CASE 1383: Application of Forest Oil Corp. for dual completion of its State "A" #1 Well Sec. 26-16S-33E.

Case No.

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Application, Transcript, Small Exhibits, Etc.

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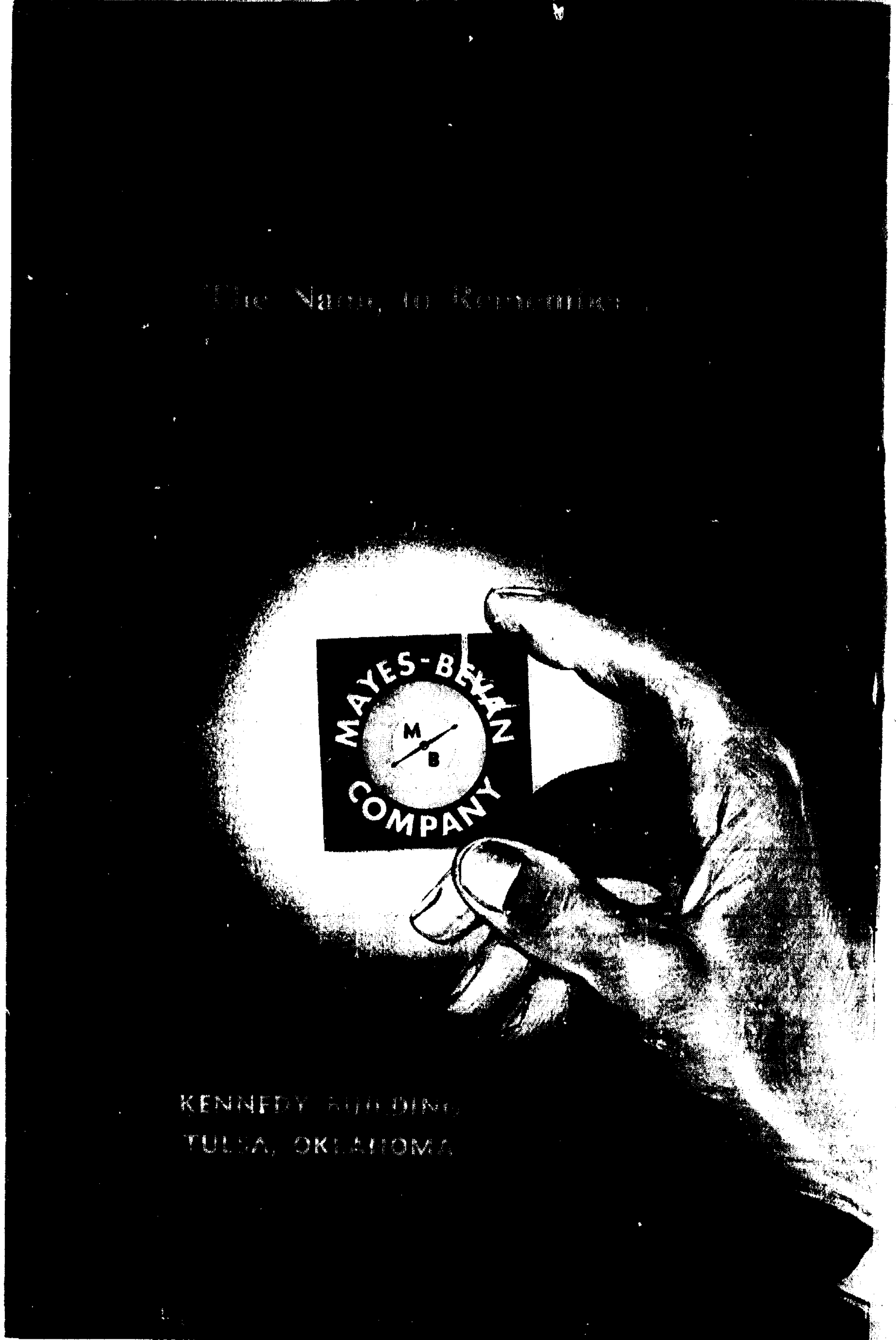

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NOVEMBER, 1957

PORPHYRIN RESEARCH AND ORIGIN OF PETROLEUM[1]

H. N. DUNNING[2] AND J. W. MOORE[2]
Bartlesville, Oklahoma

ABSTRACT

Several analytical and physical methods for porphyrin research recently have been developed or applied to problems of the petroleum industry. Methods for isolating metal-porphyrin complexes from bituminous materials include solvent extraction or precipitation, emulsification, chromatography, and molecular volatilization. The classical method of Treibs and Groennings remains the basic method for extracting porphyrin aggregates from bituminous materials. Analytical methods for determining the metal contents of extracts rich in porphyrin complexes include emission spectroscopy and spectrography, colorimetry, flame photometry, and X-ray spectrography.

The results of porphyrin research have several important implications on the geochemistry of petroleum. The widespread occurrence of porphyrin materials in bituminous materials is evidence of their biological origin. The carboxylated porphyrin contents of some crude oils indicate that these oils, and presumably others, have a low-temperature history. Correlations of porphyrin studies indicate that the common nickel- and vanadium-porphyrin complexes are formed by metal exchange reactions with animal and plant metabolic pigments such as hemoglobin and chlorophyll which were present during the early stages of petroleum formation. Porphyrin studies offer considerable support for the current theories that petroleum is formed slowly in marine or brackish environments from marine and terrestrial plant and animal matter and that the asphaltic constituents of crude oils are of primary formation. During the evolution of the oil these simplify to form the clean, paraffinic oils commonly associated with older formations.

INTRODUCTION

The discovery of porphyrins (natural pigments related to chlorophyll and hemoglobin) in petroleum was one of the most significant achievements relating to the origin of petroleum. However, it is only recently that the importance of these substances throughout the petroleum industry has been generally recognized. An intensive research program of this laboratory has resulted in the accumulation of considerable data on the properties of the porphyrins and their effects on the exploration, production, and refining of petroleum.

The porphyrins and their metal complexes may be readily recognized by

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physicochemical methods. The vanadium-porphyrin complex, indigenous to many bituminous substances, is remarkably stable. Therefore, these substances serve as natural "tracers"; observations of their occurrence and properties permit an insight of some of the mysterious processes of petroleum formation.

The complexity of the porphyrins requires specialized equipment and methods of research but at the same time affords methods for their identification and isolation. Several of the methods available for porphyrin research are discussed briefly together with the implications of the experimental results on the exploration and production of petroleum.

EXPERIMENTAL METHODS AND RESULTS

ISOLATION AND IDENTIFICATION OF METAL-PORPHYRIN COMPLEXES

The metal-porphyrin complexes usually are identified in crude-oil extracts by the distinctive spectra observed when light, passing through the samples, is partly absorbed at different wavelengths in the visible region (Fig. 1). The porphyrin complexes commonly have a major and minor peak in the visible region between 510 and 580 mμ, and a very strong peak in the near ultraviolet region at about 400 mμ. The visible peaks are the most useful because the strong peak at 400 mμ often is obscured by colorless substances that have strong absorbance at lower wavelengths.

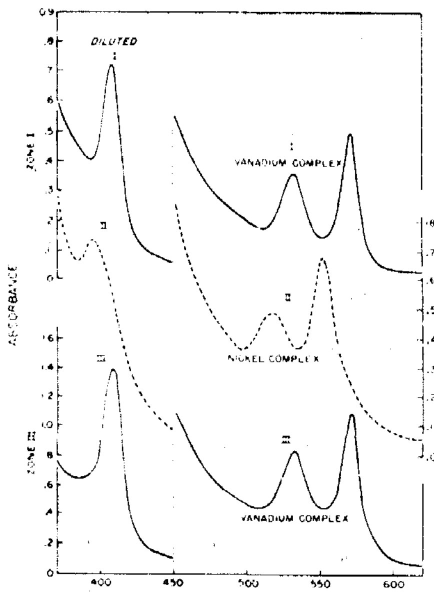

FIG. 1.—Absorption spectra of final chromatographic fractions containing porphyrin complexes. 3.0 mg. per ml. of benzene.

Several methods for isolation of metal-porphyrin complexes from crude oils and oil shales have been found effective. In general, their effectiveness decreases rapidly with the porphyrin contents of the oils.

Propane precipitation results in the separation of a considerable amount of the metal-porphyrin complexes from the refined portion of the oil because the metal-porphyrin complexes are mainly associated with the asphaltic portion of petroleum. Extracts relatively rich in metal-porphyrin complexes are obtained when this precipitation is followed by extraction of the asphalt with solvents of increasing polarity. This method was used by Skinner (1952) and by Dunning and co-workers (1953, 1954) to isolate vanadium- and nickel-porphyrin complexes from California crude oils. Glebovskaya and Volkenshtein (1948), Blumer (1950), and Treibs (1934, 1935) studied extracts of petroleum and bituminous materials obtained by direct extraction with alcohol, chloroform, acetic acid, or pyridine.

Treibs (1935) first used chromatographic methods for the isolation of metal-porphyrin complexes from extracts of oil and other bituminous materials. Chromatographic methods should suffice for the isolation of such substances directly from crude oil. However, the chromatographic separation is made more efficient and rapid by denaturation of the crude oil by processes such as solvent precipitation preceding chromatographic separation.

Dunning and Rabon (1956) isolated nickel- and vanadium-porphyrin complexes from the asphaltenes and also from the raffinate resulting from the propane precipitation of an asphaltic Mid-Continent crude oil. The isolation procedure involved extensive chromatography with silica gel and alumina columns. The spectra of the chromatographic zones containing metal-porphyrin complexes are shown in Figure 1. Molecular volatilization also was used in these studies for the separation of metal-porphyrin complexes from asphaltic material. The vanadium- and nickel-porphyrin complexes are readily volatilized at a pressure of about 10 microns at temperatures from 250°–300°C. A relatively impure extract containing the vanadium-complex was molecularly volatilized to yield fractions of considerable vanadium-porphyrin content. Vacuum distillations of mixtures of the nickel- and vanadium-porphyrin complexes indicated that the nickel-porphyrin complex had a degree of volatility comparable with that of the vanadium-porphyrin complex. Vacuum distillation methods offer a promising way of purifying the porphyrin complexes, and may be useful for purifying the free porphyrins as well.

ISOLATION AND IDENTIFICATION OF PORPHYRIN AGGREGATES

The complicated mixtures of porphyrins, freed of the metals with which they were complexed, obtained from petroleum are referred to as "porphyrin aggregates." Free porphyrins commonly have four strong absorbance peaks in the visible region (Fig. 2). The location of these peaks (I–IV) vary somewhat with porphyrin type and solvent used but generally are located at about 620, 565, 535, and 500 mμ, respectively. In addition, porphyrins have a very strong absorbance peak at about 400 mμ which is known as the Soret peak. These peaks cause the porphyrin solutions to have a typical red-violet color and to be easily and definitely recognized with a simple spectroscope.

Another property of importance in analyzing for porphyrins is their strong red fluorescence under ultraviolet light. Porphyrins typically have a strong fluorescence band at about 625 mμ and weaker bands at other wavelengths. This strong red fluorescence allows the detection of porphyrins at levels far below those detectable by absorbance studies and is a valuable tool for this purpose.

The isolation of porphyrin aggregates from crude oils or asphaltic materials depends on removing the metals from the metal porphyrin complexes so that the central nitrogens may exhibit their basic characteristics. The porphyrins then

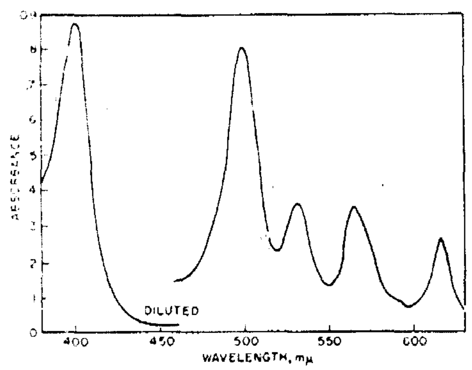

FIG. 2.—Absorption spectrum of porphyrin aggregate from crude oil from Tatums field. 160 mg. (original oil) per ml. of chloroform.

may be separated from the crude-oil components by physicochemical methods. Procedures for removing the metal components from metal-porphyrin complexes have advanced little since the work of Treibs (1934), but recently Groennings (1953) has published a revised and simplified method. The procedure involves prolonged digestion of the crude oil with glacial acetic acid saturated with HBr in a sealed ampoule at 50°C. The free porphyrins are basic and therefore are extracted from the digestion products by strong hydrochloric acid. Although this is an old procedure it effectively takes advantage of the peculiar properties of porphyrins.

After the aggregate has been isolated, the porphyrin content may be determined colorimetrically or, more precisely, by a spectrophotometric procedure in which the heights of the four peaks, above background, in the visible region are compared with those of a pure porphyrin sample. The absorption spectrum of a typical porphyrin aggregate is shown in Figure 2.

The metal contents of extracts rich in metal-porphyrin complexes presumably could be determined by usual methods of analyses. However, the amounts of relatively pure extracts are normally very small so that micro methods are required

Several methods that have been used in this laboratory are qualitative emission spectroscopy, spectrography, flame photometry, colorimetry, and X-ray spectrography.

RESOLUTION OF PORPHYRIN AGGREGATE

Free porphyrins have either acidic or basic properties and isoelectric (neutral) points at pH values from 3 to 5. Their acidic characteristics are caused by side chains containing carboxylic acid groups while the two tertiary nitrogens of their nuclei lend them a weakly basic character. The structures of two typical porphyrins are shown in Figure 3. The partition of porphyrins between organic and aqueous solvents depends on the oil-soluble nature of the ring and the water-soluble nature of the central nitrogens and the polar side chains.

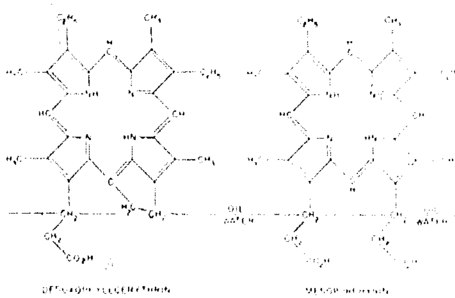

FIG. 3.—Structures of typical porphyrins and orientation at oil-water interface.

The extraction of porphyrins from ethyl ether by acids is an important property for their purification. Lemberg and Legge (1949) report that different porphyrins require hydrochloric acid of different concentration for extraction from ether and list the "HCl numbers" of common porphyrins. This method has been most useful in clinical or other work where the porphyrins have major differences. However, much of the porphyrin content of petroleum is decarboxylated and the common carboxylated form contains one carboxylic group. Therefore, the partition method is limited in its applicability for resolving the porphyrin aggregates of petroleum.

Paper chromatographic methods were developed by Dunning and Carlton (1956) to allow resolution of the porphyrin aggregates of crude oils into several distinct groups. Several of the groups consisted of decarboxylated porphyrins which differed in spectral and/or "R_f" values (rate of movement relative to solvent front). Correlations of these data indicated that the more mobile of these porphyrin groups probably were of "animal type." The other decarboxylated groups, which comprised the bulk of the aggregates, and the carboxylated porphyrins were of plant origin. In addition to a large amount of decarboxylated porphyrin material, the porphyrin material of two heavy, asphaltic oils from California (Santa Maria Valley) and Oklahoma (Tatums) contained about 8 per cent of carboxylated porphyrins. The carboxylated porphyrins were studied by the paper-chromatographic method of Nicholas and Rimington (1949). The results indicated that the major portion of the carboxylated porphyrins contained one carboxylic acid group and probably was desoxophylloerythrin, a porphyrin previously identified in oil-shale extracts by Treibs (1934).

Paper-pulp chromatography affords a simple method of accomplishing the usually difficult separation of carboxylated and decarboxylated porphyrins. Preliminary steps have been taken in developing this method into a routine laboratory procedure. The peculiar geochemical significance of carboxylated porphyrins in petroleum lends importance to such work.

DISCUSSION

The origin of petroleum is one of the most basic and intriguing questions of petroleum geochemistry. In a recent extensive review of this subject, Stevens (1956) concluded that petroleum is undoubtedly of organic origin and probably formed by sedimentation and related processes in marine or brackish-water environment from marine and non-marine organic matter. Studies of the porphyrins in this laboratory are in agreement with this conclusion and supply additional evidence in its support.

The widespread occurrence of porphyrins in petroleum is evidence of its biological origin. Crude oils, in their migration, presumably could have assimilated porphyrin materials from substances not originally in the source bed. However, this seems very unlikely as a general phenomenon. The identification of porphyrin materials in crude oil from the Uinta basin and the high content of these materials in Santa Maria Valley crude oil, both of which are believed to exist in the reservoir in which they were formed, is rather convincing evidence that the porphyrin aggregates extracted from these oils actually were present during the formation of the crude oils. The high porphyrin contents of extracts from Colorado oil shales reported by Moore and Dunning (1955), in which the organic material is immobile, corroborate this view. Dyemenkova and Kurbatskaya (1955), in reviewing the results of several Russian workers, concluded that vanadium and nickel are present in crude oils from the beginning. This is in agreement with the conclusion of Treibs (1934) as well as Glebovskaya and Volkenshtein (1948).

Treibs (1934, 1935) has emphasized that the presence of carboxylated porphyrins in petroleum is evidence of a low-temperature history of the reservoirs with which they are associated. This conclusion was based on observations that pure porphyrins are decarboxylated at temperatures from 300° to 350°C. The reaction occurs even at lower temperatures over extended periods. Although the effect of high pressures in inhibiting decarboxylation should be considered, the presence of carboxylated porphyrins in crude oils is evidence that these crude oils and their source materials have not been subjected to high temperatures.

Porphyrins have not been identified in all oils and, indeed, are rare in the older American crude oils. Therefore, it would be premature to assume low-temperature origins for all crude oils.

Another interesting question on the origin and evolution of petroleum is that of the geochemical relationships between asphaltic and paraffinic oils. One group of scientists attributes the asphaltic constituents to primary formation and regards such substances as the remnants of organic materials, which during the evolution of the oil, simplify to form the lighter, more paraffinic oils. Another group maintains that the tarry substances are of a secondary character and probably arise as a result of microfloral activity. The latter view has found little support but recently has been discussed by Radchenko and Sheshina (1955). They report that the vanadium complexes are associated with the asphaltic substances of crude oils and that the nickel complexes are associated with the oleaginous components. Furthermore, the vanadium-nickel ratio is higher in oils of high sulfur content. From these results, they conclude that the concentration of sulfur, porphyrins, and vanadium in petroleum is a secondary process caused by bacterial action. However, they believe that the nickel porphyrins are related to the biochromes of the organisms originally present during the formation of the oil. These conclusions seem illogical from a philosophical approach and doubtful even if the data are accepted as being generally applicable. Studies by Dunning and co-workers (1953, 1954, 1956) show that both the nickel- and vanadium-porphyrin complexes are principally associated with the asphaltic components of crude oils. However, both of these complexes also are found in smaller amounts in the oleaginous portion of Mid-Continent and California crude oils. This work indicates no sharp distinction between the properties of vanadium- and nickel-porphyrin complexes and indicates a close relation of these materials with the original source of petroleum. With few exceptions, appreciable porphyrin contents in the oils studied are limited to highly asphaltic oils from reservoirs of geologically "new" ages. The porphyrin contents of American oils of low asphalt content, such as Bradford, Oklahoma City "Wilcox," and Bartlesville crude oils, are very low. To date it has not been possible to detect porphyrins in the Bradford crude oil which is notable for its low asphaltic content. These laboratory results support the view that the asphaltic components of crude oils generally are of a primary character and that the porphyrin complexes are related to the original organisms and new formations originating during the sedimentation phase and the period of diagenesis before the petroleum moves from its source bed. This is in agreement with the conclusions of Scott *et al.* (1954), Treibs (1934), Blumer (1950, 1952), Dyemenkova and Kurbatskaya (1955), Skinner (1952), and of Glebovskaya and Volkenshtein (1948).

In certain exceptional instances, it appears that substances of asphaltic appearance may be formed from clear crude oils by secondary processes such as weathering and oxidation of oil seeps. Recent studies have indicated some possibility of differentiating between such substances and the asphaltic constituents of "young" crude oils by porphyrin analyses. If this can be done, the results would be of considerable value in petroleum exploration.

The source of the rather common vanadium-porphyrin complex is of particular geochemical interest. Glebovskaya and Volkenshtein (1948) postulate that this complex is the respiratory pigment of marine life, particularly the ascidians. This postulate seems unlikely since it would involve such specific organisms in the origin of many widespread petroleum deposits. However, it has gained some credence because of the difficulty of synthesizing the vanadium-porphyrin complex in the laboratory. Recent work by Erdman and co-workers (1956) tends to discredit this unusual theory. They showed that the vanadium-porphyrin complex could be as readily synthesized as the nickel complex if the proper vanadium salt were used. Furthermore, after an extensive study of the blood of ascidians, Webb (1939) reported that the vanadium chromogen of these organisms was in no sense a respiratory pigment and that *it was not a porphyrin compound*. Therefore, it appears likely that the vanadium- and nickel-porphyrin complexes were formed within the reservoir or source bed by metal exchange reactions from the common magnesium (chlorophyll) or iron (hemoglobin) respiratory pigments of plants and animals. This view is widely held by petroleum scientists who have studied the porphyrins and trace metals, including Blumer (1950, 1952), Dymenkova (1955), Scott (1954), and Treibs (1935).

It is commonly believed that plant life has had a large part in the formation of petroleum. The importance of animal life in such formation appears less certain. However, Stevens (1956) concludes that animal remains contribute to petroleum formation. There has been some question that animal porphyrins exist in crude oils as claimed by Treibs (1934). However, recent paper chromatographic investigations by Dunning and Carlton (1956) have produced some evidence of the presence of animal-type porphyrins in some asphaltic American oils. Since a few plants synthesize porphyrins similar to those produced by animals, this is not positive proof that animal matter contributes to petroleum formation. However, the presence of animal remains would be in agreement with the biological origin of crude oil and would indicate that hemoglobin is capable of entering into exchange reactions to form more stable complexes much in the manner that chlorophyll apparently does. This conclusion is corroborated by laboratory results of Milroy (1909) in which the iron of hemoglobin was replaced by various metals under reducing conditions.

The high interfacial activities and film-forming tendencies of the metal-porphyrin complexes indicate that they are among the substances affecting the wettability of reservoir rocks and causing petroleum to cling tenaciously to the reservoir surfaces. These properties also cause the porphyrin complexes to be adsorbed on reservoir-rock surfaces. Therefore, the migration of a crude oil from one formation to another may be indicated by a change in porphyrin content of the crude oil. Correlations of this kind, if they can be established, would be of considerable value in studies of source beds and petroleum migration.

CONCLUSIONS

Several analytical and physical methods for porphyrin research recently have been developed or applied to problems of the petroleum industry. The results of these studies yield information of value in petroleum production, refining, and exploration.

The porphyrins and their metal complexes commonly are recognized by spectroscopic or spectrophotometric measurements of their typical absorbance spectra in the visible region. Spectroscopic or visual observation of the brilliant red fluorescence of free porphyrins under ultraviolet light may be used to detect minute amounts of these substances.

Methods for isolating metal porphyrin complexes from bituminous materials include solvent extraction or precipitation, emulsification, chromatography, and molecular volatilization. The classical method of Treibs and Groennings remains the basic method for extracting porphyrin aggregates from bituminous materials. Analytical methods for determining the metal contents of extracts rich in porphyrin complexes include emission spectroscopy and spectrography, colorimetry, flame photometry, and X-ray spectrography.

Paper chromatographic methods have been developed to allow the separation of the porphyrin aggregate of crude oil into several groups. The carboxylated porphyrins may be separated readily from decarboxylated types using paper-pulp columns.

The widespread occurrence of metal-porphyrin complexes in bituminous materials is definite evidence of the biological origin of crude oil. The carboxylated porphyrin content of some crude oils indicates that these oils, and presumably many others, have a low-temperature history. Correlations of porphyrin studies indicate that the common nickel- and vanadium-porphyrin complexes are formed by metal exchange reactions with animal and plant metabolic pigments such as hemoglobin and chlorophyll which were present during the early stages of petroleum formation.

These results offer considerable support for the current theories that petroleum is formed slowly in marine or brackish environments from marine and terrestrial plant and animal matter and that the asphaltic constituents of crude oils are of primary formation; during the evolution of the oil these simplify to form the clean, paraffinic oils commonly associated with older formations.

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VANADIUM, NICKEL, AND PORPHYRINS IN THERMAL GEOCHEMISTRY OF PETROLEUM[1]

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ABSTRACT

The thermal degradation of compounds containing vanadium and nickel in crude oil has been examined in order to throw further light on the significance of the trace metals in the geochemistry of petroleum. Almost identical first-order reaction rates were observed for the removal of the two metals, and extrapolation of the data to geological times and temperatures showed that present-day reservoir temperatures are too low to permit a significant thermal contribution to the changes which appear to have occurred in the maturation of crude oil. A study was made of the degradation of porphyrin compounds which are responsible, in part, for the presence of the metals in oil. The rate for the porphyrin degradation at 358°C. was 0.020 $hr.^{-1}$, considerably greater than that for the removal of vanadium, 0.013 $hr.^{-1}$ and the nickel, 0.012 $hr.^{-1}$. The activation energy, which is a measure of the temperature dependence of the reaction, was 52.5 Kcal./mole for porphyrin degradation; 58.6 Kcal./mole for vanadium removal; and 57.5 Kcal./mole for nickel removal. These data indicate that the spread between porphyrin degradation rates and metal removal rates would increase at all lower temperatures. Consequently, if thermal action were responsible for the maturation of crude oil in nature, the porphyrin material in a maturing oil would be lost very rapidly compared with the removal of metals. The relatively constant proportion existing between porphyrin content and metal content found for a widely varying suite of Canadian oils shows that this has, in fact, not happened. This observation tends to confirm the conclusion that thermal action has little to do with the maturation of crude oil.

INTRODUCTION

Vanadium and nickel have been recognized as constituents of petroleum for many years. How the metals enter the oil is not clearly understood, although it has been generally believed that they entered at the time of the formation of the oil. Once there, the metals have been regarded as a source of information regarding the past history of an oil, particularly with respect to its origin and accumulation.

The metals appear to have a real geochemical significance, although it is not clear at the present time exactly what that significance is. Vanadium and nickel are the most important metals in crude oils since they are related very closely to the organic matter making up the oil (Thomas, 1925; Shirley, 1931; Vinogradov, 1936; Gulyaeva *et al.*, 1941; Haberlandt, 1944; Khemelevskaya *et al.*, 1948; Katchenkov, 1951; Gulyaeva, 1952; Skinner, 1952; Woodle *et al.*, 1952; Garner *et al.*, 1953; Scott *et al.*, 1954; Hodgson, 1954; Gamble *et al.*, 1955; Horeczy, 1955; Ball *et al.*, 1956; Beach *et al.*, 1956; and Bonham, 1956).

Table I shows the occurrence of vanadium and nickel in some of the oil fields of the world. The data appear badly scattered. This is undoubtedly a result, in part, of non-uniform selection in sampling. Some investigators tried to obtain a general over-all picture by examining a small number of samples from a large number of fields, and other authors examined a large number of samples from

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TABLE I. SUMMARY OF OCCURRENCE OF VANADIUM AND NICKEL IN CRUDE OILS

Age	Location	No. of Samples	Vanadium (ppm)	Nickel (ppm)	V/Ni Ratio	Reference
Cenozoic	U.S.A. (Calif.)	4	87 (34–223)*	53 (33–97)	1.4 (0.9–2.3)	Milner *et al.* (1952)
	U.S.A.	1	0.16	3.0	0.05	Ball *et al.* (1956)
	U.S.S.R.	97	—	—	0.2	Katchenkov (1949)
	U.S.S.R.	16	46 (0.5–127)	17 (2.5–43)	2.6 (0.02–7.3)	Gulyaeva *et al.* (1941)
	Venezuela	1	1160	110	10.5	McEvoy *et al.* (1955)
Mesozoic	U.S.A. (Texas)	1	1.2	1.7	0.7	Milner *et al.* (1952)
	U.S.A.	11	40 (0.03–106)	11 (0.03–29)	2.5 (0.1–6.1)	Ball *et al.* (1956)
	Canada	37	62 (0.1–220)	25 (0.3–77)	2.0 (0.5–3.4)	Hodgson (1954)
	Kuwait	1	22.5	6.0	3.8	Milner *et al.* (1952)
	U.S.S.R.	36	—	—	0.7	Katchenkov (1949)
Paleozoic	U.S.A.	11	44 (0.8–106)	13 (0.2–27)	3.2 (1.5–4.8)	Ball *et al.* (1956)
	U.S.A. (Texas)	4	2.8 (0.8–7.0)	2.4 (1.0–4.8)	0.9 (0.5–1.6)	Milner *et al.* (1952)
	U.S.A. (Texas)	1	—	—	0.6	Shirley (1931)
	U.S.A. (Okla.)	23	0.44 (0.1–5.2)	1.6 (0.1–8.5)	0.3 (0.02–1.0)	Bonham (1956)
	U.S.A. (Okla.)	1	—	—	2.5	Shirley (1931)
	U.S.A. (Kansas)	1	—	—	0.5	Shirley (1931)
	Canada	30	9.3 (0.04–84)	8.1 (0.1–5.7)	0.8 (0.1–3.2)	Hodgson (1954)
	U.S.S.R.	28	—	—	8.0	Katchenkov (1949)
	U.S.S.R.	—	—	—	— (2–6)	Gulyaeva (1952)

* Bracketed values indicate range of variation in group of oils analyzed.

small number of fields. While it is unfair to compile all these data into one brief table, the table nevertheless does give some indication of the occurrence of vanadium and nickel in crude oil. The picture does not appear uniform. For example, Katchenkov (1949) found that there was a general trend for the oils from the oldest formations to be marked by a high vanadium-to-nickel ratio. On the other hand, Hodgson (1954) found the oils for western Canada to fit into the reverse pattern, in which the oils from the oldest formations were generally marked by a very low ratio. Ball (1956) found that the ratio for oils from some of the United States fields appeared to agree well with the ratio for oils from the Soviet Union, while for other American fields his data showed much less agreement with the Soviet data.

Hodgson (1954) suggested that the downward trend with age in the vanadium-to-nickel ratio observed for the Canadian oils might be a reflection of some general maturation effect. The geology of the western Canadian plains indicates that the oil fields there were perhaps unique among oil fields in that they are, for the most part, completely isolated from any extensive diastrophism; as a result, the Canadian oils might be regarded as having been less subject to the changes that would tend to obscure the fundamental geochemical processes than have the oils from other parts of the world.

The object of the present research program was to examine one of the various agents that might be operative in the maturation of crude oils and, specifically, the agents that might be operative in the change of the metals ratio through a general lowering of the metal content. Among the possible factors involved in the migration and accumulation of crude oil, the effect of heat is the factor which commands immediate attention. Accordingly, attention was first directed to an examination of the effect of heat upon the presence of metals in a crude oil. It is with this phase of maturation study that the present paper is concerned.

EFFECT OF HEAT ON VANADIUM AND NICKEL CONTENTS

When a petroleum oil is subjected to heat action the oil tends to break down into a lighter liquid product, a gas product, and a coke product. If an oil is pictured as migrating when this alteration occurs, it is obvious that the liquid and gaseous materials would continue to move, and that the coke, being a solid insoluble in the oil, would be left behind. The ultimate accumulation of the migrating oil would then be an oil lighter than the original. If the metal-containing compounds in the oil are subject to destruction through heat action, the metal contents of the accumulating oil would be reduced because the metals released from the oil would be left behind with the coke.

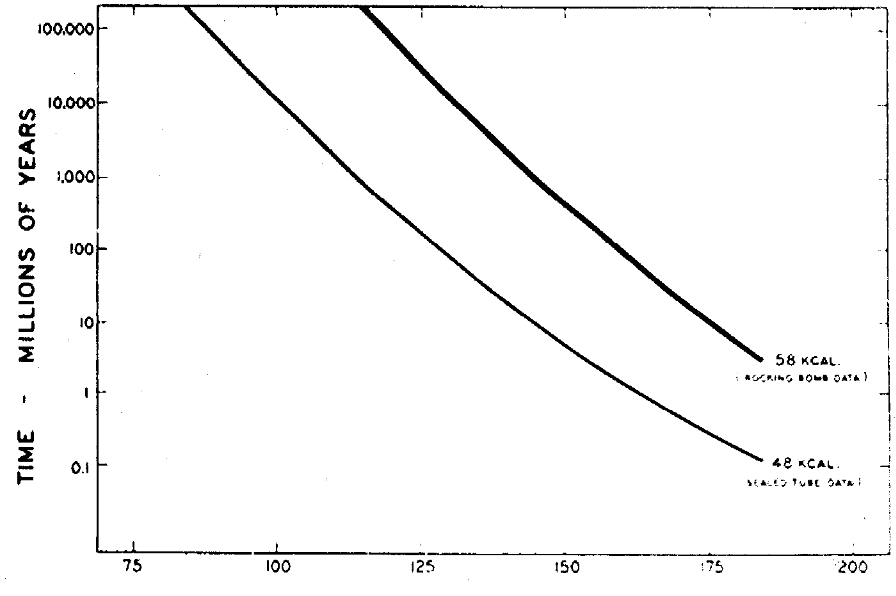

FIG. 1.—Relation between time and environmental temperatures required by a protopetroleum to mature from a vanadium content of about 300 ppm to 1 ppm.

To simulate such a change in the laboratory, an oil was heated in a stainless steel bomb at controlled temperatures for measured periods of time, and the altered oil was separated from the coke and gas and analyzed for metals content. The oil chosen for the study was the McMurray oil from the Athabasca oil sands of northeastern Alberta. Its inspection is given in Table II which shows it to be a very heavy black oil. This oil was chosen because of its high metals content, and because it is probably closer to the situation under study than any other Alberta oil since it is usually regarded as a young oil (Ball, 1935; Scott *et al.*, 1954).

TABLE II. CHANGES IN GRAVITY, VISCOSITY, SULPHUR, VANADIUM, AND NICKEL IN MCMURRAY CRUDE OIL RESULTING FROM THERMAL ACTION AT 358–428°C.

Temp. (°C.)	*Time* (*hr.*)	*Gravity* (°*A.P.I.*)	*Visc. at 70°F.* (*cstk.*)	*Sulphur* (%)	*V* (*ppm*)	*Ni* (*ppm*)	*V/Ni Ratio*
Crude oil	—	7.0	60,000	5.2	211	77.2	2.73
358	32.0	10.6	708.3	3.7	152	67.0	2.27
358	62.5	14.5	67.0	3.7	113	33.5	3.37
358	63.0	14.3	102.5	3.7	107	34.5	3.10
358	88.0	16.3	40.34	3.5	67.5	26.6	2.54
358	152.5	20.1	12.91	3.2	18.2	7.07	2.57
383	12.2	12.6	225.6	3.7	122	43.6	2.80
383	19.0	18.8	19.12	3.7	43.5	17.9	2.43
383	23.0	18.4	16.32	3.2	32.1	13.4	2.33
383	47.0	23.4	5.13	3.1	6.70	2.95	2.27
383	100.0	20.0		2.3	0.83	0.63	1.32
408	1.5	14.1	108.0	4.1	161	45.9	3.51
408	2.5	15.3	75.16	4.6	84.3	34.2	2.47
408	4.0	19.3	12.02	3.7	36.9	15.8	2.33
408	5.7	20.3	9.60	3.4	18.9	7.3	2.59
408	12.3	27.2	2.78	3.2	3.37	1.37	2.46
428	1.25	19.0	10.33	—	30.4	13.4	2.27
428	2.0	22.4	4.80	3.6	15.0	5.76	2.61
428	3.0	26.4	2.82	3.3	2.22	1.48	1.50
428	4.3	27.6	2.55	2.9	1.82	0.80	2.05

A 300-gram sample of dry McMurray oil obtained from the separation plant at Bitumount, Alberta, was placed in a 800-ml. bomb (American Instrument Company Superpressure A.I.S.I. 347 stainless steel) which was then purged with high-purity nitrogen. The system was pressure-tested, and the thermal reaction was started by heating the bomb to the desired reaction temperature. Initial results indicated that temperatures below about 350°C. were not sufficient to bring about an appreciable reaction within a reasonable time. Consequently, the studies were carried out at temperatures of about 350°, 375°, 400°, and 420°C. The oil in the bomb was kept agitated during the entire period by a motor-driven rocking mechanism.

At the completion of the heating, the bomb was cooled to room temperature and depressurized. The contents of the bomb were then separated into liquid and solid by centrifuging. The liquid phase was examined for gravity, viscosity, sulphur content, and vanadium and nickel contents. The sulphur determination was made by a combustion-titration method, and the metals were determined colorimetrically as previously described (Hodgson, 1954).

Table II shows the results of the thermal maturation of the McMurray oil in the rocking bomb. It is obvious that the McMurray crude oil was altered considerably. The viscosity data show the most marked changes. The A.P.I. gravity was increased to values roughly comparable with Redwater crude oil, a typical light crude oil of the western plains. Sulphur was reduced only to about half of its original value. With the exception of the sulphur results, the data indicate that the heavy black oil was altered markedly in the direction of a normal light crude oil.

The vanadium and nickel contents of the oil were lowered to a great extent—in some cases to values less than one per cent of the original. The change in metals content with reaction time at a given temperature was quite regular, and the data appeared to fit into first-order rate expressions. The rate constants were calculated for the removal of vanadium and the removal of nickel from the liquid oil, and the results are shown in Table III. The reaction rates for the two reactions are nearly the same, although at the higher temperatures the vanadium appears to be removed at a somewhat more rapid rate than the nickel.

The temperature of the reaction varied over a range of nearly 10° and the timing of the reaction was not very precise because the heating and cooling of the

TABLE III. FIRST-ORDER RATE CONSTANTS FOR REMOVAL OF VANADIUM AND NICKEL IN ROCKING BOMB THERMAL DEGRADATION OF MCMURRAY CRUDE OIL

Temp. (°C.)	*Time* (*hr.*)	k_V (*hr.*$^{-1}$)	k_{Ni} (*hr.*$^{-1}$)
358	62.5	0.0100	0.0133
	63.0	0.0108	0.0128
	72.25	0.0103	0.0106
	88.0	0.0130	0.0121
	126.0	0.0129	0.0123
	152.5	0.0161	0.0157
	Average:	0.0122	0.0128
383	19.0	0.0831	0.077
	23.0	0.0832	0.076
	29.0	0.0692	0.064
	47.0	0.0734	0.070
	65.0	0.0628	0.056
	100.0	0.0554	0.048
	Average:	0.0712	0.0652
408	2.5	0.368	0.324
	4.0	0.443	0.396
	4.5	0.443	0.396
	4.5	0.338	0.299
	5.7	0.422	0.413
	12.25	0.336	0.327
	Average	0.390	0.359
428	1.25	1.551	1.400
	2.0	1.320	1.300
	3.0	1.515	1.318
	4.25	1.104	1.038
	4.25	1.030	0.918
	Average:	1.304	1.195

Activation energies: Vanadium removal = 58.6 Kcal./mole
Nickel removal = 57.5 Kcal./mole

reactor bomb was very slow at these temperatures. To improve the control on the thermal reactions, the study was repeated using sealed glass tubes rather than the large bomb. The oil sample—about 10 grams—was weighed into the tube and the tube sealed. It was then placed in an aluminum block furnace, along with several other samples. The temperature of the block was controlled to ±0.5°C. Although pressures in the tubes reached at least 1,000 psi during some of the reactions, no tube failures were experienced. At the end of the reaction time the tube was withdrawn, cooled, and opened. The contents were diluted with benzene, and the coke centrifuged off. The coke material was extracted with benzene, and the residue dried and weighed to arrive at an approximate oil yield by difference; the benzene solution was evaporated, wet-ashed, and the metals determined as before.

Table IV shows the metal results for the sealed-tube study. Again the data appeared to fit into first order rate expressions. The data at the lowest temperature agreed well with the rocking bomb data, but at the higher temperatures the sealed-tube rates were somewhat lower than the rocking bomb rates. The reason for the lack of agreement is not immediately clear. It is obvious that possible leaks in the bomb system could not account for the higher bomb reaction rate at the higher temperatures. Possible catalysis of the reactions by the stainless steel surface was probably insignificant because addition of stainless steel cuttings to sealed-tube reactions showed little effect on the reaction rates. It is possible that the higher reaction rates in the bomb can be attributed to a different sort of catalysis. The crude McMurray oil contained solids to the extent of about 1.5 per cent. These solids consisted of kaolinite, illite, pyrite, and quartz as shown by X-ray diffraction. In the stationary sealed tubes these minerals undoubtedly settled out immediately, but in the rocking bomb the minerals would have been held in suspension during the entire reaction period. Since it is generally believed that clay minerals do have some catalytic effect in the maturation of crude oil, it is probable that such catalysis would be much more pronounced in the rocking bomb than in the sealed tubes. In any case, the difference in rates was not great, and either set of data could be used with considerable confidence.

The activation energies shown with the foregoing data indicate the temperature dependence of the metal-removal reactions. The values are very similar for the two metals, and the slight differences are probably not significant.

To test the applicability of the McMurray results to crude oils in general, a few rocking bomb determinations were made on two other crude oils: Lloydminster oil—another heavy black oil, and Redwater—a relatively light oil. The data for these two oils shown in Table V give little reason to believe that the McMurray results are not applicable to crude oils in general.

It is significant to note that the activation energies found for the two metal-

TABLE IV. FIRST-ORDER RATE CONSTANTS FOR REMOVAL OF VANADIUM AND NICKEL IN SEALED-TUBE THERMAL DEGRADATION OF McMURRAY CRUDE OIL

Temp. °C.	Time, (hr.)	V (ppm)	Ni, (ppm)	V/Ni	k_V (hr.$^{-1}$)	k_{Ni} (hr.$^{-1}$)
350	88.0	102.9	41.1	2.50	0.00813	0.00718
	185.0	66.5	30.3	2.19	0.00623	0.00503
	232.5	45.1	17.8	2.53	0.00663	0.00630
				Average:	0.00700	0.00617
354	124.8	96.3	36.7	2.62	0.00627	0.00594
377	8.0	188.6	—	—	0.0142	—
	32.0	139.0	—	—	0.0130	—
	48.0	81.8	43.5	1.88	0.0196	0.0119
	72.0	65.5	29.1	2.25	0.0163	0.0135
	163.0	5.5	3.2	1.73	0.0224	0.0195
	187.0	8.2	—	—	0.01[illegible]4	—
				Average:	0.0171	0.0150
400	8.0	84.1	33.1	2.54	0.115	0.106
405	6.0	107.4	43.0	2.45	0.113	0.094
	8.0	74.2	30.5	2.43	0.131	0.116
	16.0	34.7	28.5	1.22	0.113	0.062
	16.0	34.8	11.4	3.06	0.113	0.119
				Average:	0.118	0.098
423	3.0	111.2	39.7	2.80	0.214	0.221
	4.0	71.0	23.3	3.05	0.273	0.299
	6.0	39.3	18.6	2.11	0.280	0.237
	8.0	18.2	11.0	1.66	0.307	0.244
				Average:	0.269	0.250

Activation energies: Vanadium removal—47.6 Kcal./mole
Nickel removal —47.8 Kcal./mole

TABLE V. FIRST-ORDER RATE CONSTANTS FOR REMOVAL OF VANADIUM AND NICKEL IN ROCKING BOMB THERMAL DEGRADATION OF LLOYDMINSTER AND REDWATER CRUDE OILS

	Temp. (°C.)	Time (hr.)	V (ppm)	Ni (ppm)	V/Ni	K_V (hr.$^{-1}$)	k_{Ni} (hr.$^{-1}$)
Lloydminster							
Initial			92.5	38.7	2.39		
Heated	358	144	11.8	7.12	1.66	0.0143	0.0118
Heated	410	5.25	15.3	8.38	1.83	0.343	0.286

Activation energies: Vanadium removal—54.6 Kcal./mole
Nickel removal —55.3 Kcal./mole

	Temp. (°C.)	Time (hr.)	V (ppm)	Ni (ppm)	V/Ni	K_V (hr.$^{-1}$)	k_{Ni} (hr.$^{-1}$)
Redwater							
Initial			4.05	9.96	0.41		
Heated	358	171	0.99	2.60	0.38	0.0083	0.0070
Heated	408	10	0.11	0.53	0.21	0.360	0.293
Heated	408	5.5	1.06	2.31	0.46	0.243	0.270
Heated	416	14.5	0.20	0.28	0.73	0.207	0.410

Activation energies: Vanadium removal—54.2 Kcal./mole
Nickel removal—59.7 Kcal./mole

removal reactions, and the absolute rates of reaction for the two reactions, are not greatly different from the data published by McNab *et al.* (1952) for the general changes brought about in the McMurray oil by thermal action.

VANADIUM AND NICKEL DURING GEOLOGIC TIMES AND TEMPERATURES

Having measured the rates of removal of vanadium and nickel under laboratory conditions, and having measured the temperature dependence of the same reactions, it is possible to project the data to geologic times and temperatures. This approach can not be regarded as giving an indisputable answer; nevertheless, it should give an answer in which considerable confidence can be placed.

One method of examining the situation is to make an estimate of what the starting materials of the oils were. Then, knowing the periods of time involved from the beginning to the present, an estimate can be made of the temperatures that must have prevailed during those periods to account for the conversion that appears to have occurred. An examination of the trace metals content of the original organic material shows that for most plant material a metal content higher than 10 ppm is not common (Bertrand, 1950). Animal life in some fairly isolated instances exceeds this figure but, by and large, the 10 ppm limit holds with animal life too (Noddack *et al.*, 1939). The mechanism by which this organic material undergoes its early conversion to petroleum is very obscure, but it seems reasonable to believe that a large proportion of the total organic material would have been lost. The present study has shown that the metal-containing structures are quite resistant to thermal action, and it seems logical to believe that the metal-containing materials would perhaps tend to be preserved to a greater extent than many of the more fragile organic structures making up the organic residues from plant and animal life. This would result in an effective increase in concentration of the metals in the protopetroleum beyond the 10 ppm limit. This suggestion is borne out by the observation that many crude oils have metal contents in excess of 100 ppm. The crude oil of the McMurray oil sands and the crude oil of the Santa Maria Valley in California are marked by probably the highest vanadium concentrations of the oils of North America—211 and 223 ppm respectively. The vanadium concentrations in protopetroleums must obviously have been higher than these—probably as high as 500 ppm. The time required to bring about a reduction in vanadium content from about 500 ppm to 1 ppm, which is a common figure for ordinary light crude oils, can be calculated readily from the observed rates and the activation energies. The curves shown in Figure 1 were developed from such calculations, and it is apparent that thermal action alone has little effect on the metal maturation of a crude oil. For example, the oil from the Leduc reefs in Alberta has a metal content of roughly 1 ppm, and the age of the reefs is about 250 million years. Assuming that the age of the oil is somewhat greater than that of the reef—say 300 million years—the temperature required for the metal maturation would be in the range 121°–152°C., and probably nearer the higher value. With Pembina oil, assuming an

age of 100 million years, a temperature range of 128°–157°C. is indicated. If the Pembina oil were 300 million years old, the temperature range would be much the same as for the Leduc oil. Conversely, if the temperature had been only 100°C., the time required for the metal maturation would have been at least 10,000 million years, which is roughly twice the age of the earth.

It is difficult to say what the temperatures of the reservoir rocks were during the millions of years when maturation of crude oils was in progress. Several investigators have found that there is evidence to support high reservoir temperatures, one of the most recent groups being Mironov *et al.* (1955) which reported equilibrium temperatures of around 170°C. for 32 petroleums in the United States and the U.S.S.R. On the other hand, present-day reservoir temperatures

TABLE VI. SUBSURFACE TEMPERATURES IN ALBERTA, CANADA*

$$\text{S.S.T.} = \text{S.T.}\ (35°\text{–}40°\text{F.}) + \left\{\begin{matrix} 0.0113\ \text{(foothills)} \\ 0.202\ \text{(plains)} \end{matrix} \times \text{depth in feet}\right\}$$

Oil Field	*Zone*	*Temp.* (°C.)
Redwater	Leduc	34
Pembina	Belly River	40
Pembina	Cardium	53
Joarcam	Viking	40
Turner Valley	Madison	64
Leduc Woodbend	Lower Cretaceous	54
North Woodbend	Lower Cretaceous	57
West Devon	Lower Cretaceous	62
West Devon	Nisku	63
West Devon	Leduc	66
Bonnie Glen	Leduc	81

* Data obtained through courtesy of Petroleum and Natural Gas Conservation Board of Alberta.

in western Canada are much lower, as shown in Table VI where all the temperatures are below 100°C. Until further information is obtained to clarify this point about reservoir temperatures, it is necessary to conclude that reservoir temperatures are two low to attribute the metal maturation of the crude oils to thermal action. And if the metal reduction rates are too slow to account for the apparent loss of metals from crude oils, it can be concluded also that the change in metals ratio can not be attributed to thermal action.

EFFECT OF HEAT ON PORPHYRINS

It has been reasonably well established that at least some of the vanadium and nickel content of a crude oil exists in metal-organic complexes known as porphyrins. Evidence for this type of structure for the McMurray oil has been given by Scott *et al.* (1954) and Montgomery (1953). Nickel and vanadium complexes have been described by Dunning *et al.* (1956) for an Oklahoma crude oil. Although most investigators have reported that crude oils do not contain enough porphyrin to accommodate all the vanadium and all the nickel present in the oil, Beach *et al.* (1956) believe that this is because some of the porphyrin is obscured by high molecular weight components of the oil that are very closely associated with the porphyrin structure. It is possible also that the procedures used for determining total porphyrin (Treibs, 1936; Groennings, 1953) are not entirely satisfactory, either because not all the porphyrin is recovered, or because the extinction coefficients are not known precisely. Indications from the present investigation of the McMurray oil are that there is enough porphyrin present to account for less than 10 per cent of the vanadium.

To gain a better understanding of the relation between the metals and the porphyrin material in crude oil, and also to gain a better understanding of the thermal history of crude oil, the fate of porphyrin metal complexes during thermal maturation was investigated.

Samples of oil from the rocking bomb study were subjected to porphyrin aggregate determination as laid down by Groennings (1953). The procedure was altered somewhat by the use of cyclohexane instead of chloroform for the final solutions to prevent rather rapid decomposition of the porphyrin. The absorption spectrum of the porphyrin aggregate was measured with a Hilger spectrophotometer. The four peak heights at about 615, 563, 523, and 494 mμ—were measured by the baseline technique, and the ratio of the "reacted" to "original" peak heights, averaged for the four peaks, was used as the x/x_0 value in the standard first-order rate reaction expression. For this purpose Beer's law for dilution of a colored solution was assumed to hold; previous work had shown this to be sound. It is of importance to note that these calculations were completely independent of any extinction coefficient data. The reacted porphyrin was compared directly with the original unreacted porphyrin content.

TABLE VII. RATE CONSTANTS FOR REMOVAL OF PORPHYRIN IN ROCKING BOMB THERMAL DEGRADATION OF MCMURRAY CRUDE OIL

Temp. (°C.)	Time (hr.)		k_p (hr.$^{-1}$)
358	42.0		0.0174
	62.5		0.0234
	63.0		0.0241
	88.0		0.0207
	152.5		0.0165
		Average	0.0204
383	12.2		0.115
	19.0		0.091
	23.0		0.104
	47.0		0.088
		Average	0.099
408	1.5		0.423
	4.0		0.661
	5.7		0.443
	12.3		0.307
		Average	0.459
428	1.25		1.93
	2.0		1.68
	3.0		1.04
		Average	1.55

Activation energy: 52.5 Kcal./mole

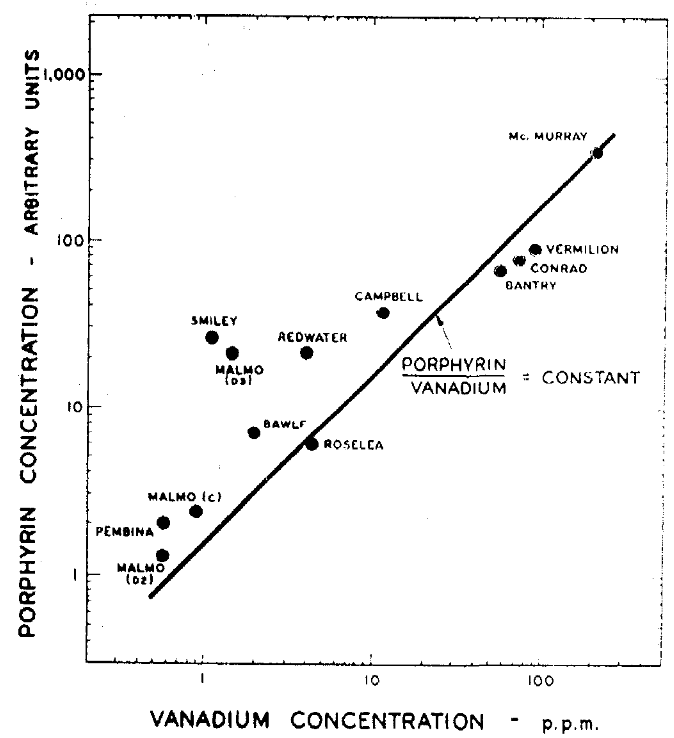

FIG. 2.—Relation between porphyrin and vanadium cont[e]nts for representative group of western Canadian crude oils.

The data obtained for the decomposition of the porphyrin metal complexes appeared to follow a first-order reaction system as did the data for the two metals. These data, shown in Table VII, indicate that at the three lower temperatures, the porphyrin metal complexes were destroyed in the oil at a rate distinctly higher than the rate of removal of the metals. The temperature dependence of the porphyrin reaction was somewhat lower, with a value of about 52 Kcal./mole for the activation energy[4] as compared with the value of about 58 Kcal./mole for

[4] This value agrees reasonably well with the 53.3 Kcal. per mole determined by Montgomery (1953) for the degradation of the porphyrin in the McMurray oil in the presence of the reservoir sand aggregate.

the two metals. The significance of this observation is that at still lower temperatures, that is, geological temperatures, the porphyrin destruction rates would be expected to be very much greater than the metal removal rates. Thus, if thermal action were the controlling factor in the maturation of crude oils, maturing crude oils should have sharply decreasing values for the porphyrin-to-metal ratios. And an oil which has been matured very extensively should have virtually no porphyrin metal complexes, although it could still have an appreciable metal content.

PORPHYRINS IN CRUDE OILS

Thirteen crude oils were examined for porphyrin content. They represent eight producing formations widely scattered over the western Canadian plains, and they are described in some detail by Hodgson (1954).

The relation between porphyrin and vanadium content is shown in Figure 2.

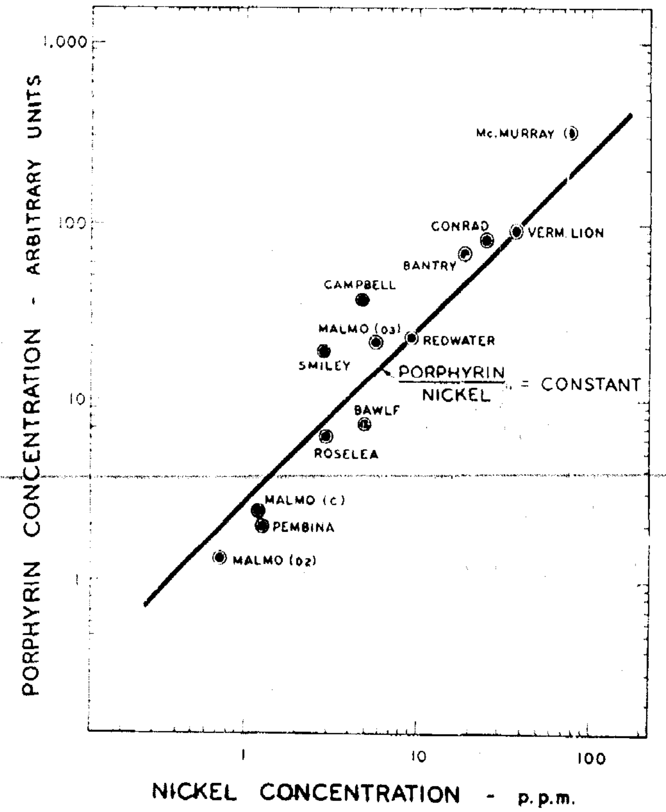

FIG. 3.—Relation between prophyrin and nickel contents for a representative group of western Canadian crude oils.

The porphyrin concentration is reported in arbitrary units since considerable doubt exists regarding the extinction coefficient which should be used to convert peak heights to absolute concentration terms. The line sketched through the point for McMurray oil represents the path that would be followed if the McMurray oil matured with identical porphyrin and metal rates, producing a constant porphyrin-to-vanadium ratio throughout the maturation. Figure 3 shows the relation between porphyrin and nickel for the same oils, and again the line shows the path for a constant porphyrin-to-metal ratio.

It is obvious that the relations shown in Figures 2 and 3 do not agree with the predictions of the thermal reactions because there has not been in geological time the marked fall-off in the porphyrin-to-metal ratio that has been indicated by the measured rates. Also, this observation indicates that thermal action can not be regarded as responsible for what appears to have happened in nature. It is very important to note further that it is not a question of an environment that was not quite warm enough to bring about the observed changes in the oil; rather it is a matter of an environment that could not account for the changes at any temperatures below about 400°C.

CONCLUSIONS

Thermal action in oil-field rocks appears to have little or no significance in the maturation of a crude oil. This is indicated by two observations: (1) the measured rates of removal of vanadium and nickel from crude oil at present-day reservoir temperatures are much too low to have achieved any appreciable metals removal; and (2) the measured rates of porphyrin destruction and metals removal are so different at all environmental temperatures below about 400°C. that the observed constant porphyrin-to-metal ratios can not be explained by thermal action alone.

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ENVIRONMENTAL STUDIES OF CARBONIFEROUS SEDIMENTS PART I: GEOCHEMICAL CRITERIA FOR DIFFERENTIATING MARINE FROM FRESH-WATER SHALES[1]

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ABSTRACT

Investigation shows that trace-element assemblages and clay-mineral ratios are in some respects characteristic of the environment of deposition of shales. Boron and rubidium are more abundant in a group of marine shales than in a group of fresh-water shales of Pennsylvanian age, whereas gallium is more abundant in the fresh-water group. Nickel and vanadium are concentrated in the organic fraction of the marine shales whereas lead, zinc, copper, and tin are more highly concentrated in the organic fraction of the fresh-water shales. In the region studied it appears possible to differentiate marine shales from fresh-water shales by quantitative spectrographic determination of boron, gallium, and rubidium.

INTRODUCTION

Environmental studies of sediments are used for paleogeographic reconstructions which are finding increasing application in petroleum geology. The purpose of the present investigation was to determine to what extent marine, brackish- and fresh-water shales can be differentiated by chemical and petrographic techniques. The Pennsylvanian strata of the Appalachian coal basin in Pennsylvania provide exceptional opportunities for environmental studies because of the alternation of marine and fresh-water sediments.

The investigation involved a study of the trace elements and clay mineralogy of 75 shale samples collected from the Allegheny cycles of the northern part of the Appalachian coal basin. All samples were analyzed for boron, gallium, and rubidium; 59 were examined by x-ray diffraction for illite, kaolinite, and chlorite; 33 were analyzed for the common trace elements; and 10 for the trace-element content of the ash of organic material mechanically separated from the shales. Sandstones, underclays, limestones, and coals, the rocks associated with the shales, were not analyzed but will receive attention in a forthcoming study.

PREVIOUS ENVIRONMENTAL INVESTIGATIONS

The occurrence of characteristic fossils and the gross lithologic aspects of a sediment, have been and still are the principal methods of environmental interpretation. More specific methods are based on indicator minerals such as glauconite and on clay-mineral ratios. The use of clay-mineral ratios was discussed in detail by Millot (1952), Grim and Johns (1954), Murray (1954), Keller (1956), and others.

Geochemical methods have received increasing emphasis in recent years as a

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means of reconstructing ancient environments. Among the most important contributions in this field to date are the use of oxygen isotopes (Silverman, 1951), and the geochemical distribution of certain common and trace elements (Goldschmidt and Peters, 1932, a and b; Landergren, 1945; Bradacs and Ernst, 1956; Brinkmann and Degens, 1956; Degens, 1957).

MARINE AND NON-MARINE INDICATORS

A good environmental indicator for marine or non-marine sediments should be: (1) markedly affected by salinity changes, (2) relatively widespread, (3) abundant enough to be detected and measured with a reasonable degree of precision, (4) formed or concentrated in the rock in which it is found, and (5) relatively unaffected by post-depositional changes. The most critical indicators are those which most nearly approach these requirements.

The main factors which influence the distribution of elements and clay minerals in a sedimentary rock are as follows: (1) the kinds and proportions of clay minerals in the source rocks, (2) climatic conditions and consequent soil types in the source area, (3) selective sorting during transportation and deposition, (4) selective adsorption of elements on clays and other colloids, (5) use of elements in the life cycle of plants and animals, and (6) formation of new minerals in the basin of deposition.

The last three factors are partly dependent on temperature, pressure, salinity, pH, and redox potential in the basin of deposition and therefore are most likely to result in useful differences between rocks formed in different environments.

GENERAL STRATIGRAPHY

The Pennsylvanian rocks of the northeastern part of the Eastern bituminous coal basin consist predominantly of sandstones, siltstones, silty shales, and less amounts of coal, clay, limestone, and clay shale. The succession exhibits cyclic characteristics but to less extent than the typical Illinois cyclothems. The samples for this study were largely obtained from the Allegheny series of the first four coal basins west of the Allegheny escarpment in Clearfield and Jefferson counties. Structural features and sampling localities are shown in Figure 1. Table I is an index to the sampling localities. The stratigraphy and paleontology of the Allegheny series in Clearfield County are based on the work of Williams (1957), and that of the Brookville basin on the work of Ferm (1948, 1957).

A typical Allegheny cycle of the Clearfield basin is shown in Figure 2. Members 1, 2, 3, and 9 are the most persistent, whereas members 4, 5, 6, and 7 are variable and can not be traced any great distance. Stout (1931) showed that there is a progressive change in the character of Pennsylvanian cycles in Ohio from marine at the base to fresh water at the top. Ferm (1948) and Williams (1957) showed a similar sequence of changes in the Allegheny series of the Brookville and Clearfield basins, respectively.

In the present investigation, samples were collected from members 2 and 3

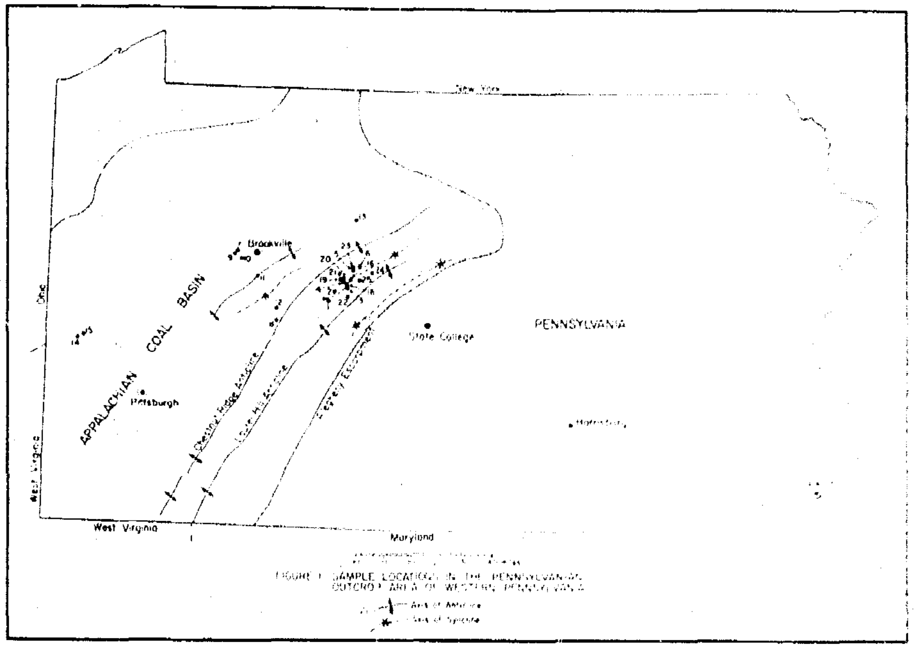

FIG. 1.—Sample locations in Pennsylvanian outcrop area of western Pennsylvania.

of the upper Clarion, lower Kittanning, and upper Freeport cycles. These members consist of dark gray to black, fissile, concretion-bearing shales and are the only ones which consistently contain fossils. No samples were collected from any other member in the cycle. The environmental interpretations of the three shale bodies (Fig. 3) are based largely on the paleontological investigations of Williams (1957). A list of fossils from the clay shales of these cycles is presented in Table II.

TABLE I. INDEX TO SAMPLING LOCALITIES SHOWN IN FIGURE 1

Loc.	*Shale Member*	*Environmental Group*	*Loc.*	*Shale Member*	*Environmental Group*
1	Up. Freeport	Fresh	14	Low. Kittanning	Marine
2	Low. Kittanning	Brackish	15	Low. Kittanning	Marine
3	Up. Freeport	Fresh	16	Up. Clarion	Marine
4	Low. Kittanning	Brackish	17	Up. Freeport	Fresh
5	Low. Kittanning	Brackish	18	Up. Freeport	Fresh
6	Up. Freeport	Fresh	19	Up. Freeport	Fresh
7	Low. Kittanning	Marine	20	Up. Freeport	Fresh
8	Up. Clarion	Marine	21	Up. Freeport	Fresh
9	Low. Kittanning	Marine	22	Up. Freeport	Fresh
10	Low. Kittanning	Marine	23	Low. Kittanning	Brackish
11	Low. Kittanning	Marine	24	Low. Kittanning	Brackish
12	Up. Freeport	Fresh	25	Low. Kittanning	Brackish
13	Low. Kittanning	Marine			

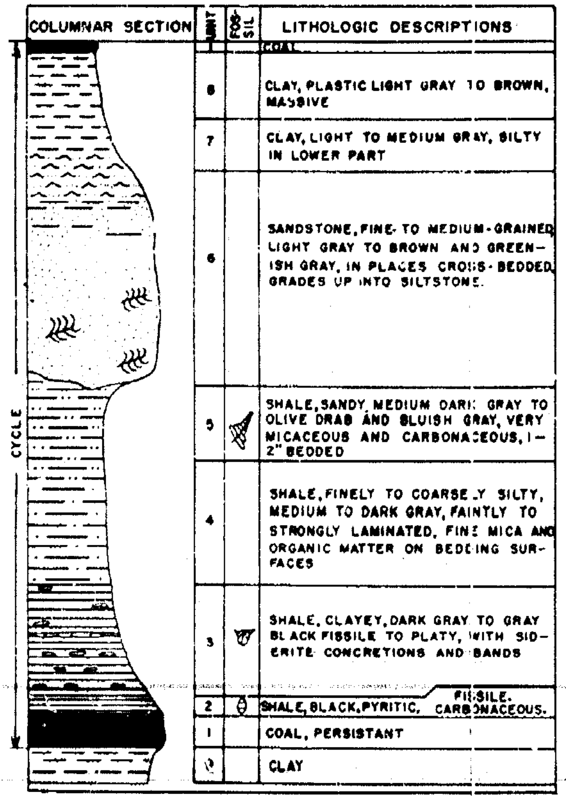

FIG. 2. Diagram of typical Allegheny cycle in Clearfield basin.

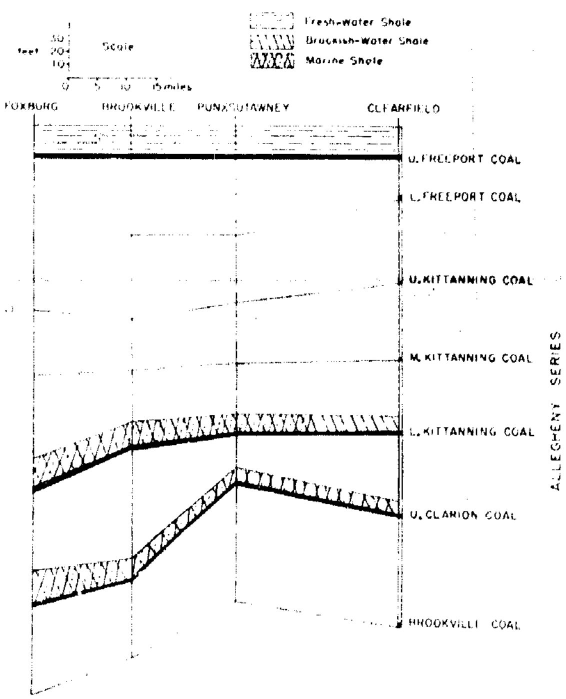

FIG. 3. Diagram of shale members sampled and their environmental distribution.

TABLE II. FOSSILS FOUND IN UPPER CLARION, LOWER KITTANNING, AND UPPER FREEPORT SHALE MEMBERS

Upper Clarion Cycle (Marine)	*Lower Kittanning Cycle (Marine and Brackish)*	*Upper Freeport Cycle (Fresh)*
Composita subtilata	*Brackish*	*Estheria* sp.
Marginifera muricata	*Lingula lemniscata*	*Carbonicola* sp.
Dunbarella rectalaterarea	*Orbiculoidea missouriensis*	*Lepidoderma* sp.
Mesolobus mesolobus	*Marine*	
Chonetina sp.	*Mesolobus mesolobus*	
Cephalopoda sp.	*Marginifera muricata*	
Pseudorthoceras sp.	*Linoproductus prattenianus*	
Pecten sp.	*Dunbarella whitei*	
Gastropoda sp.	*Lingula* sp.	
	Orbiculoidea missouriensis	
	Pecten sp.	
	Dawsonella sp.	
	Aviculopecten eaglensis	

PETROGRAPHY OF SHALES

Megascopic descriptions will be presented together with other information in a separate paper. Ten samples were studied in thin section by use of a 1200X oil-immersion lens and a combination transmitting and reflecting microscope. One thousand point counts of various components were made per slide; results are shown in Table III. The total amount of clay ranges from 75 to 89 per cent. Pyrite is very finely divided, ranges from 0 to 10 per cent, and is less than 2 per cent in most samples. Both detrital and authigenic quartz are present, ranging in size from 2 microns to about 80 microns. The organic content ranges from 1.7 to 11.8 per cent. Electron micrographs show that the organic fraction in marine shales is finely dispersed throughout the clay, whereas in the fresh-water shales, both finely dispersed and large fragments are found. In general, the marine shales are darker in color than the fresh-water ones, a feature which may be due to the size and the distribution of the organic matter, more than to the total amount.

TABLE III. PETROGRAPHIC DATA FOR SOME TYPICAL ALLEGHENY SHALE SAMPLES

Cycle	*Quartz*	*Mica*	*Matrix*	*Opaques*	*Pyrite*	*Misc.*	*Organics*	*Environment*
Brookville	9.7	0.2	86.4	0	0.1	0.1	[illegible]	Marine
Brookville	1.1	0.2	88.4	0	0	0	10.3	Marine
L. Kittanning	8.3	0.2	89.1	0.2	0	0	1.7	Brackish
L. Kittanning	3.3	0	74.8	0	10.0	0.2	11.8	Brackish
M. Kittanning	9.3	0.8	80.1	0.1	1.2	0.1	8.6	Brackish
U. Kittanning	15.1	0.1	81.4	0.2	0.1	0	3.1	Fresh
L. Freeport	13.8	5.2	71.6	0	0.8	0	8.6	Fresh
L. Freeport	6.0	0.3	85.6	0.1	0.2	0	7.8	Fresh
U. Freeport	7.2	0	86.2	0.3	0.2	0	6.2	Fresh
U. Freeport	17.5	1.0	78.8	0	0	0.1	2.5	Fresh

METHODS OF ANALYSIS

A. Preparation of samples.—A flow diagram showing the steps in sample preparation is given in Figure 4. Most of the mechanical operations are self-evident but the separation of organic fraction and clays requires some explanation. The sample was ground to about 10 microns in a ball mill. It was found that this was the optimum size for efficient separation. After grinding, the organic material was separated by froth flotation. To a water-suspension containing about 300 grams of the powdered shale, 2 drops of mineral oil were added to act as a collector and 3 drops of pine oil as a frother. The first float usually contained some clay and this was separated by settling for 24 hours in water.

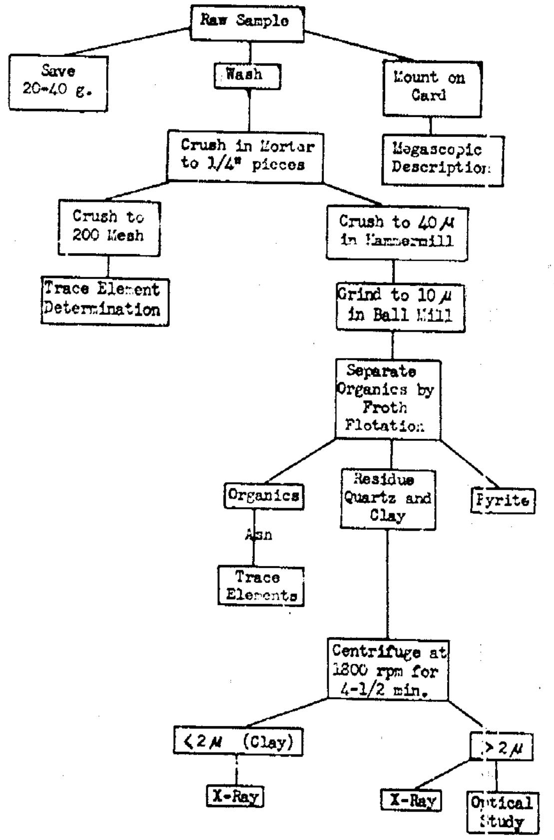

FIG. 4.—Flow diagram for shale analysis.

The organic fraction so obtained was ashed at 700°C., after which trace elements were determined on the ash.

B. Trace-element determination.—The trace-element analyses on raw samples and on ash of the organic matter were made with a Jarrel Ash 21-foot Wadsworth spectrograph having a reciprocal linear dispersion of 5 Å/mm. in the first order. Exposures were made with a logged stepped sector having a step ratio of 1 to 1.585. Quantitative values were determined by a direct relationship between element concentration and recorded transmittance from the photographic plates, as measured with a densitometer (Applied Res. Lab. Model). Exposure of a standard sample on each plate permitted a check on the calibration curves. The arrangements used are shown in Table IV.

A graphite buffer was mixed in ratio 1:1 with each shale sample except those used for determination of gallium. As the CN lines interfere with the 4172 Å line of gallium, it is necessary to use only the initial arcing; at this stage gallium and the alkalies are volatilized. To hold down the CN lines, H. Lovell (personal communication) suggested using KH_2PO_4 instead of graphite. The excitation was constant for all analyses, and high enough to completely volatilize the whole sample.

Two kinds of calibration curves were computed, one for shales, and one for the organic ash. The two curves are necessary because the ash contains relatively less silica, more alumina, iron, and calcium than the raw shale sample. Details of the spectrographic method and the synthetic mixtures used in the standards are given in Tables IV and V.

Each of the mixtures was ground for 30 hours in a ball mill and then checked spectrographically

TABLE IV. DETAILS OF SPECTROGRAPHIC METHOD FOR TRACE-ELEMENT DETERMINATIONS
(Slit width = 40 mm.; slit height = 10.5 mm.; sample weight = 5 mg.)

Element	*Order*	*Buffer*	*Amperes*	*Eastman Emulsion*	*Exposure Time (Sec.)*
Boron (2496.778 Å) / (2497.733 Å)	2	5 mg. graphite	8	SA1	120
Gallium (4172.056 Å) 4032 Å interference with Mn	1	5 mg. KH_2PO_4	6	SA1	10
Rubidium (7947.60 Å) yellow / (7800.227 Å) filter	1	5 mg. graphite	6	1N	30
Other trace elements (center of camera = 3570 Å)	1	5 mg. graphite	8	SA1	120

TABLE V. MIXTURES USED OF PREPARATION OF SPECTROGRAPHIC STANDARDS

	Shale Standard	*Organic Ash Standard*
	Wt. %	*Wt. %*
SiO_2 (silica gel)	35	
SiO_2 (quartz)	27	35
Al_2O_3	27	35
Fe_2O_3	5	12
CaO	2	10
K_2O	2	4
Na_2O	1	2
MgO	1	2
	100	100

for purity. Known amounts of the elements to be analyzed were mixed in varying proportions with the synthetic mixtures and calibration curves were constructed.

In general, for this method, the error in estimating the percentage of several elements for the same exposure, ranges from 30 to 50 per cent, depending on the element. The error is larger in the analyses of ash, because of the variation in amount of ash.

For each of the elements boron, gallium, and rubidium, separate exposures were made and this allowed greater precision and reduced the error to less than 20 per cent. Table VI shows sampling and experimental error. The pine oil and mineral oil used in froth flotation were analyzed spectrographically and found to be free of the trace elements which were measured.

C. Determination of clay minerals.—After separating the organic material from the 10-micron fraction, the residue was dispersed in distilled water and NH_4OH was added to bring the pH to 10. The dispersion was centrifuged to separate the clay fraction (<2 microns) and it was then sedimented on glass slides following the method of Grim (1934).

X-ray diffraction patterns were obtained with a high-angle Norelco diffractometer. Representative samples were run at 2° per minute in order to identify the clay minerals present and to estimate crystallinity. The slides were then run at 0.5°/min. and the peak areas of selected clay-mineral reflections were measured with a planimeter. Eleven of the samples were treated with ethylene glycol in order to attempt to expand the 14 Å peaks.

Table VIIa. Trace-Element Data for Fresh-Water Shales (ppm)

LOCALITY (Shale Member) Sample Number	Ag	B	Ba	Be	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Rb	Sn	Sr	V	Zn
Loc. 1 Up. Freeport																	
56-108	ND	70	400	10	ND	150	70	40	2000	ND	30	40	70	3	400	70	ND*
56-110	ND (2)	35 (30)	400 (300)	20 (20)	ND (40)	100 (100)	40 (500)	15	300 (200)	ND (4)	20 (20)	10 (400)	60 (80)	2 (30)	300 (200)	40 (100)	ND (400)**
56-112	ND	45	300	10	ND	90	90	35	2000	ND	30	60	100	3	500	70	ND
56-114	ND (5)	20 (15)	500 (400)	10 (10)	ND (10)	100 (90)	70 (1500)	25	400 (200)	ND (4)	25 (25)	25 (150)	50 (90)	3 (40)	300 (300)	40 (100)	ND (600)
56-116	ND	40	250	9	ND	40	45	7	200	ND	15	25	40	ND	500	40	ND
Loc. 3 Up. Freeport																	
56-130	ND	20	700	15	10	200	100	9	2000	ND	40	80	20	3	300	80	ND
56-133	ND	15	700	10	ND	100	90	7	1500	ND	25	35	300	7	300	50	ND
56-135	ND (2)	20 (30)	500 (400)	9 (10)	ND (20)	50 (60)	60 (1000)	7 (15)	800 ([illegible])	ND (3)	15 (20)	25 (100)	150 (100)	4 (20)	400 (300)	40 (80)	ND (1500)
Loc. 6 Up. Freeport																	
56-159	ND	45	1000	10	10	150	90	15	700	ND	30	20	300	3	200	50	ND
56-161	ND	45	600	9	ND	90	100	20	3000	3	30	30	100	10	200	40	ND
56-162	ND	20	1000	10	ND	150	100	15	200	ND	25	60	150	2	600	30	ND
Lower Limit of Detection	1	5	200	1	10	5	1	2	1	2	5	10	10	2	200	10	200

* ND = Not Detected

** Numbers in parenthesis give the abundance (p.p.m.) of elements in the ash of the organic fraction

TABLE VIIb. TRACE-ELEMENT DATA FOR BRACKISH-WATER SHALES (PPM)

LOCALITY (Shale Member) Sample Number	Ag	B	Ba	Be	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Rb	Sn	Sr	V	Zn
Loc. 2 Low. Kittanning																	
56-119	ND	130	500	9	ND	100	35	40	300	3	10	25	150	3	800	30	ND
56-121	ND	110	600	10	ND	70	80	3	300	ND	15	35	450	2	400	20	ND
56-124	ND	130	400	10	ND	70	50	9	250	ND	10	25	200	ND	300	20	ND
Loc. 4 Low. Kittanning																	
56-139	ND	100	600	20	10	90	70	20	500	ND	20	30	300	2	700	40	ND
56-141	ND	130	600	15	10	70	90	2	500	ND	25	10	150	2	400	40	ND
56-144	ND	70	500	7	10	40	50	2	800	ND	10	10	200	2	400	30	ND
Loc. 5 Low. Kittanning																	
56-148	ND (1)	80 (80)	600 (400)	20 (15)	ND (10)	70 (50)	80 (300)	25	400 (200)	ND (ND)	40 (35)	35 (30)	60 (150)	15 (20)	600 (400)	60 (80)	ND ND
56-149	ND (2)	140	500 (400)	20 (15)	ND (10)	40 (70)	80 (900)	45	350 (350)	ND (2)	30 (30)	30 (40)	150	5 (80)	500 (400)	40 (60)	ND 1500
56-150	ND	130	700	10	ND	70	80	4	600	ND	30	ND	300	8	500	30	ND
56-153	ND	45	500	10	10	70	100	6	2000	ND	40	70	70	15	500	50	ND
56-156	ND (4)	80 (60)	500 (600)	7 (15)	ND (30)	50 (70)	100 (200)	25	250 200	ND (3)	15 (40)	40 (50)	150 (200)	30 (50)	400 (400)	20 (60)	ND ND

TABLE VIIc. TRACE-ELEMENT DATA FOR MARINE SHALES (PPM)

LOCALITY (Shale Member) Sample Number	Ag	B	Ba	Be	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Rb	Sn	Sr	V	Zn
Loc. 7 Low. Kittanning																	
56-287	ND	120	300	15	10	100	70	40	1500		100	30	250	5	400	70	ND
56-289	ND	90	600	7	20	60	80	9	4000	ND	80	40	90	3	600	50	ND
56-291	ND (2)	70 (70)	400 (400)	10 (10)	ND (20)	80 (70)	70 (150)	15	3500 (2500)	4 (6)	70 (150)	40 (40)	100 (100)	5 (7)	400 (300)	50 (150)	ND (400)
56-294	ND	50	300	10	ND	80	60	2	250	4	60	50	70	5	600	40	ND
56-296	ND	90	600	9	ND	40	60	2	200	ND	20	40	150	3	500	20	ND
Loc. 8 Up. Clarion																	
56-297	ND (8)	70	400 (300)	8 (10)	40 (20)	40 (60)	50 (100)	3	3000 (2000)	ND (2)	50 (100)	40 (50)	100	3 (5)	400 (300)	40 (150)	ND (300)
56-299	ND (ND)	140	500 (400)	6 (10)	ND (ND)	50 (80)	80 (150)	7	600 (700)	ND (ND)	50 (7[illegible])	40 (40)	300	2 (5)	400 (400)	50 (100)	ND (500)
56-302	ND (2)	150	300 250	9 (10)	ND (40)	40 (60)	80 (800)	2	250 (200)	ND (5)	40 (80)	30 (150)	400	2 (10)	300 (200)	30 (200)	250 (1000)
Loc. 13 Low. Kittanning																	
56-317	ND	150	500	10	ND	70	120	6	350	ND	20	25	350	3	400	50	ND
56-318	ND	130	600	10	10	70	80	ND	1500	4	40	40	350	2	500	60	ND
56-319	ND	140	500	8	ND	50	60	7	500	ND	30	15	500	[illegible]	400	30	ND

It was found, as shown in Figure 6 and Table VIII, that certain elements are selectively enriched in the ash of the organic matter of ten shale samples. These elements are Ag, Co, Cu, Ni, Pb, Sn, V, Zn, and Mo. The remaining elements investigated show no tendency to be concentrated in the ash. The organic material from two marine samples was analyzed by x-ray fluorescence for iodine, with negative results.

TABLE VIII. ELEMENTS ENRICHED IN ORGANIC FRACTION OF SHALES

Fresh-Water Shales	*Marine Shales*
Pb	—
--	Ni
Sn*	Sn
Cu*	Cu
Zn*	Zn
Ag	Ag
Co	Co
Mo	Mo
V	V*

* Very high abundance values.

