SPE

Society of Petroleum Engineers

SPE 23956

The Redevelopment of Depleted Queen Waterflood Projects in the Permian Basin

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Revised 3/19/92

Introduction

Significant future reserve additions in the Permian Basin of West Texas and Southeastern New Mexico will come about through improved oil recovery techniques (IOR) applied to existing reservoirs. The major companies have an impressive list of improved or enhanced recovery projects on their strategic lists. On the other side of the street, independents are competing to acquire the major's non-strategical properties that are judged to have IOR potential. The Permian Basin is certainly one of the world's most mature producing provinces, but it is also a frontier for advanced IOR technology.

Primary development of the world class Permian Age producing horizons in the Permian Basin occurred from the mid-1930's through the 1950's. The 1960's was the era of secondary recovery with the establishment of many of the Basin's water injection projects. A majority of these waterflood projects were probably based on the "Tank Model" concept of a reservoir, involving little or no geologic input. The fallout from the initial failure of some of these projects started industry on the road to developing a joint geo-logical/engineering approach. One of the earlier papers to appear in engineering literature discussing the geological aspects was Dowling's 1970 paper titled "Application of Carbonate Environmental Concepts to Secondary Recovery Projects"[1]. A recent contribution in this area is a 1991 SPE Paper by Holtz, Ruppel and Hocott with the Bureau of Economic Geology at the University of Texas[2]. Reading these two papers together shows the advances in carbonate geology and it's application to reservoir exploitation.

On the engineering side, much of the emphasis has been infill drilling. A 1974 paper by Driscoll listed nine factors that influence additional recovery through infill drilling[3]. In 1976, Stiles authored a paper on optimizing waterflood recovery in the Clearfork[4]. This was the first of several papers by Stiles and his colleagues at Exxon that has served as the foundation for the technology that has evolved into reservoir characterization. A good summary of what has been accomplished through infill drilling and reservoir characterization in West Texas carbonates is contained in a 1991 article by Wu et.al.[5]

Nearly all the current IOR efforts, and hence the literature, in the Permian Basin have been directed towards the San Andres and Clearfork carbonates. To paraphrase Willy Sutton, the infamous bank robber, in justifying his profession, "that's where the money is." The bulk of the remaining oil-in-place (ROIP) exists in these two horizons where the facies stacking nature of the marine depositional cycles creates complex, heterogeneous reservoirs often over a thousand feet in gross thickness. Following primary depletion, the remaining mobile oil volumes within these thick sections were the targets for secondary recovery through water injection. Now both the remaining mobile oil and residual oil are targets

References at end of paper

and depositional setting is based on study in the Keystone (Colby) field in Winkler County, Texas. This field produces from the lower half of the Queen formation which is the equivalent of the Penrose formation in New Mexico[7]. In contrast to the depositional environment described by Holly and Mazzullo for the northeastern margin area, Vanderhill attributes the numerous separate rock units to minor shifts in the local depositional environment and not large sea level fluctuations. The sands were deposited in a shallow marine setting but in somewhat deeper water than the shallow tidal or strandline dolomites. Although both papers agree that the majority of the porosity is secondary in nature, Vanderhill attributes it to the dissolution of feldspar. A total of 32 sand units six inches or greater in thickness have been identified in the Colby section. Figure 4 is a type log from the Myers Langlie Mattix Unit which identifies ten correlatable sand units within the gross productive interval.

Concepts

At first glance the old adage, poor primary recovery gives poor secondary recovery, would appear to hold true within the Queen formation. Projects with good primary performance exhibited good secondary recovery. Conversely projects with poor secondary recovery invariably had low primary recovery. That mindset combined with the concept that the pay intervals are continuous sands across structural traps may help explain why many projects were essentially abandoned after poor initial secondary response.

High remaining mobile oil saturation in a depleted waterflood is due to a lack of vertical and areal injection coverage. Poor vertical coverage can result from: 1) pay intervals not fully identified, 2) inefficient completion techniques, 3) out of zone injection, 4) pay intervals not completely penetrated, 5) water quality. The lack of areal injection coverage can be due to: 1) lateral discontinuity, 2) insufficient well density, 3) inadequate injection to withdrawal ratio, 4) improper pattern alignment, 5) directional permeability, 6) inadequate withdrawals.

