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The occurrence of gas in the Cretaceous rocks of the San Juan Basin, New Mexico and Colorado

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THE OCCURRENCE OF GAS IN THE CRETACEOUS ROCKS OF THE SAN JUAN BASIN, NEW MEXICO AND COLORADO

By Caswell Silver
Consulting Geologist

Abstract

Gas occurs over wide areas in three principal lithologic units in the San Juan Basin: the Pictured Cliffs sandstone, the Cliff House sandstone, and the Point Lookout sandstone. The Pictured Cliffs sandstone is separated into northeast and southwest lobes. The massive sandstone member of the Point Lookout sandstone grades into shale to the northeast. The area of gas saturation in at least one of these units may exceed 1,500,000 acres and together these reservoirs constitute one of the major fields of "gas in place" in North America. The three reservoir beds occur within a wedge belt of porosity. They terminate to the northeast and have a common post-depositional geologic history. The structure of the gas area is a basin. The presence of gas and absence of water in the lower ends of inclined lenses on the southwest limb of the basin is anomalous in originally water-saturated rocks and indicates a reversal of attitude after accumulation. An isopach map of the Kirtland formation defines part of a late Cretaceous basin of deposition. It is deduced that accumulation in the wedge-belt resulted from initial uplifts of the Laramide revolution, the present structure of the reservoir being completed sometime in middle or late Tertiary time. The author suggests that some gas is escaping from the reservoirs at the present time. The rate of dissipation is retarded because of low permeability which is further diminished by water invasion. However, it is too slow to interfere with commercial exploitation.

Introduction

This paper is an elaboration of ideas expressed in an abstract bearing the same title and presented at the 35th Annual Meeting of the American Association of Petroleum Geologists, April, 1950, by title and published in the annual meeting abstracts.

Gas occurs in commercial quantities in three principal Cretaceous lithologic units in the San Juan Basin, the Pictured Cliffs sandstone, the Cliff House sandstone, and the Point Lookout sandstone. It is the purpose of this paper to summarize the geologic conditions related to this occurrence of gas and to present a hypothesis for accumulation. The Cretaceous gas deposits of the San Juan Basin are believed to be unique in that they are being destroyed by erosion. The rate, however, is too slow to affect their commercial exploitation.

Separation of the Pictured Cliffs sandstone into a southwestern, older lobe and a northeastern, younger lobe is emphasized, but the age relationship shown is the reverse of that reported by Dane (1946).

The massive sandstone member of the Point Lookout sandstone grades into shale toward the northeast but, contrary to the opinions of Zapp (1949) is believed to have a marked stratigraphic rise in a seaward direction.

Bates (1942, pp. 83-129) gives a description of the gas fields, but other papers have not dealt at any length with the presence of gas. Previous work has shown that the Cretaceous sediments are related to the transgressions and regressions of a shallow sea across the area (Sears 1934; Hunt 1936; Dane 1936; Sears, et al. 1941; Pike 1947; and Zapp 1949).

Acknowledgements

The author wishes to acknowledge the data and samples contributed by various individuals and companies which included Paul Umbach and J. J. Harris of the Stanolind Oil and Gas Company, Al Greer and Frank Barnes of the New Mexico Oil Conservation Commission, O. J. Lilly and Van Thompson of the Southern Union Gas Company, and Frank Shultz of the Delhi Oil Company. Many of the ideas presented here were formulated while the writer was employed by M. J. Florance, who was not only an encouraging employer but by his stimulating inquiries contributed much to the growth of ideas.

Stratigraphy

General

The Cretaceous stratigraphy of the basin is treated elsewhere in this guidebook. Figure 1 shows the general stratigraphic section. However, those features of the stratigraphy significant to the occurrence of gas are briefly reviewed herein. Strata comprising the Cretaceous are made up almost entirely of clastic materials. Sandstone and shale comprise about 99 per cent of the Cretaceous stratigraphic column at any point in the basin, and the large-scale intertonguing shown in Figure 1 is part of more extensive intertonguing in areas to the south and west (Sears, et al. 1941).

This intertonguing is the result of transgressions and regressions of the sea. Shorelines during these movements of the sea trended generally northwesterly.

All units of the Mesaverde show a dimunition in their grain size northeastward away from the source area. The Mesaverde group is an over-all wedge of porosity between the converging Lewis and Mancos shale formations. Within the Mesaverde group there are numerous lenses and irregularities of beds.

However, this paper is concerned only with that part of the Mesaverde group which has been divided on the basis of lithology into the Point Lookout sandstone, Menefee formation, and Cliff House sandstone. The term Mesaverde in this paper will be used in that very restricted sense. Pertinent features of each of these formations are discussed below.

Point Lookout Sandstone

The lower part of the Point Lookout sandstone is transitional with the underlying Mancos shale and consists of thin, fine-grained sandstone interbedded with sandy shale. Over a wide area the upper part of the formation consists of a massive bed of medium-grained sandstone. This bed is extensive in the subsurface and is the principal gas horizon within the Mesaverde group. It is referred to here as the massive sandstone member of the Point Lookout sandstone. This unit becomes less porous and loses its identity before it reaches the vicinity of the Rosa Unit No. 1 well in the subsurface. Figure 1 shows the general nature of the massive sandstone member. It is 300 feet thick in the British American Federal-Cronigan No. 1 well, 100 feet thick in the Southern Union Production Company-Davis No. 1 well, and 120 feet thick in the Florance Drilling Company-William Mansfield No. 4 well. It gradually thins and becomes finer grained and siltier to the northeast and is correlated possibly with a very fine grained, silty unit at the top of the Point Lookout sandstone in the Rosa Unit No. 1 well. On the surface, the massive sandstone member which Zapp mapped in the Durango area loses its identity northeastward along the divide between the Florida and Pine rivers, T 35 and 36 N, R 8 W, in Colorado as it grades into shale (Zapp 1949, para. 9).

In like manner, the upper part of the Hosta sandstone member, which Pike (1947, p. 37) calls the same unit as the Point Lookout sandstone, thins and appears transitional to shale in the Senorita area in T 20 N, R 1 W. The top 42 feet of the basal Mesaverde sandstone measured by Renick (1931, p. 44) in Section 35, T 21 N, R 1 E, may be Point Lookout (i. e., Hosta) but the outcrop to the south dips steeply and the facies change is difficult to follow.

Throughout its extent the upper surface is recognized as a distinct bedding plane. Zapp, however, thinks that the ". . . top of the Point Lookout sandstone is virtually a stratigraphic plane, which is in contrast to the gradual seaward stratigraphic rise of regressive sandstone beds in other parts of the San Juan Basin as described by Sears, et al. . ." (1949, para. 42).

Examination of Figure 1, which is a line of sections taken in a direction not at right angles to the many shorelines, will reveal a marked convergence between the top of the Point Lookout sandstone and the top of the Pictured Cliffs sandstone. The convergence shown would be more pronounced if taken in a direction at a right angle to the greatest number or shorelines. Unfortunately, there is no known true stratigraphic plane with which to relate this convergence. Sears, Hunt, and Hendricks (1941, pp. 103-104) have shown both by reasoning and field evidence that conditions of regressive deposition in the southern part of the San Juan Basin fit best into the theoretical continued sinking of the marine trough and rise of regressive deposits across planes of time equivalence in a seaward direction. Evidence of erosion or reworking of the regressive sandstone member in its western exposures is completely lacking, and its relation to the overlying deposits forming the Menefee formation is similar to the sedimentary succession found above the regressive sandstones to the south. The similar relation between the Pictured Cliffs sandstone and the overlying deposits forming the Fruitland formation in addition to the aforementioned convergence, indicates that both the Pictured Cliffs sandstone and the Point Lookout sandstone rose across time lines northeastward and seaward, with such rise being more pronounced in the Point Lookout sandstone.