The amount of organic matter is not appreciably different in shales of the two environmental groups. However, some larger fragments of organic matter occur in the fresh-water shales, whereas the organic material is finely dispersed with the clay in the marine shales. This condition is reflected in the ease with which the organic fraction can be separated by froth flotation; more complete separation was obtained with fresh-water shales.

The observed variations in trace-element content of the organic matter of marine and fresh-water shales may be due to: (1) variations in ultimate availability, that is, variations in the trace elements in the environment, (2) variation in the adsorptive capacity of different organic substances and in the adsorption tendency of different elements, and (3) post-depositional solution and asdorption.

In attempting to evaluate these factors, the work of Krauskopf (1956) is especially interesting. He found by experiment a difference in element adsorption on peat moss (representing organic matter of fresh water) and on marine plankton Krauskopf found that Pb, Zn, and Cu were more concentrated in peat moss than in the plankton. The results of the present study support his observation.

In attempting to use trace elements in organic matter as environmental indicators, allowance must be made for possible error due to the presence of reworked organic material. The organic matter in shales directly above a coal bed may represent in part material derived from the underlying coal. Another difficulty in using such methods in shales which overlie coal beds, is that post-depositional effects of gases and acids escaping from the coal may leach or precipitate some elements and minerals. Evidence that such conditions may have occurred has been found in the composition of siderite concretions occurring in marine shales 2–4 feet above the coal. Some of these concretions contain rela-

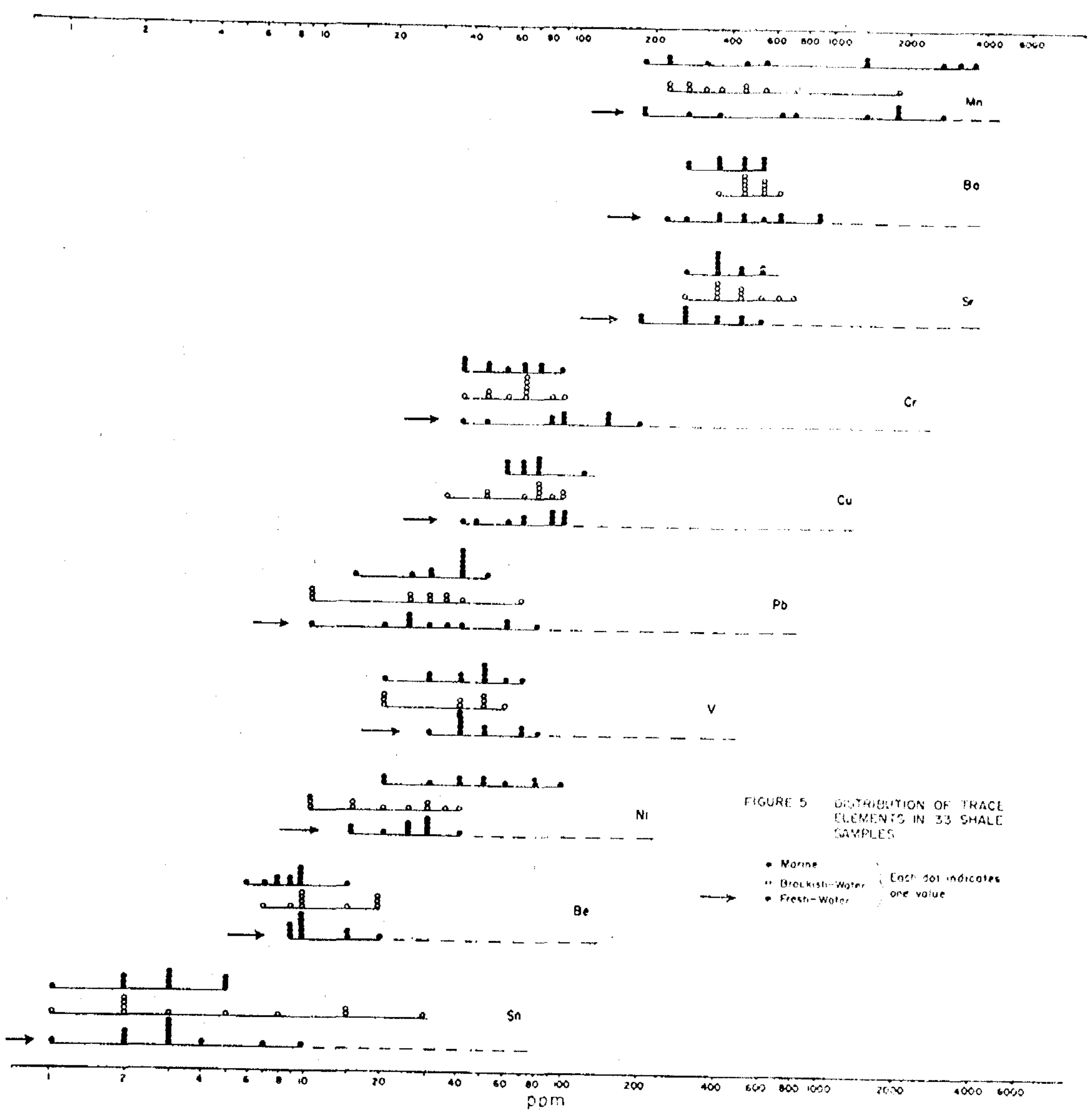

FIG. 5.—Distribution of trace elements in thirty-three shale samples.

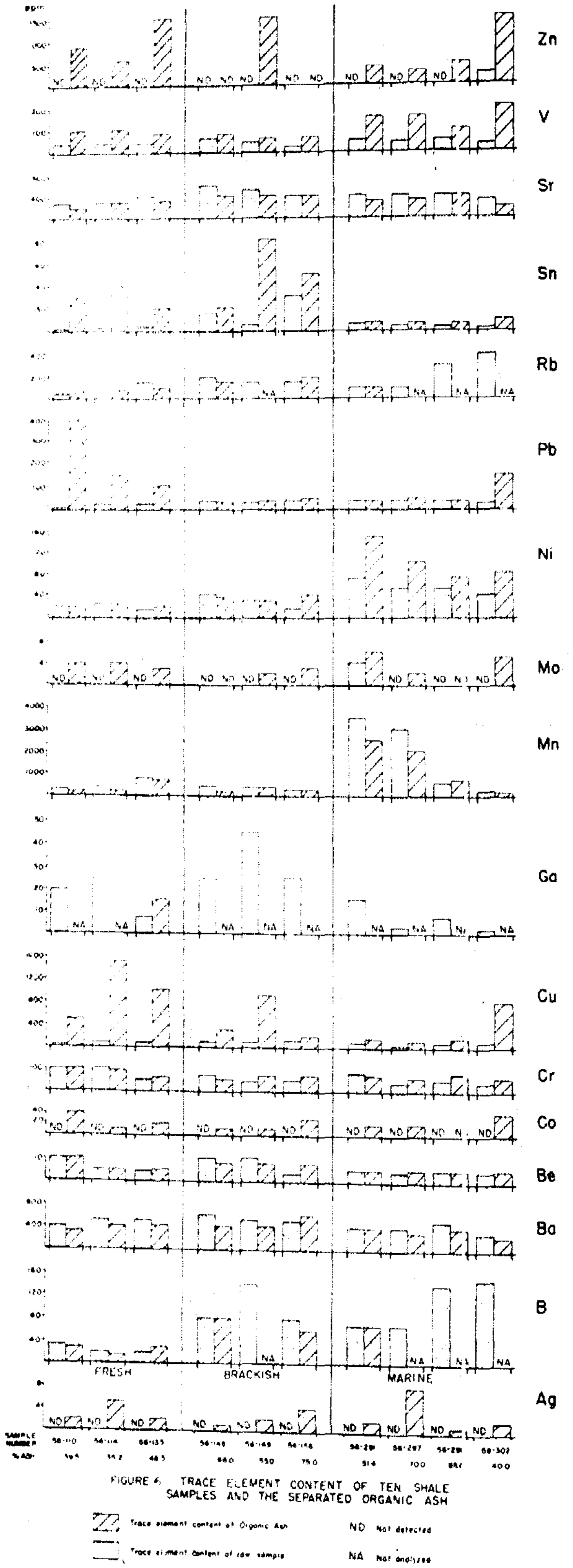

FIG. 6.—Trace element content of ten shale samples and the separated organic ash.

tively high amounts of sphalerite and smaller amounts of galena and chalcopyrite. The sphalerite contains large amounts of cadmium and gallium (95 ppm).

In general, it would appear that with due precautions the trace-element analysis of organic matter might be valuable in environmental interpretations.

ANALYSES FOR BORON, GALLIUM, AND RUBIDIUM AND ESTIMATION OF CLAY MINERALS

A. Discussion of results.—The results of 75 determinations of boron, rubidium, and gallium and 59 determinations of illite, kaolinite, and chlorite are presented in Table IX and Figures 7–13. Statistical analyses of the data are shown in Tables X, XI, and XII.

Table X shows that the mean values for the various measurements are different in the environmental groups. Gallium decreases whereas boron, rubidium, and the illite:kaolinite ratio increase in mean value from fresh-water to brackish to marine shales. Because the standard deviations are relatively large, complete confidence can not be placed in mean differences which are not pronounced. Therefore statistical tests were run to determine the significance of mean differences. In cases where parametric tests were not appropriate, non-parametric tests were run for differences in central tendency. In order to show the relationship between the various measurements, correlation and regressions analyses were also made.

Boron shows the greatest mean difference between the various environments. The "t" value calculated for the fresh-water and marine shales is significant at the 1 per cent level. However, because the variances are heterogeneous, the gallium and rubidium means could not be compared by the "t" test. By use of the Kolmogorov-Smirnov non-parametric test (Siegel, 1956) for differences in central tendencies, gallium and rubidium were found to be significantly different in fresh-water and marine shales (Table XI), and boron was found to be significantly different in fresh-water and brackish-water shales. None of the elements measured shows a significant difference between brackish-water shales and marine shales.

The three clay minerals identified in the shales are illite, kaolinite, and chlorite. These minerals were identified principally by their first-order basal reflections. The 001 reflection of illite most commonly occurred at 10.1 Å but some marine samples gave a 10.4 Å reflection, which probably indicates an interlayered structure.* The illite peaks are broader and more asymmetrical in marine shales than in fresh-water ones and the higher spacing for illite is confined to the marine shales, although not all marine samples showed this.

The first order basal kaolinite reflection was found at 7.2 Å for almost all samples. The number of higher order reflections would indicate it is a poorly crystallized variety. Chlorite was identified in almost all samples by the 14.5 Å

* Some glauconite may be present; it is not distinguishable from magnesian illite by x-ray diffraction.

TABLE IXa. TRACE-ELEMENT AND CLAY-MINERAL DATA FOR FRESH-WATER SHALES (PPM)

LOCALITY (Shale Member) Sample Number	B	Ga	Rb	B:Ga	Illite/Kaolinite	
Loc. 1 Up. Freeport						
56-108	70	40	70	1.8	0.49	0.56
56-109	45	7	40	6.4	0.84	
56-110	35	15	60	2.3		
56-111	35	40	90	0.9	0.76	
56-112	45	35	100	1.3	0.96	0.98
56-114	20	25	50	0.8	0.69	0.76
56-115	50	3	300	16.6	1.60	
56-116	40	7	40	5.7	1.23	1.10
Loc. 3 Up. Freeport						
56-126	20	5	40	4.0		
56-129	15	3	10	5.0	87	
56-130	20	9	20	2.2	80	
56-132	60	20	100	3.0		
56-133	15	7	300	2.1	1.62	
56-135	20	7	150	2.9	0.98	0.76
56-136	40	15	250	2.7	1.69	
56-137	50	55	100	0.9	1.49	
Loc. 6 Up. Freeport						
56-159	45	15	300	3.0	0.91	
56-160	30	4	150	7.5	1.85	
56-161	45	20	100	2.3		
56-162	20	15	150	1.3	1.79	
56-165	100	15	150	6.7	1.50	
Loc. 12 Up. Freeport						
56-314	130	8	250	16.3	2.16	
Repl.	110	6	200	18.3	2.16	
56-315	110	40	150	5.5	1.85	
56-316	70	35	100	2.0		
Loc. 17 Up. Freeport						
56-357	30	4	200	7.5	1.97	
Loc. 18 Up. Freeport						
56-358	20	35	250	0.6	1.01	
Loc. 19 Up. Freeport						
56-359	35	30	60	1.2	0.94	
Loc. 20 Up. Freeport						
56-360	40	7	150	5.7	1.05	
Loc. 21 Up. Freeport						
56-361	35	9	350	3.9	1.38	
Loc. 22 Up. Freeport						
56-362	15	2	100	7.5	1.17	

TABLE IXb. TRACE-ELEMENT AND CLAY-MINERAL DATA FOR BRACKISH-WATER SHALES (PPM)

LOCALITY (Shale Member) Sample Number	B	Ga	Rb	B:Ga	Illite/Kaolinite	
Loc. 10 L. Kittanning						
56-119	130	40	150	3.3	2.41	
56-121	110	3	450	36.7	2.12	
56-124	130	9	200	14.4	1.99	
Loc. 80 L. Kittanning						
56-139	100	20	300	5.0	1.69	
56-142	130	2	150	65.0	1.53	
56-144	70	2	200	35.0	1.72	
Loc. 86 L. Kittanning						
56-148	80	25	60	3.4	86	0.72
56-149	140	45	150	3.2	0.91	1.00
56-150	130	4	300	32.2	1.07	1.09
56-153	45	6	70	7.5	1.01	1.45
56-156	80	25	150	3.2	1.07	1.24
56-151					2.10	
Loc. 24 L. Kittanning						
56-363	80	7	150	11.4		
56-364	80	9	250	8.9	1.82	
Loc. 23 L. Kittanning						
56-365	35	3	150	11.7	1.51	
Loc. 25 L. Kittanning						
56-366	45	15	60	3.0	0.92	

basal reflection. Eleven samples treated with ethylene glycol did not show expansion of this peak. The chlorite 001 peak is so small in the samples studied that the 002 reflection which coincides with the 001 reflection of kaolinite can be neglected.

The peak areas, rather than peak heights, were used to estimate the relative changes in clay-mineral proportions, because peak areas, especially for illite, are less likely to be influenced by changes in crystallinity and grain size or by instrument variation. In most cases the increase in illite: kaolinite ratios involves a broadening of the illite peak as well as an increase in peak height. It is therefore difficult to say exactly what the increase in illite/kaolinite peak area ratio means; certainly grain size and crystallinity are factors as well as composition of the clay fraction. In the following discussions of the illite/kaolinite area ratios, the term area, for convenience, is dropped.

Table X shows that the mean values for the illite: kaolinite ratio increase from fresh-water to marine shales. However, the variances are so large that the means could not be compared by parametric tests. The Kolmogorov-Smirnov test showed a difference in central tendency at the 5 per cent level between fresh-water and marine shales.

TABLE IXc. TRACE-ELEMENT AND CLAY-MINERAL DATA FOR MARINE SHALES (PPM)

LOCALITY (Shale Member) Sample Number	B	Ga	Rb	B:Ga	Illite/Kaolinite	
Loc. 7						
L. Kittanning						
56-287	120	40	250	3.0	1.62	1.72
56-288	90	7	100	12.9		
56-289	90	9	90	10.0	1.69	1.14
56-290	60	9	450	6.7	1.47	
56-291	70	15	100	4.7	0.67	0.98
56-293	150	8	300	18.8	1.57	
56-294	50	2	70	25.0	1.75	1.75
56-296	90	2	150	45.0	1.42	1.35
Loc. 9						
L. Kittanning						
56-308	100	10	100	10	1.99	
56-309	150	15	70	10	1.77	
56-310	150	2	250	75.0	3.48	
56-311	120	3	350	40.0	3.40	3.40
56-312	80	3	300	26.7	1.08	
Loc. 11						
L. Kittanning						
56-313	130	2	150	65.0		
Loc. 8						
Up. Clarion						
56-297	70	3	100	23.3	2.27	2.20
56-299	140	7	300	20.0	1.96	1.99
56-300	90	4	300	22.5		
56-301	150	7	300	21.4	1.80	
56-302	150	8	400	78.8	1.26	1.40
56-305	60	3	300	20.0		
Loc. 16						
Up. Clarion						
56-367	170	8	550	21.3	2.20	1.65
Loc. 13						
L. Kittanning						
56-317	150	6	350	25.0		
56-318	130	ND	350	65.0		
56-319	140	7	500	20.0		
Loc. 14						
L. Kittanning						
56-320	90	4	300	22.5		
56-321	130	15	300	8.7		
56-322	120	10	400	12		
Loc. 15						
L. Kittanning						
56-323	140	4	450	25.0	3.36	
56-324	120	2	200	60.0	1.87	
56-325	160	10	600	16.0	1.91	

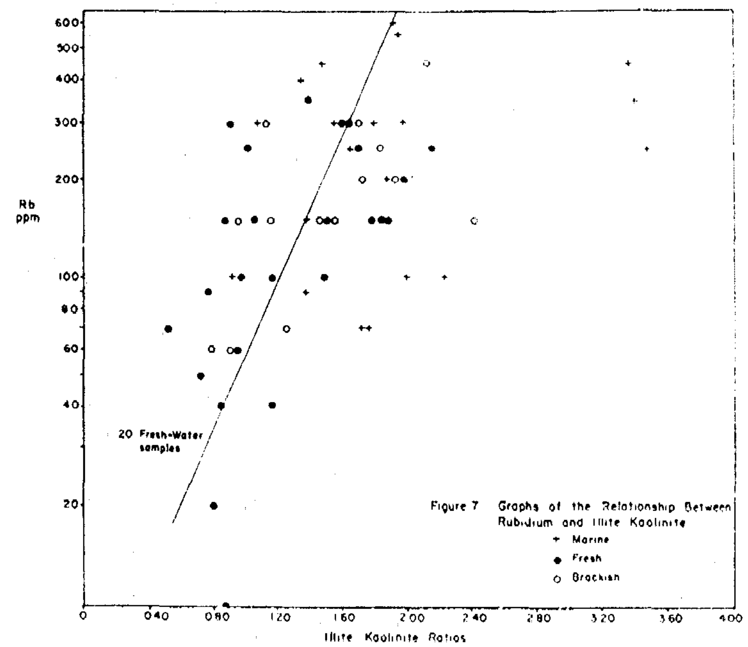

FIG. 7.—Graphs of relationship between rubidium and illite:kaolinite.

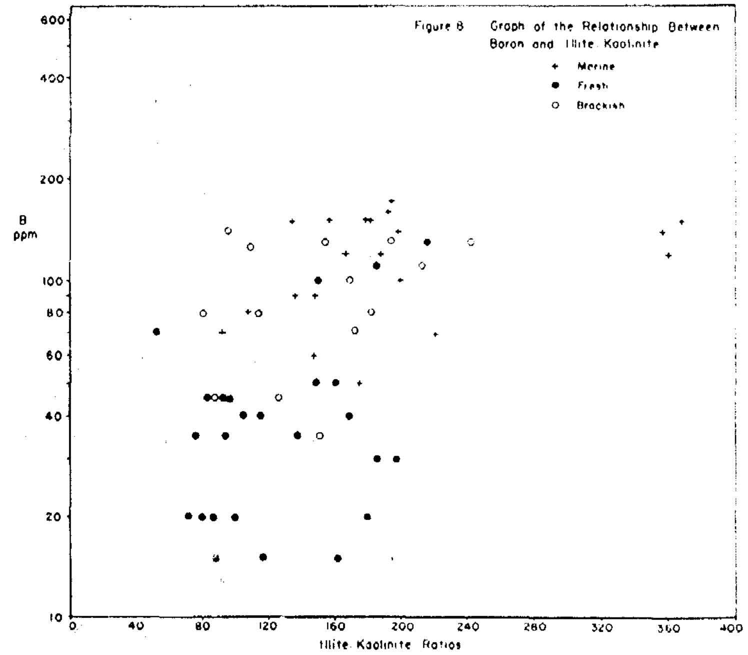

FIG. 8.—Graph of relationship between boron and illite:kaolinite.

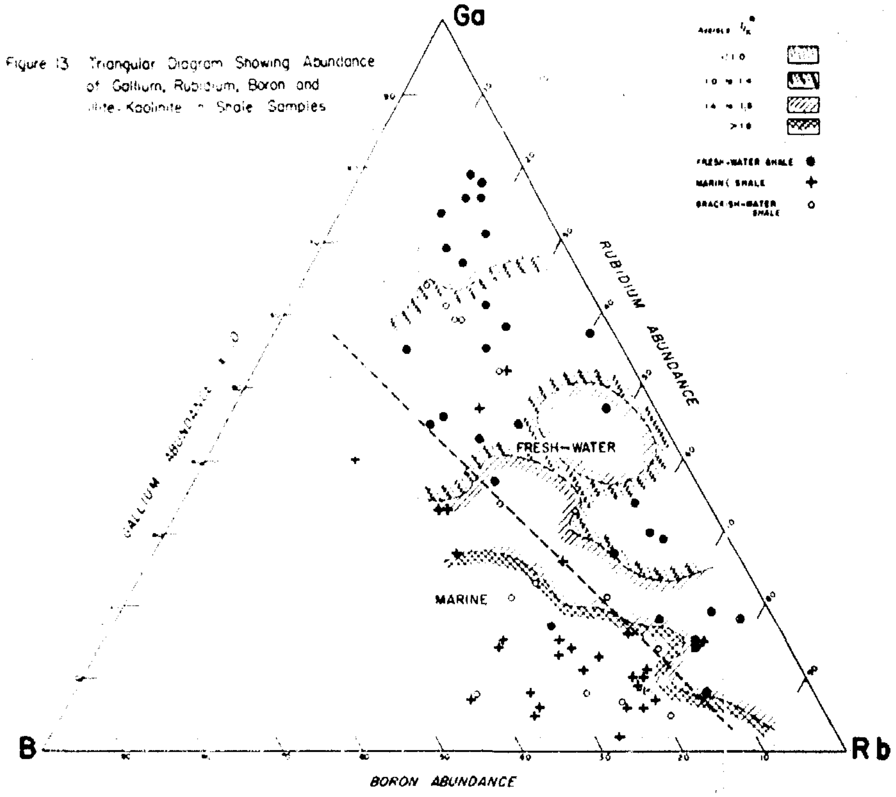

FIG. 13. Triangular diagram showing abundance of gallium, rubidium, boron, and illite:kaolinite in shale samples.

* K = Ratio of peak areas of first-order basal reflections of illite and kaolinite.

TABLE X. STATISTICAL ANALYSIS OF RAW DATA (PPM)

	Fresh		Brackish		Marine		Fresh:Marine Significance Tests		
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	t	F	N
Boron	[illegible]	28	[illegible]	35	115	34	8.70**	1.456	30
Rubidium	[illegible]	95	180	105	281	147		2.395**	30
Gallium	[illegible]	[illegible]	14	14	8	7		2.581**	30
Illite: Kaolinite	[illegible]	[illegible]	1.5	0.49	1.9	0.72		2.47*	20:25

$\bar{X}$ = arithmetic mean value of X.
s = standard deviation, or the root mean squared deviation.
t = Student's t = difference of means / standard error of difference
F = Variance Ratio test = greater estimate of the variance of the population / lesser estimate of the variance of the population
N = sample size.
* = significant at the 5% level.
** = significant at the 1% level.

TABLE XI. SIGNIFICANCE VALUES (D*) FOR KOLMOGOROV-SMIRNOV TEST (Non-Parametric)

	$N=30$ Fresh vs. Marine	$N=15$ Fresh vs. Brackish	$N=15$ Brackish vs. Marine
Boron	23*	15**	NS
Rubidium	14**	NS	NS
Gallium	12**	NS	NS
Illite / Kaolinite	NS	NS	NS

* = The Kolmogorov-Smirnov test (Siegel, 1956) is applied by preparing a cumulative frequency distribution table for each set of observations, using the same intervals for both distributions. "D" is the *maximum* difference between any corresponding pair of cumulative steps.
** = significant at the 1% level.
NS = not significant at the 1% level.

B. Correlations.—The proportions of clay minerals in a sediment are affected by factors other than salinity and cation availability, namely, by variations in source material and climate. Therefore, it is necessary to evaluate the relationship between the elements and the amounts of the different clay minerals. Correlation and regression coefficients were calculated for B, Ga, and Rb against the illite:kaolinite ratio, chosen as independent variable. The relationships among these elements and the clay minerals are shown in Figures 7–13. Regression and correlation coefficients are presented in Table XII.

Figure 8 shows the relationship between boron and the illite:kaolinite ratio. For all 59 samples the correlation coefficient "r" is significant at the 1 per cent level, although only 25 per cent of the variation in boron can be explained by the variation in illite:kaolinite ratio. No significant correlation was obtained between boron and illite:kaolinite in any of the separate environmental groups. The upper part of the graph contains most of the marine and brackish samples, the lower part all but three of the fresh-water samples.

Figure 7 shows the significant positive correlation between rubidium and the illite:kaolinite ratio. The "r" value for all 59 samples and for the fresh-water samples is significant at the 1 per cent level. It is obvious that no physical subdivision can be made between marine and fresh-water samples on the basis of this particular graph.

The graph of the relationship between gallium and the illite:kaolinite ratio is shown in Figure 9. The correlation coefficient is negative and significant at the 1 per cent level. As in the case of Figure 7, no physical separation is possible.

The graphs of the relationships of three elements to each other (Figs. 10–12) show that only boron and rubidium are correlated. The boron:rubidium correlation in marine samples is significant at the 1 per cent level but there is no significant correlation between boron and rubidium in fresh-water samples. Figure 11 provides a good separation of marine and fresh-water samples.

In order better to see the relationship between the three elements and the illite:kaolinite ratio, a triangular diagram was constructed (Fig. 13). The Ga,

TABLE XII. REGRESSION AND CORRELATION COEFFICIENTS FOR TRACE ELEMENTS AND CLAYS

Variables Compared	N	r	r^2	b	a	Environment
B:Rb	30	0.2502		0.1815	1.1969	Fresh
B:Ga	30	0.1666				Fresh
Rb:Ga	30	0.0162				Fresh
B:Rb	30	0.457**	0.2088	0.2421*	1.4662	Marine
B:Ga	30	1.1208				Marine
Rb:Ga	30	0.0322				Marine
B:I/K	25	0.3097				Fresh
Rb:I/K	25	0.5578**	0.311	0.4696**	1.4574	Fresh
Ga:I/K	25	0.3999*	0.1599	0.3715*	1.4845	Fresh
B:I/K	20	0.3508				Marine
Rb:I/K	20	0.2477				Marine
Ga:I/K	20	0.3696				Marine
B:Rb	75	0.5404**	0.202	0.4676**	0.7996	
B:Ga	75	0.1256				
Rb:Ga	75	0.2102				
B:I/K	50	0.4854**	0.236	0.2410**	1.438	
Rb:I/K	50	0.5019**	0.2510	0.282**	1.7518	
Ga:I/K	50	0.4052**	0.164	0.2783**	1.337	

r = correlation coefficient = $\frac{\text{covariance of } x \text{ and } y}{\sqrt{(\text{variance of } x)(\text{variance of } y)}}$

X, Y = independent variables.
N = number of samples.
r^2 = percentage of variation due to association.
b = slope of the least-squares regression line (min. sq'd. deviation).
a = Y intercept of least-squares regression line.
* = 5% significance level.
** = 1% significance level.

B, and Rb values were recalculated to 100 per cent (after the gallium values had been multiplied by 10). The diagram illustrates that the fresh-water and marine samples can be physically grouped on the basis of the trace elements so that from 60 samples only three marine samples overlap the fresh-water group and one fresh-water sample falls in with the marine group. The brackish-water samples are about equally divided in both groups.

The mean values of the illite:kaolinite ratio at different points in the diagram were calculated by using a mask with a "window" outlining a hexagonal unit area centered at each point and of a size chosen to represent a change of ±10 per cent in the amount of each chemical element represented. The mean of all values within the unit area was recorded at each central point and the means were then contoured on the triangular diagram. The diagram shows the higher illite:kaolinite ratio of most marine samples and illustrates the relationships of that ratio to the abundance of the trace elements.

C. *Interpretations.*—It is to be emphasized that although the correlations between B, Ga, and Rb respectively and the illite:kaolinite ratio are statistically significant, "r^2" which expresses the degree of association is at a maximum only 30 per cent. The remaining 70 per cent or more of the variation can be explained in part by experimental errors and by differences in availability of elements in the different environments. The positive correlation between rubidium and the illite:kaolinite ratio in fresh-water shales probably is due mainly to its selective incorporation in layer-lattice minerals of the rocks and soils of the source area. The rubidium ion is only slightly larger than potassium and can substitute for potassium in interlayer positions of minerals such as micas, montmorillonite and illite. There is no structural position for rubidium in kaolinite. It is therefore postulated that the observed correlation between Rb and the illite:kaolinite ratio in fresh-water shales is mainly due to the rubidium being combined in detrital illite and mica.

The positive correlation between boron and the illite:kaolinite ratio may be due in part to the formation of authigenic illite in the boron-rich environment of the ocean. It has previously been observed that boron is precipitated or adsorbed with argillaceous marine sediments (Goldschmidt and Peters, 1932; Landergren, 1945). The depositional form of boron is not known; whether it is adsorbed in some form or whether it is precipitated because of its use in the life cycle of organisms, it is likely that the boron in shales goes into the formation of tourmaline at an early stage of diagenesis or metamorphism. This tendency of boron was pointed out by Goldschmidt (1954, p. 284). A study of authigenic tourmaline in sediments was made by Krynine (1946).

In order to obtain evidence regarding the form of combination of boron in the shales, six finely ground shale samples were leached for 2 hours in concentrated HCl, then washed 4 times in distilled water, centrifuged after each wash, and finally dried at 140°C. Following this treatment, a redetermination of boron was made on each sample. Results are shown in Table XIII. It is evident that

TABLE XIII. COMPARISON OF BORON CONTENT OF SHALE SAMPLES BEFORE AND AFTER ACID TREATMENT

Sample Number	Boron Content	
	Before Treatment (ppm)	After Treatment (ppm)
56-108	70	70
56-111	35	40
56-135	20	35
56-302	150	150
56-323	140	140
56-70A	170	160

little or no boron was removed by the acid treatment, and the boron must therefore be in a very insoluble form. The boron present would be equivalent to 0.05–0.15 per cent tourmaline in fresh-water shales, 0.25–0.50 per cent tourmaline in marine shales.

The size and charge of gallium make it a suitable deputy for aluminum, particularly in six-fold coordination; therefore, a positive relationship is to be expected between gallium and aluminum and consequently, between gallium and the amount of kaolinite (because of its higher aluminum content in comparison with illite).

THEORY OF GENESIS OF CLAY MINERALS

The genesis of clay minerals is still a matter of controversy, largely centered on the question as to whether clay minerals in sediments are authigenic or detrital. Various aspects of this problem have been discussed by several authors (Millot, 1952; Grim and Johns, 1954; Keller, 1956; Correns and Engelhardt, 1939). The evidence presented for the various theories is based mainly on studies of modern sediments.

Possibly one of the difficulties is the rather loose definition of the terms authigenic and detrital. In this discussion authigenic clay minerals will be defined as those which are formed in the basin of sedimentation from dissolved material or amorphous material or which result from a change in the Al:Si ratio of preexisting minerals. Detrital clay minerals are defined as those brought from outside into the basin of sedimentation with little or no accompanying change in the Al:Si ratio. Thus a degraded illite (leached of some alkali) is regarded as detrital. However, an illite formed from montmorillonite, by substitution of interlayer ions and a change in the Al:Si ratio is regarded as authigenic.

The fact that Rb is correlated with the illite:kaolinite ratio in the fresh-water samples but not in the marine ones suggests that much of the illite in the fresh-water shales is of different origin than the bulk of the illite in the marine shales. Krynine (1940) pointed out the occurrence of detrital illite in rock fragments and authigenic illite replacing quartz in the same samples of the third Bradford

sandstone. Sandstones which interfinger with marine shales, included in the present study, contain numerous illitic rock fragments. A third point of evidence is that some of the marine shales contain illites with 10.4 Å basal reflections, whereas the illite of fresh-water shales showed only a 10.1 Å reflection. This means that some interlayering probably is present in the illite of the marine shales; such illite may result in part from a chemical modification of montmorillonite.

The presence of higher amounts of dissolved Si and Al in river and lake water as compared with the almost neligible values in sea water must mean that compounds of Si and Al are precipitated when terrestrial waters reach the ocean. It is suggested that authigenic illite is one of the principal new minerals formed and that this results in the high illite:kaolinite ratio of the marine shales in comparison with the fresh-water shales in which both the illite and kaolinite probably are mainly detrital.

CONCLUSIONS

It is concluded that there is a relationship between the clay mineralogy of the samples and the distribution of some trace elements; for diagnostic purposes it would be desirable to develop more accurate methods of determining clay mineral ratios. In extending the environmental studies to sandstones, the writers propose to determine trace elements in the separated clay fraction.

In the region studied, it is possible to differentiate marine shales from fresh-water shales by quantitative determination of boron, gallium, and rubidium. The boron content appears to be the most sensitive indicator of marine conditions (Fig. 11), but it is preferable to use a number of variables, as is done in Figure 13.

Studies of the organic fraction of the shale samples show that lead, zinc, copper, and tin are more highly concentrated in organic material of the fresh-water shales than in the organic material of the marine shales. On the other hand, nickel and vanadium are more strongly concentrated in the organic material of the marine shales. The differences in concentration are potentially useful for differentiating marine and fresh-water shales, and are deserving of further investigation.

It is concluded that the trace-element assemblage in the untreated shale samples and the assemblage in the separated organic fraction reflect the chemistry of the environment of sedimentation to an extent sufficient to permit differentiation of the environments of ancient sedimentary rocks. It is emphasized, however, that it may be misleading to attempt to use absolute abundance values of a single element as an indicator of the environment, because it has been shown that trace-element distribution is controlled in part by the bulk mineral composition of the sediment. It is expected that the absolute abundance values of trace elements in rocks in other areas may differ considerably from data given in the present paper, because of differences in the rocks and climate of the source areas. However, elemental abundance ratios may be found to show similar relationships to the bulk mineral composition. More work is needed in order to test the general applicability of the suggested diagnostic methods to rocks of other regions and of different geologic age.

USE OF PROPOSED CRITERIA

In the present investigation it was possible, by the use of known samples, to test the significance of each variable as a criterion for differentiating marine and fresh-water shales. It is not to be expected that criteria based on the abundance data (for boron, rubidium, gallium, and clay minerals) or criteria based on the graphs can be used directly by different laboratories for investigating samples from different geographic and stratigraphic locations. The only criteria which offer hope of general application without prior establishment of standard diagrams for each laboratory, are those criteria which depend on the presence or absence of a significant statistical correlation between two variables. For example, these results (Fig. 10) lead the writers to expect a significant positive correlation between boron and rubidium in a group of marine samples, but no significant correlation between boron and rubidium in a group of fresh-water samples. Conversely, they would expect a significant positive correlation between rubidium content and the illite:kaolinite peak-area ratio in a group of fresh-water samples but not in a group of marine samples.

The advantage of this method of discrimination is that practical use of the criteria is thus freed from the effects of systematic errors in the determination of any one variable. If, for example, another laboratory were to investigate this suite of samples, using a method of determining boron which yielded boron abundance values twice as large as the writers' then the data of that laboratory could not be used in conjunction with the triangular diagram (Fig. 13) to differentiate marine from fresh-water shales, because the line of division would lie at a different place. However, provided that sufficient sensitivity and precision were attained, the difference in boron abundance data should not affect the use of a "correlation criterion"; a significant positive correlation should still be found between boron and rubidium in the marine samples and should serve to differentiate them as a group from the group of fresh-water samples.

Use of a "correlation criterion," as described, has the disadvantage that a large number of samples is required from each stratigraphic unit, in comparison with the minimum number needed for a determination using a triangular diagram such as Figure 13, in which four variables are combined.

The writers propose to file the samples on which their spectrographic and x-ray measurements were made and they will try to provide small sub-samples to interested investigators at laboratories which are set up to do quantitative spectrographic analysis.

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EFFECT OF OVERBURDEN AND RESERVOIR PRESSURE ON ELECTRIC LOGGING FORMATION FACTOR[1]

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ABSTRACT

Electrical resistance of 21 brine-saturated reservoir sandstones was measured at various internal and external pressures. The resistance, and therefore the electric logging formation factor, increased with increase in the difference between the external and internal pressure. The exponents and coefficients in the Archie and Winsauer relations between formation factor and porosity were found to be functions of this difference in pressure. For a given sandstone, formation factor increases more rapidly with decrease in porosity during compression than would be expected from the average line through the formation factor versus porosity data for the 21 core samples.

INTRODUCTION

The ratio of the electrical resistivity of a brine-saturated porous rock to the resistivity of the brine is known among electric logging technologists as the formation factor. Two empirical relations between formation factor, F, and fractional porosity, ϕ, have been proposed. Archie (1942) proposed the relation

$$F = \phi^{-m} \qquad (1)$$

where m is an empirically determined constant which supposedly only depends upon the amount of cementing material between the sand grains. Winsauer *et al.* (1952) proposed the relation

$$F = C\phi^{-k} \qquad (2)$$

where C and k are empirical constants. The Winsauer equation contains two parameters and, therefore, is more easily adjusted to fit scattered data in natural systems. These equations are used to estimate formation porosity from electric log measurement. If the formation porosity is known from an independent measurement, such as by core analysis or from a neutron log, the Archie or Winsauer relations can be used to estimate water saturation from the electric log formation resistivity. For this purpose the foregoing formation factor relations are combined with a second relation proposed by Archie to give

$$\frac{R_t}{\phi^{-m}R_w} = S^{-n} \quad \text{or} \quad \frac{R_t}{C\phi^{-k}R_w} = S^{-n} \qquad (3)$$

where R_t is true formation resistivity, R_w is formation water resistivity, S is fractional water saturation, and n is a constant (usually about 2.0).

The Archie and Winsauer relations were established by laboratory measurements on rock samples which were not subjected to the compression of the overburden and in which the fluid pressure was atmospheric instead of being typical of reservoir pressure. No data have been published previously to show the relation between porosity and formation factors when the rock is compressed by overburden pressure and the fluid is above atmospheric pressure.

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The effect of rock compression on porosity, permeability, and relative permeability has already been reported (Fatt, 1952, 1953; Wilson, 1956). Electrical conductivity of a brine-saturated rock would be expected to be more sensitive to compression than is porosity, but less sensitive than permeability. This is because porosity is only a volume effect, whereas electrical conductivity and permeability depend on the volume and shape of the pores. For an idealized, cylindrical pore, permeability is proportional to the fourth power of the radius, whereas electrical conductivity is proportional to the square of the radius. This leads to greater sensitivity of permeability to small changes in pore radius. Porosity has been previously shown (Fatt, 1953) to decrease only 1–5 per cent of the porosity at no compression by application of 5,000 psi pressure. Permeability, however, has been shown (Fatt, 1952, 1953) to be reduced by as much as 50 per cent by applying 5,000 psi overburden pressure. Increases in formation factor resulting from application of 5,000 psi overburden pressure are then expected to range from zero to about 35 per cent.

When only downhole measured formation resistivities are used to estimate water saturations, the error resulting from neglect of overburden effect will be small, because this estimate is based on a comparison of resistivities of formations and fluids which are all under the pressure of the overburden. If, however, water saturations are calculated from laboratory measured formation factors and porosities, together with downhole measured resistivities, the error in calculated water saturation resulting from neglect of pressure effects may be significant.

The effect of overburden pressure on the coefficients and exponents of the Archie and Winsauer equations are reported in this paper.

EXPERIMENTAL

Measurements were made on 20 sandstone cores and one synthetic aluminum oxide core. The geographical distribution of the sandstone samples was as follows: 7 from San Joaquin Valley, California; 3 from West Texas; 7 from the Rocky Mountain area; 2 from the Gulf Coast area; and 1 from Pennsylvania.

The sandstone core samples were diamond-drilled to give plugs 1 inch in diameter and 2 inches long. After toluene extraction and vacuum drying, the samples were saturated with sodium chloride brine. The brine saturation was done under a pressure of 5,000 psi to insure complete filling of all pore spaces. For these measurements, the electrodes were gold-plated brass plugs, about 2 inches in diameter and 2 inches long. A diatomaceous earth paste was used to make electrical contact to the rock. Formation factors were measured as a function of salinity of the brine in the samples. These measurements were required for calculation of the conductivity due to conducting solids in the rock. This, in turn, allowed calculation of the true formation factor by the method of Patnode and Wyllie (1950). After completing the measurements of formation factor as a function of salinity at atmospheric pressure, the plugs were mounted in lucite in a manner such as to allow both electrical and fluid connection while the plug was under high pressure. The details of the mounting are shown in Figure 1. Before mounting in lucite, the ends of the plugs were painted with microcircuit silver paint to insure contact between the rock and the lead disk which served as the electrode. After saturation with brine, the mounted plugs were placed in a hydraulic pressure cell to give the arrangment shown in Figure 2. The fluid in the Jerguson gauge above the meniscus in the pipette was a white mineral oil.

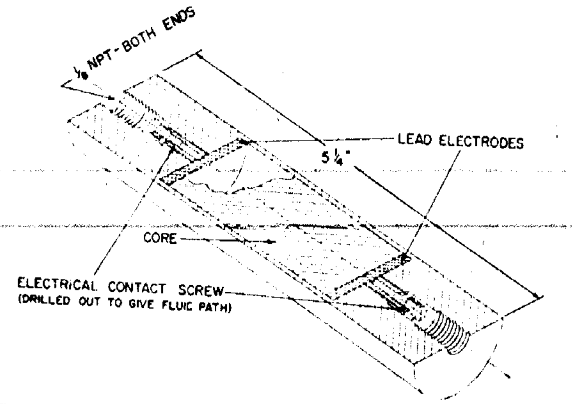

FIG. 1.—Diagrammatic sketch of core mounted for formation factor measurements under pressure.

All resistance measurements were made with an a-c wheatstone bridge operating at 1,000 cps and accurate to about ±1.0 per cent. The bridge circuit had provisions for capacity and resistivity balance and was similar to that of Jones, Mysels, and Juda (1940).

The reduction in electrical conductivity of a brine-saturated rock brought about by compression is a result of a decrease in the pore sizes. This reduction is smaller for rocks which have electrical conducting solids, assumed to be clay in sandstones, in parallel with the electrolyte in the pore spaces. To obtain the change in conductivity of the rock during compression due to change in pore size only, the constant conductivity of the clay must be subtracted from the total conductivity at all pressures.

The assumption that conducting solids are in parallel with electrolytes in the pore spaces is not completely justifiable. However, Patnode and Wyllie showed that for most reservoir sandstones, an equation, which assumes parallel conduction, is obeyed. This equation is

$$C_M = C_S + \frac{1}{F} C_F \qquad (4)$$

where C_M is the measured conductivity of the electrolyte-saturated core, C_S is the conductivity due to conducting solids in the rock, F is the true formation factor, and C_F is the conductivity of the electrolytes in the rock.

Conductivity of the rock, as a function of brine conductivity, was measured only at atmospheric pressure. Formation factors measured under compression were corrected for clay conductivity by use of equation 4 and the clay conductivity measured at atmospheric pressure. This gives a formation factor which is

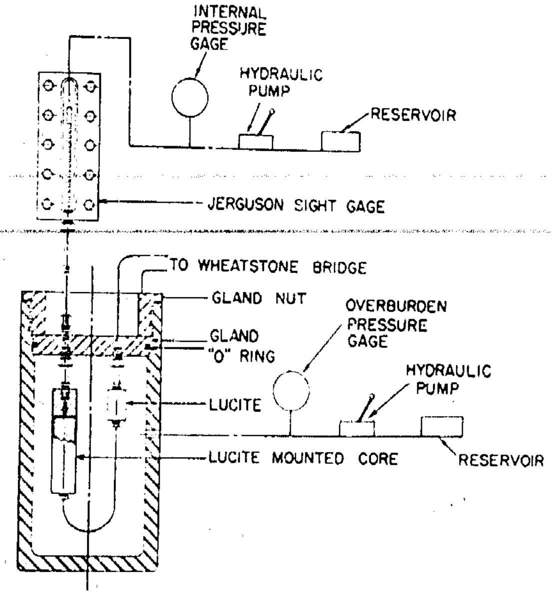

FIG. 2.—Diagrammatic view of pressure cell with core in place for formation factor measurement.

dependent only upon the geometry of the pore spaces. For most rocks, the true formation factor was not significantly different from the apparent formation factor which includes the conductivity of the conducting solids in the rock.

RESULTS

The data obtained on the 21 cores used in this study are tabulated in Table I. Figure 3 illustrates the shape of plots of formation factor as a function of overburden pressure. The internal pressure was atmospheric for all of these measurements. All data reported were obtained by progressively increasing the overburden pressure. There was little or no difference between these curves and those obtained when the overburden pressure was first increased and then decreased if sufficient time were allowed for equilibrium during the decreasing pressure cycle. Time required to reach equilibrium was greater for decreasing pressure than for

TABLE I. FORMATION FACTORS AT VARIOUS OVERBURDEN PRESSURES

Sample Number	Source	Clay Conductivity (ohm cm)$^{-1}$	Apparent Formation Factor (Porosity, Per Cent) 0 psi	1000 psi	2000 psi	3000 psi	4000 psi	5000 psi	True Formation Factor (Porosity, Per Cent) 0 psi	1000 psi	2000 psi	3000 psi	4000 psi	5000 psi
1	Sespe Sand, West Montalvo Field, Ventura, California K = 200 md		72.2 (9.9)	81.4 (9.7)	89.2 (9.5)	97.5 (9.4)	104.6 (9.3)	109.0 (9.2)	(not measured)					
2	Sespe Sand, West Montalvo Field, Ventura, California K = 275 md		26.1 (15.2)	28.8 (15.0)	30.5 (14.8)	32.8 (14.7)	34.2 (14.5)	35.3 (14.5)	(same as apparent)					
3	Sespe Sand, Oxnard Area California K = 10 md		30.6 (11.2)	33.6 (11.1)	36.6 (11.0)	38.8 (10.8)	40.6 (10.7)	42.8 (10.6)	(not measured)					
4	Allison Sand, Chaparral Hills, California	1.4 x 10^{-4}	27.0 (19.8)	30.2 (19.5)	32.3 (19.3)	33.7 (19.1)	34.9 (19.0)	35.6 (18.9)	29.2 (19.8)	33.0 (19.5)	35.5 (19.3)	37.2 (19.1)	38.8 (19.0)	39.5 (18.9)
5	Temblor Sand, Kettleman Hills, California K = 50 md	1.6 x 10^{-4}	37.0 (12.7)	42.0 (12.2)	46.2 (12.0)	49.6 (11.9)	51.6 (11.8)	54.0 (11.7)	41.8 (12.6)	48.4 (12.2)	53.6 (12.0)	58.4 (11.9)	61.2 (11.8)	65.0 (11.7)
6	Temblor Sand, Kettleman Hills, California K = [illegible] md		37.0 (12.3)	[illegible] (12.7)	[illegible] (12.6)	[illegible] (12.4)	51.8 (12.2)	54.0 (12.0)	(same as apparent)					
7	Upper Ashton Sand Huntington Beach, California K = 41 md	1.2 x 10^{-4}	79.5 (11.7)	83.[illegible] (11.4)	[illegible] (11.3)	99.3 (11.3)	102.2 (11.2)	104.5 (11.2)	[illegible] (11.7)	[illegible] (11.4)	[illegible] (11.3)	124.5 (11.3)	128.[illegible] (11.[illegible])	[illegible] (11.2)
8	Bradford Sand Pennsylvania, K = 20 md		42.4 (14.5)	46.6 (14.4)	[illegible] (14.3)	51.0 (14.3)	51.8 (14.2)	52.2 (14.2)	(same as apparent)					
9	Strawn Sand, Sherman Field, Texas	1.1 x 10^{-4}	34.4 (12.6)	37.5 (12.5)	38.9 (12.4)	39.6 (12.4)	40.4 (12.3)	40.8 (12.3)	38.7 (12.6)	41.1 (12.5)	42.[illegible] (12.4)	44.0 (12.4)	44.8 (12.3)	45.2 (12.3)
10	Cisco Sand Kelly-Snyder Field, Texas K = 22 md	0.8 x 10^{-4}	23.6 (16.8)	25.8 (16.5)	27.3 (16.4)	28.2 (16.3)	28.9 (16.2)	29.4 (16.1)	24.5 (16.8)	26.[illegible] (16.5)	28.4 (16.4)	29.5 (16.3)	30.3 (16.2)	30.8 (16.1)
11	Cisco Sand Kelly-Snyder Field, Texas K = 35 md		21.4 (18.1)	22.6 (18.0)	23.3 (17.9)	24.1 (17.8)	24.6 (17.8)	24.9 (17.7)	(same as apparent)					
12	Lyons Sand, Black Hollow Field, Colorado K = 50 md		18.6 (23.7)	20.0 (23.6)	20.6 (23.5)	21.2 (23.5)	21.4 (23.4)	21.6 (23.4)	(not measured)					
13	Weber Sand, Rangely Field, Colorado K = 25 md		60.4 (11.3)	68.8 (11.1)	76.2 (11.0)	82.8 (10.9)	87.4 (10.8)	90.6 (10.8)	(not measured)					
14	Lyons Sand, Black Hollow Field, Colorado K = 50 md		19.6 (18.5)	20.3 (18.5)	20.6 (18.4)	21.0 (18.3)	21.2 (18.3)	21.3 (18.2)	(same as apparent)					
15	Weber Sand, Rangely Field, Colorado K = 25 md	0.8 x 10^{-4}	37.4 (12.4)	42.1 (12.2)	46.0 (12.1)	49.0 (12.1)	51.2 (12.0)	52.8 (12.0)	39.8 (12.4)	45.1 (12.2)	49.6 (12.1)	53.2 (12.1)	55.6 (12.0)	57.8 (12.0)
16	Tensleep Sand Neiber Dome, Wyoming K = 30 md		30.0 (14.4)	32.2 (14.3)	34.0 (14.2)	35.1 (14.2)	35.9 (14.1)	36.4 (14.1)	(same as apparent)					
17	Tensleep Sand Neiber Dome, Wyoming K = 50 md		79.0 (9.3)	88.0 (9.2)	95.6 (9.1)	101.0 (9.0)	105.6 (9.0)	109.0 (8.9)	(not measured)					
18	Lower Wilcox Sand Louisiana	2.0 x 10^{-4}	50.8 (11.8)	55.0 (11.7)	59.0 (11.6)	61.7 (11.5)	64.3 (11.3)	66.5 (11.2)	64.0 (11.8)	70.7 (11.7)	77.0 (11.6)	82.5 (11.5)	87.0 (11.3)	90.5 (11.2)
19	Basal Tuscaloosa Sand, Mississippi K = 163 md		14.0 (29.7)	15.2 (29.5)	15.8 (29.3)	16.2 (29.2)	16.4 (29.1)	16.6 (28.9)	(not measured)					
20	Tensleep Sand, Wyoming K = [illegible] md		19.0 (14.[illegible])	19.7 (14.6)	19.9 (14.[illegible])	20.1 (14.5)	20.2 (14.4)	20.3 (14.4)	(not measured)					
21	Alundum Core		13.5 (28.6)	13.7 (28.6)	13.7 (28.6)	13.8 (28.5)	13.8 (28.5)	13.9 (28.5)	(same as apparent)					

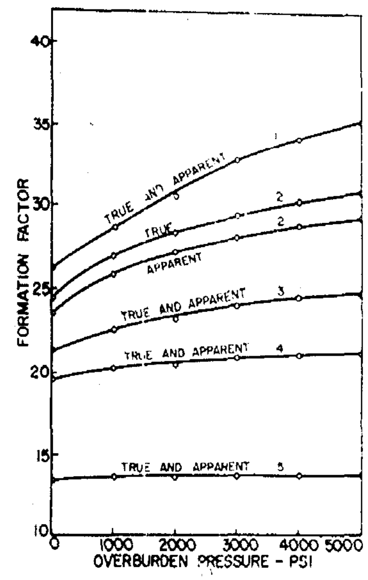

FIG. 3.—True and apparent formation factor as function of overburden pressure. Legend (numbers in parentheses refer to sample number in Table I); Curve 1, Sespe sand, West Montalvo field, Ventura, Calif. (2); Curve 2, Cisco sand, Kelly-Snyder field, Texas (10); Curve 3, Cisco sand, Kelly-Snyder field, Texas (11); Curve 4, Lyons sand, Black Hollow field, Colo. (14); Curve 5, Alundum core (21).

increasing pressure. The reason for this difference is not known. The two curves shown for Core 2 in Figure 3 illustrate the typical difference between true and apparent formation factor in cores which have a significant amount of conducting solids. There was no measurable difference between true and apparent formation factor for the other cores of Figure 3.

The relative increase in formation factor with increase in overburden pressure (when internal pressure is maintained at atmospheric) is shown in Figure 4. The relative true and apparent formation factors are identical in this plot.

Figures 5 and 6 show the formation factor as a function of porosity, at 2,000

TABLE II. FORMATION FACTOR EQUATIONS AT VARIOUS OVERBURDEN PRESSURES

Overburden Pressure psi	Archie Equation	Winsauer Equation
0	$F=\phi^{-1.85}$	$F=1.91\phi^{-1.59}$
1,000	$F=\phi^{-1.87}$	$F=1.80\phi^{-1.55}$
2,000	$F=\phi^{-1.89}$	$F=1.74\phi^{-1.61}$
3,000	$F=\phi^{-1.91}$	$F=1.67\phi^{-1.65}$
4,000	$F=\phi^{-1.92}$	$F=1.60\phi^{-1.68}$
5,000	$F=\phi^{-1.93}$	$F=1.55\phi^{-1.71}$

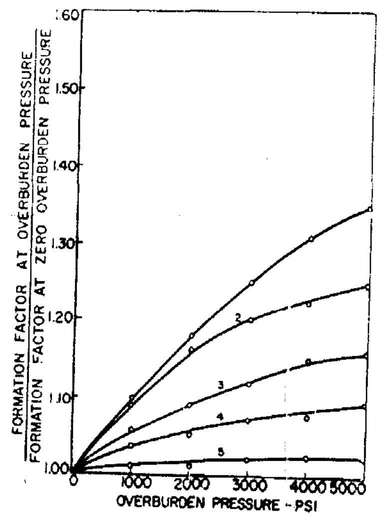

FIG. 4.—Relative formation factor as function of overburden pressure. Legend same as in Figure 3.

psi and 5,000 psi overburden pressure with internal pressure at atmospheric. The dash lines in these figures are a least squares fit to the Archie equation. The solid lines are the least squares fit to the Winsauer equation. Table II gives the Archie and Winsauer equations for each pressure from a least squares fit to the data for that pressure. Figure 7 shows a plot of the exponents versus pressure, and Figure 8 shows a plot of the coefficient of the Winsauer equation as a function of pressure.

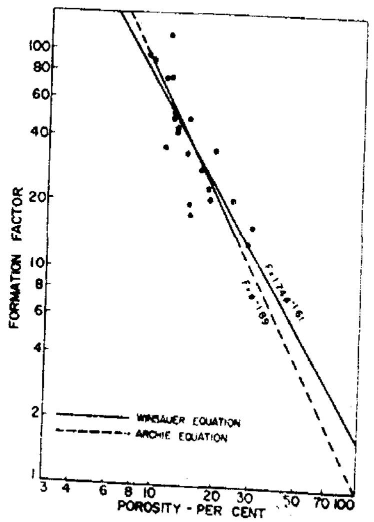

FIG. 5.—Formation factor versus porosity at 2,000 psi overburden pressure.

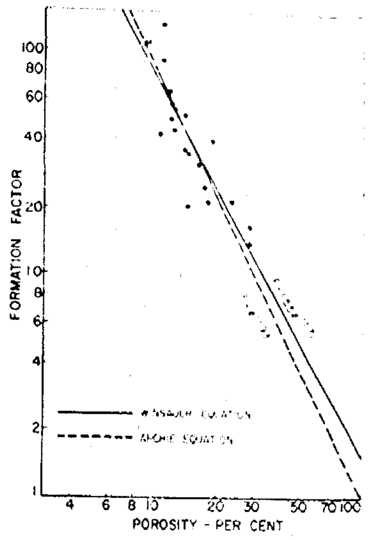

FIG. 6.—Formation factor versus porosity at 5,000 psi overburden pressure.

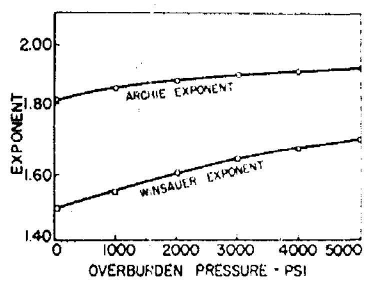

FIG. 7.—Exponents of Archie and Winsauer equations as function of overburden pressure.

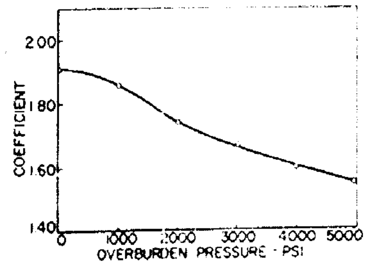

FIG. 8.—Coefficient of Winsauer equation as function of overburden pressure.

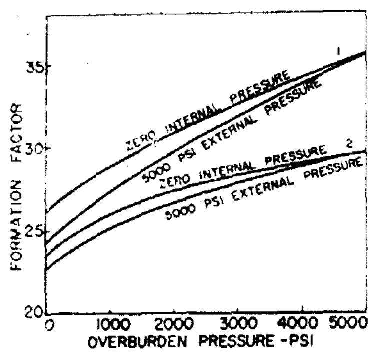

FIG. 9.—Formation factor as function of external and internal pressure. Legend same as Figure 3.

Figure 9 shows formation factor as a function of the net overburden pressure for a California and a Texas sandstone. The net overburden pressure is the external pressure less 85 per cent of the internal pressure. The factor, 0.85, appears because the internal pressure does not act entirely against the external pressure. Brandt (1955) has previously discussed this factor. The graph shows the formation factor changing with overburden pressure for constant zero internal pressure and for constant 5,000 psi external pressure with the internal pressure varied.

Porosity, permeability, and electrical conductivity, as a function of overburden pressure, were measured on a Wyoming and a Mississippi sandstone. The permeability measurements were made by the methods previously described by Fatt (1952). Internal pressure was atmospheric. Figures 10 and 11 show these properties as a function of overburden pressure.

DISCUSSION OF RESULTS

This study of effect of compression on formation factor shows clearly that the formation factor may increase by as much as 35 per cent under 5,000 psi net over-

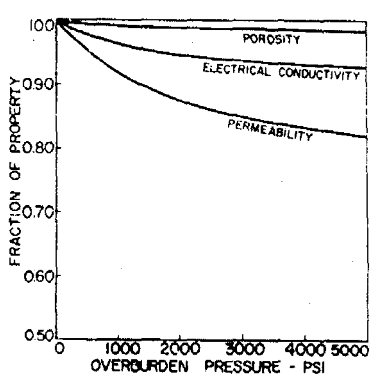

FIG. 10—Relative change in porosity, electrical conductivity, and permeability as function of overburden pressure for Tensleep sand, Wyoming (Sample Number 20 in Table I).

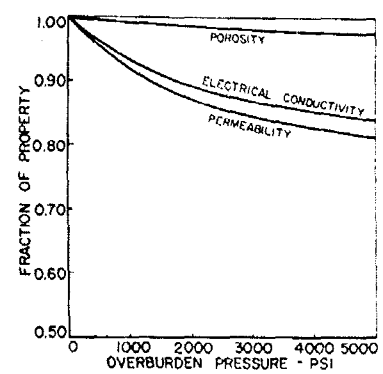

FIG. 11.—Relative change in porosity, electrical conductivity, and permeability as function of overburden pressure for basal Tuscaloosa sand, Cranfield, Mississippi (Sample Number 19 in Table I).

burden pressure. This net overburden pressure would normally be expected at about 10,000 feet below the surface (based on the assumption of 1 psi per foot rock pressure minus $\frac{1}{2}$ psi per foot hydrostatic pressure in a column of water to the surface). Therefore, it seems reasonable to expect significant differences between formation factor measured at the laboratory on core samples not subjected to overburden pressure and the formation factor in place at depths greater than a few thousand feet.

Both the formation factor and the porosity vary with increase of overburden pressure. The variation, however, is not such as to maintain the coefficients and exponents as constants in the Archie and Winsauer equations. Therefore, at overburden pressure, the Archie and Winsauer equations have coefficients and

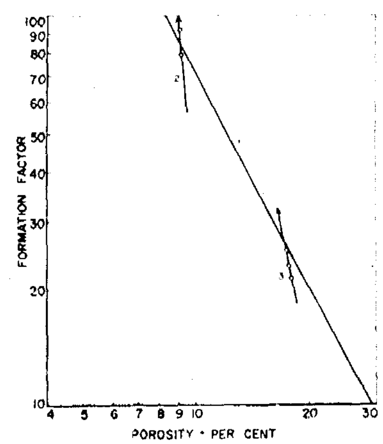

FIG. 12.—Effect of overburden pressure on formation factor and porosity. Pressure increasing in direction of arrow. Line 1 is formation factor versus porosity fitted by least squares to all cores listed in Table I at atmospheric pressure. Line 2 is a Tensleep sand, Neiber Dome, Wyoming, core under compression (Sample Number 17 in Table I). Line 3 is a Cisco sand, Kelly-Snyder field, Texas, core under compression (Sample Number 11 in Table I).

exponents which differ from those which may be measured in the laboratory on core samples at atmospheric pressure. A significant observation is shown in Figure 12. Here it is observed that the increase in formation factor for a given core with decrease in porosity during compression is more rapid than would be expected from the average line of formation factors versus porosity. This means that compression of the rock causes a more radical change in pore structure than does the change in porosity from sample to sample caused by the geological processes that reduce porosity.

The results of experiments in which the external pressure was maintained constant while the internal pressure was varied shows that if the concept of a net overburden pressure is adopted, then it is the difference between the external pressure (which in a reservoir is the weight of the overburden) and 85 per cent of the internal fluid pressure, which determines the effect of compression on the pore spaces. Therefore, laboratory-measured formation factors, in which only the external pressure is varied, are sufficient to give information on the effect of overburden pressure on conductivity properties of porous rocks.

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MODERN EVAPORITE DEPOSITION IN PERU[1]

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ABSTRACT

The Bocana de Virrila, located near Bayovar in the central part of the Sechura, illustrates principles of evaporite deposition. The Bocana, a marine estuary which normally lacks fresh-water inflow, extends about 20 kilometers inland and is about 2 kilometers wide.

Gypsum is being precipitated near the head, and halite at the extreme end of the Bocana. Black muds are found on the bottom. Life in the upper reaches of the Bocana includes red and green algae and insect larvae.

The high rate of evaporation of the lagoonal waters causes an increase in the degree of concentration of the various salts found in normal sea water. Chemical studies have shown a horizontal salinity gradient in which the concentration of total salts increases to more than 350,000 parts per million at the head of the estuary. A vertical salinity stratification was also noted near the head, where warmer, more saline waters are found on the bottom, below a cooler, less saline surface layer. It is believed that normal marine waters enter the Bocana at the surface to replace the lagoonal waters lost by evaporation, become more concentrated by evaporation and mixing, sink, and tend to escape seaward near the bottom. Physical and dynamic barriers inhibit the escape of the bottom brines.

INTRODUCTION

The Bocana de Virrila is located on the coast of northwestern Peru in the Sechura Desert (Fig. 1). It is a relict river channel which forms an estuary with an open connection to the Pacific Ocean. The topographic features of this ancient river bottom and the excessive aridity of the region have combined to form an interesting example of the deposition of evaporites in an arid climate. It is the purpose of this report to describe where and how these processes are taking place and to confirm some of the hypotheses postulated by other workers concerning the deposition of salts in a restricted estuary where evaporation exceeds precipitation plus runoff.

The report summarizes a reconnaissance investigation of this interesting area made by A. G. Fischer and the writers in August, 1955. No detailed study has ever been made.

DESCRIPTION OF CHANNEL

Beginning near the village of Sechura in the Sechura Desert near Paita, Peru, a broad area slightly lower than the surrounding flat Pleistocene beach deposits extends southward about 30 kilometers, encounters a ridge of flat Miocene shale beds, then curves westward out to the Pacific Ocean. During exceptional years when rain falls on the western slopes of the Andes Mountains, this whole lowland is covered by large sheets of water derived from the spill-over of the Piura River, which normally enters the sea west of Sechura. For example, during the rainy

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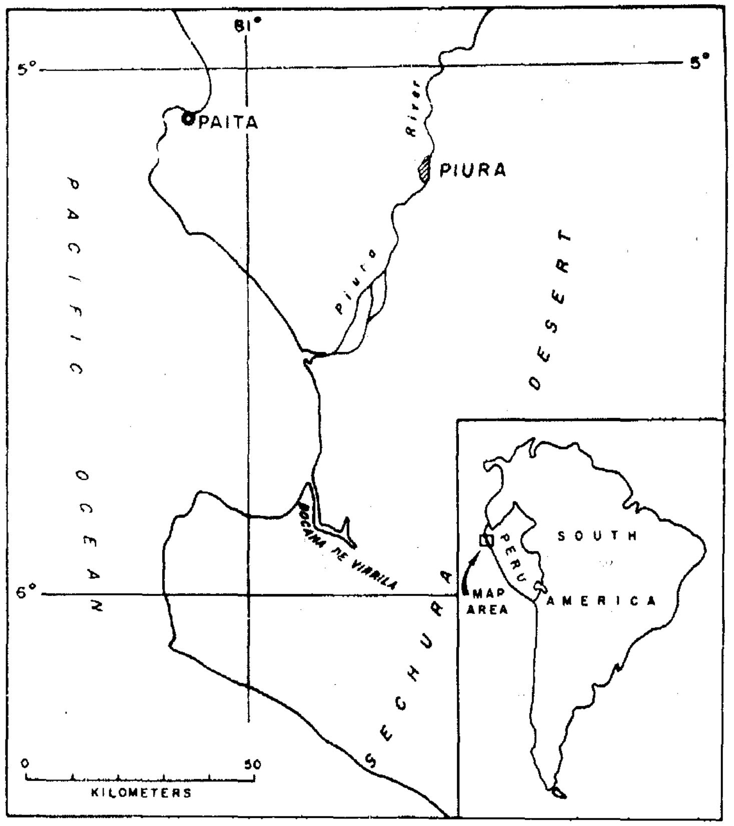

FIG. 1.—Location of Bocana de Virrila, Peru.

year of 1925, geological maps made at that time show the Piura River flowing along this course. However, during normal years, the upper part of this low area is generally dry except for a few shallow evaporating pans. Thin salt and gypsum crusts surround these areas. In the subsurface, gypsum has been observed in numerous shot holes at depths of 30 feet, presumably formed during recent time. Small mining operations for salt and gypsum have been carried out for years throughout this area. No vegetation is present. Although it is some distance from the sea, the area is very near sea-level.

Closer to the sea, the broad area becomes more constricted to form a channel that gradually falls below sea-level. This channel forms an estuary called the Bocana de Virrila, about 20 kilometers long and 2 kilometers maximum width. As this lower part of the channel contains a year-round supply of sea water, considerable quantities of salt and gypsum are being deposited at the present time.

DEPOSITIONAL ENVIRONMENTS

In accord with the classification used by Sloss (1953), the depositional environments of the Bocana have been classified as normal marine, penesaline, and saline. Each of these environments is quite distinct geographically and is represented by characteristic mineral associations and water compositions. The nature and location of the environments may change seasonally, and certainly change in those occasional years when there is abnormal rainfall on the coast of Peru. The present paper describes the condition as it was in August, 1955.

The area extending from somewhere just inside the mouth of the Bocana to a sill near the upper reaches of the lagoon has been designated as penesaline and is intermediate in salinity between normal marine and saline waters. According to Sloss (1953), the penesaline environment is characterized by deposition of evaporitic carbonates, interbedded with anhydrite. The waters from the Bocana are a milky, yellowish green. Water depths probably do not exceed 2 meters. Surface waters had a temperature of about 23°C. Throughout the penesaline environment, no indications of sodium chloride or calcium sulphate being deposited were to be found. Black muds covered the floor of the estuary near shore. Farther from shore, a white marl $\frac{1}{4}$–$\frac{1}{2}$ inch thick covered the floor of the estuary. Directly below were found soft black muds approximately 1 foot thick. This mud in turn overlies gypsum crystals. This gypsum might indicate that higher salinities had previously prevailed much closer to the mouth.

The saline environment of the Bocana occurs at the extreme upper end of the estuary. A small sill composed of several small islands and shallow sand bars greatly increases the physical restrictions of the dense, outflowing brines. This sill was located approximately where the two forks of the upper part of the Bocana meet. Just inside the sill, black muds are found on the bottom. The margins of small islands which occur in the area contain small gypsum crystals. Many of these crystals have a leached, indistinct appearance, as if they have partly gone into solution several times. This is probably due to fluctuations in the horizontal salinity gradient caused by tides, changes in rate of evaporation, or possibly some other reason.

Most of the halite and gypsum deposits are found at the extreme margins of the saline environment. Water depths do not exceed 1 foot. Large interlocking crystals of gypsum up to $\frac{1}{2}$ inch in length have been observed. The growth of these interlocking crystals has bowed up the floor of the estuary, in some places thrusting large folds of the crystals completely above water level. The transition zone between the principal gypsum and halite deposits is very indistinct as both halite and gypsum crystals appear the same when seen under shallow depths of water. The color of the water in the saline environment, especially in the upper reaches where the vast majority of the evaporites are being deposited, is a bright pink. This pink color is thought to be due to red algae in the water. The same color has been noted in other evaporating pans on the western coast of Peru.

The only forms of life noted in the saline environment are red and green algae and insect larvae. The temperatures in this environment ranged between 25° to 27°C., somewhat warmer than in the lower reaches of the Bocana.

COMPOSITION OF WATER SAMPLES

Analyses of six water samples taken from the different environments are shown in Table I. Sample locations are shown on the map (Fig. 2). An analysis of normal sea water taken from Clarke's "Data of Geochemistry" is also presented for comparison (Table I). The columns are arranged in order of increasing salinity from left to right. The absolute concentration of the ions is given in parts per million of total water sample. The relative amount of each ion is given in percentage of total solids.

Although a detailed sampling project of the entire estuary would be much more desirable, these preliminary figures readily bring certain facts to light concerning relative ion concentrations in the different environments.

Calcium ions show an increase in concentration in the penesaline environment and a decrease in the saline environment. Percentage-wise, however, calcium ion concentration drops steadily from normal marine to saline conditions. This is because the calcium is precipitated in the lower reaches of the estuary in the normal and penesaline environments, which increases the relative percentage of the more soluble ions, such as sodium, remaining in solution.

Sodium ions show a gradual increase in concentration until the innermost samples are reached; then a sharp decrease is noted. Sodium is not precipitated until the highly saline environment is reached.

TABLE I. CHEMICAL ANALYSES OF BOCANA DE VIRRILA WATER SAMPLES

Ion	Normal Sea Water	Loc. E Surface	Loc. D Surface	Loc. C Surface	Loc. C Bottom	Loc. B Surface	Loc. A Surface
Ion Concentration Expressed as Parts Per Million of Water Sample							
K^+	380	2,314	2,600	1,426	1,912	6,645	9,962
Na^+	10,560	26,110	30,150	40,515	58,550	94,170	67,500
Ca^{++}	400	966	1,040	1,000	1,040	300	300
Mg^{++}	1,272	3,436	4,316	5,580	8,340	22,390	39,612
Cl^-	18,980	48,980	57,155	74,105	107,020	190,200	190,200
$SO_4^=$	2,649	6,568	7,828	9,507	13,480	31,210	46,417
HCO_3	142	175	173	171	245	551	948
Total	34,48[illegible]	88,863	103,262	132,454	191,496	345,478	354,939
Ion Concentration Expressed as Percentage of Total Solids							
K^+	1.1	2.6	2.5	1.1	1.0	1.9	2.8
Na^+	30.6	29.4	29.2	30.6	30.6	27.2	19.0
Ca^{++}	1.2	1.1	1.01	0.75	0.54	0.1	0.1
Mg^{++}	3.7	3.9	4.17	4.2	4.4	6.5	11.1
Cl^-	55.0	55.1	55.3	56.0	56.3	55.1	53.6
$SO_4^=$	7.7	7.7	7.6	7.2	7.0	9.0	13.1
HCO_3	0.40	0.20	0.17	0.13	0.13	0.16	0.27
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sp. gr.		1.057	1.077	1.094	1.135	1.227	1.243
pH		7.4	7.6	7.8	6.65	7.3	7.1
Temperature		25°C.	25°C.	25°C.	27°C.	26°C.	27°C.

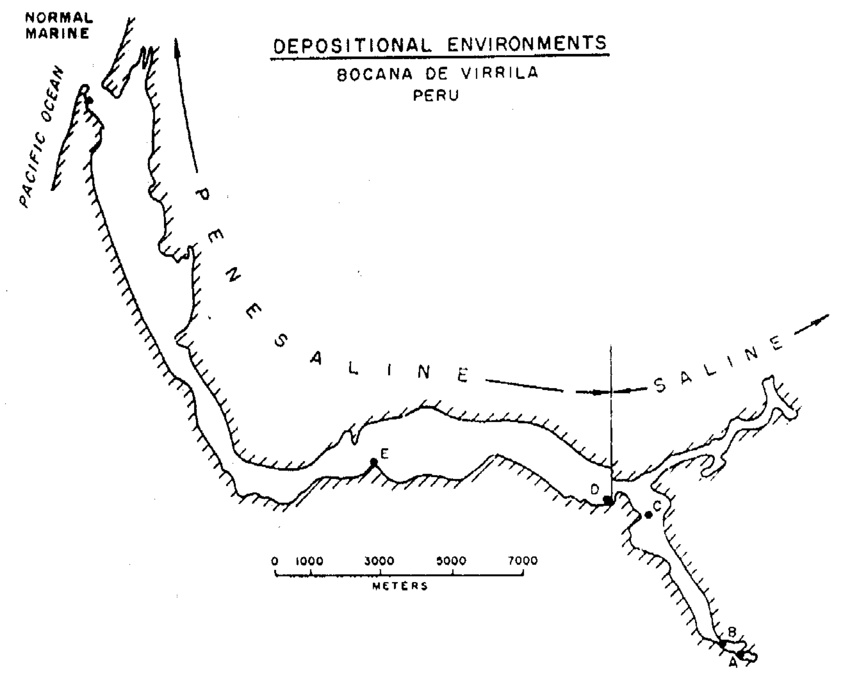

FIG. 2.—Depositional environments, Bocana de Virrila, Peru.

Magnesium ions show a slight increase in concentration until the innermost saline environment is reached, where a sharp increase is noted both in absolute concentration and relative percentage of total solids. Potassium ion concentration is fairly constant until the innermost end of the estuary is reached, where a sharp increase is apparent. The relative percentage is about the same in all samples. Thus neither of these ions is being precipitated appreciably under present conditions, but both are being concentrated by loss of less soluble ions and by evaporation. Still more restricted conditions would be necessary before they could be deposited.

Among the anions, the chloride ions increase in absolute concentration from the lower part of the estuary to the extreme upper end. However, their relative percentage first increases slightly as a result of the precipitation of calcium sulphate, and finally decreases markedly in the place where sodium chloride is precipitated. This comes also as a result of concentration of magnesium and sulphate ions in the last stages.

The sulphate ions show a steady rise in absolute concentration, increasing in the upper reaches of the estuary. There is a slight decrease in relative amount in the lower reaches where gypsum is precipitating. The bi-carbonate ions increase in concentration toward the upper end, but decrease in relative per cent.

Summarizing these results, we find that at first there is a simple increase in concentration of the individual ions above that of normal sea water. As precipitation of calcium carbonate, calcium sulphate, and sodium chloride takes place successively, the relative concentration of these ions decreases while other ions, such as magnesium, potassium, and sulphate increase. Should further concentration of the salts take place due to evaporation, magnesium sulphate and magnesium chloride would probably be precipitated, with the last bitterns being rich in potassium and chloride ions.

LITHOLOGIC DESCRIPTION OF CORES FROM BOCANA VIRRILA

At locality A in the upper reaches of the estuary, the stratified evaporite deposits were sampled to a depth of about 3 feet by driving 3-inch pipes into the sediments. The cores contain interstratified beds of halite, gypsum, and unconsolidated sandstone, indicating that both water level and salinity have fluctuated in the past. Following is a description of the cores.

Unit	*Thickness (Centimeters)*	*Description*
11	7.0	Halite, very light gray, with minor amounts (±5%) of silt (quartz and feldspar), dark organic material, and gypsum; halite is euhedral to subhedral and ranges in size from 0.3 to 2.0 mm.; some larger halite crystals contain inclusions of silt or organic material; organic material is unevenly distributed, concentrated in places along bedding or in isolated spots; bedding shows considerable disturbance due to downward thrust of core tube
10	1.0	Mixed layer of fine sand, gypsum and halite; dark gray color due to 15–25% content of organic material; sand consists mainly of quartz with minor plagioclase feldspar
9	11.0	Gypsum, light greenish gray, anhedral to subhedral grains 0.5–3.0 mm. in diameter; contains several 1-cm. layers of gypsum with 15–20% dark organic material and several pockets of soft greenish gray microcrystalline (.01 mm.) halite; X-ray shows trace quartz
8	2.0	Gypsum, solid crust of crystals, 1–5 mm. in length
7	2.0	Gypsum, acicular crystals 0.5–2 mm. in length with massive gypsum in center of unit; layers, 2 mm. in length with massive gypsum in center of unit; layers, 2 mm. thick, of greenish gray, microcrystalline halite at top and bottom of unit
6	6.0	Fine sand, yellowish brown; with 15–20% acicular gypsum crystals 0.5–1.8 mm. in length, and several pockets of soft, greenish gray; microcrystalline halite near base of unit; microcrystalline halite is also disseminated throughout with total content possibly 20–25%; sand is chiefly quartz with minor plagioclase and orthoclase feldspars; X-ray analysis shows trace illite
5	1.0	Gypsum, white, acicular crystals up to 1.0 mm. in length
4	8.0	Gypsum, greenish gray, acicular crystals 1.0–4.0 mm. in length, oriented largely in vertical position; lower 4 cm. is solid layer of vertical gypsum crystals 2–2.5 cm. in length
3	7.5	Fine sand, yellowish brown, well sorted, with microcrystalline halite distributed throughout (10–15% approx.); sand composed chiefly of quartz (subangular) 65–70%, gypsum (cleavage fragments)—10%, and plagioclase feldspar—5–10%; 5 cm. below top of unit is 3-mm. layer of fine sand with 40–50% acicular gypsum crystals 0.5–1.5 mm. in length

Unit	*Thickness (Centimeters)*	*Description*
2	7.5	Gypsum, greenish gray to white, acicular crystals 0.5–6.0 mm. in length; contains 10–15% subangular sand and coarse silt grains (mainly quartz-minor plagioclase) distributed throughout; contains several pockets of soft greenish gray microcrystalline halite with considerable silt (10–20%), less amounts of gypsum, illite, and trace of feldspar
1	17.0	Sand, yellowish brown, fine- to medium-grained, well sorted, subangular to subrounded grains; composed mainly of quartz grains (70–80%) with minor basic plagioclase feldspar (15–20%), halite (5–10%), and gypsum (1–5%)

Bottom of core

PHYSICAL AND CHEMICAL PROCESSES

The order of the precipitation of the evaporites in the estuary conforms closely to Usiglio's order of precipitation. He has shown that calcium carbonate will be precipitated from solutions with salinities ranging from 72 to 190 parts per thousand. The gray marls from the floor of Bocana Virrila were found to be underlying waters with salinities ranging from 88 to 103 parts per thousand. Usiglio showed that calcium sulphate would be precipitated from waters with salinities ranging between 199 and 353 parts per thousand. A water sample taken above gypsum deposits in the estuary totalled 354 parts per thousand. Finally, Usiglio showed that sodium chloride would be deposited when the salinities reached 457 parts per thousand. A water sample taken above halite deposits from the estuary contained a salinity of 355 parts per thousand. Thus, a good correlation exists between the laboratory data prepared by Usiglio and actual concentrations found above the various salts from Bocana Virrila.

The presence of black muds covering the floor of the estuary in the lower part of the saline environment is believed to furnish a valuable clue in explaining the frequent association of black shales with evaporites. Black muds from the Bocana Virrila were observed to occur below thin crusts of gypsum in the saline environment. In the transition zone between the penesaline and saline environments, black muds were observed on the floor of the estuary, and presumably are being deposited at the present time. The pH of the surface waters measured 7.8 while the bottom waters directly overlying the black muds were slightly acidic and measured 6.6. The acid conditions may be brought about by sulphate-reducing bacteria which reduce the sulphates to sulphides, thus freeing hydrogen sulphide gas which tends to acidize the water.

COMPARISON WITH OTHER LOCALITIES

Super-saline waters are not uncommon in many places throughout the world. The majority of those found along coasts, such as the Bocana Virrila, contain modified sea water. As the sodium chloride crystallizes out they become enriched in magnesium sulphate like that in the Bocana Virrila. Their actual chemical composition, however, varies rather widely, depending on local circumstances and the contribution of water from other sources. The published analyses most closely resembling that of the Bocana Virrila are from the Gulf of Karaboghaz on the east side of the Caspian Sea (Clarke, 1924, p. 169) where a similar inflow from the sea area occurs, although on a much larger scale than here. The same disappearance of calcium, decrease in sodium chloride, and increase in magnesium sulphate is noted. The water of the Dead Sea is quite different, containing practically no sulphate and substantial amounts of calcium. The interior lakes of the Rocky Mountains and Great Basin areas of the United States are still different, containing sulphate and carbonate as the predominant anions and calcium in quantities comparable with sodium among the anions. These lakes were not derived directly from the evaporation of sea water.

The possibility that evaporite deposition could occur as a result of a countercurrent, with less dense brine entering from the sea at the surface, concentrating by evaporation, and returning seaward along the bottom was suggested by P. B. King in 1942 to explain evaporite deposition in the Permian of Texas and New Mexico. Scruton in 1953 pointed out that counterflows of this type had been observed repeatedly in estuaries and river mouths, and might have been a dominant factor in the deposition of evaporites. The counterflow has not yet actually been observed at the Bocana de Virrila, but it may be going on.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 41, NO. 11 (NOVEMBER, 1957), PP. 2475–2492, 12 FIGS.

PALEONTOLOGY AND STRATIGRAPHY OF SOME MARINE PLEISTOCENE DEPOSITS IN NORTHWEST LOS ANGELES BASIN, CALIFORNIA[1]

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ABSTRACT

Recent excavations made in the Cheviot Hills, Los Angeles County, California, have exposed fossiliferous marine Pleistocene strata. Two new formations occur in this area. The lower Pleistocene Anchor silt consists of 60 feet of soft buff silts, and is unconformably overlain by the upper Pleistocene Medill sand, consisting of 60 feet of grayish, loosely consolidated sand and gravel.

Eighty-three species of fossils, mostly mollusks, are identified from five localities in the Anchor silt, and 21 species of mollusks are identified from a single locality in the Medill sand. The fauna of the Anchor silt probably lived offshore at a depth of 25–35 fathoms on a silty or muddy bottom, and in water considerably colder than that present today at this latitude and depth. The fauna of the Medill sand represents a warm bay habitat.

The Anchor silt is faunally and lithologically similar to parts of the San Pedro and Timms Point formations at San Pedro, to small exposures of lower Pleistocene in the Pacific Palisades area, and to unnamed lower Pleistocene units in the Baldwin Hills.

The Cheviot Hills are along the Newport-Inglewood uplift, 1½ miles southwest of the Beverly Hills oil field.

INTRODUCTION

Recent excavations made in connection with real estate development near Castle Heights Avenue in the Cheviot Hills, Los Angeles, have exposed fossiliferous marine Pleistocene strata. The fauna is chiefly molluscan, and it is the purpose of this paper to describe the stratigraphy and paleontology of the Castle Heights area with emphasis on the molluscan paleontology. The work on which this report is based was done during parts of 1954 and 1955.

LOCATION

Pleistocene deposits of the Castle Heights area are exposed in east-facing artificial cuts above an unnamed watercourse, one mile southeast of Twentieth Century Fox Studios (Figs. 1 and 2). The exposures are bounded by the watercourse on the east, McConnel Drive on the west, Monte Mar Place on the north, and Club Drive on the south. As the real estate development of the area proceeds, strata temporarily exposed in homesite cuts are rapidly being covered by houses and landscaping. At present some of the fossil localities are inaccessible.