Overall the lack of injection coverage results from the relationship between natural, i.e. reservoir and fluid parameters, and controlled, i.e. reservoir management, factors. Within the thick Permian carbonate sequences, the IOR potential is predominately a function of reservoir heterogeneity. In the Queen, where the lithologies are not nearly so complex, the potential results more from low reservoir energy, completion in efficiencies and operational difficulties. The primary and secondary development techniques utilized in the Queen reflected prevailing concepts which have since been rendered obsolete by engineering and geological advances.

TANFL (there ain't no free lunches), applies also to depleted Queen waterfloods. Contrary to popular belief, blanket infill drilling is not necessarily the solution. An integrated geological /engineering analysis is required to focus redevelopment on the most highly productive areas. Emphasis is not on maximizing recovery, but optimizing economics. This requires sound reservoir management techniques at every stage from the analysis and design through the implementation and surveillance. Companies that acquire depleted waterfloods without doing their homework may achieve less than anticipated results.

Approach

This section was initially titled methodology, which suggested a routine approach to a problem. The peculiar nature of each project, the availability of data and the financial situation of the operator requires flexibility and innovations in the analysis and exploitation. However, the goals of each study were similar: 1) identify the potential, 2) quantify the potential, 3) map the distribution of the potential, 4) design an optimum exploitation plan, 5) project performance, 6) forecast economics, 7) set up a surveillance and data gathering program.

1. Identifying the potential requires determination or understanding of why primary and/or secondary recovery was low. The starting point is to characterize the reservoir which fortunately does not require the complex facies identification process necessary with carbonate reservoirs. Defining the net pay sequence from logs, cores, and tests is usually sufficient. A key step is determining the well completion efficiency from cross-sections connotated with completion and test information. This involves tedious and time-consuming work, but is indispensable for identifying zones that have not been drained due to being behind pipe, inefficiently completed or not penetrated. Knowledge is also gained about zonation and continuity. This characterization effort combined with information about original reservoir conditions, usually explains the primary recovery.

Understanding the reasons for low secondary response is critical to judging the potential. This requires a secondary performance review to analyze injection/withdrawal ratio, injection efficiency, oil response, pattern alignment, directional permeability and operational problems.

occurred on projects in an advanced stage of depletion where injection had been reduced to the return of produced water. Although some of the infill wells achieved economic recoveries without active water injection support, they are the exceptions. Effective water injection into closed patterns is required to provide the reservoir energy and sweep necessary for the economic recovery of remaining mobile oil through infill drilling.

The Bridge operated MFQAU is a direct south offset to the Sirgo SUC2U (Figure 5A). A total of 17 wells were drilled in the eastern two-thirds of the Unit during 1988-89 either as 20-acre infill or replacement wells (Figure 7). A semi-symmetrical injection pattern was established creating several situations that approximate 20-acre infill drilling with full injection support. Some wells have maintained high producing rates for several years in contrast to the rapid decline experienced by most Queen infill wells. Well No. 4532, which is offset by 3 injection wells, potentialed for 110 BOPD on 8/89 and was tested for 70 BOPD on 3/91 and 108 BOPD on 7/91. The performance of this unit with infill drilling is shown by Figure 6. The incremental average infill recovery is estimated at 52 MB per well.

Bridge has done similar redevelopment on the ULB4QU. Individual well information was not available, but the recent unit performance suggests that the production increases realized from the drilling of infill and replacement wells are being sustained by water injection (Figure 8).

All of the projects in the study areas have been subjected to millions of barrels of water injection. Water saturations and consequently permeability to water, while erratic, are high throughout much of the reservoir. The redeveloped projects will produce at high water cuts from the start, requiring the handling of large volumes of water. Economic recovery under these circumstances dictates that the redevelopment focus on the most prospective areas and be designed to produce the most oil in the least time.

Project Analysis

Table 4 summarizes basic data on the six redevelopment projects. The development and performance history of the individual units are summarized on Figures 9-14. Table 5 presents primary and secondary performance parameters for the projects. Each project is scheduled to be redeveloped on forty-acre five-spot injection patterns (20-acre well density) in phases starting with the lowest risk phase first. Implementation of each phase depends on results from the preceding phase. Redevelopment plans and the basis for recovery projections are summarized on Table 6. A final residual oil saturation of 30% was assumed for all cases. The conformance factors were based on estimates of vertical coverage and areal sweep for each project as modified by the detailed performance analyses.