Menefee Formation

The Menefee formation is characterized by extreme irregularity of the individual beds. It consists of sandstone, shale, and coal, coal usually being found in the upper and lower parts. The formation is also an over-all wedge within the converging Point Lookout sandstone and Cliff House sandstone. As it thins northeastward, sandstone becomes more predominant until the Menefee formation finally merges into part of the over-all sandy Mesaverde formation.

Cliff House Sandstone

The Cliff House sandstone is a transition zone between the marine Lewis shale and the largely non-marine Menefee formation. Lensing of sandstones within the Cliff House is often apparent in subsurface records, and lenses appear to be gradational at any horizon northeastward into shale of the Lewis formation, and gradational southwestward into the highly variable shale and sandstone of the Menefee formation. Figure 2 shows the relationship in the Blanco field. Locally, the Cliff House sandstone contains lenses, as in the Blanco area, which have an extent of two to five miles, in contrast to the massive sandstone member of the Point Lookout which extends tens of miles.

Pictured Cliffs sandstone

In addition to being an important producing horizon, the Pictured Cliffs is the most persistent and valuable subsurface stratigraphic datum in the basin. Many workers have noted its close resemb-

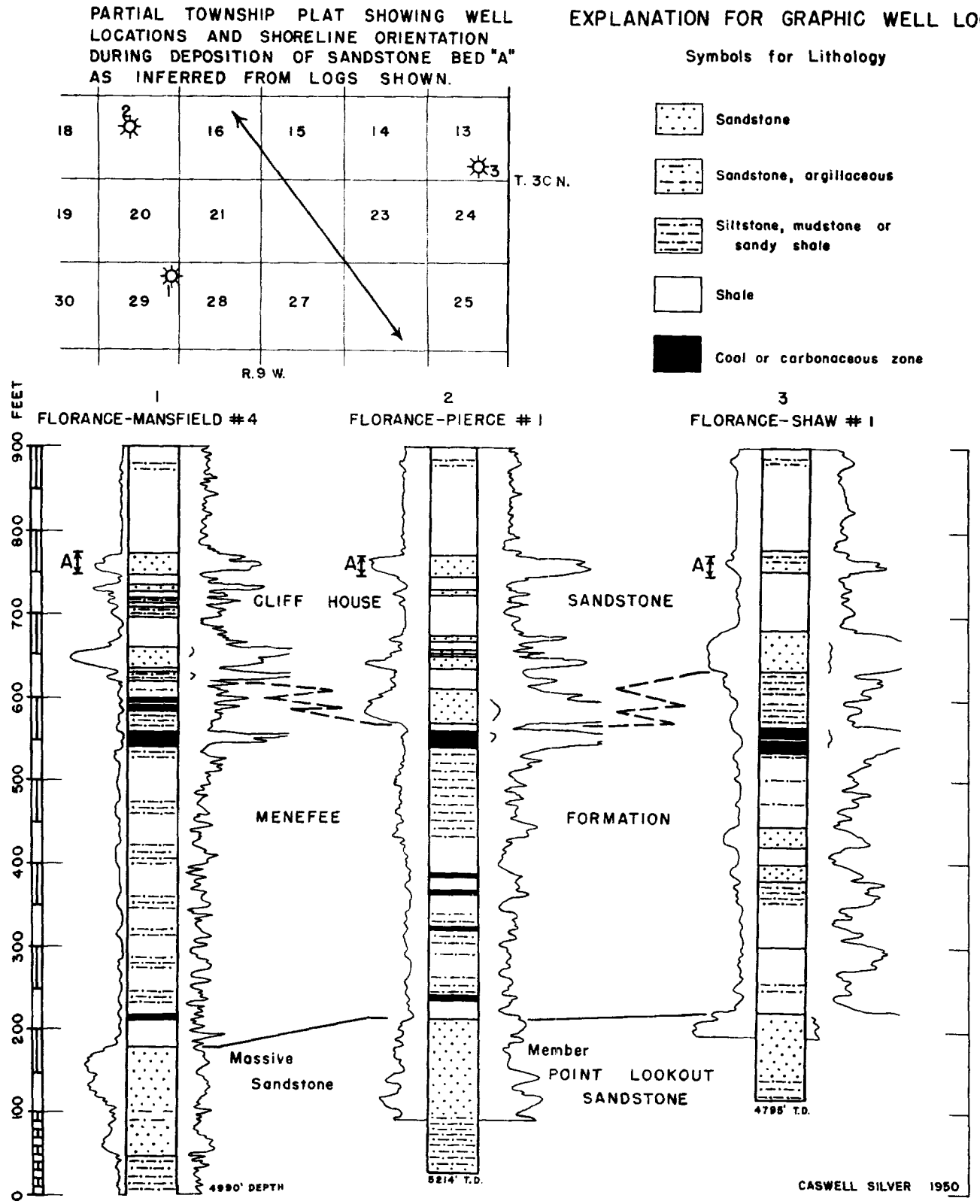


FIGURE 2. LOGS OF THREE WELLS IN THE BLANCO FIELD SHOWING CHANGES IN LITHOLOGY OF THE MESAVERDE GROUP

lance in lithology and general appearance to the Point Lookout sandstone (Zapp, Sheet 1). It is the uppermost wholly marine lithologic unit in the basin and it records the final withdrawal of the Cretaceous sea in the area. Wherever it is found it is medium to fine grained, and at any stratigraphic horizon it is gradational northeastward into Lewis shale. It ranges from 50 to 400 feet in thickness and crops out on the north, west, and south sides of the basin. It is notably absent on the east side. Its top over large areas is recognized as virtually a stratigraphic plane and it is used as such in Figure 1.

The writer believes that the Pictured Cliffs sandstone can be divided into an older southwestern and a somewhat younger northeastern unit, and that the southwestern unit or lobe is the important gas horizon in the basin. Evidence for this division is contained in both the surface and subsurface. Zapp (op. cit., Sheet 2) in his graphic sections 65 through 88 and in his mapped relationships shows an upper Pictured Cliffs tongue as a transgressive sand body above a unit of the Fruitland formation. This upper tongue continues east as the main body of Pictured Cliffs sandstone. This is in conflict with Dane's findings and requires reinterpretation of Dane's history of deposition (1946, para. 7 and 15) including indicated age relationships. Dane (1936, pp. 112-113) in tracing the Pictured Cliffs sandstone around the south side of the basin did not find it east of T 20 N, R 2 W, and presumably it is here transitional into beds of the Lewis shale. In tracing the Pictured Cliffs around the east side of the basin, Dane (1946, para. 3) calls attention in the text to its separation in the northeast and southwest parts of the basin but calls the northeast lobe the older unit. Wells to the Pictured Cliffs sandstone in the Gavilan area, T 25 and 26 N, R 2 W, have encountered gas. This is believed by the author to be the northernmost extension of the southwestern lobe. The outcrop east and northeast of this area does not show any continuous Pictured Cliffs sandstone but only sandy zones in the top of the Lewis shale containing the marine fossil Halymenites major.

In the Rosa Unit No. 1 well both the upper northeastern lobe and the lower southwestern lobe are present as shown in Figure 1. The southwestern lobe persists to the northeast as a sandy phase of the Lewis shale and results in the unusual thickness of shaly sand encountered in the Barella dome well of the Florance Drilling Company.