This report also includes the description of a small exposure of fossiliferous marine Pleistocene near the hilltop on Overland Avenue, about 1,000 feet south

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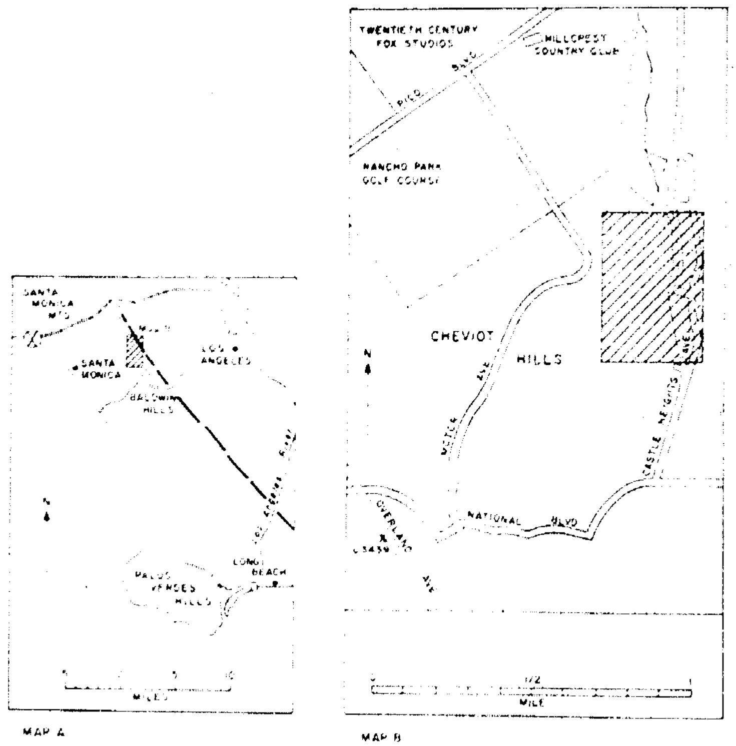

FIG. 1.—Index maps showing western Los Angeles basin and location of Castle Heights area. In Map A, heavy dashed line is trace of Newport-Inglewood fault zone, and X indicates location of lower Pleistocene localities of Hoots (1931). In Map B, shaded rectangle is Castle Heights area, shown in detail on geologic map (Fig. 3).

of National Boulevard, and one mile southwest of the Castle Heights area (Figs. 1 and 2).

PREVIOUS WORK

Published geologic maps that incorporate the Castle Heights area include those by Eldridge and Arnold (1907, Pl. 8), Hoots (1931, Pl. 16), Hoots and Kew (1932, Pl. 6), Woodford *et al.* (1954, Pl. 1), and Woodring (1938, Pl. 2). The areas discussed in this paper have previously been mapped as marine upper Pleistocene. The work of Hoots is the most detailed.

The only previous report of Pleistocene fossils from the Cheviot Hills is the Overland Avenue locality of Hoots (1931, p. 122 and Pl. 16), which contained a very small fauna and was assigned to the upper Pleistocene. A locality probably identical with this was collected by the writer and is discussed.

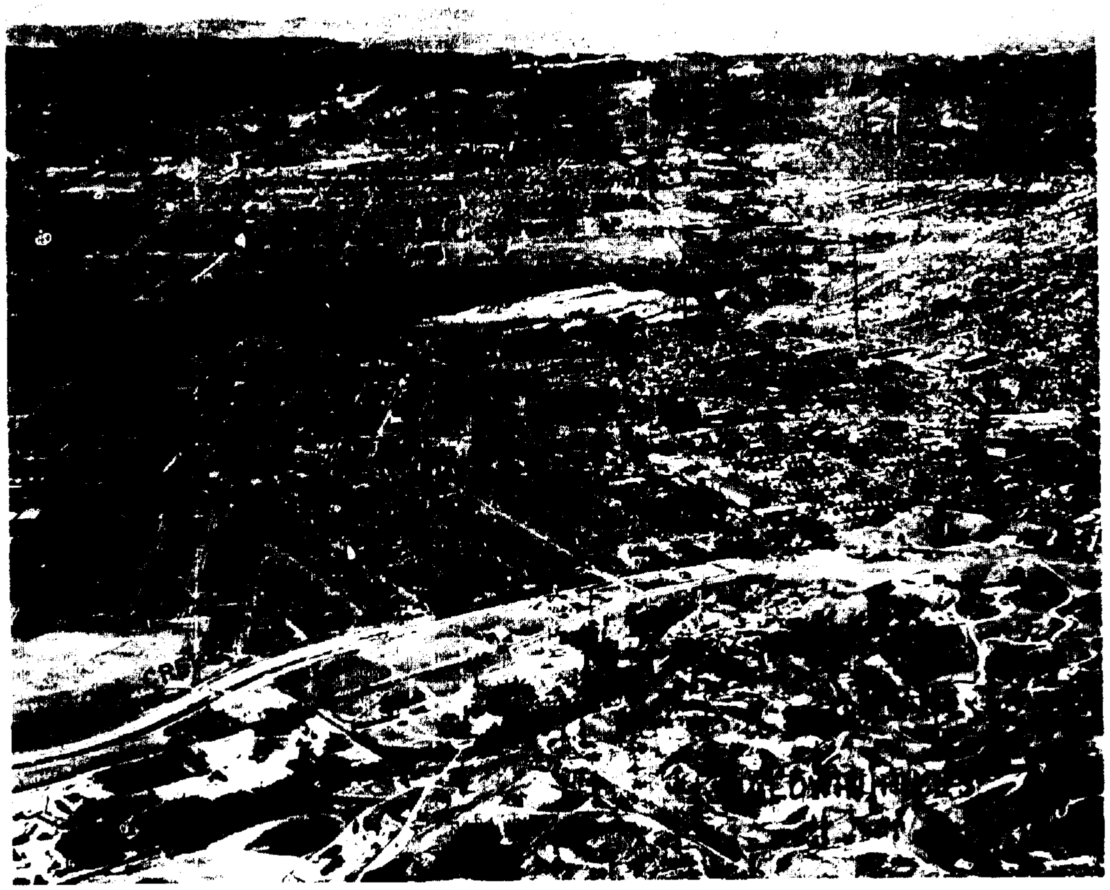

FIG. 2.—Air view northward from Baldwin Hills across Culver City to Santa Monica Mountains and beyond. Rectangle encloses Castle Heights area; recent homesite cuts exposing fossiliferous strata have been made in bare east-facing bluffs. X is Overland Avenue locality (L 3459). Photograph by Spence Air Photos, August 6, 1951.

STRATIGRAPHY

General. The strata exposed in the Castle Heights area are composed of soft silts, sands, and gravels, and are divided into two superposed formations. Significant exposures are confined to the recently made cuts between Anchor Avenue and McConnel Drive. Total thickness of the exposed section is about 120 feet, and the beds are nearly horizontal, with 7° the highest recorded dip. However, some local contorted bedding was noted at a few localities in the Anchor silt (Fig. 7).

The Castle Heights area lies along the axis of the Newport-Inglewood uplift, 1½ miles southwest of the Beverly Hills oil field.

Anchor silt.—This unit, the older of the two formations, is named from exposures along Anchor Avenue. Its maximum thickness is 60 feet, and consists largely of massive, buff-colored, fine sands and silts with thin, irregular beds of cobble gravel. This unit is well developed north of Beverlywood Street in the cuts between Anchor Avenue and Krim Drive, and at the northwest corner of Beverlywood Street and Krim Drive.

The base of the formation is not exposed. The stratigraphically lowest exposures crop out at the northern end of Anchor Avenue, and consist of 5 feet of gravelly sand containing abundant well rounded pebbles and cobbles of white siliceous shale 2–3 inches in diameter (Fig. 6).

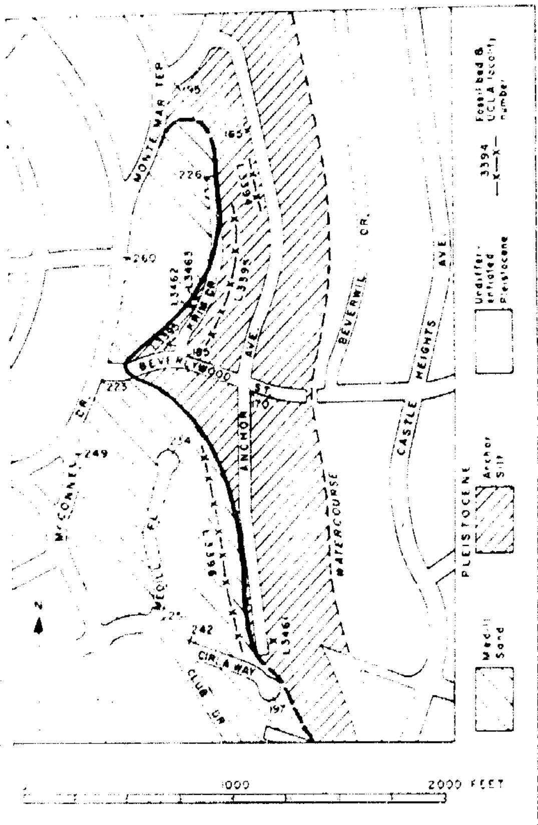

FIG. 3.—Geologic map of Castle Heights area. Figures at street corners give curb elevations to nearest foot. Street base and curb elevations from Los Angeles City Engineering Bureau, 1955. Line of cross section of Fig. 4 is approximately coincident with trace of fossil bed L 3396.

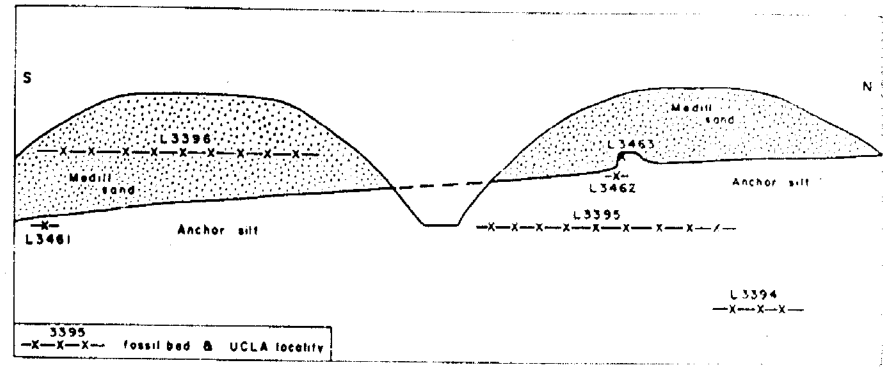

FIG. 4.—Schematic cross section showing relations of Anchor silt and Medill sand. L 3463 is "stack." Not to scale.

The lowest fossil bed is superjacent to this gravel, and is exposed for 150 feet along Anchor Avenue (Fig. 3). This bed is 3 feet thick, and the fossils are in a matrix of buff, sandy silt.

Twenty feet of non-fossiliferous silt and gravelly sand separate the lower and upper fossil beds in the Anchor silt. This second gravelly sand, which is confined to the upper 4 feet, is similar in composition to the lower gravel. The overlying fossil bed has a matrix of sandy silt, is 2 feet thick, and is exposed for a distance of 500 feet, from Beverlywood Street to a point nearly opposite the north end of Krim Drive (Fig. 5). It also crops out at the northwest corner of Beverlywood Street and Krim Drive (Figs. 7 and 8). The sandy silt above and below the fossil bed is concretionary and hard.

FIG. 5.—Looking west from Anchor Avenue, 200 feet north of Beverlywood Street. Thin white band above piles of lumber on house foundation is upper fossil bed (L 3395) in Anchor silt.

FIG. 6. Close-up of lower part of Anchor silt showing gravelly character. Photograph taken along west side of Anchor Avenue, 400 feet south of Monte Mar Place. Length of hammer, 12 inches. Small white patches in upper part of photograph are fossils in lower fossil bed (L 3394).

The upper 25 feet of the Anchor silt are composed of fine sand and silt, sparingly fossiliferous and irregularly concretionary.

The Anchor silt is in disconformable contact with the overlying Medill sand. Cut-and-fill structures are present at the top of the Anchor silt, and the contact is characterized by a rather abrupt increase in grain size from the Anchor silt to

FIG. 7. Northwest corner of Krim Drive and Beverlywood Street looking northwest. Contact of Anchor silt and Medill sand is few feet above bench cut on lot in foreground. Contorted bedding shows above fireplug.

the Medill sand. The contact between the two formations, though locally irregular, has a rather even slope of less than 2°S. The contact is at an elevation of about 225 feet along the northern part of Krim Drive, and is at about 195 feet at the southern end of Anchor Avenue (Figs. 3 and 4).

Medill sand. This formation, named from exposures along, and adjacent to, Medill Place, is a mixture of fine to coarse sand and gravel. It has a maximum thickness of near 60 feet in the Castle Heights area, and is well exposed north and south of Beverlywood Street.

The base of the Medill formation is a coarse sand and, or, gravel. The irregular pockets of gravel consist of well rounded metamorphic and granitic cobbles

FIG. 8. Northwest corner of Krim Drive and Beverlywood Street looking north. Fossil bed (L 3395), 2 feet thick.

and boulders up to 15 inches in diameter. White siliceous shale fragments, so common in the gravelly sections of the Anchor silt, are not present in the Medill gravels. These Medill gravels have a fine to coarse, gray-brown, sandy matrix, and have a maximum thickness of about 10 feet, though the thickness and lateral extent vary greatly from place to place.

The rest of the section consists of irregularly mixed and interbedded fine to coarse, gray to brown sand, and a small amount of cobble gravel. The single fossil bed in the Medill sand is in coarse grayish sand at an elevation of about 220 feet, and is exposed along the east-facing cuts for a distance of 500 feet, from Girla Way north toward Beverlywood Street (Figs. 11 and 12). The sands below and including the fossil bed are generally grayish, and contrast markedly with the overlying brown sands. The cause of this color difference is not known. The present soil is developed on these brownish sands.

FAUNAL LIST

Seven separate localities are discussed in this paper. Five of these (3394, 3395, 3461, 3462, and 3463) are in the Anchor silt; one (3396) is in the Medill sand; and the seventh (3439) is in unnamed sands exposed along Overland Avenue 1,000 feet south of National Boulevard. The last-named locality is presumably the same as Hoots' locality [illegible], pp. 122, 124 and Pl. 16). Locality 3439 is listed under the Medill sand heading.

Ninety-six species and varieties have been identified from the seven localities, including 92 mollusks (48 gastropods, 1 scaphopod, and 43 pelecypods), 1 echinoid, 1 barnacle, and 2 bryozoans.

SYSTEMATIC NOTES

PHYLUM MOLLUSCA
CLASS GASTROPODA
ORDER CTENOBRANCHIATA
Family TRICHOTROPIDAE
Genus TRICHOTROPIS Sowerby, 1829
Trichotropis cancellata Hinds, 1843

Trichotropis cancellata Hinds, Proc. Zool. Soc. London, p. 17, 1843; Zool. Voy. Sulphur, Moll., p. 39, pl. 11, figs. 11–12, 1844 (*fide* Binney, Smith. Misc. Coll., pt. 2, pp. 10, 188, 1864).
Trichotropis cancellata Hinds, Morris, Field Guide to Shells of Pacific Coast and Hawaii, p. 103, pl. 29, fig. 22 (two views), 1952.

A single specimen was recovered from locality 3394 in the Anchor silt (length, 30 mm.; diameter of last whorl, 15 mm.). This is apparently the first fossil record of this species in Southern California. It has been recorded fossil from British Columbia by Wagner (1954).

Geologic range: Pleistocene to Recent.
Recent distribution: Southern part of the Bering Sea and south to Oregon (Dall, 1921, p. 148).
Habitat: 6–15 fathoms (Burch, 1945, no. 54, p. 36).

Family NEPTUNIDAE
Genus MACRON H. & A. Adams, 1853
Macron aethiops var. *kellettii* (A. Adams), 1853

Pseudoliva kellettii A. Adams, Proc. Zool. Soc. London for 1853, p. 185.
Macron aethiops var. *kellettii* (A. Adams), Grant and Gale, San Diego Soc. Nat. Hist., Mem., vol. 1, p. 650, pl. 28, fig. 8, 1931.

This southern species is rather rare in the Southern California Pleistocene. The specimen from the Medill sand, locality 3396, is of moderate size and is especially well preserved. Height of shell, 50 mm.

Geologic range: Pliocene (?) to Recent (Grant and Gale, 1931, *loc. cit.*).
Recent distribution: Lower California and Gulf of California (Dall, 1921, p. 89).
Habitat: Protected shallow water.

CLASS PELECYPODA
ORDER TELEODESMACEA
Family CARDITIDAE
Genus CYCLOCARDIA Conrad, 1867
Cyclocardia cf. *C. occidentalis* (Conrad), 1855

Cardita occidentalis Conrad, Proc. Acad. Nat. Sci. Phila., vol. 7, p. 267, 1855; U. S. Pac. R. R. Reports, vol. 6, Pt. 2, p. 73, pl. [illegible], fig. 2a, 1856 (1857).
Venericardia monilicosta (Gabb) Arnold, U. S. Geol. Survey Bull. 321, pl. 14, fig. 2, 1907.

Specimens from the Anchor silt identified as *Cyclocardia* cf. *C. occidentalis* (Conrad) have strong ribs and nodes, and have an average length of [illegible] millimeters. These forms closely resemble small specimens of *Cyclocardia*, identified in the U.C.L.A. collections as *C. monilicosta* (Gabb), from the Santa Barbara formation at the type locality. Similar forms are known from the San Pedro area and were discussed by Woodring ([illegible], pp. 82–83) who noted their resemblance to forms collected from the Santa Barbara formation by Arnold. Woodring, however, chose not to identify the small San Pedro form specifically. The writer feels that the present assignment seems warranted if, as Woodring

CHECKLIST OF FOSSILS

Key to symbols
R—Rare, 1–10 specimens
C—Common, 11–40 specimens
A—Abundant, 41–100 specimens
S—Superabundant, more than 100 specimens

SYSTEMATIC CHECKLIST

Species and Varieties	UCLA Localities						
	Anchor Silt					Medill Sand	
	3394	3395	3461	3462	3463	3396	3439
BRYOZOA							
Tubucellaria cf. *T. punctulata* Gabb & Horn	C	A					
Idmonea cf. *I. californica* d'Oribgny	C	P					
GASTROPODA							
Calliostoma annulatum (Humphreys)		R					
Calliostoma doliarium (Holten)		R					
Tegula gallina Forbes						R	
Margarites lirulatus Carpenter					R		
Margarites optabilis (Carpenter)						R	
Tricolia compta (Gould)						R	
Turbonilla pedroana Dall & Bartsch	R						
Turbonilla tridentata Carpenter	R	R					
Odostomia talpa Dall & Bartsch	R						
Epitonium indianorum (Carpenter)	C	C					
Epitonium tinctum (Carpenter)		R					
Epitonium tabulatum Dall	R	R					
Epitonium cooperi Strong		C					
Cryptonatica cf. *C. aleutica* (Dall)	C	C	R				
Polinices draconis (Dall)		R					
Neverita reclusiana (Deshayes)	R	C				R	
Calyptraea fastigiata Gould	R	R					
Credpidula princeps Conrad	C	C					
Crepidula nummaria Gould	R						
Crepidula onyx Sowerby	R						
Turritella cooperi Carpenter	S	S	R				
Trichoptropis cancellata Hinds	R						
Cerithidea californica (Haldeman)						A	C
Bittium rugatum Carpenter	S	A					
Bittium rugatum var. *larum* Bartsch	C	C					
Alabina tenuisculpta Carpenter						R	R
Fusitriton oregonensis (Redfield)	R	R					
Ocinebra barbarensis (Gabb)		R					
Ocinebra foveolata (Hinds)	R	R					
Boreotrophon orpheus (Gould)	A	C					
Boreotrophon multicostatus (Eschscholtz)	R						
Amphisa versicolor Dall	C	C					
Mitrella carinata (Hinds)	R						
Mitrella carinata var. *gausapata* (Gould)	C						
Mitrella gouldii (Carpenter)	S	A	R		R		
"*Nassa*" *perpinguis* Hinds	S	A	R	R	R		
"*Nassa*" *mendica* Gould	C	R					
"*Nassa*" *fossata* (Gould)	R						
Nassarius tegula (Reeve)						C	C
Neptunea tabulata (Baird)	C	C		R			
Macron aethiops var. *kellettii* (A. Adams)						R	
Olivella pedroana (Conrad)	R						
Clathurella conradiana Gabb	C	R					
"*Mangelia*" *variegata* Carpenter	R						

Species and Varieties	UCLA Localities						
	Anchor Silt					Medill Sand	
	3394	3395	3461	3462	3463	3396	3493
Antiplanes perversa (Gabb)	R	R					
"Lora" fidicula (Gould)	R						
Bulla gouldiana Pilsbry						R	
Acteocina culcitella (Gould)	R	R				R	
SCAPHOPODA							
Dentalium neohexagonum Sharp & Pilsbry	R	R					
PELECYPODA							
Acila castrensis Hinds	R						
Yoldia scissurata Dall	R	R					
Ostrea lurida Carpenter		R					
Pecten stearnsii var. *diegensis* Dall		R				S	S
Chlamys hastatus (Sowerby)	C	A					
Chlamys islandicus var. *jordani* (Arnold)		R					
Patinopecten caurinus (Gould)	C	A					
Leptopecten latiauratus (Conrad)		R					
Thracia trapezoides Conrad	C	C				C	R
Pandora bilirata Conrad		R					
Pandora grandis Dall	C	C					
Cyclocardia cf. *C. occidentalis* (Conrad)	S	S	R	R	R		
Thyasira gouldii (Philippi)	R	R					
Lucinoma annulata (Reeve)	C	C					
Lucina tenuisculpta Carpenter		R					
Lucina nuttali (Conrad)							
Trachycardium quadragenarium (Conrad)	R	C	R	R		R	
Nemocardium centifilosum (Carpenter)	R	R				R	
Chione undatella var. *simillima* (Sowerby)							
Chione fluctifraga (Sowerby)		R				C	C
Protothaca staminea (Conrad)		R				A	
Compsomyax subdiaphana (Carpenter)	C	C	R	R			
Psephidia lordi (Baird)	S	S	R				
Tivela cf. *T. stultorum* (Mawe)		R					
Saxidomus nuttallii Conrad		R					
Tellina cf. *T. idae* Dall		R					
Tellina meropsis Dall							
Tellina buttoni Dall	R					A	A
Macoma nasuta (Conrad)		R					
Macoma incongrua (Martens)	R	R				A	R
Macoma calcarea (Gmelin)	C	C	R				
Macoma secta (Conrad)							
Donax gouldii Dall	R					R	
Psammobia californica Conrad?	R						
Psammobia edentula (Gabb)		R					
Tagelus californianus (Conrad)		R					
Solen sicarius Gould	A	A	R	R	R	A	C
Schizothaerus nuttallii (Conrad)		R					
Mya truncata Linnaeus	C	C					
Cryptomya californica (Conrad)							
"Corbula" luteola Carpenter	R	R				R	R
Panope generosa Gould		R					
Panomya baringianus Dall		R					
ECHINOIDEA							
Dendraster excenticus (Eschscholtz)		R					
CIRRIPIDEA							
Balanus sp.	R						

states, *Cyclocardia monilicosta* (Gabb) is to be considered as a synonym of *Cyclocardia occidentalis* (Conrad).

Geologic range: Pliocene to Recent.

Recent distribution: Not known. The range of the closely related *C. ventricosa* is given as Alaska to Coronado Islands (Dall, 1921, p. 31).

Habitat: 25–124 fathoms off Southern California (Woodring, 1946, p. 83).

Family SAXICAVIDAE
Genus PANOMYA Gray, 1857
Panomya beringianus Dall, 1916

Panomya beringiana Dall, Proc. U. S. Nat. Mus., vol. 52, p. 416, 1916.
Panomya beringianus Dall, Woodring, Bramlette, and Kew, U. S. Geol. Survey Prof. Paper 207, p. 85, pl. 33, figs. 13–14, 1946.

Four single valves of this northern species have been recovered from locality 3395 in the Anchor silt. All of these specimens have a peculiar, thick, irregular, internal, encrusting layer of calcitic shell material. This feature was not observed on any other shells from the Castle Heights area. It appears to have been deposited by the animal itself, and does not seem to be the result of any secondary process. The cause of this phenomenon is not known.

Geologic range: Pleistocene to Recent.

Recent distribution: East Bering Sea (Dall, 1916, p. 416).

Habitat: 56 fathoms at the type locality (Dall, *loc. cit.*).

PALEOECOLOGY

Anchor silt.—The fossils of the Anchor silt are rather poorly preserved for Pleistocene material. Most of them are soft, very easily broken, if not already broken, and many are corroded. This condition appears not to have been the result of transport, as the overwhelming majority of the pelecypods have their valves articulated. It is apparently due to the extreme fragility of the shells, which in turn is probably the result of ground-water action.

Localities 3394 and 3395 contain essentially the same fauna. Those species found only at one or the other locality are represented by only one or two specimens. Table II summarizes the fauna of these localities. The three other localities in the Anchor silt contain very small faunas, and with one exception, duplicate species found in the two richer localities.

A marked feature of the fossil assemblages of the Anchor silt is the presence of species that live today only well north of the latitude of the Castle Heights area (Burch, 1944–46; Hertlein, 1940). Several of these have the southern limits of their geographic ranges north of California. These include *Trichotropis cancellata*, *Pandora grandis*, *Panomya beringianus*, and *Mya truncata*. Many others are typically "northern" forms (Table III).

TABLE I. CASTLE HEIGHTS—FAUNAL SUMMARY (SPECIES)

	Anchor Silt	Medill Sand	Totals
Bryozoans	2	....	2
Gastropods	40	10	48
Scaphopods	1	....	1
Pelecypods	38	11	43
Echinoids	1	....	1
Barnacles	1	....	1
Total	83	21	96

TABLE II. ANCHOR SILT—FAUNAL SUMMARY (SPECIES)

	Locality 3394	Locality 3395	Common to Both Localities	Totals
Bryozoans	2	2	2	2
Gastropods	33	27	21	39
Scaphopods	1	1	1	1
Pelecypods	21	34	17	38
Echinoids		1	—	1
Barnacles	1		—	1
Totals	58	65	41	82

TABLE III. DISTRIBUTIONAL SUMMARY OF LIVING SPECIES REPRESENTED IN CASTLE HEIGHTS PLEISTOCENE

Species with Geographic Ranges	Anchor Silt						Medill Sand	
	3394		3395		Total		3396	
	No.	%	No.	%	No.	%	No.	%
Entirely north of Los Angeles	7	12	6	10	8	10	0	0
Near south limit at latitude of Los Angeles ("northern" forms)	11	19	11	19	15	19	0	0
Entirely south of Los Angeles	0	0	0	0	0	0	2	10
Near north limit at latitude of Los Angeles ("southern" forms)	3	5	4	7	4	5	3	14

In order to determine the general type of environment in which the Anchor silt faunas lived, each of the two principal localities has been divided into several generalized ecologic groups (Table IV). It is seen that the greater part of the fauna is made up of species whose living representatives have a great depth range, and are of comparatively little value in the determination of the depth at which the fauna lived. Although a few of the more abundant species live today only at depths below 25 fathoms, they are known to live in water as shallow as 25–35 fathoms. The presence of abundant articulated specimens of *Solen sicarius*,

TABLE IV. ECOLOGIC DISTRIBUTION OF RECENT SPECIES REPRESENTED IN ANCHOR SILT

Environment	L 3394		L 3395	
	% Species	% Specimens	% Species	% Specimens
Exposed rocky; less than 10 fathoms	0	0	0	0
Exposed sandy; less than 10 fathoms	2	0.15	0	0
Protected shallow; less than 10 fathoms	2	0.45	17	4
Offshore shallow; 5–25 fathoms	31	14	26	10
Offshore moderate; more than 25 fathoms	7	3	7	4
Offshore; great depth range, 5 to below 25 fathoms	47	64	41	71
Questionable	11	18	9	11

not reported living below 25 fathoms, seems to establish a lower limit that is fairly shallow. From the available data (Burch, 1944–46) it is suggested that the fauna of the Anchor silt lived offshore at a depth of 25–35 fathoms on a muddy or silty bottom. Faunal differences between the two major localities are slight, and the same depth and bottom conditions are inferred for each.

Several species from the Anchor silt are not known to live in waters above 10°C. The average temperature of the water in which the Anchor silt fauna lived probably did not exceed this value, and was possibly less.

Though the bulk of the Anchor silt fauna is assumed to have lived at a depth of about 30 fathoms in water considerably colder than exists today at this depth and at the latitude of the Castle Heights area, there are species present that are not known to live below the littoral. These species, *Chione fluctifraga*, *Tagelus californianus*, and *Donax gouldii*, indicate shallow water with a temperature not nocticeably different from that of today. Thus there were essentially contemporaneous water temperatures that ranged from significantly colder than at present, at moderate depths, to shallow waters substantially the same as today at the latitude of this area. A mechanism to account for this anomalous situation has recently been proposed by Valentine (1955). He points out that under Simpson's glacial hypothesis increased solar radiation and oceanic circulation might well account for the relative rise in the temperature of protected shallow waters during Pleistocene glaciation. At the same time the southward drift of increased amounts of glacial meltwaters, and intensification of upwelling, would lower temperatures at moderate depths offshore, and in areas of upwelling.

Medill sand.—The fauna of the Medill sand is much smaller, and is somewhat

FIG. 9.—Stack-like concretionary structure at contact of Anchor silt (A) and Medill sand (M). Looking northwest across Krim Drive about 400 feet north of Beverlywood Street. Height of cut, about 20 feet.

Fig. 10. View of "stack," looking north.

better preserved than that of the Anchor silt. Probably the most characteristic fossil from the Medill sand is *Cerithidea californica*, which is abundant, though not well preserved. *Ostrea lurida* is extremely abundant, usually in reef-like pods, at the north and south ends of the Medill sand fossil bed, but is nearly absent between (Fig. 12).

This fauna, as pointed out by Woodring for the Overland Avenue locality (Hoots, 1931, p. 122), has a warm-water aspect. It most probably represents a bay habitat, and is suggestive of conditions similar to those existing today at Newport Lagoon, Orange County, California, though probably warmer.

[illegible] Fossil bed (L 3306) in Medill sand. Looking west between Anchor Avenue and Medill Place, about 300 feet south of Beverlywood Street. Length of hammer, 11 inches.

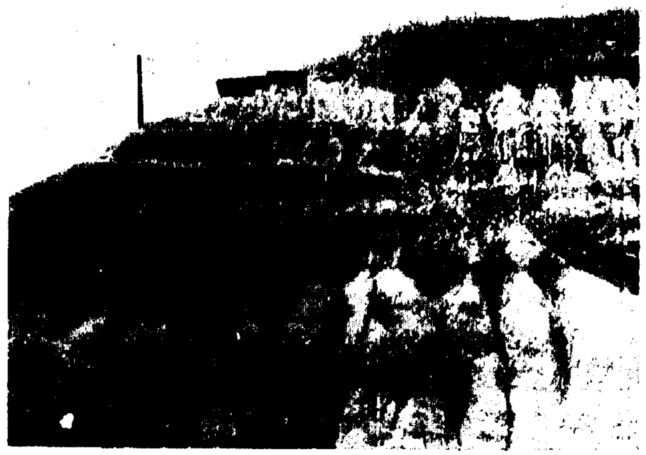

Fig. 12. Fossil bed (L 3306) in Medill sand. Looking west from near northeast end of Gira Way. Beds of *Ostrea lurida* weathering in relief. Length of hammer, 12 inches.

AGE AND CORRELATIONS

Anchor silt.—The Anchor silt is assigned to the lower Pleistocene on the basis of its faunal similarity to other formations in the Los Angeles basin that have been dated as lower Pleistocene (Woodring, Bramlette, and Kew, 1946, pp. 98–99; Hoots, 1931, p. 120). Only one of the species from the Anchor silt is extinct (*Crepidula princeps*), and this is related to a species of the Recent northern fauna (*Crepidula grandis*).

About 85 per cent of the species from the Anchor silt have also been reported from the Timms Point silt at San Pedro (Arnold, 1903; Clark, 1931; Crickmay, 1929; and Woodring, Bramlette, and Kew, 1946). The differences between the two faunas appear to be those due to depth, the Timms Point fauna representing deeper water.

About 85 per cent of the Anchor silt species are also reported from the San Pedro sand (Arnold, 1903; Clark, 1931; Crickmay, 1929; DeLong, 1941; and Woodring, Bramlette, and Kew, 1946). The differences here seem more related to bottom sediment. Mud- and silt-dwelling pelecypods, *Thracia trapezoides* and *Pandora grandis*, common in the Anchor silt, are not reported from the San Pedro sand. The inferred depths of the faunas of the two formations are much the same, but possibly the Anchor silt fauna represents cooler water.

Hoots (1931, p. 120) reports lower Pleistocene marine fossils from two localities in the southern piedmont of the Santa Monica Mountains, 10 miles northwest of the Castle Heights area (Fig. 1, Map A). According to Woodring (Woodring, Bramlette, and Kew, 1946, p. 104) these cool-water faunas suggest "the Lomita and Timms Point and also parts of the San Pedro sand." This "suggestion" may be extended to include the Anchor silt of the Cheviot Hills.

Lower Pleistocene deposits have been mapped in the Baldwin Hills (Woodford *et al.*, 1954, Pl. 1; Woodring, 1938, Pl. 2) and, though no faunal lists have been published, small fossil assemblages from localities in this area are in the collections of the University of California, Los Angeles. A cursory examination of this material served to establish its similarity to the Anchor silt both faunally and lithologically. Tieje (1926, p. 506) mentions a cold-water fauna from Trench 10 of the Los Angeles Outfall Sewer dug in 1924 along the north border of the Baldwin Hills. No faunal list was included, but mention is made of species "now limited to circumboreal waters." This fauna was correlated with that of the Timms Point silt, and dated as upper Pliocene in accordance with Arnold's (1903) designation of this formation. Presumably the fauna from the outfall trench is lower Pleistocene, and is perhaps the equivalent of the material in the collections of the University of California, Los Angeles. These Baldwin Hills localities are 3 miles southeast of the Castle Heights area along the Newport-Inglewood fault zone.

Medill sand. The Medill sand, and the Overland Avenue locality as well, are believed to be of upper Pleistocene age on the basis of their warm-water aspect, seemingly typical of assigned upper Pleistocene deposits in the Los Angeles basin.

The Anchor silt is channeled and filled with the coarse sand and gravel of the Medill sand. The two formations are separated by a noteworthy disconformity. The Anchor silt appears to have been uplifted and eroded prior to the deposition of the Medill sand. The best expression of this is the buried topography exposed along the west side of Krim Drive. This "topography" is a stack-like, "honeycombed," hard, concretionary structure which is 8 feet in diameter and rises 15 feet above the general upper surface of the Anchor silt (Figs. 9 and 10). Fossil locality 3463, in the upper 6 inches of this "stack," contains five species, four of which are found elsewhere in the Anchor silt, and the fifth, *Margarites lirulatus*, is a northern form known only from this locality. Along the lower flanks of the "stack," silt containing scattered specimens of typical Anchor silt fossils (L 3462) is overlain disconformably by the coarse sand and gravel of the Medill sand. This erosional feature was apparently along or near the margin of the bay in which the Medill sand fauna was living. The fossil bed of the Medill sand is at the same elevation as the upper part of the "stack," though it does not extend far enough north to intersect this feature (Fig. 4). Presumably the edge of the bay was at a point between the two. The character of the northern end of the Medill sand fossil bed, with the abundant, almost reef-like, *Ostrea lurida*, gives indications of being at or near the margin of the bay.

From the assumed depositional environments of the respective faunas a vertical separation of about 200 feet is indicated between the deposition of the uppermost Anchor silt and the deposition of the fossil bed in the Medill sand. The position of the Castle Heights area along the Newport-Inglewood uplift easily accounts for the vertical movement and possibly accounts also for some of the contorted bedding locally present in the Anchor silt. However, the latter might also be attributed to submarine slumping.

All of the species from the Medill sand locality are living, and have been reported from other Los Angeles basin upper Pleistocene deposits. The four species reported from Hoots' locality 68 (1931, p. 122), and an additional six species as well, were identified from the Overland Avenue locality of this paper (L 3439).

While the fauna of the Medill sand is too small for significant comparisons with other upper Pleistocene deposits, the following localities in the Baldwin Hills are worthy of mention. Tieje (1926, pp. 508, 510) refers to a warm-water "Palos Verdes" fauna from Trench 10 of the Los Angeles Outfall Sewer along the north margin of the Baldwin Hills. He also mentions a correlative of this unit in Trench 6 along the northwest edge of the Hills. To this latter unit he gave the name of Centinela gravels. Faunal lists were not published for either locality, and *Dendraster excentricus* was the only fossil mentioned.

A very large warm-water fauna from a locality in the northwest part of the Baldwin Hills, and in what is undoubtedly the Centinela gravels, have been described by Willett (1937). The inferred habitat for this fauna is a sandy ocean bottom at a depth of 10–12 fathoms near the mouth of a bay. It is possible that the Medill sand is a correlative of the Centinela gravel, but a definite statement must await further study.

Fossil Localities

Department of Geology, University of California, Los Angeles

3394. Buff silts on W. side of Anchor Avenue, just above sidewalk level. About 500 ft. N. of Beverlywood St. Three mi. SE. of campus of University of California, Los Angeles. Elev., 175 ft.
Coll.: Peter Rodda, October, 1955.

3395. Buff silts in E.-facing artificial cuts behind houses on W. side of Anchor Ave.; extending 500 ft. N. from Beverlywood St., Los Angeles. Elev., 195 ft.
Coll.: Peter Rodda and J. W. Valentine, May, 1954.

3396. Gray-buff sands exposed in E.-facing artificial cuts between Anchor Ave. and Medill Pl. Fossils in 1-ft. bed in upper half of cuts; extending N. about 500 ft., from Girla Way almost to Beverlywood St., Los Angeles. Elev., 225 ft.
Coll.: Peter Rodda and J. W. Valentine, May, 1954.

3439. Coarse gray-buff sand on W. side of Overland Ave., 1,000 ft. S. of National Blvd., on SE. side of hill just below crest. Fossils are in cut on N. side of driveway at 3230 Overland Ave., Los Angeles. Elev., 175 ft.
Coll.: Peter Rodda, October, 1955.

3461. Buff silt on W. side of street at S. end of Anchor Ave. Fossil bed is 1–2 ft. below surface of lot. Material taken from foundation excavation, and now covered by house. Three mi. SE. of campus of University of California, Los Angeles. Elev., 194 ft.
Coll.: Peter Rodda, October, 1955.

3462. Concretionary buff silt on W. side of Krim Dr., about 250 ft. N. of Beverlywood St. Scattered fossils a few feet below coarse sand at base of concretionary "stack like" structure. Los Angeles. Elev., 215 ft.
Coll.: Peter Rodda, November, 1955.

3463. Concretionary "stack-like" structure on W. side of Krim Dr., 250 ft. N. of Beverlywood St. Fossils are in upper 6 in. of "stack." Los Angeles. Elev., 225 ft.
Coll.: Peter Rodda, November, 1955.

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VOL. 41, NO. 11 (NOVEMBER, 1957), PP. 2493–2507, 5 FIGS., 1 PLATE

PETROLOGY OF BEAVER LODGE MADISON LIMESTONE RESERVOIR, NORTH DAKOTA[1]

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ABSTRACT

The Mississippian Madison limestone reservoir rock in the Beaver Lodge field, Williams County, North Dakota, was studied to determine its lithologic character and distribution of the porous zones.

The reservoir is a fine- to medium-grained fragmental limestone and dolomitic limestone. Grains include fossil fragments, crystal fragments, and fecal pellets. Originally, porosity was intergranular but later it was increased by solution and dolomitization and decreased by recrystallization and cementation.

There are three major, separate, porous zones in the reservoir; each zone contains lenticular streaks of porous rock which form an interfingering pattern like that of interbedded sandstone and shale. Porosity, controlled by original texture, has been increased through dolomitization by 3 to 5 times. Fracturing is most common in the finer parts of the rock, and the fracturing provides permeability connections between the porous lentils.

The mineralogy is similar to that found in modern deposits on the Bahama Banks; the environment of deposition was probably similar.

The porosity pattern at Beaver Lodge Mississippian limestone reservoir appears to be due partly to a sedimentary response to intermittent uplift and folding during Mississippian time.

INTRODUCTION

The Beaver Lodge field is located in Williams County in northwestern North Dakota. It was discovered by the Amerada Petroleum Corporation in 1951. Discoveries were in Devonian and Silurian carbonate rocks. However, the shallower Mississippian Madison limestone pay zone has been more extensively developed in the Beaver Lodge field and others on the Nesson anticline.

The Madison was a new pay zone in a new province, and the petrology was inadequately known when this study was begun in 1953. Most of the laboratory work was done then, but the project halted until the fall of 1956, when final compilations and analyses of data were made. A progress report was presented (Towse, 1954).

The pay zone in the Beaver Lodge Madison pool is limestone. In spite of generally low permeability and porosity, the engineering data of Keplinger (1954) indicate good reservoir continuity and oil recovery. Stratigraphic relationships and the variations in rock petrography that affect reservoir characteristics of the rock are discussed. Many beds in the Madison at Beaver Lodge, and all of the Madison in many places, are too dense for commercial production, although oil

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Without the help of several individuals and organizations, this study would have been impossible. Their help is acknowledged with thanks. K. W. Roth, Amerada Petroleum Corporation, Williston, made the cores available and provided sampling facilities. W. J. McCabe assisted in the sampling. Cross sections were compiled and plotted under the writer's direction by W. W. Arneson, D. E. Hansen, K. P. Haugen, and E. R. Schmitz, then graduate students at the University of North Dakota. Travel expenses and thin sections were provided by the North Dakota Geological Survey, W. M. Laird, director. A. R. Denison, Amerada Petroleum Corporation, made the core analyses available. Drafting and final manuscript preparation were provided by the Department of Geology, University of California, Los Angeles. K. W. Roth and A. R. Denison kindly read the original manuscript.

saturation is present. Geologic reasons for these favorable and unfavorable porosity-permeability relationships are presented. Other studies of this type should be made in the district.

Stratigraphy. "Beaver Lodge Madison" is the legal name given to this pool by the North Dakota State Industrial Commission. The regional stratigraphy and correlation of the Madison rocks are beyond the scope of this paper. It is generally agreed that the pay zone at Beaver Lodge is correlative with part of the Mission Canyon formation in Montana. Where the section is better defined, Mission Canyon lies below the limestone, dolomite, salt, and anhydrite of the Charles formation; it overlies the grayer fragmental limestones and shales of the Lodgepole formation.

For local purposes in the field, the top of the Mission Canyon or "Madison" is placed at the base of the lowest Charles salt. This is easily recognized in samples and on mechanical well logs. This lithologic boundary, called the top of the "Madison" in this paper, is shown in Figure 1.

For structural mapping, a shaly layer just above the main porosity zone in the field, and easily recognized on gamma ray logs, is used as a marker bed, and is called the top of the main porosity, or top of the "pay."

In order to trace the individual porous streaks from well to well, the "pay" itself is here divided into three "porous zones," numbered from top to bottom, 1, 2, and 3. These zones are bounded by persistent beds of tight, fine-grained, slightly shaly limestone that can be traced readily on mechanical logs.

Previous work. Cox (1953) published the first brief description of the Beaver Lodge Madison reservoir. Sloss and Hamblin (1942), Nordquist (1953), McCabe (1954), and Andrichuk (1955) have reported on the regional stratigraphy of the Madison in this and adjoining areas. Anderson (1954) and Anderson and Nelson (1956) published detailed subsurface sections and correlations of the Mississippian rocks in North Dakota. Keplinger (1954) made extensive studies of reservoir performance in both the Beaver Lodge and Tioga pools.

No detailed data on the stratigraphy or petrography of the pay zone have heretofore been published.

Procedure. Some of the wells in the field were cored, but only a few were cored completely through the pay section. Cores were studied for gross lithologic character and gross structural features. Mechanical well logs of the intervals cored were used as a guide, and descriptions of chip samples from most of the wells are readily available. The Amerada Petroleum Corporation's State "A" well No. 1 was cored continously through the pay. That core was sampled systematically and at every lithologic break, and the samples were used for the petrographic study.

Micrologs were run on most wells and gamma ray-neutron logs are available for many wells. Micrologs, supplemented by gamma ray-neutron logs, were used to compile detailed cross sections of the porous intervals. Log interpretation was based on the core-sample information. Porosity determinations from the microlog

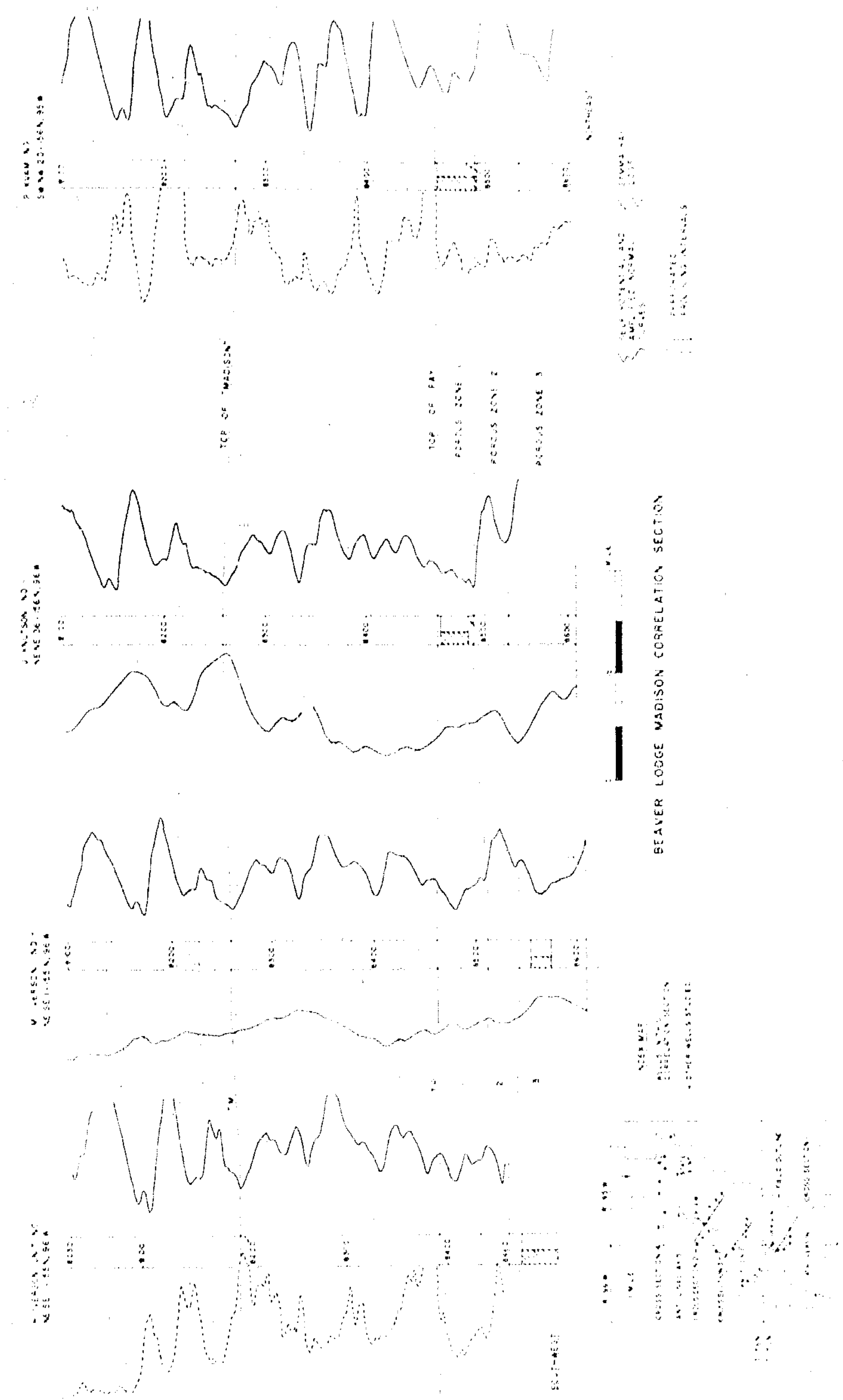


FIG. 1

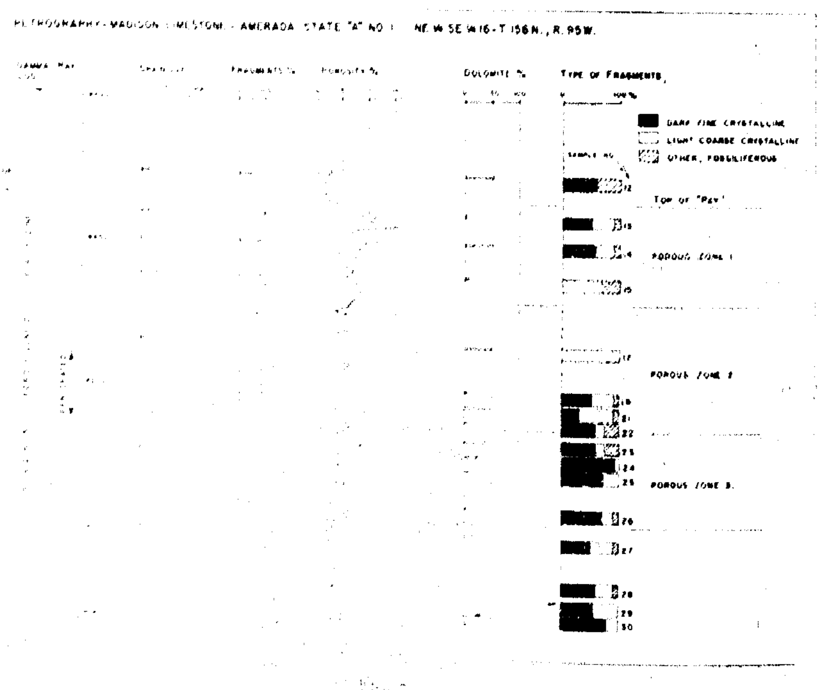
[illegible] analyses. The complete core of the [illegible] at intervals of 2 feet or less by Core Labora[illegible] The core [illegible] by the Amerada Petroleum Corporation. [illegible] described in detail and many of them [illegible] slices were polished and etched with dilute [illegible] fabric. Identical slices were etched with [illegible] Rodgers (1940). This stained the calcite and [illegible] The results of these studies are shown in the petrog[illegible] chart (Fig. 2).

Research was [illegible] examination of records including mechanical [illegible] many wells, core examinations and descriptions of other wells, and de[illegible] petrographic analysis and core analysis of the complete core through the pay section in one well.

The data obtained were correlated and analyzed, significant factors were determined, and processes operating on the reservoir rock were described.

RESERVOIR CHARACTERISTICS

Petrography. Petrography, porosity, and gamma ray log are summarized graphically for a complete section of the pay zone in Figure 2. Modal grain size



of the fragments was measured on thin sections with a calibrated microscope ocular.

These rocks are composed of calcite fragments with interstitial crystalline calcite or dolomite. The chart shows the per cent of the rock composed of fragments. The remainder of the rock in each case is interstitial crystalline material. Per cent dolomite is reported from thin-section analysis and copper nitrate stain and is estimated to the nearest 10 per cent. The mineral composition of the fragments is shown by bar graphs.

Megascopically, the Madison pay zone is a fine- to medium-grained pale to medium brown fragmental limestone. There is some crystalline structure visible. The coarser and more porous sections are lighter colored and have a somewhat sugary texture. The finer and better cemented sections, however, are darker and look more crystalline. More detail is apparent with microscopic and chemical analysis.

The rocks have a generally well sorted fragmental texture and varying amounts of interstitial mineral cement. The grains include mono- and multi-crystal skeletal fragments and non-skeletal grains. Modal grain size ranges from 0.08 to about 0.55 mm., but most of the grains are in the 0.2 to 0.5 mm. range. This places them in the medium-grained class of Krumbein and Sloss (1951, p. 86), and it corresponds with the fine- and medium-grained sand of the Wentworth scale. The finest-grained sections have a microbreccia texture (Krynine, 1948) like some siltstones. The Madison pay is a fossiliferous-fragmental limestone according to the classification of Krumbein and Sloss (1951, p. 138).

All of the samples examined contain some dolomite. Dolomite content ranges from less than 5 per cent to 50 or 55 per cent. The lower part of porous zone 3 and the section below that zone have consistently less dolomite than the rest of the section. Dolomite content varies widely elsewhere in the section. Except for one instance, dolomite content was either 10 per cent or less, or it was near 50 per cent. Intermediate grades were absent. The low dolomite rocks are limestones or magnesian limestones, whereas the rocks with higher dolomite content are dolomitic limestone, according to the classification of Pettijohn (1949, p. 290). None of the section can be classified as the rocks dolomite or calcitic dolomite.

Mineralogy of fragments.—Three types of detrital calcite grains are commonly present: polycrystalline fossil fragments, monocrystalline fossil fragments and dark fine-grained non-skeletal grains.

The polycrystalline fossil fragments are the smallest part of the rock. These grains include foraminifera, ostracods, fragments of bryozoans, and scraps and shards of brachiopod and mollusk shells.

Many fragments are composed of one crystal. Some of these are identifiable crinoidal fragments, but due to the small size many are not positively identified. Most are probably from echinoderms. The crystal fragments and cleavage faces give a crystalline appearance to some hand specimens of the limestone. The grains are generally light-colored and clear, except where they are etched or altered along the grain boundaries. The monocrystalline fragments are an important part of the rock, except in porous zone 2, where they are usually only 5–20 per cent of the rock.

The non-skeletal grains are the most common of the fragment types. They are dark, very fine crystalline calcite, and they are always rounded or botryoidal. Some contain small black specks probably of organic origin, and a few have fragments of shells included. Some of the larger grains would be classified in hand specimens as oölites, but no concentric structure is present. They might be fragments derived from an older fine-grained limestone deposit. Because of the similarity of their composition to that of the fine clastic matrix material found in the voids between the larger grains, however, it is more likely that the grains were formed during the deposition of the Madison pay zone. These grains resemble the fecal pellets described by Illing (1954) from the Bahama Banks. Similar fragments were also figured by Goodman (1945) from Mississippian limestone at Turner Valley, Alberta.

Cement.—Interfragmental material consists of either very fine-grained slightly recrystallized fragments of silt size, fine-grained crystals, or coarse crystals. The crystals may be either wholly or partly replaced by dolomite. All gradations between the three types are observed, and the sequence of formation seems to be as follows: fine detritus, fine crystals, coarse crystals. Some of the rocks consist of separate larger fragments apparently "floating" in a coarse crystalline matrix. These must once have had a clastic matrix that has since been recrystallized. In the more fine-grained rocks the recrystallization process has not been completed, and some of the original porosity and texture have been retained. The original fine matrix material appears identical with the material in the rounded non-skeletal grains.

Replacement.—Many of the larger fragments are etched and corroded around their boundaries and recrystallized in continuity with the matrix. Some grains invade other grains on contact points, like the solution and recrystallization of quartz grains under pressure.

Dolomite forms both in the fine matrix as very small euhedral grains and along the borders of larger grains. Some small dolomite crystals form along stylolite seams. In places the dolomite has replaced large areas of the matrix and the borders of grains, and the dolomite content is large. In general, the dolomitization seems to have been guided along streaks of original permeability, in coarse fragmental streaks, along grain boundaries, or on stylolite seams. Dolomite is less common in the very fine-grained, poorly sorted rocks that were originally less permeable. In those rocks diagenesis has been the corrosion of the larger grains and recrystallization of the fine calcite matrix.

One sample of well sorted limestone had layers of very fine- and medium-size fragments. The very fine fragments are replaced by dolomite; the coarser ones are not. This is probably due to the large surface area subject to alteration.

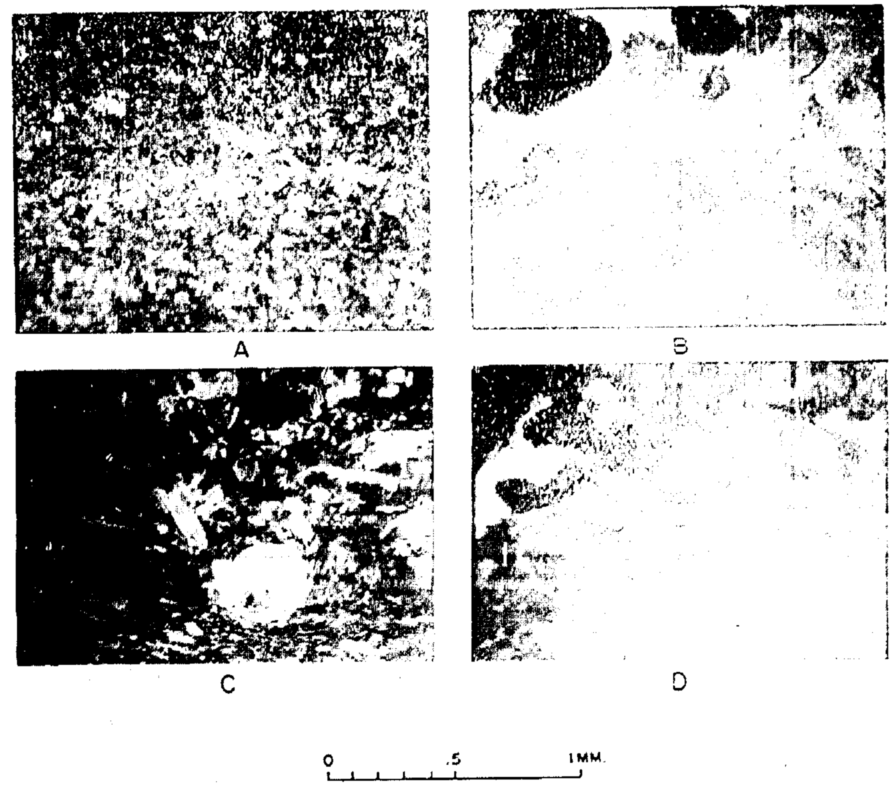


PLATE 1. Thin sections of Beaver Lodge Madison limestone [illegible] core samples from Amerada's State "V" No. 1 [illegible]

A. *Light gray finely bedded very fine-grained dolomitic limestone.* Sample [illegible]; Depth [illegible]. Modal size, 0.08 mm.; 50% dolomite; 50% fragments; 2.7% porosity.

Calcitic silt has been recrystallized. In coarse layer (bottom half) silt is still calcite. Many fine-grained light-colored crystals in upper half are dolomite. Oil was concentrated on [illegible] plane (middle of photo).

B. *Light grayish brown medium grained dolomitic limestone.* Sample [illegible]; Depth [illegible]; Modal size, 0.25 mm.; 30% dolomite; 60% fragments; [illegible]% porosity.

Three types of fragments are present: dark fecal pellets, large [illegible] crystalline fragments, and fossil parts. Matrix is thoroughly recrystallized. Some of matrix is dolomite, and some subhedral dolomite faces can be seen. Partly open pores are present near crystal fragment in upper right quadrant.

C. *Light brown fine- to medium-grained dolomitic limestone.* Sample 1[illegible]; Depth, 8,150 ft.; Modal size, 0.20 mm.; 50% dolomite; 80% fragments; 12.[illegible]% porosity.

Rock is mostly very fine-grained rounded fecal pellets and a few larger crystal and brachiopod fragments. All fragments corroded and recrystallized. Many small stylolitic seams are saturated with oil. Some small light-colored crystals are subhedral dolomite.

D. *Grayish brown medium-grained limestone.* Sample 10; Depth, 8,[illegible] ft.; Modal size, 0.[illegible] mm.; 4% dolomite; 60% fragments; 4.4% porosity.

Rock is mostly crystal fragments and fossil fragments with very fine-grained matrix. Matrix and fragments thoroughly recrystallized. Whiter areas in center and lower right are clear crystalline calcite. Clear spot at right center is open pore. Many stylolitic seams and contacts at grain boundaries. Oil occurs in stylolitic seams.

In most cases this relationship is obscured by other differences, but it may be expected that re... will selectively work on the finest-grained fragments first when they are ... otherwise coarser and more permeable part of the rock.

Other minerals.—The samples examined are mostly carbonate minerals. The most common impurity is a small amount of fine clay in the finer-grained parts of the rock. Chert is rare, and small amounts of anhydrite are found in the upper part of the Mission section. Sloss and Hamblin (1942) found that the Mission Canyon in Montana had a very small insoluble content. This differentiates Mission Canyon from the underlying shaly and cherty Lodgepole formation. Their insoluble residues from Montana were similar to those in the Beaver Lodge Madison.

Pores.—In hand specimens there is a suggestion of intergranular porosity in the softer samples, and there are some fine pinpoint pores. The finer-grained and more crystalline samples show no visible porosity.

In thin section three types of small pores are visible. The most common type of pore is a fine irregular channel along grain boundaries. That type of porosity is commonly found in the finer matrix where the matrix is not completely crystallized. Areas that are partly dolomite usually have fine intergranular porosity along the boundaries of the small dolomite crystals. If recrystallization is complete, the fine boundary pores are filled. Some larger intergranular pores are found at the edges of and between the larger grains where the matrix is not recrystallized.

The second type of pore is a larger type of intergranular pore, and megascopically it would be classified as fine pinpoint porosity. These pores are usually partly lined with fine crystals of either calcite or dolomite and are the remnants of original larger spaces between the larger grains. Some of the pores may be due to solution of part of the original matrix material. Some that are in dolomitic patches may have been enlarged during dolomite recrystallization.

The third type of pore is a long, irregular, narrow void along small fractures and stylolitic contacts between the larger grains. Some of these are partly lined with dolomite crystals. Some fractures have been filled by later coarse crystalline calcite.

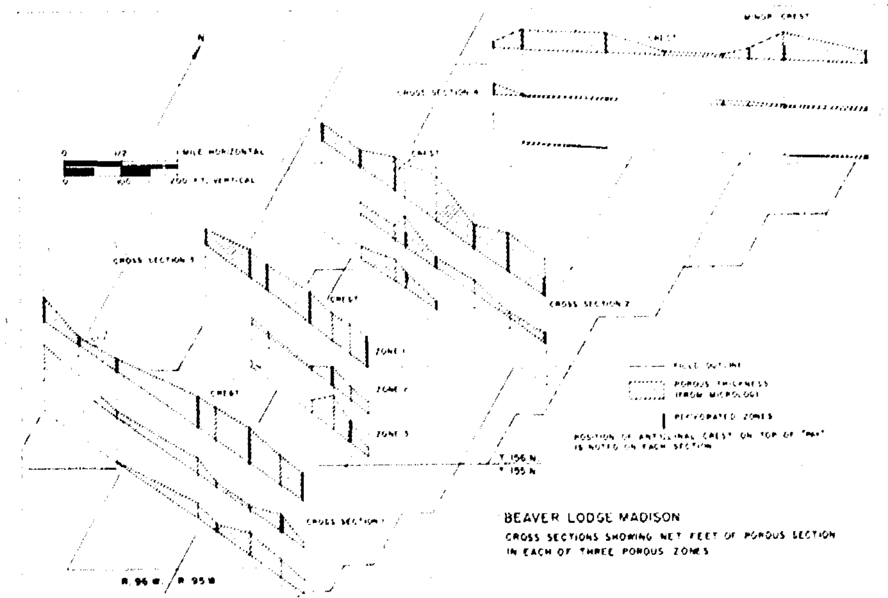
These pores form a system that provides some porosity in rock of all types of texture or structure. Those pores in the coarser portions, however, are larger and more open and should provide better permeability than the fine intergranular pores in the fine-grained sections and in the matrix. There is no simple direct cause-and-effect relation between dolomite and porosity, but the dolomite recrystallization increases the porosity in the finer-grained parts of the rock if dolomitization is only partly complete.

Together with the fractures that are present in the densest parts of the rock, these systems of pores must operate to form a connected permeability system.

Distribution of porosity.—The Madison pay zone has been divided here into three zones. The zones can be correlated throughout the field by electric and gamma ray logs as shown in the correlation section Figure 1. Each zone contains a group of porous streaks and is separated from the adjacent zones by more dense layers. Although these zones are separated stratigraphically, pressure data prove connection in the reservoir. Wells are completed by perforations through casing in any of the zones or in any combination of two zones.

The porous zones are each 30–50 feet thick, but the porosity within each zone is irregular and in streaks. Upper zone 1 is generally more porous and has greater net porous section than the two lower zones. The upper zone has 20–35 feet of net porous thickness. Much of the lower zones have less than 10 feet of porous section, and porous thickness rarely amounts to more than 20 feet. The net porous thickness in selected cross sections is shown in Figure 3; and Figure 4 is a detailed section of the porous streaks in cross section 2 across the middle of the field. The porous intervals thicken and thin, and they interfinger with the dense, less porous streaks. The pattern is similar to that found in irregularly bedded sandstone and shale deposits.

The cross sections were prepared to study the distribution of porosity and the relation of porous thickness to structural position. There is some thickening of net porosity near the anticlinal axis, but in many places the porous section abruptly thins near the anticlinal crest. Because the structure is very low, it is probable that the folding is a very small factor in producing sedimentological



BEAVER LODGE MADISON
CROSS SECTIONS SHOWING NET FEET OF POROUS SECTION IN EACH OF THREE POROUS ZONES

FIG. 3

effects. If the present porosity is partly a function of clastic texture, the sorting variations and the erosional thinning to be expected at the top of a bar of shell debris could cause the porosity pattern. Solution effects would probably be similar. In either case, the bar or mound would have to have been on the present anticlinal crest.

Analysis of petrographic and porosity data. Petrographic and porosity data from one complete core in the pay zone are shown graphically in Figure 2. Variables that were measured were modal grain size, per cent of fragments, per cent of dolomite, mineralogy of fragments, porosity, and fracturing. Other variables that could be measured are sorting, calcium-magnesium ratio, and insoluble residue. Many other variables, some of them unmeasurable, could also be listed.

Value of the measured variables was determined by environment of deposition, materials available, penecontemporaneous solution and recrystallization, and later diagenesis. In order to find the relation of these measured variables to the rock porosity, each was compared in turn with the other variables and with rock porosity. In order to determine which were the dependent and independent variables in the function determining porosity, and which had no bearing on porosity but were a function of time of deposition, comparison and plotting of many combinations were necessary.

Both the type of fragment and the amount of dolomite vary vertically; they are a function of time of deposition. The type of fragment has no direct relation to porosity, but it has an indirect relation to porosity through grain size. Fine matrix material is more abundant where the content of fine-grained fecal pellets is large. Dolomite is directly related to the amount of porosity. Of the simple variables, the proportion of fragments in the rock has the most direct relation to porosity. The secondary crystalline cement, which is the complement of fragment content, directly reduces porosity.

The relations between the various variables are summarized in Figure 5 and as follows.

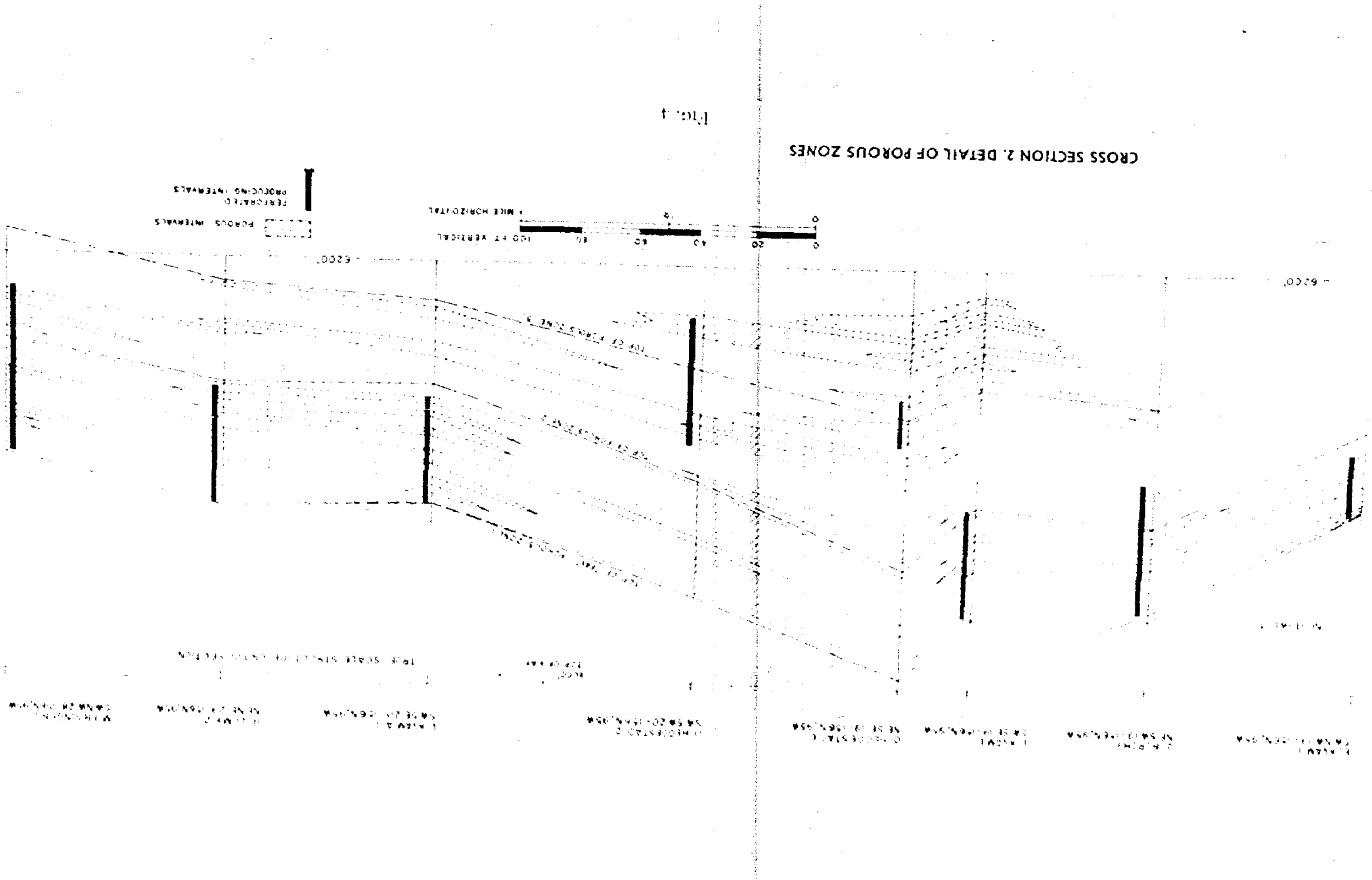
1. *Grain size vs. per cent fragments.* The number of samples with less than 55 per cent fragments is independent of grain size. The proportion of samples with greater than 75 per cent fragments is greatest in rocks with grain size less than 0.4 mm.

2. *Grain size vs. dolomite content.* Most dolomite is found in the rocks with grain size less than 0.2 mm.; the least is found in rocks with grains from 0.2 to 0.4 mm.

3. *Grain size vs. porosity.* The rocks in the 0.3–0.6 mm. classes are slightly more porous. The greatest porosity is in the 0.1–0.2 mm. class, but size was not the important factor; amount of fragments was.

4. *Dolomite content vs. porosity.* Porosity increases slightly with dolomite content.

5. *Fragment content vs. porosity.* Porosity increased sharply with increased fragment content.



CROSS SECTION 2. DETAIL OF POROUS ZONES

FIG. 4

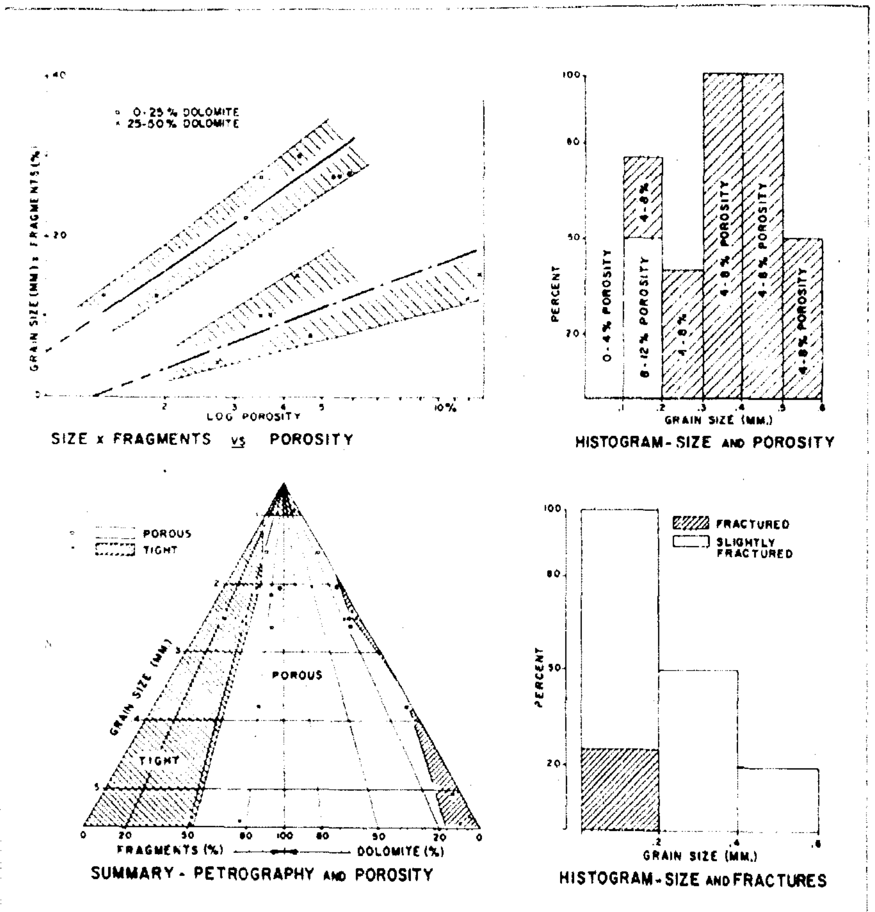


FIG. 5

Porosity is a function of the fragment content, dolomite content, and in part the grain size. If the product of grain size multiplied by per cent fragments be plotted against the logarithm of porosity, two nearly straight line plots could be made from the data (Fig. 5). One line connects the samples containing less than 25 per cent dolomite, and one connects the samples with more than 25 per cent dolomite. The logarithm of porosity increases directly with the product of grain size and fragment content. Rocks with more than 25 per cent dolomite have 3–5 times the porosity of similar rocks with less than 25 per cent dolomite. There is not a direct linear relationship between dolomite and porosity, but the 3:1 or 5:1 increase in porosity is apparent in all samples with dolomite content above 25 per cent. Dolomite content below 25 per cent has no significant effect on porosity.

The curves are accurate only for the samples analyzed, but the general relationships could probably be extrapolated qualitatively to other similar limestone and dolomitic limestone rocks. The data are incomplete for this study, in that no intermediate or high grades of dolomite content are found in the rocks examined.

The coarsest-grained rocks had the least porosity; this was probably due to more complete recrystallization of the matrix and to filling of intergranular voids. The maximum porosity in the rocks with fragments from 0.1 to 0.2 mm. is probably due to incomplete crystallization and the retention of intergranular pores.

Fractures.—Vertical fractures and some horizontal fractures are common in cores of the pay zone. These are reported in routine core descriptions and logs. It can be seen on inspection of cores that the finer-grained, more dense rocks are fractured, whereas the coarser, more porous rocks are not. Of the samples measured for grain size, 100 per cent of those below 0.2 mm., 50 per cent between 0.2 and 0.4 mm., and 20 per cent between 0.4 and 0.6 mm. were fractured. The rocks above 0.2 mm. in grain size were reported as only slightly fractured.

The finer rocks are probably more brittle due to more complete interlocking of the finer fragments. The tendency of the dense rocks to fracture must help to provide pressure and fluid communication through the normally impermeable layers between the porous and permeable streaks. Some of the wider fractures are filled or partly filled with calcite crystals. This proves that they were present naturally and were not induced by the drilling and coring process.

The composition of fluids in the Beaver Lodge Madison reservoir is shown in the following analyses supplied by the Amerada Petroleum Corporation.

COMPOSITION OF RESERVOIR FLUIDS—BEAVER LODGE MADISON RESERVOIR
(Analysis supplied by the Amerada Petroleum Corporation)

Oil Gravity, 43° A.P.I.; Sulphur, 0.24%; Pour point: −60°F.

Gas	*Mol. %*	Water	*P.P.M.*
CO_2	1.83	Cl	169,452
H_2S	2.27	SO_4	376
C_1	73.77	CO_3	0
C_{2-5}	20.35	Na, K	90,964
C_6	0.09	Ca	13,300
		Total solids (by evaporation)	304,000

SUMMARY

Porosity in the Beaver Lodge Madison reservoir varies according to grain size, amount of mineral cement, and amount of dolomite. The last two factors are dependent on original sorting because recrystallization and dolomitization occur along original porous and permeable zones.

Sorting and grain size were established by sedimentary processes during deposition.

The Madison reservoir is a clastic rock, and the pattern of interfingering of the porous (coarser, better sorted rocks) and the non-porous (finer, less well sorted rocks) is similar to the pattern typical of sandstone bodies.

Cross sections of net porous thickness in the various intervals suggest structural control of the porosity in each locality. The cross sections show either a slight thickening or an abrupt thinning of net porous thickness on the anticlinal crest. Other evidence cited by McCabe (1954) points to a history of intermittent uplift of the Beaver Lodge anticline. The changes in porosity may reflect slight differences in texture due to shoaling conditions during deposition of the limestone.

The mixture of fecal pellets, calcite silt, and mixed fossil fragments is similar to that found by Illing (1954) on the Bahama Banks. The Beaver Lodge Madison may have been deposited in a similar environment.

The original porosity in the clastic limestone was due to conditions of deposition; it was lowered by cementation and increased by dolomitization. These processes were probably active at or soon after deposition. No major unconformity is present to suggest long subaerial solution.

The finer, tighter, more crystalline rocks tend to fracture more readily. The fractures provide fluid and pressure communication between the porous beds, and the reservoir acts as one pool.

The environment of formation of the fine-grained calcite siltstone may be favorable for oil formation, but coarser-grained clastic rock is necessary to provide a reservoir. Where coarser rocks are absent, tight, non-productive oil-stained rocks are found. Distribution of porosity appears to be local, whether it is primary porosity or is a combination of primary and secondary types. Local porous areas occur throughout the pool even within a large area of tight limestone. Porosity and permeability appear commonly on structures that were rising during deposition of the limestone.

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VOL. 41, NO. 11 (NOVEMBER, 1957), PP. 2508-2518, 8 FIGS.

IGNACIO QUARTZITE OF SOUTHWESTERN COLORADO[1]

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ABSTRACT

The Ignacio quartzite of southwestern Colorado is referred to the Late Cambrian or Early Ordovician on the basis of the occurrence of oboloid brachiopods. This is contrary to the recent conclusion of Barnes (1954), but in support of the age provisionally assigned by earlier workers. A major unconformity occurs between the Ignacio and the overlying Elbert formation of Late Devonian age. The Ignacio was deposited on an eroded, essentially Precambrian terrane. It is suggested that the rocks underlying the Ignacio in the Animas Valley are not intrusive into the Ignacio formation.

INTRODUCTION

This paper is a preliminary report on the age and stratigraphic relations of the Ignacio quartzite in the Animas River Valley, southwestern Colorado.

The Animas Valley is located in southwestern Colorado on the southern flank of the San Juan Mountains (Fig. 1). The upper part of the valley trends north-south and exposes a section of strata ranging in age from Precambrian to Tertiary. These strata dip gently south into the San Juan Basin.

PREVIOUS RESEARCH AND PRESENT PROBLEM

A number of workers, among them Cross and Howe (1905), Cross (1910), Cross and Larsen (1935), Bass (1944), Read *et al.* (1949), and Barnes (1954), have contributed to the study of the regional stratigraphy of the older rocks of southwestern Colorado.

The Ignacio quartzite has maximum thickness of 200 feet in the Animas River Valley. It is somewhat variable in lithologic character and is underlain by a complex series of granites, schists, and gneisses. The Ignacio is overlain by the Elbert formation, the contact between the two appearing to be transitional, with no obvious evidence of any major stratigraphic hiatus. The Elbert has maximum thickness of 100 feet in the Animas Valley and consists of sandy, calcareous shales, dense, dolomitic limestones, and fine- to coarse-grained sandstones. The overlying Ouray limestone reaches a thickness of 70 feet and consists of siliceous, dolomitic limestones with subordinate interbedded calcareous shales and sandstones.

Until recently, the generally accepted interpretation of this sequence was that the Ignacio quartzite was deposited in Late Cambrian time on an erosional surface of older, probably Precambrian, igneous and metamorphic rocks. The Elbert was considered to be of Late Devonian age, and was therefore believed to

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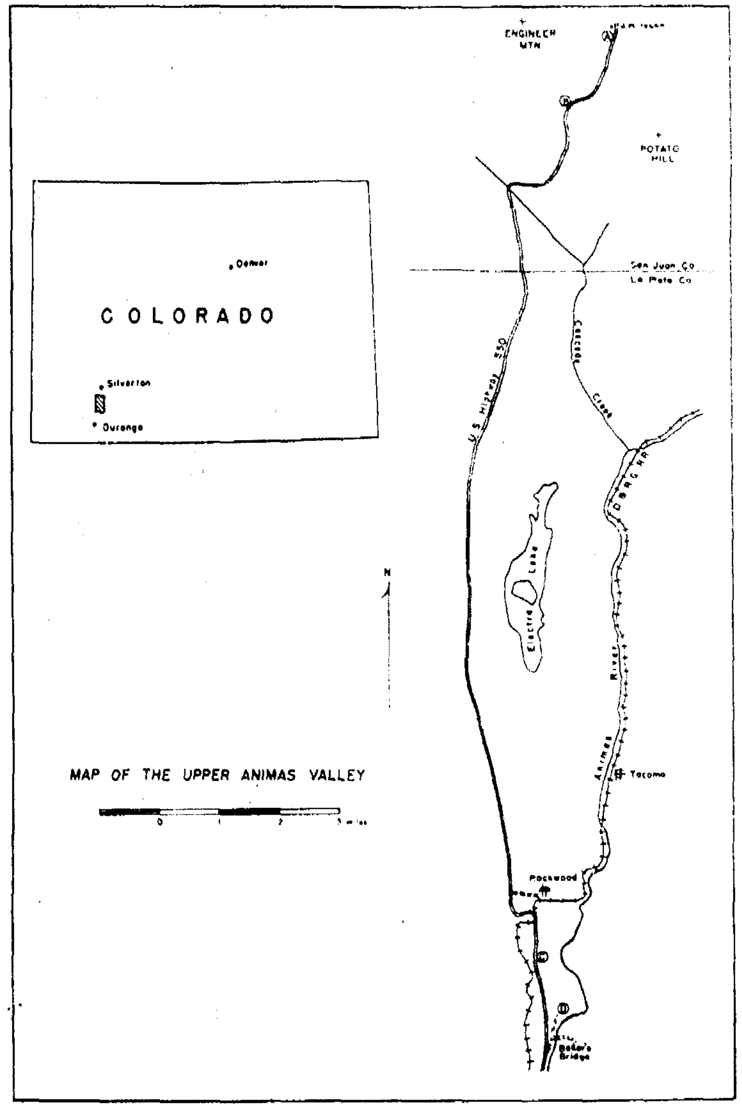

FIG. 1.—Map of upper Animas Valley.

be disconformably separated from the Ignacio by a hiatus representing Ordovician, Silurian, and Early and Medial Devonian time.

The first published use of the term Ignacio occurs in the La Plata Folio (Cross and Spencer, 1899, p. 8), but in the later Engineer Mountain Folio, Cross and

Hole (1910) state that the Ignacio was first described in the Silverton Folio. This original description (Cross *et al.*, 1905a, p. 3) follows.