Infill drilling has been completed on just one of the six redevelopment projects. Full scale pattern injection has not yet been implemented in any project. The presence of high mobile oil saturation has been established on all the projects either by infill drilling within the project or on a direct offset.

The pace of development is dependent upon the ability of small independents to raise capital in today's market. Not only are the redevelopment stages ranked according to risk and potential, but also the projects. The lower priority projects are deferred until the investment climate improves or the project is upgraded by additional information or offset performance.

1. West Dollarhide Queen Unit

The Sirgo-operated WDQU produces from what is termed the Penrose but is equivalent to the total Queen Section at 3600 feet. The development and performance history is shown on Figure 9. The project was acquired essentially as a salvage operation with plans to work over wells in an attempt to increase production. The original feasibility study suggested that the unit had good infill potential due to numerous possible productive zones either behind pipe or not penetrated. A preliminarily study in 1986 used limited data to make a volumetric estimation of OOIP and remaining mobile oil (Table 4). The unit was divided into five phases based on potential and risk as determined by individual well performance analysis (Figure 16). Phases 1 and 2 were located in the area of good secondary response (Figure 17). Based on the 1986 study, thirty infill wells were drilled and the study revised in 1988 utilizing the information gained. As each well was drilled, the logs were analyzed to improve the data base for volumetric calculations and reserve estimations. The OOIP volume was revised from 34 MMB to 44 MMB, so the original volumetrics proved reasonable in spite of the lack of data. Figures 15A and 15B show the original and revised net pay isopach maps.

The unit production increased from 40 BOPD to 1500 BOPD upon completion of the first 30 infill wells which almost equals the peak primary response from 60 wells. A number of the infill wells had initial potential in excess of 200 BOPD, positive evidence of the high mobile oil saturation remaining within areas of the unit. Without water injection support, the 15% range. Similar to the other Queen projects studied, areas of good secondary response were found in both projects.

A low injection-withdrawal balance and operational problems contributed to poor secondary performance. Both units received pressured water from the Means System in lieu of having their own injection facilities. The Bridge-operated MFQAU project has achieved some significant results where infill wells are being supported by water injection (Table 3 and Figure 8). MFQAU offsets the SUC1U and SUC2U to the south (Figure 5). Redevelopment of the SUC1U is projected to give an improved/primary recovery ratio of 3.0 for a 23% ultimate recovery. Similarly, redevelopment of the SUC2U is projected to give an improved/primary ratio of 2.3 for a 23% ultimate recovery also.

Conclusions

1. Infill drilling has confirmed that some depleted Queen Sand Waterfloods still contain high mobile oil saturations.

2. This mobile oil saturation is not uniformly distributed and detailed analysis is required to define the more prospective areas.

3. The economic recovery of the remaining mobile oil requires redevelopment of the waterfloods by infill drilling and adequate water injection support.

4. Good reservoir management and financing requirements dictate that the most prospective areas be exploited first and the results used to upgrade the other stages.

Acknowledgements

Appreciation is expressed to Sirgo Operating, Inc. for permission to publish this paper and also Bridge Oil Inc. for allowing use of certain production data.

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OPERATOR	UNIT	NO. WELLS	PERIOD	AVERAGE INITIAL (BOPD/WELL)	AVERAGE RATE (BWPD/WELL)	EUR (MB/WELL)	COMMENTS
Texaco	S-PAU	5 1	1973-74 1985	82 65	139 145	90 24	Full injection support Located near 3MMB injector
Sirgo	WDSQU	52	1987-88	55	115	43	Marginal support from injection of produced water only
Sirgo	S-PBU	6	1988	15	176	12	No injection support
Bridge	MFQAU	13	1988-89	62	39	52	Full injection support on some wells since mid 1989
Texaco	MLMU	5	1986	61	226	78	Partial injection support from existing line drive
Sirgo	SUC1U & SUC2U	5	1990	46	77	15	No injection support