Fruitland and Kirtland Formations

The beds lying between the Pictured Cliffs sandstone and the base of the Animas formation are notable for what they reveal of the geologic history between the end of marine deposition and the beginning of Animas deposition. Figure 3, an isopach and lithofacies map of this interval, would indicate that after marine deposition in the San Juan Basin there developed a late Cretaceous basin of deposition lying somewhat to the west of the present area of Tertiary outcrop. Possibly the axis of the basin crossed the Colorado-New Mexico line in T 14 W. These beds are everywhere conformable to the beds below, and they are also in many places conformable to the overlying Animas and Nacimiento beds. Variations in the thickness of this unit would indicate that there is a hiatus present at the top, but erosion noted along the outcrop on the east side of the San Juan Basin is not pronounced. Facies changes would suggest in this instance that these beds thin as they lap upon the flank of a basin from the west.

Most of the evidence points to the top of the Kirtland formation as being a surface of low relief. Dane (1946, para. 10) states that "On the eastern side of the basin there is no evidence of angular discordance or erosional unconformity at the base of the Nacimiento formation". If this is correct, the structural attitude of the Pictured Cliffs sandstone and underlying Cretaceous beds should be related to this surface at the beginning of Animas-Nacimiento deposition by the interval of present stratigraphic thickness. Figure 1 shows the relationship.

Animas and Nacimiento Formations

Strata which are called Animas on the north and west sides of the basin have been shown by Dane (1946, Chart 24) to be essentially equivalent to strata called Nacimiento on the east side. In this paper, following past usage, "Animas" will apply to strata in Colorado and in San Juan County, New Mexico; "Nacimiento" for equivalent strata in Rio Arriba and Sandoval Counties, New Mexico.

Although the Animas formation appears essentially conformable to the underlying beds in San Juan County, the relationship is that of a disconformity. There are well-marked local erosion surfaces at both the top and base of the Ojo Alamo sandstone, but these have been interpreted by Dane (1936, pp. 119-121; 1946, para. 7) as not being significant either as time lapses or as intervals of erosion. The wells drilled in the Gavilan area show a very marked difference in the interval between the top of the Pictured Cliffs sandstone and the base of the Nacimiento formation. Some reworking of beds appears to be indicated, and there may be 100 to 200 feet of relief in a distance of ten miles. The erosion surfaces noted, the indicated relief on the top of the Kirtland formation, and the change in source and composition of sediments all would indicate a major hiatus below the base of the Animas beds either at the base of the Ojo Alamo or within its reworked beds. This would be in conflict with Dane's more recent interpretation and a return to the interpretation of Reeside (1924, pp. 48-49).

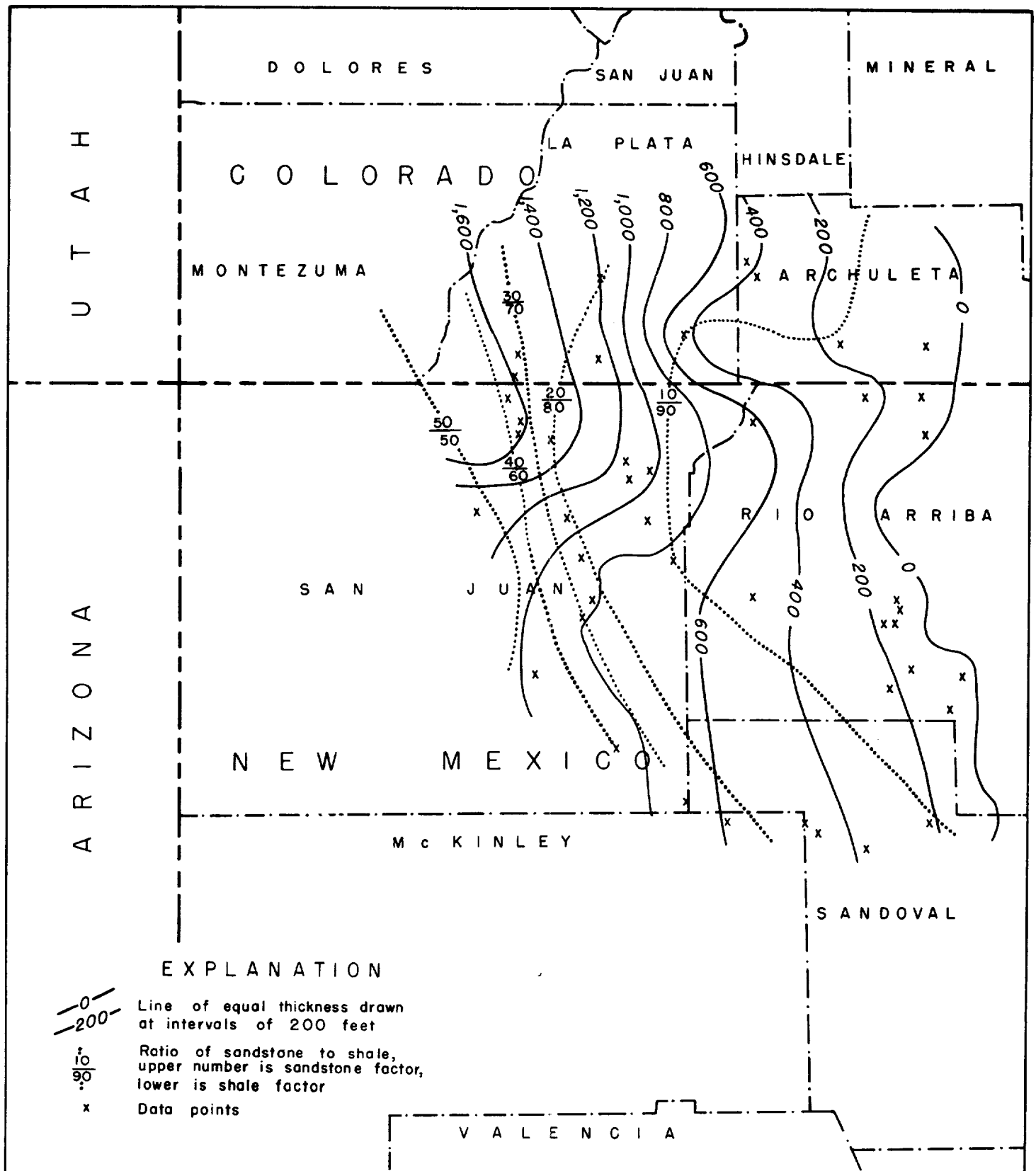


FIGURE 3. MAP SHOWING THICKNESS AND FACIES OF THE COMBINED FRUITLAND AND KIRTLAND FORMATIONS IN PART OF THE SAN JUAN BASIN