> The lowest lithologic division of the Paleozoic section in the Animas Valley is made up of quartzites, and varies in thickness, in the area thus far examined, from a few feet to 200 feet. In layers near the middle of these quartzites a single generically determinable shell has been found. From the stratigraphic relationships and the evidence of this fossil it is assumed that in this region the Cambrian system is represented only by a thin series of quartzites belonging probably to its upper division, and for those the name Ignacio formation or quartzite is proposed, from the lakes in the Animas Valley about 18 miles west of south from Silverton, near which the formation is well exposed. . . .
>
> The only identifiable fossil invertebrate yet obtained from the Ignacio beds was found on a remnant capping Overlook Point, one of the hills of Mountain View Crest, in the Needle Mountains quadrangle, south of Needle Creek. Specimens of this fossil were found scattered through a hard, dark, quartzite above the middle of the formation, which was there 110 feet thick. Mr. Wolcott identified this shell as an *Obolus*, but is unable, from the material at hand, to determine its species.

Cross *et al.*, in the Needle Mountains Folio (1905b, p. 8) stated:

> The Eolus granite is older than the Paleozoic sedimentary rocks, for the Ignacio quartzite, of late Cambrian age, is found to rest unconformably on the granite.

Cross *et al.*, in the Silverton Folio (1905a, p. 1) added:

> Following this quartzite [Ignacio] conformably are thin limestones and shaly strata, the latter characterized by casts of cubical salt crystals, with a total thickness of less than 100 feet. These beds are distinguished as the Elbert formation and are assigned to the upper part of the Devonian, on the evidence of characteristic fish remains. . . . In the Uncompahgre Valley near Ouray the Ignacio formation is lacking and the Elbert formation is not everywhere present, and at certain localities in the Silverton quadrangle the Ignacio is absent. These facts show that the seeming conformity in the section seen on the slopes of the Needle Mountains is misleading and that there is a stratigraphic break of great importance between the Ignacio and Elbert formations.

Read *et al.* (1949) and Barnes (1954) have suggested that the Ignacio may represent the basal transgressive phase of a single marine invasion, of which the Elbert represents a later, but continuously successive phase. Barnes (1954, p. 1782) stated this view as follows.

> In an essentially continuous depositional sequence the Ignacio quartzite with its lenses of conglomerate might represent coarse clastic material deposited in a littoral environment, the Ouray limestone might represent fine-grained clastic and chemical materials laid down in quiet water relatively far from shore, and the Elbert formation might be a lithological and environmental transition between the two.

Barnes based this interpretation on the following criteria.

1. The "scanty" fossil evidence for the Cambrian age assigned to the Ignacio.

2. The presence of Devonian fossils in beds of sandstone and quartzite at the base of the Elbert formation. Field relations suggested to him that these beds of sandstone and quartzite might well belong in the uppermost part of the Ignacio quartzite instead of in the lowermost part of the Elbert formation.

3. The regional variation in thickness and lithologic character of the Ignacio quartzite and the Elbert formation was regarded as supporting the idea that these formations were part of one depositional sequence, and were both of Late Devonian age.

4. In many areas along the southern flank of the San Juan Mountains, the Ignacio quartzite rests on an erosional surface of foliated metamorphic and igneous rocks. In other localities, however, Barnes considered the Ignacio to have been intruded by a "younger" non-foliated granite, which had previously been regarded as older than the Ignacio. This interpretation was based on the recognition of small veinlets of "granitic material" intruded along joints and bedding planes in the quartzite, the apparent absence of an erosional surface between the two formations, and the character of the quartzite at the contact. Barnes suggested that both the gross and the microscopic mineralogical character of the quartzite supported the suggestion that it had been intruded by the granite. The intrusions, according to this interpretation, were largely determined by the bedding and jointing of the Ignacio.

5. At one locality Barnes suggested that beds of quartzite had been partly assimilated by the intruding granite.

STRATIGRAPHY OF IGNACIO QUARTZITE

The following section was measured at locality B (Fig. 1), a roadcut on U. S. Highway 550, 2.3 miles south of the summit of Coal Bank Hill, Engineer Mountain Quadrangle, Colorado. At this point (N. 37° 4', W. 107° 47.5'), a small unnamed creek intersects the highway at right angles. The Ignacio here has a strike and dip of N. 50° W., 12° SW. The base of the Ignacio is exposed along the south bank of the creek.

Unit	*Description*	*Thickness (Feet)*
ELBERT FORMATION		
26	Thinly and regularly bedded, dark gray, fine-grained dolomites, with subordinate interbedded shales. Toward top of this member, shales become less abundant, and dolomites become more thickly bedded, the beds reaching maximum thickness of 1 ft.	20.0
25	Interbedded shales and dolomites, the lithologic character being similar to that of No. 26. In this unit, shales become more thickly bedded (individual beds reaching thickness of 2½ in.), and dolomites become more thinly bedded and occur in much less quantity than the shales	19.0
24	Thinly and somewhat irregularly bedded shales, bedding ranging between ¼ and ½ in.; weathering tan, but greenish gray when fresh. Interbedded thin, blocky beds of dark gray lithographic dolomites in subordinate amounts in lower part of section, where beds range from 1 to 6 in. in thickness; upward in unit, dolomites predominate and bedding becomes more massive	21.0
Total Elbert formation		60.0
IGNACIO QUARTZITE		
23	Massively weathering quartzite with some subordinate bedding up to 6 in. in thickness	5.0
22	White quartzite, with limonitic weathering stains	0.5
21	Gray, shaly sandstone, medium-grained	0.5
20	Massively weathering quartzite with subordinate bedding averaging about 1 ft. in thickness visible in weathered face; weathers white-gray, with limonitic stains	17.0
19	Grayish green, shaly sandstone, with limonitic clay pebbles and concretions	0.8
18	Massively weathering, fine- to medium-grained sandstone, with thin-bedded stringers of white quartzite; tan to yellow; thin (¼ in.) bedding visible on massive weathered face	6.0
17	Green, sandy shale	0.2
16	Lenticular, limonitic sandstone, with some liesegang structure; basal layers contain small (¼ in.) subrounded, quartz pebbles. This sandstone increases in thickness and cuts out underlying quartzite	2.0 8.0

Unit	Description	Thickness (Feet)
15	Massively weathering quartzite; weathers white to buff brown; light gray when fresh; medium grained; within it are isolated regular or lens-shaped traces of bedding	6.0
14	Bright green, sandy shale	1.0
13	Brown, medium grained sandstone, with subrounded grains and conspicuous ⅛ in. cavities; evenly bedded; grades upward into light green, fine grained sandstone	3.5
12	Covered interval	9.0
11	Interbedded sands, shales and quartzites, the quartzites becoming predominant toward top of unit; weathers tan to gray to green	10.0
10	Bed of blocky, fine to medium grained, micaceous quartzite; weathers with prominent limonite-stained surface; gray when fresh	1.0
9	Thin bedded, sandy, soft, micaceous shale; predominantly green when fresh but with thin purplish beds up to 2½ in. in thickness	2.5
8	Coarse grained sandstone, weathering to limonitic yellowish brown; light greenish gray when fresh; grains subangular to subrounded, predominantly quartz with subordinate pink feldspar and muscovite; contains *Obolus*	3.0
7	Green, sandy shale	0.5
6	Fine grained, indurated sandstone; subrounded grains predominantly quartz, with subordinate limonite, feldspar and muscovite; blotchy purple	0.8
5	Massively weathering purple, indurated gritty conglomeratic shale; thin-bedded within massive weathered face; matrix fine-grained; abundant subangular pebbles of milky quartz, ¼–½ in. in diameter	4.2
4	Interbedded purplish green and grayish purple shales and conglomeratic quartz grits; latter are grayish green when fresh with limonitic stains present, grains are subangular; beds of grit may reach maximum thickness of 10 in., but most are thinner; whole unit displays even bedding	12.0
3	Covered interval	7.5
2	Alternating green and red sandy shales, and conglomeratic grits up to 9 in. in thickness	6.5
1	Weathered dark red, shaly sandstone, grit and schist, with milky quartz pebbles up to ½ in. in diameter, reddish brown surface coating, and subangular shape	4.0
Total Ignacio formation		112.5
PRECAMBRIAN		
	Dark red, very weathered, micaceous schist	

It has already been remarked that the only identifiable fossil previously recorded from the Ignacio was a single inarticulate brachiopod, which was tentatively identified by Charles Walcott as *Obolus*. Barnes (1954 p. 1782), because of the loss of this original specimen, the subsequent lack of any fossils collected from the Ignacio, and the difficulty of precise identification of inarticulate brachiopods, rejected Walcott's suggestion of a Cambrian age for the Ignacio, in favor of a Devonian age.

Except for one isolated occurrence, an extensive search of the Ignacio formation by the present writers, has failed to yield any fossils. The only stratum which has yielded fossils is a thin bed of sandstone, 36 feet above the base of the formation, exposed at locality B on Coal Bank Hill. More than two hundred inarticulate brachiopods, in varying states of preservation, have been collected from this bed (Fig. 2). G. Arthur Cooper has studied these specimens and made the following observations (personal communication, March, 1957).

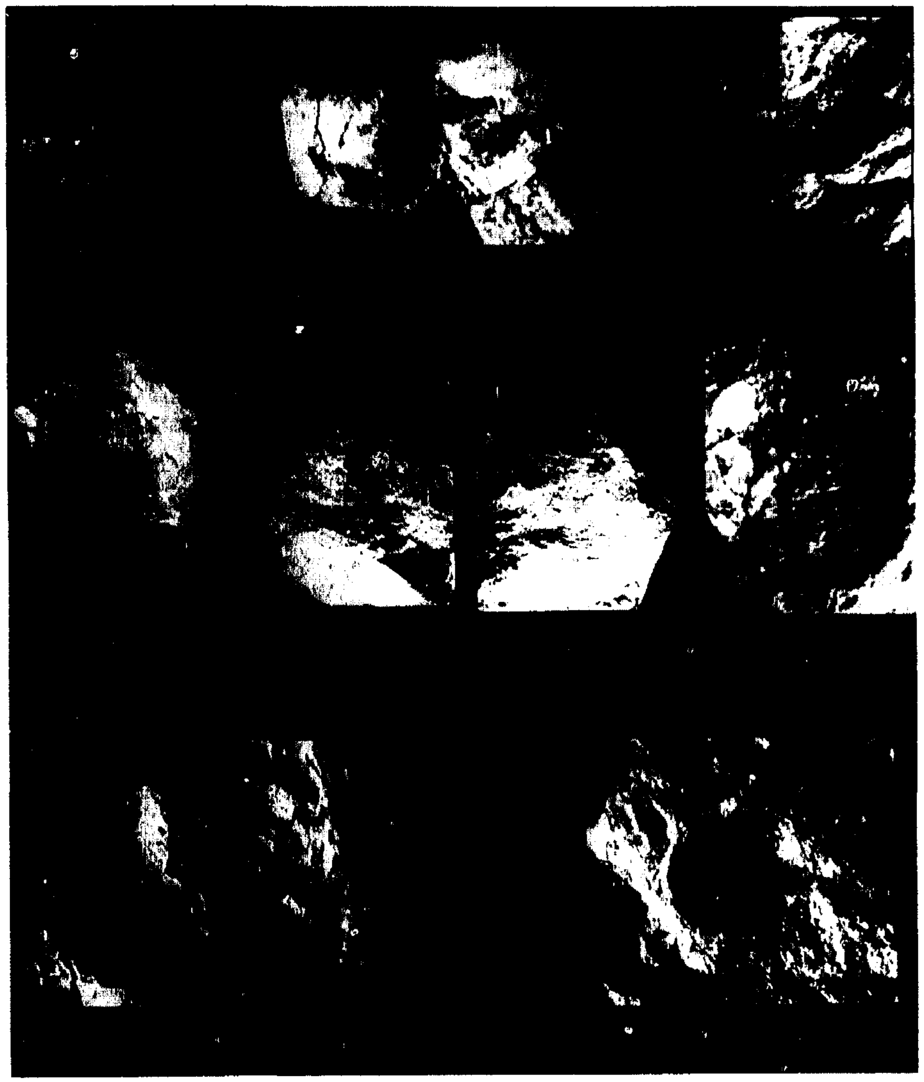

FIG. 2.—Oboloid brachiopods from Ignacio quartzite of southwestern Colorado. Magnification approx. ×3.

I have compared your specimens with all of our material from the Cambrian and Lower Ordovician which is generally regarded as being of the genus *Obolus*.

The results of my comparisons of your specimens with Cambrian and Ordovician oboloids are equivocal. I saw no species with which I could identify your specimens, but similarities seem to exist between yours and *O. anceps* and *O. ion*. The former is identified in both Cambrian and Lower Ordovician sediments; the latter is identified from the Mons, which is probably basal Ordovician. Your specimens, thus, I should say are either very low Ordovician, or very high Cambrian.

The Ignacio quartzite is referred to the Late Cambrian or Early Ordovician on the basis of the cited fossils. According to Cross (1904), the Elbert contains a faunal assemblage of fish remains identified as "Upper Devonian." Therefore, despite the fact that the outcrop studied fails to display a marked hiatus, an unconformity does exist between the Ignacio and the Elbert. Such relationships are not unusual in Rocky Mountain stratigraphy.

RELATION OF IGNACIO TO UNDERLYING ROCKS

In the upper Animas Valley the rocks underlying the Ignacio display three lithologic types: (1) the oldest is a schist which has been classified as Archean by Cross and Hole (1910); (2) the Twilight granite, which over most of the area of its occurrence is light in color, intrudes the schist; however, in the localities where the Twilight underlies the Ignacio, the Twilight is dark-colored and contains abundant biotite which is oriented to give a distinct foliation; (3) pink, coarse-grained granite containing minor amounts of biotite and hornblende. This unit may be the Eolus granite, and if so, it is younger than the Twilight granite.

Near Coalbank Pass (locality A, Fig. 1), the Ignacio rests with marked unconformity on the Twilight which is a purple schist in this area. The planes of schistosity are almost perpendicular to the bedding of the Ignacio. A pegmatite dike 3 feet in width intrudes the schist, but it terminates abruptly at the Ignacio.

At locality B (Fig. 1) the Twilight granite unconformably underlies the Ignacio. Dikes of coarse-grained pink granite are intruded into the Twilight but do not cut the Ignacio.

Fig. 3.—West face of Ignacio quartzite overlying granite at Baker's Bridge.

Fig. 4.—Hammer rests on rhyolite porphyry dike intruded into granite at Baker's Bridge. Ignacio quartzite appears in upper third of photo. For gross relations, refer to the left side of Figure 3.

At Baker's Bridge (locality D, Fig. 1), the Ignacio quartzite is underlain by pink, coarse-grained granite, which is possibly the Eolus. The upper surface of the granite in the vicinity is undulating (Fig. 3) and has a relief of at least 20 feet. The contact of granite and quartzite is fairly well defined. The basal part of the Ignacio here is coarse-grained and contains abundant feldspar as well as small angular fragments of granite up to 5 millimeters in diameter. The granite is intruded by an almost vertical dike of rhyolite porphyry (Figs. 4 and 5). The dike is 3-4 feet wide and can be traced to within 5 feet of the exposed base of the Ignacio. The covered interval is in the area of the granite, but it is significant that the dike does not occur in the Ignacio. The dike is very fine-grained and contains large well formed phenocrysts of potash feldspar, 1-5 millimeters in length.

In a roadcut (locality C, Fig. 1) approximately 1¼ miles north of Baker's Bridge, Barnes (1954, p. 1790) described "beds of quartzite partly assimilated by the intruding granite." This outcrop was visited by the writers who concluded that a definite interpretation could be made only on the basis of a microscopic examination.

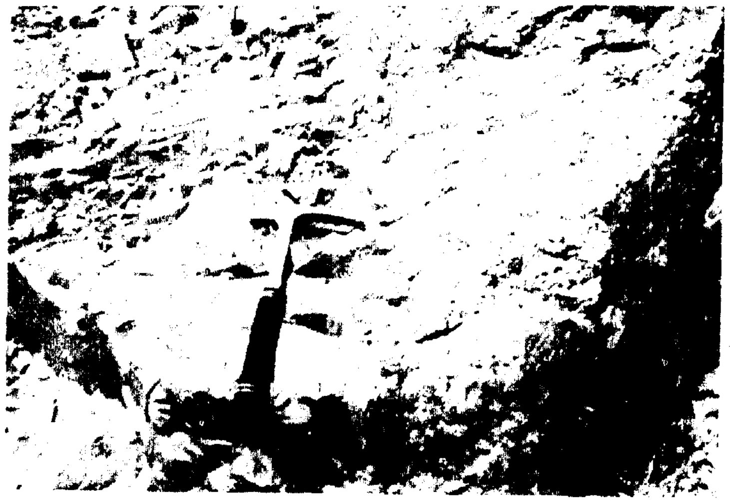

FIG. 5.—Detail of Figure 4.

Proceeding horizontally along the face of this outcrop (locality C), one encounters masses of coarse pink granite (similar to that at Baker's Bridge), sharply separated by almost vertical contacts from masses of fine-grained pink material superficially resembling quartzite. Thin sections made of these contacts, however, show the fine-grained material to be dikes of rhyolite porphyry. The dikes show chilled zones about ½ inch wide and exhibit a marked flow structure (Fig. 6). They also contain spherulitic masses of feldspar and display well de-

FIG. 6.—Contact of granite and rhyolite porphyry dike at locality C, showing chilled zone and marked flow structure. Crossed nicols, ×22.

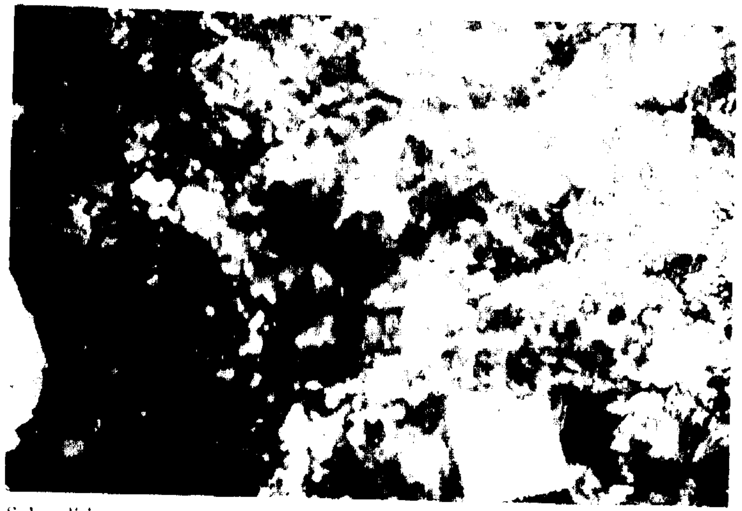

FIG. 7.—Spherulitic masses of feldspar in dike of rhyolite porphyry at locality C. Crossed nicols, ×22.

veloped phenocrysts of potash feldspar (Figs. 7 and 8). The euhedral crystal shown in Figure 8 is best explained as a phenocryst growing in the magma which ultimately formed the dike. The fracturing of the crystal occurred during the last

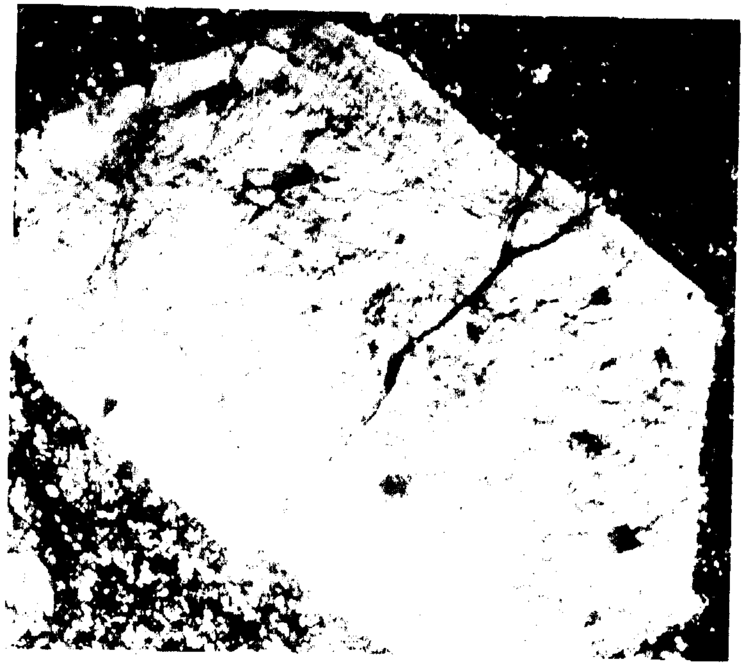

FIG. 8.—Phenocryst of potash feldspar in rhyolite porphyry dike at locality C. Crossed nicols, ×22.

stages of movement and cooling within the dike. It seems unlikely that so perfect a crystal could have developed as a metacryst within the quartzite through the action of granitic juices as Barnes suggested. Petrographically these dikes are similar to the dike at Baker's Bridge. There is a considerable talus slope at locality C between the roadcut and a higher cliff of Ignacio, but once again, examination of the Ignacio failed to disclose the presence of dikes in that formation.

It is evident that the Ignacio quartzite unconformably overlies the Archean schist and the Twilight granite. It is suggested, in view of the evidence cited, that the relation of the Ignacio quartzite to the granite in the Baker's Bridge area is also an unconformable one.

CONCLUSIONS

Contrary to the conclusions of Barnes (1954), the earlier identification of the Ignacio as Cambrian by Cross *et al.* (1905a) is reaffirmed, with the reservation that the Ignacio may be of early Ordovician age. Fossils are cited in support of this classification. There is a major unconformity between the Ignacio and the Late Devonian Elbert formation. No explanation is offered for the parallelism of the bedding of the Ignacio and the Elbert, nor for the seeming transition in lithology between the two units. The Ignacio sea transgressed, in the Animas Valley region, over an eroded, weathered surface of granites, gneisses, and schists probably Precambrian in age. The granite at Baker's Bridge and at locality C, which may be Eolus, is pre-Ignacio and probably (but not necessarily) Precambrian. There is an unconformity between this granite and the Ignacio.

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CONTACT OF BURRO CANYON FORMATION WITH DAKOTA SANDSTONE, SLICK ROCK DISTRICT, COLORADO, AND CORRELATION OF BURRO CANYON FORMATION[1]

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ABSTRACT

Weathering of shales in the upper part of the Burro Canyon formation and the lower part of the overlying Dakota sandstone has made recognition of the disconformity between the formations difficult in the Disappointment basin area of the Slick Rock district, San Miguel and Dolores counties, Colorado. In lieu of the basal conglomerate of the Dakota sandstone, which marks the contact between the formations in the surrounding region, the presence of abundant carbonaceous material in shales of the Dakota sandstone differentiates them from the green shales in the Burro Canyon formation. The contact of the two formations, where clearly exposed in Disappointment basin, is conformable, sharp, and not gradational.

Correlation of the Burro Canyon formation of western Colorado with the Cedar Mountain formation of central and eastern Utah is substantiated by the discovery in the Burro Canyon formation of two pelecypods, ***Protelliptio douglassi*** and "*Unio*" *farri*, with the conifer, *Frenelopsis varians*. The pelecypods also occur in the Kootenai-Cloverly fauna of Montana and Wyoming. The Kootenai-Cloverly fauna contains the pelecypod *Eupera onestae* which is found in the Cedar Mountain formation. The conifer also occurs in the Trinity group of Texas. The Trinity group contains the charophyte *Clavator harrisi* which is found in the Cedar Mountain formation.

INTRODUCTION

During the past two decades Lower Cretaceous sedimentary rocks have been recognized over a large part of the Colorado Plateau. Post-Morrison, pre-Dakota rocks have long been recognized as a distinct lithologic unit in the region (Coffin, 1921, pp. 97-118), but for a number of years were believed to be Jurassic or Late Cretaceous in age. Later, mapping and the discovery of fossils led to the assignment of an Early Cretaceous age. The first formation names applied to rocks of probable Early Cretaceous age on the Colorado Plateau were Stokes' Buckhorn conglomerate and Cedar Mountain shale (Stokes, 1944, pp. 958, 965-67). In 1952, Stokes (p. 1774) revised this to make the Buckhorn conglomerate the lower member of the Cedar Mountain formation. The Cedar Mountain formation occurs in central and eastern Utah. Stokes and Phoenix (1948) applied the name Burro Canyon formation to rocks of the same stratigraphic position in western Colorado.

This paper discusses the contact of the Burro Canyon formation with the Dakota sandstone in the Slick Rock district, western San Miguel and Dolores counties, Colorado (Figs. 1 and 2), with special attention given to its unusual nature in the structural basin underlying the northwest end of Disappointment Valley. In addition, fossil evidence is presented that substantiates the correlation of the Burro Canyon formation with the Cedar Mountain formation.

For the past 3 years the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission has been making a de-

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[2] United States Geological Survey.

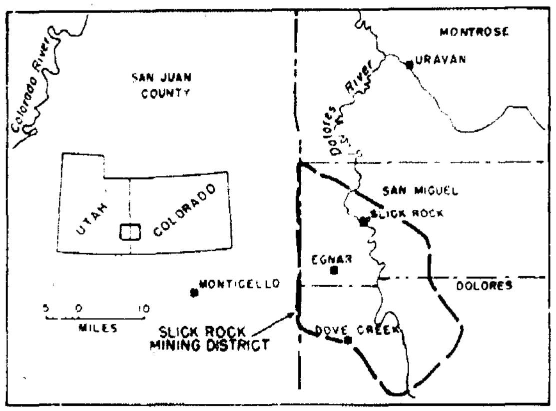

FIG. 1.—Map of part of Colorado Plateau, showing location of Slick Rock district, San Miguel and Dolores counties, Colorado.

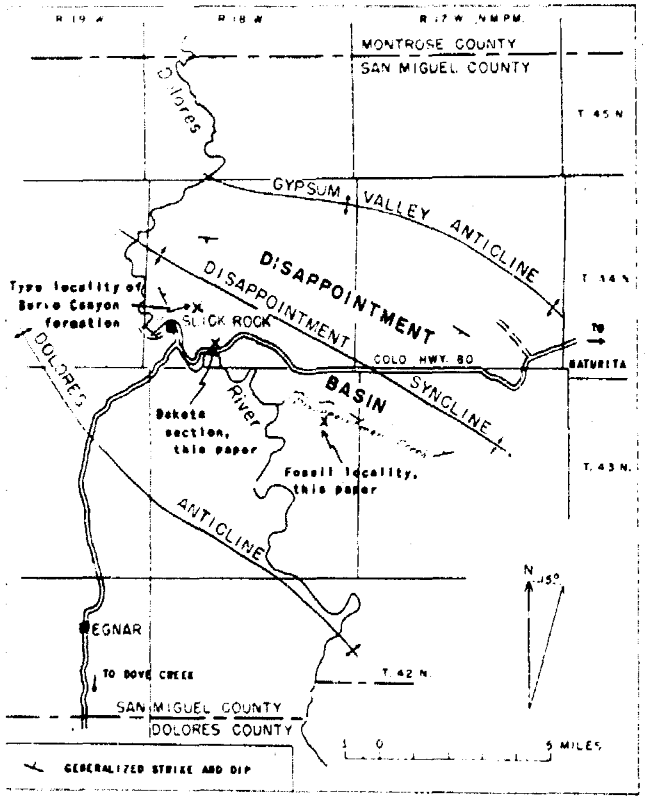

FIG. 2.—Map of part of Slick Rock district, showing localities referred to in text.

tailed study of the geology and uranium deposits in the Slick Rock district. This report is an outgrowth of that study.

GENERAL GEOLOGY

The oldest rock unit exposed in the Slick Rock district is the Cutler formation of Permian age. Rocks of Mesozoic age above the Cutler formation are, in ascending order: the Chinle formation and Wingate sandstone of Triassic age; the Kayenta formation of Jurassic(?) age; the Navajo sandstone of Jurassic and Jurassic(?) age; the Carmel formation, Entrada sandstone, Summerville formation, Junction Creek sandstone, and Salt Wash sandstone and Brushy Basin shale members of the Morrison formation, all of Jurassic age; and the Burro Canyon formation, Dakota sandstone, and Mancos shale of Cretaceous age. The Junction Creek sandstone is recognized in only the southeast part of the district. The Navajo sandstone is locally absent on the axis of the Dolores anticline. All other rock units are present throughout the district.

The dominant structural features of the district are the northwest-trending Dolores anticline and the parallel Disappointment syncline 6 miles northeast. The Disappointment syncline lies between the Dolores anticline and the collapsed Gypsum Valley anticline which is farther northeast, outside of the district (Fig. 2). Disappointment Valley coincides with most of the Disappointment syncline. At the northeast end of the valley along the synclinal axis there is a structural basin known as Disappointment basin (Fig. 2).

Most of the formations younger than the Wingate are thicker along the Disappointment syncline than along the Dolores anticline. The thickening is most noticeable in Disappointment basin where the post-Wingate, pre-Mancos section is twice the thickness of the same section on the Dolores anticline (Fig. 3). Within this stratigraphic interval the rock units that thicken most are the Navajo sandstone, both members of the Morrison formation, and the Burro Canyon formation.

BURRO CANYON FORMATION

The name, Burro Canyon formation, was proposed by Stokes and Phoenix (1948) for:

> . . . . a relatively thin sequence of rocks of probable Lower Cretaceous age lying between the Morrison formation and the Dakota sandstone. It includes essentially the same rocks as those designated "Post-McElmo" by Coffin (1921). The type locality is in Burro Canyon, sec. 29, T. 44 N., R. 18 W. The formation consists of alternating conglomerate, sandstone, shale, limestone and chert ranging from 150 to 260 feet in thickness. The sandstones and conglomerates are gray, yellow, and brown, and the shales are varicolored, mainly purple and green. Assignment to the Lower Cretaceous is mainly by analogy with surrounding regions and is tentative pending study of fossil evidence. The lower contact is at the base of the lowest, resistant, light-colored, conglomeratic sandstone above the varicolored Brushy Basin shale member of the Morrison; the upper boundary is placed above the highest varicolored beds so as to exclude any carbonaceous shales or sandstones in which plant fragments are abundant. This contact has no topographic expression but is remarkably persistent and usable over a wide area in and adjoining Gypsum Valley. The Burro Canyon formation shows a slight thinning in passing over the crests of the Dolores anticline and the Gypsum Valley anticline; this may indicate a slight upgrowth of these structures during the early Cretaceous.

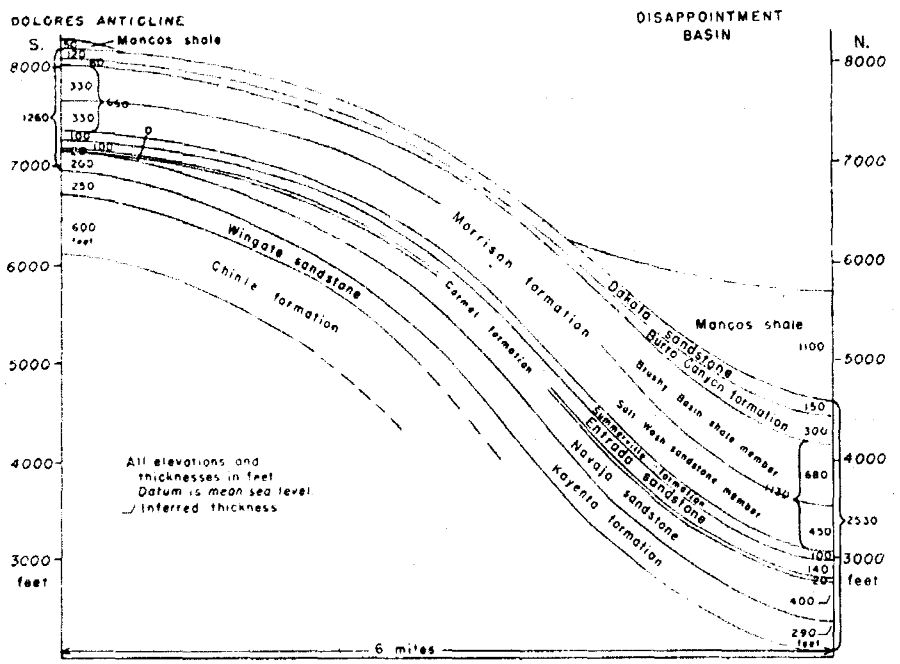

FIG. 3.—Diagrammatic section showing relation of formation thicknesses to Dolores anticline and Disappointment basin.

The lithology of the Burro Canyon formation at the type locality is not typical of the formation throughout the Slick Rock district. In most places in the district the Burro Canyon formation consists of one conglomeratic sandstone bed, as much as 80 feet thick but in most places about 60 feet thick, which contains a few thin greenish gray mudstone "splits." Locally a few feet of greenish gray mudstone occurs above the sandstone.

In and about Disappointment basin, the Burro Canyon formation is lithologically like that at the type locality (Fig. 2). The sandstones are more numerous and thicker than they are away from the basin, and the formation includes green shale and green and gray limestone and chert. The lower part of the formation is dominantly gray to light brown conglomeratic sandstone with some shale, and grades upward into a dominantly argillaceous sequence containing limestone, chert, and sandstone. The upper sixth of the formation is almost entirely green shale. A 240-foot-thick section was measured by Stokes (1952, p. 1773) near the type locality. The maximum thickness of the Burro Canyon formation in Disappointment basin is in excess of 300 feet, as indicated by exploratory diamond drilling for the U. S. Geological Survey.

Most sandstones in the Burro Canyon formation in the Slick Rock district are conglomeratic, but particles larger than small pebbles are rare. In a few places thin layers of "basal conglomerate" in sandstone beds contain cobbles and small boulders of sandstone, mudstone, limestone, and quartzite. Sandstone units in the Burro Canyon formation are commonly 60 feet or more thick. Weathering of sparse pyrite to limonite imparts a light buff color to sandstones of the Burro Canyon in most places.

The contact of the Burro Canyon formation with the underlying Brushy Basin shale member of the Morrison formation is mapped, in the Slick Rock district, at the base of a prominent sandstone unit which generally is in contact with shale units of the Brushy Basin member. Although the contact is commonly a disconformity marked by scours and sandstone filled channels, the contact in many other places is gradational, marked by intertonguing of sandstone of the Burro Canyon with shale of the Brushy Basin. Also, in many places, thicker sandstones near the base of the Brushy Basin shale member resemble sandstones of the underlying Salt Wash sandstone member whereas thicker sandstones near the top of the Brushy Basin resemble sandstones of the overlying Burro Canyon formation. These relations indicate that in the Slick Rock district deposition was essentially continuous from Morrison (Late Jurassic) into Burro Canyon (Early Cretaceous) time.

DAKOTA SANDSTONE

The term Dakota sandstone has been applied to rocks on the Colorado Plateau that are similar in lithologic character and stratigraphic position to rocks of the Dakota sandstone in the western Great Plains. The Dakota sandstone in much of the Slick Rock district is like that of the surrounding region: a lower sandstone unit with a basal conglomerate, intermediate carbonaceous shale unit, and an upper sandstone unit.

The poorly exposed contact of the Dakota sandstone with the overlying Mancos shale seems sharp, but carbonaceous sandstones similar to those of the Dakota occur near the base of the Mancos shale, and the two formations may interfinger. As shown in drill core, the contact of the Mancos and Dakota formation in Disappointment Valley is gradational within a few feet.

Except for the basal conglomerate in the Dakota sandstone, conglomerates are rare in the formation in the Slick Rock district. Carbonaceous material is abundant throughout most of the Dakota sandstone, though locally it is absent, particularly in the lower sandstone unit. However, limonitic and siliceous plant molds are common in the basal conglomerate. Sandstone units in the Dakota are generally less than 40 feet thick. Weathering of abundant pyrite in the Dakota has imparted a yellowish brown color to the sandstones in most places.

In Disappointment basin the Dakota sandstone lacks the lower sandstone unit. A section of Dakota sandstone from top to bottom, measured in Joe Davis Canyon and in adjacent Disappointment Valley (SW. ¼, Sec. 28, T. 44 N., R. 18 W., Hamm Canyon Quadrangle, Colorado), is typical of the Dakota sandstone in Disappointment basin.

	Thickness (Feet)
Sandstone, light brown, medium fine-grained; 10% interstitial clay; trace limonite stain; thin-bedded; cross-bedded; top of Dakota sandstone; overlain by Mancos shale	25
Shale, dark gray; 15% carbonaceous material; abundant limonite stain; few thin sandstone and siltstone lenses	17
Sandstone, light greenish brown, medium- to medium fine-grained; 10% interstitial clay; abundant carbonaceous material in a few thin layers, trace limonite stain; thin-bedded; cross-bedded	19
Shale, dark gray; 10% carbonaceous material; trace limonite stain	4
Sandstone, light brown and light and dark gray, medium- to fine-grained; moderate limonite stain; sparse carbonaceous material; thin-bedded; cross-bedded	6
Shale, dark gray; few thin sandstone lenses; poorly exposed	11
Sandstone, light greenish gray, fine-grained; 10% interstitial clay; trace mica; trace limonite stain cross-bedded	7
Mudstone, shale, coal, and claystone, dark and light gray; sparse limonite stain; trace hematite stain; few thin sandstone lenses	13
Sandstone, light brown, very fine-grained; 15% interstitial clay; sparse carbonaceous seams and flakes	6
Thin alternating layers of sandstone, light greenish gray, fine-grained, with dark gray shale; abundant carbonaceous material; trade limonite stain; trace pyrite in twig fragments; thin coatings of gypsum on a few fractures	10
Coal, dark brown to black; 20% mudstone; trace limonite stain	2
Sandstone, gray to light yellowish brown; fine-grained; 10% carbonaceous material; 10% interstitial clay	3
Shale, dark gray; abundant carbonaceous material; abundant limonite stain; base of Dakota sandstone; underlain by shales of Burro Canyon formation	2
Total thickness of Dakota sandstone	125

CONTACT OF BURRO CANYON FORMATION WITH DAKOTA SANDSTONE

Several of the better criteria used to differentiate the Burro Canyon formation from the Dakota sandstone in the Slick Rock district are the following. 1. Fossil plants and carbonaceous material are rare in the Burro Canyon formation and abundant in the Dakota sandstone. 2. Pyrite is more abundant in the Dakota sandstone than in the Burro Canyon formation. Oxidation of the pyrite has imparted a yellowish brown color to both formations, but the color is more intense in the Dakota sandstone. 3. Shales of the Dakota sandstone are carbonaceous, and hence some shade of gray. The shales of the Burro Canyon formation are greenish gray except for minor occurrences of reddish brown shale and rare occurrences of gray carbonaceous shales. 4. Conglomerates are common in the Burro Canyon formation, less common in the Dakota sandstone. 5. Because of their greater thickness, sandstones of the Burro Canyon generally form more prominent cliffs and hogbacks than the thinner sandstones of the Dakota.

The contact between the Burro Canyon formation and the overlying Dakota sandstone, as described by Stokes, is marked by a disconformity. In tracing the contact into New Mexico and Arizona, Craig and others (1955, p. 161) have noted that the disconformity between the Burro Canyon and Dakota becomes an angular unconformity and pre-Dakota warping and erosion have removed Lower Cretaceous and Upper and Lower Jurassic rocks.

The contact between the two formations has been described by Carter (1957, p. 311) in the nearby Mt. Peale No. 1 Quadrangle, Utah and Colorado, as

. . . extremely undulatory . . . Broad channels filled with conglomerate of the Dakota have been observed in contact with light-green mudstone, limestone, and chert of the Burro Canyon formation, and, in many places with the thick sandstone and conglomerate lenses which comprises the basal unit of the Burro Canyon. Included in the basal unit of the Dakota are angular and subangular fragments of rock from the beds through which the channels have been scoured.

Over most of the Slick Rock district too, the Burro Canyon formation and Dakota sandstone are separated by a disconformity; that is, the contact is slightly irregular and is marked by channel scours. In the scours the basal conglomerate of the Dakota contains cobbles and slabs of sandstone of the Burro Canyon. The sandstone of the Burro Canyon in places is bleached to as much as 3 feet below the disconformity; this may represent pre-Dakota weathering on a surface of the Burro Canyon formation.

Toward Disappointment basin the contact becomes more conformable with relatively few and shallow scours. In this peripheral area the Burro Canyon formation thickens and the lower arenaceous unit of the Dakota sandstone becomes shaly and loses its identity.

In Disappointment basin the contact of the Burro Canyon with the Dakota is apparently conformable. The lower sandstone unit of the Dakota sandstone is absent, and the contact must be determined by the presence of carbonaceous material in the shale of the Dakota sandstone and by a silty chert marker bed near the top of the Burro Canyon formation. The latter is 1–5 feet thick and is overlain by as much as 12 feet of greenish gray, carbon-free shale of the Burro Canyon formation. Exposures of the contact in Disappointment basin are not common, because of weathering of shales above and below the contact. However, at all exposures found, the contact of carbonaceous shales of the Dakota with green shales of the Burro Canyon is conformable, sharp, and not gradational.

FOSSIL EVIDENCE FOR AGE OF BURRO CANYON FORMATION

Fossils were collected from the Burro Canyon formation by Stokes in T. 43 N., R. 18 W., about ½ mile east-southeast of the junction of Disappointment Creek with the Dolores River, in the Slick Rock district (Fig. 2). The collection includes ganoid fish scales, fresh-water ostracods, and plant fragments. The plant fragments were identified by Brown (Stokes, 1952, p. 1767) as *Frenelopsis varians*. Brown (1950, p. 50) regards *Frenelopsis varians* as an Early Cretaceous index fossil because neither it nor any of its close relatives has been found outside strata of Early Cretaceous age.

In November, 1955, the writer and D. R. Shawe, while looking for Stokes' locality, found a new fossil locality at approximately the same horizon. A few days later the site was revisited with L. C. Craig and others, and a large collection of fossils was made. The locality (Fig. 2) is in the NE. ¼, NW. ¼, NE. ¼, Sec. 11, T. 43 N., R. 18 W., San Miguel County, Colorado, in the Hamm Canyon Quadrangle, 1,000 feet south of Disappointment Creek in a wash indicated as an intermittent stream on the quadrangle map. The wash enters Disappointment Creek on its south side, and the mouth of the wash is 6,000 feet from the junction of Disappointment Creek with the Dolores River.

The fossils occur in a 10-foot zone of interbedded black to green shale, green siltstone, and fine-grained sandstone. The top of the interval is 18 feet below the top of the Burro Canyon formation. The following fossils have been identified: *Protelliptio douglassi* Stanton; "*Unio*" *farri* Stanton; *Nippononaia asinaria* Reeside (in press); *Nippononaia* sp. (in press); viviparid gastropod; *Cypridea?; Darwinula?;* ganoid fish scales; *Frenelopsis varians* Fontaine; *Pinus susquaensis* Dawson; and fern pinnules.

The mollusca were identified by J. B. Reeside, Jr. (written communication, 1956), who states:

> This assemblage, like most nonmarine faunas, contains many individuals of a few species. It is only moderately well preserved, but can be determined with considerable confidence. The new species is unlike anything I have seen in the older faunas.

According to J. B. Reeside, Jr. (written communication, 1956), the pelecypods are all unioid types. *Protelliptio douglassi* and "*Unio*" *farri* are well known and widespread Early Cretaceous (Aptian) species in the faunas of the Kootenai and Cloverly formations in Montana and Wyoming (Henderson, 1935, pp. 25, 76; Yen, 1949, p. 466; Yen, 1951, pp. 1-3). The new species belongs to *Nippononaia*, an Early Cretaceous genus of Japan and Korea (written communication from J. B. Reeside, Jr., 1956).

The ostracods, *Cypridea?* and *Darwinula?* were examined by I. G. Sohn (written communication, 1956) who states:

> The ostracodes are fairly common, but unfortunately, the preservation is such that they cannot be identified with any degree of certainty. Gross form suggests the genera to which they are referred with a great deal of uncertainty.

The plant material was examined by R. W. Brown who found *Frenelopsis varians* to be abundant. *Frenelopsis varians* has been described from the Trinity group of Texas (Fontaine, 1893, p. 273). Only one specimen of *Pinus susquaensis* was found.

The age of both Stokes' collection and the present collection is certainly Early Cretaceous. However, no fossil evidence has been found to determine the age of the sandstone beds that form the lower part of the Burro Canyon formation in Disappointment basin and most of the formation away from the basin. Therefore, the sandstone beds may theoretically be Late Jurassic age or Early Cretaceous in age, or both.

FOSSIL EVIDENCE FOR AGE OF CEDAR MOUNTAIN FORMATION

Stokes (1944, p. 967) was the first to report fossils from the Cedar Mountain formation. The fossils were non-diagnostic dinosaur bone fragments from the upper or shale member of the formation. More recently collections have been made from two localities in the shale member, both yielding Early Cretaceous fossils.

The first of the two localities is about 6 miles southeast of Castle Dale, Utah, and is in Sec. 20, T. 19 S., R. 9 E. The collection, made by Katich (1951), included: the fresh-water pelecypod, *Eupera onestae* (McLearn); the fern, *Tempskya* sp.; and abundant unidentified ostracods. Cobban (in Katich, 1951, p. 2094) notes *Eupera onestae* (of Aptian age) as common in the Kootenai formation of northern Montana and southern Alberta. Stokes later collected from the same locality, adding ganoid fish scales to the list of fossils. Stokes also collected specimens of *Tempskya* sp. which were tentatively identified by Andrews (in Stokes, 1952, p. 1769) as *Tempskya minor* Read and Brown. *Tempskya minor* is known from the Aspen shale of Wyoming and equivalent parts of the Wayan formation in Idaho.

The second locality is in Sec. 22, T. 22 S., R. 20 E., on the southwest flank of the Salt Valley anticline, Grand County, Utah. The site was discovered by Stokes who collected gastropods, pelecypods, and microfossil material. Stokes referred the microfossil material to Peck (Stokes, 1952, p. 1768), who identified three ostracod species: *Metacypris angularis, Cypridea* cf. *C. brevicornis, Cypridea wyomingensis;* and the charophyte, *Clavator harrisi*. In regard to these fossils Peck states:

> All of these are common fossils in the Gannett group, the Cloverly of northwestern Wyoming, and the limestones in the upper Kootenai of Montana. *Clavator harrisi* is common in the Trinity of the Gulf coast. None of these species occurs in the Morrison of the Front Range in Colorado, in eastern Wyoming, or in the Black Hills. Their occurrence is an excellent indication of the Lower Cretaceous age of the formation.

In view of the identifications, an Early Cretaceous age seems assured for the shale member of the Cedar Mountain formation. No fossil evidence has been found to establish the age of Stokes' Buckhorn conglomerate member of the Cedar Mountain. Like the age of the thick sandstone units of the Burro Canyon formation, the age of Stokes' Buckhorn conglomerate member theoretically may be Late Jurassic or Early Cretaceous, or both.

CORRELATION OF BURRO CANYON FORMATION WITH CEDAR MOUNTAIN FORMATION

Collections of fossils from the upper part of the Burro Canyon formation in Disappointment basin and from the shale member of the Cedar Mountain formation have been determined to be of Early Cretaceous age. As yet, collections have not shown any species common to both formations. However, both formations have species found together in other Lower Cretaceous rock units. Table I lists the index fossils used to correlate the Burro Canyon formation with the Cedar Mountain formation, and also lists the rock units in which the fossils occur.

SUMMARY

Throughout most of the Slick Rock district the Burro Canyon formation is composed of a conglomeratic sandstone about 60 feet thick, locally with a few feet of overlying green shale. In the same area the Dakota sandstone is composed

TABLE I. FOSSILS AND ROCK UNITS USED TO CORRELATE BURRO CANYON FORMATION WITH CEDAR MOUNTAIN FORMATION

Fossils	Rock Units and Regions			
	Burro Canyon Fm. W. Colo.	*Cloverly Fm. Wyo. Kootenai Fm. Mont.*	*Trinity Group Texas*	*Cedar Mtn. Fm. Central and E. Utah*
Protelliptio douglassi	X	X		
"*Unio*" *farri*	X	X		
Eupera onestae		X		X
Clavator harrisi			X	X
Frenelopsis varians	X		X	

of three units: an upper sandstone unit, a middle carbonaceous shale unit, and a lower sandstone unit with a basal conglomerate. The disconformable contact between the formations is most readily recognized by the presence of the basal conglomerate of the Dakota.

In Disappointment basin the upper part of the Burro Canyon formation is composed largely of shale. In the same area the lower part of the Dakota sandstone is also composed largely of shale. Weathering of the shales in the two formations has resulted in a poorly exposed contact. However, at favorable exposures the contact is conformable, sharp, and not gradational. This determination is made possible by the presence of carbonaceous material in the gray shales of the Dakota sandstone and the absence of carbonaceous material in the greenish gray shales of the Burro Canyon formation.

The correlation of the Burro Canyon formation with the Cedar Mountain formation was confirmed through two analogies. 1. The Burro Canyon formation was correlated with the Kootenai and Cloverly formations of Montana and Wyoming by the pelecypods, *Protelliptio douglassi* and "*Unio*" *farri*. The Kootenai and Cloverly formations contain the pelecypod, *Eupera onestae*, which is found in the Cedar Mountain formation. 2. The Burro Canyon formation was correlated with the Trinity group of Texas by the plant, *Frenelopsis varians*. The Trinity group contains the charophyte, *Clavator harrisi*, which is also found in the Cedar Mountain formation.

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MISSISSIPPIAN BIOHERMS IN NORTHEAST OKLAHOMA[1]

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ABSTRACT

In northeast Oklahoma, the Mississippian Boone formation contains numerous striking bioherms composed of crinoidal debris. Most of the exposed bioherms occur in the St. Joe, or lowest, member of the Boone formation. The Reeds Spring, or middle member, contains no bioherms, and the Keokuk, or upper member, contains a few known bioherms. The bioherms occur in widespread, thin-bedded crinoidal limestones and are related in origin to the thin-bedded limestones. Each bioherm consists of a lens-shaped core of massive limestone which is surrounded by and interfingers with thin-bedded limestones. The massive cores are 10–40 feet thick and 50–1,000 feet wide. The thin-bedded limestones dip steeply away from the massive cores.

The bioherms are interpreted as having been formed by the accentuated growth and accumulation of crinoids. The bioherms formed mounds which were elevated as much as 50 feet above the floor of a shallow sea. The massive bioherm cores were probably created by the continuous deposition of crinoidal debris; whereas the bedded limestones represent deposition which was interrupted from time to time. The thin-bedded limestones on the flanks of bioherms were deposited on slopes as steep as 15°. A debris-binding agent, such as inorganically precipitated calcium carbonate or calcareous algae, is postulated to have bound the deposits of crinoidal debris together, permitting them to persist on such steep slopes. The bioherms are considered to have been organic reefs because they formed wave-resistant organic structures which formed elevated prominences in a shallow sea.

INTRODUCTION

The Mississippian Boone formation in northeast Oklahoma contains numerous striking bioherms composed of fragmental crinoid-stem material. The bioherms are usually exposed in river bluffs and appear as swollen lenses of massive crinoidal limestone which interfinger with thin-bedded crinoidal limestones. The bioherms occur mostly in the St. Joe member, or lowest of the three members of the Boone formation, although bioherms are also present in the Keokuk, or upper member. The bioherms are of particular interest because they reveal information suggesting that they were formed as small crinoid reefs close to the surface of a shallow sea. They are also of interest because they are responsible for the development of small anticlines in the strata which lie over them. It is conceivable that anticlines of the type formed over the larger bioherms might serve as small oil-trapping structures under appropriate conditions in other regions.

STRATIGRAPHY OF BOONE FORMATION[3]

The Boone formation crops out over a large area in northeast Oklahoma and in adjacent parts of Arkansas, Missouri, and Kansas. The Boone is composed of beds of limestone and chert which represent the Osagean series. Correlatives of the Boone formation, other limestones and cherty limestones of Osagean age,

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This study was conceived when several of the bioherms in northeast Oklahoma were visited in the company of Fred T. Holden, of The Carter Oil Company. His contributions of ideas is acknowledged here, as is the assistance of Ruperto Laniz, thin-section technician at Stanford University, who prepared the thin sections and photographs used in this study.

[3] Partly after L. R. Laudon, 1939, "Stratigraphy of the Osage Subseries of Northeastern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, pp. 325–38.

are widely distributed in North America. Other formations which are wholly or partly equivalent in age to the Boone formation include: the Osage formation of southern Illinois; the group consisting of the Keokuk, Burlington, and Fern Glen limestones of Missouri and Illinois; the Fort Payne chert of Tennessee, Alabama, and Georgia; the Lake Valley limestone of New Mexico; the Escabrosa limestone of southern Arizona; the Redwall limestone of northern Arizona; the Leadville limestone of Colorado; and the Madison limestone of Wyoming, Montana, Idaho, and Utah.

The Boone formation in northeast Oklahoma is 300–400 feet thick and is conveniently divided into three members which are, in ascending order, the St. Joe, the Reeds Spring, and the Keokuk members (Fig. 2). The Boone formation is underlain by the Chattanooga shale and overlain by the Mayes formations.

The St. Joe, or lower member, in most places consists of thin-bedded crinoidal limestone with subordinate amounts of soft gray-green marl. The thickness ranges from zero to about 100 feet. Massive bioherm cores, in contrast to the thin-bedded limestone, occur where the St. Joe member is relatively thick.

The Reeds Spring, or middle member, ranges from 75 to 150 feet thick and consists of alternating beds of dark limestone and chert. The alternation of the thin beds of chert and limestone causes the Reeds Spring member to appear as a wall of horizontal stripes where exposed in cliffs. Limestone beds in the Reeds Spring member are fine-grained and contain much less crinoidal material than the St. Joe member.

The Keokuk, or upper member, consists of thick-bedded light gray limestone and light gray, or white, chert. Some of the beds in the Keokuk member consist wholly of chert; whereas others, particularly of bioherm origin, consist solely of limestone. The Keokuk member is very resistant to erosion, and commonly caps the plateaus of the region.

BIOHERMS IN ST. JOE MEMBER

Bioherms[4] consisting of massive lenses of coarse crinoidal limestone and flanking thin-bedded crinoidal limestones occur scattered over a wide area in northeast Oklahoma (Fig. 1). The bioherms are exposed in bluffs formed where streams have incised valleys into a broad plateau capped by the Boone formation. Although the number of exposed bioherms is not large, it seems probable that many more are hidden from view in the hilly plateau areas between the streams.

The bioherms of the St. Joe member show a great diversity in size and shape. However, most of them have several common features. Each bioherm has a

[4] "A bioherm is defined as consisting of any dome-like, mound-like, or otherwise circumscribed mass, built exclusively or mainly by sedentary organisms such as corals, stromatoporoids, algae, brachiopods, mollusca, crinoids, etc. and enclosed in normal rock of different lithologic character." (E. R. Cummings, 1930, "List of Species from the New Corydon, Kokomo, and Kenneth Formations of Indiana and from Reefs in the Mississinewa and Liston Creek Formations," *Proc. Indiana Acad. Sci.*, Vol. 30, p. 207.)

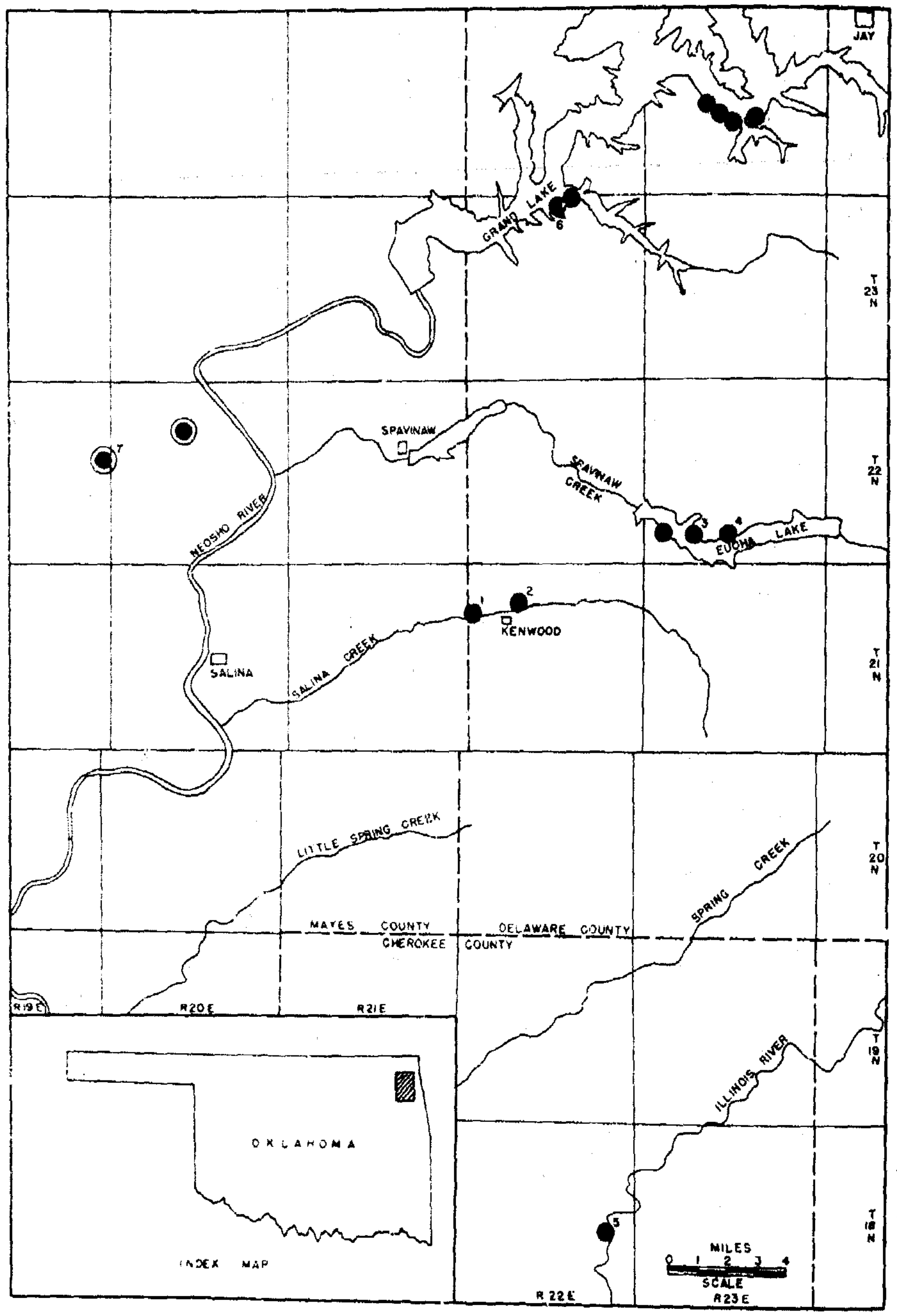

FIG. 1.—Map of area in northeast Oklahoma showing location of exposed bioherms in Boone formation. Solid dark circles indicate locations of bioherms in St. Joe member of Boone formation, and dark circles surrounded by an additional circular line indicate locations of bioherms in Keokuk member. Numbers adjacent to circles refer to descriptions of bioherms in text.

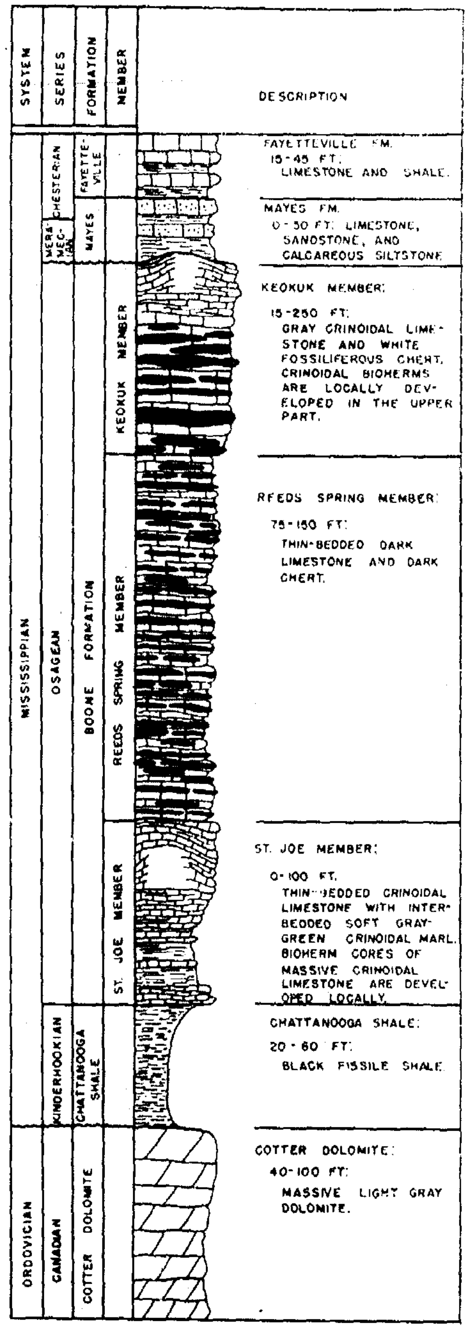

FIG. 2.—Columnar diagram showing lithologic character and stratigraphic relations of Boone formation in northeast Oklahoma.

core consisting of a lenticular mass of non-bedded crinoidal limestone which is surrounded by thin-bedded, steeply dipping crinoidal limestones. Some of the thin-bedded limestones are interfingered with the massive core; others are deflected underneath it or arched over it. Both massive and thin-bedded limestones consist of fine to coarse crinoidal material. Near the bioherms, very large crinoid-stem fragments are common.

The locations of twelve exposed bioherms in the St. Joe member are shown in Figure 1. Six of them correspondingly numbered in Figure 1, are here described.

1. *Bioherm complex west of Kenwood.*—A striking bioherm complex is exposed in the north bluff of Salina Creek about 1½ miles west of Kenwood in Sec.

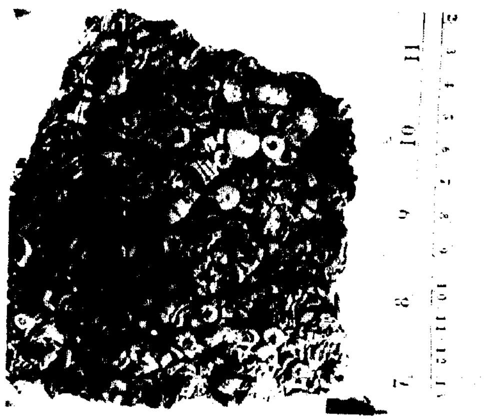

FIG. 3.—Coarse crinoidal limestone typical of that in bioherms in St. Joe member of Boone formation. Button-like crinoid-stem plates are disarticulated, although otherwise well preserved and showing little abrasion. Ruler at side gives scale in inches and centimeters.

7, T. 21 N., R. 22 E., and Sec. 12, T. 21 N., R. 21 E. At this locality, the bluff extends east-west for about ¾ mile, exposing the St. Joe member in two places which are separated by a gap of about 1,500 feet (Fig. 5). The eastern exposure (Sec. B, Fig. 5) reveals a bioherm core of massive crinoidal limestone which is surrounded by steeply dipping, thin-bedded limestones (Fig. 4). The massive core is about 35 feet thick and 500 feet wide, and tapers toward its edges where it interfingers with thin-bedded limestones. The thin-bedded limestones dip relatively steeply for some distance from the core. Just west of the massive core, the thin beds dip from 20° to 45°, forming giant cross-beds which persist for about 400 feet beyond the core. On the other side of the core, toward the east, the transition to thin-bedded limestones is much more gradual and the dips are much less. The thin-bedded limestones which pass over the core are arched upward to form a gentle anticline.

The western exposure is portrayed in the upper section (A) of Figure 5.

Two elongate massive cores are exposed here, one core lapping over the other in shingle-like fashion. The cores are 20–25 feet thick and taper sharply toward their margins where they grade abruptly into undulating, thin-bedded limestones. The thin-bedded limestones which pass under and over the massive cores are warped and deflected by the presence of cores, forming a localized irregular anticline.

2. *Bioherm northeast of Kenwood.* Perhaps the most striking of the exposed St. Joe bioherms is revealed in the bluffs along Salina Creek, in Sec. 8, T. 21 N., R. 22 E. This bioherm consists of a large asymmetrical lens of massive crinoidal

FIG. 4.—Massive bioherm core which interfingers with steeply dipping flank beds. Exposure (No. 1, Fig. 1) in north bluff of Salina Creek, 1½ miles west of Kenwood in Sec. 7, T. 21 N., R. 22 E.; part of larger bioherm complex (Fig. 5).

limestone which is surrounded by thin-bedded crinoidal limestones (Figs. 6 and 7). The thin-bedded limestones interfinger with the core, and are also deflected around the core. At the western edge of the core, the transition to thin-bedded limestones is abrupt, but at the eastern edge, the transition is less distinct, with two long tails of massive limestone projecting into thin-bedded limestone for about 100 feet. The thin-bedded limestones which pass over the core are arched upward to form a pronounced local anticline.

Both the massive and thin-bedded limestone at this bioherm are exceptionally coarse. Parts of crinoid stems as much as 8 inches long and 1¼ inches in diameter are common, and much of the rock consists of crinoid-stem plates which have been separated from each other but which are very little abraded (Fig. 3).

3. *Bioherm at Allens Cove on Eucha Lake.* Several striking bioherms in the St. Joe member are exposed in the high bluffs which bound Eucha Lake. The largest bioherm is located at the mouth of Allen Cove in Sec. 32, T. 22 N., R. 23 E. This bioherm consists of a core of massive crinoidal limestone which is surrounded by steeply dipping thin-bedded crinoidal limestones (Fig. 9). Although the dips are steepest near the core, they persist for distances of more than 400 feet on either side of the core. The bioherm has also affected the attitude of beds which pass over the core, for they are arched in a very gentle anticline.

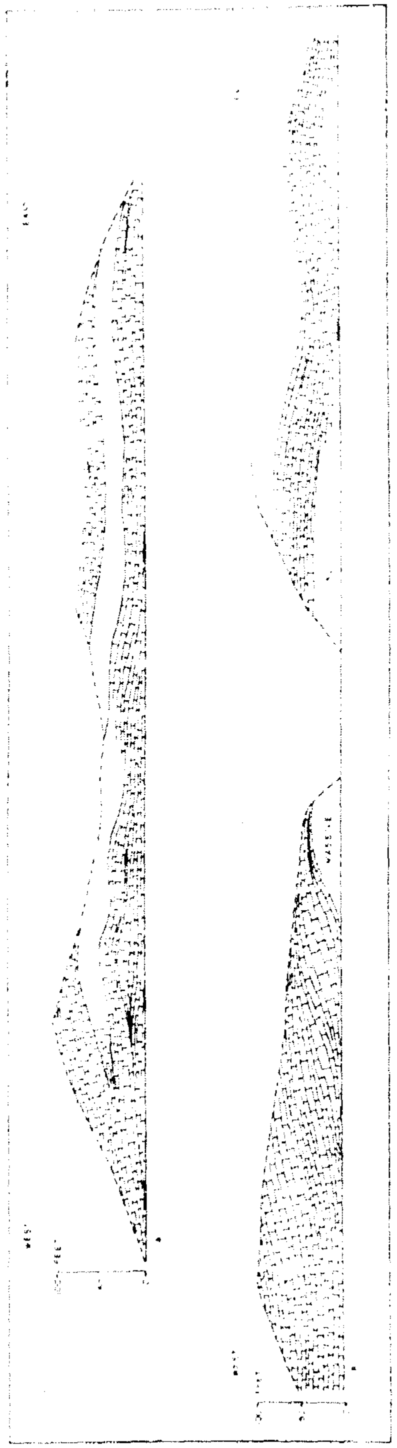

FIG. 5.—St. Joe bioherm complex in north bluff of Salina Creek 1½ miles west of Kenwood (Sec. 7, T. 21 N., R. 22 E., and Sec. 12, T. 21 N., R. 21 E.). The upper and lower cross sections (A, B) are separated by interval of about 1,500 feet in which there are few rock exposures. Dashed lines outline exposed parts of St. Joe member. Vertical and horizontal scales the same. Figure 4 is photograph of west end of massive bioherm core shown in sec. B, Fig. 5.

FIG. 6.—St. Joe bioherm complex (No. 2, Fig. 1) exposed in bluff ½ mile northeast of Kenwood in Sec. 8, T. 21 N., R. 22 E. Lens-shaped massive bioherm core in right part of picture is surrounded by bedded limestones draped around it. This bioherm complex is also shown in Figure 7.

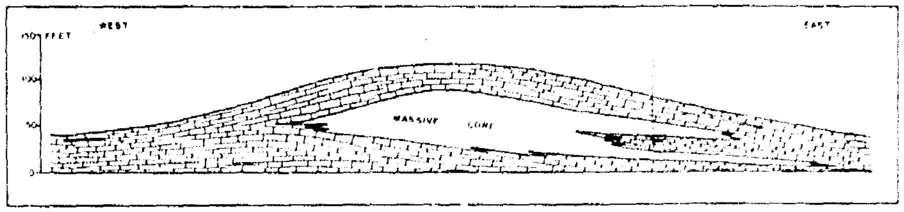

FIG. 7. St. Joe bioherm complex ½ mile northeast of Kenwood (also shown in Figure 6) in which massive core interfingers with thin-bedded limestones.

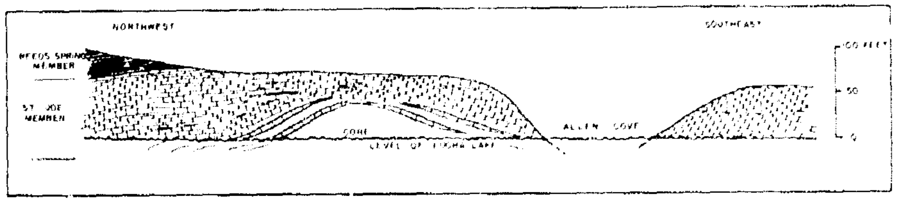

FIG. 8.—Bioherm complex (No. 3, Fig. 1) along north bluff of Eucha Lake in Sec. 32, T. 22 N., R. 23 E. Massive bioherm core flanked by steeply dipping limestone beds which are thinned and truncated under other bedded limestones. Top of bluff indicated by lines bounding upper part of cross section.

4. *Small bioherm on north bluff of Eucha Lake.* A very small bioherm occurs high up on the north bluff of Eucha Lake in Sec. 33, T. 22 N., R. 23 E. It consists of a core of massive crinoidal limestone which is thicker than the adjacent thin-bedded limestone into which it grades. The thin-bedded limestones which

FIG. 9.—Small "swollen" bioherm core (No. 4, Fig. 1) in upper part of St. Joe member on north bluff of Eucha Lake in Sec. 33, T. 22 N., R. 23 E. Thin-bedded limestones interfinger with core and are draped around it.

pass under and over the massive core are very gently draped or warped around the core (Fig. 9).

5. *Bioherm in west bluffs of Illinois River.* One of the largest bioherms exposed in northeast Oklahoma occurs in the west bluffs of the Illinois River, about 10 miles north-northeast of Tahlequah, in Secs. 23 and 24, T. 18 N., R. 22 E. This bioherm consists of a core of crinoidal limestone which undu[illegible]es in thickness in an irregular manner (Fig. 10). The core is surrounded by and interfingers with thin-bedded crinoidal limestones. It was observed that the massive core occurs only where the St. Joe member is thickest. Toward the south and north, where the St. Joe member thins, the massive core is no longer present. The St. Joe member pinches out completely ½ mile north of the massive core, suggesting that the mere existence of the St. Joe member at this locality is governed by the bioherm's presence.

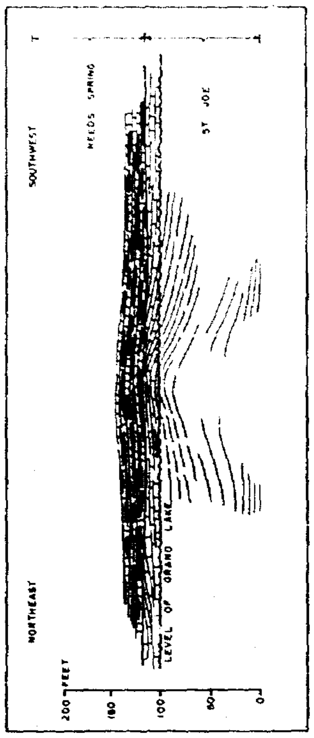

FIG. 12.—Cross section through bioherm in Sec. 4, T. 23 N., R. 22 E. Bioherm caused overlying beds to be thinned and arched upward (shown also in Fig. 11).

6. *Bioherms along Grand Lake.*—At least six bioherms are revealed in the bluffs along the south side of Grand Lake. The bioherms themselves are either wholly or partially submerged under the level of Grand Lake. However, the location of each bioherm is strikingly marked by the warping of the [illegible]rata which are exposed over the bioherms and remain above the level of the lake. Figures 11 and 12 illustrate the appearance of a typical bioherm which has had a marked effect in warping overlying strata. This bioherm is located in Sec. 4, T. 23 N., R. 22 E., and is largely submerged beneath the lake. The strata which pass over the bioherm consist of beds in the upper part of the St. Joe member and in the lower part of the Reeds Spring member. The upper St. Joe beds dip as steeply as 10°–15°, and are generally thinnest over the crest of the bioherm. Some of the more steeply dipping beds are truncated and are overlain in turn by less steeply dipping beds. These features suggest that the presence of the bioherm caused a topographic high to persist for a considerable length of time after the bioherm had been buried under younger strata.

FIG. 11.—Draping and truncation of beds over bioherm (No. 6, Fig. 1) now submerged beneath level of Grand Lake in Sec. 4, T. 23 N., R. 22 W. Although obscured, bioherm is readily indicated by effect on overlying beds.

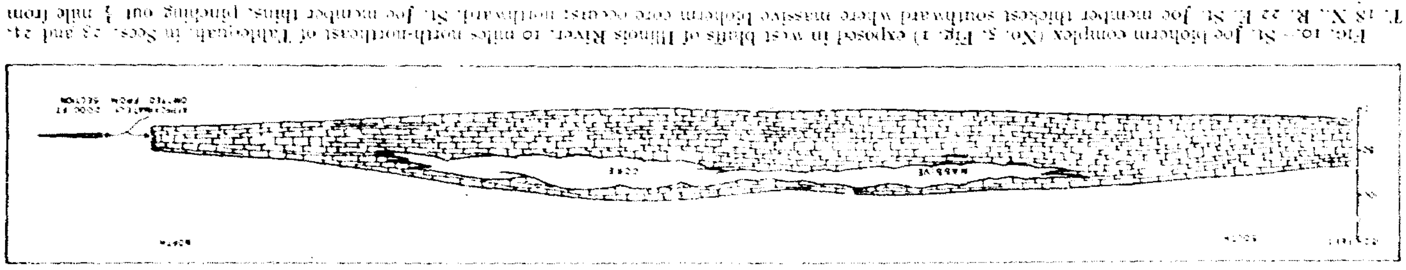

FIG. 10.—St. Joe bioherm complex (No. 5, Fig. 1) exposed in west bluffs of Illinois River, 10 miles north-northeast of Tahlequah, in Secs. 23 and 24, T. 18 N., R. 22 E. St. Joe member thickest southward where massive bioherm core occurs; northward, St. Joe member thins, pinching out ½ mile from massive core.

BIOHERMS OCCURRING IN KEOKUK MEMBER

Although the most numerous and conspicuous bioherms of the Boone formation occur in the St. Joe member, there are at least two small exposed crinoidal bioherms in the Keokuk member. The two known Keokuk bioherms occur on the prairies west of the Neosho River, and are revealed because they form resistant mounds which protrude through poorly resistant younger Mississippian strata. One of the bioherms (No. 7, Fig. 1) occurs in the SE. ¼ of Sec. 13, T. 22 N., R. 19 E., and is shown in Figure 13. The bioherm forms a mound about 300 feet in diameter which rises about 15 feet above the general level of the surrounding prairie. The mound is created by the massive core of the bioherm, which

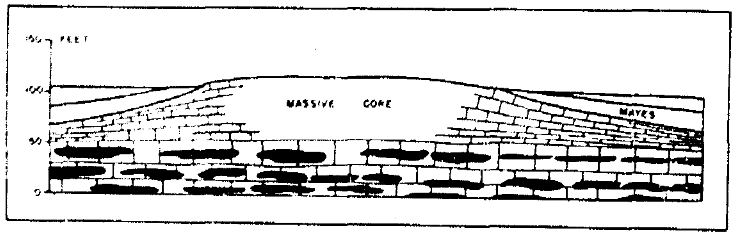

FIG. 13.—Cross section through bioherm (No. 7, Fig. 1) in Keokuk member of Boone formation in SE. ¼ of Sec. 13, T. 22 N., R. 19 E. Bioherm consists of massive core of coarse crinoidal limestone protruding through younger beds. Massive core forms topographic mound from which younger beds dip radially. Dark patches represent chert.

consists of very coarse crinoidal limestone. Some parts of crinoid stems are as large as 8 inches long and 1¼ inches in diameter, indicating that individual crinoids of exceptional size were among those which created the bioherm. The massive core appears to thin abruptly at its edges before interfingering with beds which are not exposed. The bioherm must have stood as a submarine topographic prominence for some time after it was formed, for the younger strata are thinned and are warped upward where they pass over the core.

ORIGIN OF BIOHERMS

The question of the origin of the bioherms of the Boone formation is closely related to the problem of the origin of the widespread crinoidal limestones in which the bioherms occur. It is obvious that both crinoidal bioherms and crinoidal limestones have been formed from vast numbers of crinoids which flourished on the floor of a clear shallow sea. The crinoids, because of their calcareous skeletons, were capable of providing large quantities of fragmental material to create the limestones. Each crinoid consisted of a calyx and its appendages, and a long flexible stem by which the organism was attached to the sea floor. The skeletal plates of the stem and calyx, which composed the great bulk of the organism, were bound together by ligaments. Upon the death of a crinoid, the ligaments were relaxed and the skeletal plates released so that they could be strewn about by waves and currents before coming to rest.

Since the bioherms are so closely associated with the widespread crinoidal limestones, it is desirable to contrast in detail the differences between the bioherms and the thin-bedded limestones. The structural and lithologic differences which bear on an interpretation of origin are here tabulated.

Bioherms	*Widespread, Thin-Bedded Limestones*
1. The bioherm cores consist of massive limestones which lack bedding planes	1. Uniformly thin-bedded
2. The limestones tend to thicken abruptly in the vicinity of massive cores	2. Variations in thickness are gradual
3. Thin-bedded limestones on the flanks of bioherms commonly dip steeply; dips up to 45° are common	3. The beds are essentially flat; few dips exceed 5°
4. The largest crinoid-stem fragments are 1¼ inches in diameter	4. The largest crinoid-stem fragments are generally smaller than those near the bioherms
5. Much of the limestone is composed of crinoid-stem plates which are separated from each other but not otherwise fragmented or abraded (Fig. 3)	5. Crinoid-stem plates are generally fragmented and abraded

The first of these differences, massive versus thin-bedded limestones, suggests that the massive bioherm cores were formed as a result of continuous and unvarying deposition which provided little opportunity for bedding planes to be developed. The thin-bedded limestones, on the other hand, appear to have been formed under conditions in which deposition was interrupted from time to time, thus creating bedding surfaces. Consequently, it appears that the growth and accumulation of crinoids were more continuously favorable at the bioherms rather than on the surrounding sea floor. This greater favorability for growth is also indicated by the greater thickness of the thin-bedded limestones in the proximity of bioherms, as in the St. Joe member along the Illinois River (Fig. 10). Here, the St. Joe member is thickest in the vicinity of the massive bioherm core and pinches out north of the core.

The more rapid and continuous growth and accumulation of crinoids near bioherms caused the bioherms to take the form of elevated mounds (Fig. 14). The mounds appear to have risen high enough above the general level of the sea floor to provide sloping sides on which bedded limestones were deposited. The evidence for this lies in the relatively steep dips of thin-bedded limestones which interfinger with the massive limestone cores. Although the dips have doubtlessly been accentuated by differential compaction, much of the dip is initial, stemming from the time when the beds were deposited, and is a rough measure of the angle of slope during deposition.

Another point of evidence which suggests that the bioherms were more favorable for the growth of crinoids is the larger size of the crinoid stems which are found in bioherms. Some of the stems are 1¼ inches in diameter, indicating that the bioherms fostered the growth of giant crinoids. Thus, it is clear that the bioherms owe their origin to factors which accentuated the growth of crinoids.

Although these factors remain largely unknown, it is suspected that the elevated nature of the bioherms and their closer proximity to the surface of the sea encouraged the growth of crinoids.

The question arises whether the bioherms should be considered as organic reefs. To qualify as reefs, it must be shown that (1) the elevated bioherms projected upward into shallow, turbulent water where they would form reefs in the mariner's sense, lying close to the surface of the water. To be considered as organic reefs, it must be shown that (2) the bioherms were strengthend and partly formed by organisms capable of building and raising a resistant structure into near-surface, turbulent waters.

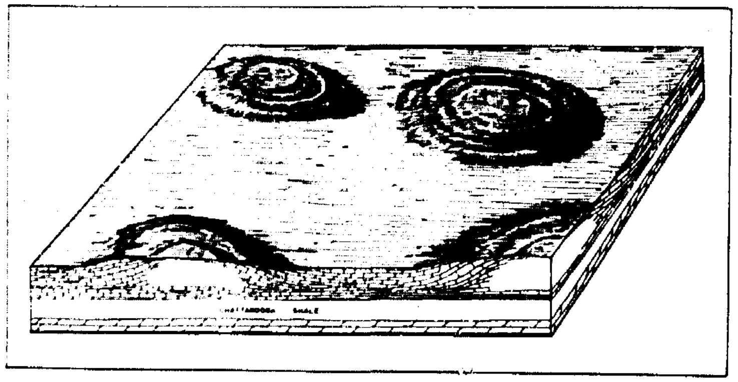

FIG. 14.—Schematic block diagram illustrating development of St. Joe bioherms. Massive bioherm cores interpreted as elevated, reef-like accumulations of crinoidal debris. Areal shape of bioherms was not necessarily round as shown here, but may have been irregular. Sides of block diagram are approximately ½ mile long.

The evidence to satisfy the first qualification, that the bioherms were elevated into shallow water, is indirect. It is obvious that the bioherms were elevated above the sea floor, but the actual depth of water over them is, of course, unknown. However, evidence that the sea was shallow is provided by the enormous quantities of bioclastic debris which comprise the crinoidal limestone. The crinoidal debris must have been produced in fairly shallow water, where strong wave action provided a mechanism for fragmenting and distributing the crinoid skeletal plates. Therefore, the bioherms which rose above the floor of the shallow sea would form reefs in the mariner's sense.

Evidence to show that the bioherms formed wave-resistant organic structures, satisfying the second qualification, is found in the steep dips of beds flanking the massive cores. These dips, which are as great as 45°, are assumed to represent initial dips, which originated when the crinoidal debris was deposited on steep slopes. The existence of steep slopes implies that deposits laid upon them must have been coherent, for otherwise, the loose fragmental material would have moved down the slopes until coming to the angle of repose, which would certainly be much less than 45°. Therefore, a sediment-binding agent is postulated to have been necessary to permit the crinoidal debris to persist on steep slopes. There is little direct evidence of a binding agent, but it is probable that small quantities of a cementing material, such as inorganically precipitated calcium carbonate or calcareous algae, were capable of transforming the loose crinoidal debris into firm rock. Such a binding agent would have imparted wave-resistant qualities to the bioherm rock, thus creating a true organic reef. A binding agent would also tend to preserve the easily disintegrated crinoid plates from further destruction, perhaps accounting for less abrasion of skeletal plates in the bioherms as compared with those in widespread, thin-bedded limestones.

In conclusion, it appears the the bioherms were formed as resistant mounds of crinoidal debris. Crinoids flourished on both the mounds and the surrounding sea floor, but the growth and accumulation of crinoids were accentuated at the bioherms, causing the bioherms to be elevated above the general level of the sea floor. The steeply sloping sides of the bioherms were maintained because the crinoidal debris was probably bound together by an unrecognized sediment-binding agent, perhaps calcareous algae or inorganically precipitated calcium carbonate. The bioherm sites persisted as topographic highs for a considerable length of time after growth ceased, for they caused overlying beds to thin and to be draped over the bioherms. Differential compaction probably caused the dips to be accentuated, ultimately producing small anticlines over the massive bioherm cores.

SUMMARY

1. The Boone formation, of lower-middle Mississippian age, is readily separated into three members in northeast Oklahoma (Fig. 2). The St. Joe, or lower member, consists of thin-bedded crinoidal limestones in which crinoidal bioherms occur locally. The Reeds Spring, or middle member, consists of thin alternating beds of dark limestone and chert and is lacking in bioherms. The Keokuk, or upper member, consists of limestone and chert and contains bioherms in its extreme upper part at one general locality.

