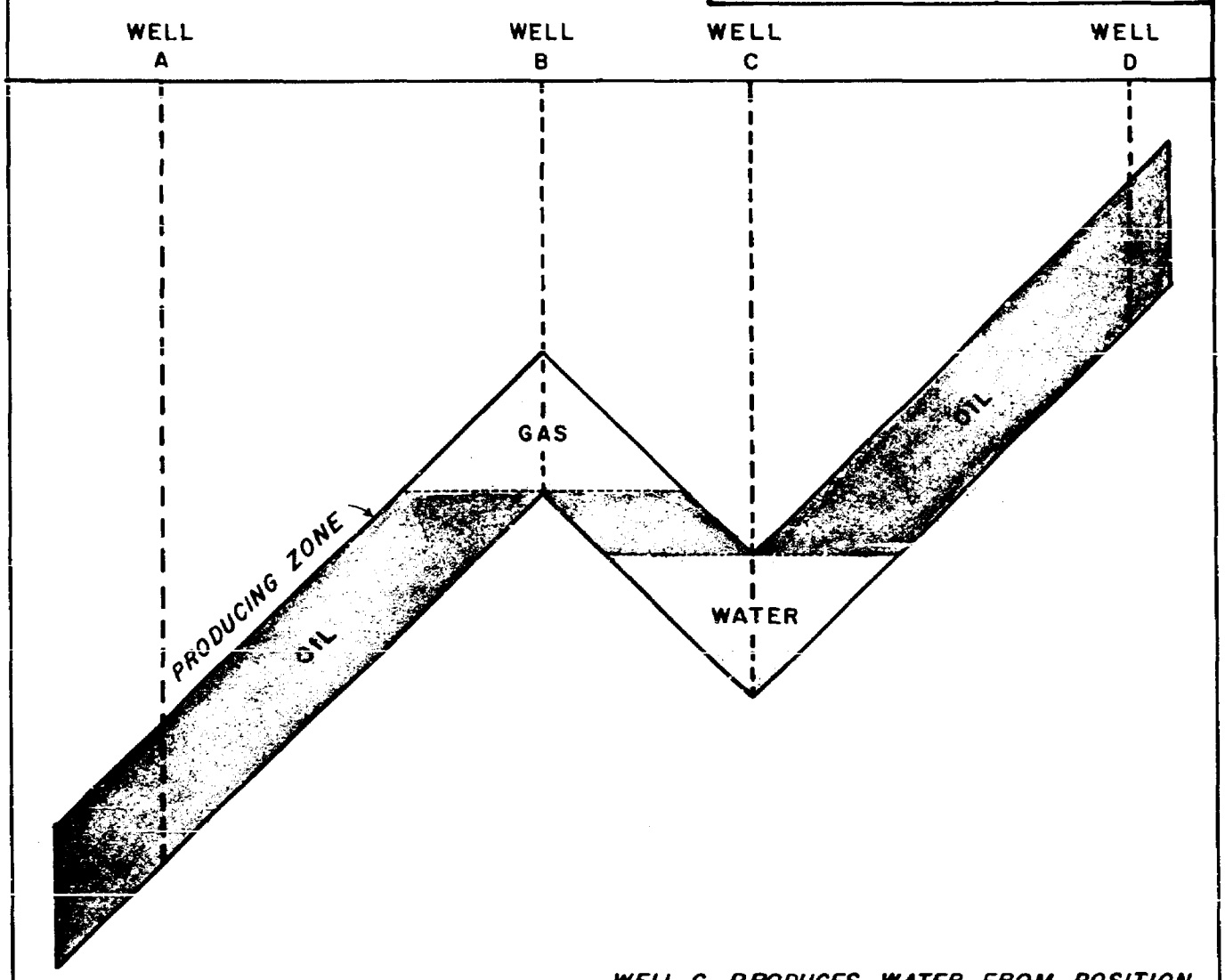
NORTHEAST PUERTO CHIQUITO CUMMULATIVE PRODUCTION - THOUSANDS OF BARRELS

7-30-63
10-24-63
6-9-64
1-7-66
6-20-66

ALL WELLS SHUT IN 10 DAYS

ALL WELLS PRODUCING

SKETCH SHOWING
POSSIBLE STRUCTURAL
CONDITION WHICH
WOULD TRAP
RESERVOIR FLUIDS
CONTRARY TO
NORMAL GRAVITATIONAL
SEGREGATION