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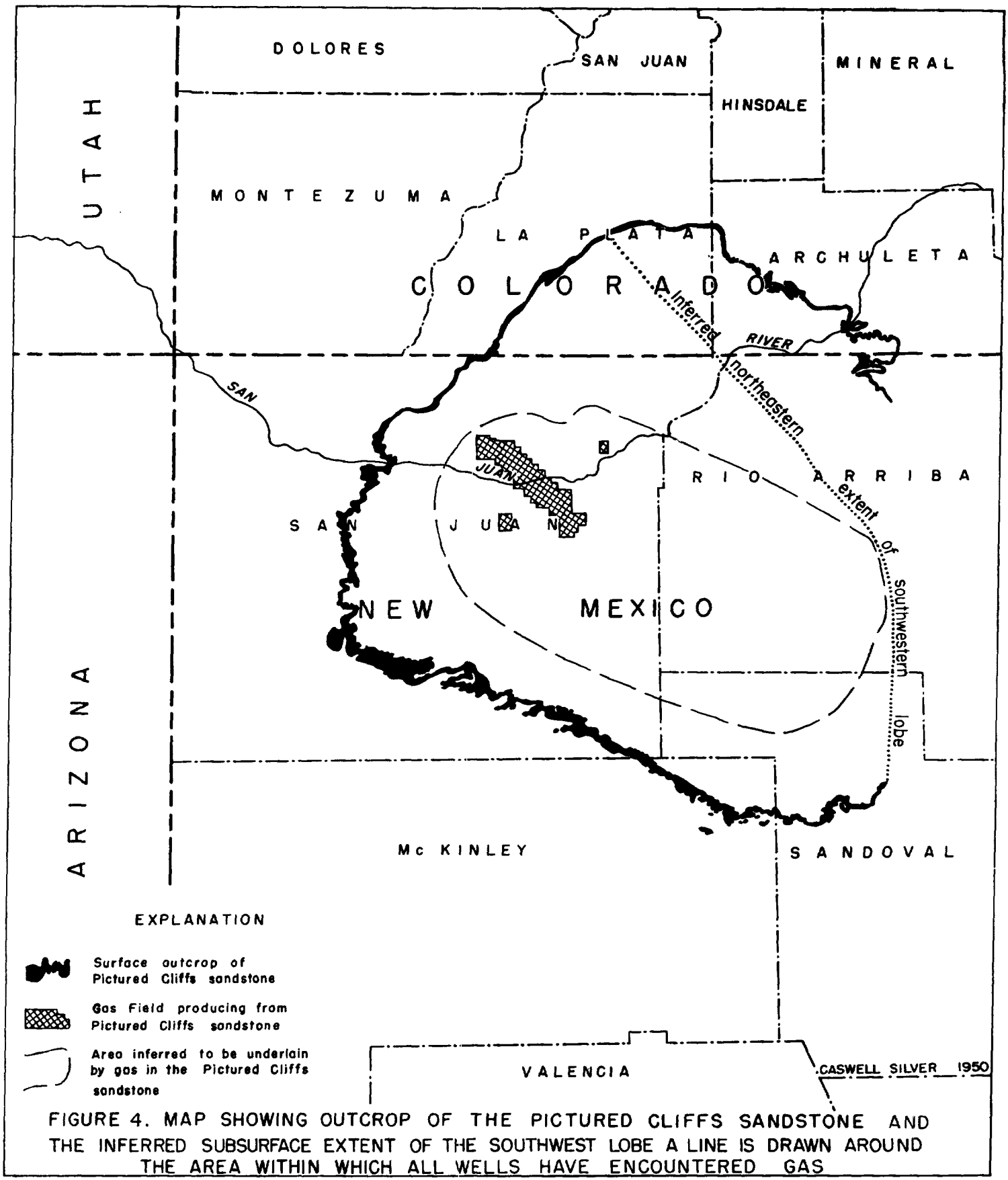


FIGURE 4. MAP SHOWING OUTCROP OF THE PICTURED CLIFFS SANDSTONE AND THE INFERRED SUBSURFACE EXTENT OF THE SOUTHWEST LOBE A LINE IS DRAWN AROUND THE AREA WITHIN WHICH ALL WELLS HAVE ENCOUNTERED GAS

San Jose Formation

Following George Gaylord Simpson (1948, pp. 257-285) the name "San Jose" is used for the "Wasatch" of past papers on the San Juan Basin.

Distribution of Gas

Pictured Cliffs

The area underlain by gas in the Pictured Cliffs sandstone as indicated at the present time is shown in Figure 4. This area is approximately 1,500,000 acres. As more information becomes available, the known gas area will probably be greater. Although there are wide gaps between wells, it is significant that no wells have been drilled within this area that have not encountered gas. A few wells close to the outcrop have encountered some water with the gas; the nature of the drilling operations and completion in each case have lent some doubt as to the source of such water. All the water reported, however, was considered brackish and not salty.

Water appears to be present in the P. B. English well in Section 8, T 27 N, R 13 W, and in wells drilled in the La Plata field. Water is also reported in the Pictured Cliffs sandstone at the northwest end of the Fulcher Basin field. The Fulcher Basin-Kutz Canyon trend is the principal gas area being produced from this horizon at the present time.

Wells indicating possible commercial deliverabilities of gas have been drilled in widely scattered areas of the basin, at Ignacio, Gavilan, and Largo Canyons. However, lack of market has deterred development, so that the above areas offer neither sufficient reservoir information or production history to delineate potential reserves, if any.

Mesaverde

The area occupied by gas in the Mesaverde has not been so well defined as that for the Pictured Cliffs sandstone. Wells drilled up to the present time indicate that the sandstone beds of the Mesaverde containing gas will coincide only generally with the area found productive for the Pictured Cliffs sandstone. It is also evident that the occurrence of gas in the various units of the Mesaverde will not coincide notwithstanding the general similarity in conditions of accumulation.

Cliff House. The only definite occurrence of gas in the Cliff House sandstone so far determined as showing some continuity is in a restricted area of approximately 30,000 acres, within the Blanco trend. Figure 5 shows the present known area of Cliff House gas. Gas has been found in the lower ends of lenses of the Cliff House sandstone in the Blanco area. Lense A of Figure 3 is an example. Water has definitely been encountered in the Cliff House sandstone in La Plata and Fulcher Basin fields and possibly in the Cedar Hill area. In the Blanco area lithologic and physical characteristics of the Cliff House sandstone are similar to those of the Pictured Cliffs sandstone and Point Lookout sandstone, and they will be discussed together.

Menefee. Gas has been encountered in the Menefee formation in scattered wells. However, only in the general area of the Blanco trend has it been the policy to test the entire Mesaverde section with open hole. Open well bores there have proved the absence of water under an area of approximately 30,000 acres in the Menefee. Judging from the few cores that have been taken from the Menefee, it may be assumed that the Menefee section contains gas in this area where permeable or where not containing high-gravity oil. Elsewhere in the basin the Menefee has yielded interbedded shows of oil and gas with water. Recorded occurrences of water in the Menefee are at Fulcher Basin, La Plata field, Cedar Hill, and possibly Kutz Canyon. A few of these areas have also indicated shows of gas in individual lenses. However, no trend or linear zone of better porosity is indicated as yet for this formation.

Point Lookout. The Point Lookout formation, like the Pictured Cliffs sandstone, has received development over a wide area. This area exceeds 900,000 acres. Several localized areas have been developed and designated as "fields". Figure 5 shows the outcrop of the Mesaverde group with the postulated distribution of known Point Lookout gas. This area will probably be enlarged. In each case of commercial gas development, the massive sandstone member has been the principal producing horizon. As in the Pictured Cliffs sandstone, the best porosity is usually at the top. Some increase in volume of gas has been noted in the sandy shale and streaks of sand below the massive sandstone member. But such increases have generally been minor. Vertical fractures in cores and "lost circulation" would indicate that jointing may be extensive in the Point Lookout sandstone. Water has been reported in wells close to its southern and western outcrop. The sandstone bed encountered in wells in the Lindrith area having a similar stratigraphic position apparently contained water.