Table 3 – Results of 20 ac. Infill Drilling in Queen Waterfloods

PROJECT	ZONE	DEPTH (ft)	AREA (ac)	WELL DENSITY (ac)	Ø (%)	NET PAY (ft)	Sw (%)	K (md)	FVF1 (VOL/VOL)	POROSITY CUTOFF (%)	OOIP (MMB)
					----AVERAGE PROPERTIES---						
Lea County, New Mexico											
WDQSU	QUEEN/ PENROSE	3700	2500	40	13.5	34	40	0.1-167	1.20	9.5	44
S-PBU	PENROSE	3600	2612	41	NA	NA	NA	NA	NA	NA	NA
MLMU	QUEEN/ PENROSE	3600	9560	42	13.0	23	40	0.1-100	1.18	9.0	115
Andrews County, Texas											
MXQU	UPPER QUEEN	4800	2144	40	14.0	16	40	1.0-31	1.17	10.0	20
SUC1U	UPPER QUEEN	4800	2560	57	14.0	18	35	0.3-32	1.15	10.0	29
SUC2U	UPPER QUEEN	4800	2120	40	14.5	20	35	0.3-29	1.15	10.0	32

Table 4 – Basic Reserve Data for Redevelopment Projects

PROJECT	PRIMARY ULTIMATE (MB/WELL)	PRIMARY RECOVERY (%)	SECONDARY START INJECTION	SECONDARY/ PRIMARY (VOL/VOL)	INJECTORS/ PRODUCERS (RATIO)	INJECTION/ RECOVERY (VOL/VOL)	TOTAL ULTIMATE (MB/WELL)	TOTAL RECOVERY (%)
Lea County, New Mexico								
WDSQU	50	7.4	1964	0.43	0.73	24	72	10.6
S-PBU	28	NA	1966	0.98	0.70	25	52	NA
MLMU	40	7.8	1975	0.76	0.92	27	68	13.8
Andrews County, Texas								
MXQU	26	7.2	1963	1.09	0.93	9	54	15.0
SUC1U	38	5.8	1961	1.51	1.04	11	95	14.6
SUC2U	42	6.8	1961	1.33	1.30	7	97	15.9

Table 5 – Primary & Secondary Performance for Redevelopment Projects

PROJECT	INFILL LOCATIONS PROPOSED	INFILL LOCATIONS DRILLED	INJECTORS/ PRODUCERS (RATIO)	RMOIP/ OMOIP (VOL/VOL)	CONFORMANCE (DECIMAL)	PROJECTED IMPROVED/ PRIMARY (VOL/VOL)	PROJECTED TOTAL RECOVERY (%)
Lea County, New Mexico							
WDSQU	67	52	0.98	.53	.29	1.59	19.1
S-PBU	57	6	1.10	NA	NA	3.2	NA
MLMU	142	5	1.23	.54	.39	2.0	23.0
Andrews County, Texas							
MXQU	21	0	1.17	.48	.33	2.2	22.7
SUC1U	47	0	1.12	.40	.50	3.0	23.0
SUC2U	21	0	1.85	.38	.41	2.3	23.0

