NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

Report of Investigation Number 36

Oil Fields in the Burke County Area, North Dakota

GEOLOGICAL, MAGNETIC, and ENGINEERING STUDIES

Grand Forks, North Dakota, 1960

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LOCATION MAP.

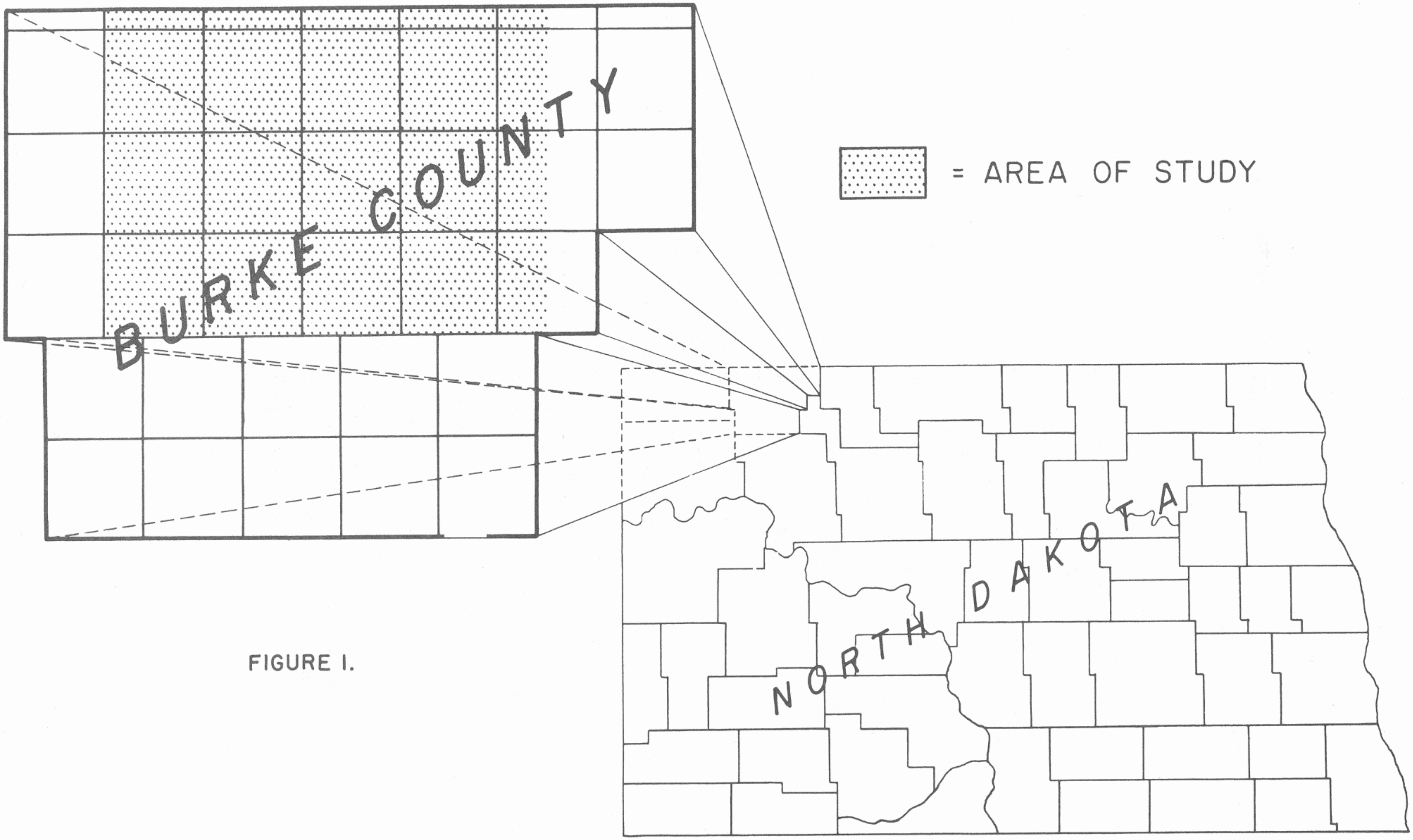


FIGURE I.

SUBSURFACE STUDIES

by
Sidney B. Anderson, Dan E. Hansen,
and William P. Eastwood

Abstract

In northern Burke County, North Dakota, the important oil-producing units are the Rival subinterval of the Frobisher-Alida interval and the Midale subinterval of the Ratcliffe interval.

The Rival subinterval consists of (from west to east) pelletoidal limestone, oolitic and pelletoidal limestone with common secondary anhydrite, and interbedded anhydrite and sucrosic limestone. Oil accumulations in this subinterval appear to be controlled by the infilling of the limestone by secondary anhydrite.

The Midale subinterval consists of fine granular to sucrosic, dolomitic, slightly argillaceous limestone. Oil accumulations in this subinterval are mainly controlled by permeability changes related to dolomitization. Minor structures influence these accumulations to a lesser extent.

Future production may be found in the Rival by exploring the trend of the secondary anhydrite infilling, and in the Midale by drilling on the structural trends. Horizons deeper than the Mississippian have not been explored.

Introduction

This report is concerned with the geology of the Mississippian Madison fields located in northern Burke County, North Dakota (Figure 1). The area of study encompasses townships 160 through 164 North and ranges 90 through 93 West in the north-central part of the Williston Basin. The fifteen fields included in the study are Columbus, Short Creek, Portal, Entry, Rival, Lignite, Flaxton, Stony Run, Woburn, Black Slough, Rennie Lake, Bowbells, Foot Hills, Northeast Foot Hills and Coteau as named and defined January 1, 1960 by the North Dakota State Industrial Commission (Figure 2). For the most part, all the fields produce from the Midale and/or Rival subintervals of the Mississippian Madison group.