2. Exposed bioherms are most numerous in the St. Joe member (Fig. 1) where they are revealed in bluffs which lie adjacent to stream valleys that are carved into a Boone-capped southwestward extension of the Ozark Plateau. Exposed bioherms in the Keokuk member are much fewer, and are revealed as small mounds. The mounds rise above a level prairie produced by non-resistant younger Mississippian strata which crop out west of the Boone plateau. Both the St. Joe and the Keokuk members undoubtedly contain many more bioherms which are not exposed.

3. The bioherms range greatly in size and shape (Figs. 4–10). Each bioherm consists of a lens-shaped core of massive crinoidal limestone which is surrounded by and interfingers with thin-bedded limestones. Both the core and the thin-bedded limestones are composed almost exclusively of fragments of crinoid-stem

plates. The massive cores range from 10 to 40 feet in thickness and from 50 to 1,000 feet in width. The thin-bedded limestones commonly dip steeply away from the massive cores.

4. The bioherms are interpreted as having been formed under conditions which accentuated the growth and accumulation of crinoids. Where the growth of crinoids was continuous and unvarying, the massive or non-bedded cores were formed. Where deposition was interrupted from time to time, the thin-bedded limestones were formed. More favorable growth conditions at the site of bioherms allowed the crinoids to build mound-shaped prominences which rose as much as 50 feet above the general level of the sea floor (Fig. 14). The mounds had steeply sloping sides on which beds of crinoidal debris accumulated. A sediment-binding agent, such as inorganically precipitated calcium carbonate or calcareous algae, is postulated to have been necessary to make the beds of crinoid fragments sufficiently firm to persist on such steep slopes. Such a sediment-binding agent probably imparted a considerable degree of wave resistance to the bioherm.

5. The bioherm can be considered as organic reefs because they formed wave-resistant structures which were elevated above the floor of a shallow sea.

6. The strata which pass over the bioherms are commonly warped upward to form local anticlines. Some of the warping is probably due to later differential compaction, but it appears that much of it was produced during deposition over a submarine topographic high.

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BASAL CLAIBORNE OF TEXAS, RECORD OF APPALACHIAN TECTONISM DURING EOCENE[1]

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ABSTRACT

The Carrizo formation and the superjacent Newby member of the Reklaw formation (Eocene, Claiborne group) are lithologically similar sandstone units which crop out in Bastrop County, central Texas.

The basal Carrizo is a strongly cross-bedded, poorly to moderately sorted, granular medium sandstone; it grades upward into moderately to well sorted fine sandstone, very fine sandy siltstone, and silty carbonaceous shale. The average lower Newby sample is a moderately to well sorted fine sandstone, and the middle Newby section includes clayey siltstone and carbonaceous shale beds which grade upward into cross-bedded, glauconitic sandstone lenticularly laminated with chocolate shale.

Both Carrizo and Newby units are texturally submature to mature chert-bearing subgraywackes containing 65–75 per cent quartz, 5–10 per cent potash feldspar, 5–25 per cent phyllite, slate and metaquartzite fragments, and 5–10 per cent chert; there is little or no clay or silt matrix. The non-opaque heavy-mineral fraction consists of subangular kyanite and staurolite, angular and rounded zircon and tourmaline, and smaller amounts of garnet and rutile. Glauconite and authigenic feldspar are common in the upper, more marine part of the section.

Most of the Carrizo and Newby detritus in Texas was originally derived from erosion of parts of the Ouachita foldbelt and particularly from uplift of the southern Appalachian Mountains—not from the Laramide orogenic belt as has been previously supposed. Sources north and west contributed reworked sedimentary material, but volcanic quartz and some feldspar were probably transported to the area of Bastrop County from a local source on the south.

In Texas the Carrizo formation rests disconformably on the Wilcox (Eocene), and is placed in the Claiborne group. On the Sabine uplift and eastward, the Carrizo reportedly lies conformably on the Wilcox, and is considered the uppermost formation of the Wilcox group. This apparently local disconformity was probably produced by uplift and erosion of an uppermost Wilcox beach sand in south and central Texas. Erosion of this beach produced the subangular, highly polished grains which were reworked to form a large part of the Carrizo and Newby sandstones in Bastrop County. The region of maximum uplift may exist as a subsurface Wilcox high between Bastrop County and the Rio Grande embayment.

On the basis of this study, augmented by petrographic examination of scattered samples throughout the rest of Texas Eocene sediments, a large-scale uplift of the southern Appalachian area is believed to have begun during the Midway or Sabine age and culminated during deposition of the great volume of upper Wilcox and lower Claiborne sediments in the western Gulf Coast.

INTRODUCTION

During middle Eocene time, large amounts of sand and mud were deposited in variety of near-strand environments along the East Texas and Rio Grande structural embayments. The closely related depositional environments impressed on these sediments such similar aspects that in many places it is difficult to separate and correctly identify the various stratigraphic units, particularly where lack of exposure makes it impossible to establish contiguity. Two similar sandstones in this stratigraphic sequence are the Carrizo formation and the superjacent Newby member of the Reklaw formation, the lowermost units of the Claiborne group in Texas. The Carrizo is thought to have been deposited under fluvial

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[2] The University of Texas. This study formed part of a thesis submitted by Todd in partial fulfillment of the requirements for the degree of Master of Arts. The thesis was supervised by Folk; H. B. Stenzel and S. E. Clabaugh also served on the thesis committee and offered helpful suggestions. The writers are indebted to R. K. DeFord for reading the final manuscript.

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conditions, not far from the shore line, whereas the Newby is believed to be near-shore marine (Plummer, 1933). As a result, these sandstones provide an admirable opportunity to study the effect of differing environments of deposition on the sedimentary characteristics of two closely related rocks.

A detailed thin-section study was made of grid-controlled rock samples from a carefully measured composite section of these sandstones in southern Bastrop County, central Texas (Todd, 1956), (Fig. 1). One aspect of this study—which

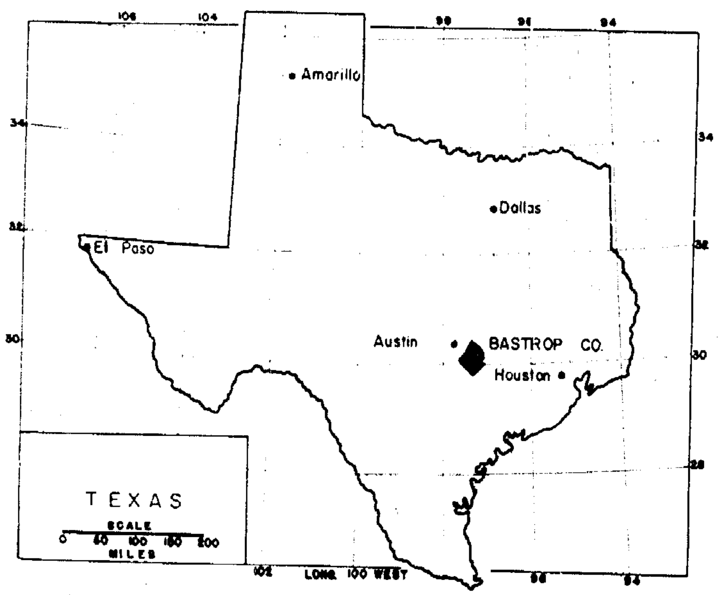

FIG. 1.—Index map, showing location of Bastrop County, Texas.

also included sieve and pipette analysis, shape, and surface-feature examination—was the development of hypotheses concerning the source of the detritus making up the Carrizo and Newby units.

STRATIGRAPHY

The Carrizo and Newby sandstones crop out across Bastrop County as a northeast-trending strip, averaging 3 miles wide. The strike is approximately N. 23° E., and the dip averages 95 feet per mile southeast.

CARRIZO FORMATION

A typical sample of lower Carrizo sandstone may be described as a crumbly to friable, light brown (5YR6/4–5YR5/6)[4] to gray (5YR6/1), cross-bedded,

[4] Color designations after E. N. Goddard *et al.* (1948), *Rock Color Chart*, National Research Council.

cherty, micaceous, feldspathic, moderately sorted, subangular, predominatly medium-grained sand. Two-thirds of the samples analyzed had mean grain diameters between 0.25 ϕ (0.84 mm.) and 2.25 ϕ (0.21 mm.) with an average figure of 1.25 ϕ (0.42 mm.). Most sorting values (in terms of σ) range between 0.50–1.05 ϕ. The over-all outcrop color varies from bright red near upper soil zones or underneath ferruginous Pleistocene terrace gravels, to white in deep, fresh stream cuts; commonly it is some shade of pink or pale yellowish white. Near the unconformable Wilcox contact, the Carrizo usually contains light gray boulders of Wilcox silty shale up to 3 or 4 feet in diameter.

Locally the lower Carrizo is a very hard, black to maroon (5R2/2–5R2/6), hematite-cemented, poorly sorted, granular coarse-grained sandstone suitable for road metal. It is evident that the hematite cement is secondary, but whether it has been derived from the overlying Newby, from well cemented Pleistocene terrace deposits, or from some other source is not known. Sedimentary structures such as fossil stream channels and sand bars (Ridley, 1955, p. 30) are not uncommon. The direction and magnitude of cross-bed dip were measured at ten localities. These measurements yielded an average dip direction of S. 45° E. with maximum variation of 90° on either side. Thus the immediate source of the lower Carrizo sediments was at the north, northwest, or west.

The lower Carrizo grades upward into lenticularly interlaminated beds of well sorted fine sandstone, very fine sandy siltstone, and silty carbonaceous shale.

In Bastrop County the Carrizo formation ranges in thickness from 70 to 150 feet. It rests with marked disconformity on the Wilcox group; the elevation of the contact varies as much as 50 feet or more because of the rough topographic surface developed on the Wilcox before the Carrizo was laid down.

NEWBY MEMBER, REKLAW FORMATION

The lower Newby is commonly hard, reddish yellow (10YR5/5), obscurely bedded, well sorted, sparsely glauconitic, subangular, fine-grained sandstone. Extremely iron-rich zones containing rounded ironstone concretions, strange pipe-like forms, as well as ferruginous sheets alternating with sandstone stringers, are not uncommon.

The upper Newby varies somewhat in composition from place to place. For example, one exposure is made up of a series of tough, fissile, plastic when wet, gray-weathering (5PB7/2–N7), chocolate-brown (5YR4/1?), silty shales and thinly interbedded siltstones. Elsewhere an approximately equivalent section is composed of friable, alternating gray and yellow-banded, finely cross-bedded, feldspathic, slightly glauconitic, well sorted, fine-grained sand. A few concretions of calcite-cemented sandstone are present at the top of the section.

The over-all mean size of Newby detritus is 2.42 ϕ (0.185 mm.), and two-thirds of the samples have mean grain diameters between 1.99 ϕ (0.25 mm.) and 2.85 ϕ (0.14 mm.). Most sorting (σ) values lie between 0.40–0.80 ϕ.

The thickness of the Newby member, unlike the thickness of the Carrizo, does not vary radically from place to place. There is no one outcrop, however, where a complete section can be measured. Correlation of a composite section yields a total thickness of about 130 feet.

The Newby sandstone rests disconformably on the Carrizo formation. At one outcrop the uneven surface of unconformity is cut in a dark, reworked, bedded shale layer which contains silty shale pebbles. This uneven, contorted shale is overlain by coarse red sandstone which contains silty shale pebbles to a height of 0.5 foot above the contact. In other places pipes of red sandstone penetrate 0.5 foot into the Carrizo. These were probably made by burrowing animals in the floor of the Newby sea. At most exposures the Newby is apparently overlain conformably by the Marquez lignitic, pyritic shale. In many localities the Newby grades into the Marquez through a 5–20 foot section of interbedded very fine sand, silt, and chocolate-colored clay shale. But in other areas the contact between a medium- to fine-grained glauconitic sand containing thin chocolate-colored shale laminae, and a tough, thinly bedded, copiapitic, lignitic, silty clay is sharp and easily recognized. Five miles northwest of Smithville on Little Alum Creek there is an exposure of a local but important Newby-Marquez marine disconformity. This disconformity is marked by a thin zone of shale and subangular sandstone pebbles set in a glauconitic, sandy matrix which contains upright corals and other marine fossils. Some of the pebbles are hard, red, medium- to coarse-grained sandstone (typical of the lower Newby) up to 3 inches in diameter. The presence of pebbles of lower Newby at the base of the Marquez indicates that the disconformity must represent a considerable interval of erosion in some areas.

MINERALOGY

INTRODUCTION

Description of thirty-one thin sections from the Carrizo and Newby revealed little difference in their terrigenous mineral composition (Fig. 2) except that the Newby contains a smaller amount of metamorphic rock fragments because of increased abrasion in the nearshore marine environment in which it accumulated. Apparently both sands were derived from the same combination of sources; hence, are lumped together in the ensuing discussion.

Based on Folk's (1954) classification, both Carrizo and Newby sands are texturally submature to mature chert-bearing subgraywackes because they lack a clay matrix, are moderately to well sorted and contain 5–25 per cent metamorphic rock fragments and micas (Fig. 9). Point counts of 100 grains per slide yielded the following averages: subangular common quartz, 65 per cent; well rounded, reworked sedimentary quartz, 3 per cent; vein quartz, 2 per cent; volcanic quartz phenocrysts, much less than 1 per cent; chert, 5 per cent; potash feldspar, 8 per cent; muscovite, trace; metaquartzite, 10 per cent; metamorphic rock fragments, 7 per cent; and clay, 2 per cent.

Chemically precipitated minerals are only locally present in the Carrizo and

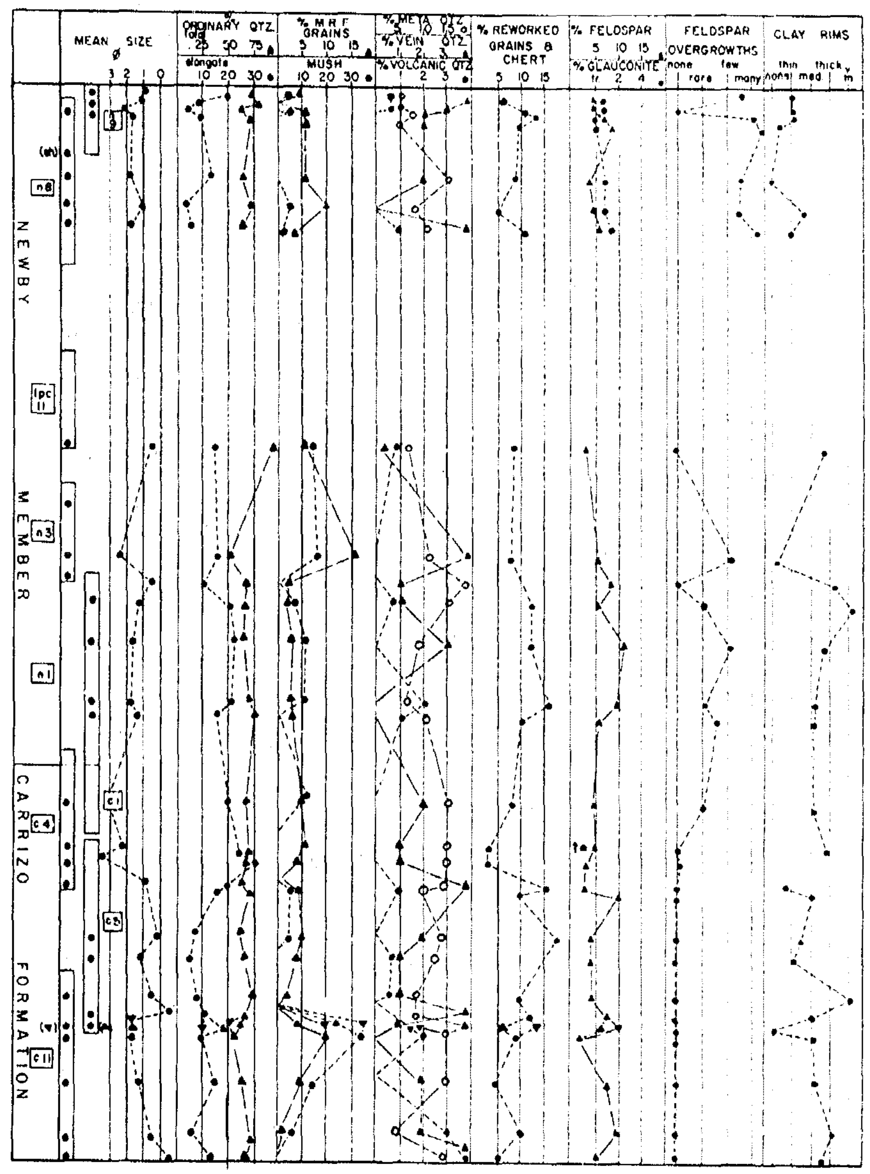

FIG. 2.—Vertical variations in mineralogy, Carrizo and Newby sandstones. Boxes on left refer to specific measured sections (c4, n3, *etc.*), shown in proper stratigraphic position. Vertical scale is 1 inch equals 34.5 feet. Significance of various symbols in body of graph (circles, triangles, *etc.*) is indicated by legend at top for each constituent.

Newby sandstones. Hematite, glauconite, authigenic feldspar overgrowths, and authigenic kaolinite pore-fillings together constitute about one per cent.

MAIN CONSTITUENTS

Common quartz, termed "plutonic" by Krynine (1946), is characterized by single grains with straight to slightly undulose extinction, with or without microlites and small quantities of bubbles. Most grains are subangular but they range from subround to very angular flake-shaped chips. Under the binocular microscope more than half of the grains exhibit a high surface polish.

Reworked grains of very well rounded, highly spherical common quartz (Fig. 3) form 2–5 per cent of the samples and are sharply differentiated from the dominant subangular quartz. Under the binocular they are highly frosted. The size of these grains is restricted to 0.15–0.30 mm.; hence, this must have been the grain size of the supermature Cretaceous or Cambro-Ordovician orthoquartzitic sandstones whence they were derived. Some of the rounded grains possess reworked quartz overgrowths, most of which show crystal faces, but some are fractured or abraded. The lack of calcite inclusions in the overgrowths as well as the presence of crystal faces indicates derivation from a weakly cemented sandstone rather than a limestone. No indigenous authigenic quartz occurs in the Carrizo or Newby sands of Bastrop County.

Volcanic quartz phenocrysts (Fig. 4) occur chiefly in the lower Carrizo, where they constitute 1–4 per cent of the grains, but in the rest of the section they form much less than 1 per cent. These equant, straight-extinguishing grains contain almost no inclusions and are characterized by the presence of one to several geometrically straight borders, many of which have well developed crystal outlines. In the binocular they appear as very highly polished, water-clear, doubly terminated hexagonal dipyramids, lacking prism faces. Some of the phenocrysts are embayed and most have rounded corners due to corrosion in the parent lava, but they show no evidence of abrasion; crystals range from 0.25 mm. to 2 mm. long. Phenocrysts with adamantine luster occur abundantly in loose gully wash derived from lower Carrizo exposures. Vein quartz (Fig. 5), loaded with liquid-filled bubbles, comprises 4 per cent of the grains. Stretched metaquartzite (Fig. 6) is abundant in these slides, averaging 7 per cent and ranging from 5 to 15 per cent. The subangular grains are composite with sutured boundaries and undulose extinction. These are included as a constituent of the "M" pole for compositional classification (Folk, 1954), because they are really fragments of metamorphic rock. Recrystallized metamorphic quartz (3 per cent) was identified by composite grain habit, with straight boundaries and straight extinction.

Subangular grains of detrital chert (5–10 per cent) are visible as black to brown specks in hand specimens; almost all are the microcrystalline variety.

The feldspar (5–10 per cent) is subangular and more than half shows microcline twinning; the remainder is untwinned and identified as orthoclase. Only one or two fragments of plagioclase were seen among more than 500 feldspar

FIG. 3

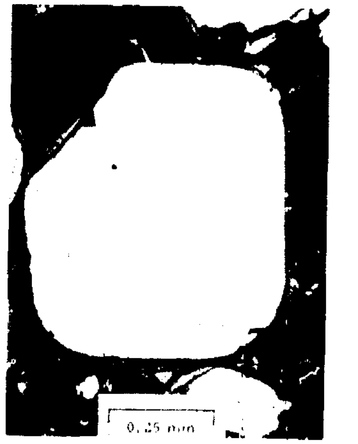

FIG. 4

FIG. 5

FIG. 6

FIG. 3.—Rounded grain of common quartz with slightly abraded overgrowth (crossed nicols). Grains have been reworked from older supermature orthoquartzitic sandstones, probably Cretaceous or Cambro-Ordovician.

FIG. 4.—Volcanic quartz phenocryst with straight boundaries, corrosion-rounded corners and no inclusions (crossed nicols).

FIG. 5.—Vein quartz with abundant vacuoles (plain light). Dark areas surrounding grain are hematite-stained clay rims infiltrated during outcrop weathering.

FIG. 6.—Stretched metaquartzite, composite grain with sutured internal boundaries and strong undulose extinction (crossed nicols).

grains identified, but one sand-size fragment of aphanitic volcanic rock was observed in a calcite-cemented concretion in the uppermost Newby sand.

Most feldspar grains are fresh, but three types of alteration have been observed. The most common form is that of cavernous solution (Miller, 1955) which affects one-fourth of the microcline but three-fourths of the orthoclase. Clean, irregular holes, some nearly as large as the detrital grain itself, have been dissolved in the centers of the grains, and are now filled with Canada balsam. This type of alteration is believed to have been effected by migrating fluids after deposition because even the slightest transport would have destroyed the skeletal feldspars. Because feldspar overgrowths bridge some of the solution holes and the overgrowths are unaltered, cavernous solution probably occurred prior to or simultaneously with formation of overgrowths; this relationship also negates outcrop weathering as the cause. The second most important form of alteration is vacuolization or bubbly alteration (Folk, 1955) which appears as "turbid" swarms of minute, brown, liquid-filled vacuoles about one micron in diameter; about one-third of the orthoclase grains are affected, but only rarely is microcline vacuolized. This type of alteration apparently took place before deposition because neighboring grains show wide variance in degree of vacuolization, and many heavily vacuolized detrital feldspar grains are enclosed in perfectly clear and fresh overgrowths. Consequently, vacuolization is interpreted as the result of weathering that proceeded in the soils of the source area under a warm humid climate and moderate relief. Minor kaolinization has taken place, and it usually occurs in sands that have had thick clay rims infiltrated on outcrop weathering. Kaolin within feldspar grains appears as clear shreds or flakes with index slightly above that of feldspar. No sericite or illite alteration was observed.

Overgrowths of untwinned K-feldspar have been identified on both microcline and orthoclase grains. Absent almost throughout the dominantly non-marine Carrizo, overgrowths occur sparsely throughout the lower Newby, but commonly and conspicuously in the more marine upper Newby as small hacksaw projections to thick (.01–.02 mm.) rims showing crystal faces (Fig. 7). All are clear, unabraded and unaltered, hence formed within the sandstones after deposition. Even in such porous and permeable sands, outcrop weathering has not attacked the overgrowths at all.

The presence of authigenic feldspar in the marine Newby and its lack in the subjacent non-marine Carrizo (except in one topmost sample) contributes good evidence on the conditions of origin of this mineral. It would be possible for feldspar to form at three different times: (1) while the sand was on the sea floor or only slightly buried and in connection with relatively free-moving, nearly normal sea water; (2) upon deeper burial of the sand, under the influence of migrating connate waters; or (3) after uncovering of the sands, subjecting them to outcrop weathering or percolation of meteoric waters downdip through these aquifers. Hypotheses (2) and (3) both require that waters travel considerable distances through the sands; although both sands are quite clean and permeable, the Carrizo, being coarser, is a much better aquifer than the Newby (the Carrizo supplies water to many towns in south Texas). Therefore, if hypotheses (2) and (3) were operative, one should expect to find more authigenic feldspar in the more permeable Carrizo. Actually, the reverse is true. Therefore hypothesis (1), that the feldspar formed from sea water very shortly after deposition seems to be

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 7.—Microcline with untwinned overgrowth (crossed nicols).

Fig. 8.—Metamorphic rock fragment, probably high-rank slate, indented by adjacent quartz grain (crossed nicols).

Fig. 9.—Typical "dirty" upper Carrizo sandstone (crossed nicols). Field consists of about 20 per cent slate and phyllite fragments (speckled areas) and 5 per cent potash feldspar; hence, is a subgraywacke. Note angularity of quartz.

Fig. 10.—Banded hematitic clay lining pore space (plain light). This material has infiltrated sand upon outcrop weathering.

most likely, especially since it is most abundant in the more open-marine upper Newby. But here a difficulty arises: once the non-marine Carrizo deposits were submerged under the advancing Newby sea, nothing would prevent intrusion of the sea water into the underlying loose Carrizo sand, because the two formations are in many places in sand-to-sand contact, that is, there is no impermeable clay "diaphragm" between them. Then why did the sea water precipitate feldspar only into the Newby, and not into the now-saturated Carrizo below? The answer may be that precipitation of authigenic feldspar takes place relatively rapidly, in the first few (possibly up to 20) feet below sea floor; perhaps marine waters that soak down deeper lose their capacity to precipitate feldspar either because of lack of free intercirculation with the normal sea water above, because of changes in Eh, pH, *etc.*, or else because the proper ions have been used up by reaction with the sediment in the top few feet.

Metamorphic-rock fragments (Figs. 8, 9) occur as significant components of these samples, and consist chiefly of subround, elongate slate and phyllite grains. Because of their susceptibility to abrasion, the frequency is remarkedly variable and ranges from 0 to 40 per cent, 5–10 per cent being a reasonable average; they are more abundant in the finer, more poorly sorted sands. Most of the fragments show fairly well oriented very fine muscovite, sericite, and finely recrystallized quartz. Metamorphic-rock fragments are more abundant in the Carrizo than in the Newby, probably because the better sorted Newby sand underwent more abrasion. Metamorphic-fragment-rich sands are identifiable in outcrop by the abundance of small specks that look like white flour.

Mica, although conspicuous in outcrop, averages by count much less than one per cent, and is entirely muscovite. Flakes average 0.25 mm. and range up to 1 mm.

Optically, the clay minerals in the slides appear to be illite. The average clay content is about 1 or 2 per cent; hence, the sands are usually quite "clean." In many red sandstone slides, clay with illite-like birefringence occurs as tangentially oriented, hematite-stained rims concentrically wrapped about the detrital grains in crusts up to 0.10 mm. thick (Figs. 5, 10); it has been infiltrated into the sand during outcrop weathering. The clay flakes are deposited on the sand grains parallel with the grain surface. Rarely, authigenic kaolinite or dickite "worms" up to 0.5 mm. long have grown in pore spaces in heavily outcrop-weathered and highly permeable sands.

Glauconite was identified throughout the Newby unit, although in the lower Newby it is rare. The upper Newby contains prominent glauconite in the form of green pellets and reworked silty glauconite hash. In parts of the hard, red, lower Newby, pellets have been completely converted to red or brown opaque iron oxides. Glauconite pellets range from a trace to 3 per cent, but glauconite hash in some places constitutes as much as 10 per cent of a sample.

Red hematite (verified by X-ray) is common throughout both the Carrizo and Newby units but is particularly prominent on Newby outcrops. In southern Bastrop County the basal 10 feet of Newby is persistently very hard and completely cemented with thick black to deep red hematite. Some of the red stain is derived from leaching of overlying Pleistocene gravel, but much of the iron has come from within these Eocene formations. Small oval holes in many hand specimens and altered "pellet ghosts" in thin sections testify to the oxidation of glauconite on outcrop to ferric iron minerals. It is doubtful that all the iron

came from this source, however, as there is not enough glauconite available. The presence of reworked, indurated hematite-cemented Newby pebbles at the local Newby-Marquez disconformity near Smithville indicates that some of the cement formed during Claibornian time, and it may have been directly precipitated from sea water.

HEAVY MINERALS

Heavy minerals make up about 0.15 per cent of the average sample. Opaques include magnetite, ilmenite, leucoxene, hematite, and pyrite, and an unknown resinous honey-colored to brown mineral which averages 15 per cent of the heavy-mineral fraction; it has been tentatively identified as tapiolite.

The non-opaque suite includes staurolite, kyanite, several varieties of zircon and tourmaline, rutile, garnet, and a trace of green hornblende and epidote. Non-opaque minerals average 25 per cent of the total heavy-mineral fraction. No obvious differences were found between the Carrizo suite and the Newby suite; average percentages are shown in Table I.

TABLE I

Mineral	*Per Cent of Non-Opaques*	
Zircon		24 ± 1
1. Euhedral	10	
2. Angular	9 ± 1	
3. Rounded	5	
Tourmaline		18 ± 1
1. Euhedral prisms	9	
2. Angular	7 ± 1	
3. Well rounded	2	
Staurolite		18 ± 1
Kyanite		21 ± 1
Rutile		12 ± 1
Garnet		7 ± 1
Epidote		Trace
Hornblende		Trace
		100

Kyanite exhibits cleavage-controlled form, and in general the corners are angular but grains in the Newby have slightly rounded corners (Fig. 11a). Both kyanite and staurolite are unusually large, ranging up to 0.25 mm. long. The staurolite is deep yellow and the grains are uniformly angular.

Zircon types range from perfectly euhedral crystals (Fig. 11b) to perfectly rounded or angular, anhedral grains. Many are pink or purple. Tourmaline grains are commonly black, brown, or green. The shapes include very well rounded grains reworked from older sediments (Fig. 11c); subhedral, prismatic crystals; and angular anhedral grains. Rutile forms small red-brown prisms or subangular anhedrons.

Pink to colorless garnet grains are anhedral and quite angular, and most exhibit heavily corroded, etched, or mammillary surfaces. Skeletal grains are common. The amount of garnet among the non-opaque heavy minerals is very erratic, ranging from 0 to 54 per cent. No correlation exists between mean grain size of the sample and percentage of garnets. Both the extensive grain corrosion and the percentage variability of the garnet indicate probable post-depositional, intrastratal solution; originally garnet must have been one of the most abundant heavy minerals.

Several yellow-green, subround, equant grains of epidote and a few dark green, angular hornblende grains were also encountered.

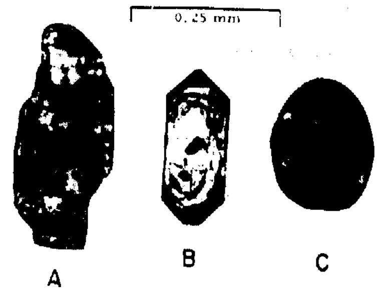

FIG. 11.—Representative heavy minerals. A, kyanite from Newby sand showing slightly rounded corners; B, euhedral zircon; C, well rounded tourmaline, reworked from older supermature sedimentary rocks.

EFFECT OF ENVIRONMENT

The change in depositional environment from the fluviatile Carrizo to the open-water, shallow-marine Newby affected both physical and chemical properties of the sediments. Increased abrasion during Newby deposition eliminated about half of the soft metamorphic-rock fragments and imparted slight rounding to the corners of kyanite grains, but had no other obvious effects. The shapes and surface features of quartz, chert, and feldspar grains are essentially similar in the two sands, probably because abrasion was either insufficiently potent or too brief. The change in the chemistry of the environment—probably most importantly the increase in potassium concentration in marine waters—favored production of significant glauconite and authigenic feldspar overgrowths in the Newby, constituents that are lacking in the Carrizo.

DETERMINATION OF SEDIMENT SOURCES

ROCK TYPES PROVIDING DETRITUS

A mineral assemblage such as is detailed here indicates the following source rocks: (1) a plutonic terrane in which rocks such as granite or gneiss or both are exposed to provide much of the straight-extinguishing quartz, the potash feldspar, and possibly the angular grains of the more common heavy minerals such as

zircon, tourmaline, and rutile; (2) pegmatites and hydrothermal veins may have accompanied the intrusive rock as suggested by the high percentages of microcline, and the bubbly vein quartz; (3) a source of high-rank metamorphics to account for the metamorphic quartz, staurolite, kyanite, and garnet; (4) slates and phyllites contributing the low-rank metamorphic rock fragments; (5) older sedimentary rocks, as evidenced by the well rounded quartz with overgrowths, and the well rounded tourmaline and zircon—possibly Cambrian or Cretaceous, as the best rounded Texas sands come from beds of these systems; the abundant angular chert and much of the subangular quartz also came from older sedimentary rocks, but probably not the same strata that furnished the well rounded grains; and (6) volcanic ejecta accounting for the clear, straight-edged quartz phenocrysts. Of these sources, (1), (3), (4), and (5) are volumetrically the most important (Fig. 12.)

A seventh, more local source is suggested by the extensive bimodality of some of the Carrizo and Newby samples. From all parts of the section certain slides show a well developed, minor, coarse mode. This mode ranges between 1 and 2 mm. in grain diameter, and is well sorted. The coarse fraction consists largely of clear, subangular common quartz with a little feldspar and a few metamorphic and volcanic quartz grains; well rounded grains, chert, and vein quartz are nearly lacking. It may well be that these mineralogically and texturally anomalous coarser grains are derived from the reworking of material laid down on a temporary beach near the present site of deposition. Three facts support this conclusion:

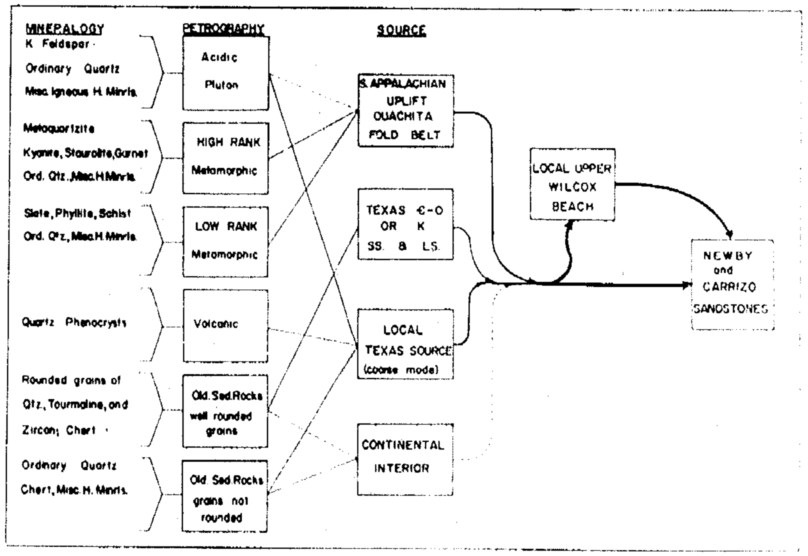

FIG. 12.—Flow sheet showing derivation of Carrizo and Newby sandstones. Thickness of lines indicates relative volumetric importance of each source.

(1) the grains are well sorted—if derived from a distant source they should vary more in size; (2) they are anomalous in otherwise moderately sorted to well sorted sediments—suggesting they have not traveled far with the bulk of the deposits; and (3) the uniform subangularity and similar high degree of polish betray exposure to rather brief beach action. No doubt they reflect the recognized autophagous tendencies of geosyncline-flank areas to rise slightly, exposing recently formed marginal basin deposits to re-erosion.

GEOGRAPHIC LOCATION OF SOURCE AREAS

Geographic requirements limit to four the number of possible source areas for the Eocene sediments deposited in the Texas Gulf Coast. The placing of mineralogic-petrographic data obtained from this study into the framework provided by current Gulf Coast paleogeologic thought has resulted in the elimination of two of the four possible sources—the Rocky Mountains Province and the Llano uplift. Of the two remaining, the southern Appalachian-Ouachita foldbelt is rendered most likely, and the fourth, northern Mexico, is considered much less probable (Fig. 13).

ROCKY MOUNTAIN PROVINCE

It has been common belief for some time that the Rocky Mountains and central interior supplied most of the clastic material making up Gulf Coast Tertiary deposits (Storm, 1945; Murray, 1955). Transfer of sediments to the

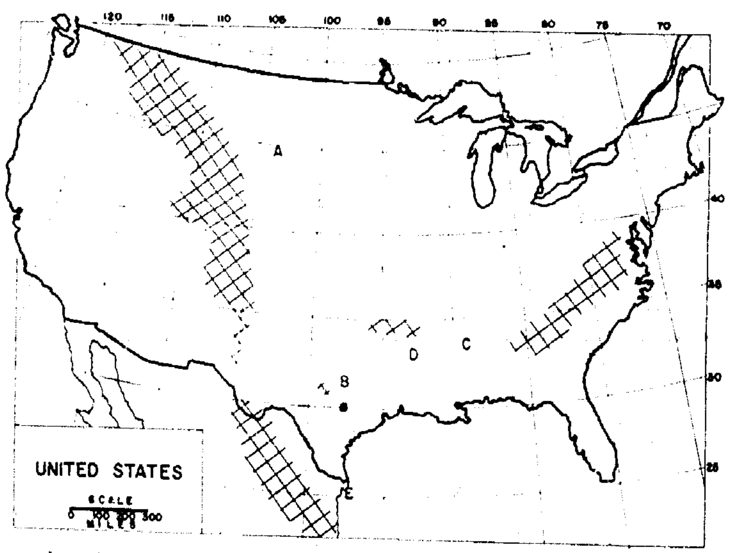

FIG. 13.—Location of possible source areas. A, Rocky Mountain area; B, Llano uplift; C, Southern Appalachian Mountains; D, Ouachita Mountains; E, Northern Mexico. Small square indicates location of samples studied.

Gulf Coast during Eocene time could have been accomplished by longshore distribution of detritus carried to the Gulf by the Mississippi River system or other southeast-draining rivers. A study of lower Carrizo crossbeds reveals that final transport was indeed in this direction.

Russell's (1937) study of Mississippi River sands from Cape Girardeau to the Delta revealed little or no kyanite and staurolite—the distinctive heavy-mineral suite which accounts for approximately 40 per cent of the non-opaque heavy minerals found in Carrizo and Newby sands. Sidwell's (1937, 1939, 1940, 1947) many investigations of the material being carried by rivers draining the High Plains (which are covered by late Tertiary deposits derived from the Rocky Mountains) failed to show either low-rank metamorphic rock fragments or kyanite and staurolite. The Rio Grande, in its upper reaches, drains areas of high-rank metamorphic rocks, but because of their close association with volcanic outcrops the river carries large amounts of basaltic hornblende and volcanic rock fragments (Bullard, 1942), types which do not appear in the Carrizo or Newby. Nor were other basic igneous minerals identified from the Carrizo or Newby although they would be expected in material from the Rocky Mountains or the Precambrian of the Great Lakes region.

Failure to identify kyanite, staurolite, and low-rank metamorphic-rock fragments in sands carried by present-day rivers draining the Rocky Mountains and the central interior strongly suggests that these minerals were also absent from Eocene rivers presumably draining the same areas, and therefore the Rocky Mountain province could have contributed little to Eocene Gulf Coast sedimentation. Furthermore, that part of the Rockies accessible to rivers draining into the Gulf contains no large areas of intensely folded and thrusted slates, phyllites, and fine-grained metaquartzites; that is, it lacks the kind of terrane required for the production of the subgraywacke sands of the Carrizo and Newby. The lack of Eocene rocks in the subsurface High Plains also argues against a source in that direction.

LLANO UPLIFT

The Llano uplift of Central Mineral region of Texas may be advanced as a possible source of Carrizo and Newby sediments for several reasons. The rocks which crop out in this structural dome include Precambrian granite, gneiss, schist, metaquartzite, and pegmatite, and all the minerals characteristic of the Carrizo and Newby sands occur there. The area, moreover, is only about 150 miles northwest of Bastrop County, and lower Carrizo crossbedding indicates a regional slope from that direction. Nevertheless, there are both mineralogic and paleogeological facts which cast doubt on this choice. Heavy-mineral analyses of sands from the Colorado River (Bullard, 1942; also unpublished analyses, Univ. of Texas) which flows through the Llano uplift show high percentages (50 per cent) of green hornblende and low percentages of staurolite and kyanite. The Carrizo and Newby exhibit the opposite relation. Inasmuch as the distribution of rock types in the Llano area is complex, it is doubtful that erosion during Eocene time could have preferentially selected staurolite and kyanite-rich rock for destruction and left the hornblende schists and amphibolites almost untouched. There is, in fact, evidence that the Llano area was largely covered with Cretaceous carbonate rock until Miocene time when the first floods of reworked limestone characteristic of that region appeared in Oakville sediments. Not until the Quaternary period does hornblende begin to be an important heavy mineral (Bornhauser, 1940), signifying extensive removal of the carbonate cover and erosion of the Precambrian rocks.

Inasmuch as hornblende is the key mineral for identifying the primary rocks of the Llano dome as a contributing source area, it becomes essential to demonstrate that the pronounced scarcity of hornblende in pre-Miocene sediments is not due to intrastratal solution. This study, as well as current research on the Wilcox sands of central Texas (Adams, 1957; Harris, 1957), has shown that garnet is readily susceptible to post-depositional etching and even complete solution except where protected in concretionary zones or clayey, relatively impermeable beds. Hornblende, also a rather unstable ferromagnesian mineral, conceivably could have been removed from pre-Miocene sands by similar intrastratal solutions (Bornhauser, 1940; Cogen, 1940). Yet not only is hornblende rare in the loose sand, it is also virtually lacking in a calcitic, sandy concretion in the upper Newby. This concretion also contains well preserved pelecypods, indicating that it was formed soon after deposition of the sand; hence, it would have provided an almost immediate seal to protect the heavy-mineral grains in the sand. The near absence of hornblende in this concretion strongly suggests that it was never present in the sand in significant amounts, because it was lacking in the source area. Work in progress by Callender (1957) strengthens the argument by showing the *ineffectiveness* of intrastratal solutions in attacking hornblende, even when ample opportunity for attack is provided. He discovered one thin zone in the Queen City sand (lower-middle Claiborne) that contains more than 70 per cent green hornblende in its heavy-mineral suite. This bed of clean, very friable fine-grained sand is completely uncemented, contains no concretions, and is very porous and permeable. As a result it would be easily susceptible to the effects of migrating solutions. Yet the hornblende in this bed (as well as the rare hornblende grains which occur in Wilcox and younger beds) shows no sign of chemical attack, etching, or oxidation.

Thus the almost complete absence of hornblende in Carrizo and Newby sands can not be ascribed to post-depositional solution, but is due to a lack of hornblende in the source area. This argues overwhelmingly against the Llano dome as a significant source for the sediments.

APPALACHIAN MOUNTAINS

The southern Appalachian Mountains are favored as the primary source of minerals from rock types (1), (2), and (3). Present streams draining this area carry similar minerals, especially the diagnostic kyanite-staurolite suite. Goldstein (1942), for example, reports in his study of heavy-mineral provinces of the northern Gulf Coast, that the heavy minerals in the East Gulf province (east of the Mississippi River) are derived directly from the southern Appalachian Mountains. Kyanite and staurolite account for 20 per cent of the non-opaque heavy minerals in that province, whereas west of the mouth of the Mississippi the percentage drops abruptly to zero. Bornhauser (1940) and Cogen (1940), in investigations of heavy-mineral zones in the upper Tertiary of the Gulf Coast, observed a similar trend. They found that the percentage of kyanite and staurolite in several well defined zones increased eastward toward Louisiana, but fell off markedly toward southwest Texas. Transfer of detritus from the Appalachian Mountains to its present site in the Carrizo and Newby sandstones was probably effected during the Eocene time by stream transport to the littoral and neritic zones bordering the Mississippi embayment. There longshore and offshore currents distributed the sediments to beach and neritic environments. The effectiveness of longshore currents in transporting sand-size material substantial distances along the present Texas coast has been demonstrated by Bullard (1942).

Low-rank metamorphic-rock fragments (source 4) were derived either from the Ouachita foldbelt (Goldstein and Reno, 1952) or more probably from the southern Appalachians. The low mechanical resistance of phyllite and slate to abrasion precludes extensive transport, and there is no other major nearby source for large volumes of this material.

The broad belt of Lower Cretaceous sandstone and carbonate rock which crosses Texas may have furnished the well rounded, frosted quartz grains and the well rounded tourmaline and zircon grains (source rock 5) that occur throughout the Carrizo and Newby sands. Alternatively, the rounded quartz and heavy minerals may, in part, have been reworked from Cambro-Ordovician rocks. A noticeable lack of large chert grains in the Carrizo and Newby suggests that the source of the chert sand was not close by; nearby cherty limestone would have supplied chert pebbles to the sediment, but they are not present in the coarser mode. Paleozoic sandstones in north Texas offer a likely source of chert and much of the angular quartz sand.

The volcanic source (source 6), on the other hand, must have been quite near, and possibly in a southwesterly direction. Carrizo samples from Leon County (200 miles northeast of Bastrop County, Texas) reveal no large quartz phenocrysts, whereas phenocrysts are common in the Bastrop County specimens and are exceedingly common farther south near Lockhart. The source of the coarser mode (providing plutonic quartz and orthoclase feldspar) also probably lay nearby on the south or southwest, as this mode (and nearly all feldspar) disappears in Leon County (Roberson, 1957).

Another reason for advancing the Appalachian and Ouachita mountains as the most likely source of the bulk of Carrizo and Newby material is derived from a recent examination of several Carrizo samples from northwest Louisiana. The Louisiana Carrizo strongly resembles the Bastrop County Carrizo in that it contains a high percentage of slate and phyllite fragments, an abundance of kyanite and staurolite, and has little or no hornblende. Recent streams which drain the southwest Appalachians are also deficient in hornblende (Goldstein, 1942). Grim (1936) reported an abundance of kyanite and staurolite and a deficiency in basic igneous minerals from lower Claiborne deposits in Mississippi. The petrographic similarity of east Gulf coast and west Gulf Coast Eocene sands indicates that both have originated from a common major terrane, although the Texas material contains additional detritus from more local sources. Hence, petrographic evidence suggests that the striking increase in clasticity of lower Tertiary over Cretaceous sediments in the western Gulf Coast may be largely due to tectonism in the southern Appalachians during the Eocene epoch.

NORTHERN MEXICO

In northern Mexico plutonic and high-rank metamorphic rocks are reported to be exposed in areas not blanketed by post-Eocene volcanic rocks. This region possesses two possible advantages: (1) it is relatively near the depositional area—in keeping with the angularity of the grains of kyanite and the other minerals in general, and (2) the Eocene section thickens southwest into the Rio Grande embayment.

The main problem of evaluating northern Mexico as a source area is that its geology has not been adequately described. It is known that the Laramide orogeny produced a mountainous belt in northern Mexico, the Sierra Madre Oriental. Detritus carried eastward by streams flowing over the intensely folded Mesozoic limestones during the Eocene epoch should have contained no metamorphic minerals, because crystalline basement rock was probably not exposed at that time. It has not yet been uncovered, despite further uplift and erosion, except in small areas such as that west of Cuidad Victoria, Tamaulipas. Later basin-and-range faulting created uplifted areas west of the Sierra Madre Oriental, but these areas have supplied sediments to the Gulf of Mexico only in late Tertiary or Quaternary time with the growth of eastward drainage into the Rio Grande and similar rivers. The increase in thickness of Tertiary units in southwest Texas and northeast Mexico probably reflects the fact that the Rio Grande embayment was tectonically negative rather than that it was near the source. Another factor unfavorable to the acceptance of this area as a source of a significant part of Carrizo and Newby sediments is the sharp decrease in kyanite and staurolite in that direction (Bornhauser, 1940).

CLAIBORNE GROUP VERSUS WILCOX GROUP

It is probable that in Texas a large part of the material making up the Carrizo and Newby units formed a temporary but extensive beach deposit between the time it was eroded from the primary or secondary source and its ultimate deposition at the present site. The lower Carrizo is a fluvial continental deposit; the upper Carrizo and lower Newby are coastal, shallow brackish-water deposits; and the upper Newby is a coastal marine deposit. The relative proportion of polished grains to frosted and dull grains does not vary significantly throughout

the Carrizo and Newby sections. Of all characteristics of clastic grains, surface features are most rapidly effaced by exposure to differing depositional environments. Consequently the mixture of polish and frosting exhibited by the Carrizo and Newby grains proves that modification at the final depositional site was ineffective because of brief exposure, and that the surface features are largely inherited. More than half of the detrital-quartz grains exhibit a high polish. This indicates that the intermediate site of deposition for these grains was a beach, for only on beaches do sand grains receive the continuous, relatively gentle attrition in an aqueous medium which is necessary to produce a glossy surface.

There has been some disagreement between Gulf Coast stratigraphers whether the Carrizo formation should be included as the uppermost unit in the Wilcox group or the lowermost unit in the Claiborne group. Murray and Thomas (1945) did not find a disconformity between the Wilcox shale and the Carrizo sandstone near the Sabine uplift. Stenzel (1953) described a pronounced disconformity between the Carrizo and the Wilcox in east Texas. When these observational differences are united with the evidence for a beach phase immediately prior to the last deposition of the Carrizo and Newby sandstones, the explanation seems plain. In central Texas, the Carrizo and Newby sandstones of lower Claiborne age were immediately derived from reworking of the upper Wilcox beach sands (mixed with some additional detritus) as a result of local uplift and subaerial exposure in central and south-central Texas near the end of Wilcox deposition. This explains the greater magnitude of the unconformity in central Texas, and its apparent diminution or disappearance eastward.

Additional evidence for the previous existence of such an upper Wilcox beach near Bastrop County is the presence of a well sorted, minor, granule and very coarse sand mode in many samples throughout the section. These grains were probably transported to the Gulf during upper Wilcox time from a local southerly source by streams which had higher velocities than the streams in existence throughout most of lower Claiborne time. The granules were sorted and polished by the surf and finally deposited as a well sorted coarse unit. After uplift, this unit may have formed a thin cap, much as present-day Pleistocene gravels do in Bastrop County. Lower Claiborne streams, carrying material from far back in the source area, undercut the blanket of coarser sediment and caused the unconsolidated former beach material to slide into the stream and be added to the far-travelled detritus. Rapid transport to the final site of deposition did not allow sufficient time to separate the two well sorted phases, and the observed bimodal deposit resulted.

EARLY TERTIARY TECTONISM IN SOUTHERN APPALACHIAN MOUNTAINS

The discussion has thus far been limited to consideration of a restricted part of the Texas Gulf Coast Tertiary section in one locale. Indications of an Appalachian source for much of the Carrizo and Newby sandstones, however, permits speculation on Tertiary sedimentation throughout the Gulf coast.

The close of the Cretaceous period was marked in the Gulf coast by general [illegible] development of a regional disconformity (Murray, [illegible] reinstated with the deposition of a flood of Paleo-[illegible]. This radical change in composition and grain [illegible] marl, and clay to much coarser, dominantly [illegible] has been traditionally ascribed to the effects [illegible] United States (Storm, 1945; Murray, 1955, [illegible]

[illegible] here, however, shows that the sediments of [illegible] different mineralogy from that which could be [illegible]. Instead, the abundance of kyanite and stauro-[illegible] demonstrates that these belong to the southern [illegible] came from the same metamorphic source as [illegible] far to the east in Mississippi and Alabama [illegible]. Current work by Harris (1957) shows that the [illegible] suite extends (although in diminished amount) [illegible] youngest formation of the Wilcox group. The low-[illegible] rock fragments that are so abundant in upper Wilcox and lower Claiborne [illegible] of central Texas also point to an extensive source area composed of metasediments, such as would be present in intensely folded areas like the southern Appalachian (or the Ouachita) Mountains.

These facts make it difficult to avoid the conclusion that resurgence of terrigenous deposition on both the eastern and western Gulf coast following withdrawal of the Cretaceous sea was largely the result of tectonism and uplift (not folding) in the southern Appalachian Mountains, rather than the result of Laramide orogeny in western United States. Judged by the volume of sediment produced, this must have been a significant event in the history of the continent; it is here designated the Mitchell uplift, named from Mt. Mitchell, the highest peak in the southern Appalachian Mountains.

At what time during the Eocene did the Mitchell uplift occur? It is difficult to determine the beginning or end of this pulse from such a distant spot as Bastrop County, Texas, some 800 miles from the site of activity; yet the wave of detritus produced by the Mitchell uplift certainly was entering this area in late Sabinian time (Sabinetown formation of Wilcox group). By early Claibornian time (Carrizo-Newby formations), contributions from this source seem to have supplied the bulk of sediments being deposited in central Texas, and the tectonic pulse probably reached its culmination. The debris shed by the Mitchell uplift now spread as a great sheet over the Gulf Coastal Plain from Georgia to at least south Texas. Scattered samples from younger Eocene through Miocene sediments of central Texas indicate that the effects of the Mitchell uplift gradually died out from late Claibornian time onward, and always-present contributions from more local sources and the continental interior had reasserted their dominance by Miocene time. Restriction of the southern Appalachian source has continued, until today its influence is confined to deposition east of the Mississippi delta. Detailed petrographic work on the lower Wilcox and middle Claiborne (Queen City) sands in central Texas is now being done in order to fix more precisely the beginning and the end of this enormous influx of detritus from the Appalachian area, and to determine whether any minor tongues preceded or followed the main wave of sediment.

The Mitchell uplift was epeirogenic, and the area rose largely as a stable mass which did not undergo any significant deformation. Uplift was presumably most intense in the southern Appalachians, as this part of the range is most rugged today. Relief is not so great as in the Rocky Mountains because the Rockies owe most of their elevation to post-Miocene orogeny, and the more humid climate in the southern Appalachians has accelerated topographic reduction and softened their surface contours.

The most important conclusions reached as a result of this study are the following.

1. Most of the detrital material making up the Carrizo and Newby subgraywacke sands in Texas was derived ultimately from the southern Appalachian area.

2. A tectonic pulse, here called the Mitchell uplift, elevated parts of the southern Appalachians in early Eocene time and culminated with the deposition of a large thickness of basal Claiborne sediments across almost the entire Gulf Coastal Plain.

3. Much of the Carrizo and Newby detritus was deposited as an upper Wilcox beach sand before re-erosion and transport to its present site.

4. An area of maximum Wilcox uplift may exist as a subsurface high along the Eocene trend between Bastrop County and the northeast edge of the Rio Grande embayment where middle Wilcox rocks may be overlapped by the Marquez shale or even younger units.

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DEEP DRILLING THROUGH CUMBERLAND OVERTHRUST BLOCK IN SOUTHWESTERN VIRGINIA[1]

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ABSTRACT

Since 1948, when gas was discovered in commercial quantity in Buchanan County, 180 wells have been completed in southwestern Virginia. Much of the area under development lies within the boundaries of the Cumberland overthrust block and 38 of the deeper wells have penetrated a zone of shearing near the base of the Devonian shale. This zone, which is very definitely indicated by strong gas blow-outs when drilled, is regarded as the sole of the Cumberland overthrust block.

INTRODUCTION

Thirty years ago Charles Butts (1927) published the results of his discovery and study of the famous fenster localities in southwestern Virginia where upper Cambrian and Ozarkian rocks have been thrust over Silurian. Butts' interpretation materially changed earlier ideas as he was of the opinion that the thrust plane exposed in the fensters was the same as that exposed at the base of Pine Mountain and that the thrust plane must, therefore, underlie the whole of the Cumberland block at shallow depth. This was the first expression of the idea of a "sole" of the thrust block. The suggestion was made that the Devonian shale was the zone followed by the thrust because of the greater likelihood of shearing on or within such a formation.

Rich (1934) accepted Butts' interpretation as the foundation for his explanation of the mechanics of low-angle faulting as revealed by the Cumberland overthrust block. In Rich's words (pp. 1589–90)

> the thrust plane may be pictured as following some zone of easy gliding such as the lower shale of Figure 4 until frictional resistance became too great; then shearing diagonally up across the bedding to another shale; following that for several miles, and finally shearing across the bedding to the surface.

Prior to the work of Butts and Rich there were various earlier investigations of the overthrust block and boundary faults, notably those of Safford, Keith, Hinds, and Campbell.

However, it was not until 1921 that the name "Cumberland" was first applied by Wentworth who also established the presence of the Russell Fork fault entirely across the block, thus showing a structural unit bounded on all sides by overthrust faults. Wentworth's cross sections, however, as well as others drawn prior to Butts' discovery and interpretation of the fensters, showed a thrust fault extending indefinitely downward from the base of Pine Mountain.

SUMMARY OF DEEP DRILLING IN CUMBERLAND BLOCK

In 1948 gas in commercial quantity was discovered in Buchanan County, Virginia. Operators immediately undertook a leasing program in this and adja-

[1] Presented during the joint field conference of the Geological Society of Kentucky and the Appalachian Geological Society, Middlesboro, Kentucky, April 26, 1957.

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cent areas in the attempt to secure large acreage blocks held by the coal companies.

The Clinchfield Coal Corporation, now a division of the Pittston Company, held about 300,000 acres in Buchanan, Dickenson, and Wise counties, most of it within the boundaries of the Cumberland overthrust block.

Instead of leasing its property, this company started its own drilling program in 1948 and completed a discovery well in the Greenbrier limestone, or Big Lime, early in 1949. Since that time the company has acquired a total of 400,000 acres of oil and gas rights and has completed 90 wells, 35 of which were drilled to or through a shear zone near the base of the Devonian shale. In addition, other operators have drilled three wells through this zone. The locations of the wells penetrating the shear zone are shown on the accompanying map (Fig. 1) which also delineates the boundaries of the Cumberland overthrust block in southwestern Virginia as well as its major structural features.

Table I presents a summary of these 38 wells.

The total footage drilled in the 38 wells amounts to 225,000 feet or about 43 miles. Both 36L spudders and standard rigs were used with daily average footage of as much as 45 feet for spudders and 39 feet for standard rigs. At the present average over-all cost per foot for drilling and completing wells in the area, a total expenditure of about $2\frac{1}{2}$ million dollars is represented. This does not include the cost of fishing for tools stuck in the blow-out zone which in most of the wells was the responsibility of the contractor. Nineteen or one-half of the wells developed fishing jobs in the blow-out zone and about 450 days were consumed in costly fishing operations.

CHARACTERISTICS OF BLOW-OUT OR SHEAR ZONE

In all but one of the 38 wells there was no question or doubt when the zone of shearing near the base of the Devonian shale was penetrated. At the moment of penetration the gas blow-outs were strong enough to blow the heavy drilling tools up the hole. And, as previously stated, long and expensive fishing jobs developed in many of the wells. In most instances, the gas was exhausted within a few hours. It seems probable that this gas originated during the time of shearing of the highly bituminous Marcellus shale at the base of the Devonian shale section.

The Devonian shale in southwestern Virginia within the area of the Cumberland overthrust block has about the normal thickness one would expect if eastern Kentucky subsurface sections are compared and allowance made for regional dip and thickening. The total shale thickness in wells drilled in the area ranges from about 1,000 feet in those wells nearest the Pine Mountain fault to about 1,500 feet in those nearest the St. Paul fault on the southeastern boundary of the block. Within the area of the Cumberland overthrust block, particularly in Dickenson County, there is a higher percentage of light or non-bituminous shale than is usually encountered in eastern Kentucky wells. In Wise County,

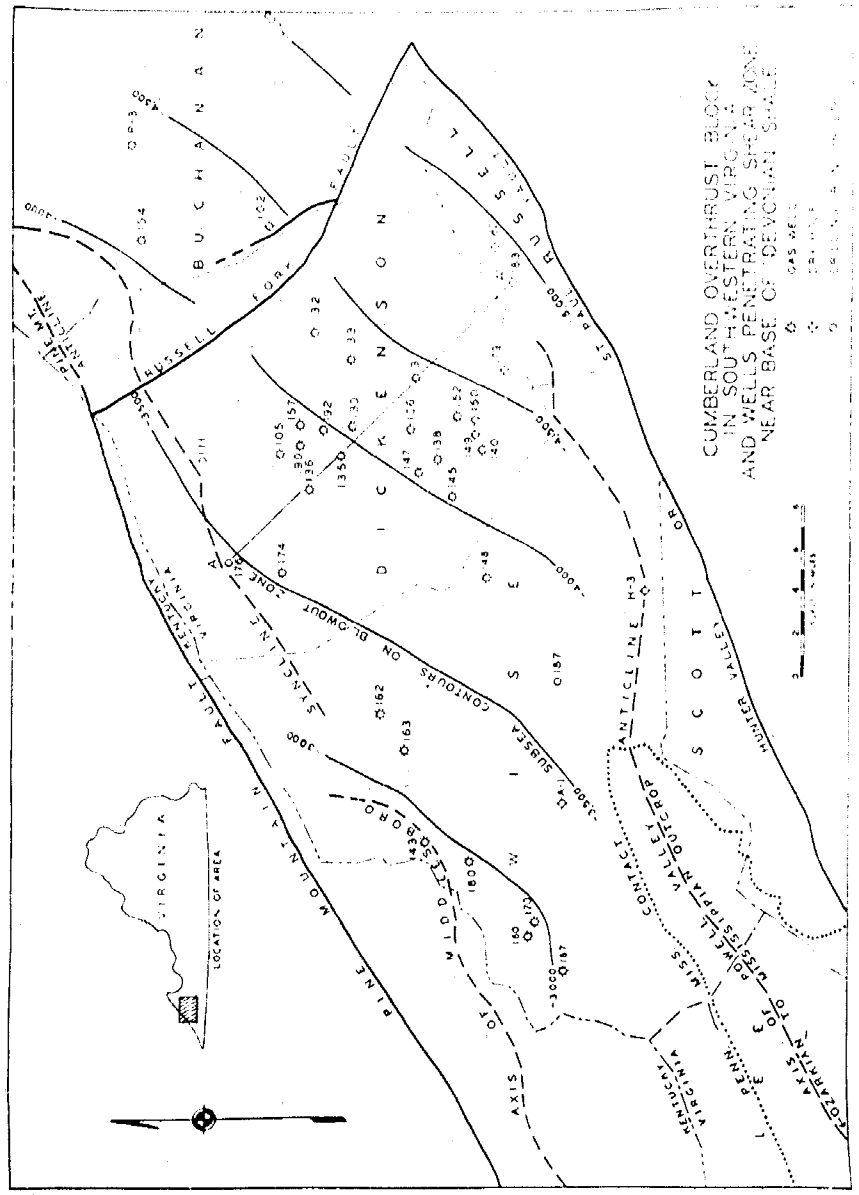

FIG. 1.—Map of Cumberland overthrust block in southwestern Virginia, showing major structural features and wells penetrating shear zone near base of Devonian shale.

TABLE I. DATA FOR 38 DEEP WELLS IN SOUTHWESTERN VIRGINIA DRILLED TO OR THROUGH SHEAR ZONE NEAR BASE OF DEVONIAN SHALE

35 wells (102–192) Drilled by Clinchfield Coal Company
Well A-1 by Appalachian Development Company
Well H-3 by Southwest Oil and Gas Company
Well P-3 by Pipeline Construction and Drilling Company

Well No.	Elevation	Total Depth	Depth of Blow-Out	Interval to Top of Corniferous	Days Fishing Stuck Tools from Blow-Out
	(Feet)	(Feet)	(Feet)	(Feet)	
102	1,373	5,847	5,809	Not drilled	0
105	1,427	5,764	5,270	90	35
106	1,525	5,754	5,752	Not drilled	0
111	1,335	6,070	4,947	213	1
130	1,759	5,914	5,829	80	16
131	1,823	6,264	6,264	Not drilled	94
132	1,500	5,866	5,824	42	0
133	1,508	5,920	5,850	75	0
135	1,462	5,515	5,434	76	6
136	1,656	5,527	5,455	72	17
138	1,850	6,104	6,028	65	0
140	2,564	6,084	6,831	150	20
			6,015	65	
143	2,225	5,349	5,124	104	0
145	2,300	6,436	6,365	69	74
147	1,987	6,123	6,055	64	82
148	1,874	5,738	5,680	56	1
149	2,118	6,496	6,454	40	0
150	2,462	6,035	6,841	93	26
152	1,700	6,160	6,067	66	27
154	1,515	5,806	5,700	95	0
157	1,616	5,693	5,603	82	0
160	2,038	5,192	4,940	240	1
162	1,691	5,744	5,005	35	0
163	1,027	5,248	5,195	53	0
167	1,885	5,143	4,917	173	2
170	2,193	5,400	5,157	234	0
174	1,915	5,568	5,480	52	1
176	1,441	5,899	4,860	54	0
179	1,956	6,680	6,575	97	28
180	2,387	5,596	5,386	206	0
182	1,881	6,050	6,824	118	1
183	1,966	7,044	6,917	118	5
187	2,198	5,875	5,875	Not drilled	Currently fishing
190	1,435	5,451	5,370	79	0
192	1,672	5,775	5,680	94	0
A-1	2,136	6,057	4,855	754	0
			5,576	33	0
H-3	2,600	5,348	No blow-out	Drilled	0
P-3	1,209	5,751	5,620	128	7

however, the few wells drilled through the Devonian shale exhibit characteristics more similar to wells in the eastern Kentucky gas field.

Less than 10 per cent of productive wells in the Devonian shale in this and adjoining areas are completed as "natural" wells. Most are brought in by heavy shots of the entire shale section, usually with 80 per cent gelatine.

Usually, before penetrating the blow-out zone, the shale becomes dark and highly bituminous. However, samples from the blow-out istelf are remarkably different (Fig. 2). The shale has been metamorphosed to the extent that it is coal-like in character. Commonly, veinlets of fibrous white calcite are associated with the coal-like shale. The zone is thin, only a few feet, as samples are rarely obtained from more than one run of the tools.

In Well 106 about 50 pounds of asphalt were recovered from a depth of 5,752 feet in the blow-out zone. According to Headlee (1957) this asphalt is similar to grahamite.

In two of the wells a blow-out was penetrated above the usual zone near the base of the Devonian shale.

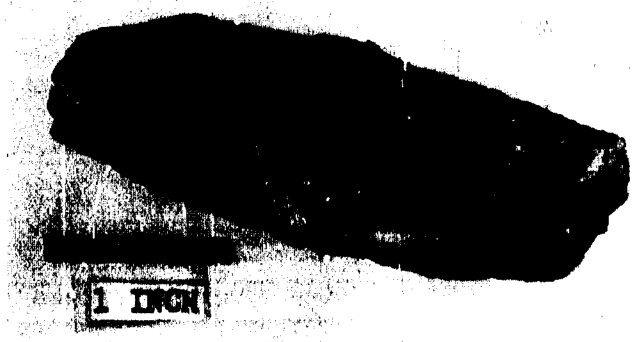

FIG. 2.—Sample of metamorphosed shale from shear zone near base of Devonian shale, in Clinchfield Coal Company well No. 152, on Open Fork of McClure River near Nora, Virginia.

The interval from the top of the shear zone or blow-out to the top of the Corniferous limestone is variable, usually from 35 to 100 feet. The five Wise County wells in the vicinity of the −3,000-foot contour show an interval from about 175 to 240 feet.

Three of the wells were drilled from 2 to 10 miles northeast of the Russell Fork fault and a shear zone was penetrated near the base of the Devonian shale at depths comparable with those of the wells within the boundaries of the overthrust block (Fig. 1). In one well, drilled on the nose of the Powell Valley anticline about 8 miles east of the Mississippian-Pennsylvanian contact, there was no evidence of the blow-out usually encountered.

Subsea contours on top of the zone of shearing exhibit a dip toward the east and south of about 1,500 feet measured from Well 176, near the axis of the Middlesboro syncline, to Well 183 or at the rate of about 80 feet per mile. In the same wells dip as measured on the base of the Big Lime is slightly more than 1,200 feet with southeastward thickening of the Devonian shale amounting to about 500 feet. These relationships are shown in the cross section (Fig. 3).

Toward the northwest, the shear zone rises to −3,000 feet and from that contour to Pine Mountain the thrust plane must rise sharply as its outcrop on the northwest flank of Pine Mountain is approximately 1,750 feet above sea-level at Pound Gap. From Well 176 in a distance of about 4 miles to the outcrop, the thrust plane rises from about −3,500 feet to about +1,750 feet or just a little less than one mile. The base of the Lee conglomerate between the same points rises from an elevation of about −700 feet to about +2,500 feet or a total rise of

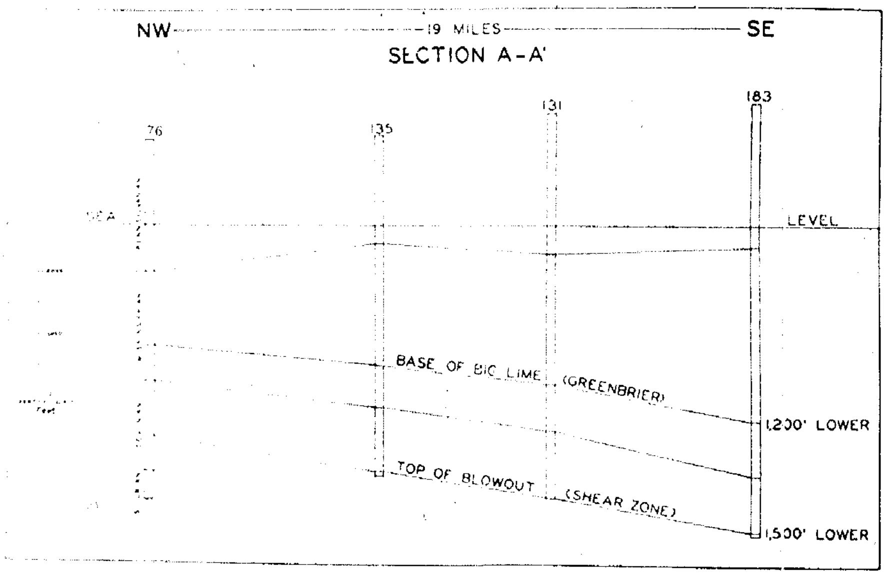

FIG. 3.—Cross section AA from Clinchfield Coal Company well No. 176 to well No. 183, showing regional dip.

3,200 feet. The base of the Big Lime in the same distance has a total rise of about 3,900 feet.

As indicated on the map (Fig. 1), the subsea elevations of the shear zone in the 3 wells drilled northeast of the Russell Fork fault seem to fall into the pattern of those wells drilled within the limits of the Cumberland block.

CONCLUSIONS

Evidence afforded by the 38 deep wells drilled proves a zone of shearing near the base of the Devonian shale. The intense metamorphism of the shale in the shear zone of most of the wells indicates considerable movement. The amount of movement, as estimated by Butts (1927) ranges from 2 miles along the Russell Fork fault to 10 miles on the Jacksboro fault in Tennessee and about 7 miles in the area of the Lee County fensters.

The greater movement toward the southwestern end of the block is evidenced

by the configuration of the Powell Valley anticline—broad and flat-topped at the southwest end and narrow and sharp at the northeast. Also, there was very extensive thrusting at the southwest end along the Wallen Valley fault which disappears toward the northeast end of the Powell Valley anticline.

According to Rich's interpretation of the mechanics involved, toward the southwest end of the anticline, the thrust sheared through from the lower to the upper gliding bed and pushed beds forward for several miles. At the northeast end with less forward movement on the lower gliding plane, a much narrower and sharper anticline was formed. Still farther east thrusting was confined to only the upper gliding zone with no anticlinal folding.

The evidence from certain of the deep wells seems to bear out the foregoing. The Southwest Oil and Gas Company well drilled on the crest of the Powell Valley anticline and 7 miles from the Mississippian-Pennsylvanian boundary exhibited no evidence of blow-out or shear zone where the base of the Devonian shale was drilled. Apparently here, the movement was on some plane lower than the base of the Devonian shale. Well 187, located 4 miles northeast of the Mississippian-Pennsylvanian boundary, drilled the blow-out and is currently fishing. The only wells drilled east of the Southwest Oil and Gas Company well are located beyond the point where the axis of the Powell Valley anticline can be traced in surface mapping. Three wells drilled within 2–4 miles of this point penetrated the blow-out and zone of shearing in the Devonian shale.

Samples from the zone of blow-out and shearing penetrated in three wells drilled northeast of the Russell Fork fault show less metamorphism and consequently indicate less movement than in wells on the southwest. These wells are in an area where diminishing movement is indicated by the northeastward expression of the Pine Mountain fault as the Pine Mountain anticline, the gradual disappearance of the axis of the Middlesboro syncline, and the presence of Little Pawpaw fault, a northwestern offshoot of the Russell Fork fault.

In conclusion, it seems appropriate to quote that great scholar of Appalachian geology, Charles Butts (1940), who wrote as follows in concluding a discussion of the Cumberland overthrust block in his "Geology of the Appalachian Valley in Virginia."

> The interpretation stated above seems to be reasonably deducible from the facts as known at present, but it should not be accepted as final.

Who knows what deeper drilling may reveal?

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VOL. 41, NO. 11 (NOVEMBER, 1957), PP. 2574-2575

STRATIGRAPHIC COMMISSION

DISCUSSION OF REPORT 5—NATURE, USAGE, AND NOMENCLATURE OF BIOSTRATIGRAPHIC UNITS

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

In connection with Report 5 of the American Commission on Stratigraphic Nomenclature, published in the August, 1957, issue of the A.A.P.G. *Bulletin*, comments on this report were invited. The following response is considered worthy of publication.

EDWIN D. MCKEE, Chairman

COMMENTS BY CURT TEICHERT
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A revision and clarification of biostratigraphic nomenclature have long been overdue and the American Commission on Stratigraphic Nomenclature is to be commended for its initiative in this matter. Nobody will be surprised to learn of differences in fundamental concepts that have to be ironed out before a compromise can be reached. The following comments on Report 5 of the ACSN are offered at the request of E. D. McKee in an endeavor to stimulate discussion by presenting alternative viewpoints.

1. The Commission Report maintains that the use of the term "zone" in biostratigraphy is discredited by the fact that this word is also used in many other kinds of stratigraphic classification. However, many other terms, such as formation and series, used in formal stratigraphic nomenclature, have more than one meaning in stratigraphy. In a biostratigraphic sense the term "zone" is always tied to the name of a fossil genus or species, and, if so used, no doubt as to the meaning of the term can possibly arise. Therefore, in my opinion, the term "assemblage-zone," proposed by the Commission is unnecessarily cumbersome. I can see no advantage in substituting "*Globotruncana appenninica* assemblage-zone" for the simpler term "Zone of *Globotruncana appenninica*." It is generally understood that this zone is characterized by the occurrence of *Globotruncana appenninica*, but may (and generally does) contain other species as well. That biostratigraphic zones are defined by assemblages, though, for the sake of convenience, named after just one species or genus, has been well established since Oppel's time (about 1858) and needs no further elaboration. An "assemblage-zone" as proposed in the Commission Report is synonymous with a biostratigraphic "zone" as previously used. A faunizone is a zone characterized by an assemblage of animal fossils, a florizone is a zone characterized by an assemblage of plant fossils. Mixed fauni-flori-zones do, of course, exist.

It is difficult to see how confusion with "mineral zones" or any other kind of zones, which are not named after fossil species or genera, could arise.

2. The Commission proposes the term "range-zone" for the concept which many, perhaps most, geologists now designate as "biozone." The latter term was first proposed by Buckman, in 1902, as a time term "to signify the range of organisms in time." Later authors used the term for rocks in which defined genera and species occur and it is being used thus in this country. It is because of this basic confusion that the Commission suggests abandonment of the term biozone. In proposing the term "range-zone," however, it would seem that the Commission Report is not entirely consistent. Thus we read, firstly, that "range-zone" is being proposed for rocks "comprising the total body of strata through which specimens of a particular taxonomic entity (species, genus, etc.) range or occur."

But later in the report we read that "range-zone" is defined as a stratigraphic unit whose limits "should always be drawn at the extreme limits of occurrence of a particular form, vertically and horizontally, to include all of the strata encompassed by these boundaries regardless of how much of the rock is lacking of the particular form." This latter definition makes range-zone a time-stratigraphic, not a biostratigraphic term.

Time-stratigraphic units are rocks which have been deposited during a defined interval of geologic time. Such an interval may be identified as the time between the appearance and the disappearance of a species, genus, or other taxonomic unit. During such a time interval many kinds of rocks will be deposited all over the world, in places where this particular species, genus, etc., did not exist, and correlation of such rocks can be made only by indirect means. Hence, all the rocks deposited during this time belong to a time-stratigraphic unit. A biostratigraphic unit, on the other hand, can be recognized only by presence of its diagnostic fossil constituents. Where these are absent, the biostratigraphic unit cannot be defined and rocks in which a biostratigraphically significant fauna or flora does not occur cannot be recognized as parts of a biostratigraphic unit. It follows then that the term range-zone as defined in the Commission Report does not fulfill the requirements of a biostratigraphic term.

It seems to me that no formal term is required for a "range-zone" as defined in the Commission Report ("biozone" of authors). Although trilobites occur throughout the Paleozoic era, no necessity is felt to designate the total of Paleozoic rocks as the "Trilobite range-zone." This is an extreme example, but the case for families, genera, and even most species would be analogous. Thus, the term "*Atrypa reticularis* range-zone," while including a wide range of rocks of Silurian and probably Devonian age, would convey a concept of only limited geological interest. In 1901, H. S. Williams proposed the term "biochron" to designate the duration in time of a taxonomic unit. For such a term there seems to be every justification, but rocks, other than biostratigraphic zones, deposited during such paleontologically defined time intervals are better grouped as time-stratigraphic units such as era, period, epoch, and stage.

3. The statement in the Commission Report that fossils are "particularly valuable" in the "placing of rocks in a world-wide geologic time scale," strikes me as an understatement, because it is difficult to think of any presently available method or tool other than the study of fossils by which the same goal might be achieved. The basic unit in which this fossil evidence is organized, is the biostratigraphic zone. No "mineral zones" or "zones" based on any other physical evidence are known at present on which a time scale of world-wide validity could be based. It would, therefore, be more correct to say that "fossils at present provide the only available evidence for the placing of rocks in a world-wide geologic time scale."

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BULLETIN OF [illegible] AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
[illegible] 41, NO. 11 (NOVEMBER, 1957), PP. 2576-2583, 2 FIGS.

GEOLOGICAL NOTES

JURASSIC STRATIGRAPHY IN ELK MOUNTAINS, WEST-CENTRAL COLORADO[1]

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The Jurassic formations of the Colorado Plateau are relatively well understood, but comparatively little is known of their detailed stratigraphy in the high mountains of central and west-central Colorado. Between 1948 and 1955 these rocks were examined in the Elk Mountains (Fig. 1), at first while investigating older rocks in the area (Langenheim, 1952, 1954), and later in the hope of adequately describing and interpreting Jurassic stratigraphy in west-central Colorado. It is intended to continue this project but publication of available information seems justified because of recent requests for some of the measured sections.

Three lithologic subdivisions are widely recognizable in the Jurassic rocks of this area (Fig. 2). A mudstone member at the top of the Morrison formation is similar to the Brushy Basin member on the west (Craig and others, 1955) and constitutes [illegible] per cent of the formation. This member is underlain at most localities by a relatively pure, fossiliferous, non-*marine* limestone member which is [illegible] developed in the central Elk Mountains. It is poorly defined because of interbedded mudstone at Marion Creek, Thompson Creek, and Heuschkel Ridge and is not recognized at Almont. The basal subdivision is almost entirely sandstone and includes the basal sandstone member of the Morrison formation, the Curtis (?) formation, and the Entrada sandstone. The sandstone, in contrast to the limestone member, is thickest on the north and south and thinnest in the central part of the range. The sandstone member of the Morrison formation may represent the Saltwash sandstone member on the west (Craig and others, 1955).

The basal white, Upper Jurassic sandstone sharply succeeds bright red sandstone, red siltstone, or coarse white sandstone in the Maroon and younger formations north of [illegible] Mountain (Donnell, 1954; Langenheim, 1952, 1954), but [illegible] Brush Creek and Jack's Cabin underlying rocks belong to the Gothic

[1] [illegible] Rocky Mountain Section of the Geological Society of America at the Logan, [illegible] Manuscript received, April 22, 1957; revised manuscript, September [illegible]

[2] [illegible] Museum of Paleontology, University of California at Berkeley. This note is a [illegible] Museum of Paleontology of the University of California at Berkeley and the [illegible] Laboratory, Gothic, Colorado. The American Association for the Advancement of [illegible] financial support of the 1952 field season through an Iowa [illegible] Jean H. Langenheim (1948–52) and John T. Nasse (1955) [illegible] C. [illegible] Craig and F. G. Poole criticized the manuscript and their [illegible] acknowledged. The writer, however, assumes full responsibility for the form [illegible] the illustrations.

formation. The basal contact in these areas is considered a disconformity because the greatest observed divergence in attitude is only 2° of difference in dip at Jack's Cabin. The Jurassic, however, non-conformably overlies Precambrian schist toward the south near the town of Almont. Thus the pre-Jurassic hiatus increases gradually between Marion Creek and Virginia Ridge, increases moderately between Virginia Ridge and Jack's Cabin, but expands drastically south-

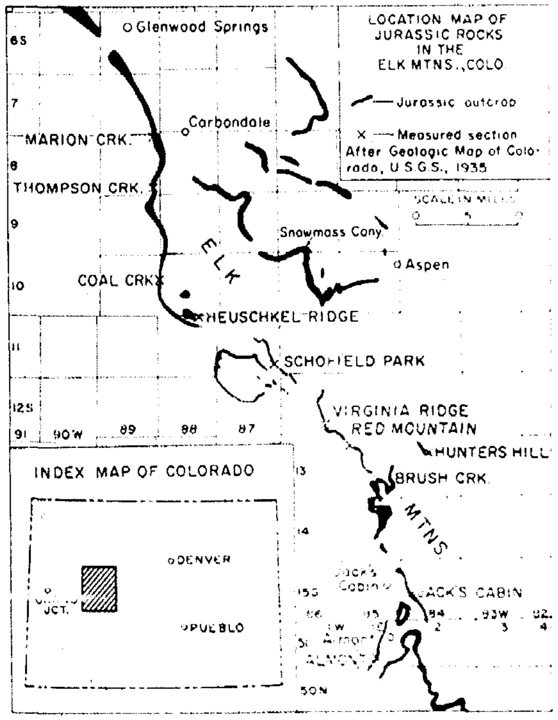

FIG. 1.—Location map of Elk Mountains.

west of Jack's Cabin. Much of the hiatus in the southern part of the area may result from erosion before or during Pennsylvanian time (Langenheim, 1952, 1954) but it is also possible that more erosion took place in the Almont area immediately preceding Jurassic deposition than elsewhere in the Elk Mountains.