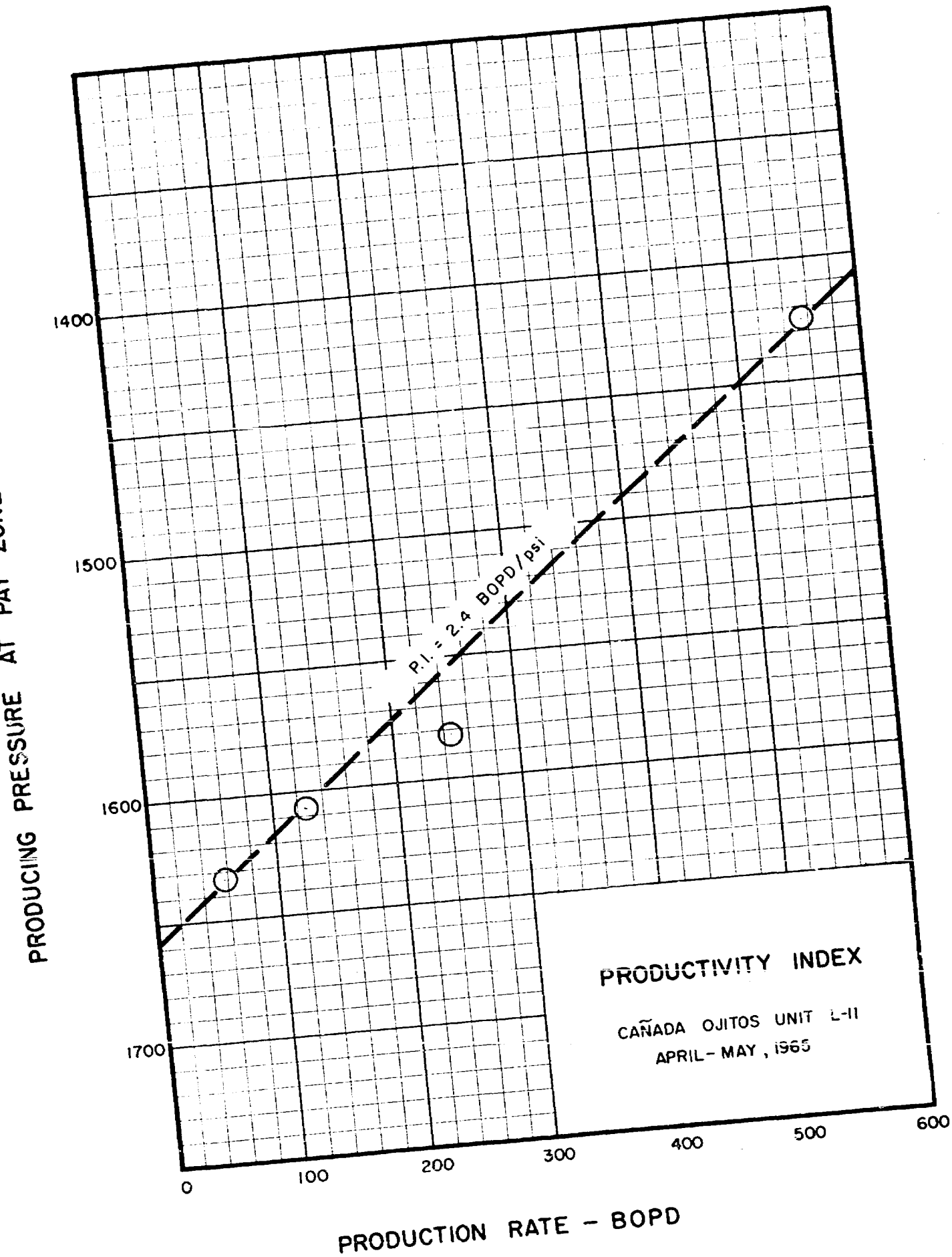
WELL C PRODUCES WATER FROM POSITION STRUCTURALLY HIGHER THAN WELL A WHICH PRODUCES OIL