Structure

Contours on the tops of the various gas horizons have failed to reveal any structural closure in areas so far determined to have gas. Present gas producing areas have not been defined, but the areas themselves have grown so large as to rule out the possibility of structural closure. Local structural highs occur in the basin, but until such highs are found containing gas within otherwise

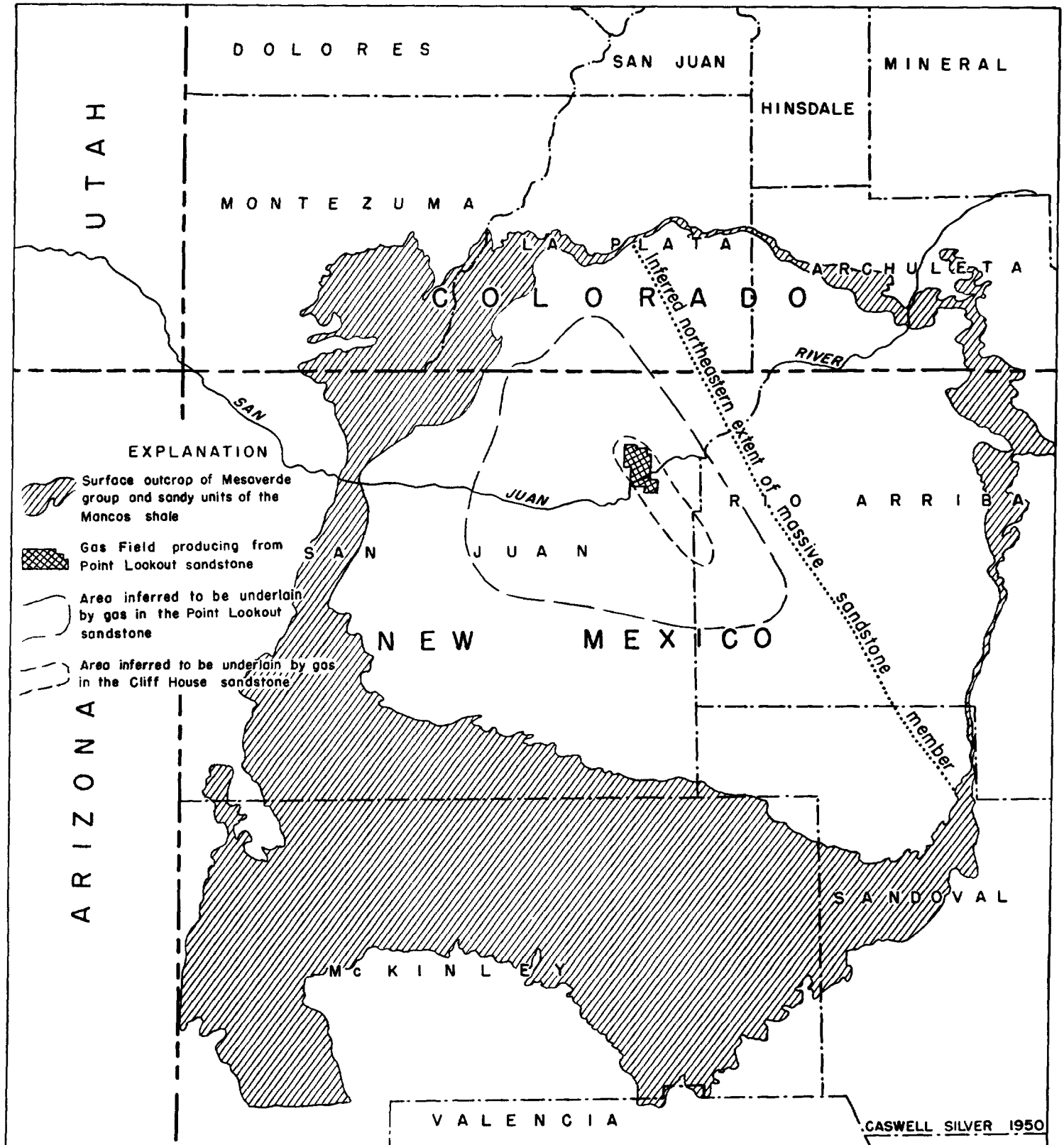


FIGURE 5. MAP SHOWING OUTCROP OF THE MESAVERDE GROUP AND SANDY UNITS OF THE MANCOS SHALE AND THE INFERRED SUBSURFACE EXTENT OF THE MASSIVE SANDSTONE MEMBER OF THE POINT LOOKOUT SANDSTONE. A LINE IS DRAWN AROUND THE AREA WITHIN WHICH ALL WELLS HAVE ENCOUNTERED GAS IN THE POINT LOOKOUT SANDSTONE

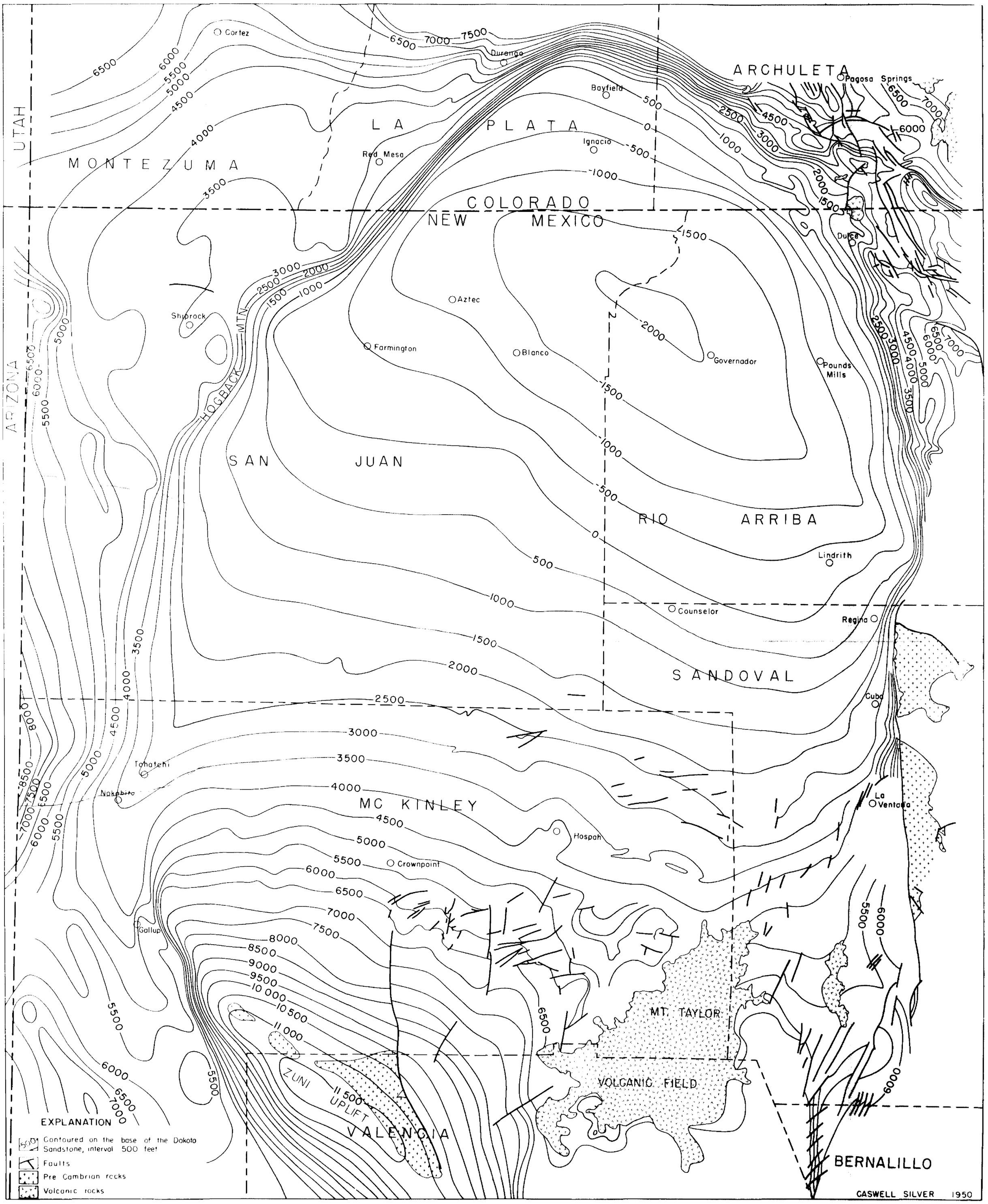


FIG. 6. MAP SHOWING STRUCTURE OF THE SAN JUAN BASIN, NEW MEXICO AND COLORADO

IN PART AFTER SEARS, J D, HUNT, C B, DANE, C H, WOOD, G H, ZAPP, A D, AND OTHERS WITH ADDITIONS AND MODIFICATIONS BY CASWELL SILVER, 1950

water-saturated rocks there is no proof that the occurrence of gas is related to structural traps. Figure 6 shows a structure map of the basin contoured on the base of the Dakota sandstone. The overlying Pictured Cliffs sandstone and Point Lookout sandstone are essentially parallel to the Dakota. A comparison with Figure 6 of the maps of Figures 4 and 5 (present known areas of gas in the Pictured Cliffs sandstone and the Point Lookout sandstone) will reveal that the gas areas are structurally a part of a large basin. The slope of beds in the gas areas is approximately fifty feet to the mile.