The significantly thicker basal sandstone sequence at Marion Creek and Thompson Creek consists of two thick units of fine to medium, white, medium-scale cross-bedded sandstone separated by a much thinner limestone, shale, and siltstone unit. The lower sandstone is the Entrada sandstone as recognized by Baker, Dane, and Reeside (1936, p. 27, Fig. 5, secs. 15 and 19). The intermediate fine clastic and calcareous unit may be the Curtis formation. This thin-bedded,

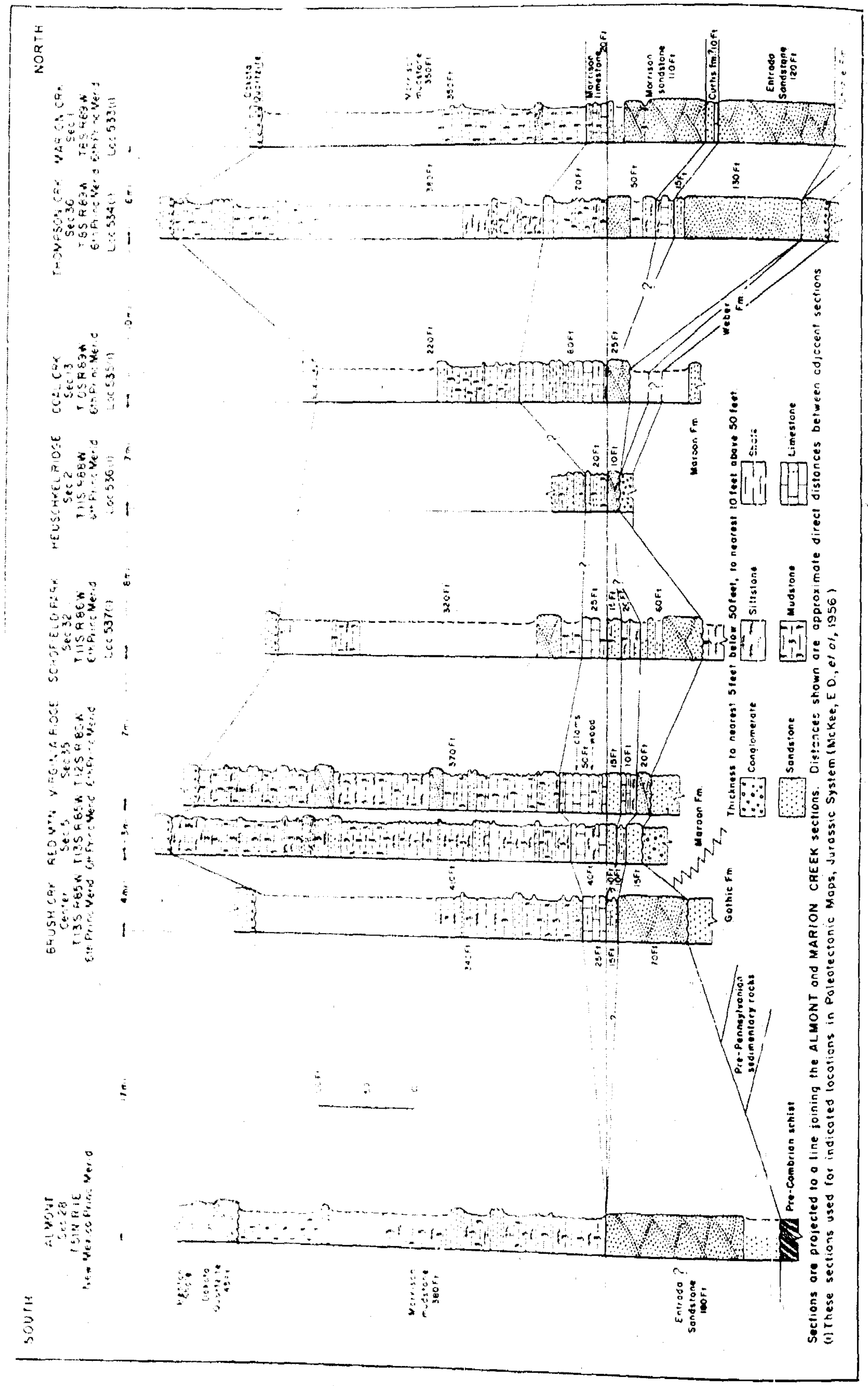

FIG. 2.—Jurassic columnar sections in Elk Mountains.

dark gray limestone with interbedded dark gray to black, calcareous shale is distinct from limestone and mudstone in the overlying Morrison formation. Baker, Dane, and Reeside (1936, pp. 18–19, Fig. 3, sec. 70) report fossils characteristic of the Curtis formation a few feet above the Entrada sandstone at Snowmass Canyon 17 miles southeast of Thompson Creek. Tentative correlation with this outcrop of the Curtis formation is proposed on the basis of its similar stratigraphic position and because it also contains distinctive fine clastic and carbonate material. It is suggested that these rocks are a more shoreward facies of the Curtis formation at Snowmass Canyon. The upper part of the basal sandstone sequence is assigned to the Morrison formation, again following Baker, Dane, and Reeside (1936, p. 27, Fig. 5, secs. 15 and 19).

The basal sandstone is much thinner at Coal Creek and Heuschkel Ridge and does not contain interbedded fine clastic or calcareous rocks. As satisfactory criteria for separating the basal sandstone member of the Morrison formation from the Entrada sandstone were not observed, the formational status of the sandstone here is left indefinite. The basal sandstone sequence at Schofield Park reaches an intermediate thickness of 100 feet and is divided by a 20-foot interval of fine clastic rock. This interval, as well as similar rocks on the south, is tentatively assigned to the Curtis formation because it contains limestone beds similar to those of the Curtis formation and because it occurs within the sandy basal sequence. Two sandstone units separated by fine clastic and carbonate Curtis (?) formation are also recognized, although thinner, at Virginia Ridge and Red Mountain. Vanderwilt (1937, pp. 33–36), in previously assigning both sandstone beds at Virginia Ridge and Schofield Park to the Entrada sandstone, apparently did not differentiate the fine, calcareous rock separating them. Baker, Dane, and Reeside (1936, p. 27, Fig. 5, sec. 72) were unable unequivocally to assign the sandstone at Schofield Park to either formation and, after expression of doubt, arbitrarily placed it in the Morrison formation. The sequence at Hunter's Hill is similar to that at Schofield Park, consisting of 30 feet of Entrada sandstone, 30 feet of covered rock presumably including the Curtis (?) formation, and 25 feet sandstone assigned to the basal member of the Morrison formation.

The basal sandstone sequence at Brush Creek and Almont differs significantly in having only a single, thick massive unit of medium to fine, buff to white, medium-scale cross-bedded sandstone. This unit is 180 feet thick at Almont, in sharp contrast to the very thin sandstone at the base of the Morrison formation shown in Baker, Dane, and Reeside's (1936, p. 18, Fig. 3, sec. 32) nearby Gunnison section. Craig (McKee and others, 1956, Pls. I and V, loc. 439) assigns the basal sandstone in this area to the Morrison formation. Craig (personal communication) also points out its similarity to the Bluff-Junction Creek sandstones of southwestern Colorado and to sandstone in the lower part of the Morrison formation at Burns as well as the fact that it does not closely resemble Entrada sandstone of normal aspect. Nevertheless the sandstone at Almont is tentatively assigned to the Entrada sandstone because of its similarity to the Entrada sandstone at Thompson Creek and Marion Creek and because of the apparent continuity of the Entrada sandstone between the two areas.

The Entrada formation in the Elk Mountains is thus considered a wedge-like mass, thinning generally southwest toward the Uncompahgre uplift. This wedge also thins across minor positive areas extending into the Coal Creek-Heuschkel Ridge and Virginia Ridge-Red Mountain districts. The Curtis (?) formation in the same area consists of a thin, discontinuous sheet of fine clastic and carbonate rocks. The basal sandstone member of the Morrison formation repeats the pattern of the Entrada sandstone in the central and northern Elk Mountains, but is assumed absent in the southern part of the range.

Non-marine limestone with interbedded fine clastic rock characterizes the medial limestone member of the Morrison formation which overlies the basal sandstone sequence. Baker, Dane, and Reeside (1936, p. 59) and Vanderwilt (1937, p. 37) mention prominent non-marine limestone beds in the lower Morrison of the Roaring Fork Valley, Snowmass Mountain area, and at Virginia Ridge. This limestone is fine-grained to sublithographic, light gray, and weathers white. It contains prominent fresh-water clam shells at many localities and bits of organic debris at most places. Coniferous wood of an undescribed genus (H. P. Banks, personal communication) occurs in interbedded mudstone at Virginia Ridge. As characteristically developed, this limestone is differentiated from that in the overlying mudstone by its light gray color, thicker beds, parallel bedding, fossils, and relative purity. It lacks the included sand, dark color, thin bedding, and associated black shale of the Curtis (?) formation. The non-marine limestone member is readily recognized and includes little mudstone between Brush Creek and Schofield Park, at Hunter's Hill, and at Coal Creek. The member is poorly defined because of interbedded mudstone at Thompson Creek and Marion Creek and is not recognized at Almont.

The overlying mudstone member of the Morrison formation ranges from 320 to 380 feet thick, excepting the 410-foot Red Mountain section and the 220-foot Coal Creek section. Green and purple mudstone in layers up to several feet thick dominates the member and weathers to form bench-like slopes. Blocky chips of weathered mudstone retain the color of the fresh rock. Layers of dark gray to green or purple-gray siltstone and sandstone are of secondary importance. These layers are lenticular and generally have a sharp basal contact, graded bedding, and small-scale cross-bedding. Coarse material is notably absent, excepting chips of reworked mudstone. The sandstone and siltstone is generally less well sorted to size and composition than the Entrada sandstone or sandstone member of the Morrison formation, but some coarser beds are comparable with the basal sandstone member of the Morrison formation. Beds range in thickness from less than 1 inch to approximately 2 feet and may be grouped in units 20 feet thick. These units are lenticular and not traceable over long distances, but comparison of the Virginia Ridge and Red Mountain sections (Fig. 2) suggests that some are at

least 3 miles long. Furthermore, generally coarser sequences within the mudstone seem to be roughly correlative over longer distances (Fig. 2). Some of the mudstone is calcareous and grades into muddy, nodular limestone. These rocks are dull purple to gray-purple, form nodular beds 1-4 inches thick, and weather to thin plates rather than blocky chips.

The mudstone member has not yielded fossils in this area. It appears lithologically similar to the Brushy Basin member of Craig and others (1955) but does not contain abundant coarse clastic rocks characteristic of the Salt Wash sandstone and Westwater Canyon members on the west and southwest.

The Morrison formation is succeeded by medium to coarse, buff, generally quartzitic sandstone of the Dakota quartzite. At some localities, granule or pebble conglomerate marks the base of the Dakota quartzite. North of Almont the two formations are easily recognized, but near Almont abnormally thin Dakota quartzite rests on 65 feet of covered rocks. Twenty-five feet of mudstone resting on a prominent 7-foot sandstone ledge are below the covered interval. This sandstone might be confused with the basal Dakota quartzite as minor interbeds of mudstone are known in the Dakota quartzite. The sandstone is, however, closely similar to sandstone in the Morrison mudstone and the overlying mudstone is more closely comparable with Morrison mudstone than with Dakota mudstone.

The roughly similar pattern of thickness of the Entrada sandstone and the underlying Maroon and Gothic formations (Langenheim, 1952, 1954) suggests the continued importance of the Uncompahgre element of the Ancestral Rockies during Jurassic time in this area. Local extent of this positive area toward the northeast is, however, restricted to the central part of the Elk Mountains during deposition of the Entrada sandstone. Relative uniformity of the mudstone member of the Morrison formation, furthermore, suggests that the Uncompahgre element was inactive in latest Jurassic time and no residual highlands are indicated by the rocks.

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SNOWY RANGE FORMATION (UPPER CAMBRIAN) OF MONTANA[1]

CHRISTINA LOCHMAN-BALK[2]
Socorro, New Mexico

In the Treatise on Marine Ecology and Paleoecology, Volume 2, Geological Society of America Memoir 67 (1957), the juxtaposition of two articles—"Paleoecology of the Precambrian of Northwestern North America," Chapter 7, and "Paleoecology of the Cambrian in Montana and Wyoming," Chapter 8—called attention to a duplication of the term Snowy Range as a rock name.

The name Snowy Range series was used by Runner (1928) to include formations of Precambrian age described by Blackwelder (1926) in the Medicine Bow Mountains, Wyoming. Blackwelder (1935), however, did not use the name Snowy Range series in his paper, "Summary of the Pre-Cambrian Rocks of Utah and Wyoming," which included a discussion of the Precambrian rocks in the Medicine Bow Mountains. According to the records of the Geologic Names Committee of the U. S. Geological Survey, the name Snowy Range series has not appeared in print subsequently until the 1957 article by Fenton and Fenton in which the series name was used without reference to the formation names established by Blackwelder. Apparently through an oversight the use of the term Snowy Range series in 1928 was not entered by Wilmarth in the "Lexicon of Geologic Names of the United States" (1938) as at that time abstracts as well as formal papers were checked for new nomenclature. However, now authors are advised against introducting new names in abstracts.

In 1938 Dorf and Lochman established the name Snowy Range formation for an Upper Cambrian lithic unit in southern Montana and in their 1940 paper, "Upper Cambrian Formations in Southern Montana," the unit was fully discussed, giving a detailed lithologic description of the unit at its type locality. Subsequently, the name has been used consistently throughout southern Montana and has appeared in print many times.

According to article 9 of "Classification and Nomenclature of Rock Units," Ashley *et al.* (1933), and Report 4 of the American Commission on Stratigraphic Nomenclature on "Nature, Usage, and Nomenclature of Rock-Stratigraphic Units," Cohee *et al.* (1956), a name that has become well established in use shall not be displaced, merely on account of priority, by a term not well known or only slightly used. George V. Cohee, chairman of the Geologic Names Committee of the United States Geological Survey, advises: "that the Snowy Range formation of Dorf and Lochman has been adopted by the U. S. Geological Survey and at present we do not see any need for a change in our official classification."

It therefore seems advisable that the widely used name Snowy Range formation be retained for the Upper Cambrian unit rather than abandoned in favor of

[1] Manuscript received, September 5, 1957.

[2] New Mexico Institute of Mining and Technology.

the slightly used series name in the Medicine Bow Mountains. I wish to thank R. M. Stainforth for calling my attention to the duplication of names.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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DISCUSSION

WHENCE CAME THE HYDROCARBONS?[1]

WALLACE E. PRATT[2]
Carlsbad, New Mexico

In his presidential address, as reported in the July *Bulletin*, pages 1387–1402, our salty past-president, Ted Link, takes mild issue with Fred Hoyle, author of *Frontiers of Astronomy*, and chafis him lightly for his cavalier dismissal of our favorite theory of the organic origin of oil. Hoyle dubs this theory an idea that oil is "produced from decayed fish—a strange theory that has been in vogue for many years."

Ted then looks skeptically at Hoyle's own theory of the origin of the earth's oil resources. Hoyle—noting the common occurrence of hydrocarbons in meteorites—suggests that our stores of hydrocarbons have been concentrated out of the original disseminated hydrocarbon content of the planetesimals and meteoritic fragments which constitute the bulk of the earth substance.

Ted is clearly not convinced of the validity of this theory of origin but even if it were valid our oil might still have had an organic origin, he thinks because the hydrocarbons of meteorites may themselves be of organic origin. Many meteorites which the earth sweeps up in its orbit around the sun are believed to be fragments of a disrupted former planet whose own orbit lay between those of Mars and Jupiter. This former planet, Ted believes, may have supported life.

These reflections on the petroleum geology of the Planetary system lead Ted to a plea for closer cooperation and exchange of opinion between earth scientists and astronomers. "The origin of life itself must be introduced into the picture" . . . "In general the biologists believe . . . that sun-light acting upon certain inorganic substances under given physical conditions gives rise to what appears to be the most primitive of organic cells. Such being the case, it appears that if the earth were a globe all by itself wandering about in space too far removed from our sun, or any other similar sun, no life would be generated on it, and consequently no hydrocarbons as we know them."

Petroleum geologists will applaud our past-president's plea that geologists and astronomers work in closer unison. Both sciences are confronted with problems of the occurrence of hydrocarbons. But, geologists, overwhelmingly devoted to a theory of organic origin for the earth's bounteous stores of hydrocarbons, are puzzled that the astronomers find evidences of even larger volumes of hydrocarbons than the earth possesses, on those planets most distant from the sun—"Too far removed from our sun, or any other similar sun" for life to "be generated," to quote again our past-president.

Methane, the simplest hydrocarbon, from which by polymerization the whole petroleum family can be derived, abounds in the presumably lifeless outer regions of the solar system. According to *Encyclopaedia Britannica* (1956):

> The conspicuous absorption bands in the red and infra-red of Jupiter's spectrum arise from ammonia and methane. The methane bands corresponds to about ½ mile of methane at atmospheric pressure.
>
> Saturn's spectrum (temperature −150°C.) displays red and infra-red absorption bands that have been identified with compounds of ammonia and methane.
>
> The spectrum of Uranus contains a number of absorption bands similar to those in the spectra of Jupiter, Saturn and Neptune.
>
> Neptune's spectrum shows that the absorption by its atmosphere of the red in the incident sunlight, is due, like that of Jupiter, Saturn and Uranus primarily to strong bands of methane. Neptune's temperature is placed at −330°C. It is 30 times as distant from the sun as is the earth. The thickness of its methane blanket, measured under atmospheric conditions of temperature and pressure, is estimated at 25 miles (50 times that of Jupiter).

If all this inconceivable volume of hydrocarbons came from pre-existing life, where did that life abide?

Whence came the hydrocarbons?!

[1] Manuscript received, August 1, 1957.

[2] Consultant, Box 209, Carlsbad.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available to menbers.

DÉTERMINATION PRATIQUE DES FOSSILES, BY ANDRÉ CHAVAN AND ANDRÉ CAILLIEUX

REVIEW BY NORMAN D. NEWELL[1]
New York, N. Y.

Détermination Pratique des Fossiles, by André Chavan and André Cailleux. 388 pp., 586 figs., Masson et Cie., Éditeurs, 120 Boulevard Saint-Germain, Paris 6e, France. Price, 5,800 fr.

This is an attempt to provide general geologists with a handy one-volume guide for the identification of genera of fossil animals, including both invertebrates and vertebrates, and plants. Publishers have long been aware of a real need for handbooks on fossils comparable with the popular guides available for identification of minerals, plants, insects, *etc.* Fossils are very much neglected in this publication field for very good reasons. The market is small and diffuse, and the kinds of fossils are legion in number. They are far more diverse than living birds, which require many fat volumes for even summary descriptions. Thus it is out of the question to assemble the data in one volume on all the fossil genera that are likely to be encountered by amateur or field geologist. Yet general handbooks that are incomplete are necessarily of limited value.

The most useful handbooks in paleontology illustrate and describe the chief species of particular regions. Because of the limited market this kind of publication is generally feasible only for public agencies such as geological surveys and natural history museums.

The fossil genera selected for this book are mainly cosmopolitan with emphasis on Mesozoic and Cenozoic forms. Genera are broadly conceived (*e.g.*, the fusulines are represented by two genera), and not all of the fossils cited are illustrated. There are more than 2,900 entries and these are covered in an extraordinary synthetic key of 150 pages, similar to those of entomology and botany, to aid in identification.

The general plan of the book suggests that the authors have written especially for geologists and amateurs with little or no formal training in paleontology. From the standpoint of the amateur this may be considered laudable although he probably would consider the book very expensive. If the field geologist considers the accurate identification of his fossils really important, he will, of course, have the good judgment to submit them to a qualified expert for study.

RECENT PUBLICATIONS

ALBERTA

*"Cambrian and Precambrian Geology of Southern Alberta," by William Carruthers Gussow. *Alberta Soc. Petrol. Geol. Guidebook*, 7th Ann. Field Conf., Waterton, September, 1957. Reprint of 15 pp., 2 figs., 4 tables.

AUSTRALIA

*"The Oil Geology of the Australasian Regions," by J. C. M. Taylor. *Petroleum*, Vol. 20, No. 9 (September, 1957), pp. 327–30; 1 photo, 1 map. Leonard Hill Technical Group, Stratford House, 9 Eden Street, London NW. 1, England.

[1] Professor of Geology, Columbia University. Review received, August 29, 1957.

BRITISH GUIANA

*"Report on the Oil Reconnaissance Survey of the Coastal Area North West District, British Guinea," by D. Bleackley. *Rept. Geol. Survey Dept. Brit. Guiana, 1955* (1956), Appendix II, pp. 30–36. Georgetown, Demerara. Price of complete report, $2.

CALIFORNIA

"The Pennsylvanian and Permian Rocks of the Southern Inyo Mountains, California." *U. S. Geol. Survey Bull. 1061-A* (1957). Govt. Printing Office, Washington 25, D. C. Price, $0.15.

"Geology of a Part of the Manly Peak Quadrangle, Southern Panamint Range, California," by Bradford K. Johnson. *Univ. California Pub. Geol. Sci.*, Vol. 30, No. 5 (1957), pp. 353–424; Pls. 43–46; 9 figs. in text. University of California Press, Berkeley and Los Angeles. Price, $1.50.

COLORADO

*"Recent Developments in Oil Shale," by Arthur Matzick and Russell J. Cameron. *World Petroleum*, Vol. 28, No. 10 (September, 1957), pp. 68–71; 5 photos, 2 sketches.

GENERAL

Pre-Permian Handbook of the Hugoton Embayment, edited by William R. King (December, 1956). County-by-county data on pre-Permian tests in Hugoton embayment of Anadarko basin, embracing parts of southwestern Kansas, southeastern Colorado, the Texas Panhandle, and all of the Oklahoma Panhandle. 214 pp. 6×9 inches. Clothbound. Liberal Geological Society, Box 504, Liberal, Kansas. Price, $15.

"Trough Facies of the Hugoton Embayment in Morton County, Kansas, Texas County, Oklahoma, and Cimarron County, Oklahoma," *Liberal Geol. Soc. Type Log No. 2* (January, 1956). Prepared by Stratigraphic Committee, W. R. King, chairman. *Ibid.* Price, $2.

"Bibliography of North American Geology, 1940–1949," by R. R. King, E. M. Thom, E. S. Loud, and Marjorie Hooker. *U. S. Geol. Survey Bull. 1049* (1957), Pt. 1, Bibliography, pp. 1–1033; Pt. 2, Index, pp. 1035–2205. Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price, $5.75 per set.

"Annotated Bibliography and Index Map of Salt Deposits in the United States," *U. S. Geol. Survey Bull. 1019-J*. Govt. Printing Office, Div. Public Documents, Washington 25, D. C. Price, $0.60.

*"Behavior of Materials in the Earth's Crust," 2d annual symposium on Rock Mechanics. *Quar. Colorado School Mines*, Vol. 52, No. 3 (Golden, July, 1957). 306 pp., illus. Price, $2.

KENTUCKY

"Coal Resources of the Campton Quadrangle, Wolfe, Lee, and Breathitt Counties, Kentucky," by R. P. Briggs. *U. S. Geol. Survey C42*, Coal Inv. Map Ser. (September, 1957). Sheet 41×42 inches. Geological Survey, Washington 25, D. C. Price, $0.75.

LOUISIANA

*"Pleistocene Beds near the Edge of the Continental Shelf, Southeastern Louisiana," by A. H. Akers and A. J. J. Holck. *Bull. Geol. Soc. America*, Vol. 68, No. 8 (August, 1957), pp. 983–92; 3 figs., 2 pls.

"Nearsurface Sediments of the Continental Shelf off Louisiana," by H. N. Fisk. *Proc. 8th Texas Conf. Soil Mechanics and Foundation Engineering* (Austin, September 14–15, 1956). Reprint of 36 pp., 26 figs. in colors.

MARYLAND

*"Miocene Fossils of Maryland," by Harold E. Vokes. *Maryland Dept. Geol. Mines and Water Res. Bull. 20* (Baltimore, 1957). 85 pp., 31 pls.

MEXICO

*"Bosquejo Geólogico del Territorio Sur de la Baja California," by Federico Mina U. *Bol. Asoc. Mexicana Geol. Petroleros*, Vol. 9, Nos. 3–4 (March-April, 1957), pp. 139–269; 18 figs. Apartado Postal 20901, Paseo de la Reforma 1, Mexico 1, D. F.

MIDDLE EAST

*"A Short History of Exploration in Kuwait," by A. F. Fox. *World Petroleum*, Vol. 28, No. 10 (September, 1957), pp. 94–99, 102, 107; 3 figs.

MINNESOTA

"Upper Middle Ordovician Stratigraphy of Fillmore County, Minnesota," by Malcolm P. Weiss. *Bull. Geol. Soc. America*, Vol. 68, No. 8 (August, 1957), pp. 1027–62; 2 figs., 5 pls.

NORTH DAKOTA

"Halite Deposits in North Dakota," by Sidney B. Anderson and Dan E. Hansen. *North Dakota Geol. Survey Rept. Inv. 28* (Grand Forks, September, 1957). 2 sheets. Price, $1.

Pre-Mesozoic Paleogeologic Map. Ibid., special map. Scale 1:1,000,000. Price, $1.

OHIO

*"Geologic Cross Section of the Paleozoic Rocks from Northwestern to Southeastern Ohio," by George G. Shearrow. *Ohio Geol. Survey Rept. Inv. 33* (Columbus, 1957). 42 pp., 2 figs. Cross section on sheet 26×21 inches. Price, $0.50 plus 2¢ in Ohio.

OKLAHOMA

Geologic Map of Criner Hills, Oklahoma, by E. A. Frederickson. *Oklahoma Geol. Survey Map GM-4*. In color. Scale 1:20,000. Norman, Oklahoma (1957). Price, mailed in tube, $0.75.

Proc. 5th Biennial Symposium on Subsurface Geology, edited by Carl A. Moore, Univ. Oklahoma School of Geology, Norman (1957). 167 pp., 10 original articles. Problems of carbonate reservoirs. University of Oklahoma, Business and Industrial Services, Extension Division, North Campus. Price, $5.

OKLAHOMA-TEXAS PANHANDLE

*"Pinpointing Panhandle Possibilities," by Carl A. Moore. *World Oil*, Vol. 145, No. 4 (Houston, Texas, September, 1957), pp. 83–88; 2 figs., 1 table.

ROCKY MOUNTAINS

**Rocky Mountain Oil Directory, 1957–58*. 14th annual issue. 102 pp. Compiled and published by the editors of the monthly *Rocky Mountain Oil Reporter*, Box 1460, Denver, Colorado. Price, $3.

RUSSIA

Geological Science Section of Proceedings of Academic of Sciences, USSR (Doklady), (1957), covering advanced Russian research in geology, in complete English translation. 6 issues per year. Staple bound, including all illustrations. Consultants Bureau, 227 West

17th Street, New York 11, N. Y. Annual subscription, $200.00. Single articles, $5. Table of contents free on request.

***Papers on Origin and Migration of Petroleum* (1955). A collection of 11 papers in Russian. 362 pp., 30 figs. The Geological Institute, Academy of Science, USSR, State Public Library, Ukraine Academy of Science, USSR, Kiev, Vladimirski 55a. Price, 18 rub., 55 kop.

TASMANIA

*"Stratigraphy of Tasmanian Limestones," by Maxwell R. Banks. *Tasmanian Dept. Mines, Geol. Survey, Min. Res. 10* (Hobart, 1957), pp. 39–85; 12 figs. Reprint by Univ. Tasmania Geol. Dept., Pub. 48 (June, 1957).

*"A Type Section of the Permian System in the Hobart Area, Tasmania," by M. R. Banks and G. E. Hale. *Papers and Proc. Royal Soc. Tasmania*, Vol. 91 (Hobart, 1957), pp. 41–64; 9 figs. Reprint by Univ. Tasmania Geol. Dept., Pub. 52 (June, 1957).

TENNESSEE

"Geology and Coal Resources of the Pioneer Quadrangle, Scott and Campbell Counties, Tennessee," by Kenneth J. England. *U. S. Geol. Survey Map C39*, Coal Inv. Ser. (August, 1957). Sheet 42×56 inches. Scale 1:24,000 (1 inch equals 2,000 feet). Geological Survey, Washington, D. C. Price, $0.75.

TEXAS

***Occurrence of Oil and Gas in West Texas*, compiled by the Bureau of Economic Geology, University of Texas, in cooperation with the West Texas Geological Society. Edited by Frank A. Herald. *Univ. Texas Pub. 5716* (Austin, 1957). 442 pp., illus. 112 papers by 104 authors. 8.5×11 inches. Clothbound. 2d volume in a series on data pertaining to occurrence of oil and gas in Texas. The prior volume was, "Occurrence of Oil and Gas in Northeast Texas" (Pub. 5116). Contains structure maps, graphic type sections of rocks penetrated, and cross sections for most of the fields. Bureau of Economic Geology, University Station, Box 8022, Austin 12, Texas. Price, $10.

UTAH

*"Collapse Features, Temple Mountain Uranium Area, Utah," by Paul F. Kerr, Marc W. Bodine, Jr., Dana R. Kelley, and W. Scott Keys. *Bull. Geol. Soc. America*, Vol. 68, No. 8 (August, 1957), pp. 933–82; 33 figs., 3 pls.

WYOMING

"Geologic and Structure Contour Map of the Tisdale Anticline and Vicinity, Johnson and Natrona Counties, Wyoming," by Everett E. Richardson. *U. S. Geol. Survey OM 194*, Oil and Gas Inv. Ser. (September, 1957). Sheet 40×51 inches. Scale 1:31,680 (2 inches equal 1 mile). Geological Survey, Washington D. C., and Denver Federal Center, Denver, Colorado. Price, $0.50.

Southwest Wind River Basin Guidebook, 1957, prepared by the Guidebook Committee for the 12th Annual Field Conference of the Wyoming Geological Association. 226 pp., 4 enclosures. Stratigraphy, structure, maps, and extensive road logs. Petroleum Information, Sales Agent, Wyoming Geological Association, Box 2452, Casper, Wyoming. Price, bound volume, $8.

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ASSOCIATION ROUND TABLE

ANNOUNCEMENT OF ANNUAL MEETINGS
A.A.P.G.-S.E.P.M.
LOS ANGELES, CALIFORNIA, MARCH 10–13, 1958

(The Pacific Section is host)

The 43d Annual Meeting will be held jointly with S.E.P.M.'s 32d at the Biltmore Hotel in Los Angeles, March 10–13, 1958. These meetings will be outstanding in every respect. The Philharmonic Auditorium, directly across the street from Convention Headquarters, will be used for joint meetings and A.A.P.G. technical sessions. Exhibits will be in the Biltmore Ballroom and Foyer, and S.E.P.M. technical sessions will be in the Biltmore's Music room. Association fellowship will be promoted in all these places and in the Biltmore's beautiful "Galleria" rooms where registration will begin on March 9 and continue throughout the convention.

Technical Program.—The list of technical papers will appear in a later Bulletin. John Hazzard and the Program Committee already have a long list of excellent papers. A joint symposium arranged by S.E.P.M. and the A.A.P.G. Research Committee on correlation methods and criteria will be held Monday. Tuesday morning after joint opening ceremonies, H. S. M. Burns, president of Shell Oil Company, New York, will speak on a topic of importance and interest to all members. Technical sessions of A.A.P.G. will offer a collection of papers of continental scope concerning lands bordering the Pacific and also on the subject of overthrusting in relation to oil occurrences. Outstanding papers of general interest on other subjects will be presented at still another session. S.E.P.M. will cover a wide range of topics: silica in sediments, mineralogy, sedimentary petrology, and paleontologic and stratigraphic subjects.

Field Trips.—Harold H. Sullwold, Jr., and a capable and enthusiastic committee are planning the following trips:

A. 320-mile, 3½-hr. aerial-guided tour affording an unsurpassed view of the spectacular structural geology of Southern California (repeated several times)	approx.	$30.00
B. To Western L. A. Basin and Harbor area, Mon., 8 hrs., including lunch	approx.	5.00
C. To Northern L. A. Basin, Wed., 8 hrs., including lunch	approx.	5.00
D. To SE. L. A. Basin, Thurs., 8 hrs., including lunch	approx.	5.00
E. Ventura Basin, Fri., 10 hrs., including lunch	approx.	6.00
F. L. A. County Museum and Hancock Foundation (repeated several times)	4 hrs.	1.50

A continuous program of field excursions is being planned to operate throughout the convention as both a geological supplement to, and an outdoor diversion from, the technical sessions. A select crew of writers and guides is being assembled to compile the guidebook and conduct the tours on the land, on the sea, and in the air. Committee chairman is Harold H. Sullwold, Jr., and guidebook editor is James W. Higgins. Road logs for all the trips, as well as many additional geological articles on the Los Angeles and Ventura basins, will be included in a single guidebook. Washed Foraminifera typical of the formations visited will be provided trip-goers by the S.E.P.M.

In order to make it possible for you to mark the proper boxes in the pre-convention questionnaire a brief summary of each trip is herewith presented. These plans are fairly definite, but not absolutely fixed, and are therefore subject to some modifications.

TRIP A. AIRPLANE TRIP. This trip, arranged by John Shelton, will be by chartered airliners, probably the Constellation Super G. It will cover 320 miles, affording the geological sight-seer opportunity to see and photograph the typical spectacular faults, folds, geomorphology, and oil fields of a large part of Southern California. The flight will include the Los Angeles, Ventura, Cuyama, and San Joaquin Valley oil districts with their structurally complex adjacent mountains plus a 75-mile segment of the San Andreas fault. These flights are planned for early morning and late afternoon to take advantage of side lighting and will be repeated as often as necessary to satisfy demand. Each flight will be directed and narrated by a competent guide. Seats will not be sold over the wing; the plan is to have two passengers at each large window with a good view. As the planes must be reserved in advance it may be necessary to sell some seats by mail for the early flights. Cancellation and refund may be necessary in case of bad weather or insufficient sales. The estimated cost is $30 including bus ride to airport.

TRIP B. WESTERN LOS ANGELES BASIN. This trip will include several of the oil fields along the fabulous Newport-Inglewood trend, outcrops in the Palos Verdes Hills, the huge Wilmington oil field with its drastic subsidence problems, and a two-hour boat trip through Long Beach harbor to an offshore oil field on a man-made island. Tom Rothwell is in charge, and each bus will have an eloquent guide (as on all the trips). This trip which is scheduled for Monday, will take about eight hours, and will cost about $5 including lunch.

TRIP C. NORTHERN LOS ANGELES BASIN. Paul See has arranged an eight-hour trip for Wednesday which will include structure and stratigraphy exposed at the surface in the Puente Hills-Santa Monica Mountains area, about a dozen oil fields such as the rich Santa Fe Springs and Whittier fields, plus additional points of interest such as the U. C. L. A. Campus, La Brea pits, and unusual drilling techniques in residential and industrial areas. The cost is estimated at $5 including lunch.

TRIP D. SOUTHERN AND EASTERN LOS ANGELES BASIN. This trip contains fewer oil fields, but is no less interesting to a geologist. It will cover the stratigraphy and structure of the San Joaquin Hills and Santa Ana Mountains and will be routed by such points of interest as Disneyland, the remarkable batteries of wells draining the off-shore pools at Huntington Beach, Newport Beach resort area, Santiago Canyon, Santa Ana Canyon, and the Chino fault. Lunch will be provided on the beach near Laguna where you can see unusual outcrops in the sea cliff while running your toes through the sand and munching on a ham sandwich. Jack Schoellhamer is in charge of this trip which is scheduled for Thursday. This is about an eight-hour trip and will cost about $5 including lunch.

TRIP E. VENTURA BASIN. This trip is slated for Friday, the day following the convention, because it will require about ten hours. Rex Grivetti has arranged the trip with a series of stops at which the geology will be clearly exhibited and explained. The Castaic basin, the major Oak Ridge and San Cayetano thrust faults which conceal many newly found important oil pools, the beautifully exposed anticlines at South Mountain and Ventura Avenue fields, king-size oil seeps, the immensely thick section of folded Tertiary strata, and well exposed turbidity current structures will be featured. The cost will be about $6 including lunch with a view.

TRIP F. CULTURAL TRIP. Professor W. H. Easton is arranging an afternoon program which will include a short bus ride to the Los Angeles County Museum, short walk through the campus of the University of Southern California, visit to the Allan Hancock Foundation, thence back to the Biltmore Hotel by bus. At the museum the primary interest to geologists will be the La Brea room, renowned for its Pleistocene mammal restorations, while the wives would perhaps be more interested in the equally impressive Costume Gallery and the display of French Rooms. The Hancock Foundation is primarily concerned with oceanography and contains modern laboratories in sedimentation

COPY OF RESERVATION APPLICATION FORM
HOTEL RATES

Hotel	Singles	Rooms For Two Persons: Doubles	Twins	Suites
Biltmore (Convention Headquarters)	$7.00–10.00	$ 9.50–12.50	$11.00–16.00	$20.00–30.00
Alexandria	5.00– 8.00	6.50–10.00	8.00–10.50	12.00–25.00
Hayward	4.50– 8.50	6.00–10.00	7.00–10.00	11.00–14.00
Mayflower	6.00– 9.00	6.00– 9.00	7.00–10.00	14.50–18.00
New Clark	5.00– 8.00	6.00–10.00	7.00–12.00	18.00–24.00
Savoy Plaza	5.00– 7.00	8.00– 9.00	8.00– 9.00	
Statler	8.00–22.00	11.50–16.50	14.00–22.00	22.00 & Up

(This is copy of form already mailed to members)

ALL RESERVATIONS MUST BE RECEIVED PRIOR TO FEBRUARY 14, 1958

Housing Bureau A.A.P.G.-S.E.P.M.
404 South Bixel Street
Los Angeles 54, Calif.

DON'T BE A "NO-SHOW"

Please reserve the following accommodations for the A.A.P.G.-S.E.P.M. Meetings in Los Angeles, March 10–13, 1958.

Single Room ________ Double-Bedded Room ________ Twin-Bedded Room ________

2-Room Suite ________ Other Type of Room ________ First Choice Hotel ________

Rate: From $________ to $________ Second Choice Hotel ________

Third Choice Hotel ________

ARRIVAL TIME (Date) ________ Hour ________ A.M. ________ P.M.

Leaving (Date) ________ Hour ________ A.M. ________ P.M.

THE NAME OF EACH GUEST MUST BE LISTED. Therefore, please include the names of both persons for each double room or twin-bedded room requested. Names and addresses of all persons for whom you are requesting reservations and who will occupy the rooms asked for:

____

(Individual Requesting Reservations:)

Name________________________

Company________________________

If the Hotels of your choice are unable to accept your reservation the Hotels Convention Reservation Bureau will make as good a reservation as possible elsewhere provided that all hotel rooms available have not already been taken.

POLL TO HELP THE COMMITTEES

A.A.P.G. Registration Committee
c/o Continental Oil Company
1137 Wilshire Boulevard
Los Angeles 17, Calif

Members "probably coming" to the convention as well as all those whose plans to do so are already definite are asked to help hard working Convention Committees by checking appropriate squares below and returning to A.A.P.G. Registration Committee before November 1, 1957. This is for statistical use only; your best guess now will be helpful and you incur no obligation whatsoever. Return unsigned if you like, but please return it if you think you are coming.

	Yes	*Probably*	*No*
I plan to attend the convention	☐	☐	
I plan to bring my wife	☐	☐	☐
I shall want a reservation at a downtown hotel	☐	☐	☐

I plan to sign up for field trips as follows *A* ☐ *B* ☐ *C* ☐ *D* ☐ *E* ☐ *F* ☐

I plan to attend the social hour ☐; the dinner-dance ☐

My wife plans to attend the social hour ☐; dinner-dance ☐; fashion show luncheon ☐;

Disneyland tour ☐; ladies brunch ☐.

and life sciences at the research level. Cost will be about $1.50, and the trip will be repeated if demand is sufficient.

Entertainment.—Plans are being made for members and their ladies by Glen Ledingham and a group of imaginative and versatile assistants. Events will include a social "hour" (no charge) on Sunday, superbly arranged dinner dance at the new Beverly-Hilton Hotel in Beverly Hills on Wednesday (about $12.50 per plate), and for the ladies—a Fashion Show Luncheon and Studio tour (about $8), Disneyland tour ($4 up), Thursday Brunch ($1), and other attractive features will be available.

College and University Affairs.—Alumni functions will be arranged by a committee headed by John Isberg, Superior Oil Company, Box 3015, Los Angeles 54. Low-cost student housing ($4.50 for singles, $6.00 for double rooms) can be obtained on application to Warren Hagist, same address, and employment interviews will be arranged by Isberg's committee.

Hotel Reservations.—For your convenience in making hotel reservations, Los Angeles hotels and their rates are listed. Use the form already mailed you, indicating your first, second, and third choice. Because of the limited number of single rooms available, you will have a better chance of securing accommodations of your choice if your request calls for rooms to be occupied by two or more persons. *All reservations must be cleared through the Convention Housing Bureau.* ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE; ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED MUST BE INCLUDED.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Baird, Edward Redington, Houston, Tex.
Carlos S. Fleischmann, W. E. Belt, Jr., Harry H. Sisson
Bell, William Willard, Denver, Colo.
George H. Fentress, Howard H. Odiorne, Eugene M. Shearer
Bingham, Frederick Dana, Karachi, Pakistan
M. Dean Williams, Thomas H. Jones, James W. Bowler
Brehm, Donald Lee, Guatemala City, Guatemala
Glenn M. Fedderson, Edward M. Self, C. J. Nolte
Brown, Leonard Franklin, Jr., Austin, Tex.
L. M. Cline, L. R. Laudon, G. P. Woollard
Castro, Manuel John, Ventura, Calif.
Frank W. Bell, Lyle W. Smith, George C. Kuffel
Dietrich, Richard Vincent, Blacksburg, Va.
W. D. Lowry, Wayne E. Moore, Peter T. Flawn
Dooley, Roy M., Vandalia, Ill.
John J. Chapman, Jack L. Hough, Harold R. Wanless
Dorsey, Russell Alfred, Jr., Guatemala City, Guatemala
Rolf Engleman, H. J. Sawyer, W. B. Spangler
Fohr, Richard Austin, Ventura, Calif.
B. H. Mull, John M. Fouts, Jr., A. N. Johnson
Gregory, Robert Fulton, Los Angeles, Calif.
O. K. Fuller, Jr., Richard E. Faggioli, Thomas D. Barrow

Kafka, Fred Thomas, Rome, Italy
Augustin Pyre, C. H. Nett, C. H. Dresbach
Katz, Hans Rudolf, Lima, Peru, S.A.
Douglas Fyfe, Alfredo Rosenzweig, Alfred G. Fischer
Kenyon, Robert McPherson, Casper, Wyo.
Miles T. Rader, Jr., James H. McCourt, Don B. Gould
Knaap, Gerrit Johan, Caracas, Venezuela, S.A.
J. B. Woolley, D. A. Probst, E. W. Clark
Landes, Robert William, Calgary, Alta., Canada
L. G. Weeks, O. C. Wheeler, William E. Wallis
Lawler, James E., Madrid, Spain
L. P. Laudon, Glenn S. Dille, R. A. Stehr
Lee, Robert Everett, Regina, Sask., Canada
Dennis I. Holliss, C. D. Gould, John W. Porter
Madden, Trevor John, Toowong, Brisbane, Queensland, Australia
John L. Edwards, W. D. Mott, Ralph M. Perhac
Malarin, Lawrence F., Los Angeles, Calif.
James W. Higgins, John K. Cassell, Robert R. Knapp
Mathez, Muriel, Rutherford, N. J.
Paul F. Kerr, Charles H. Behre, Jr., Ethel Davis Roberts
Messineo, Anthony Vincent, Tulsa, Okla.
Paul W. Foster, Howard L. Cobb, Eugene R. Douglas
O'Driscoll, Elliot Sylvester, Adelaide, South Australia
R. C. Sprigg, E. A. Rudd, H. G. Raggatt
Schmidt di Friedberg, Paolo, Palermo, Italy
Giovanni Flores, Manuel Rigo de Righi, Enrico F. di Napoli-Alliata
Schwabenland, James Richard, Lafayette, La.
I. K. Nichols, James E. Werner, Park G. Ogden, Jr.
Winkle, Henry Norman, Oklahoma City, Okla.
Edwin P. Matthews, A. J. Howell, R. Browning Hudson

FOR JUNIOR MEMBERSHIP

Apple, John Boyd, Dallas, Tex.
Frank E. Kendrick, P. G. Russell, Fredda Bullard Lachman
Armstrong, Augustus Keathly, Albuquerque, N. Mex.
Kenneth E. Caster, William F. Jenks, V. C. Kelley
Carter, Peggy Lou, Albuquerque, N. Mex.
Henry S. Birdseye, Philip T. Hayes, V. C. Kelley
Cunningham, Harry H., Meeker, Colo.
L. W. LeRoy, John D. Haun, John R. Hayes
Davis, James Harrison, Houston, Tex.
Marcellus H. Stow, George Sawtelle, Shirley L. Mason
Duane, David Bierlein, Abilene, Tex.
Robert W. Decker, Andrew H. McNair, Robert W. Wagner
Espenschied, Ernest Kurt, Oildale, Calif.
S. H. Knight, Horace D. Thomas, D. L. Blackstone, Jr.
Evans, David Kenneth, San Francisco, Calif.
H. E. Vokes, Hubert C. Skinner, N. E. Crockett
Evans, George Carman, Caracas, Venezuela, S.A.
Donald A. Taylor, Claude W. Shenkel, Jr., W. L. Burnham
Fisher, Carl Edgar, Midland, Tex.
Perry E. Barnhart, Jr., Charles R. Jones, James A. Weig
Fulreader, Rufus Everett, Fairport, N. Y.
Robert G. Sutton, Donalson A. Robertson, William F. Jenks
Greenlee, Clark Wayne, Lawton, Okla.
Philip A. Chenoweth, E. L. Lucas, Carl A. Moore
Kirn, George Joseph, Solomon, Kan.
L. W. LeRoy, John R. Hayes, John D. Haun
Lagunoff, Victor, Fort St. John, B.C., Canada
L. M. Clark, R. S. Johnson, C. E. Cleveland
Lamb, Ronald Bennett, Durango, Colo.
J. Stewart Williams, Clyde T. Hardy, Dean F. Sharp
LeBleu, Thomas Robbins, Corpus Christi, Tex.
James R. Underwood, Jr., W. C. Bell, Richard W. Rush

Lent, Raymond Harry, Bradford, Pa.
William D. Pitt, E. A. Frederickson, Arthur J. Myers
Lerner, Theodore Allen, Kansas City, Mo.
Philip A. Chenoweth, V. E. Monnett, Doris M. Curtis
Nicholas, Anthony Maurice, Wichita Falls, Tex.
Ernest E. Tisdale, Richard H. Dawson, William M. Patterson
Ohrbom, Richard R. Altadena, Calif.
Orrin J. Wangsness, M. C. Lachenbruch, William J. Morris
Parks, William Scott, Greenwood, Miss.
R. R. Priddy, Ernest E. Russell, William H. Smith
Pooley, Robert Neville, Madison, Wis.
L. M. Cline, L. R. Laudon, G. P. Woollard
Stroker, Marion Clair, Caracas, Venezuela, S.A.
Claude W. Shenkel, Jr., Donald A. Taylor, Robert G. Couch
Strong, Walter Morrill, Ithaca, N. Y.
William R. Maehlberger, Keith Young, Sylvain J. Pirson
Straby, William Deming, Oklahoma City, Okla.
Warren O. Thompson, John Chronic, Theodore R. Walker
Tamesis, Emmanuel Valerio, Quezon City, P. I.
Joseph J. Graham, Hubert G. Schenck, Hans E. Thalmann
Ware, Glen Chase, Jr., Ventura, Calif.
John C. Crowell, M. W. Zaikowsky, R. M. Grivetti
Welch, William Walter, Jr., Laredo, Tex.
J. W. Hoover, H. L. Richardson, H. E. Stommel
Welsh, Gordon Jared, Bakersfield, Calif.
Everett W. Pease, Robert J. McConville, Francis A. Reynolds
Wilson, Wyant Stone, Abilene, Tex.
Joseph M. Wilson, John H. DeFord, Samuel P. Ellison, Jr.
Yarbrough, James Baxter, Meridian, Miss.
Ernest E. Russell, William H. Smith, Paul H. Dunn

FOR ASSOCIATE MEMBERSHIP

Green, William Newton, Magnolia, Ark.
John D. Marr, A. A. Hunzicker, R. R. Rosenkrans
Kimmel, Herbert Oscar, Regina, Sask., Canada
William J. Sanderson, Alex Milne, Peter Stauft
Pallister, Alfred Ernest, Calgary, Alta., Canada
John D. Hale, R. G. McCrossan, William P. Ogilvie
Putnam, Jack Wiley, Shawnee, Okla.
G. D. Gibson, Delbert F. Smith, E. F. Wroblewski
Ruby, James Murray, Moab, Utah
Robert R. Norman, Leo H. Hansen, Kenneth T. Smith

FOR TRANSFER TO ACTIVE MEMBERSHIP

Brown, Charles Ellis, Jackson, Miss.
L. R. McFarland, Grover E. Murray, Charles A. Hickcox
Chuman, Richard Wayne, Billings, Mont.
Loren E. Johnson, A. Rex Hafer, Jr., Warren A. Bald
Coe, A. V. Robertson, Cody, Wyo.
George S. Buchanan, Horace D. Thomas, James C. Gilbert
Davis, Doyle William, Harvey, La.
Douglas E. White, Keith Webb, R. Lee Hunter
Franks, Willie Edward, Caracas, Venezuela, S.A.
K. F. Dallmus, F. W. Johnson, J. H. Regan
Fargason, Pleasant Vernon, Spring Valley, N. Y.
Ben A. Tator, L. H. Lattman, C. H. Neff
Gardner, Erwin Alton, Jr., Oklahoma City, Okla.
Milan D. Maravich, T. Deane Rodgers, Howard M. Cotten
Gosman, Robert F., Billings, Mont.
Carl A. Moritz, W. E. West, Jr., James A. Barlow, Jr.
Grimes, Erwin E., Houston, Tex.
Matthew W. Daura, C. S. Hervey, C. W. Sanders
Hamilton, James Marvin, Midland, Tex.
E. A. Vogler, John D. Edwards, R. E. Oppel

Holt, Olin R., Bloomington, Ind.
John D. Patton, Gerald Carpenter, T. A. Dawson
Horowitz, Alan Stanley, Englewood, Colo.
R. Dana Russell, Lloyd C. Pray, Charles F. Deiss
Irwin, Joseph Stewart, Jr., Calgary, Alta., Canada
Sol Meltzer, R. S. Buckland, J. S. Crewson
Johnson, Glenden Fordice, Lake Charles, La.
Robey H. Clark, F. Alton Wade, W. R. Canada
Masten, Douglas Everett, Midland, Tex.
Jane Ferrell, R. P. McMurtry, Owen H. Blexrud
McGirk, Donald Dea, Bogota, Colombia, S.A.
W. C. Hatfield, George A. Severson, C. L. Lee
McNamee, Donald Fairman, Midland, Tex.
W. C. Osborne, Thomas F. Thagard, John E. Scherer
Mercurio, Richard Nicholas, Liberal, Kan.
Max G. Hare, Clayton L. Roloson, Glenn F. Thomas
Mudie, Walter, Calgary, Alta., Canada
E. A. Fulmer, F. G. Lines, J. G. Gray
Neill, Charles R., Jr., Billings, Mont.
Howard L. Garrett, James H. Clement, Higbee G. Williams
Oros, Margaret Olava, Urbana, Ill.
Alfred H. Bell, Harold R. Wanless, Virginia Kline
Perkins, James Murrie, Jackson, Miss.
L. R. McFarland, Clemont H. Bruce, John H. Marshall, Jr.
Reinke, Charles Austin, Jr., Midland, Tex.
Owen H. Blexrud, Walter Wayne Rove, H. V. Fitzgerald, Jr.
Ricci, Armando Tunon, Jr., Jackson, Miss.
L. R. McFarland, John H. Marshall, Jr., Clemont H. Bruce
Poadifer, Roy Eldon, Casper, Wyo.
John T. Rouse, John Paul Gries, Philip Andrews
Robertson, Jay Riley, Nowata, Okla.
Horace D. Thomas, D. L. Blackstone, Jr., William J. Sherry
Rucks, Norman Herbert, Lafayette, La.
K. O. Houston, W. Dow Hamm, Robert H. Robie
Schoenfeld, Albert Anthony, Abilene, Tex.
James H. Parrish, Joseph Wheeler Luckett, Jr., M. D. Mauck
Smith, Lyle Valentine, Tulsa, Okla.
Arthur J. Robnett, John J. Collier, L. H. Smith
Tipton, William Everett, Houston, Tex.
Lloyd D. Traupe, W. A. Thomas, Malcolm D. Bennett, Jr.
Welch, Bobby Guinn, Wichita Falls, Tex.
Wilmer R. Shirk, Lennart T. Teir, A. C. Baker
Yeager, John William, Paso Robles, Calif.
Fred E. Smith, Jr., R. R. Simonson, Thomas A. Roy

NOMINEES FOR A.A.P.G. PRESIDENT, 1958-1959

GEO. S. BUCHANAN

Vice-Pres., Dir., Husky Oil Co., Cody, Wyo.
Born, Sept. 1, 1902, Sterling, Colorado

Academic Training

Univ. Michigan, A.B., 22; M.S., 24
Harvard Business School, A.M.P., 50

Experience

1924-25	Pure Oil Co., Tulsa, paleon.
1925-28	Carter Oil Co., Tulsa, pal.-geol.
1928-32	Tulsa Oil Co., dir., chief geol.
1932-33	Barnsdall, Tulsa, Houston, c.g.
1934-39	Adams O.& G., Houston, pres., dir.
1940-44	Yegua Corp., Houston, pres., dir.
1944-53	Sohio Petrol. Co., Houston, v.-p.
1953-	Husky Oil Co., Cody, v.-pres., dir. Canadian Husky Oil Ltd., dir. Rimrock Tidelands, chm., dir. Israel-Amer. Oil Corp., pres., dir. Marmara Petr., Turkey, pres., dir. Argus Petr., Guatemala, pres., dir.

Publications.—Field of petroleum geology

Professional Affiliations (National)

Geological Society of America, fellow
American Geophysical Union
American Geographical Society
American Petroleum Institute (councillor)
Sigma Xi, Sigma Gamma Epsilon

A.A.P.G. Activity (Assoc., 25; Member, 29)

1939-40	Trustee, Revolving Pub. Fund
1940	New Way of Electing Officers
1940	Com. on Mimeographed Pub.
1942-43	Com. on Applications of Geology
1945-46	Business Com. (chm., 45)
1947	Vice-President
1957	Chairman, Business Committee

SHERIDAN A. THOMPSON

Vice-Pres., Dir., Manager of Exploration, Magnolia Petroleum Co., Dallas, Tex.
Born, Apr. 28, 1893, Conquest, New York

Academic Training

Yale Univ., B.A., 16; Grad. School, 17

Experience

1917-18	The Texas Co., Okla., geol.
1918-21	Wonder Syndicate, New York
1921-22	Ohio Oil Co., Wyoming
1922-32	Vacuum Oil Co., Tex., geol., chief
1932-	Magnolia Petrol. Co., La., Tex., div. geol., chief, mgr. of explor., dir. and mgr. of explor., vice-pres. and mgr. of explor.

Publications.—Vinton salt dome, Calcasieu Parish, Louisiana; Fredericksburg group of Lower Cretaceous with special reference to north-central Texas

Professional Affiliations (National)

Geological Society of America, fellow
Society Econ. Paleon. and Mineralogists
American Institute Mining Met. Engineers
American Petroleum Institute
Sigma Xi, Sigma Gamma Epsilon
Phi Beta Kappa

A.A.P.G. Activity (Member, 23)

1924	General Committee
1950, 54-56	Business Committee

NOMINEES FOR VICE-PRESIDENT, 1958-1959

GORDON I. ATWATER

Senior Member, Atwater, Cowan, and Associates, New Orleans, La.
Born, June 17, 1907, Milwaukee, Wis.

Academic Training

1925-30	U. Iowa, B.A., 29; M.S., geol., 30
1930-31	Univ. Wisconsin, geol.
1931-32	Columbia University, geol.
1932-36	Univ. Wisconsin, Ph.D., geol., 36

Experience

1930	Univ. Iowa, instructor, geol.
1931-32	Columbia Univ., asst., geol.
1932-34	Iowa Geol. Survey
1934-35	Univ. Buffalo, instr., summers N.Y. Geol. Survey, geol., summers
1935-37	Amerada Petrol., Houston, geol.
1937-38	Skelly Oil Co., Houston, geol.
1938-46	William Helis, ch. geol., hd. land
1946-	Consulting geologist

Publications.—Stratigraphy of Upper Mississippi Valley; iron ores, Mich. and Wis.; authigenic feldspars; drilling-time data; University field, La.; offshore province, La.

Professional Affiliations (National)

Geological Society of America, fellow
American Institute Mining Met. Engineers
American Assoc. Advancement Science
American Geophysical Union
Society of Exploration Geophysicists

A.A.P.G. Activity (Member, 38)

1944-45	Business Committee
1944-46	Committee for Publication
1944-46	Geol. Names and Correlations
1949-51	Medal Award Committee
1952	Nominating Committee
1957	Distinguished Lecturer

CLAUDE N. VALERIUS

Consulting Geologist, Shreveport, La.
Born, Dec. 9, 1904, Hoisington, Kans.

Academic Training

1921-25	Missouri Sch. Mines, B.S., min. geol.

Experience

1925-27	Twin State Oil Co., Tulsa, geol.
1927	Phillips Petroleum Company Fort Stockton, Texas, geol.
1928	Amerada Petroleum Corporation Pecos, Texas, geol.
1929-35	M. M. Valerius Royalty Corporation Wichita, Kansas; Tulsa, Oklahoma, geol. and gen. mgr.
1935-49	Barnsdall Oil Company Okla., Tex., Ark., La., geol.
1949-	Consulting geologist, Shreveport

Publications.—Midway field discovery, Lafayette County, Arkansas; History of Benton field, Bossier Parish, Louisiana

Professional Affiliations (National)

Geological Society of America
American Institute Mining Met. Engineers
American Assoc. Advancement Science
American Geophysical Union

A.A.P.G. Activity (Assoc., 25; Member, 32)

1949-50	Business Committee
1954	Nominating Committee
1955	Emblem Committee

NOMINEES FOR SECRETARY-TREASURER, 1958–1959

KENNETH COTTINGHAM

Consulting Geologist, Columbus, Ohio
Born, April 20, 1892, Columbus, Ohio

Academic Training

1909–13 Ohio State Univ., B.A., 13; M.A., 14

Experience

1914–17 Ohio State Univ., instr., geol.
1914–16 Ohio Geol. Survey, summer asst.
1919–21 Union Oil Co. (Delaware), geol.
1921–22 Private geological practice
1923–25 Ohio Fuel Gas Co., Columbus
1926–32 Columbia Engineering and Mgt.
1933–57 Ohio Fuel Gas Co., ch. geol., 40–57
1957– Consulting geologist, Columbus

Publications.—Ohio geology; history of oil and gas production; reviews of Ohio oil and gas production; underground gas storage; geology and Ohio place names; terminology; drainage derangement; Ohio caverns

Professional Affiliations (National)

Geological Society of America, fellow
American Assoc. Advancement Science, fellow
American Petroleum Institute
American Gas Association
Sigma Xi
Amer. Geol. Institute Glossary Com.

A.A.P.G. Activity (Member, 28)

1946–57 Com. Statistics Explor. Drilling
1957– Business Committee

HAROLD T. MORLEY

Chief Geologist, Pan American Petroleum Corporation, Tulsa, Oklahoma
Born, June 22, 1897, Denver, Colorado

Academic Training

1914–18 Univ. of Colorado, B.A., geol.

Experience

1919 Lone Star Gas, Tex., field asst.
1919–26 Midwest Ref. Co., Wyo., Colo.
1926–31 Midwest Expl. Co., Tex., dist. geol.
1931–32 Stanolind Oil and Gas Company Division explor. supt., Tex.
1932– Pan American Petrol. Corp. (formerly Stanolind), chief geol.

Publications.—Future of petroleum geology; Elk Basin structure, Wyoming and Montana

Professional Affiliations (National)

Geological Association of Canada
Sigma Xi (assoc.)

A.A.P.G. Activity (Member, 19)

1948–52 Distinguished Lecture Com. Chm., 50 and 51
1954 Chm. Ann. Mtg. Employ. Interviews
1955– Headquarters Advisory Com.
1956 Vice-chm. Business Com.
1956 Nominating Committee
1957 Gen. chm. St. Louis Ann. Meeting

NOMINEE FOR EDITOR, 1958–1959

SHERMAN A. WENGERD

Prof. of Geol., Univ. of New Mexico, Albuquerque, New Mex.
Born, Feb. 17, 1915, Millersburg, Ohio

Academic Training

1932–36 Coll. of Wooster, A.B., geol., 36
1936–40 Harvard, A.M., 38; Ph.D., 47

Military Service

1942–45 U. S. Navy
1953– Commander, U. S. Naval Reserve

Experience

1935–36 Instr., geol., mineral., Wooster
1937 Seis. helper, Shell Oil, Tulsa
1938 Geol., Ramshorn Min. Co., Ida.
1940–42 Sur.-sub., Shell Oil, Tulsa
1945–47 Research, Shell Oil, Tulsa
1947–57 Asst. to Prof. Geol., New Mexico Consulting research geologist

Publications.—Sedimentation; petroleum geology; lithologic variation of Viola limestone, south-central Oklahoma; reefing limestones of Majuro, and of Hermosa formation in Utah; Pennsylvanian stratigraphy of Four Corners region; oil and gas in San Juan basin, Paradox basin, and Four Corners region

Professional Affiliations (National)

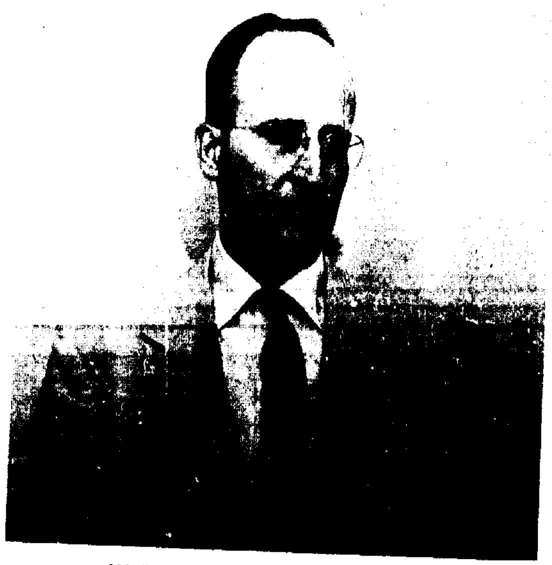
Geological Society of America (fellow)
American Geophysical Union
American Geographic Society (fellow)
American Soc. of Photogrammetry
Soc. Econ. Paleon. and Mineralogists

A.A.P.G. Activity (Assoc., 42; Member, 46)

1948 President's Award
1950 Distinguished Lecturer
1955–57 Com. for Publication
1957– Editor

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
NO. 11 (NOVEMBER, 1957), PP. 2600-2601, 1 FIG.

MEMORIAL



WILLIAM EDGERTON COX

(1912–1957)

To the many friends of Bill Cox, his death on June 9, 1957, is still most difficult to accept. He fought valiantly and for many years an increasingly incapacitating lung illness that would long since have taken a lesser man.

We will always remember and be enriched by our knowledge of the life Bill led; his love of his family, his home, his friends, and his work was ever present, and his ready joke or verse brightened the lives of all of us—and frequently when we needed it most.

Bill was born January 15, 1912, in Hico, Hamilton County, Texas, the son of Robert A. and Julia Murry Cox. He had a sister, Mary Miller Cox, and a brother, James Murry Cox. His father was born in Mississippi, attended college in Nashville, Tennessee, and received a Masters degree in economics at the University of Texas. His mother, who also was born in Mississippi and attended the University of Mississippi, died in 1936.

Mr. Cox was an instructor in economics at the University of Texas from 1923 to 1943 at which time he retired. In 1940, he married Linda Lancaster in Austin; she was at that time an instructor at the University of Texas. Mr. Cox died in 1947.

Bill attended Woolridge Elementary School and Austin High School in Austin, Texas, and was a member of the University Methodist Church there. He went on to attend the University of Texas, receiving his B.S. degree in geology in 1933 and his M.A. degree in geology in 1934. He was a member of Sigma Gamma Epsilon. Bill was a fine student and made many lasting friendships at the University.

Following graduation, Bill was employed by Humble Oil & Refining Company as a gangman in the production department. In September, 1934, he was transferred to the

exploration department. Practically all of his career, which ranged from scouting in 1934 through many different geologic assignments, was in the West Texas-New Mexico area, and his knowledge of the geology of this country became widely recognized. His professional career was interrupted by World War II, and he served in the Army Air Corps from June, 1942, to December, 1944, at which time his health was responsible for his separation from the services. At the time of his death, Bill was a senior exploration geologist for Humble's Western Division, which embraces West Texas, New Mexico, and the northeastern half of Arizona.

In 1946, with Theodore S. Jones, John W. Skinner, and William B. Hoover as sponsors, Bill joined the American Association of Petroleum Geologists. He also was a member of the West Texas Geological Society.

It was in Midland, Texas, in 1937, that Bill met Miss Geneva Risinger, later to become his wife. Geneva was born April 14, 1916, in Needville, Texas, attended school in Rosenberg, Texas, and later earned her B.A. degree in geology from the University of Texas. Upon employment as a geologist by Humble Oil & Refining Company, she was assigned to the West Texas area with headquarters in Midland. Bill and Geneva were married August 9, 1941, and were proud parents of a lovely daughter, Martha Edgerton Cox, born on April 27, 1946. Geneva and Martha are indeed two fine people whose understanding and constant help were reflected by Bill's firm hold on the brighter side of life.

Bill is survived by his wife and daughter, both of Midland, Texas; a sister, Mrs. Mary Cox Marberry, also of Midland; a brother, James M. Cox of Abilene, Texas; and his stepmother, Mrs. Linda Cox of Austin, Texas.

Death has taken Bill Cox from our lives only physically—his enduring courage, contagious humor, complete sincerity, and desire always to help others will ever remain as a guide to those of us who were privileged to know him and call him our friend.

W. E. DOUGHERTY

Houston, Texas
September 17, 1957

AT HOME AND ABROAD

The Southeastern Section of the Geological Society of America, sponsored by the Alabama Geological Survey and the Department of Geology, University of Alabama, will meet at Tuscaloosa, Alabama, May 1-3, 1958. The general theme is to be "Economic Geology of the Southeastern United States in Relation to Future World Events." It is planned to invite general summary papers on recent developments affecting the broad fields of metals, coal, oil and gas, non-metallic non-fuels, and radioactive minerals. WALTER B. JONES is program chairman, Drawer "O," University, Alabama. LYMAN D. TOULMIN, Florida State University, Tallahassee, is secretary of the Southeastern Section.

WARREN JAMES JACKSON died at Dallas, Texas, on October 1, at the age of fifty-four years. He was an independent petroleum engineer and geologist.

J. D. WILLIAMSON is a staff geologist in the production and supply department of the Trunkline Gas Company of Houston, Texas. During the past 7 years he was staff geologist for the Gulf Oil Corporation.

RICHARD F. SVOBODA has opened his office as consulting geologist in the Trust Building, Lincoln, Nebraska, after resigning his position with the Nebraska Geological Survey.

A Lectureship in Geophysics or, alternatively, in Volcanology or Hydrology at the University of Arequipa, Peru, March-December, 1958, is offered under the Fulbright Program with Peru. Application forms and general information on the operation of the Fulbright Program may be obtained from the Committee on International Exchange of Persons, Conference Board of Associated Research Councils, 2101 Constitution Avenue, Washington 25, D. C. Applications for the lectureship in Peru will be accepted until the award is filled. CHARLES C. BATES is chairman of the Screening Board for Fulbright Fellowships (Geology), Office of Naval Research (926), Navy Department, Washington 25, D. C.

WILLIAM W. CLAWSON, coordinator of domestic production for Socony Mobil Oil Company, Inc., will become a member of the Magnolia Petroleum Company management, with headquarters in Dallas, Texas, effective December 1. He will be responsible for coordinating Magnolia's exploration and producing activities.

D. B. HOLLAND is district production geologist for the Humble Oil and Refining Company at Hobbs, New Mexico.

GRAHAM B. MOODY, president of the Association, spoke on "Relation of Exploration of Petroleum to Reserves in the United States," at the meeting of the Tulsa Geological Society, October 7.

The New Orleans Geological Society has elected new officers: president, CARL F. GRUBB, Superior Oil Company; vice-president, JOHN G. WATSON, Shell Oil Company; secretary, KENNETH M. WATERS, The California Company; treasurer, LAWRENCE B. EUSTIS, Republic Natural Gas Company.

IRA H. CRAM, Houston, Texas, senior vice-president of the Continental Oil Company, was recently honored by the University of Minnesota for "noted professional attainment" and was presented the school's Outstanding Achievement Award for distinguished engineering graduates. The award cites Cram for his service as senior vice-president of the Continental Oil Company and as a past-president of the American Association of Petroleum Geologists: "an intrepid seeker of scientific data on oil in all parts of the world."

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Regional Meeting—Casper, Wyoming, April 27-30, 1958. Please address correspondence to the Secretary.

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28th *Annual Meeting*, Oct. 13-16, 1958, San Antonio, Texas

29th *Annual Meeting*, Nov. 9-12, 1959, Los Angeles, California

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Shell Oil Co., New Orleans, La.

Annual Fall Meeting—November 6-8, 1957. Address requests for copies of the annual G.C.A.G.S. *Transactions* to the treasurer of member societies at Corpus Christi, Houston, San Antonio, and Tyler, Texas; Baton Rouge, Lafayette, Lake Charles, New Orleans, and Shreveport, Louisiana; Jackson, Mississippi; and Tallahassee, Florida.

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Secretary . . . . George Y. Wheatley
Superior Oil Co., Box 3015, Terminal Annex
Los Angeles, California
Treasurer . . . . Robert R. Knapp
Standard Oil Company, Los Angeles

Permanent address of Pacific Section, and of Membership Secretary: 799 Subway Terminal Building, Los Angeles 13, California.

Monthly luncheons: first Thursday, each month.

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Secretary-Treasurer . . . . . . John E. Clare
The Superior Oil Company
3301 Brundage Lane

Dinner meetings on first Tuesday of each month, or as announced, El Tejon Hotel, Bakersfield.

CAN[illegible]A

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Baroid Well [illegible] Service

Past-President . . . . . . A. W. [illegible]
Western Lea[illegible]

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Monthly meetings are by announcement. Visiting geologists and friends are welcome.

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Regular luncheon meetings on 2d Tuesday of each month. Evening meetings by announcement. Visiting geologists and friends cordially invited.

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[illegible]

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Evening dinner (6:30), technical program (8:00) [illegible] announcement. [illegible] Petroleum Club. Visiting geologists and friends are welcome.

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SOUTHEASTERN GEOLOGICAL SOCIETY

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The California Company
The California Company Building

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Meets the first Monday of every month, Blue Room of the Roosevelt Hotel. Special meetings by announcement. Visiting geologists and friends cordially invited.

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Meets monthly, September to May, inclusive, in Science Hall, Centenary College. All meetings by announcement.

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Meetings: Monthly, October through May at Michigan State University, East Lansing, Michigan. Visitors welcome.

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Luncheon meetings first and third Thursdays of each month, October through May, evening meetings by announcement, Hotel Heidelberg. Visiting geologists and friends cordially invited.

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Meetings: Regular luncheons, every Wednesday, 12:00 noon, September through May, Northern Hotel. Dinner meeting by announcement. Visitors welcome.

NEW M[illegible]CO

THE ROSWELL [illegible]OGICAL SOC[illegible]

P.O. [illegible]

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The Atlantic R[illegible] Company

Secretary . . . . Douglas Wilson
Intex Oil [illegible]

Treasurer . . . . Julian Walker
The Ohio O[illegible]mpany

Dinner meetings are hel[illegible] [illegible]0 P.M. on the last Thursday of every month [illegible]oughout the year at the Roswell Country Club. Visiting geologists are welcome.

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NEW YORK, NEW YORK

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Meetings by announcement to members. Visiting geologists and friends cordially invited.

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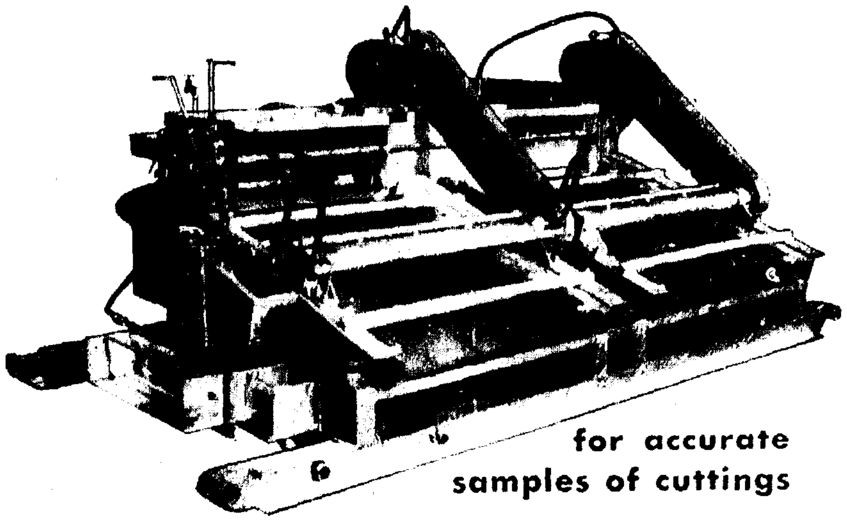

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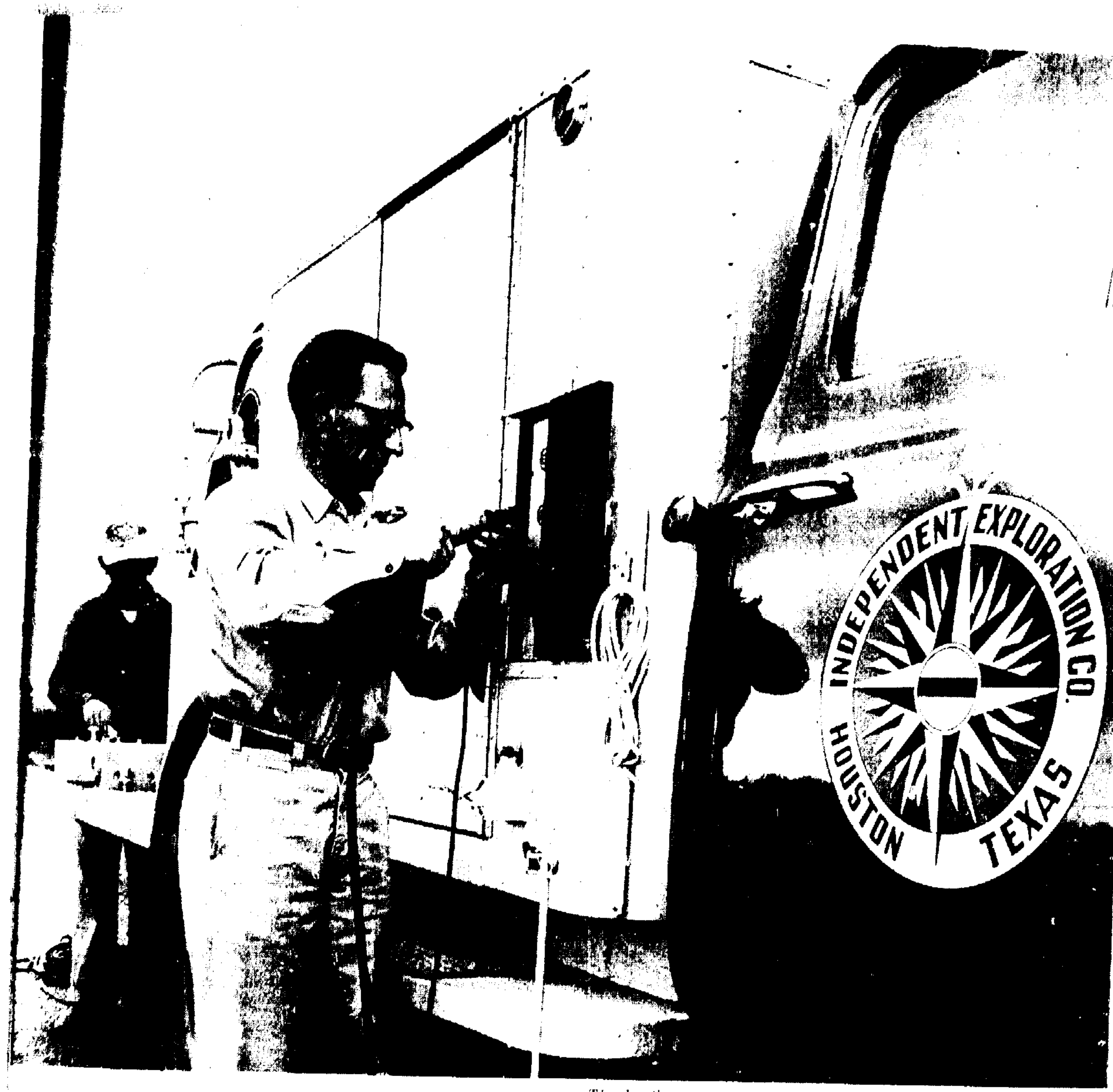

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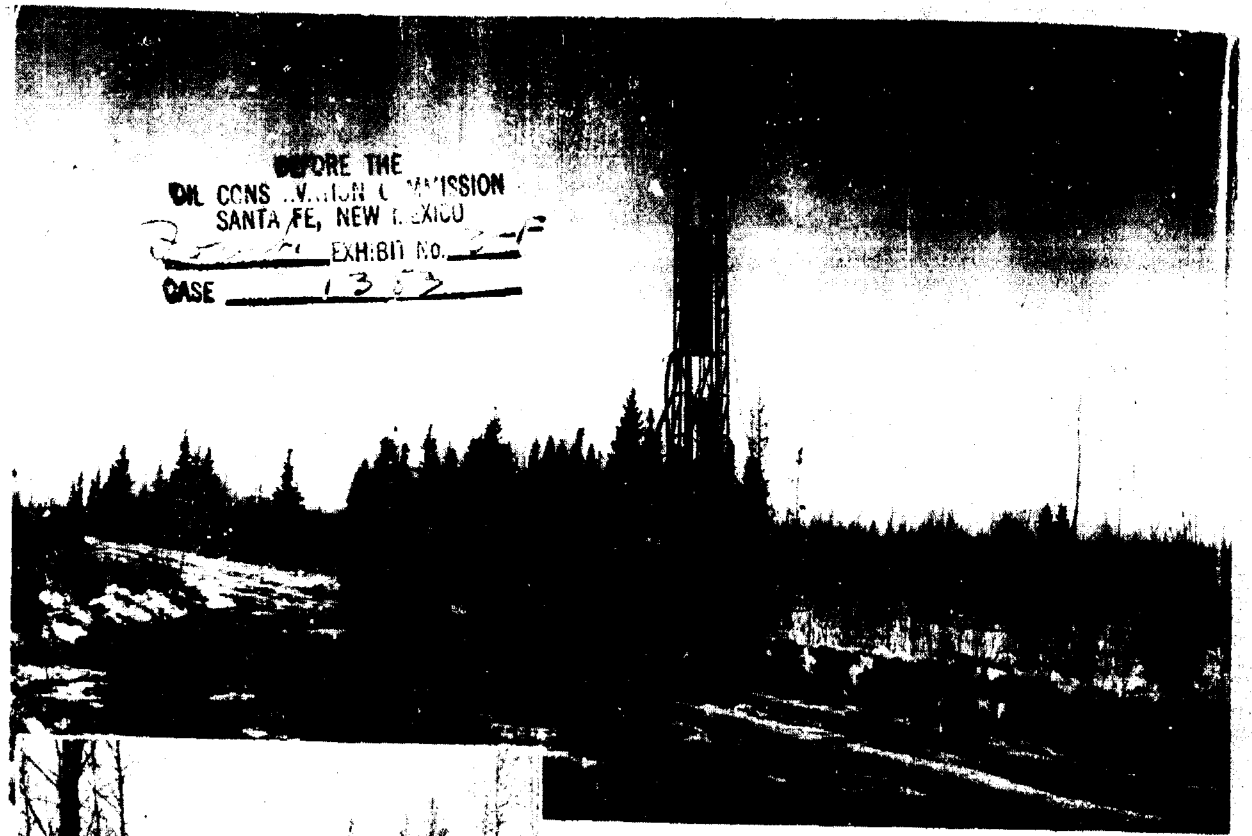

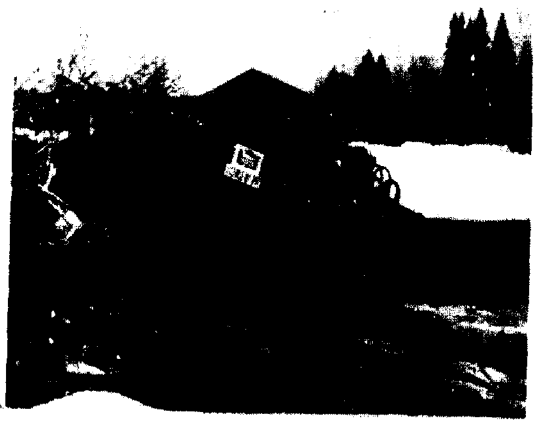

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BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO

IN THE MATTER OF:

CASE NO. 1383

TRANSCRIPT OF PROCEEDINGS

FEBRUARY 26, 1958

DEARNLEY - MEIER & ASSOCIATES
INCORPORATED
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ALBUQUERQUE, NEW MEXICO
3-6691 5-9546

I N D E X

MARTIN E. DEHLINGER

RAY CLARK

JOE M. PARSLEY

BEFORE THE
OIL CONSERVATION COMMISSION
February 26, 1958

IN THE MATTER OF:

Application of Forest Oil Corporation for a dual completion. Applicant, in the above-styled cause, seeks an order authorizing the dual completion of its State "A" No. 1 Well located 660 feet from the North line and 660 feet from the East line of Section 26, Township 16 South, Range 33 East, Lea County, New Mexico, in such a manner as to permit the production of oil from the Wolfcamp formation adjacent to the Kemnitz Wolfcamp Pool through the casing-tubing annulus, and to permit the production of oil from an undesignated Pennsylvanian Oil pool through the tubing.

Case No. 1383

BEFORE:

Elvis A. Utz, Examiner

TRANSCRIPT OF HEARING

MR. UTZ: The hearing will come to order, please. The next case on the Docket will be case 1383.

MR. COOLEY: Case 1383. Application of Forest Oil Corporation for a dual completion.

MR. CHRISTY: Sim Christy, of Hervey, Dow, and Hinkle for the Applicant Forest. We have three witnesses. The first one is Mr. Dehlinger. Will you stand and be sworn, please.

MR. UTZ: Will there be any other appearances in this case?

MR. KELLAHIN: Jason Kellahin, and I want to make a statement at the conclusion on behalf of Amerada

MR. COOLEY: Any other statement or appearances of any sort?

(Witness sworn.)

MARTIN E. DEHLINGER

called as a witness, having been first duly sworn, testified as follows:

DIRECT EXAMINATION

BY: MR. CHRISTY:

Q Would you please state your name, address, and occupation.

A My name is Martin E. Dehlinger, 3423 West Story Street, Midland, Texas. I am a geologist for the Forest Oil Corporation, Midland, Texas.

Q Have you ever testified before this body?

A No, sir.

Q Mr. Dehlinger, what forms of higher learning do you have, and what degrees do you have, and from what institutions?

A I have a bachelor of science degree in geology, 1951, Texas College of Mines and Metallurgy, have a master of arts in geology, 1951 -- I didn't mean that, 1948, excuse me -- a master of arts from the University of Texas, 1951, and since graduating from the University of Texas, I have worked for the Humble Oil and Refining for about a year and a half, the Murphy Corporation for a year and a half, Forest Oil Corporation about two and a half years.

Q Is this work -- excuse me.

A And with all of those companies I have acted in the capacity of geologist.

Q Have you ever testified before any other regulatory bodies? A No, sir.

Q The lands involved in this application are in Township 16 South, Range 33 East, NMPM Lea County, New Mexico. Are you familiar with that general area and the geology in connection with it?

A Yes, sir, I am. I am the district geologist for Lea County for Forest Oil.

MR. CHRISTY: Does the Commission have any questions concerning the witness' qualifications as a geologist?

MR. UTZ: The witness is qualified as an expert witness.

Q (By Mr. Christy) Mr. Dehlinger, I hand you Applicant's Exhibit 1 and ask you if you will please identify it.

A Exhibit 1 is a structure map contoured on the top of the Kemnitz lime which is a Wolfcamp lime, which produces in the Kemnitz field.

Q Does Exhibit 1 reflect the other Wolfcamp wells in the general vicinity of the subject well and show the names of the offset operators to the subject well? A Yes, sir.

Q I believe your offset operators are Humble, Shell, Tennessee Gas, Phillips, Cities Service, and Signal?

A Yes, sir.

Q Is that correct? A Yes, sir.

MR. CHRISTY: We have here waivers from all of the offset operators with the exception of Sinclair, who have been notified of this hearing.

Q (By Mr. Christy) Now, returning to Exhibit 1, Mr. Dehlinger, woul you please locate the subject well for us?

A The well in question is the Forest Oil No. 1 State "A" located 660 feet from the north and the east of Section 26, 16, 33.

Q Now, I notice just below the subject well, another well circled in red. You have a figure there. For example, subject well's minus 8462. Would you explain that, please?

A The minus figure under the circled well is the datum on top of the Kemnitz lime formation, the Kemnitz lime produces in the Kemnitz field.

Q And this Kemnitz Wolfcamp production is one of the productions encountered in the subject well?

A Yes, sir.

Q Now, from this contour on Exhibit 1, have you arrived at any conclusions as to whether or not this is a continuous formation and pool in the wells shown and producing in the Wolfcamp?

A The wells producing in the Kemnitz field seem to indicate that the Kemnitz lime pay is a continuous body, which is represented by the occurrence of a porosity in the Kemnitz lime. In other words, this map seems to suggest that the Kemnitz field is a stratigraphic field, depending upon the presence or absence of porosity.

Q Is it similar to the Townsend?

A Yes, sir.

Q General vicinity of the east --

A Yes, sir. The Townsend field produces from an equivalent zone in the Wolfcamp, and the west end of the Townsend field is about four miles to the east of us.