WELL B PRODUCES GAS FROM POSITION STRUCTURALLY LOWER THAN WELL D WHICH PRODUCES OIL

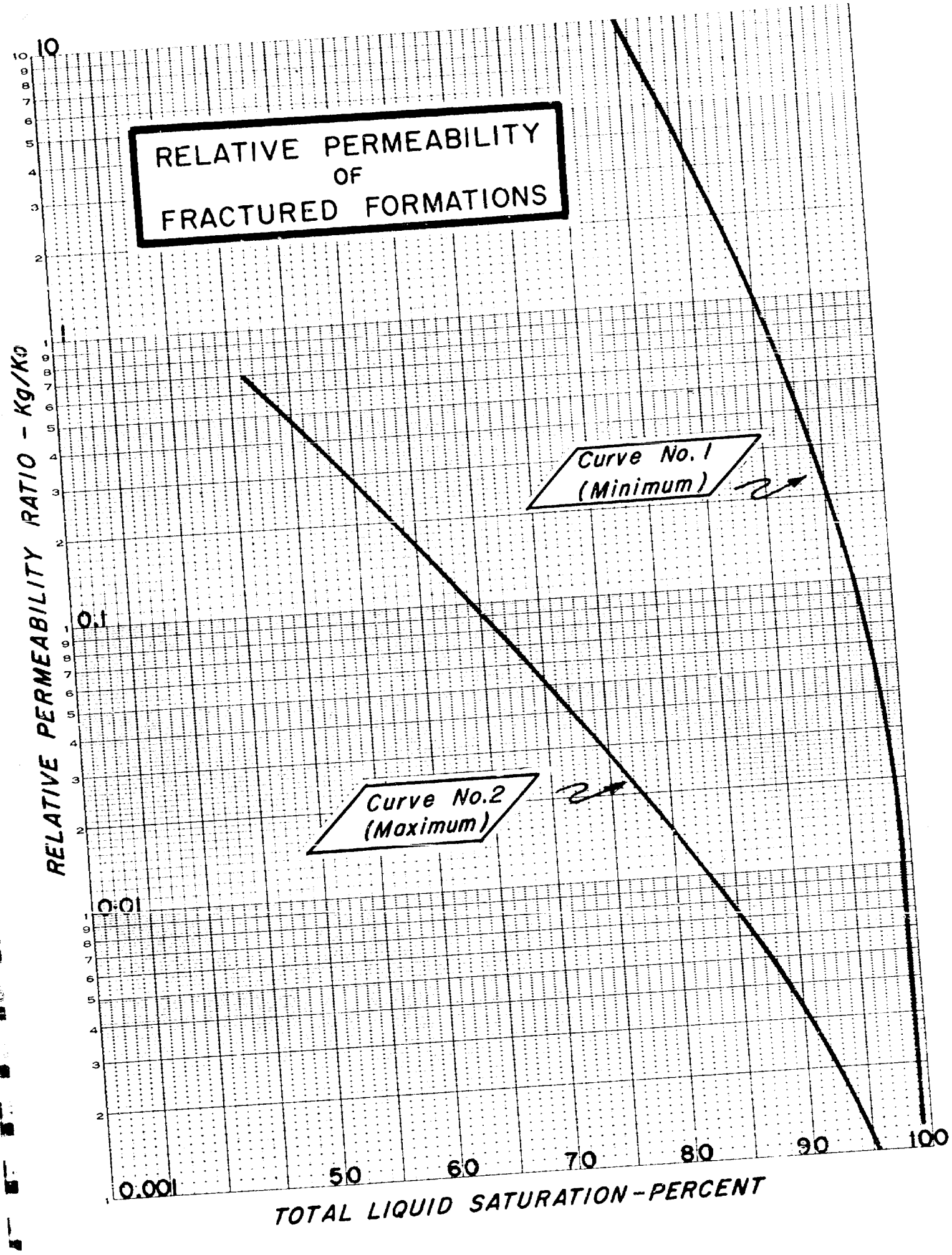
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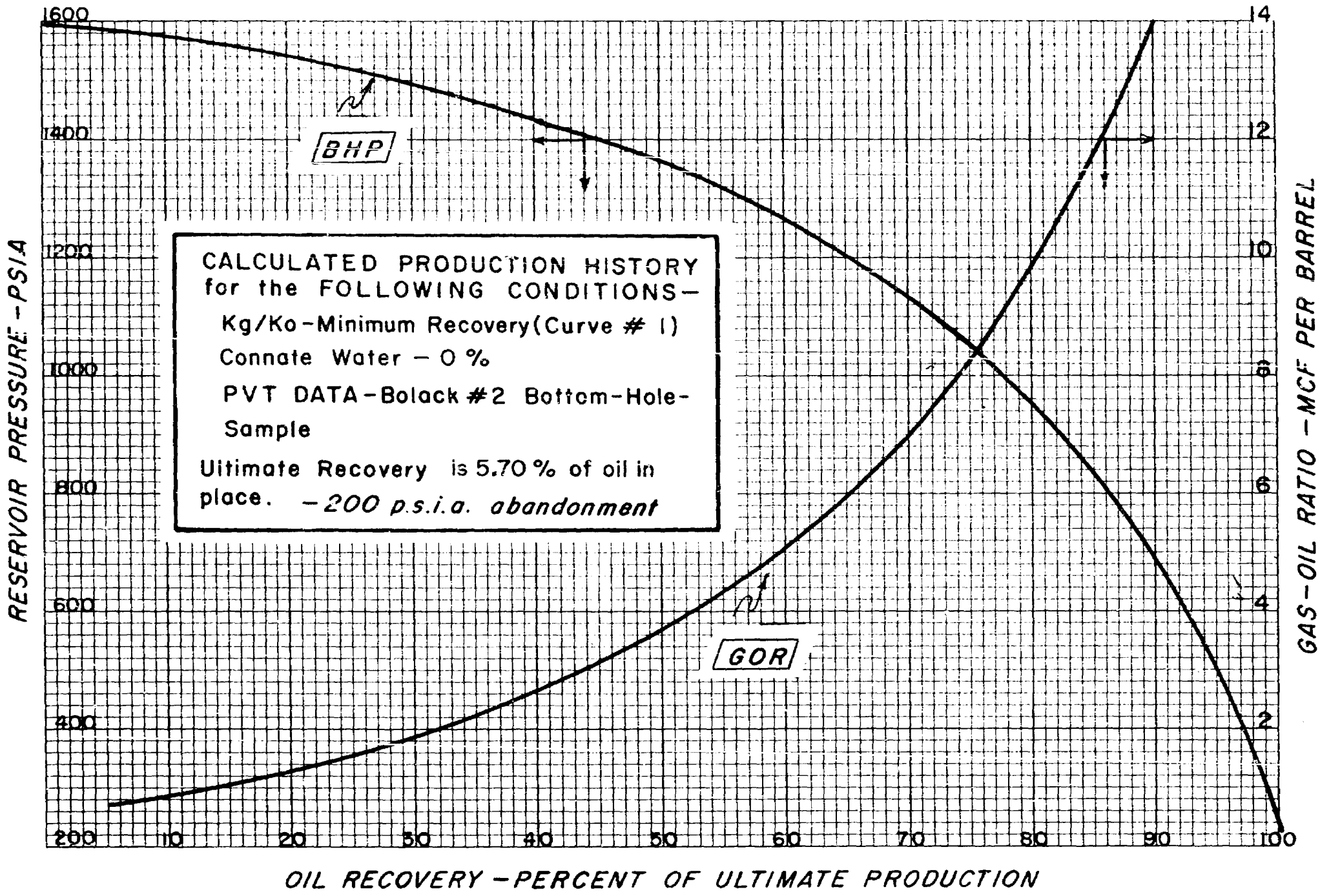
PRODUCTIVITY INDEX TEST
CANADA OJITOS UNIT NO. L-11
APRIL-MAY, 1965