Nature of the Reservoirs

The sandstone beds of the gas reservoirs or "pays" have similar lithologic characteristics. They are medium- to fine-grained, sub-rounded to sub-angular, argillaceous, slightly calcareous, somewhat fractured sandstones. The extent of the fractures is not known but may be very significant in the productive areas.

The sands range considerably as to both cement content and sorting. Porosity in individual wells varies with the amount of silt or cement. Thus, in the more continuous pays deliverabilities are more closely related to changes in porosity and permeability than to sand thickness. The Cliff House sands may be an exception in that they are more variable in thickness. Cable-tool drillers often report most of the volume from streaks in the pay rather than uniformly from the entire sand. The best parts of both the Pictured Cliffs and Point Lookout "pays" appear to be at the top immediately under the contact with the overlying beds. The Cliff House, on the other hand, has its better porosity in the lower part. The fractures encountered in some wells often produce large volumes of gas.

Commercial development has followed well-defined "trends" of better porosity and permeability. Trends so far determined have been in a northwest-southeast direction. There have been attempts to relate such alignments to present or former structural position, or to former strand lines. Evidence is not conclusive in either case. More cores are needed to test some of the following observations.

The well-defined Blanco "trend" in the Point Lookout sandstone appears to be due to better sorting. Reservoir rock in wells northeast and southwest of the trend have a much higher percentage of silt with no appreciable increase in cement content. However, fractures have been revealed by cores and these may be structurally localized in the trend. The Fulcher Basin-Kutz Canyon trend in the Pictured Cliffs sandstone appears to result from both well sorted sand and absence of cement. Poor wells to the northeast of this trend encounter a high content of silt in the sandstone. Poor wells to the southwest appear to have a higher cement content.

Poorly sorted sands might be due to rapid subsidence, excessive supply of material, or deposition a shorter distance off shore. The amount of cement could be related to the length of stand of the sea during or shortly after deposition or to water-table conditions, which in turn could be related to present or past structural attitudes. Whatever the primary cause, present information, though incomplete, suggests that both degree of sorting and cementation are the principal causes of the trends and these are related to shoreline alignments.

Well completion methods appear to affect permeability. The generally poorer results obtained from completions by rotary tools have been attributed to the contact of water-base muds with the "pay". There appears to be considerable merit to this concept. Analysis of the argillaceous cement of the Pictured Cliffs sandstone indicates that it contains bentonite and has swelling properties in the presence of water. Fundamental research on these reservoir sandstone beds would be extremely helpful to operators in the basin. Core analyses of the reservoir sandstone beds in the basin are meager and the few available may or may not be representative. Based on present core analyses, it may be said that the sandstone beds have relatively low permeability and porosity. In general the range of porosities is from seven to fifteen per cent and the range of permeabilities up to 400 millidarcies. The modal porosity is approximately ten per cent and the modal permeability one millidarcy or less. This modal permeability is generally considered non-commercial for any but gaseous fluids. Wide ranges in volumetric estimates of reserves have been made on the basis of information available now.

The generally "tight" nature of the "pays" is reflected by the natural open-flow potential of many of the wells, a few of which have come in for less than 10,000 cubic feet per day. The range of natural open-flow potentials is from 50,000 to 4,000,000 cubic feet per day from Pictured Cliffs wells to 100,000 to 10,000,000 cubic feet per day from Point Lookout wells. The natural potentials might be less significant in each case were the method of completion to be analyzed. On the other hand, some wells have encountered sands so "tight" that they did not yield fluid of any kind and had only a slight odor of gas.

Recent practice has been to give these low-potential wells a heavy "shot" of nitroglycerin, which has improved the open-flow potential from one to ten times. Results from "shooting", however, have not always been satisfactory, and it appears probable that "shooting" markedly benefits wells in areas of fair porosity and permeability but is not effective or lasting in extremely poor permeability areas. Undoubtedly some of the wells abandoned as non-commercial in past years could have been commercial with present completion practice.

Initial rock pressures in the reservoirs may be significant to an understanding of the distribution of gas. Few if any well pressures were checked with a dead-weight recording gauge. The shut-in casing-head pressures reported for adjoining wells to the same reservoir sandstone in the same field vary by some tens of pounds. This is to be expected from gauge readings of wells in low permeability reservoirs, which require days to stabilize. The following table shows the pressures, the depth of the wells, the lowest elevation known for the outcrop of the principal gas horizons, and comparisons between field pressures, depth, and possible hydrostatic columns, as reported from various sources, for a few fields and wells.

Column	1	2	3	4	5	6	7
Field & Pay Horizon or Well	Elev. of outcrop on San Juan River	Depth of well to top of pay	Aver. elev. of top of pay	Diff. in elev. betw. top of pay & outcrop in feet	Col. 2 x 0.436	Col. 4 x 0.436	Reported formation pressure and source
Blanco							
Mansfield #4							
Cliff House	5050	4218	1760	3240	1840	1412	1356 psia FPC
Point Lookout	5000	4815	1160	3840	2100	1672	1372 psia FPC
La Plata							
Point Lookout							
Decker #1	5000	4885	1312	3688	2115	1608	1074 sich. psig. S. U.
Culpepper-							
Martin #1	5000	4640	1367	3423	2020	1490	967 sich. psig. S. U.
Fulcher Basin							
Pictured Cliffs	5100	1800	3900	1200	785	521	513-592 sich. psig. S. U
West Kutz Canyon							
Pictured Cliffs							
Hancock #1	5100	1761	4347	753	770	328	490 sich. psig. NMOCC
Aztec							
Pictured Cliffs							
A. Greer-							
Thompson #1	5100	2220	3550	1550	980	675	690 sich. psig. NMOCC
Gavilan							
Pictured Cliffs							
Dunham #1	5100	3417	3912	1188	1490	520	1091 psia NMOCC

SOME GAS PRESSURES REPORTED IN THE SAN JUAN BASIN. Abbreviations: FPC: Federal Power Commission; S. U.: Southern Union Gas Company; NMOCC: New Mexico Oil Conservation Commission; psia: pounds per square inch absolute; psig.: pounds per square inch gauge; sich.: shut-in casing head.

The foregoing table is meager and inexact. However, it shows one pertinent fact. The pressures found within the Pictured Cliffs sandstone differ geographically. It also appears that they cannot be related to depth or structural position. Not enough pressures are available to the writer to plot a pressure distribution map of the basin for each reservoir, but a pressure gradient is apparent in the general direction of the outcrop. More pressure data are needed. They may be the most significant geologic information yet to be compiled for the understanding of the occurrence of gas.

Summary

The several sandstone units of the Cretaceous formations decrease in porosity to the northeast in a direction seaward from the source areas. Regressive sands show more continuity than the transgressive sands. The Point Lookout sandstone has an upper massive sandstone member which is even and continuous over a considerable area and has a marked stratigraphic rise to seaward.