Q Now, also based on this, have you arrived at any conclusions as to whether or not in your opinion drainage is occurring at the present time under the Wolfcamp in the subject well?

A It is believed that we are being drained in the Forest No. 1 "A" State in Section 26 by the Kemnitz field as a whole, and specifically by the Tennessee Gas No. 3 "B" State Kemnitz in Section 25.

Q All right sir, I will refer you to Applicant's Exhibit 2 and I will ask you if you will identify that instrument for us.

A Exhibit No. 2 is an isopach map of the net microlog porosity found in wells penetrating the Kemnitz lime porosity.

Q And of what benefit might this exhibit be to the Commission in consideration of the application?

A This map, when compared with Exhibit 2, suggests and bears out our statement that the Kemnitz field is less dependent on structure than on presence of porosity for its production. In other words, this is another indication that the Kemnitz Wolfcamp field is a stratigraphic field.

Q Is this a water drive field?

A No, sir. Our information now indicates it is a gas solution drive field. Only three wells in the Kemnitz field proper, and I will quote the wells; the Tennessee Gas No. 1, State-Phillips, in the southeast corner of Section 25, 16, 33; the Tennessee Gas No. 5 "A", State-Kemnitz, in Section 30, 16, 34, and the Shell No. 1 "WC" State, in the South Half of Section 29, 16, 34, only those wells had indications of water in the Kemnitz zone.

Now, you will notice on this exhibit there are two figures under each of those wells. The top figure, and I specifically refer again to the Tennessee Gas No. 1, State-Phillips, you have 78 feet there, that indicates you have 78 feet of net microlog porosity in that well, but there is a figure under there, a figure 42 feet, that indicates only 42 feet of the available porosity was above the field water table. The field water table is estimated to be at a minus 6670.

Q Now, the figures then shown below each of the wells circled in red here on Exhibit 2 represent the net feet of porosity as distinguished necessarily from pay?

A Yes, sir, specifically in the three wells previously mentioned. However, in the remainder of the wells in the Kemnitz proper, the net microlog porosity is tantamount to being the net pay. Of course, this net pay varies in quality of the porosity as well as in quantity.

Q Now, I refer you to Applicant's Exhibit 3 and ask you if you will identify it, sir.

A Exhibit No. 3 is a structure map contoured on top of the Seaman lime, which is a Pennsylvanian lime and which is found in all of the wells that have been drilled in the Kemnitz field proper and in several of the other wells in the area.

Q What benefit might Applicant's Exhibit 3 be in the consideration of this application, what does it purport to demonstrate?

A This structure map also strongly suggests that the Seaman lime pay is of a stratigraphic type accumulation. I specifically refer to three wells, the Sinclair No. 1 Seaman unit, which is located in the southeast corner, Section 13, 16, 33; the Forest 1 "A" State, Section 26, and the Penrose No. 1 TGP "C" State in the southeast corner of Section 34. All of those three wells are circled in red on the exhibit.

Now, if you will compare the datums on top of the Seaman lime as marked below the well, you will notice that the Forest well is approximately 245 feet low to the No. 1 Seaman unit, and the Forest well in turn is approximately 180 feet high to the Penrose well. These zones appear to be stratigraphically equivalent, but they are definitely not structurally equivalent, suggesting that a stratigraphic trap has been penetrated by each of the wells.

Q Is there any indication of communication between the stratigraphic traps encountered in the three wells you mentioned?

A No, sir. There seems to be evidence to the contrary because of the well characteristics. For example, the Penrose well in Section 34 in the Seaman zone has extremely high pressures, and they potentialled the well for an extremely high potential, whereas our well, the Forest 1 "A" State in Section 26 seemed to have abnormally low pressures as demonstrated by the original drill stem test in the equivalent zones, and our well does not seem to have the capacity of the Penrose well.

Q Geologically speaking, does this present an unusual situation, the Seaman zone in this area?

A The Seaman zone in this area seems to be rather unique in its erratic nature, and what at this moment seems to be a discontinuous nature also.

Q Have you ever encountered this unusual type situation before, or have you made studies in connection with such a situation as this?

A I cannot personally cite any other field that appears to have this exact same occurrence, but a professional bulletin, the bulletin of the American Association of Petroleum Geologists, Volume 14, No. 11, has an article which seems to be applicable to this instance, and the article is on the Mississippian bioherms of Northeast Oklahoma. That article seems to set forth a condition, a sedimentary condition very much like we find in our area in that you have a porosity developed along the flanks of a reef which has a very massive dense core, the sides of which project these dense fingers of the reef, and intercalated between these fingers you have porous zones developed, which are not particularly continuous vertically or horizontally.

Now, the massive reef core would, of this reef, would be more or less represented by the Line A-B on Exhibit 3. The Line A-B more or less represents the axis of the main, the long axis of the main reef core, and the short axis represented by the Line C-D.

Now, you'll find that the porosity developments which are associated with this reef seem to be very discontinuous and on the flanks of it.

Q Now, what are the primary problems that you encounter in this unusual type of situation?

A The ability to predict the absence or presence of porosity, which is the governing feature of this type of reservoir.

Q Can't you predict that geologically or geophysically?

A There seems to be no way to geologically or geophysically predict porosity in that, except drilling for it.

Q And these are small isolated traps, as I understand you, along the flanks of the fingers which you mentioned?

A Yes, sir.

Q These four producing wells on Exhibit 3?

A Yes, sir.

Q Now, are you familiar with the other wells drilled in the general vicinity of the subject well?

A Yes, sir.

Q Do you have any logs from any of the other wells in the general vicinity?

A We have logs, electrical logs on the Sinclair No. 1 Seaman, Section 13, the Forest 1 "A" State, Section 26, the Penrose, Section 34, the Tennessee 1 "B" State-Kemnitz, Section 25, the Tennessee 1 State-Phillips in the southeast of 25, and a log on the Pure No. 1 State "E" in 16 South, 35 East, Section 21.

Q Now, do the logs reveal any data which might be of assistance to us in consideration of this application?

A The logs seem to indicate that you have a thinning and thickening of the Pennsylvanian section in which the Seaman lime is found, and you also have a thickening and thinning presence, or absence of porosity in the Seaman lime. The last feature is specifically demonstrated comparing the Forest 1 "A" State with the, in Section 26, with the Tennessee 1 "B" State-Kemnitz in Section 25. The micrologs indicate that the Forest 1 "A" State has about 52 feet of net microlog pay or porosity in the Seaman lime, whereas the Tennessee 1 "B" State-Kemnitz in Section 25 had no porosity in that zone. That is the net microlog porosity. The values are not under the subsea datums of the subject well.

Q In which exhibit, sir?

A In Exhibit 3.

Q Now, on these electric logs of the wells that you have mentioned, was any water found in the zone, in the Seaman zone in any of the wells?

A No water has been found in the Seaman lime zone in the producing wells, or the wells drilled to the Seaman zone in the Kemnitz field proper.

Q Now, as I understand Applicant's Exhibit 3, the Seaman, the Forest, the Penrose, and the Pure are Pennsylvanian producers in the Seaman formation? A Yes, sir.

Q And the other three -- the other two, Tennessee 1 "B" and Tennessee 1 Phillips are not producing in that formation, but were drilled to it? A Yes, sir, they were.

Q Now, sir, is there any other Seaman production in that area?

A The Pure No. 1 "E" State is the only other Seaman lime production in the area.

Q Now, were any other Seaman wells drilled other than those which you have mentioned and the logs that you have?

A There have been about twenty wells that have penetrated this section in the immediate area. I am taking in, say five miles in any direction from the Seaman No. 1 or the Sinclair No. 1 Seaman unit in Section 13.

Q Those are the ones indicated in Applicant's Exhibit 3 in green or red? A Yes, sir.

Q All right, sir. Do you have any, or have you formed an opinion as to why these other Seaman tests did not produce?

A The wells that penetrated the Seaman zone but were not capable of production found either the section was missing or there was no porosity development in the Seaman lime, and it appears that the Seaman lime is reasonably well distributed over the area, but the porosity is very seldomly developed.

Q Were Applicant's Exhibits 1, 2, and 3 prepared by you or under your supervision? A They were.

Q As a geologist, can you think of any other matter which you feel should be brought to the attention of the Examiner in connection with the application?

A No, sir, I cannot.

MR. CHRISTY: We would like to, at this time, offer in evidence Applicant's Exhibits 1, 2, 3, and 3-A through 3-E inclusive.

MR. UTZ: Is there objection to the entrance of the Applicant's Exhibits as stated? If there are no objections, they will be entered.

MR. CHRISTY: We have no other questions of this witness. We will attempt to develop the production problems, the mechanics of it from other witnesses. This is all we have on the geological portion.

MR. UTZ: Are both your other witnesses engineering witnesses?

MR. CHRISTY: They are. Production engineer and reservoir engineer.

MR. UTZ: Are there any questions of Mr. Dahlinger?

MR. NUTTER: I have some questions.

MR. UTZ: Mr. Nutter.

CROSS EXAMINATION

BY: MR. NUTTER:

Q Mr. Dehlinger, you have frequently in your testimony referred to the Kemnitz zone and the Seaman zone. What is the Kemnitz zone more commonly called in this pool?

A The Kemnitz Wolfcamp, I think, is the field designation.

Q That is the zone that is producing from the pool designated by the Commission as the Kemnitz Wolfcamp pool?

A Yes, sir.

Q Now, this Seaman zone that you have referred to, what is that more commonly called?

A I think the Commission has called the Seaman zone in the discovery well, the Sinclair No. 1 Seaman unit in Section 13, the Kemnitz Pennsylvanian.

Q Thank you. I just wanted to clarify that for the record.

A Yes, sir.

Q Mr. Dehlinger, you have mentioned the Townsend Wolfcamp pool in your testimony, and that this was a similar type of structure, you felt?

A Yes, sir.

Q Do you think that the producing characteristics of the Wolfcamp zone in this pool would be similar to the Wolfcamp producing characteristics in the Townsend pool?

A Yes, sir, it appears that the conditions of accumulation were the same, and they seem to be statrigraphically equivalent, and the reservoir types are basically the same, and the well performances seem to be of the same type as found in the Townsend.

Q As I recall, at the hearing which was held in May, 1957, to establish 80-acre spacing for the Kemnitz Wolfcamp pool, various geologists and engineers compared the two pools and stated that they believed they were equivalent in many respects. You don't have any quarrel with that evidence or testimony, do you?

A No, sir.

Q You concur with it?

A Yes, sir.

Q Do you have any knowledge as to what the gas-oil ratios are in the Townsend Wolfcamp pool?

A No, sir, but I understand they are high.

Q I hand you the Commission's proration schedule for February, 1958, on Page 98, on which starts the listing of the wells in the Townsend Wolfcamp pool, and on the right hand side of the listings for each well are listed the gas-oil ratios as reported by the Commission. Are those gas-oil ratios high, intermediate, or low as far as the average oil pool is concerned?

A I would say they are intermediate. They are definitely not low.

Q Are there a number of wells in that pool that have penalized allowables as a result of high gas-oil ratios?

A in the Townsend?

Q Yes, sir.

A Yes, sir, there are.

Q You stated that you thought this was a gas solution drive field? A Yes, sir.

Q Do you think that -- First, I'll ask you this, has any well which has been completed in the Pennsylvanian zone in this pool been offset by another well drilled to that same formation, completed in that same formation?

A The Sinclair No. 2 Seaman unit in Section 29, 16, 34 was drilled, and the southeast diagonal offset to the No. 1 Seaman unit was drilled as an offset to the Sinclair No. 1 Seaman, and it unfortunately did not, or could not be completed commercially from the Seaman zone. Also, the Pure 1 "E" State, Section 21, 16, 34, was offset to the west by the Tennessee No. 2 State "B" which apparently, according to my correlations, is producing from a zone not equivalent to the 1 "E" State. It seems to be from a lime stringer above what we would call the Seaman zone.

In the Seaman zone, the Tennessee well had approximately three feet of net microlog pay, and so they had to plug back up and complete it from this other zone, which appears to be very close to the absolute top of the Pennsylvanian.

The Pure No. 2 State "E" in the South Half of Section 21 was also drilled to the Seaman zone, the one producing Pure well, but it found no porosity and consequently was plugged back and made a Wolfcamp well.

Q So to date, no well which is producing from the Pennsylvanian has been offset by another producer in that zone?

A No, sir.

Q And you stated that in your opinion there was no communication among any of the four wells which have been completed in the Pennsylvanian, didn't you?

A Yes, sir.

MR. NUTTER: I believe that's all, thank you.

MR. UTZ: Anyone else have a question of the witness?

MR. STAMETS: I have some.

QUESTIONS BY MR. STAMETS:

Q Mr. Dehlinger, can you divide this area into a battery, this reef structure?

A It is a very nebulose thing. It is difficult to do. I would say that to the northwest of the Sinclair No. 1 Seaman unit is a battery for lagoonal sedimentary environment. The Phillips Well in Section 13, 16, 33, and the Skelly Well in Section 12 both seem to be lacking the lime development in the Seaman zone.

Q Did I understand you correctly to say that the Seaman lime was locally missing? Is that the entire section there, or just the lime?

A Either the lime or the porosity. More specifically, the porosity is missing locally. You can carry the Seaman lime, or its equivalent reasonably widely. You can find it over in the

Townsend area, but now, you can take, for instance, the previously mentioned Skelly and Phillips well, and they seem to be in an area where something happened to the Seaman lime.

Q Is that a battery area that you would expect some sand in the reef.

A Not specifically sand, I don't think, but if you will compare the Tennessee Gas No. 1 State-Phillips in Section 25 to the Tennessee Gas No. 1 "B" State-Kemnitz in the north half of Section 25, you will see that the Seaman lime unit in the 1 "B" Kemnitz, the northern most well there had no porosity, but that in the No. 1 State-Phillips, the lime had turned to shale, or it seems to be shaling up. Although we don't have a log here to represent it, I think the Humble well in Section 1, 16, 33, seems to have an unusual amount of sand or sandy shale in the Pennsylvanian section.

Q Just one more question. What are your other types of sediment which don't seem to have any porosity material?

A I don't think I really understand your question.

Q In the main reef area, I think it is safe to assume that these wells weren't completed in the lime stone because the lime stone had poor porosity, but these wells, say in Section 2 and Section 3 of 16, 33, which penetrated that zone and weren't completed in that zone, what type of sediment do they have?

A They had a lime equivalent, but it appears the porosity was absent in these wells, specifically the Humble 1 "AQ" State there in Section 3, and a Humble well not shown on this plat, but over in Section 4, the southeast corner of Section 4, both wells were completed as Pennsylvanian producers from zones which roughly speaking are equivalance of the Townsend, but they had a, they were completed apparently as gas wells, but they produced -- As I understand it, the 1 "AQ" produced eight thousand barrels of oil total, and that was it, and the Humble well in Section 4 was completed, or potential flowing for somewhat over five hundred barrels per day, and by the time that the White Eagle well in Section 10, before it could get down, why its diagonal northwest offset had been depleted and plugged, and the White Eagle well completely missed the porosity also.

Q These three wells on the west side of the reef, or what would seem to be the west side of the reef, seem to form rather a straight line through there. It is reasonable to assume that one could get a producing well in that zone interspersed between these wells?

A The question there comes in of the structural relation of the wells. In other words, the great variation in the datums, like the Forest well in Section 26 is about 200 feet low to the Seaman well. It is hard to imagine that that would be one particular and continuous reservoir without having gotten some water, and the difference between the Sinclair well in Section 13 and the Penrose well in Section 34 is 327 feet of difference, sub-sea difference, and it is hard to imagine that such a small reservoir could be continuous, or such a thin reservoir. The Seaman lime various in thickness from 75 to 150 feet in the area, and it is hard to imagine that that could be one continuous reservoir without having some water, so that you then think that you have a series of porosity developments ranged in sort of a stair-step manner, and that each time you begin to look for a reservoir in the Seaman lime, why you are looking for a brand new reservoir for all practical purposes. That seems to be indicated over here by the Pure Well in Section 21, 16, 34.

Q Well still, it seems you could call it a zone. There is a fairly decent zone there. I don't think Forest Oil would be opposed to finding oil --

A But the question is, would you drill to it. Now, like we are drilling on our No. 2 State "A" there on Section 26 now, and we just don't feel that in view of the present production statistics of these Pennsylvanian wells, specifically the Penrose down there in Section 34, that well was potentialled flowing for fourteen hundred and some odd barrels, I think, that may not be an exact figure, but now it is dead. It is completely dead, in less than four months. That thing has gone from fourteen hundred barrels to virtually nothing.

MR. STAMETS: That's all.

QUESTIONS BY MR. NUTTER:

Q What is the cause of that? Wouldn't it make anything with the pump?

A No, sir, they don't have a pump, but I think they originally acidized it with five hundred gallons of mud acid, and then they potentialled it. About a month later they acidized it with ten thousand gallons, and they could get only about twenty or twenty-five barrels a day out of it, and then it completely died, and as of yesterday, I think they went in and were going to frac it, and we haven't heard anything after that.

Q They are going to attempt to make a flowing well out of it?

A They are trying to get something, yes, sir, and the indications seem to be that this well, the Penrose well, is similar to the Humble wells up there in Sections 3 and 4 in that you had a very limited reservoir, which was under high pressure, and you got the flush production right fast, and that's it.

Q Do you think the same thing will hold true of your State No. 1 in Section 26?

A The indications are that that is happening, because we potentialled the Pennsylvanian with, let's see, for three hundred and fifty-six barrels a day, and with a tubing pressure of, flowing tubing pressure of eight hundred pounds, and as of the last time I heard, which was yesterday, they had produced two hundred and seven barrels of oil per day, and the flowing pressure was down to three hundred and seventy-five pounds. In other words, it seems to be losing its get up and go. The same productive character in particular, seems to apply to the Pure 1

"E" State over there in Section 21. If I am not mistaken, they completed that well for sixteen hundred barrels or something a day, and they say now that the pressures are way down.

Q How did the initial pressure in your well compare with the initial pressure in the other three wells in the Pennsylvanian?

A We were abnormally low in comparison to the Penrose well in Section 34. I think our initial shutin pressure on the drill stem test of the Seaman zone in the Forest 1 "A" State was about thirty four hundred pounds, or would you let me get some more information?

Q Yes, sir.

MR. CHRISTY: We will try and develop a number of these things with the other witnesses as we go along, Mr. Nutter.

A Could I get him to answer the question on the initial shutin pressure?

MR. NUTTER: We will defer these questions regarding initial potentials and pressures.

MR. CHRISTY: We have another witness to testify as to that. As I said, this is purely for the geologically --

MR. NUTTER: I withdraw the question.

MR. UTZ: Is there any other questions of the witness?

MR. COOLEY: One question.

MR. UTZ: Mr.Cooley.

QUESTIONS BY MR. COOLEY:

Q Mr. Dehlinger, how does the geology compare between you Forest 1 "A" Well and the Tennessee Gas "B" well in the North Half of Section 25 in the Wolfcamp formation?

A In the Wolfcamp we are only slightly low to the Tennessee well, but we seem to have less than half of the net microlog porosity. It seems to be a characteristic of the Kemnitz field that you have three zones of porosity, and the relation between the Tennessee and our well is that we seem to have lost the bottom porosity zone. It is pinched out some place between the Tennessee 3 "B" in Section 25, and our 1 "A" State in 26.

Q What correlations would you say are missing in the well which zones are referred to in Case 1253, Order R-1011, Special Rules and Regulations for the Kemnitz Wolfcamp Pool? Are you aware that Rule 4 of those rules provides, and I quote, "That no well shall be opened to any other zone of the Wolfcamp formation simultaneously with production zone in the lower portion of the formation from which the Tennessee Gas Transmission Company, State "AA" Kemnitz No. 1 "A" Well is presently producing until it has been established, after notice and hearing, that the same can be accomplished without causing underground waste." It prohibits production from the zone from which the Tennessee Gas Transmission State "AA" Kemnitz No. 1 Well.

A It is in Section 30, is it not?

Q Yes, sir.

A 16, 34.

Q Now, let's compare it with that zone to which the Order refers. Is that productive zone missing in your Forest State "A" 1?

A As I understand it, that rule was specifically aimed at the upper Wolfcamp porosity, was it not? It was to prohibit simultaneous production from those zones, from the upper and the lower?

Q It was, yes, sir.

A The rule there separates the zone about six hundred feet above the zone from which we are producing. In other words, what I would call an upper Wolfcamp from the lower Wolfcamp, which I consider the Kemnitz field to be producing, but to answer your question, we did not have the upper Wolfcamp zone in the 1 "A" State. We dropped a core barrel in there and tried to find it, but we were unable to.

Q You do have the lower zone, which is considered the most proliferant, and which was referred to in Order 1011, which I just quoted? A Yes, sir.

Q And all of your production would come from that lower zone?

A Yes, sir, what is generally considered to be the Kemnitz field pay.

Q Well, it is identified by the Order as that zone from which the State "AA" Kemnitz "A" No. 1 well is presently producing.

A Yes, sir.

Q Top of perforations on that well are at ten thousand seven hundred forty-two feet?

A Yes, sir. The top of our perforations are approximately ten eight.

Q And would not encompass any of the other and less proliferant stringers which were intentionally excluded from this Order?

A No, sir, it would not. Maybe I misled you when I said three zones.

Q Well, there was a number of zones referred to at that hearing, and everyone agreed upon, understood the significant zones in the Kemnitz "A" 1 well to be the most proliferant zones.

A Yes, sir.

Q And there was some fear at that time that opening both zones simultaneously would cause waste.

A Yes, sir.

Q Thus simultaneous opening was prohibited.

A Yes, sir.

Q But you would not have this problem in your case?

A No, sir, we do not have that.

Q Since the upper and most proliferant zones are completely absent?

A Yes, sir.

MR. COOLEY: That's all.

QUESTIONS BY MR. NUTTER:

Q Now, Mr. Dehlinger, State No. 3 offsetting your well there to the east, is it open in the main Kemnitz zone?

A Yes, sir. Yes, sir.

Q However, it has a certain section of this lower Kemnitz zone which you don't have in your well?

A Yes, sir. Roughly speaking, they have a zone with a gross, let's say, a gross pay of a hundred feet, and their fifty-seven feet of net microlog porosity is distributed over that hundred feet in roughly three better porosity zones, whereas in an equivalent gross of a hundred feet in our well, we have twenty-four feet of net microlog porosity in basically two zones.

Q Do these two zones with porosity in your well correlate with any of the zones in their wells?

A Yes, sir, it does, the upper west and lower zone, separated from each other by a hard spot about, oh, it must be, let's see if we can look at the log here. Do we have a Forest log? That would be equivalent to this hard spot there.

Q You are referring to an interval about what depth, Mr. Dehlinger?

A From ten seven eighty-four to eighty-eight would be the hard spot separating the two zones of porosity that are present in the Forest well. Unfortunately, I didn't bring the one on the 3 "B" State.

Q What are these intervals in black as depicted on this log?

A The intervals in black shown on the microlog of the Forest well depicts the distribution of porosity as found by the measurements of the log.

Q Is that an exhibit? A Yes, sir.

Q On this log which as been identified as Exhibit No. 3-C, there are depicted six areas of microlog porosity, is that correct, Mr. Dehlinger? A Yes, sir.

Q Now, which of these areas -- You are acquainted with the log of the Tennessee 3 well to the east?

A Yes, sir.

Q Which of these microlog porosities depicted on your Exhibit 3-C are present in the log of the Tennessee Gas Transmission Company's State "B" 3 well offsetting yours to the east?

A The upper most zone would be equivalent to Tennessee, 70684, and then roughly you have a hard spot, or tight dense zone, and then you have the second zone which would pick up then at 10788, and then continue down to 107 -- I can't see that, 10802. Those would be equivalent, or the two top porosity zones in the Tennessee Gas No. 3 "D" State-Kemnitz.

MR. NUTTER: I think that's all, thank you.

QUESTIONS BY MR. COOLEY:

Q Mr. Dehlinger, how does the geology on your Forest State "A" No. 1 well compare with the geology on the average of the wells throughout the Kemnitz Wolfcamp pool proper? The quality of the wells.

A The Forest No. 1 State "A" appears to be about average, both reservoir -wise, and its relation to the major sedimentary conditions forming the reservoir. In other words, its neither high nor low particularly, and it has about what the average net porosity -- Well, I think the average net microlog porosity in the Kemnitz field would be considered at about thirty-four feet. That is just strictly a mathematical average, and we have twenty-four feet. There are wells that have less net microlog porosity than we have, and then there are wells that have considerably more.

Q If that were the only producing formation present in the area, knowing the geology being what it is, would you advise that it be drilled to that formation?

A Yes, sir.

Q If you could undrill that well and know what was there, would you advise them to drill it?

A I think I would move it.

Q No, sir, I mean --

A It didn't come in like we had it drawn originally, put it that way.

Q It wasn't quite as good as you anticipated it?

A No, sir.

Q Is it still a commercial well in the Wolfcamp?

A Yes, sir.

Q The Tennessee Gas Transmission Company's State "B" well No. 3 offsetting your well to the east is a Sinclair completion in the Wolfcamp formation, is it not? A Yes, sir.

MR. COOLEY: That's all the questions I have, thank you.

QUESTIONS BY MR. UTZ:

Q Mr. Dehlinger, you application stated that you were to complete the well in the Wolfcamp from 10,674 to 10,816. That 142 feet, is that whole interval perforated?

A No, sir, it is not.

Q Can you say what interval it is perforated --

MR. CHRISTY: We will develop that, Mr. Utz, with the next witness.

MR. UTZ: All right, sir.

Q (By Mr. Utz) Mr. Dehlinger, was this zone, the Wolfcamp zone cored?

A No, sir, unfortunately we missed the porosity. We got the core barrel in the tight zone below it.

Q With reference to the Pennsylvanian or Seaman lime, you also stated that it was 11,547 to 11,450, 97 -- I presume you would like to defer that question as to perforations to an engineering witness? A Yes, sir, please.

Q Was that zone cored?

A All but the zone represented by your upper five feet of perforations there. All of it was cored.

Q When you--you may want to defer this question--when you rejected this well, was it your intention to drill to the Pennsylvanian?

MR. CHRISTY: I would like to defer that question to the last witness, Mr. Utz, he will be glad to answer it.

MR. UTZ: Is there any other questions of the witness?

MR. CHRISTY: I would like to ask one more question. Everyone else has had a turn.

MR. UTZ: All right, sir.

REDIRECT EXAMINATION

BY: MR. CHRISTY:

Q Mr. Dehlinger, referring again to Applicant's Exhibit 3, would you give us a little more detail on this A-B Line and C-D Line and what it represents in this fingering that you spoke about, and you might make reference to the article which you previously mentioned. I am a little unclear on your mass core.

A The Lines A-B and C-D on Exhibit 3 are roughly the axis of what we consider to be a massive tight reef in this area. In other words, where you do not have porosity, and in reference to the article in the AAPG Bulletin, there on Page 2535, they have what looks like -- it is a picture of a reef found on the surface, which shows a very massive and undoubtedly dense reef mass, and on the flanks of the thing you seem to have a development of porosity along the flanks of it. These local porosity developments are made up basically of a reef detrital, as in our case. Even in our case, while it is of a different geological age, why it is similar to the type of detrital that is indicated here on Page 2534. It seems to be a mass of broken up organisms which have been, probably were growing on the main reef, but lay activity broke it off and then probably distributed it in the low areas around the rim of the main massive tight reef core, and some of these other pictures in here give you about the same idea, and you can see that where you would have the massive tongues coming out and probably separating the zones which in our particular case refer to the porous zones, and so that there is probably no connection between these zones vertically and probably very little connection horizontally because the horizontal distribution of the reef detrital would depend on the very irregular ocean bottom probably either in the back reef or the fore reef zones, and in this back reef-fore reef zone, it is a pretty hard question to answer.

Q As I understand you, this mass core shown on Figure 7 of the article is represented by your A-B Line on Applicant's Exhibit 3? A Yes, sir.

Q And your entire thickness of the core is shown by your C-D Line, the hung, is that the word, hung?

A Bioherms

Q That is shown on C-D? A Yes.

Q Showing that is the width? A The width?

Q Yes. A Yes.

Q Now, there is a little arrow down here on Figure 7 of the article. Is that where you would obtain production as distinguished from the center mass core?

A Yes, sir. If you were applying our present situation here to the theory of this thing, why it would be equivalent to having the Tennessee Gas No. 1 State "B" in Section 25 drilled at the crest of the massive reef core, so that you had no porosity developed in the reef, but if you moved down dip slightly in what is our Forest 1 "A" State relation, you would penetrate a finger of tight reef rock and then you probably would go into, or possibly go into a local detrital accumulation where you had the porosity developed, and also the massive reef finger has supplied a trap to the top of the accumulation, so that you have all of the necessary requirements for an oil field of whatever size when it looks like it is limited.

Q If I put my hand on Exhibit 3 and cup it over toward the southeast and spread my fingers a little, it is in this area between the fingers that you would obtain the production, wouldn't you?

A No, sir.

Q You would obtain it to the side of these fingers?

A Yes, sir.

Q And between the two there would be a hard mass?

A Probably not only between the two, but above and below.

Q Vertically as well as horizontally?

A Yes, sir.

MR. NUTTER: Which direction is your finger pointed?

MR. CHRISTY: Southeast.

MR. NUTTER: Or southwest?

MR. CHRISTY: Southwest. I have no further questions.

MR. COOLEY: Before we proceed, Mr. Dehlinger, did you properly identify this bulletin at the outset. Did you give the full identification of this publication?

A I think I did. I gave the name and the volume and the issue.

MR. CHRISTY: Yes, he gave it all, the name and so on. We would like to offer in evidence the bulletin, and request permission to have it back when the case has been concluded. We would like to have it available to the Commission if they would like to look at it.

MR. UTZ: I have one more question.

RECROSS EXAMINATION

BY: MR. UTZ:

Q With reference to the Pennsylvanian completion on your Forest State "A" 1, can you say how much microlog pay you had in that zone?

A In the Pennsylvanian?

Q Yes, sir.

A We had fifty-two feet of net microlog porosity. May I -- Yes, fifty-two feet.

Q That's about twice as much as you had in the Wolfcamp, isn't it?

A Yes, sir, it is twice as much porosity, but the net microlog porosity, but from the core analysis of the Pennsylvanian cores, the effective porosity is low, the permeability of the core is extremely low, and the residual oil saturation was low, very low, so that if you were left with a question of whether to complete this well or not strictly on the basis of the core analysis, I think we would have gone off and left it. I mean, just considering the Pennsylvanian and on our drill stem test to the zone, we didn't have nearly the spectacular results that the Penrose well in Section 34 had, or the Pure Well in Section 21, or even for that matter, the Sinclair well had, Sinclair No. 1 Seaman in Section 13.

MR. UTZ: Any other questions of the witness? The witness may be excused.

(Witness excused.)

MR. CHRISTY: Mr. Clark, please. Would you like to swear the remaining witnesses?

MR. COOLEY: Yes.

(Witnesses sworn.)

MR. CHRISTY: I would also like to offer in evidence this bulletin previously identified by the witness, with the request that we may have the article back when the case has been concluded.

MR. UTZ: What do you want to mark this one?

MR. CHRISTY: 3-F. Is 3-F admitted?

MR. UTZ: If there are no objections, it will be admitted.

RAY CLARK

called as a witness, having been first duly sworn, testified as follows:

DIRECT EXAMINATION

BY: MR. CHRISTY:

Q Will you state your name, address, and occupation?

A Ray Clark, 2103 Redbud, Odessa, Texas. I am petroleum engineer for Forest Oil Corporation in the Production Department, Odessa, Texas.

Q Have you ever testified before this body before?

A No, sir, I haven't.

Q Would you please give us a brief summary of your schooling and places of higher learning, when you graduated, what degrees you hold, and what occupations and duties you have done since graduation in the field of petroleum engineering.

A Yes, sir. I graduated from Texas A & M in 1952 with a bachelor of science degree in petroleum engineering and mechanical engineering. I have been employed by Union Producing Company, Came Brothers Engineering Company, and Final Engineering Service Company in the capacity as engineer. I am presently employed by Forest Oil Corporation as a petroleum engineer and I am a registered professional engineer in the State of Texas.

Q Have you ever testified before any other regulatory bodies?

A No, sir.

Q Mr. Clark, the lands involved in this application are in Section 26, Township 16 South, Range 33 East, NMPM, Lea County, New Mexico. Are you familiar with the wells in the general area of, in that general area, and specifically the subject well of this application? A Yes, sir.

Q Production-wise? A Yes, sir.

MR. CHRISTY: Does the Commission have any question concerning the witness' qualifications as a production engineer?

MR. UTZ: His qualifications are acceptable.

Q (By Mr. Christy) Mr. Clark, are you familiar with the method of completion of the subject well, and if so, would you give us please a brief study on that completion data?

A Yes, sir.

MR. CHRISTY: I would like to have this marked.

MR. UTZ: You wish this to be marked Applicant's Exhibit 4?

MR. CHRISTY: Yes, please.

Q (By Mr. Christy) Now, I hand you what has been marked Applicant's Exhibit 4 to assist you in answering the question just propounded. Will you continue, please.

A Yes, sir. Exhibit 4 is a schematic sketch of a dual completion of Forest Oil Corporation's No. 1 State "A" well that has previously been identified. 5 1/2 inch production casing has been set to a total depth of 11,592 feet. There were two zones perforated. The Wolfcamp zone was perforated between the intervals -- Do you want the specific perforations?

Q You can say, I think it will be sufficient to satisfy the Examiner, that the perforation data are shown on Exhibit No. 4 without reading all those figures.

MR. UTZ: That's satisfactory.

A The perforations are stipulated on Exhibit 4 and they are correct. A single string of 2 3/8 OD 4.70 EUE production tubing was run in the well for production purposes. It was landed on a Baker Model "D" Production Packer, which was set by wire line at 11,410 feet to separate the two zones of production. Immediately above the production packer we have a P. S. I. Model "C-2" landing nipple with a "CVE" separation sleeve, commonly referred to as straight through sleeve in place. A sleeve of that particular type allows Pennsylvania production from below the packer to move upwards through the tubing to the surface, but doesn't allow it to get into the annular spaces.

Q Now, you are proposing producing the Pennsylvanian from the tubing and the Wolfcamp from the annulus, is that what you are proposing?

A Yes, sir, that's the way we propose it.

Q Go ahead.

A Immediately above the S. P. I. landing nipple that was pointed out, we have a Baker Model "C" Tubing receptacle which is in effect a small tubing packer, but it does not pack off against the casing wall itself. It is strictly a tool which is run in in order to facilitate future possible remedial work.

Q I believe that answers the question. Have production tests been run on the two zones shown in Exhibit 4?

A Yes, sir, they have.

Q Do you have any results of those production tests?

A Yes, sir, Exhibit 5.

Q Would you give us your production test reports on the Wolfcamp first, please, sir.

A Yes, sir. The Wolfcamp, on January 20, 1958, following a clean up period, after the well was acidized, after the Wolfcamp portion was acidized, the well flowed through the casing and flowed approximately 97 barrels of fluid that was approximately 25 percent acid water, fresh water. In three hours, on a half inch choke, flowing casing pressure was 300 pounds, gas-oil ratio was 988 to 1. Gravity of the oil was 40.3 degrees API corrected, and the cumulative total of the Wolfcamp oil which we have stored at the surface or sold to date, everything that has been taken out of the Wolfcamp zone, was a total of 704 barrels of oil.

Q Would you give us similar production tests on the Pennsylvanian, or Seaman zone?

A Yes, sir. In the Pennsylvanian, on January 27, 1958, we potentialled the Pennsylvanian zone, and it flowed through the tubing 325 barrels of oil and no water in 24 hours on a 15/64 choke. Flowing tubing pressure was 850 pounds. Gas-oil ratio was 1349 to 1. The gravity of oil was 41.5 degrees API corrected. There are subsequent production tests shown on this Exhibit 5.

Q Now, on Exhibit 5 you show future production tests between February 1, 1958, and February 23, 1958. Are the matters therein correct? A Yes, sir, they are.

Q Now, what zones do they relate to?

A Everything from January 27th, 1958 forward represents solely Pennsylvanian production.

Q So you have one report on the Wolfcamp in the first paragraph, and the balance of the exhibit relates to Pennsylvanian?

A That's correct.

Q Now, do you have a well history on the subject well?

A Yes, sir, a brief history. It does not go into deep details, but it shows all important operations on the well from the time that it was spudded up until the present time, and I'll have to ask that the last entry on that history be stricken from the record. It is that we have not decided to run that test, but we have simply decided to postpond the test for a while.

Q Now, Mr. Clark, as I understand you, the last line on Applicant's Exhibit 6 should be stricken for the reason that that test has not yet been run? A That's correct.

Q Now, I refer you to the pressure figures shown at Page 1 of that Exhibit on January 17, and various other pressures, are those accurate pressure measurements?

A The pressures which were actually measured by the instrument were accurate, but these are field readings of the chart that resulted from those instruments, and field readings, necessarily out on a rig, you are going to have a little air involved. You are not reading your pressure with a scanner, you are doing it just with a ruler, to get a close approximation.

Q So that the pressures shown on the exhibit are merely approximations? A That's right.

Q And you are not contending they are exactly --

A That's right.

Q Now, I refer you to Exhibit 1, which has previously been admitted. Does Exhibit 1 show the location of the well involved in this application and the leases in the general vicinity surrounding it? A Yes, sir.

Q Now --

A Exhibit 1 shows the location of the well involved in the application and location of the wells on offset leases, and in the general area, the lease embracing the subject well covers only Section 26, Township 16 South, Range 33 East.

Q Would you locate the subject well for us by legal description and distances from the North and East line?

A Yes, sir. It is 660 feet from the North and East lines of Section 26, Township 16 South, Range 33 East, NMPM, Lea County, New Mexico.

Q Now, do you have some data on your casing and cementing program in connection with this well? Is that matter shown on Exhibit 6?

A All casing and cementing that took place on the well is shown in detail on Exhibit 6.

Q And that is accurate data?

A Yes, sir, that is the accurate data.

Q Now, do you feel there is possiblity of communication or migration of fluids between this Kemnitz Wolfcamp and the Seaman Pennsylvanian zones in the annulus of the casing?

A No, sir.

Q Were any fresh water zones encountered in your drilling activities, and if so, were they cemented off and protected?

A I presume that we did encounter some fresh water zones above the red beds.

Q Would you rather defer that question?

A That is generally normal, and we set our surface casing down into the red beds and circulated cement back into the surface.

Q All the way from the surface into the red beds?

A Yes, sir.

Q And that is solid cement there?

A Yes, sir.

Q Now, on the proposed dual completion, are you familar with the proposed type of installation and so on, on that packer, and all of those which you previously mentioned?

A Yes, sir.

Q Is that, in your opinion, in accordance with good engineering practices and principals, that method of dual completion?

A Yes, sir.

Q Is the proposed dual completion installation which you mentioned, one of the standard types used in the oil industry?

A Yes, sir, it is.

Q Has the proposed type of dual completion operation proved successful in operations in actual field tests?

A Yes, sir.

Q As to your surface equipment, can it be designed and installed so that the reservoir will be separately produced and their fluids separately tanked and gauged for no commingling?

A Yes, sir. In the event a dual completion is allowed, we will set additional tankage and separators so there will be no surface commingling of oil.

Q Is the dual completion requested in the application, which you previously mentioned, recognized and accepted by, in general, by the oil industry and other regulatory bodies?

A Yes, sir.

Q How about corrosion, could that present a problem?

A No, sir, not in the subject well, it should not. We have a report from Gulf Pipeline on two wells, the Kemnitz "A" 1 -- Tennessee-Kemnitz 1 "A" and the Sinclair Seaman No. 1, and the sulfur content on both of those wells was on the order of one tenth of one per cent. Sweet crude is generally defined as being less than one per cent sulfur content.

Q Is the crude from these two producing zones sweet or sour?

A It is sweet.

Q Do you feel that the dual completion technique provides any more possiblity for leakage or communication between the two reservoirs than any other system that you might know of?

A No. As a matter of fact, it probably has less possibility for communication or leakage due to the lesser number of joints involved in only having one string of tubing.

Q Have you taken packer leakage tests on the well?

A Yes, sir.

Q Do you have any data in connection with that?

A I have.

Q Now, I refer you to Applicant's Exhibit 7 and I will ask you whether or not that reflects your packer leakage tests and the results of same, and gives diagrammatic sketchs of the graph, and I believe also there is attached a plot of packer leakage test pressures? A Yes, sir.

Q Is that what Exhibit 7 is?

A Yes, sir. I might add that this packer leakage test was run on January the 25th, and was run primarily for the benefit of Forest Oil Corporation. It was run in accordance with the rules of the New Mexico Oil Conservation Commission, and notification was given that the packer leakage test would be run. We desired to run this packer leakage test prior to the time when it might be necessary. We wanted to run the thing before we started trying to evaluate our reservoirs. That would have been done with bottom hole pressure recording instruments. We wanted to satisfy ourselves beyond any shadow of a doubt that we would be evaluating solely the one reservoir in which we were attempting to gain data.

Q Now, mechanically speaking, can separate maintenance pressure tests be run on the two zones under your proposed type of dualing, and if so, how?

A Yes, we can run, I presume you are referring to subsurface pressures, bottom hole pressures?

Q Yes, subsurface pressures, bottom hole pressures tests.

A Yes, sir, that is very easily accomplished with wire line manipulation of subsurface tools. The tools on Exhibit 4, the P. S. I. Model "C2" landing nipple, which is shown immediately above the production packer has side doors in it, with straight through sleeve installed, as we presently have it in order to produce the Pennsylvanian. The Pennsylvanian reservoir is the only one which is open to the inside of the tubing, and naturally, we can run bottom hole pressure tests, or any flowing tests through the tubing right straight up the tubing through the receptacle sleeve in the event you want to gain data on the Wolfcamp zone. All that is necessary to do is to go in with wire line tools and retrieve the straight through sleeve, which was mentioned, this separation sleeve, you retrieve that, and go back in with a second sleeve, which is referred to generally as a bottom-black or side door tool. That tool, when latched into place contains the zone below the packer; in this case, the Pennsylvanian zone. The tool contains that zone below the tool and below the packer, then the Wolfcamp zone is opened to the inner portion of the tubing through the side door ports in the P. S. I. landing nipple. Now, if you were going to use a bomb to get a subsurface pressure in your tubing there, you would flow a little in excess of tubing capacity to your tanks in order to be sure that you have a Wolfcamp gradient oil in your tubing rather than Pennsylvanian gradient in your tubing, then you would proceed just as though the tubing were suspended free and the bottom of the hole in the packer itself.

Q Is this a permanent type packer?

A Yes, sir, it has to be drilled out.

Q What is the cost of drilling a Wolfcamp well using this 5 1/2 inch casing?

A A Wolfcamp well?

Q Yes, sir.

A Two hundred sixteen thousand dollars, approximately.

Q What would it cost to drill a Pennsylvanian well and dual complete it with 5 1/2 inch casing in a single tube and complete it in the Wolfcamp and Pennsylvanian, using 5 1/2 inch casing in the single tubing?

A Two hundred and forty-eight thousand dollars.

Q What would it cost to drill a Pennsylvanian and dual complete it using 7 inch casing and two strings of 2 3/8 inch tubing?

A Two hundred eighty thousand.

Q Now, how much would it cost just to drill a straight well to the Pennsylvanian skipping the Wolfcamp, so to speak, with 5 1/2 inch casing, or whatever would be used?

A About two hundred and forty thousand dollars.

Q Now, in your 5 1/2 inch tubing that you presently have in there, can you put in another string of 2 3/8 inch tubing?

A No, sir, it is physically impossible.

Q Could you go back now and make a 7 inch casing out of your present well? A No, sir.

Q Why not?

A You have already got 5 1/2 inch casing in that hole, and it would be much cheaper, if you desired to do that, it would be much cheaper to skip over a little ways and drill yourself a new hole.

Q It is economically --

A It is physically impossible.

Q It is physically impossible?

A Frankly, I think it is physically impossible to do it and stay in the same hole.

Q Are you familiar with the Wolfcamp formation in the general area of the well? A Yes, sir.

Q Is it a continuous reservoir or pool?

A Yes, sir.

Q Based on that, have you arrived at any opinion as to whether or not the subject well may be presently being drained in the Wolfcamp?

A Yes, sir, I think it is fairly obvious that the subject well is being drained by the Kemnitz Wolfcamp producing field to the east of the subject well, being drained by that area in general, and particularly, it is being drained by the Tennessee State Kemnitz "B" well.

Q That's in Section 25?

A Yes.

MR. CHRISTY: That's all.

MR. UTZ: Let's take about a ten or fifteen minute recess.

(Recess)

MR. UTZ: The hearing will come to order, and you may proceed with Mr. Clark.

MR. CHRISTY: Mr. Examiner, we have attempted, from the first witness, to elicit the geological problems involved in the area, and from this witness we tried to elicit the mechanics of the dual completion and the production matters of the subject well. Our third witness will consider the well history and reservoir estimates, the other producing wells in the area, and the economic factors and the actual specific reasons why we request this application. It is obvious from the testimony to date, up to this point that, I believe, we do claim we are being drained in the Wolfcamp. We do not make such a claim in the Pennsylvanian, but we propose to show why the application should be granted from the third witness on the economics and on the well history and the reservoir estimates, and so forth. We will go into that with the third witness, but we do not have any other questions from this witness with regard to the mechanics of completion and the tests taken on the subject well itself, and the production.

MR. UTZ: Is there any questions of Mr. Clark. Mr. Cooley.

CROSS EXAMINATION

BY: MR. COOLEY:

Q Mr. Clark, you stated on direct that the proposed method of oil-oil dual completion flowing in the upper zone through the tubing annulus, and lower zone through tubing is a standard practice in the industry and accepted by the industry as well as several conservation bodies throughout the country?

A Yes, sir.

Q Could you enumerate what states authorized this type of dual completion, to your knowledge?

A To my knowledge, they are authorized in Mississippi, Louisiana, and Texas.

Q And do you have any knowledge of any such dual completion having been approved in the State of New Mexico?

A No, sir.

Q Do you know whether any such applications have ever been made

A No, sir, I am not aware of that.

Q Mr. Clark, in the event this application were denied, what would be the alternative left for Forest Oil Corporation as regards to these two zones and their existing wells?

A I think the only thing we could do would be, to prevent drainage in the Wolfcamp, I think we would have to eliminate our Pennsylvanian production.

Q And you do not, I believe, from the outline Mr. Christy gave us, you are not prepared to testify on the oil in place in the Wolfcamp? A No, sir.

MR. CHRISTY: We have a reservoir engineer who will do that.

MR. COOLEY: That's all the questions I have.

MR. UTZ: Any other questions of the witness?

QUESTIONS BY MR. UTZ:

Q Mr. Clark, I believe you stated that 5 1/2 inch casing completion to the Wolfcamp was two hundred sixteen thousand dollars, and proposed dual completion is two hundred forty-eight thousand dollars, and if you were to put 7 inch casing, and two, 2 3/8 inch strings, it would be two hundred eighty thousand dollars, is that correct? A Yes, sir, that is correct.

Q Obviously the reason you can't put in two, 2 3/8 inch strings is because you have 5 1/2 inch casing in the hole. Now, is there any other type of tubing that you could use two strings on?

A Yes, sir. You could run two strings of inch and a half paraffin joint, or Hydrill, either one, those both fit in 5 1/2 inch casing, or you could run one string of 2 3/8 inch casing and 1 inch string. That can be done physically.

Q Could you use two strings of 2 1/16 Hydrill?

A I am not sure right offhand whether you could or not, I would have to check clearances on that. We have some twenty pound pipe in this hole.

Q Is the Hydrill tubing more expensive than the regular EUE?

A Appreciably so.

Q It is?

A Measurably so, yes. Your tubing is your primary cost factor when you start talking about Hydrill. The pipe itself is a relative insignificant figure, as compared to the cost of tubing.

Q Are you in a position to say whether or not you intended to drill to the Pennsylvanian when you projected this well?

A We did not.

Q What caused you to go ahead to the Pennsylvanian?

A We were a little dubious about the prospects of a Wolfcamp producer when we ran drill stem tests in the Wolfcamp. We were afriad we may have a dry hole. We went on to the Pennsylvanian in order to use it as a salvage operation in the event that the

Wolfcamp did not produce.

Q Now, you are drilling another well, I believe?

A Yes, sir.

Q Offsetting this one to the south?

A That's correct.

MR. CHRISTY: It is the No. 2 well, Mr. Examiner, it is shown on Applicant's Exhibit 3.

Q Is that well now dry? A Yes, sir, it is.

Q Have you projected it to the Pennsylvanian?

A No, sir, it is now projected currently as a Wolfcamp well. If I remember correctly, our application to drill the well included a depth of ten thousand eight hundred feet, that would put us in the Wolfcamp.

Q How far along is this well drilled now?

A It is at approximately four thousand feet.

Q And what type of casing do you intend to use there?

A Five and a half inch casing.

Q Might you not be in the same position when you get to the Wolfcamp on this well?

A It is possible, yes, sir.

Q Still, in view of the fact that you had the Pennsylvanian in your No. 1 well, you still don't intend to go to the Pennsylvanian in your No. 2 well?

A No, sir, we don't. Not under our present plans, we don't.

Q If your Wolfcamp is dry, you are going to plug it?

A Well, that is a decision that will have to be made at that time.

MR. UTZ: Any other questions of the witness? Mr. Nutter.

QUESTIONS BY MR. NUTTER:

Q Mr. Clark, to get into the mechanics of flow in a flowing well, what is the principal propelling agent that moves the oil up the tubing or up the casing of the tubing annulus, as the case may be?

A Decompression of the reservoir oil and expansion of the gas in solution in addition to a driving force possibly of the expanding gas cap, if there happens to be one.

Q And you have this gas coming out in solution in the casing or tubing annulus? A That's correct.

Q As free gas?

A In conjunction with the oil that it is bringing with it. It is the piston or the driving force.

Q What is the diameter of the pipe that you have in this hole, internal diameter?

A It is about 4.9 inches.

Q Now, in response to a question by Mr. Utz a moment ago, you said it was impossible to run two 2 1/16 inch K.S. joint strings, parallel strings of this type of tubing.

A I stipulated it might be impossible. I do not know whether it is possible to run two strings of 2 1/16 inch Hydrill.

Q Do you know what the OD of the joint is on 2 1/16 inch Hydrill tubing string?

A Right offhand I don't.

Q Assuming that it were 2.33 inches, would it be possible to run parallel strings in this --

A Yes, it would.

Q What type of tubing do you usually run in accordance with the application?

A 2 3/8 inch OD, No. 4.70 EUE N80 tubing.

Q What is the outside diameter of that?

A 2 3/8 inches. The coupling diameter is 2 1/2.

Q The tubing --

A 2 3/8 nominal.

Q Do you have any idea of what the cross-sectional area of 2 3/8 inch OD tubing is?

A The cross-sectional area?

Q Yes, sir.

A Of the tubing itself?

Q Yes, sir. If you have it, would you figure that for us, please.

A All right, sir. Approximately 4 1/2 inches, square inches.

Q What would the cross-sectional area of your 5 1/2 inch casing be? That is, the internal cross-sectional area?

[illegible] the [illegible]

A Approximately 18.9 square inches.

Q What would be the area of the annulur space, the difference between the outside area of the tubing and the inside area of the casing?

A I don't recall what -- What did I give?

MR. UTZ: 4 1/2.

A That would be 14.4 square inches.

Q How would the cross-sectional area of this annulur space compare with the cross-sectional area of the two and a half inch spacing?

A It would be roughly five times as large.

Q Five times?

A I think that's right. Approximately five times as large.

Q Now, Mr. Clark, you stated that one of the driving forces to cause this fluid to move up the well bore was the expansion of gas coming out in solution? A Yes.

Q As that gas comes out in solution, it has to move a certain amount of fluid that is in the pipe, is that not true?

A That's right.

Q The amount of slippage that is encountered as this gas moves through the column of oil would be a function of the velocity with which the fluid was moving, would it not?

A Yes, sir, that would be one of the dependents.

Q Do you think that the velocity of fluid would be comparable in an inverse sense to the cross-sectional area? That is, to move a certain volume of fluid through a given cross-sectional diameter, the velocity of the fluid would be inversely proportionate to the cross-sectional diameter?

A That's correct.

Q And the velocity of this fluid coming up this annular space would be 1/5 as much as the velocity of the fluid coming up the string of tubing?

A Approximately, yes.

Q Now, would you have five times as much slippage in that event?

A I don't think so.

Q How much slippage would you have?

A I think you would have on the order of two to three times as much slippage.

Q You would increase the slippage --

A Yes, sir.

Q Then the increase of slippage is the dissipation of energy, is it not? A Yes, sir.

Q As you increase this cross-sectional area and permit more of this gas to come through the oil by slowing down the velocity of the fluid, would you have a tendency to increase the gas that is produced from a reservoir?

A Would you state that over again, please.

Q In other words, do you agree with the concept which is frequently asserted in the oil industry that the tubing of wells results in a lower gas-oil ratio for those wells?

A Yes, I think that is definitely correct.

Q Do you think that decreasing the cross-sectional area by a matter of 1/5 would have any affect on the gas-oil ratio?

A Yes.

Q Do you agree with the testimony of Mr. Dehlinger that these are rather high oil ratio, or may be expected to be high oil ratios in this area?

A Yes, I do.

Q Do you think that's in the interest of conservation, to increase the gas-oil ratio?

A No, I don't, not when you are starving for gas. I think it is a function of whether or not you are going to add the depletion of the oil portion of a reservoir, whether or not you will still have gas left.

Q What utilization is being made of the gas that is being produced here now?

A There is none at the present. There is no pipe outlet for this gas. There should be before summer.

Q What disposition is being made of it at the present?

A It is being flared. We are talking about any gas?

Q Gas in this pool, yes, sir.

A In the Kemnitz Wolfcamp pool?

Q Yes, sir.

A It is being flared. I presume that it is, there is no pipeline outlet in the vicinity that I know of.

Q What reason do you have to think that the gas slippage would be a matter of two or three times as great?

A You have a reduced friction factor, for one thing.

Q Reduced friction factor as a result of having more annular spaces?

A Yes, sir, I think so. You will have a lower velocity, and in all probability, you will have a laminar flow as opposed to turbulent flow in the tubing. I don't mean to imply that that necessarily will be the case. You don't necessarily have turbulent flow within your tubing if you are producing at the same rate that you are producing in the annular, but it may very well apply, and even if it does not, your friction factor increases with an increase in velocity.

Q Do you think that you will have a laminar flow in the application of the tubing annulus with that flow bumping into the collars all the way up the hole?

A Yes, I think the type of flow that you have is going to be a function of velocity.

Q And you would expect a laminar flow even with these high gas-oil ratio that may be encountered in the Wolfcamp?

A Possibly not in the very top of your string, say two thousand feet from the surface, from there up I wouldn't expect definitely to have laminar flow, but I would expect to have laminar flow in the lower reaches of the annular reach.

Q Where the velocities are slow?

A Yes. As the velocity increases with expansion, and gas comes out in solution, why you may very well get into a turbulent flow situation. At that point your velocity may become great enough to give rise to turbulent flow.

Q Mr. Clark, do you think that the ideal stringer and tubing that could be installed in the well would be one which would balance the friction losses and the slippage losses so as to achieve a minimum drop in pressure as the fluid moves up the hole?

A Yes, I believe, that's correct.

Q And do you think that the annulus between a stringer of two, 2 3/8 inch tubing and 5 1/2 inch casing achieves that minimum pressure drop?

A No, it doesn't. It is not the ideal. I think you have to strike a balance between the cross-sectional area that you are producing and the amount of friction drop that you get due to your frictional resistance to flow, which would, of course, be based on your hydroelectric radius.

Q Do you think that the friction drop which would be encountered in annular flow or concentric flow, as it might be called, is the same friction drop that you would have in a round pipe of the same cross-sectional area?

A No.

Q Would it be greater?

A It would be greater because you have two, you have a greater hydroelectric radius.

Q You have two surfaces? A Yes.

Q To cause friction? A That's right.

Q Mr. Clark, how long do you think that the Pennsylvanian zone will continue to flow at the present rate of decline?

A I don't believe I am prepared to answer that question.

Q Do you anticipate a long flowing life in the Pennsylvanian zone?

A By long are we including the term, years? If we are talking in terms of years, I don't anticipate that long.

Q Would you anticipate it would continue to flow for several months?

A I don't think that it will be flowing six months from now.

Q I notice on your diagrammatic sketch that you have indicated that the tail pipe at least would be an inch and a quarter OD Kobe tubing. What is the reason for that?

A We ordinarily run something small below, or seal nipples in order to avoid having any of our wire line tools being lost and going on down, so that we don't even have any fishing jobs below, and we don't have to go below our permanent packer with wire line tools.

Q Then this piece of tubing is in the nature of a restriction on the bottom of the tubing rather than an indication of putting in Kobe pumping equipment?

A No, sir, that is not for Kobe pumping equipment at all.

Q What has been the general characteristics of the wells in the Kemnitz Wolfcamp pool? How many wells are in that pool total, do you know?

A I do not.

Q Well, just answer the question this way, what percentage of the wells, to your knowledge, are flowing, and what percentage have had to go on pump?

A It is my understanding that two of the wells have gone on the pump in the Kemnitz Wolfcamp pool.

Q And the balance are flowing?

A The balance of the wells, as far as I know, are flowing.

Q Now, a summary of the wells that have been completed in the Pennsylvanian zone shows that the Penrose well is such that it can hardly be termed a well at this time. Now, what about the Sinclair well, is it a flowing well or pumping well?

A It is a flowing well.

Q What about the Pure well, what is its status?

A It is flowing.

MR. NUTTER: I believe that's all.

MR. UTZ: Any other questions of the witness?

MR. CHRISTY: I have one or two here.

REDIRECT EXAMINATION

BY: MR. CHRISTY:

Q Mr. Clark, a question was asked on raising this gas-oil ratio. Do you plan to utilize the gas as it is taken out as soon as the pipeline facilities are available?

A Yes, sir. We anticipate that our gas will be taken by the gasoline plant or the completion plant which is presently being built about three miles east of us.

Q Now, do you feel that the increase in the gas-oil ratio will endanger the reservoir and the ultimate recovery in the Kemnitz pool?

A No, sir, I don't. I think they are going to end up with excess gas in their land.

Q So that the increase in gas-oil ratio will not be detrimental to the pool? A No, sir.

Q Coupled with the fact that you will be able to utilize the gas?

A I think that's correct.

Q Now, sir, a question was asked you whether or not you could use Hydrill tubing. Did your cost estimate previously made include the use of Hydrill tubing?

A It included the cost of a stringer of one inch Hydrill tubing to be run down. It is possible to run that down beside the present string of producing tubing that is in, and 5 1/2 inch casing. We could possibly, physically run a string of Hydrill.

Q If you had completed it with the use of Hydrill tubing, wouldn't your cost have been increased from that previously testified?

A Yes.

Q Substantially, or minor?

A Well, if you are going to compare it with anticipated Pennsylvanian production, as I understand it, I think it is quite a substantial figure.

Q Do you know what that figure might be, that increase?

A I estimate it, to run a string of one inch Hydril tubing to ten thousand seven hundred feet, the estimated cost of the tubing, the equipment and installation expense, all included, would be seventeen thousand dollars. That's over and above the cost that we have in the well now.

Q Now, mechanically speaking, can either one or both of the pay zones be pumped under your present form of completion?

A Yes, sir, either zone can be pumped with the other zone shut in. The Pennsylvanian zone can be pumped up the tubing with the Wolfcamp flowing up the casing annulus.

Q Supposing you had to put the Wolfcamp on a pump.

A Block off the Pennsylvanian and pump solely the Wolfcamp, unless you are going into dual completion zone pumping equipment.

MR. CHRISTY: That is all the questions I have.

RECROSS EXAMINATION

BY: MR. NUTTER:

Q That raises one question, Mr. Clark. You stated that it would cost you seventeen thousand dollars to run a string or two strings?

A One string.

Q One string of C.S. joint?

A That's right, C. S. Hydrill.

Q Now, you were including there the cost of running the pipe as well as buying?

A That's right, buying the pipe. The pipe itself -- Ten thousand seven hundred feet of that pipe would cost fourteen thousand five hundred dollars.

Q A large part of that is capital investment, which could be recovered after the well is completed?

A It may very well be recovered from a weight standpoint, but I don't know whether we would ever use it again, and when you get something like that in your hands, in your yard, you end up selling it for junk, and you get a junk price for it.

Q Another thing, Mr. Clark, you stated that it would be physically impossible, in your opinion, to run 7 inch pipe in this well at the present time? A Yes, sir.

Q Now, would it have been physically impossible to run 7 inch pipe in the well prior to the time the 5 1/2 inch pipe was run?

A We did not have a hole large enough drilled to accommodate

7 inch pipe. That hole would have had to be rimmed.

Q Couldn't it have been rimmed under the five --

A No, sir, you would have to go back to your surface casing. We had 8 5/8 in the hole, you can't run 7 inch casing in that. We would have to set 9 5/8 inch in lieu of 8 5/8 if we wanted, anticipated running 7 inch casing. That is our normal program.

Q It is physically impossible to run 7 inch pipe inside 8 5/8?

A Right offhand I don't know whether it is physically impossible or not, but it is not in good practice. You are taking too much of a chance. If you have any clearance, you have so little clearance that a slightly crooked hole would get you stuck and you would end up junking the hole right there.

Q You don't think it would be met with success in any event?

A I don't think that you would go into a situation like that intentionally. I don't think that you would intentionally set out to have an 8 5/8 intermediate string and run a 7 inch casing inside.

Q What do you mean intentionally?

A That's what I mean.

Q When the well was originally contemplated, you mean?

A Yes, sir.

Q But as a salvage operation, do you think it would be attempted?

A I would have to find out whether or not it is even physically possible to run 7 inch casing inside 8 5/8. I don't know that right offhand.

MR. NUTTER: Thank you.

MR. UTZ: Any other questions of the witness?

QUESTIONS BY MR. STAMETS:

Q Mr. Clark, I have one question. About how much oil do you expect to get from the Pennsylvanian zone?

A That is going to come from the Reservoir Department, if you don't mind.

Mr. STAMETS: That is all.

MR. CHRISTY: I have some questions.

REDIRECT EXAMINATION

BY: MR. CHRISTY:

Q The question came up whether or not when you got to the Wolfcamp you could have rimmed out the hole?

A Yes, sir. It is physically impossible.

Q It is physically impossible. How about the cost factor on that?

A In hard rock country like this, I think that you are probably a little better off if you just go back and start over.

Q In other words, it is probably going to be cheaper to drill a new well, new hole?

A That's right. Your bits go out of gauge too fast.

MR. CHRISTY: That's all the questions I have.

(Witness excused.)

MR. CHRISTY: For the Commission's consideration, a question was made about one and a half inch tubing, using two sets of that. I will refer to Case 1365, Order No. 4-1126, in which this body found:

"That the use of 1 1/2 inch diameter tubing in the proposed dual completion would impair the flow efficiency of both producing horizons, thereby necessitating the premature use of artificial life equipment."

Our last witness is Mr. Parsley, the reservoir engineer who will sum this up.

JOE M. PARSLEY

called as a witness, having been first duly sworn, testified as follows:

DIRECT EXAMINATION

BY: MR. CHRISTY:

Q Would you please state your name, address, and occupation?

A Joe M. Parsley, 1200 Chestnut Lane, Midland, Texas. I am a reservoir engineer for Forest Oil Corporation in the Midland office.

Q Have you testified before this body before?

A No.

Q Will you please give us a brief history of your higher education, your degrees, when and what you have done since then in the way of petroleum engineering, or related subjects.

A I graduated from the Universtity of Texas with a bachelor of science degree in petroleum engineering in 1951. I have worked for the Ohio Oil Company and Forest Oil Corporation six years as a reservoir engineer, and one year in the field. I am a registered professional engineer in the State of Texas.

Q Have you ever testified before any other regulatory bodies?

A No.

Q The lands involved in this application are situated in Section 26, Township 16 South, Range 33 East, NMPM, Lea County New Mexico, involving Forest Oil Company's No. 1 State "A" Well. Are you familiar with that well, or the general wells in the vicinity of that area?

A Yes, sir.

MR. CHRISTY: Does the Commission have any questions concerning the witness' qualifications?

MR. UTZ: No. His qualifications are acceptable.

Q Now, sir, I will refer you to Applicant's Exhibit 3 which has previously been testified as showing the wells drilled and producing in the Seaman Pennsylvanian formation. Now, will you give us a little well history and reservoir estimate on the subject well in Section 26?

A Yes, sir. That well was potentialled from the Pennsylvanian for three hundred and twenty-five barrels of oil per day. 15/64 inch choke. Flowing tubing pressure of eight hundred fifty pounds. A gas-oil ratio of thirteen hundred and forty-nine. A gravity of forty-one point five degrees API. Completed, January 21, 1958, after one hundred gallons of mud acidized, and two thousand gallons of regular acid.

First, we have examined the rock proporties. The microlog shows forty-seven feet of pay in the principal zone, with a five foot zone immediately above it. Core analysis in the Pennsylvanian shows forty-seven feet of pay. The average porosity by core analysis is eight point six percent. We do not have the fluid analysis of the Pennsylvanian oil. However, we have made some estimates, comparisons based on a gas-oil ratio, flowing gas-oil ratio of thirteen forty-nine. We have assumed that to be the solution gas-oil ratio. From this we have estimated a saturation point, a bubble point of thirteen hundred pounds. Estimated compressibility of the Pennsylvanian oil above the bubble point is in the order of seventeen times ten to the minus six barrels per PSI, and a gravity of forty-one point five degrees API.

We have access to three reservoir pressures. Our first one was obtained through a drill stem test. The initial shutin pressure of our first drill stem test in the Pennsylvanian, before any oil was produced, the pressure was forty-one seventy-two. After the well had produced four hundred and ninety-eight barrels of oil, we measured the pressure with a bomb to be thirty-four eighty-four. A little later on we took some PI tests on the well and using these tests, we have calculated a reservoir pressure at that time, that calculation to be twenty-eight ninty-six, at which time thirty-nine hundred and seventy-six barrels of oil had been produced.

We have used this pressure information to calculate a reserve for the Pennsylvanian. As you can see, we have two pressures that have been measured above the bubble point, pressures of thirty-one hundred pounds. This can be used to calculate the oil in place during the fluid expansion phase of production. We have experienced six hundred eighty-eight pound pressure drop while four hundred ninty-eight barrels of oil were produced. This gives us a point seven two four barrels of production for PSI pressure drop in the reservoir --

MR. NUTTER: How much was that?

A Point seven two four. Applying the compressibility factor of seventeen times ten to the minus six to this figure of point seven two four would determine that there were forty-two thousand six hundred barrels of oil originally in place, stock tank oil.

The recovery to the saturation pressure of thirty-one hundred pounds is estimated to be seven hundred and seventy-five barrels. That is calculated by applying a one thousand seventy-two pound pressure drop from original saturation to this point seven two four barrels per PSI that we have experienced. Therefore, deducting the seven hundred and seventy-five barrels produced to saturation pressure from our forty-two thousand six hundred barrels of stock tank oil originally in place, we determined that forty-one thousand eight hundred twenty-five barrels of oil are in place when we hit the bubble point. These pressures indicate to us that we have a solution gas drive recovery mechanism. The recovery of oil in place of that type drive is in the order of twenty percent, therefore, multiplying twenty percent times the forty-one thousand eight hundred twenty-five barrels gives us a recovery, during solution gas drive, a recovery of eighty-three hundred sixty-five barrels of stock tank oil. Therefore, out total estimated recovery will be eighty-three hundred and eighty-five barrels, plus seven hundred and seventy-five barrels, or ninety-one hundred forty barrels of stock tank oil, or approximately ten thousand barrels of oil from the Pennsylvanian.

Q Have you figured those barrels using a dollar value?

A Using a gross reserve of ten thousand barrels of oil to determine the working interest share of that, we multiply ten thousand by seven-eights to get eighty-seven hundred and fifty barrels of oil to the working interest. The posted price of oil is three dollars and eight cents a barrel. From this we must deduct twenty-two cents per barrel advalorem production tax. We have estimated our lifting cost to be in the order of twenty-five cents a barrel, that gives us the working interest and net income of two dollars sixty-one cents a barrel. The total income will be two dollars and sixty-one cents per barrel times eighty-seven hundred and fifty percent, or twenty-two thousand eight hundred thirty-eight dollars. That is the value of the Pennsylvanian oil in this well.

Q Now, this method you have described in determining the apparent reservoir in the Pennsylvanian area, is that a usual and common method used by reservoir engineers in making such evaluations?

A Yes, it is.

Q Are you familiar with the production history in the Seaman Pennsylvanian, wells in the immediate vicinity of the subject well?

A Yes, sir, I am.

Q Would you give us a brief history of these wells? Let's start with the Penrose well in Section 34.

A The Penrose "PG" State No. 1 was completed October 17, 1947 for an initial potential, flowing one thousand fifty-six barrels of oil per day, with a gas-oil ratio of a thousand and thirty-seven. gravity forty-two degrees.

Q Did you give the GO?

A Yes. A drill stem test was taken in this well prior to completion, which gave a shutin pressure of approximately six thousand pounds. In December of 1957, bottom hole pressure test and PI test were run on this well. The pressure measured with a bomb at that time was twenty-three hundred and forty pounds.

Q Has there been a severe decrease in pressure in the Penrose?

A Yes. The Penrose well has, through December '57, made only ninety-three hundred and forty-seven of oil. During that time, the well has been reperforated to open all the zone that it had available, reacidized, and the well failed to produce the allowable, and at times got down to only twelve to twenty barrels a day. As has been stated, they have recently sand off the frac with fifty thousand gallons. This well also experienced an increase in gas-oil ratio from completion. The completion ratio was a thousand and thirty-seven. During the PI test, a ratio rise of three thousand and twenty-nine was measured. The well makes no water.

Q Now, I refer you to the Seaman unit well, which is in Section 13. Will you give us a brief production history of that well?

A The Sinclair Seaman unit No. 1 well was completed October 1st, 1956 for an initial potential, flowing six hundred and twelve barrels of oil per day, plus twenty-four barrels of water, with a GO of nineteen seventy-nine, and gravity of forty-two point seven. An original drill stem test was run on this well before completion. The measured pressure was thirty-nine hundred and thirty pounds after two hours and fifteen minutes shutin. Another pressure was run on this well in April, 1957. The extrapolated reservoir pressure, built-up pressure, was thirty-three hundred and nineteen pounds. The water reported on initial potential had dried up after three montns of production. The gas-oil ratio reported now is approximately a thousand. The well has accumulated, through December 1957, approximately eighty-six thousand barrels of oil.

Q Has there been severe drops in that well?

A Not as severe as on the Pennsylvanian.

Q In the vernacular, I believe, that is considered a good well?

A Yes.

Q Tell us a little about the production history of the Pure well in Section 2 of Township 21.

A The Pure State Lee "E" No. 1 was completed October the 26th, 1957, for an initial potential, flowing fourteen hundred and forty barrels of oil per day. The gas-oil ratio was thirteen hundred and fifty. Gravity, forty-four degrees. This well, on a drill stem test prior to completion, the reservoir pressure was measured to be seventy-two hundred pounds per square inch. A bottom hole pressure test with a bomb was run in November, early part of November 1957, and it measured to be sixty-nine hundred and eleven pounds. No other bottom hole pressure tests have been run, however, the well has experienced quite a drop in flowing pressure, flowing tubing pressure. The well, after completion, would produce its allowable with a flowing tubing pressure of thirty-eight hundred pounds. Tests thereafter show the tubing pressure, the well making approximately its allowable drops to fifteen hundred, twelve hundred and twenty-five, eighteen hundred and seventy-five, and on the last report we had, the well made approximately its allowable, with a flowing tubing pressure of seven hundred and sixty pounds, indicating a depletion of --

Q Evidencing severe pressure drops on the Pure well?

A Right.

Q Do you have the figures on the total amount of oil produced?

A The Pure well has accumulated twelve thousand two hundred fifty-seven barrels of oil through December 1957.

Q Now, are there any other wells in the area of the subject well producing from the Seaman Pennsylvanian formation?

A No, sir.

Q In your opinion, are these three wells you have mentioned economically sound?

A Taken individually, our well is not, the Penrose well is not, the Pure well apparently is not, the Sinclair unit well has been producing for over a year making top allowable and appears to be economically sound.

Q Now, you have heard Mr. Clark testify as to the cost factors on the subject well, various drilling methods, and production area. Could you correlate those cost factors to the reservoir estimate,, do you have those factors, those figures?

A I do.

Q Would you correlate those cost factors for us to the reservoir estimate, and particularly with reference to the Pennsylvanian well, the possible use of 5 1/2 inch casing, 7 inch casing, and two strings of tubing, please.

A All right, sir. We have several choices to recover this Pennyslvanian oil. We could drill for the Pennsylvanian oil. To drill a straight up Pennsylvanian well, it is estimated to cost two hundred forty thousand dollars. The reserve indicated by the State "A" No. 1 Forest well in the Pennsylvanian is worth twenty-two thousand eight hundred and thirty-eight dollars. That would result in a loss of, to Forest, of two hundred seventeen thousand, one hundred sixty-two dollars. It is hardly worthwhile.. We could project a Pennsylvanian well and Wolfcamp dual using 7 inch pipe, two strings of tubing, which would cost us an additional sixty-four thousand dollars above the cost of drilling to the Wolfcamp and abandoning the Pennsylvanian.

Q Plus, in good field practices, rimming it up above?

A Right, we would have to determine, before we started drilling the well, that we would drill holes large enough to accommodate the 7 inch pipe which would accommodate the two strings of tubing.

Q Excuse me right there, Mr. Parsley, as I understand you, had you been able to foresee this and had used the larger hole originally, and used a 7 inch, it still would have cost you sixty-four thousand dollars more on the 7 inch two strings than it does on the proposed method to recover the oil?

A No, sir, it would cost us sixty-four thousand dollars more to obtain Pennsylvanian production.

Q That's what I mean, sir, and you get twenty-two --

A Below the Wolfcamp.

Q All right, go ahead, sir.

A Subtracting the value of the Pennsylvanian oil from the sixty-four thousand dollars that it takes to get it, it results in a loss to Forest of forty-one thousand one hundred sixty-two dollars. We can recover the Pennsylvanian oil by dually completing the Wolfcamp and Pennsylvanian using 5 1/2 inch casing and one string of tubing in our present completion for a cost, an additional cost of thirty-two thousand dollars above that spent to get to the Wolfcamp. In other words, thirty-two thousand dollars additional to place the Pennsylvanian on production after we have reached the Wolfcamp. Subtracting the value of the Pennsylvanian oil from the thirty-two thousand dollars still results in a loss of ninety one hundred and sixty-two dollars.

Q So if you take the initial method of drilling a twin well to the Pennsylvanian, it would cost two hundred twenty thousand dollars to get this twenty-three thousand. If you had been able to anticipate it and used 7 inch with two strings, it would cost you sixty-four thousand dollars extra to get this twenty-three, and if you use it on the present or proposed method, it will cost you about thirty-one thousand to get the twenty-three thousand?

A Yes, sir.

Q Now, the question has been asked previously about pumps. Are there economic factors in placing one or more of them on the pump?

A Yes, sir. On the type recovery mechanism that we believe we have in the Pennsylvanian; that is, solution gas drive recovery, a well with an initial adequate capacity to produce like we have does not normally require pumping until later in the stages of depletion. That is because as the well is depleted, the gas-oil ratio increases,lightening the fluid column, making the well -- although the reservoir pressure is going down, the fluid column flowing through the casing, tubing, is lighter, and is not a severe pumping problem. Late in the life of a solution gas drive field, the ratios come down, and at that time it is common to instigate pumping for that particular well. However, in a reservoir as small as this one is, the amount of oil to be recovered at that late stage of depletion is insignificant, usually in the order of five percent of your reserve remains, and five percent of our ten thousand barrels of oil is hardly worth placing the well on the pump.

Q So you would not anticipate ever placing the Pennsylvanian well on the pump based on your reservoir estimates?

A No, sir.

Q Now, in the event the Wolfcamp would have to go on the pump in later years, would you still be producing from the Pennsylvanian?

A No, sir. If our estimates are correct, the Pennsylvanian will be depleted shortly.

Q Do you mean in a matter of months?

A Yes, sir, if it continues at top allowables, it would only be a month, however, it probably won't.

Q It is a relative short life equivalent?

A Yes.

Q Have you encountered any water problems in the subject well, or have the other Seaman wells encountered water problems?

A No, sir.

Q Now, are there any other wells near the subject well in the two pools on the pump?

A In the Wolfcamp, yes, sir.

Q There is none in the Seaman Pennsylvanian?

A No, sir.

Q Now, in the Wolfcamp, are there any?

A Yes, sir, there are two wells out of a total of twenty-two wells in the Kemnitz Wolfcamp field. One of those wells is the Seaman unit, Sinclair Seaman unit well No. 2, located in Section 19. The other well is the Shell "WD" No. 1 located in Section 29.

Q Now, do you know why they are on the pump?

A Yes, sir, I have an opinion.

Q All right, sir, what is that opinion?

A The Shell well is fairly low structurally in the Wolfcamp. The Shell penetrated the known estimated oil contact of minus 6670, and actually perforated into the water. Shell tried to squeeze off the zones in the water, but were not successful. The well continuous to make water, and their problem is water production, lifting the water.

Q So that's the reason for Shell's well being on the pump?

A Yes, sir.

Q How about Sinclair's No. 2 well that you mentioned before?

A Sinclair's well had a very thin section of Wolfcamp. It is not a normal Wolfcamp well. It has been a marginal well from the beginning, and it happens to be one of the wells that does not have adequate capacity to flow. It needs help, therefore, it is pumped.

Q Now, those are the only two wells on the pump in the area in question?

A Yes, sir.

Q Now, could you give us a short summary of the economic problems in the instant well, or subject well, and any future development of wells of this type in this Seaman Pennsylvanian area, and your economic problems involved?

A Well, apparently, we have made a mistake in our well. The Pennsylvanian wasn't worth it, so we apparently will lose money, however, that does not altogether condemn the area as far as Pennsylvanian is concerned, since Sinclair's Seaman unit No. 1 is a good Pennsylvanian well. If we could get wells like that, we want to explore for them. However, with the poor performance of the majority of the wells staring us on the face, you have to use some costs, and you want to do it the most economically manner possible, consistent with good production practices. We would like to -- another point, we believe the Wolfcamp is economic, we want to develop our leases, and we, occasionally we want to, when we have geologic reason, we want to test the Pennsylvanian, but we do not want to start every well as a potential elaborate dual Wolfcamp Pennsylvanian, we want to be able to place our Wolfcamp on production in the general accepted manner, and explore for the better Pennsylvanian reservoirs.

Q In your opinion, is it economically sound to commence a project to project it to the Pennsylvanian in this area and to know that you are going to have to dual it in the Wolfcamp and Pennsylvanian if you get it. Do you feel that is economically sound, based on the other Seaman Pennsylvanian wells?

A The majority of the wells, no. There is one hope that we can find. The reservoirs are small, but they are of different size, of course. Apparently, Sinclair found a better one, and we hope to find something like that, but we have no assurances of it.

Q Do you feel that a requirement on your company or any other company in the area to expend more than the additional thirty or thirty-two thousand dollars to test to the Pennsylvanian, is that an economic requirement? Economically speaking, can you meet such a requirement?

A It is not sound.

Q It is not sound? A No.

Q I have one or two other questions, Mr. Parsley, in the event this application is denied, what would you recommend the Forest Oil Corporation do concerning future development in this area with relation to Pennsylvanian Wolfcamp tests?

A I would recommend in our first well, that we abandon the Pennsylvanian and protect ourselves in the Wolfcamp, and that there would be no economical justification to continue to explore for Pennsylvanian reservoirs in this area.

MR. CHRISTY: That's all.

MR. UTZ: Are there any questions of the witness?

MR. COOLEY: I have some.

MR. UTZ: Mr. Cooley.

CROSS EXAMINATION

BY: MR. COOLEY:

Q Is your name Mr. Parsley?

A Yes, sir.

Q Mr. Parsley, it is possible, is it not, to deplete the Pennsylvanian zone with your present completion and then plug back to the Wolfcamp and produce that zone through a single completion?

A Yes.

Q The only obstacle to this procedure being that there is a possibility that you might be drained by the offset wells, especially the Tennessee Transmission Company's "B" State Kemnitz Well No. 3?

A In the Wolfcamp, yes, sir.

Q That is the moving reason here, is it not, everybody saying they got to plug back to protect themselves in the Wolfcamp, if they want to produce this way?

A Yes, sir.

Q Now, having assumed that drainage is occurring, can you tell me how far it is between those two wells?

A One half mile.

Q As a reservoir engineer and being familiar with the Wolfcamp reservoir, that well will drain a radius of one half mile?

A Yes, sir.

Q A radius of one half mile --

A Yes, sir.

Q --to any great degree? A Yes, sir.

Q How long has the Pennsylvanian well been producing?

A Several months.

Q Any oil that they have -- assuming there is drainage, any oil that they have drained is lost as of now, isn't that right, anything they have drained from you is forever lost to you?

A Right.

Q What do you estimate the remaining life of the Pennsylvaniar pool is? A Pennsylvanian?

Q Did you say that if it produced at top allowable, it would be gone in one month, or certainly in less than six months? A Yes.

Q Less than three months?

A About three months.

Q About three months. Do you have initial pressures on the Wolfcamp zone in your well?

A Yes, sir.

Q Have you ever taken drill stem pressure tests? Do you have pressures on that well? A Yes.

Q Have you ever taken any subsequent pressure --

A No, sir.

Q Would it not be possible, by taking subsequent pressures on it, to determine if any communication does exist between that well and any other well?

A It would be. I think our pressure that we have proves it.

Q Well, the pressure as you pointed out a moment ago, your initial pressure and the amount of oil that is in the reservoir and in your tank at the time you completed this is all you are entitled to, and if somebody beside you drained it out from you, it is too late to get that.

A I suppose we lost that.

Q You lost that as a matter of a race in drilling. The only drainage we are talking about is the one between the present time, and not what is behind because that is lost forever, so the only thing we can prevent in the way of drainage, is the drainage that might occur at the present time, and at the time the Pennsylvanian is depleted, and such time as you could plug back and commence production from the Wolfcamp to create your zone of low pressure, and thus try to offset the drainage problem that is occurring, if there is one?

A That's right, future drainage.

Q Future drainage is all you can prevent, you can't prevent the past drainage? A That's right.

Q You have a three month period in which you estimate --

A Approximately that. We hope we are wrong; we hope the Pennsylvanian is a little better.

Q Well, that's what they are paying for, your expert opinion as to how much longer it is going to produce, and we also accepted your qualifications as an expert witness and accepted that these figures are pretty close to correct, so you have, roughly, a three month period over which drainage could occur, if there is any at all. Now, won't the drainage danger be increased if the well would be 660 feet? Your offset well could be as near as 660 feet under the rules, and the drainage would be greater, would it not, the nearer you are to an offset well?

A Slightly.

Q You think the gradient is very slight between the outermost boundary of a drainage radius of a well than out near the well bore? Isn't it a rather constant gradient?

A As far as depletion is concerned.

Q Would it not be possible to take pressure readings on your Wolfcamp zone at the present time and tell whether there has been any material decline in pressures between the time the well was completed and the time of the test?

A Mechanically possible.

Q Would it be feasible economically, and would the result be worth it if you took such tests? Could you anticipate what quality of oil had been drained, or to what extent it is being drained, or whether the cost of --

A We could watch our pressure go down.

Q And would the cost of such tests be prohibitive? How expensive are they, to take a pressure reading on this Wolfcamp zone as you are presently completed?

A I don't know how much it would cost.

MR. COOLEY: Can any of your witnesses estimate that cost?

MR. CLARK: About seventy-five dollars.

A Seventy-five dollars for the pressure test. It would cost us an additional one hundred seventy-five.

Q (By Mr. Cooley) It would cost you about two hundred dollars?

A Two hundred dollars to get the pressure.

Q Wouldn't that be worthwhile information, to find out whether you are in fact being drained or not, or whether you could continue to produce this Wolfcamp or this Pennsylvanian zone?

A Well, it would be interesting, but I feel that it would be academic.

Q Do you feel there will be absolutely no loss in recovery as a result of casing flow of water from the Wolfcamp zone?

A Ultimate recovery from the field will not be decreased.

Q Not in the slightest?