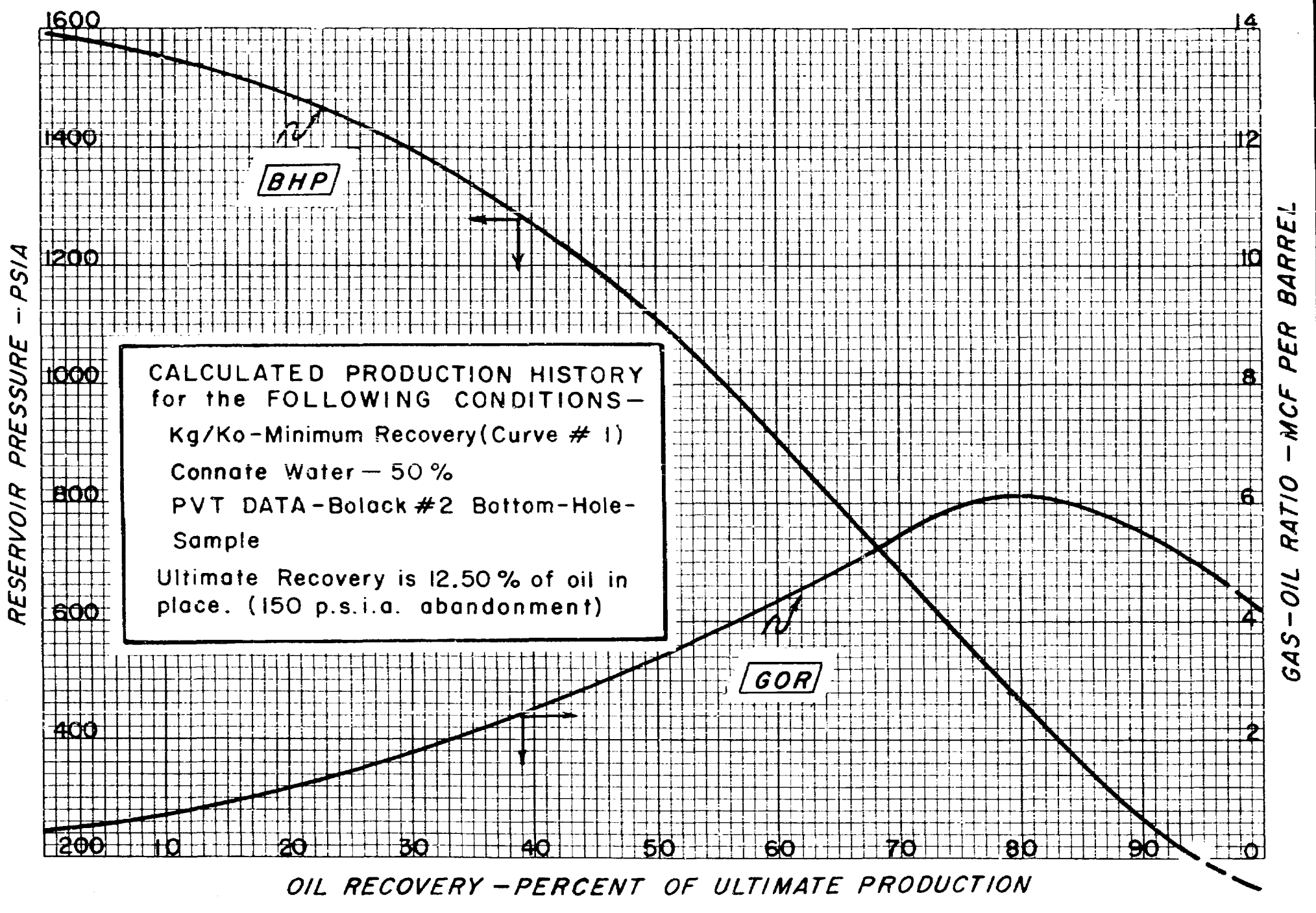
DATE	4-14	4-22	4-28	5-3
APPROXIMATE PRODUCTION RATE, BOPD	550	250	130	60
SURFACE CASING PRESSURE (PSIG)	900	1015	1035	1060
ESTIMATED WORKING BOTTOM HOLE PRESSURE AT PAY DEPTH OF 6660' (PSIG)	1423	1581	1607	1638

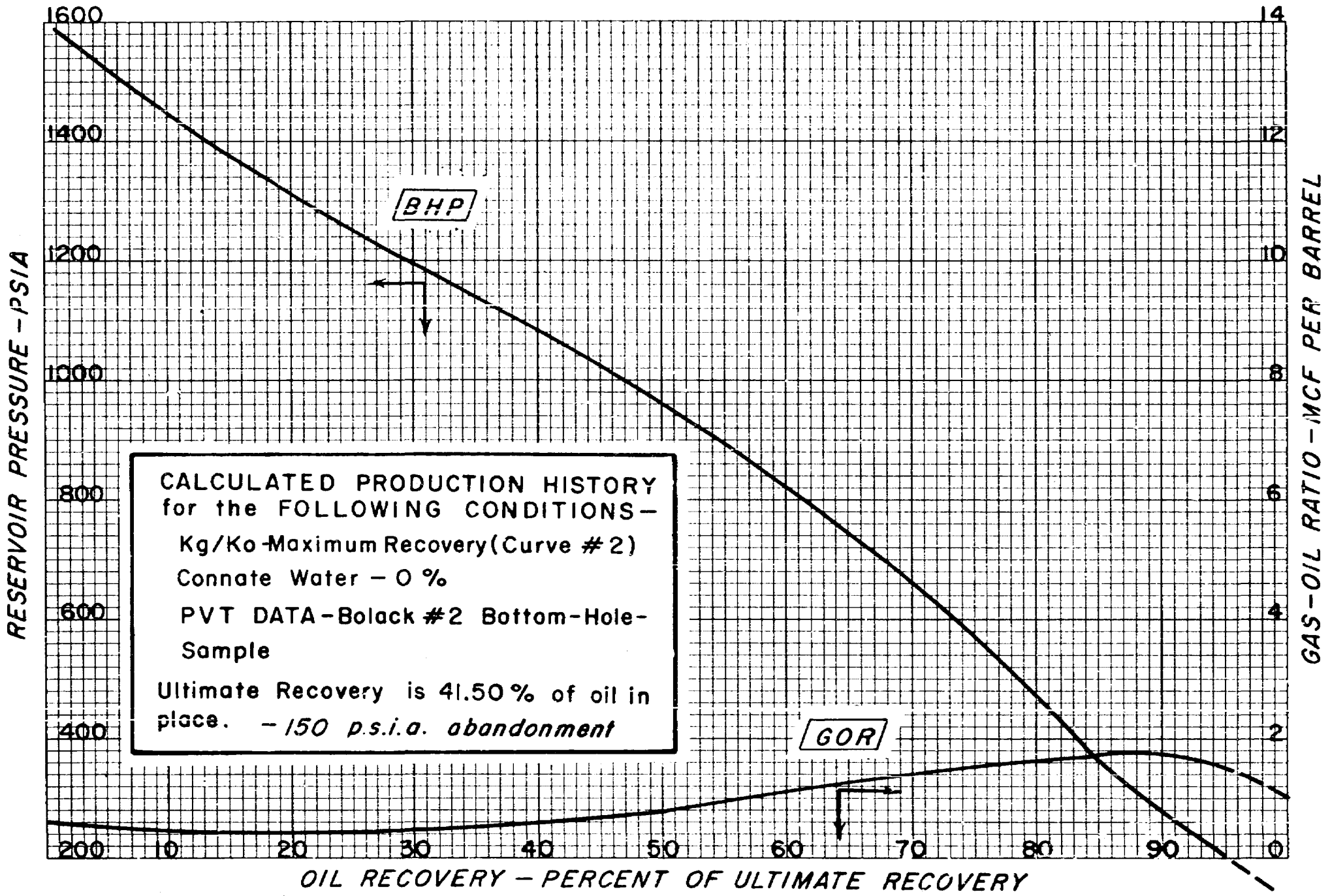

PRODUCING PRESSURE AT PAY ZONE - PSIG
1400
1500
1600
1700
P.I. = 2.4 BOPD/psi
PRODUCTIVITY INDEX
CAÑADA OJITOS UNIT L-11
APRIL - MAY, 1965
0
100
200
300
400
500
600
PRODUCTION RATE - BOPD