The Menefee formation has extremely irregular sandstone beds. The Cliff House sandstone is lenticular and does not have a sharp base. The Pictured Cliffs sandstone can be divided into two stratigraphically and geographically distinct lobes. The Fruitland and Kirtland formations form a wedge-shaped mass of sediments, thickening to the west and thinning to the east. The western and southwestern part of the present basin was relatively depressed during Fruitland and Kirtland deposition. The Animas and Nacimiento formations

lie disconformably upon a surface of low relief eroded upon the underlying beds.

Gas is found throughout much of the west-central portion of the San Juan Basin. Pictured Cliffs gas is most widespread, over an area of approximately 1,500,000 acres. Water has been found only near its western outcrop. Mesaverde gas is less well defined. Cliff House gas is limited at present to an area of approximately 30,000 acres. Gas occurs in the lower end of inclined lenses in the Blanco field. Menefee gas is also limited and very irregular in distribution. Point Lookout gas is widespread but not as much so as that of the Pictured Cliffs sandstone. It underlies at least 900,000 acres. Water in the Point Lookout has been reported only from the Lindrith area and close to its extreme western outcrop area.

The location of gas is not related to any known structures and is not related to the present structure of the San Juan Basin.

All the reservoir beds are relatively low in porosity and permeability and have a high cement content. The cement appears to be argillaceous and to contain bentonite in part. Water has the effect of reducing the permeability. Pressure differences within the Pictured Cliffs sandstone cannot be related to depth or structural position. They do show a diminishing gradient in the general direction of the outcrop.

Geologic History

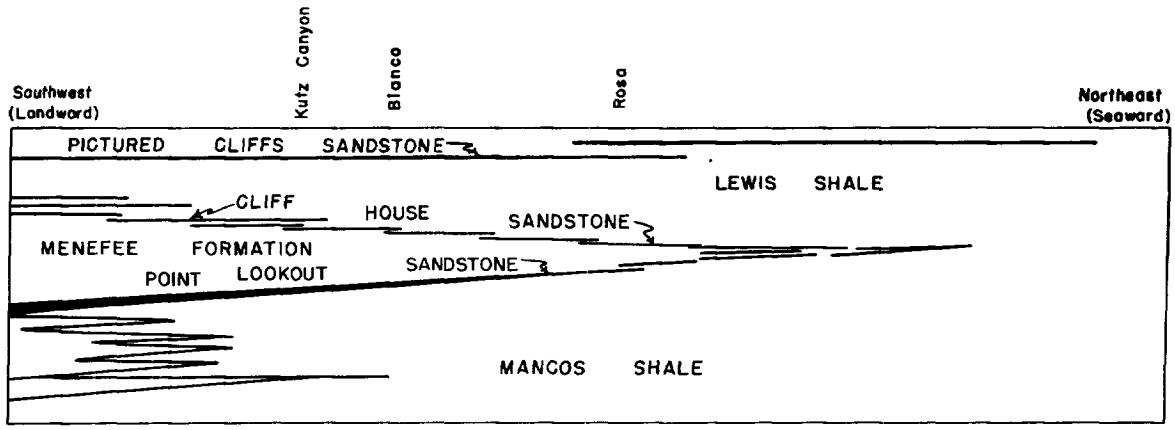
This geologic history begins with the advance of the Cretaceous seas across the area which was recorded by all or part of the coarse clastic deposits of the Dakota sandstone. The transgressive deposits of the Dakota sandstone were succeeded by finer grained clastic muds of the Mancos shale. During the time of deposition of Mancos shale, the source of the sediments was to the south and west and the shorelines had a general northwest to southeast direction. Sears, Hunt, and Hendricks (1941) have shown that the rate of subsidence of the basin varied as did also the supply of detrital material from the southwest, so that the shoreline migrated back and forth from northeast to southwest. Either retreat of the sea or increased supply of material caused regressive, coarser grained clastic beds to be deposited over finer grained marine sediments. These were covered by irregular non-marine beds of sand, clay, and organic material, which were in turn followed by near-shore sands and marine muds as the shoreline again advanced southwestward. The most extensive retreat of the shoreline to the northeast was recorded by the deposition of the Point Lookout sandstone.

During part of the deposition of the Point Lookout sandstone the shoreline moved seaward in a uniform manner as related to the supply of material. This resulted in the deposition of a widespread blanket of medium-grained sand which rose across the stratigraphic time lines. The upper part of this unit is the massive sandstone member. Along its northeastern edge it grades into silty, shaly units of of the Mancos shale. After deposition of the massive sandstone member, the rate of subsidence and the supply of material were in such balance that the shoreline remained stationary for some time. This resulted in the accumulation of the thick, largely marine sandstone and thin shale sequence just northeastward of the northeastern limits of the massive sandstone member. This sequence is less continuously divisible into the mappable units comparable to those to the west and is therefore best designated as the Mesaverde formation. During its deposition a thick wedge of floodplain deposits, the Menefee formation, accumulated to the west. Following the long stand of the shoreline in this area, it again advanced southwestward during which local transgressive sand lenses of the Cliff House sandstone were deposited on top of the floodplain and near coastal deposits of the Menefee formation. These in turn were covered by the silty marine muds of the Lewis shale.

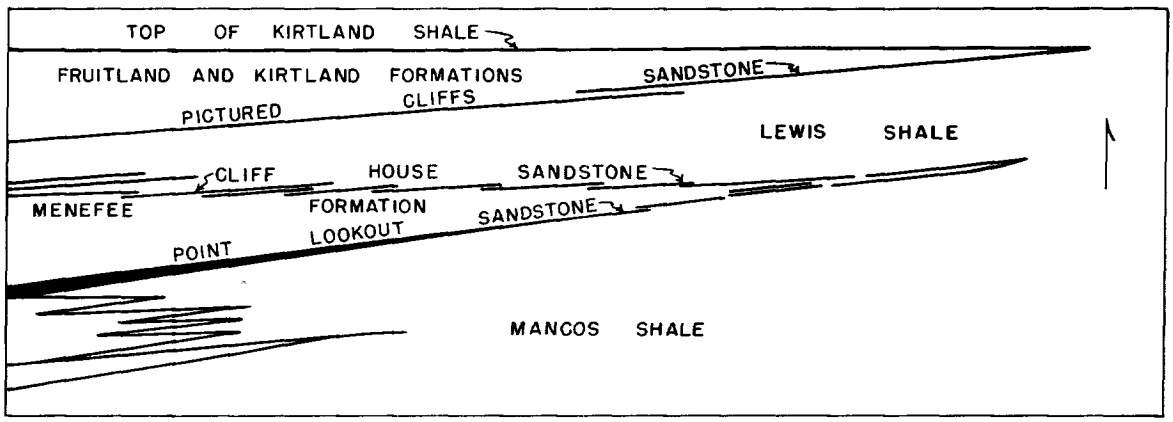
After the accumulation of Lewis shale there was again a widespread and uniform retreat of the shoreline, which resulted in the deposition of the Pictured Cliffs sandstone having a gradual seaward rise to the northeast. This major regression of the shoreline was uniform during the deposition of the southwestern lobe, but when the seaward extension of the Pictured Cliffs sandstone reached the northeastern limits of the southwest lobe there was a period of balance during which the shoreline stood in the same general area. This is marked by locally transgressive tongues of sand which were deposited above Fruitland sediments, including coal. Pictured Cliffs sand built upward rather than seaward while seaward a greater thickness of sandy and silty muds of the upper Lewis shale were accumulated.

Following deposition of this sequence, the shoreline again retreated northeastward as sands of the northwestern lobe of the Pictured Cliffs were deposited. The Pictured Cliffs intertongued with Lewis shale at higher and higher stratigraphic intervals to the northeast as its deposition shifted in that direction. Movement of the shoreline to the northeast was followed by coastal swamps and nearshore muds of the Fruitland formation.