A If you are talking about --

Q I am talking about your particular well now, your particular completion. Do you think that the recovery would be exactly the same amount through casing even though there is going to be a loss in reservoir energy?

A Well, that particular well will be a single Wolfcamp completion at depletion. Six months estimate.

Q What I was trying to get was a comparison between any loss, if there be one, as a result of casing flow, and what all you might lose as a result of drainage if you contine to produce from the Wolfcamp during the next three months period.

A We will lose three months of Wolfcamp production, if it is three months.

Q Even without any pressure information, subsequent pressure tests, you are absolutely positive that you are being drained by this well one half mile away?

A Yes, sir, we have a little information on that. The estimated original pressure in the Kemnitz Wolfcamp was thirty-seven hundred and eighty pounds, according to prior tests, and we measured the pressure of the Forest State "A" No. 1 by drill stem test and found it to be thirty-two hundred and eleven pounds. That was in December of '57. A field wide pressure test in the Kemnitz Wolfcamp indicated an average reservoir pressure of the built up wells to be approximately thirty-one hundred and ten pounds.

Q When was that field wide test taken?

A From December the 1st to the 4th, 1957.

Q And the thirty-two eleven test?

A Sir?

Q The thirty-two hundred eleven test, your drill stem test, when was that taken?

A December the 25th, 1957.

Q Is this thirty-two eleven drill stem type of testing comparable with the method used on this thirty-seven hundred eighty pounds original pressure of the drill stem test?

A I really don't know. Tennessee Gas testified to that pressure.

Q Could the method of testing, the type of testing, whether it be drill stem test or some other type, cause some variation?

A Yes.

Q Could it account for that month for the five hundred pounds?

A I don't think so.

Q Do you know what other initial pressures of wells in approximately the same point in time as your State "A" well, what pressures were found in those wells?

A No, I don't

Q The reason I ask this question at this point is that if the fieldwide pressure had fallen from thirty-two eleven, which we will say was the true fieldwide pressure of your pool at the time you drilled, then apparently there had been some drainage, but whatever is gone is gone, and forever lost to your company, and through no fault of anyone but your company's, assuming that they didn't drill quick enough.

A That's right, when we had information to drill.

Q And the interval I am particularly interested in and which we have no information on is what pressure drop you have suffered between the date of completion and the present time.

A Yes, sir.

Q You don't feel you would be willing to take such tests?

A If it would help this hearing, surely would. I don't know, it is not for me to say. I could recommend it one way or the other.

Q The only position we can take in that regard, sir, is that we won't require such a test in connection with this, and we don't intend to try to compell you to take such a test, but if your company does sometime in the future take such a test, we would like to be informed of the results.

A Yes.

MR. CHRISTY: If a test is taken, we will certainly submit it.

MR. COOLEY: That's all the question I have. Thank you very much.

MR. UTZ: Any other questions of the witness?

MR. CHRISTY: If there is no other question, I have one or two.

REDIRECT EXAMINATION

BY: MR. CHRISTY:

Q Now, Mr. Parsley, Mr. Cooley mentioned to you several times drainage by the Tennessee Gas and mentioned correctly that the two wells were approximately one half mile away, but as a matter of fact, isn't it less, the Forest lease is closer than one half mile? A Yes, sir.

Q Now, secondly, he mentioned the drainage by the Tennessee well to the east. Now, does the reduction in pressure from production throughout the whole field cause an ultimate loss of recovery to your well?

A Yes, sir.

Q The pressure in the pool is what I have relation to, that type of drainage as distinguished from actual oil moving drainage, would you explain that pressure?

A I think this is a continuous Wolfcamp reservoir.

Q Excuse me, but I believe your pressure, when you completed your well, was the same as the field pressure?

A Approximately.

Q Approximately the same. Doesn't that indicate that that is one continuous pool? A Yes, sir.

Q All right, sir, go ahead. Our well in this reservoir -- As oil is taken out, we share in the reservoir oil, or do not share, as our well is completed or not completed.

Q Now, also, the reduction in pressure in the field as such will reduce your ultimate recovery at the end of the recovery period, wouldn't it? A Our well?

Q Yes, sir, in addition to the oil migration which Mr. Cooley has mentioned, there will be a reduction of pressure in the pool as a consequence, and there again you will not be able to make as much recovery oil because of the lower pressure

A Right.

Q So there is two losses of drainage, one by oil migration and one by pressure loss in the pool? A Yes, sir.

Q One which you suffer immediately and one which you will suffer at the end of the reservoir --

A Yes, sir, we lose oil from our No. 1 well by not having it on production in this reservoir.

Q Both from oil movement and from reduction in pressure?

A Yes, sir.

Q And it does not take as much time to produce it while the reservoir is sufficient to get it out of there?

A Yes, sir.

Q Now, you mentioned this three months period in the Pennsylvanian, and I believe Mr. Cooley kept speaking of three months. Did you say an estimate of three months to six months?

A Yes, sir. Now, our well continuous to make top allowable, and one estimate would be twenty a month, if it continuous to make top allowable, and we don't think it will decline.

Q So it will probably be three to six months?

A Yes.

Q And I believe you completed the well some two months ago in the Wolfcamp, so you have already lost two months of oil migration, drainage, subsequent to your date of completion?

A True.

Q And the only way we are going to tell whether it is three months, six months, or seven months in the Pennsylvanian is to produce it out of there? A Yes, sir.

Q We could make a reasonable estimate of three to six months, and that is the best we can do right now?

A Yes, sir.

MR. CHRISTY: That's all.

MR. UTZ: Is there any further questions of the witness?

MR. COOLEY: I have one more question.

RECROSS EXAMINATION

BY: MR. COOLEY:

Q What do you estimate the life of the Wolfcamp pool to be, sir? What do you estimate the producing life of the Kemnitz Wolfcamp pool to be?

A Seven to ten years. I really have no -- The only thing I can base that on is the comparison to the Townsend. The Townsend has been on production approximately six years, I believe. Their performance history indicates they are well along in their depletion cycle.

Q There wouldn't be any physical obstacle, would there, in depleting and going back up after ten years to --

A No, sir, no physical obstacle.

Q I believe you said twenty-two thousand dollars out of it would be worth --

A Very little.

Q About zero ten years from now.

A We would have quite an investment tied up.

Q It affects the economic life of your well?

A Yes.

MR. COOLEY: Thank you.

MR. CHRISTY: One last question.

REDIRECT EXAMINATION

BY: MR. CHRISTY:

Q This thirty-two thousand that it has cost you to go to the Pennsylvanian in your present method, if you shut in your Pennsylvanian and produce from the Wolfcamp for ten years and then go back to the Pennsylvanian, you have had your thirty-two thousand sitting in the hole for ten years?

A Yes.

MR. CHIRSTY: That is all.

MR. NUTTER: You have spent that thirty-two thousand dollars whether you get anything out of the Pennsylvanian or not?

A Yes.

MR. UTZ: Are there any more questions? If not, the witness maybe excused.

(Witness excused.)

MR. CHRISTY: We have no other witnesses for the Applicant.

I would like to mention, in summary, one or two items. In the first place, it is very obvious that the well is being drained in the Wolfcamp, and unless it is produced from the Wolfcamp, the State of New Mexico is going to lose money and we are going to lose money, and our correlative rights will be violated as well as the State's, so No. 1, we have to produce in the Wolfcamp and in the Pennsylvanian, which we believe that the evidence has developed that there are small stratigraphic traps and that there is no drainage.

We have not asked for this dual completion based on drainage on the Pennsylvanian, but on the fact that there is such a small amount of recoverable oil in the Pennsylvanian that the only method that we can economically employ to recovery that oil is by the proposed type of dual completion.

We realize and recognize that the Commission noramlly likes and requires 7 inch two strings of tubing, but economically, that is just infeasible. We might as well throw the oil away, as to try to do it that way in this instance. If we got such a well as the Sinclair, that might be a different story, but we just don't have it. It is economically unsound to twin the well for two hundred forty thousand dollars. We can't physically do it in the 7 inch two strings of tubing manner without having to rig out the hole, and if we did that, we might as well twin it and spend thirty thousand dollars, so again, it in economically infeasible. It is physically impossible to run inch and a half tubing in there for two strings, but again, this Commission feels that that is poor conservation practice, and has in another case rejected it, so it appears to us that the only sound method to allow the recovery of the Pennsylvanian oil in the State of New Mexico, is to allow us to dual complete this with a small string, with five and a half inch casing. That will allow us to recover out fair and just share of the oil in the Pennsylvanian, and it will allow the State of New Mexico to recover its royalty in the Pennsylvanian oil, which is for other intents and purposes lost.

The dual completion method has been tested as a sound method and has been used in Texas, Louisiana, and Mississippi, I believe, for many years.

In the final analysis, unless some type of dual completion along this line is allowed in these isolated instances, when you run into small tanks of this nature, like the Pennsylvanian's, the effect of it is that the producers and the operators are just economically not going to be able to test for these small stratigraphic traps, they are just not going to waste the time putting in two hundred forty thousand or two hundred and eighty thousand dollars with a very very minimum chance of getting one of these small stratigraphic traps, so as a consequence, they have to go on and drill for the known producers in the Wolfcamp and take a gamble for thirty thousand, and hope that they might get a Sinclair, but if they don't, they might get a Penrose, but the odds against them are too fantastic for them to expend two hundred and forty thousand dollars as an additional investment.

That's all we have.

MR. COOLEY: Mr. Christy, I have reserved asking these questions of any of your witnesses for reasons that they are purely legal, and I am not going to make a statement to the Commission with regard to one facet of this case, but if you will refer to Rule 112-A of the New Mexico Oil Conservation Commission Rules and Regulations, Rule 112-A states:

(a) The dual completion of any well may be permitted only by order of the Commission upon hearing, except as noted by Paragraph (c) of this rule.

Rule (c) Is not applicable to this case. Then, Paragraph (b) states:

(b) The application for such hearing shall be submitted in triplicate and shall include an exhibit showing the location of all wells on applicant's lease and all offset wells on offset leases, and shall set forth all material facts on the common sources of supply involved, and the manner and method of completion proposed.

And I might emphasize the last word of that Rule, "proposed". It has been the common understanding that it is not only not permissible, but it is against the Rules and Regulations of this Commission to dual complete a well prior to seeking the Commission's approval, thus the expenditure by your client, Forest Oil Corporation, of these additional monies in completing this well without any authority whatsoever, will not be taken into consideration in this case.

MR. CHRISTY: That is perfectly satisfactory.

MR. COOLEY: It will be considered as if it were a proposed dual completion. The fact that you spent your money will not be considered in any fashion.

MR. CHRISTY: It is perfectly satisfactory. We are producing only from the Pennsylvanian, we have never attempted to dual complete it.

MR. COOLEY: I realize that, but they have equipped this well as a dual completion, and now the arguments are being made that the Commission should take into consideration the expenditure which they have made to dually complete this well.

MR. CHRISTY: The expenditure of thirty-two hundred dollars includes the drilling, that is my understanding, so that about seventeen thousand of it relates to the completion, so I agree with the Commission. You might not wish to take into consideration the seventeen thousand for completion, but I do not agree that you should not take into consideration the fifteen thousand for drilling to the Pennsylvanian in making the test.

MR. COOLEY: That is a touchy question, Mr. Christy. When you drill through two zones the well which you anticipate producing, you have two courses of action which you may take; one being producing singly and keeping one shut in until the other is depleted, and the other being dual completion. Now, if you drill this in anticipation of dual completion, I don't know what the circumstances are.

MR. CHRISTY: I believe the testimony was that it was drilled as a Wolfcamp test, and that at the point of the Wolfcamp, it was feared that they would have a dry hole, and then they went on down to the Pennsylvanian. There was never any drilling program of dual completion initially, even though it was a Wolfcamp test, but I follow the Commission's argument on this seventeen thousand dollars.

MR. COOLEY: That is the only point I wanted to raise in regard to the legal facets of this case. That's all.

MR. UTZ: Mr. Christy, did you offer your exhibits?

MR. CHRISTY: We would like in evidence Exhibits 4 through 7 inclusive.

MR. UTZ: Is there any objection to the entrance of those exhibits? If not, they will be accepted.

Are there any other statements in this case? Mr. Kellahin.

MR. KELLAHIN: Jason Kellahin, of Kellahin and Fox. I would like to make a brief statement on behalf of Amerada Petroleum Corporation.

Amerada Petroleum Corporation is not an operator in the area involved in this application, and we realize that Forest Oil Company does have an economic problem at this stage of the situation with which we have great sympathy, however, Amerada does hold the premise that this case will open the door to future applications and possibly future approval of this type of an oil-oil dual, and we want to go on record as being opposed to the completion as proposed in this case. It is a type of completion which has heretofore been denied approval by the Commission in a number of different cases, and Amerada does not feel at this time that the Commission should open the door to this type of completion. They do not feel it is efficient and effective, and we urge the Commission to follow its present policy and deny this application.

MR. UTZ: Are there any other statements?

MR. COOLEY: If there are no other statements, I would like to bring this up, I have an item I would like to bring up with Mr. Christy. Mr. Christy, I refer you to Forest Oil Corporation's letter of January 22nd, 1958 wherein they notify all the offset operators of their intention to dually complete the State "A" No. 1 well, which has been the subject of this hearing. In the letter itself there is no mention of the mechanics of the proposed dual completion. The enclosures which we received attached to this letter would apprise the operators of the fact that you proposed a casing for the flow of oil. The letter itself would not, and I would like to know if --

MR. CLARK: A schematic sketch was attached. They were aware of the fact that it was a conventional dual completion.

MR. CHRISTY: In answer to your question, Mr. Cooley, a copy of Applicant's Exhibit No. 4 was furnished to all offset operators in connection with that letter of the 22nd.

MR. COOLEY: Now, would you like to identify the six waivers?

MR. CHRISTY: We haven't previously offered to the Commission waivers from the following offset operators: Tennessee Gas Transmission Company, Humble Oil and Refining Company, Phillips Petroleum Company, Cities Service Oil Company, Signal Oil and Gas Company, and Tidewater Oil Company, and we also have one from Shell, which is erroneously shown on the map as being an offset operator to the northeast. That is incorrect, it was Sinclair, as I mentioned a while ago to the Commission. Sinclair has been notified of the hearing and was furnished a copy of the application, and Applicant's Exhibit No. 4. I would like to leave that.

MR. COOLEY: Do you want to identify that as an exhibit?

MR. CHRISTY: Yes, as an exhibit. Those letters, or waivers are marked as Applicant's Exhibit 8, which we ask the admittance of.

MR. UTZ: Is there any objection to the entrance of Applicant's Exhibit 8? If not, they will be accepted.

Are there any other statements in this case? If not, the case will be taken under advisement and the hearing is adjourned.

STATE OF NEW MEXICO)
) ss
COUNTY OF BERNALILLO)

I, J. A. Trujillo, Court Reporter, do hereby certify that the foregoing and attached Transcript of Proceedings before the New Mexico Oil Conservation Commission was reported by me in Stenotype and reduced to typewritten transcript by me, and the same is a true and correct record to the best of my knowledge, skill, and ability.

WITNESS my Hand this 5th day of March, 1958, in the City of Albuquerque, County of Bernalillo, State of New Mexico.

Joseph A. Trujillo
Court Reporter

MY COMMISSION EXPIRES:
October 5, 1960

I do hereby certify that the foregoing is a complete record of the proceedings in the Examiner hearing of Case No. 1383, heard by me on Feb. 26, 1958.

Elvis A. Utz, Examiner
New Mexico Oil Conservation Commission

Case 1383

FOREST OIL CORPORATION

P. O. Box 4106 · Odessa Texas

January 22, 1958

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

Dear Sir:

In accordance with Rule 1203, this is to request an Examiner Hearing for the purpose of considering an application for dual completion of the Forest Oil Corporation State "A" No. 1, located 660' from the North Line and 660' from the East Line of Section 26, Township 16 South, Range 33 East, NMPM.

Request is made to dually complete in the Wolfcamp (10,674'-10,816') and Pennsylvanian (Cisco Seamen Lime (1,450'-11,547') zones.

In accordance with Rule 112-A, a plat showing the location of all wells on this lease, and all offset wells on offset leases, and a diagrammatic sketch showing method and manner of completion are attached.

Copies of this application along with a request for waiver have been forwarded to all offset operators.

We would like the hearing to be held at your earliest convenience at a place of your selection.

Until such time that a ruling is made at a hearing, we elect to produce from the Pennsylvanian zone. Proper forms for allowable have been filed.

Very truly yours,

FOREST OIL CORPORATION

G. C. Griffing, Asst. Div.
Production Superintendent

GCG:am
Encls.
cc: NMOCC
Forest
Offset Operators

FOREST OIL CORPORATION

P. O. Box 1600 Odessa, Texas

January 22, 1958

Tennessee Gas Transmission Co.
203 N. Linam
Hobbs, New Mexico

Humble Oil & Refining Co.
P. O. Box 2347
Hobbs, New Mexico

Phillips Petroleum Co.
208 N. Turner
Hobbs, New Mexico

Cities Service Oil Co.
P. O. Box 97
Hobbs, New Mexico

Shell Oil Company
P. O. Box 1957
Hobbs, New Mexico

Signal Oil & Gas Company
1010 Ft. Worth Nat'l. Bank Bldg.
Ft. Worth, Texas

Tidewater Oil Company
P. O. Box 547
Hobbs, New Mexico

Gentlemen:

This is to advise that we have made application to the New Mexico Oil Conservation Commission to dually complete the Forest Oil Corporation State "A" No.1, located 660' from the North Line and 660' from the East Line of Section 26, Township 16 South, Range 33 East, N.M.P.M.

Completion, if approved, will be in the Wolfcamp and Pennsylvanian (Cisco-Seaman Lime) zones.

In accordance with New Mexico Oil Conservation Commission Rule 112-A a copy of the application for dual completion is attached.

This letter is written requesting a waiver from your Company regarding the dual completion of this well.

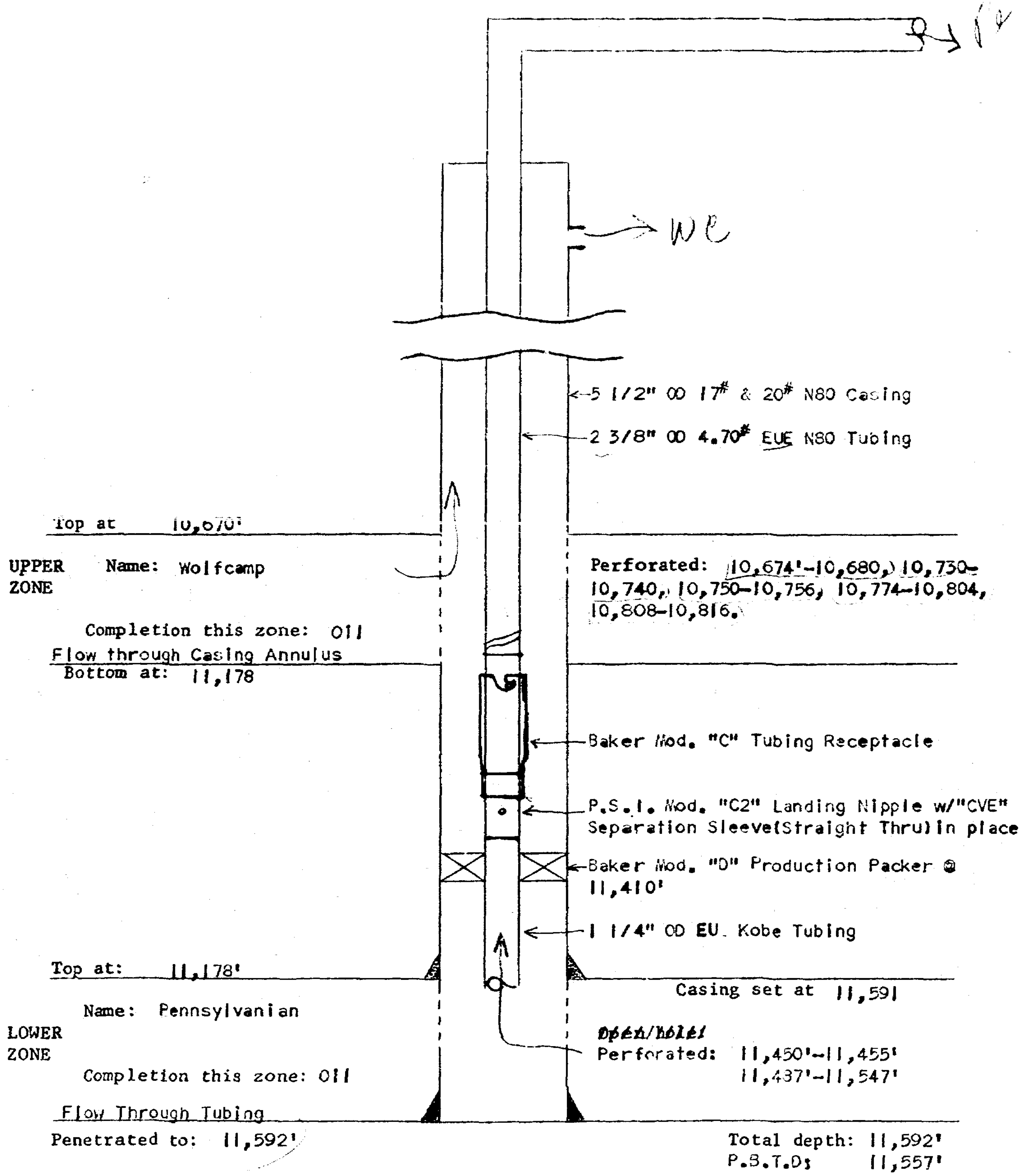
Very truly yours,

FOREST OIL CORPORATION

G. C. Griffing, Asst. Division
Production Superintendent

GCG:ap
Encl.
cc: New Mexico Oil Conservation Commission (3)

DIAGRAMMATIC SKETCH SHOWING DUAL COMPLETION INSTALLATION



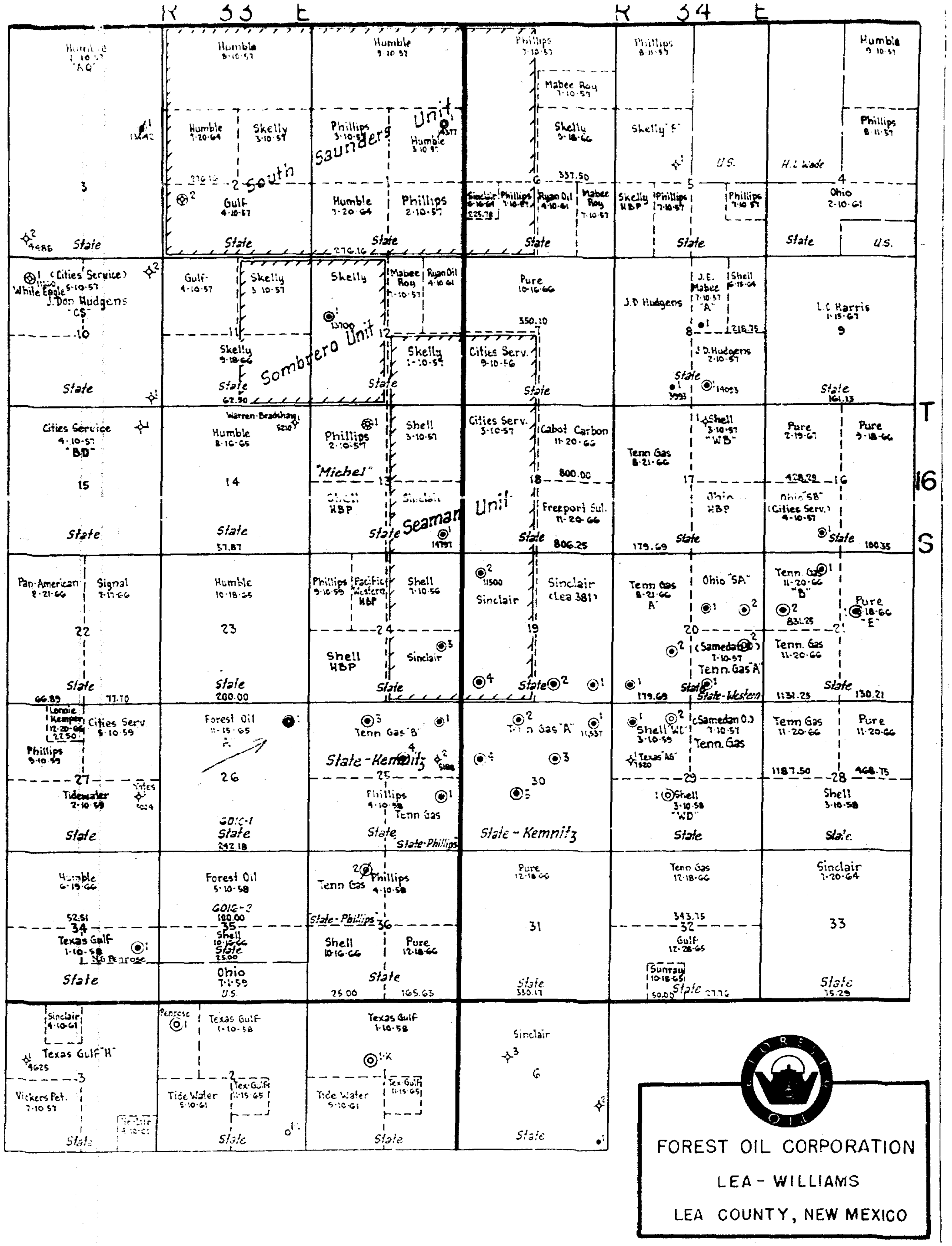
Company: Forest Oil Corporation

Lease State "A" Well No. 1

Field: Kemnitz-Wolfcamp, Pennsylvanian (Undesignated)

Location: 660' N. Line, 660' E. Line, Sec.26, T16S, R33E

Date: January 23, 1958


R 33 E
R 34 E
T 16 S
South Saunders Unit
Sombrero Unit
Seaman Unit
"Michel"
State-Kemnitz
State - Kemnitz
State-Phillips
Humble
Skelly
Phillips
Gulf
Mabee Roy
Sinclair
Ryan Oil
Cities Service
J. Don Hudgens
J.D. Hudgens
Pure
L.C. Harris
Shell
Cabot Carbon
Freeport Sul.
Tenn Gas
Ohio "SA"
Pan-American
Signal
Forest Oil
Tidewater
Texas Gulf
Sunray
Vickers Pet.
Tide Water
State
U.S.
FOREST OIL CORPORATION
LEA - WILLIAMS
LEA COUNTY, NEW MEXICO

OIL CONSERVATION COMMISSION
P. O. BOX 871
SANTA FE, NEW MEXICO

March 17, 1958

COPY

Mr. S. B. Christy, IV
Hervey, Dow & Hinkle
P.O. Box 547
Roswell, New Mexico

Dear Mr. Christy:

On behalf of your client, Forest Oil Corporation, we enclose two copies of Order R-1138 issued March 14, 1958, by the Oil Conservation Commission in Case 1383, which was heard on February 26th at Santa Fe.

Very truly yours,

A. L. Porter, Jr.
Secretary - Director

bp
Encls.

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

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

CASE NO. 1383
Order No. R-1138

APPLICATION OF FOREST OIL CORPORATION
FOR AN ORDER AUTHORIZING AN OIL-OIL
DUAL COMPLETION IN AN UNDESIGNATED
PENNSYLVANIAN OIL POOL AND THE WOLFCAMP
FORMATION ADJACENT TO THE KEMNITZ-
WOLFCAMP POOL IN LEA COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 o'clock a.m. on February 26, 1958, at Santa Fe, New Mexico, before Elvis A. Utz, Examiner duly appointed by the New Mexico Oil Conservation Commission, hereinafter referred to as the "Commission," in accordance with Rule 1214 of the Commission Rules and Regulations.

NOW, on this 14th day of March, 1958, the Commission, a quorum being present, having considered the application, the evidence adduced, and the recommendations of the Examiner, Elvis A. Utz, 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, Forest Oil Corporation, is the owner and operator of an oil well known as the State "A" No. 1 Well, located 660 feet from the North line and 660 feet from the East line of Section 26, Township 16 South, Range 33 East, NMPM, Lea County, New Mexico.

(3) That oil production was encountered in the said State "A" Well No. 1 in the Wolfcamp formation adjacent to the Kemnitz-Wolfcamp Pool and in an undesignated Pennsylvanian Oil Pool.

(4) That the applicant proposes to dually complete the State "A" No. 1 Well in such a manner as to produce oil from said Pennsylvanian formation through 2 3/8-inch tubing and oil from the Wolfcamp formation through the $5\frac{1}{2}$ x 2 3/8 casing-tubing annulus.

(5) That the production of oil from the Wolfcamp formation through the casing-tubing annulus would result in the inefficient utilization of reservoir energy and that underground waste would be caused if the subject application were approved.

(6) That the subject application should be denied.

IT IS THEREFORE ORDERED:

That the application of Forest Oil Corporation in Case No. 1383 be and the same is hereby denied.

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

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

EDWIN L. MECHEM, Chairman

MURRAY E. MORGAN, Member

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

ir/

OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO

Date 2-28-58

CASE NO. 1383 HEARING DATE 2-26-58

My recommendations for an order in the above numbered case(s) are as follows:

1. The application to dually complete the Forest Oil - State "A" #1, located 660/N+E lines of section 26 - T16S - R33E, with a single string of tubing be denied.

2. The operator failed to prove that oil from the Wolfcamp zone of the Kemnitz - oil Pool could be produced without waste. (~~too~~ efficient use of reservoir energy)

[signature]
Staff Member

DOCKET: EXAMINER HEARING FEBRUARY 26, 1958

Oil Conservation Commission 9 a.m., Mabry Hall, State Capitol, Santa Fe, NM

The following cases will be heard before Elvis A. Utz, Examiner:

CASE 1382: In the matter of the application of Buffalo Oil Company to amend Order No. 821. Applicant, in the above-styled cause, seeks an order amending Order No 821 to permit simultaneous production from the Grayburg-San Andres pay of the Maljamar Field from the Baish "A" Well No. 15 and Baish "A" Well No. 21, located in the NE/4 of the SW/4 of Section 21, Township 17 South, Range 32 East, Lea County, New Mexico.

CASE 1383: Application of Forest Oil Corporation for a dual completion. Applicant, in the above-styled cause, seeks an order authorizing the dual completion of its State "A" No. 1 Well located 660 feet from the North line and 660 feet from the East line of Section 26, Township 16 South, Range 33 East, Lea County, New Mexico, in such a manner as to permit the production of oil from the Wolfcamp formation adjacent to the Kemnitz Wolfcamp Pool through the casing-tubing annulus, and to permit the production of oil from an undesignated Pennsylvanian oil pool through the tubing.

CASE 1384: In the matter of the application of Amerada Petroleum Corporation for a dual completion. Applicant, in the above-styled cause, seeks an order authorizing an oil-gas dual completion for its State BTO No. 1 Well, located 990 feet from the South line and 2310 feet from the East line of Section 34, Township 11 South, Range 33 East, Lea County, New Mexico, in such a manner as to permit the production of oil from the Bagley-Pennsylvanian (oil) Pool and the production of gas from the Bagley-Lower Pennsylvanian Gas Pool through parallel strings of tubing.

CASE 1385: In the matter of the application of Gulf Oil Corporation for permission to produce more than eight wells into a common tank battery. Applicant, in the above-styled cause, seeks an order granting permission to produce a maximum of sixteen oil wells in the Eumont Gas Pool into a common tank battery on its Arnott-Ramsay "D" Lease comprising All of Section 33, Township 21 South, Range 36 East, Lea County, New Mexico.

CASE 1386: In the matter of the application of Shell Oil Company for permission to commingle the production from two separate leases. Applicant, in the above-styled cause, seeks an order granting permission to commingle the production from the following described leases in the Monument Pool:

Cooper "A" Lease, NW/4 NE/4 Section 4;
Cooper "B" Lease, N/2 NW/4 and SW/4 NW/4 Section 4;

all in Township 20 South, Range 37 East, Lea County, New Mexico. Applicant proposes to allocate the individual lease production on the basis of monthly well tests.

CASE 1387: In the matter of the application of Shell Oil Company for permission to commingle the production from two separate federal leases. Applicant, in the above-styled cause, seeks an order granting permission to produce the following described leases in the West Henshaw-Grayburg Pool into common storage:

Taylor Federal Lease consisting of Lots 9, 10, & 11 of Section 4;

Spencer Federal "A" Lease consisting of Lots 13, 14, 15 & 16 of Section 4;

all in Township 16 South, Range 30 East, Eddy County, New Mexico. Applicant proposes to continuously meter the production from each lease.

CASE 1388: In the matter of the application of El Paso Natural Gas Products Company for an unorthodox gas well location. Applicant, in the above-styled cause, seeks an order approving the unorthodox gas well location for its Chimney Rock No. 1 Well located 1880 feet from the South line and 340 feet from the East line of Section 23, Township 31 North, Range 17 West, in an undesignated Gallup gas pool in San Juan County, New Mexico.

CASE 1389: In the matter of the application of Skelly Oil Company for an unorthodox oil well location. Applicant, in the above-styled cause, seeks an order approving the unorthodox oil well location of its C. W. Roberts Well No. 3 located 1190 feet from the South line and 1450 feet from the East line of Section 18, Township 25 North, Range 3 West, in an undesignated Dakota oil pool in Rio Arriba County, New Mexico.

ir/

LAW OFFICES
HERVEY, DOW & HINKLE
HINKLE BUILDING
ROSWELL, NEW MEXICO

J. M. HERVEY 1874-1953
HIRAM M. DOW
CLARENCE E. HINKLE
W. E. BONDURANT, JR.
GEORGE H. HUNKER, JR.
HOWARD C. BRATTON
S. B. CHRISTY, IV.
LEWIS C. COX, JR.

PAUL W. EATON, JR.
ROBERT C. BLEDSOE

TELEPHONE MAIN 2-6510
POST OFFICE BOX 547

February 20, 1958.

New Mexico Oil Conservation Commission,
Mabrey Hall,
State Capital,
Santa Fe, New Mexico.

Attention: Mr. Pete Porter, Secretary.

Re: O.C.C. Case No. 1383
Forest Oil Corporation
Our No. 121-5

Dear Mr. Porter:

Confirming our telephone conversation of February 19, it would be appreciated if you would ask Examiner Utz to call the above case out of order towards the end of the Hearing to be held on February 26, 1958; the docket indicates that only eight cases are to be heard, and therefore, I assume that even if the case is heard last it will be in the early afternoon.

This privilege will be greatly appreciated and it will facilitate our preparation for the Hearing.

Appreciating your assistance, we are

Yours very truly,

HERVEY, DOW & HINKLE

By [signature]

SBC/ki
cc - Forest Oil Corporation,
Box 4106,
Odessa, Texas.
cc - Forest Oil Corporation,
1200 Milam Building,
San Antonio, Texas.
Attention: Mr. H. J. Warner.

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attn: Mr. J. R. Wright, Division
Production Superintendent

Dear Sir:

This is to acknowledge receipt of your letter of January 22, 1958 advising that you contemplate dually completing Forest Oil Corporation State "A" Well No. 1, located in Section 26, Township 16 South, Range 33, N.M.P.M., Lea County, New Mexico.

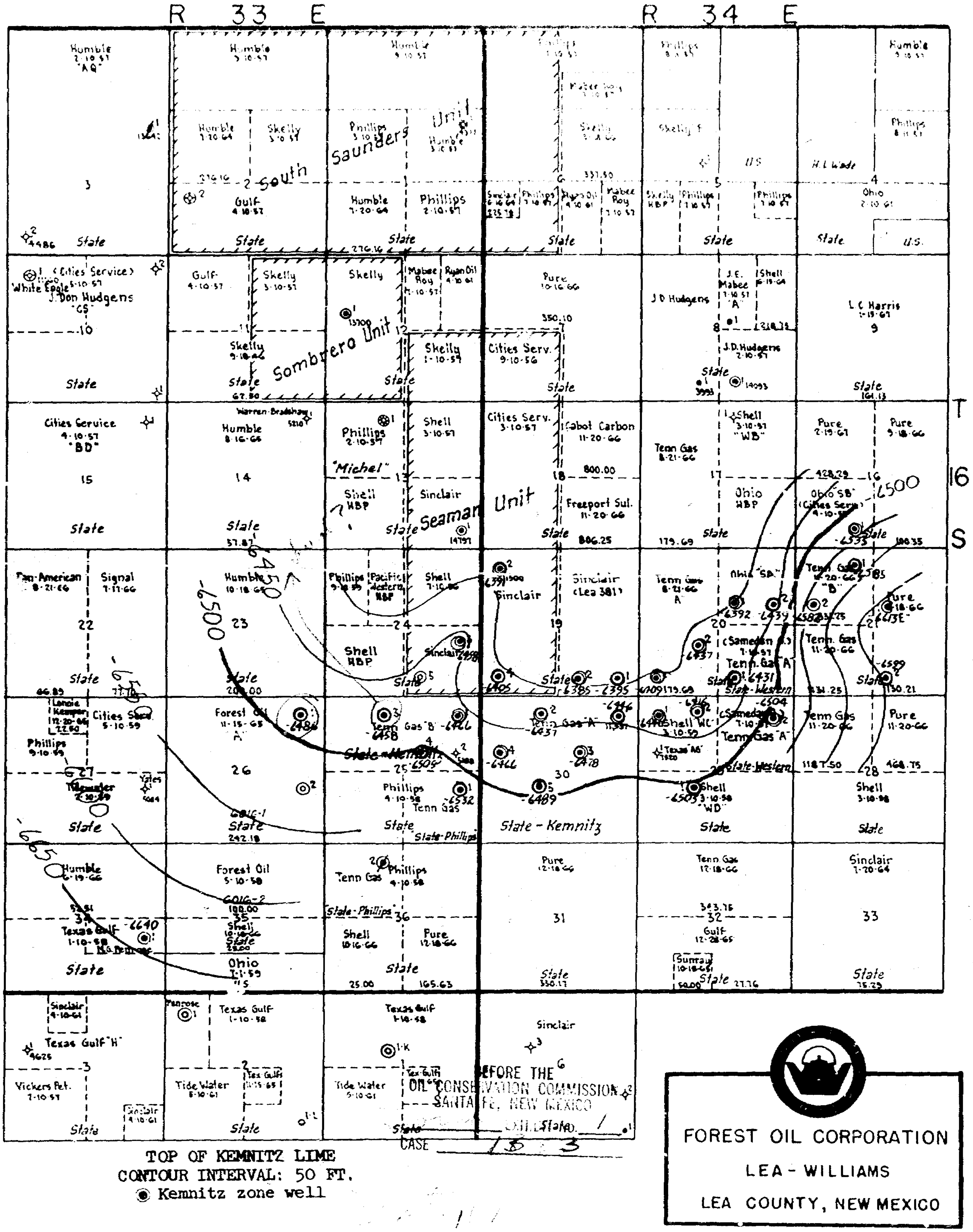
In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in the accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,

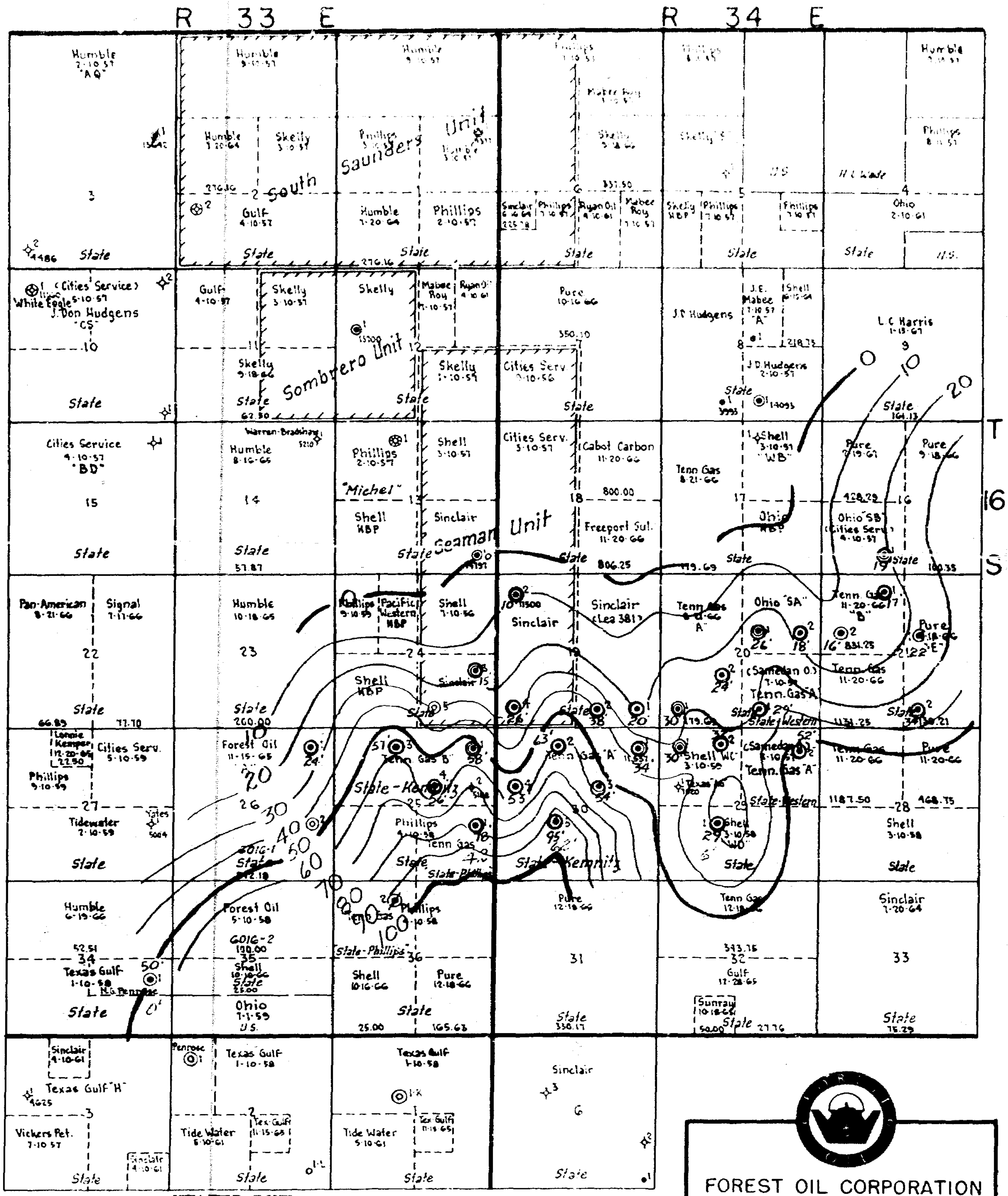
cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

Received from Shell Oil Company



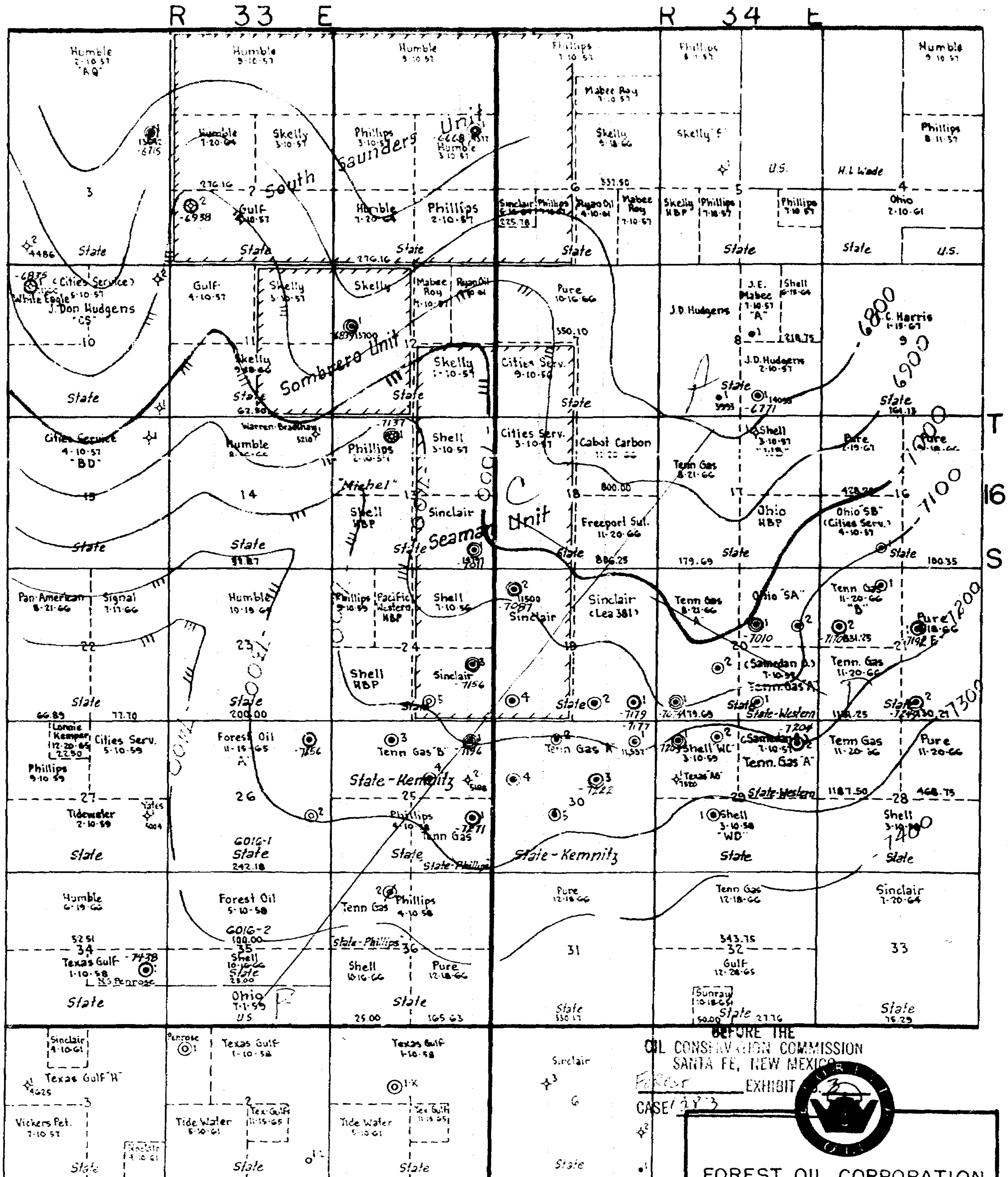
TOP OF KEMNITZ LIME
CONTOUR INTERVAL: 50 FT.
◉ Kemnitz zone well



KEMNTIZ ZONE
ISOPACH NET MICROLOG POROSITY
CONTOUR INTERVAL: 10 Ft.
◉ Kemntiz Zone Well

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO
EXHIBIT No. 2
CASE

FOREST OIL CORPORATION
LEA - WILLIAMS
LEA COUNTY, NEW MEXICO



SEAMAN ZONE
TOP OF SEAMAN LIME
CONTOUR INTERVAL: 100 FT.
● Drilled to Seaman Zone ◉ Producing from Seaman Zone

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO
EXHIBIT
CASE

FOREST OIL CORPORATION
LEA - WILLIAMS
LEA COUNTY, NEW MEXICO

Case 1393

NEW MEXICO
OIL CONSERVATION COMMISSION
P. O. Box 871
Santa Fe, New Mexico

Date February 5, 1958

Forest Oil Corporation
P.O. Box 4106
Odessa, Texas

ATTENTION: G. C. Griffing

Gentlemen:

Your application for permission to dually complete your State "A" No. 1 Well in Section 26, Township 16 South, Range 33 East, NMPM, Lea County, New Mexico,

dated January 22, 1958 has been received, and has been tentatively scheduled for hearing before an examiner on February 26, 1958.

A copy of the docket will be forwarded to you as soon as the matter is advertised.

Very truly yours,

A L Porter Jr
A. L. PORTER, Jr.,
Secretary-Director

ga

Docket Mailed 2-17-58
BP

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

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

Consolidated (CASE NO. 1253
(CASE NO. 1254
Order No. R-1011

APPLICATION OF SINCLAIR OIL AND GAS COMPANY FOR AN ORDER CREATING A NEW OIL POOL FOR PRODUCTION FROM THE ENTIRE WOLFCAMP FORMATION UNDERLYING SECTIONS 13, 24, AND 25, TOWNSHIP 16 SOUTH, RANGE 33 EAST, AND SECTIONS 16, 17, 18, 19, 20, 21, 28, 29, AND 30, TOWNSHIP 16 SOUTH, RANGE 34 EAST, NMPM, LEA COUNTY, NEW MEXICO, AND FOR THE ESTABLISHMENT OF 80-ACRE WELL SPACING AND PRORATION UNITS CONSISTING OF ANY CONTIGUOUS 80 ACRES WITHIN A GIVEN QUARTER SECTION WITH NO DESIGNATED QUARTER-QUARTER SECTION IN WHICH A WELL MUST BE DRILLED, AND FOR THE PROMULGATION OF SPECIAL RULES AND REGULATIONS FOR SAID POOL.

APPLICATION OF TENNESSEE GAS TRANSMISSION COMPANY FOR AN ORDER CREATING A NEW OIL POOL FOR LOWER WOLFCAMP PRODUCTION IN THE KEMNITZ AREA EMBRACING SECTIONS 23, 24, 25, 26, 35, AND 36, TOWNSHIP 16 SOUTH, RANGE 33 EAST, AND SECTIONS 16, 17, 18, 19, 20, 21, 28, 29, 30, 31, 32, AND 33, TOWNSHIP 16 SOUTH, RANGE 34 EAST, NMPM, LEA COUNTY, NEW MEXICO, AND FOR THE ESTABLISHMENT OF TEMPORARY 80-ACRE WELL SPACING AND PRORATION UNITS CONSISTING OF THE EAST OR WEST HALF OF EACH QUARTER SECTION, WITH DRILLING LOCATIONS LIMITED TO THE NORTHEAST QUARTER AND SOUTHWEST QUARTER OF EACH QUARTER SECTION, AND FOR THE PROMULGATION OF TEMPORARY SPECIAL RULES AND REGULATIONS FOR SAID POOL.

ORDER OF THE COMMISSION

BY THE COMMISSION:

The above-styled causes came on for hearing at 9 o'clock a.m. on May 16, 1957, at Hobbs, New Mexico, before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission," whereupon said causes were consolidated for purposes of hearing and order upon the motion of both of the above-named applicants.

NOW, on this 31st. day of May, 1957, the Commission, a quorum being present, having considered the applications and the evidence adduced, 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 the above-styled causes and the subject matter thereof.

(2) That there is need for the creation of a new pool in Lea County, New Mexico, for the production of oil from the Wolfcamp formation, said pool to bear the designation Kemnitz-Wolfcamp Pool. Said Kemnitz-Wolfcamp Pool was discovered by the Tennessee Gas Transmission Company, State A. A. Kemnitz "A" Well No. 1, located in the NE/4 NE/4 Section 30, Township 16 South, Range 34 East, NMPM, which well was completed December 9, 1956 with the top of the perforations at 10,742 feet.

(3) That the probable productive limits of the Kemnitz-Wolfcamp Pool are as follows:

TOWNSHIP 16 SOUTH, RANGE 33 EAST, NMPM
Section 24: All
Section 25: All

TOWNSHIP 16 SOUTH, RANGE 34 EAST, NMPM
Sections 16 through 21: All
Sections 28 through 30: All

(4) That the vertical limits of the Kemnitz-Wolfcamp Pool should comprise the entire Wolfcamp formation in order to permit the production and common storage of all oil produced from said formation.

(5) That development of the subject common source of supply indicates that it is possible that there are other productive zones in the Wolfcamp formation in addition to the zone in the lower portion of the formation from which the aforementioned Tennessee Gas Transmission Company, State A. A. Kemnitz "A" No. 1 Well is presently producing.

(6) That underground waste might result if the other zones referred to in Finding No. 5 are opened simultaneously with the known productive zone discovered by the said Tennessee Gas Transmission Company, State A. A. Kemnitz "A" No. 1 Well.

(7) That the geological and engineering data indicate that one well will drain 80 acres in the Kemnitz-Wolfcamp Pool, and that said pool should be developed on 80-acre drilling and proration units.

(8) That 80-acre drilling and proration units comprising the east half or the west half of each quarter section, with well locations restricted to the approximate center of the NE/4 or the SW/4 thereof, will provide the most orderly and efficient pattern of development for the Kemnitz-Wolfcamp Pool.

(9) That all wells completed in or drilling to the Kemnitz-Wolfcamp Pool prior to the effective date of this order should be excepted from the well location requirements set forth above.

(10) That any well which is completed in the Kemnitz-Wolfcamp Pool and to which is dedicated less than 79 acres or more than 81 acres should be granted an allowable in the proportion that the total number of acres assigned to the well bears to 80 acres.

(11) That the provisions of this order should be of a temporary nature in order to permit further study of the subject common source of supply.

IT IS THEREFORE ORDERED:

(1) That the Kemnitz-Wolfcamp Pool be and the same is hereby created, and that the vertical limits thereof shall consist of the entire Wolfcamp formation.

(2) That the horizontal limits of said Kemnitz-Wolfcamp Pool shall be that area described in Exhibit "A" attached hereto and made a part hereof.

IT IS FURTHER ORDERED:

That special pool rules applicable to the Kemnitz-Wolfcamp Pool be and the same are hereby promulgated as follows:

SPECIAL RULES AND REGULATIONS FOR THE
KEMNITZ-WOLFCAMP POOL

IT IS ORDERED:

RULE 1. That any well drilled to or completed in the Wolfcamp formation within one mile of the boundary of the Kemnitz-Wolfcamp Pool, as it is now defined or may hereafter be defined, shall be located, spaced, drilled, operated, and prorated in accordance with the rules and regulations in effect in said Kemnitz-Wolfcamp Pool.

RULE 2. That 80-acre drilling and proration units be and the same are hereby established for the Kemnitz-Wolfcamp Pool; further, that any well projected to or completed in the Kemnitz-Wolfcamp Pool shall be assigned a tract comprising the East half or the West half of a governmental quarter section.

RULE 3. (a) That any well projected to or completed in the Kemnitz-Wolfcamp Pool shall be located within 150 feet of the center of either the Northeast quarter or the Southwest quarter of a governmental quarter section.

(b) The Secretary of the Commission shall have authority to grant exception to the requirements of Rule 3 (a) above without notice and hearing where application has been filed in due form and the necessity for the unorthodox location is based on topographical conditions.

Applicants shall furnish all operators within a 1320-foot radius of the subject well a copy of the application to the Commission, and applicant shall include with his application a list of names and addresses of all operators within such radius, together with a stipulation that proper notice has been given said operators at the addresses given. The Secretary of the Commission shall wait at least 20 days after receipt of application before approving any such unorthodox location, and shall approve such unorthodox location only in the absence of objection by any offset operator. In the event an operator objects to the unorthodox location the Commission shall consider the matter only after proper notice and hearing.

RULE 4. That no well shall be opened to any other zone of the Wolfcamp formation simultaneously with the productive zone in the lower portion of the formation from which the Tennessee Gas Transmission Company, State A. A. Kemnitz "A" No. 1 Well is presently producing until it has been established, after notice and hearing, that the same can be accomplished without causing underground waste.

RULE 5. That any well which is completed in the Kemnitz-Wolfcamp Pool and to which is dedicated less than 79 acres or more than 81 acres shall be granted an allowable in the proportion that the total number of acres assigned to the well bears to 80 acres.

RULE 6. That no well shall be assigned an allowable until Commission Form C-128 has been filed with the Commission indicating that either the East half or the West half of a governmental quarter section has been dedicated to the well.

IT IS FURTHER ORDERED:

That the provisions of this order shall become effective immediately, with the exception of Rule 2, Rule 5, and Rule 6 of the Special Rules and Regulations of the Kemnitz-Wolfcamp Pool, which three rules shall become effective July 1, 1957.

Further, that these cases be reopened at the Commission monthly hearing in November, 1958, to show cause why the Special Rules and Regulations set forth herein should be continued beyond December 31, 1958.

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

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

EDWIN L. MECHEM, Chairman
MURRAY E. MORGAN, Member
A. L. PORTER, Jr., Member & Secretary

S E A L
ir/

EXHIBIT "A"

Horizontal limits of the Kemnitz-Wolfcamp Pool:

TOWNSHIP 16 SOUTH, RANGE 33 EAST, NMPM
Section 24: All
Section 25: All

TOWNSHIP 16 SOUTH, RANGE 34 EAST, NMPM
Sections 16 through 21: All
Sections 28 through 30: All

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

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

CASE NO. 1365
Order No. R-1126

APPLICATION OF CABOT CARBON COMPANY
FOR AN OIL-OIL DUAL COMPLETION IN THE
KING-DEVONIAN POOL AND KING-WOLFCAMP
POOL IN LEA COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 o'clock a.m. on January 7, 1958, at Santa Fe, New Mexico, before Daniel S. Nutter, Examiner duly appointed by the New Mexico Oil Conservation Commission, hereinafter referred to as the "Commission," in accordance with Rule 1214 of the Commission Rules and Regulations.

NOW, on this 12th day of February, 1958, the Commission, a quorum being present, having considered the application, the evidence adduced and the recommendations of the Examiner, Daniel S. Nutter, 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, Cabot Carbon Company, is the owner and operator of the H. L. Lowe "B" Well No. 1, located 467 feet from the South line and 850 feet from the East line of Section 26, Township 13 South, Range 37 East, NMPM, Lea County, New Mexico.

(3) That the said H. L. Lowe "B" Well No. 1, is presently completed in and producing from the King-Devonian Pool.

(4) That the applicant proposes to dually complete the said H. L. Lowe "B" Well No. 1 in such a manner as to permit the production of oil from the King-Devonian Pool and King-Wolfcamp Pool through parallel strings of $1\frac{1}{2}$ inch tubing.

(5) That the applicant proposes to utilize gas-lift in the event either or both of the above-described producing horizons require the use of artificial lift.

(6) That the use of $1\frac{1}{2}$ inch diameter tubing in the proposed dual completion would impair the flow efficiency of both producing horizons, thereby necessitating the premature use of artificial lift equipment.

(7) That it would not be mechanically feasible to artificially lift the production from both zones simultaneously in the manner proposed by the applicant.

(8) That the proposed dual completion would be impractical and inefficient, and that the subject application should, therefore, be denied.

IT IS THEREFORE ORDERED:

That the application of Cabot Carbon Company in Case No. 1365, be and the same is hereby denied.

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

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

EDWIN L. MECHEM, Chairman

MURRAY E. MORGAN, Member

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

S E A L

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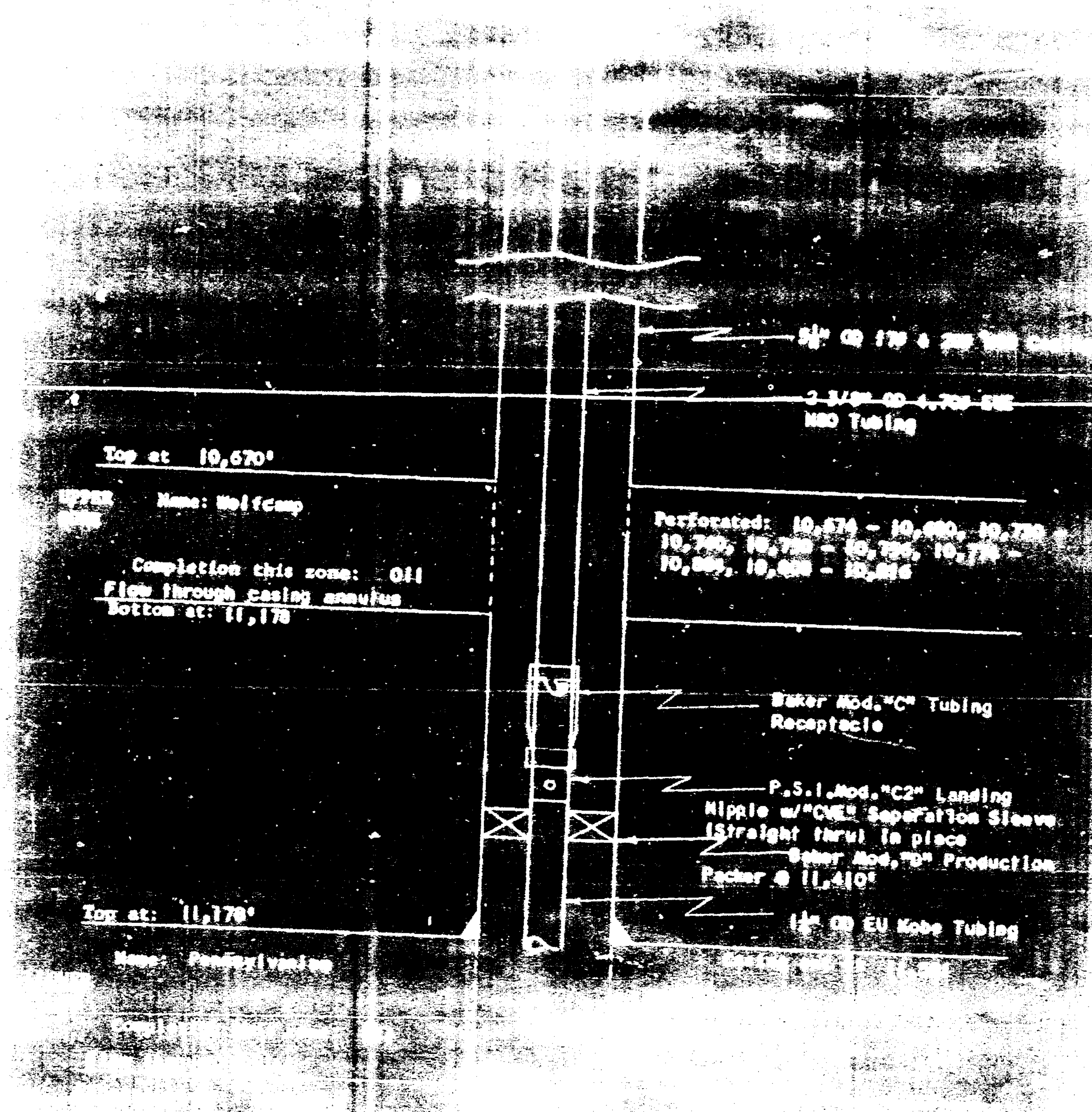


NBO Tubing
Top at 10,670'
Name: Wolfcamp
Perforated:
Completion this zone: Oil
Flow through casing annulus
Bottom at: 11,178
Baker Mod."C" Tubing
Receptacle
P.S.I.Mod."C2" Landing
Nipple w/"CWE" Separation Sleeve
(Straight thru) in place
Baker Mod."D" Production
Packer @ 11,410'
Top at: 11,178'
EU Kobe Tubing
Name: Pennsylvanian

FOREST OIL CORPORATION
State "A" No. I Well Lea, N.M.
Production Tests

	WOLFCAMP
1-20-58	Casing flowed 96.55 B/F 25% fresh water in 3 hours on 1/2" choke w/side-door tool in place. FCP 300# GOR 988/1 Gravity 40.3 API @ 60F Cumulative total 703.64 B/O
	PENN.
1-27-58	Potential. Flowed 324.79 B/O no water in 24 hours on 15/64" choke w/straight-thru tool in place. FTP 650# CP 750#. GOR 1349/1. Gravity 41.5 API @ 60F
2-1-58	Flow 32.40 B/O in 6 hrs on 12.5/64" FTP-700#
2-5-58	Flow 249.78 B/O in 24 hrs on 14.5/64" FTP-680#
2-6-58	Flow 199.80 B/O in 24 hrs on 14.5/64" FTP-575#
2-9-58	Flow 264.65 B/O in 24 hrs on 1/4" FTP-500#
2-12-58	Flow 203.81 B/O in 24 hrs on 1/4" FTP-480#
2-14-58	Flow 233.41 B/O in 24 hrs on 1/4" FTP-500#
2-20-58	Flow 210.38 B/O in 24 hrs on 1/4" FTP-400#
2-21-58	Flow 217.67 B/O in 24 hrs on 1/4" FTP-400# GOR-983/1
2-23-58	Flow 209.38 B/O in 24 hrs on 1/4" FTP-400#

FOREST OIL CORPORATION

State "A" No. 1
Brief Well History

LOCATION: 660' from North & East Lines, Sec. 26, T-16-S R-33-E NMPM, Lea County, New Mexico

10-21-57 Spudded 17½" hole.

10-22-57 Set 13 3/8", 48#/ft., H-40 casing at 344'. Cemented with 325 sx reg. neat cmt. Circulated to surface.

10-23-57 Tested casing. o.k.

11-7-57 Set 8 5/8", 32#/ft., J-55 casing at 4526'. Cemented with 2415 sx of 50/50 Pozmix, 2% gel, cmt. followed 150 sx reg. neat cmt. Did not circ. Temp. Survey found top of cmt at 300' behind 8 5/8" csg.

11-9-57 Tested casing. o.k.

12-15-57 Wolfcamp core 10,190' - 10,213'.

12-17-57 Wolfcamp core 10,213' - 10,240'.

12-25-57 DST #1 Wolfcamp 10,678' - 10,812'.
Tool open 2 hrs. GTS 33 min. Gas flow rate 97 MCF/D. No fluid to surface.
Reversed out 1000' O & G/C W.C. and 350' HO & GCM. 90' HO & GCM Under sub.
ISIP - 3200 30 min. BH SIP - 3125
IFP - 485
FFP - 720

12-27-57 Wolfcamp core 10,812' - 10,837'.

1-10-58 Penn. core 11,481' - 11,532'.

1-11-58 DST #2 Penn. 11,436' - 11,532'
Tool open 2 hrs. GTS 52 min. Gas flow rate 107 MCF/D. No fluid to surface.
Reversed out 2000' O&G/C W.C. and 1800' sl. M/C oil plus 250' O&G/C mud. Recovered sl. M/C oil & gas under sub.
ISIP - 4455 30 min BH SIP - 3445
IFP - 1100
FFP - 1585

1-12-58 Penn. core 11,532' - 11,572'.

DST #3 Penn. 11,524' - 11,572'
Tool open 1 hr. Dead test.
Recovered 2000' sl. O&G/C W.C. 1 qt. free oil on top W.C.
Under sub: 100' sl O&G/CM 30' O&G/CM
ISIP - 1305 30 min BH SIP - 3650#
IFP - 940
FFP - 960

1-15-58 Set 5 1/2" 17# & 20# N-80 csg. at 11,592'. Cemented with 275 sx 4% gel cmt. followed by 150 sx reg. neat T.I. cmt. Temp. Survey found top cmt. at 9135'.

1-17-58 Perforated W.C.: 10,674' - 10,680'
10,730' - 10,740'
10,750' - 10,754'
10,774' - 10,804'
10,808' - 10,816'

Penn: 11,450' - 11,455'
11,487' - 11,547'

Set Baker Model "D" Prod. pkr. @ 11,410'. Landed tbg. on pkr. with N.L.T. latch sub, Type "c-2" P.S.I. Nipple, and Baker tbg receptacle.

FOREST OIL CORPORATION

State "A" No. 1
Brief Well History

1-18-58	Displaced mud w/water. Ran "Side-door" tool. Treated W.C. w/500 m.a. & 6000 Jel x-100.
1-19-58	Established flow & cleaned up. Ran "straight-thru" tool. Treated Penn. w/500 m.a. & 2000 Jel x-100. Established flow and cleaned up.
1-25-58	Pkr. leakage test.
1-27-58	BHP 18-24 hr stable. 3484 psig. at -7325 datum. Elev. 4184' D.F.
2-16-58	P.I. tests. Left on 1/4" choke @ 215 BOPD
2-24-58	Begin 96 hr Bottom hole build-up.

NEW MEXICO
OIL CONSERVATION COMMISSION

4-1-56

PACKER LEAKAGE TEST

Operator **Forest Oil Corporation** Pool (Upper Completion) **Wolfcamp**
Lease **State "A"** Well **1** Pool (Lower Completion) **Pennsylvanian**
Location: Unit **A**, S. **26**, T **16S**, R **35E** **Lea** County, N. M.

Pre-Test Shut-In

	Upper Completion	Lower Completion
Shut-in at (hour, date)	11:00 AM 1-21-58	9:00 AM 1-20-58
Pressure stabilized at (hour, date)	8:00 AM 1-25-58	8:00 AM 1-25-58
Length of time required to stabilize (hours)	Not known	Not known

Flow Test No. 1

Test commenced at (hour, date) **10:00 AM 1-25-58**. Choke size **15/64**
Completion producing **Penn.** Completion shut-in **Wolfcamp**

	Upper Completion	Lower Completion
Stabilized pressure at beginning of test	1040 psi	715 psi
Maximum pressure during test	1050 psi	725 psi
Minimum pressure during test	1040 psi	715 psi
Pressure at end of test	1040 psi	725 psi
Maximum pressure change during test	10 psi	10 psi

Oil flow rate during test: **259.8** BOPD based on **21.65** BO in **2** hours.
Gas flow rate during test: **409** MCFPD based on **17.0** MCF in **1** hours.

Mid-Test Shut-In

	Upper Completion	Lower Completion
Shut-in at (hour, date)	1:05 PM 1-25-58	9:00AM 1-20-58
Pressure stabilized at (hour, date)	2:15 PM 1-25-58	8:00AM 1-25-58
Length of time required to stabilize (hours)	1.17	Not known

Flow Test No. 2

Test commenced at (hour, date) **4:15 PM 1-25-58**. Choke size **5/16"**
Completion producing **Wolfcamp** Completion shut-in **Pennsylvanian**

	Upper Completion	Lower Completion
Stabilized pressure at beginning of test	1180 psi	455 psi
Maximum pressure during test	1210 psi	460 psi
Minimum pressure during test	1180 psi	455 psi
Pressure at end of test	1210 psi	455 psi
Maximum pressure change during test	30 psi	5 psi

Oil flow rate during test: **397.2** BOPD based on **33.10** BO in **2** hours.
Gas flow rate during test: **306** MCFPD based on **12.75** MCF in **1** hours.

Test performed by **J. R. Clark, Jr.** Title **Petroleum Engineer**

Witnessed by ______ Title ______

REMARKS: **Pressure recording instrument used was bench calibrated 1-24-58**

NOTE: Recording gauge pressure charts, test data sheet, and a graphic depiction of all phases of the test shall be submitted with this report.

AFFIDAVIT:

I HEREBY CERTIFY that all conditions prescribed by Oil Conservation Commission of the State of New Mexico for this packer leakage test were complied with and carried out in full, and that all dates and facts set forth in this form and all attached material are true and correct.

Orig. signed J. R. Clark, Jr. (Representative of Company Making Test) For **Forest Oil Corporation** (Company Making Test)

SWORN TO AND SUBSCRIBED before me this the **30th** day of **January**, 19**58**

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO
_____ Exhibit No. 2
CASE _____

Orig. signed Malcolm R. Manns
Notary Public in and for the County of **Ector**
State of **Texas**.

(OVER)

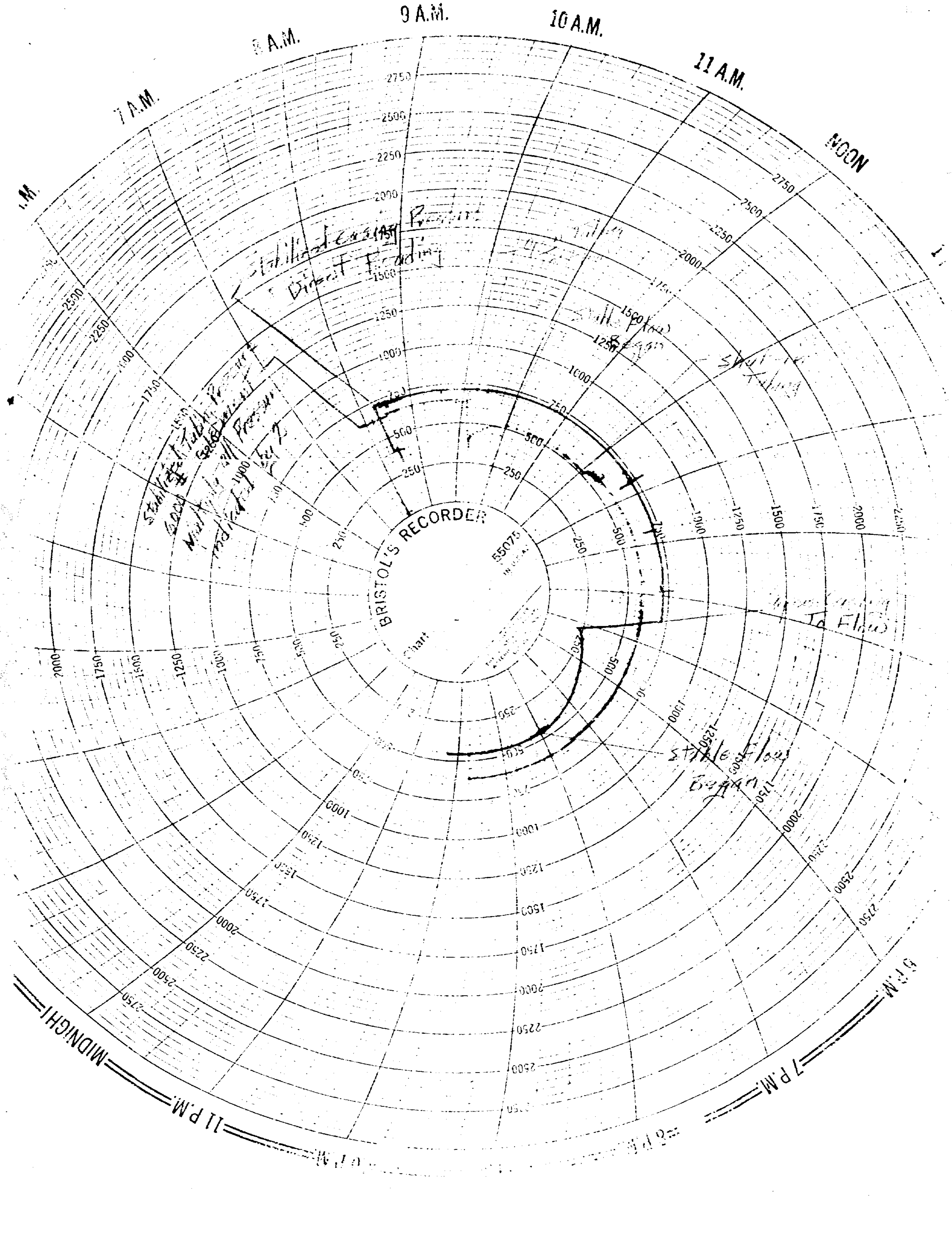
NEW MEXICO
OIL CONSERVATION COMMISSION

PACKER LEAKAGE TEST

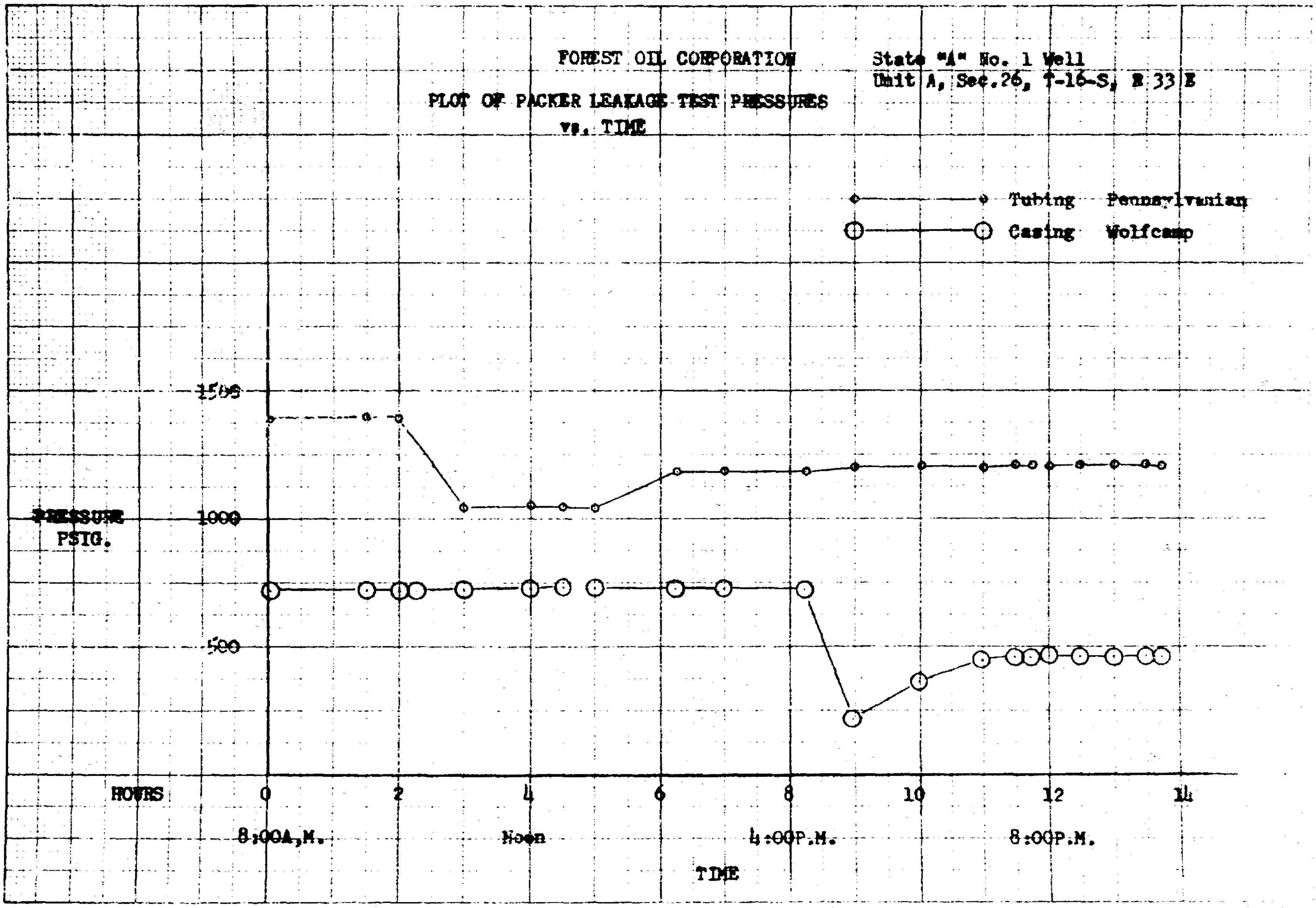
OPERATOR Forest Oil Corporation Box 4106 Odessa, Texas
LEASE NAME State "A" WELL NO. 1
LOCATION Unit A, Sec.26, T 16 S, R33E COUNTY Lea

TEST DATA SHEET

Time	Casing Pressure	Tubing Pressure	Remarks
8:00 AM	715	1380	Begin 2 hr shut-in
9:30 AM	715	1380	Pressure check
10:00 AM	715	1380	Open tubing (Penn) on 15/64" choke
10:15 AM	715	800	Oil to surface
11:00 AM	720	1040	Well appears stable
11:30 AM	725	1040	Well stable. Check gas production rate
12:01 PM	725	1050	Gas head
12:30 PM	725	1040	Check gas measurement
1:05 PM	725	1040	Shut in tubing
2:15 PM	725	1180	Shut-in pressure appears stable
3:00 PM	715	1180	Pressure reading
4:15 PM	715	1180	Open Casing (Wolfcamp) on 5/16" choke
4:55 PM	210	1200	Oil to surface
6:00 PM	360	1200	Pressure reading
7:00 PM	440	1200	Pressure reading
7:30 PM	455	1210	Well appears stable
7:45 PM	455	1210	Pressure reading
8:00 PM	460	1210	Well stable. Determine gas rate
8:30 PM	460	1210	Pressure reading
9:00 PM	460	1210	Check gas measurement
9:30 PM	455	1210	Pressure reading
9:45 PM	455	1210	Remove chart & shut-in well.



7 A.M.
9 A.M.
10 A.M.
11 A.M.
NOON
BRISTOL'S RECORDER
55075
Chart
Stabilized Casing Pressure
Direct Reading
Stable Flow Began
7 P.M.
11 P.M.
MIDNIGHT


FOREST OIL CORPORATION
State "A" No. 1 Well
Unit A, Sec.26, T-16-S, R 33 E
PLOT OF PACKER LEAKAGE TEST PRESSURES
vs. TIME
Tubing Pennsylvanian
Casing Wolfcamp
PRESSURE
PSIG.
1500
1000
500
HOURS
0
2
4
6
8
10
12
14
8:00A.M.
Noon
4:00P.M.
8:00P.M.
TIME

TENNESSEE GAS TRANSMISSION COMPANY

Post Office Box 2544
Hobbs, New Mexico
February 6, 1958

Forest Oil Corporation
Post Office Box 4106
Odessa, Texas

Attention: Mr. J. R. Wright, Division
Production Superintendent

Re: Dual Completion
~~Forest Oil Corporation~~
State "A" Well No. 1

Dear Sir:

Tennessee Gas Transmission Company has received notice of your proposal to dually complete Forest Oil Corporation State "A" Well No. 1, located in Section 26, Township 16 South, Range 33 East, N.M.P.M., Lea County, New Mexico. We understand that you will attempt completion from the Wolfcamp zone (Kemnitz Wolfcamp Field) and from the Pennsylvanian zone (Cisco - Seaman Lime).

As the owner of adjoining oil and gas leases, Tennessee Gas Transmission Company has no objections to this dual completion and hereby grants their consent, providing that all rules and regulations of the New Mexico Oil Conservation Commission governing dual completions are fulfilled.

Very truly yours

TENNESSEE GAS TRANSMISSION COMPANY

D. P. Dampf
District Production Superintendent

JFC/mh
cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO
Forest EXHIBIT No. 8 6 pages
CASE 1323

Houston, Texas
Feb. 14, 1958

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attn: Mr. J. R. Wright, Division
Production Superintendent

Dear Sir:

This is to acknowledge receipt of your letter of 1/22/58 advising that you contemplate dually completing Forest Oil Corporation State "A" Well No.1, located in Section 26, Township 16 South, Range 33, N.M.P.M., Lea County, New Mexico.

In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in the accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,
HUMBLE OIL & REFINING COMPANY
By

cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

February 13, 1958

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attn: Mr. J. R. Wright, Division
Production Superintendent

Dear Sir:

This is to acknowledge receipt of your letter of January 22, 1958 advising that you contemplate dually completing Forest Oil Corporation State "A" Well No.1, located in Section 26, Township 16 South, Range 33E, N.M.P.M., Lea County, New Mexico.

In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in the accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,
PHILLIPS PETROLEUM COMPANY

By L. E. Fitzgerald

L. E. Fitzjarrald
Manager of Production

cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attn: Mr. J. R. Wright, Division
Production Superintendent

Dear Sir:

This is to acknowledge receipt of your letter of January 22, 1958, advising that you contemplate dually completing Forest Oil Corporation State "A" Well No. 1, located in Section 26, Township 16 South, Range 33, N.M.P.M., Lea County, New Mexico.

In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in the accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,

CITIES SERVICE OIL COMPANY

By:

Division Superintendent

cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attn: Mr. J. R. Wright, Division
Production Superintendent

Dear Sir:

This is to acknowledge receipt of your letter of January 22, 1958 advising that you contemplate dually completing Forest Oil Corporation State "A" Well No. 1, located in Section 26, Township 16 South, Range 33, N.M.P.M., Lea County, New Mexico.

In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in the accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,

V. F. Fuson

SIGNAL OIL AND GAS COMPANY

cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico

Tidewater Oil Company
POST OFFICE BOX 731
TULSA 2, OKLAHOMA

H. E. Berg
MANAGER OF PRODUCTION
CENTRAL DIVISION

February 6, 1958

Forest Oil Corporation
P. O. Box 4106
Odessa, Texas

Attention: Mr. J. R. Wright

Gentlemen:

This is to acknowledge receipt of your letter of January 22, 1958 advising that you contemplate dually completing Forest Oil Corporation State "A" Well No. 1, located in Section 26, Township 16 South, Range 33, N.M.P.M., Lea County, New Mexico.

In accordance with your request, we wish to advise that we waive any objection regarding the dual completion of this well, if done in accordance with all rules and regulations of the Oil Conservation Commission of New Mexico.

Very truly yours,

H. E. Berg

HEB:hm

cc: New Mexico Oil Conservation Commission
Santa Fe, New Mexico

New Mexico Oil Conservation Commission
Hobbs, New Mexico