RELATIVE PERMEABILITY OF FRACTURED FORMATIONS

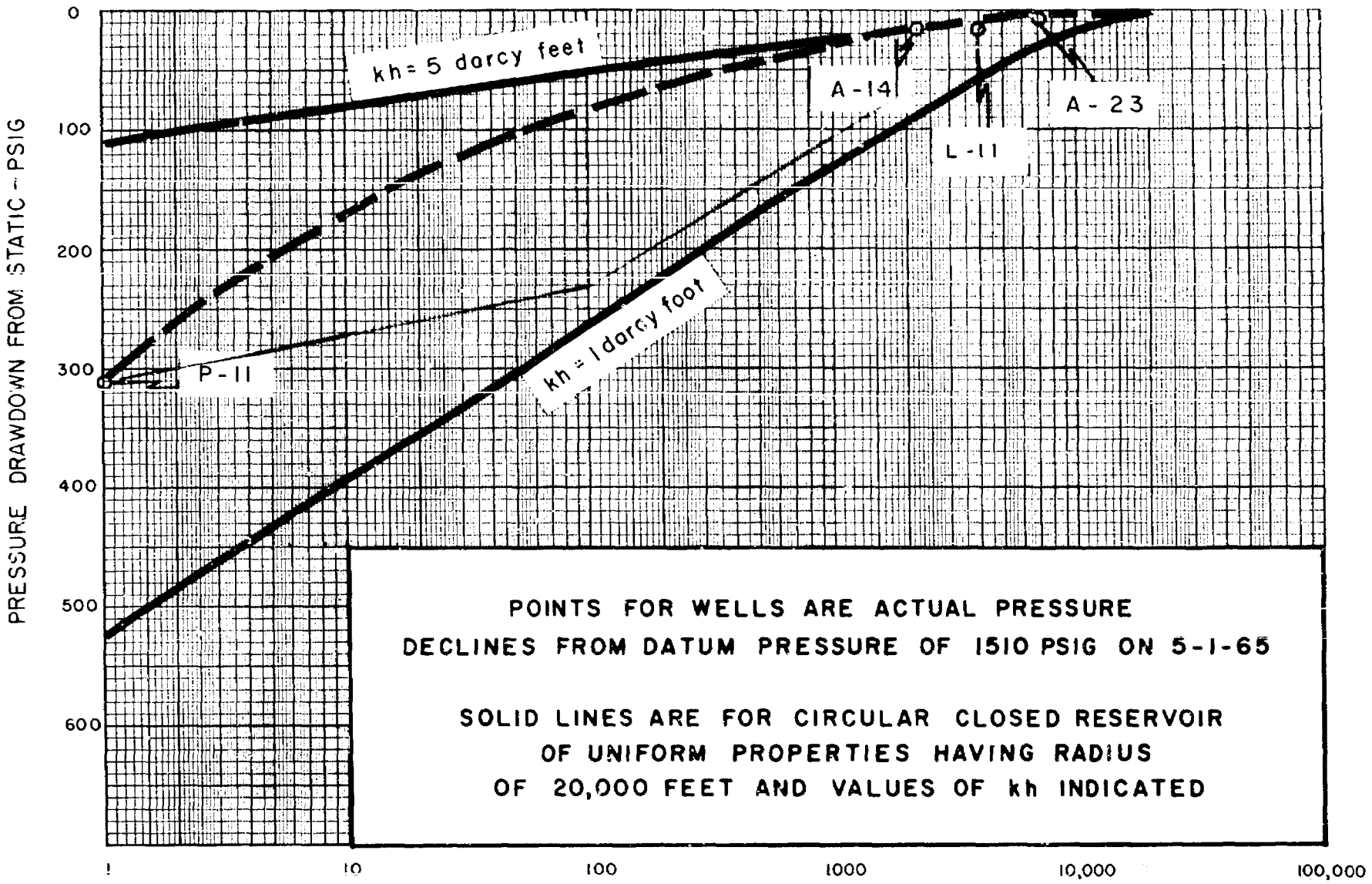


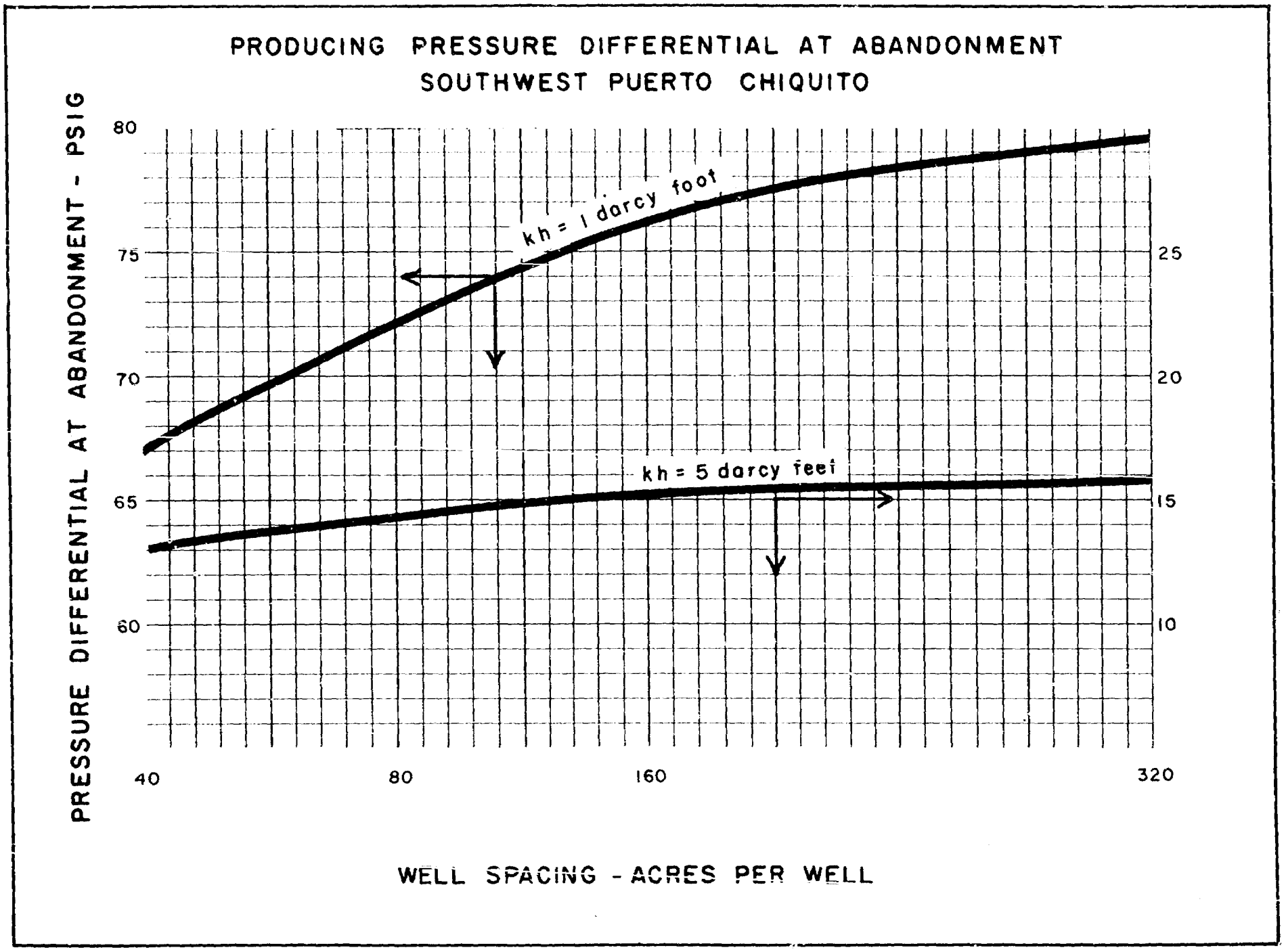

CALCULATED PRODUCTION HISTORY for the FOLLOWING CONDITIONS–
Kg/Ko – Minimum Recovery (Curve # 1)
Connate Water – 0 %
PVT DATA – Bolack #2 Bottom-Hole-Sample
Ultimate Recovery is 5.70 % of oil in place. – 200 p.s.i.a. abandonment
BHP
GOR
RESERVOIR PRESSURE – PSIA
GAS – OIL RATIO – MCF PER BARREL
OIL RECOVERY – PERCENT OF ULTIMATE PRODUCTION
1600
1400
1200
1000
800
600
400
200
14
12
10
8
6
4
2
10
20
30
40
50
60
70
80
90
100


1600
1400
1200
1000
800
600
400
200
14
12
10
8
6
4
2
0
BHP
GOR
CALCULATED PRODUCTION HISTORY for the FOLLOWING CONDITIONS—
Kg/Ko-Minimum Recovery(Curve # 1)
Connate Water — 50 %
PVT DATA-Bolack #2 Bottom-Hole-Sample
Ultimate Recovery is 12.50 % of oil in place. (150 p.s.i.a. abandonment)
10
20
30
40
50
60
70
80
90
RESERVOIR PRESSURE - PSIA
GAS-OIL RATIO - MCF PER BARREL
OIL RECOVERY - PERCENT OF ULTIMATE PRODUCTION


RESERVOIR PRESSURE – PSIA
1600
1400
1200
1000