Table 6 – Plans & Projections for Redevelopment Projects

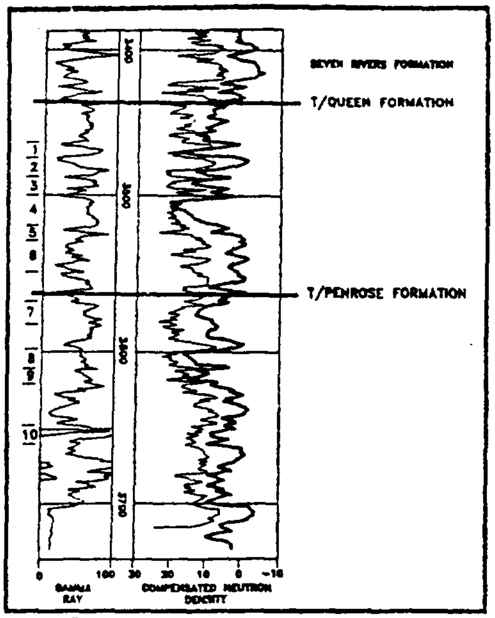

Figure 4 – Type Log – Myers Langlie Mattix Unit NO. 111
Lea County, New Mexico

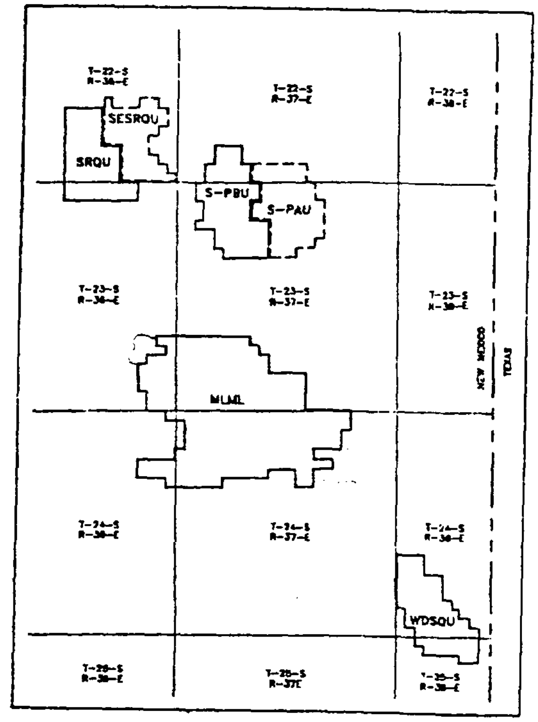

Figure 5A – Location of Projects
Lea County, New Mexico

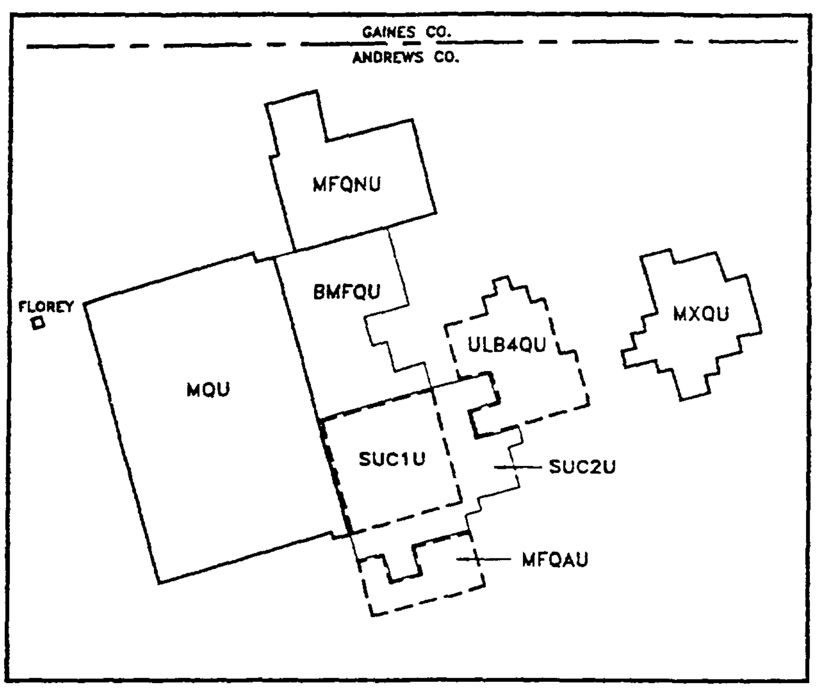

Figure 5B – Location of Projects
Andrews County, Texas

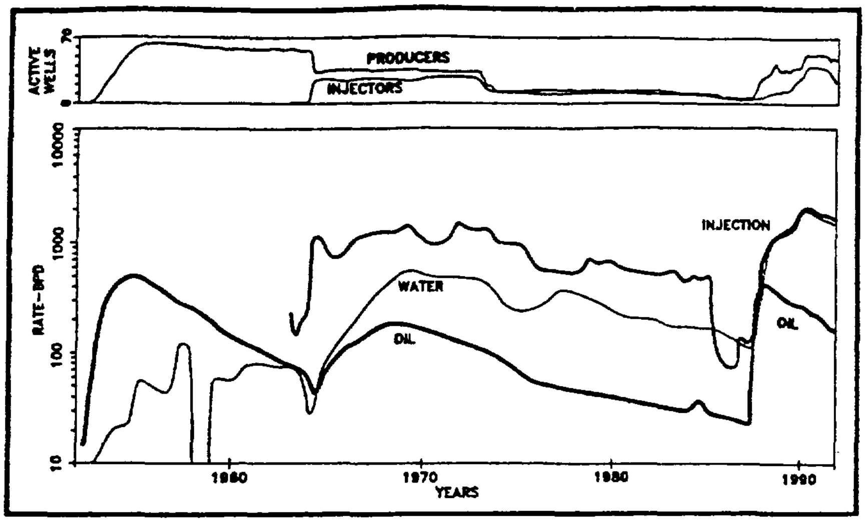

Figure 9 - Performance Graph
Sirgo-West Dollarhide Queen Sand Unit
Lea County, New Mexico