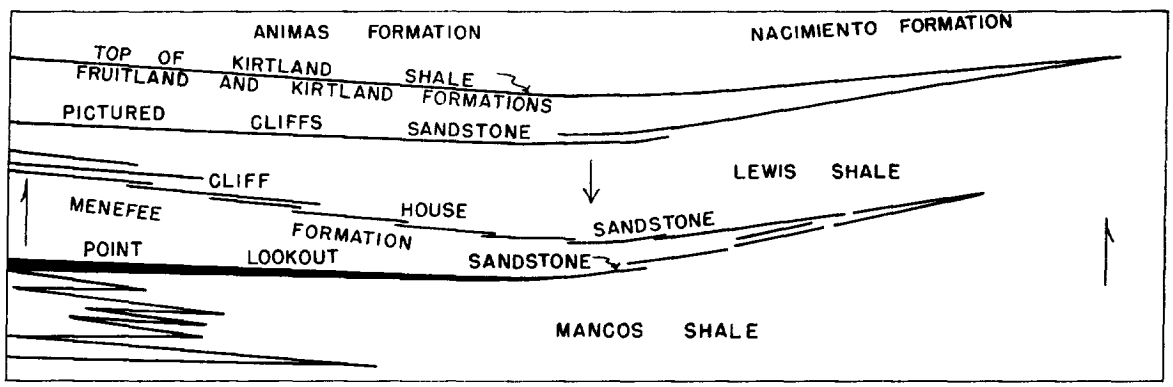
As the seas finally withdrew, or were pushed out, continental sediments began to accumulate in a lesser basin of deposition in the southwestern half of the area of the present San Juan Basin. This basin is here designated the "Kirtland Basin" after the sediments which best define it (See Fig. 3). The sediments were largely fluviatile in origin, and were derived from the same source areas as the older



A. Diagrammatic cross-section of the San Juan Basin at the end of final marine deposition represented by the Pictured Cliffs sandstone showing the initial dip of the reservoir sandstone beds which resulted from the gradual basinward stratigraphic rise of regressive sandstones.



B. Diagrammatic cross-section of the San Juan Basin showing increased dip of principal reservoir sandstone beds and the westward dip of all beds at the end of Kirtland shale deposition. In the central and western part of the Basin the present thickness of the Kirtland shale is essentially equal to the original thickness.



C. Diagrammatic cross-section of the San Juan Basin showing the present attitude of the reservoir sandstone beds. The attitude of many beds in the southwestern half of the Basin has been reversed since the time of diagram B above. Beds which wedge to the northeast and were formerly up dip in that direction are now partly down dip in that direction.

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FIGURE 7. DIAGRAMS OF THE ATTITUDE OF CRETACEOUS STRATA AT VARIOUS TIMES IN THE SAN JUAN BASIN

marine Cretaceous strata. During Kirtland deposition, early orogenic movements of the Laramide Revolution began to have effect and the western half of the present basin was relatively depressed with relation to the eastern half, as a thick wedge of coarse sand, the Farmington sandstone member, was poured into the newly formed continental basin of deposition.

The eastern part of the Kirtland basin remained close to the base level of deposition and received little or no sedimentation. It experienced minor erosion. Sediments of the Farmington sandstone were still derived from a distant source and by the time of deposition of the upper Kirtland shale the source was worn down so that mostly fine-grained sediments were contributed.

During the final stages of upper Kirtland shale deposition, volcanism occurred to the north which contributed the siliceous pebbles and andesitic debris of the McDermott formation.

Following McDermott deposition, a hiatus is indicated as relatively minor deposition and erosion occurred, during which time local pediment gravels of chert and siliceous pebbles of the Ojo Alamo beds accumulated. Mountains began to rise to the northwest and the northwest and western part of the Kirtland basin began to receive coarse-grained sand and volcanic material, which masked further contribution from the southwest.

As mountain building progressed, the centers of deposition and the sources shifted. Early sources for the Animas beds appear to be from the northwest, with local depositional areas of interior drainage developing in the southern and western parts of the present basin. As deposition progressed, areas far to the north and northeast of the present basin began to rise and contribute a great mass of sediments to the Animas beds in eastern and northeastern parts. At some time after the deposition of the lower Animas beds and prior to the deposition of the San Jose beds, the structure of the present basin began to form and continued to develop until after the final deposition of the San Jose formation.

Discussion and Conclusions

The Cretaceous rocks of the San Juan Basin contain a belt of porosity within which the principal gas-producing horizons wedge out to the northeast. The southwest part of the basin was depressed relative to the northeast part during the time of Cretaceous deposition that began with the Kirtland shale (See Fig. 7B). This regional tilt was accentuated and maintained during at least early and possibly all of Animas deposition. While the strata were inclined, gas which was within the originally water-saturated reservoir beds or was entering the beds, moved by buoyant separation to the sealed up-dip ends of the porosity wedges. The quantity of gas so accumulated was sufficient to occupy all or most of the present extent of the southwest lobe of the Pictured Cliffs sandstone and all or most of the present massive sandstone member of the Point Lookout sandstone. After accumulation, the present structure of the basin was formed (See Fig. 7C). This basinal structure is not related to the occurrence of gas. Erosion has removed some of the overburden and portions of the reservoir beds since the accumulation of gas and the subsequent deformation.

Water occurs structurally higher than gas within the homoclinal, porous strata of the southwest limb of the basin. The magnitude of the known pressures indicates a considerable volume of gas down dip from the outcrop. No evidence is available to prove or disprove that some portions of the major gas areas extend to the outcrop. Gas seeps are known along the outcrop, but their importance is difficult to evaluate. Coincidence could possibly, but not probably have stopped erosion short of reaching the gas accumulations. The principal problem of the occurrence of gas in the basin is its confinement.

It is possible that the gas is not being retained but is being dissipated at a natural rate at the outcrop and that water encroachment down dip is proceeding as fast as the slope of beds and effective permeability will permit. Evidence for this lies in the fact that the pressure decreases within the same reservoir beds generally toward the outcrop. Gas is, of course, moving in the direction of the gradient. The rate of water encroachment can be determined mathematically, assuming uniform conditions. C. V. Theis estimates from the data given in this paper that it is possible that water is encroaching down dip at rates on the order of one mile every 500,000 to 1,000,000 years. It is not possible to date closely the formation of the basinal structure or the first exposure of the reservoir beds by erosion, but such estimates suggest interesting speculations.

There is much gas in place in the Cretaceous strata of the San Juan Basin, which remains to be proved by further development. The greatest part of this gas probably will be found in the southwestern lobe of the Pictured Cliffs sandstone and the massive sandstone member of the Point Lookout sandstone. The areas of gas in these units will be limited by the extent of water encroachment. Some gas also occurs in the northeast wedge ends of other beds, but the accumulations do not cover large areas. The reservoir beds are of relatively low permeability, and development has taken place in "trends" of better permeability. Commercial development for many areas will be dependent upon the field price that is paid. The gas deposits are being dissipated by erosion. However, the generally low dips of the reservoir beds away from the outcrop, the low permeabilities, and the type of cement

greatly restrict the rates of water encroachment and gas escape. Pressure gradients in the gas areas should indicate areas of escape at the outcrop.

Some problems which merit investigation are: (1) pressure gradients within reservoir beds; (2) dry and wet permeability as related to cement composition; (3) mathematical treatments of the rate of fluid movements for both water and gas; (4) geologic investigation of the Animas and San Jose formations, including thickness and facies maps and a delineation of the early Tertiary history and paleogeography of the basin; (5) geologic investigation of the Tohatchi shale and Chuska sandstone on the Arizona-New Mexico boundary and their bearing on the late Tertiary history of the basin.

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