800
600
400
200
BHP
GOR
CALCULATED PRODUCTION HISTORY for the FOLLOWING CONDITIONS–
Kg/Ko-Maximum Recovery (Curve #2)
Connate Water – 0 %
PVT DATA-Bolack #2 Bottom-Hole-Sample
Ultimate Recovery is 41.50 % of oil in place. – 150 p.s.i.a. abandonment
10
20
30
40
50
60
70
80
90
OIL RECOVERY – PERCENT OF ULTIMATE RECOVERY
14
12
10
8
6
4
2
0
GAS-OIL RATIO – MCF PER BARREL

PRODUCING PRESSURE DIFFERENTIAL
SOUTHWEST PUERTO CHIQUITO
SEPTEMBER, 1965




PRODUCING PRESSURE DIFFERENTIAL AT ABANDONMENT
SOUTHWEST PUERTO CHIQUITO
PRESSURE DIFFERENTIAL AT ABANDONMENT - PSIG
80
75
70
65
60
25
20
15
10
kh = 1 darcy foot
kh = 5 darcy feet
40
80
160
320
WELL SPACING - ACRES PER WELL

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page No.

CORE ANALYSIS RESULTS

Company	BOLACK & GREER, INC.	Formation	GALLUP	File	RP-3-1916
Well	CANADA-OJITOS UNIT 12-T	Core Type	DIA. CONV.	Date Report	8-30-64
Field	WILDCAT	Drilling Fluid	100% OIL	Analysts	HUFF
County	RIO ARRIBA State NEW MEX.	Elev. 7220 GR	Location NW SW Sec 11 T25N R1W		