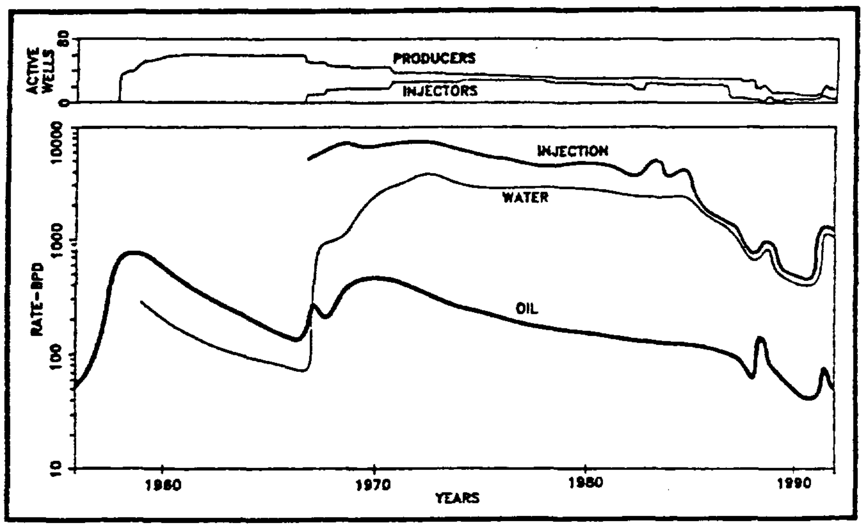

Figure 10 - Performance Graph
Sirgo-Skelly-Penrose B Unit
Lea County, New Mexico

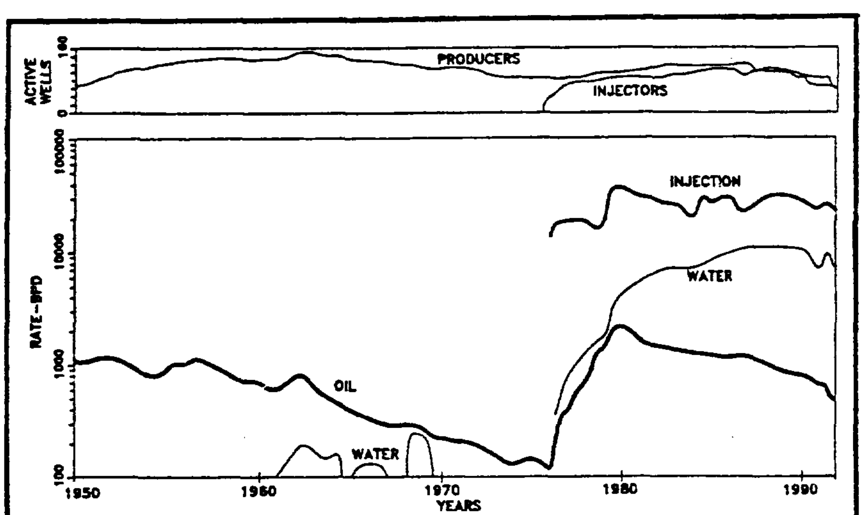

Figure 11 - Performance Graph
Sirgo-Myers Langlie Mattix Unit
Lea County, New Mexico

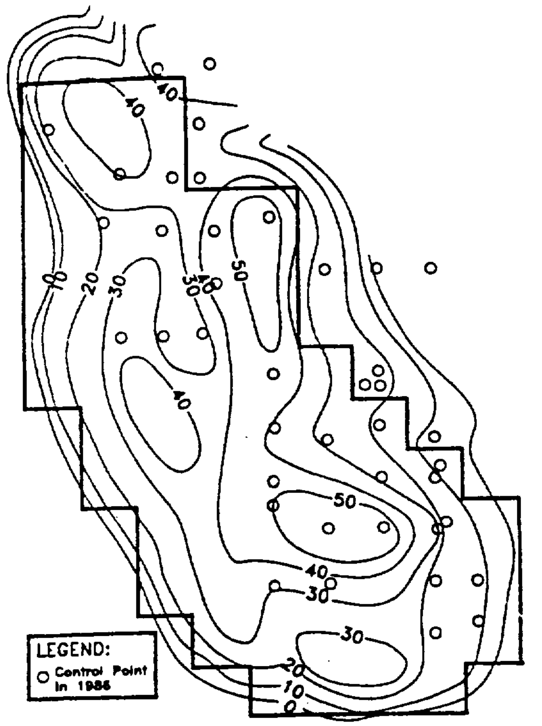

Figure 15A – Net Pay Isopach, 1986
Sirgo–West Dollarhide Queen Sand Unit

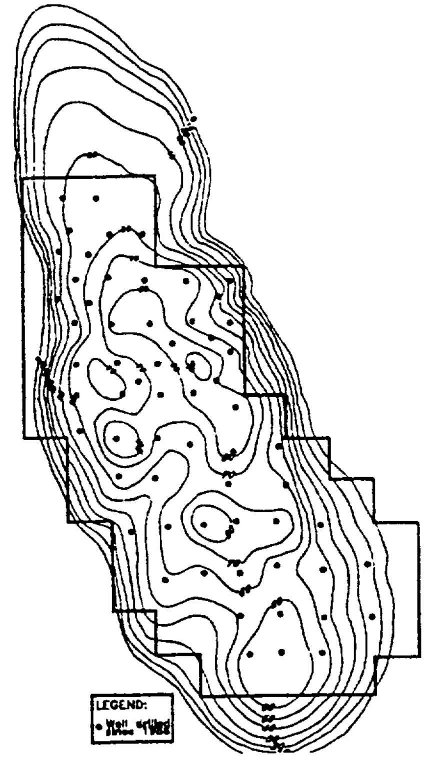

Figure 15B – Net Pay Isopach, 1988
Sirgo–West Dollarhide Queen Sand Unit

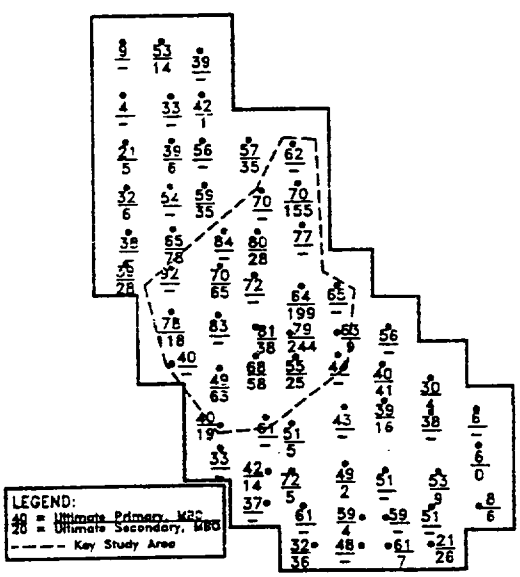

Figure 16 – Initial Estimated Recoveries as of 5–1–87
Sirgo–West Dollarhide Queen Sand Unit

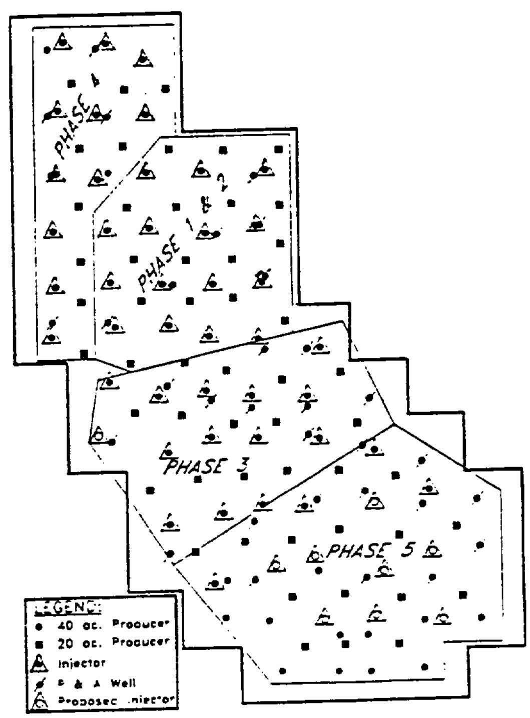

Figure 17 – Redevelopment Phase Areas
Sirgo–West Dollarhide Queen Sand Unit