Lithological Abbreviations

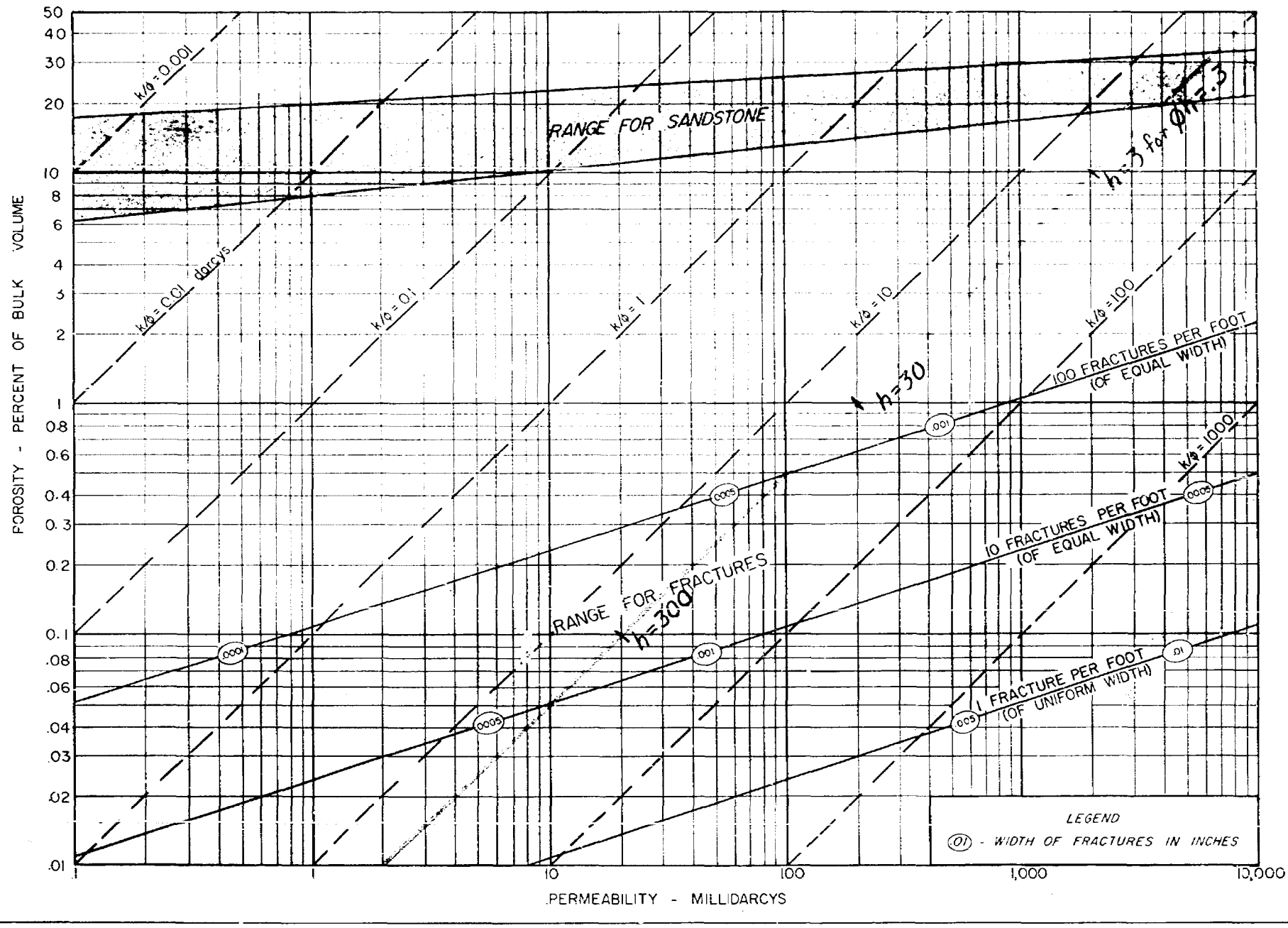
SAMPLE NUMBER	DEPTH FEET	PERMEABILITY MILLIDARCYS	POROSITY PERCENT	% OIL SATURATION PERCENT PORE SPACE	% WATER SATURATION PERCENT PORE SPACE	SAMPLE DESCRIPTION AND REMARKS	
1	6673-74	0.02	3.3	39.4	57.6	Sandstone, silty, carb	97 ⊘ ⊻
2	6674-75	0.22	4.4	22.6	68.2	Sandstone, silty, carb	90 ⊘ ⊻
3	6675-76	0.12	4.1	28.4	63.4	Sandstone, silty, carb	87 ⊘ ⊻
4	6676-77	0.03	4.0	25.0	52.6	Sandstone, silty, carb	77 ⊘ ⊻

SERVICE NO. 8

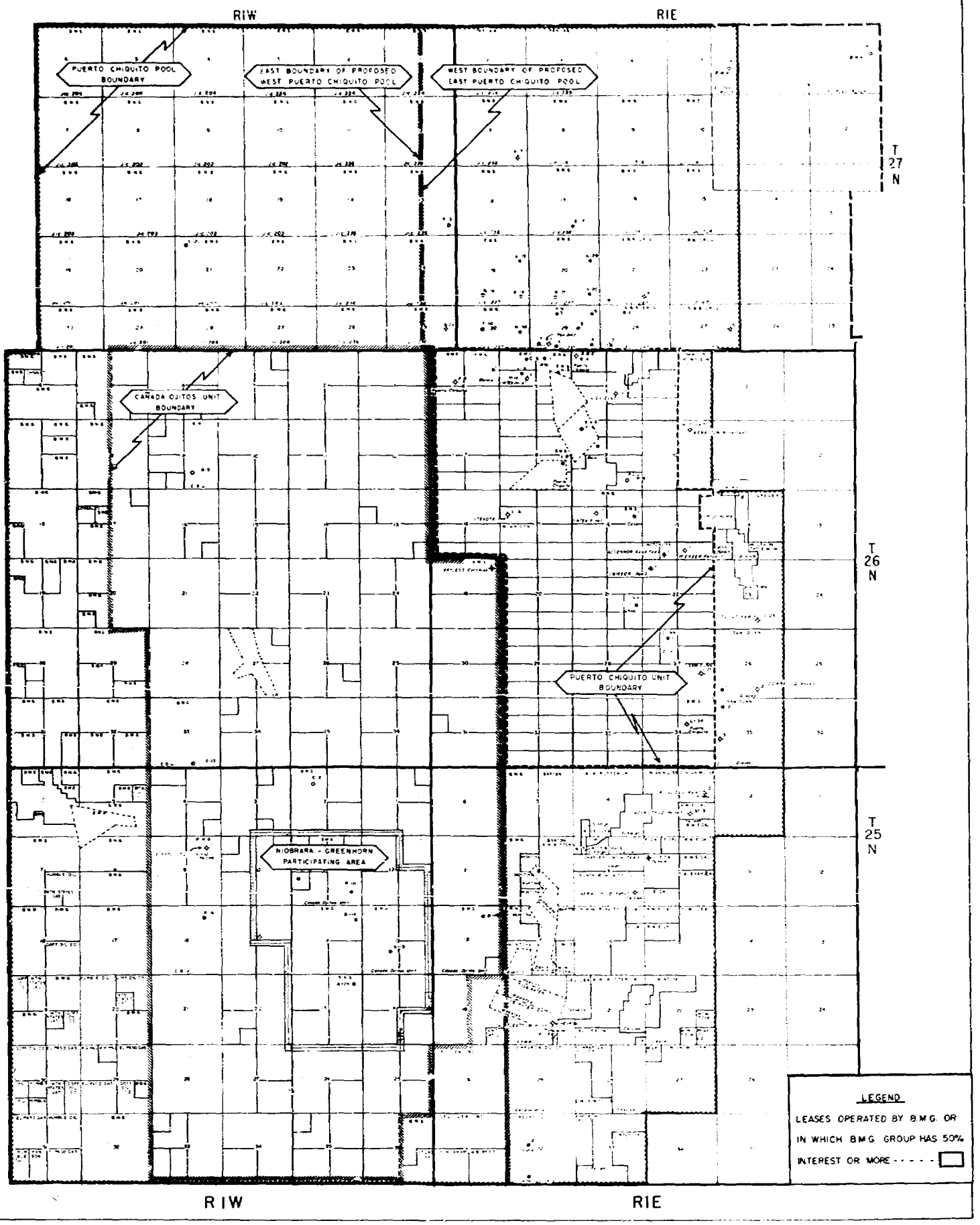
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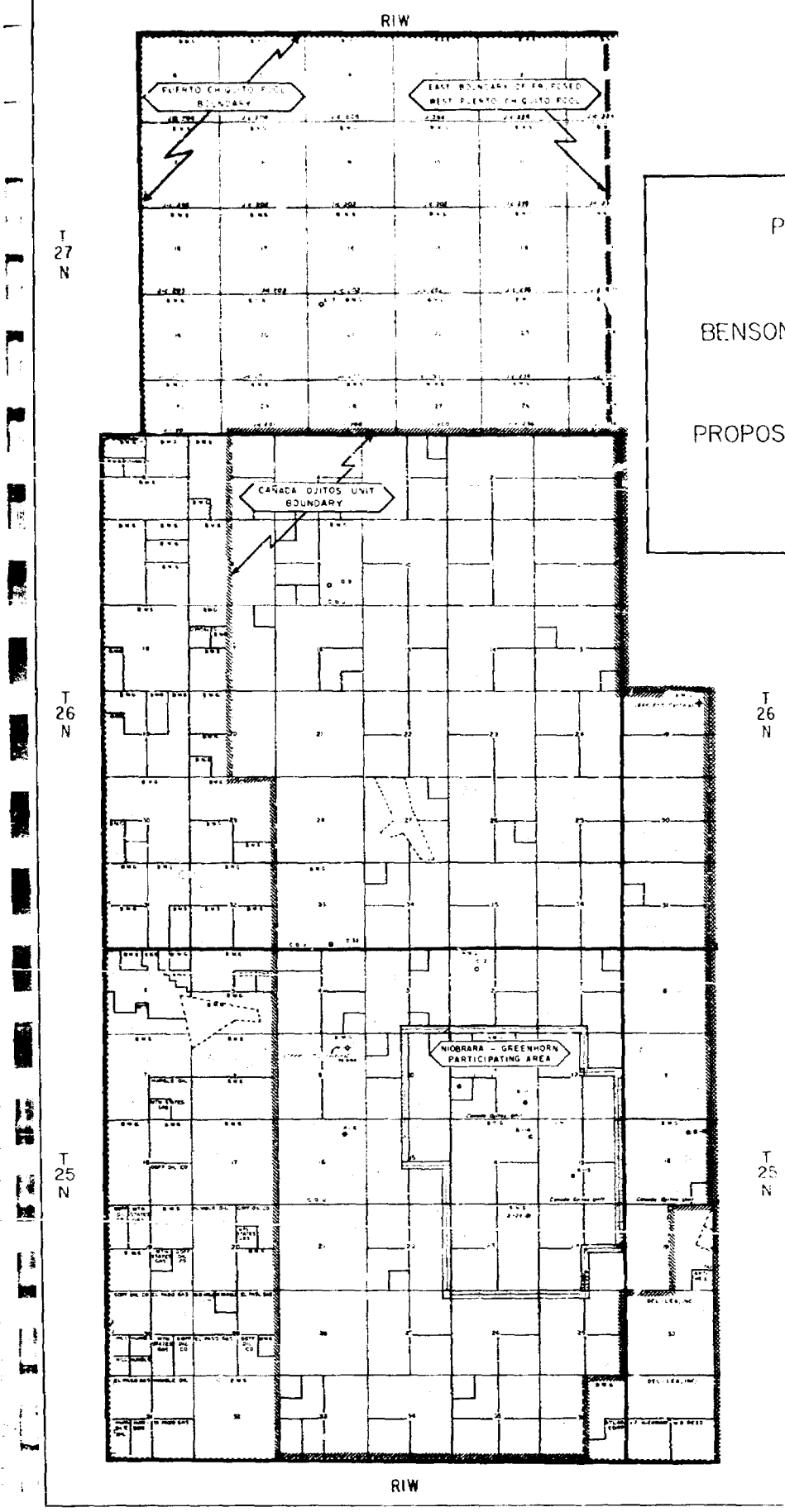
VALUES OF K/φ FOR SANDSTONE RESERVOIRS AND FOR FLOW SYSTEMS OF FRACTURES IN AN IMPERMEABLE MATRIX

FRACTURES PARALLEL TO DIRECTION OF FLOW



OIL AND GAS LEASE OWNERSHIP
PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO





POSITION OF LEASE OWNERS
REGARDING APPLICATION
OF
BENSON - MONTIN - GREER DRLG. CORP.
FOR
320 ACRE SPACING IN
PROPOSED WEST PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY
NEW MEXICO

LEGEND

LEASES HELD BY OWNERS WHOSE POSITION REGARDING APPLICATION FOR 320 ACRE SPACING IN PROPOSED WEST PUERTO CHIQUITO POOL IS:

FOR - - - - - - - - - - -

AGAINST - - - - - - - - -

UNDECLARED - - - - - - -

UNLEASED LANDS - - - -