The part of the stratigraphic column discussed in this report includes the Midale and Rival subintervals with a brief description of the adjacent intervals, the upper Frobisher-Alida and Ratcliffe respectively. No wells have penetrated formations below the Madison group.

OIL FIELDS IN BURKE COUNTY AREA

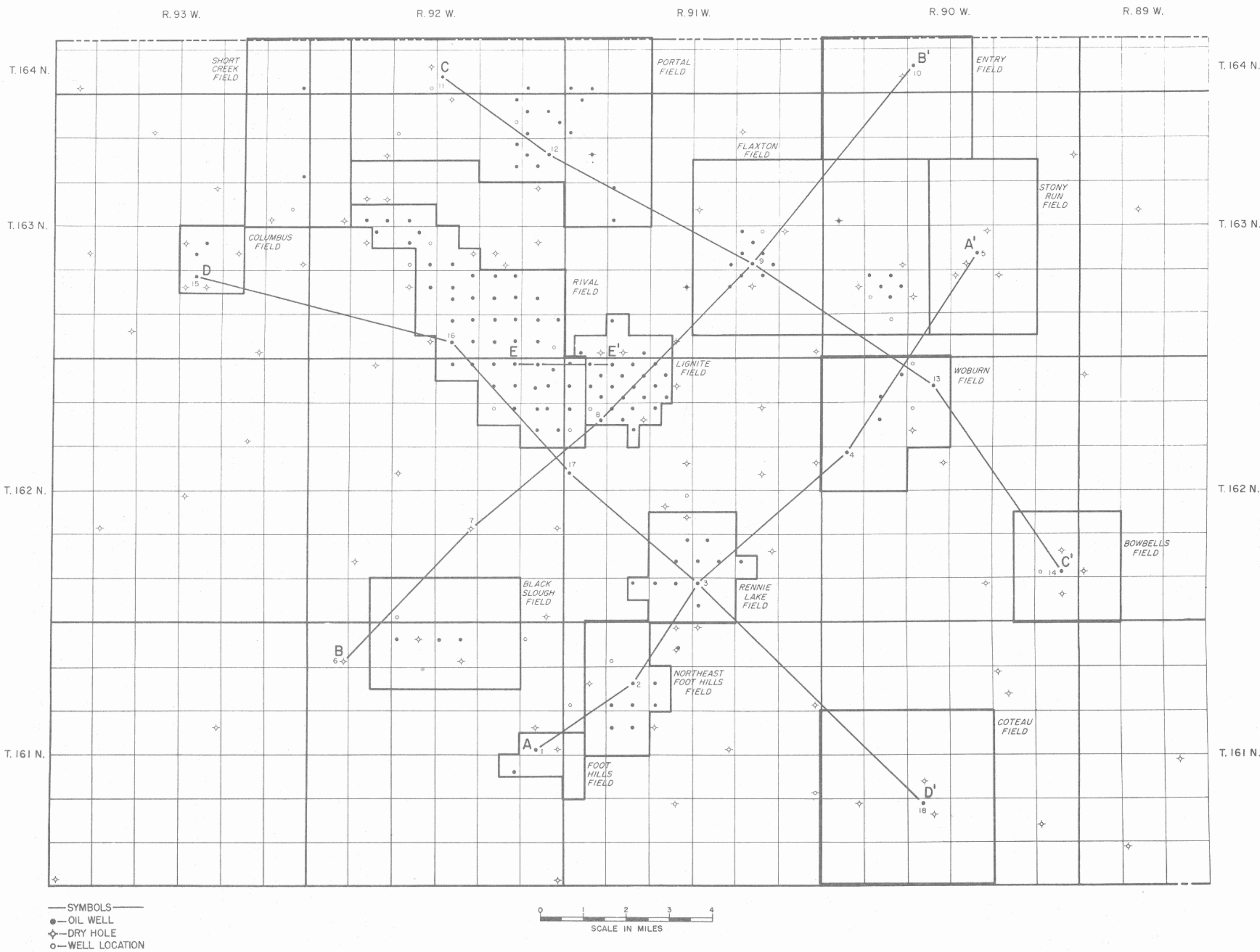


FIGURE 2.

The writers wish to thank the other staff members of the North Dakota Geological Survey for helpful suggestions and criticisms. Thanks are also due to Mr. Ronald Guttenberg who drafted the illustrations.

Stratigraphy

The section studied consists of brownish to very light brownish gray fragmental pelletoidal limestones, granular dolomitic limestones, and white to light gray dolomitic anhydrites with minor amounts of salt, gray shale and dense dolomites. Within this carbonate and evaporite sequence are a number of lateral and vertical changes in lithology. These variations are analyzed by selecting a few stratigraphic units based on mechanical log characteristics and associated strata similar to the method of Fuller (1956) rather than erecting units based upon lithologic criteria.

Prior to the recent increase in subsurface data in this area, the units picked in this part of the column were the Charles and Mission Canyon formations. With the increase in control it became apparent that the Charles and Mission Canyon are evaporite and carbonate facies and are in part time equivalents. These lithologic units were then discarded, except as facies names, in favor of the more practical mechanical log marker defined units of laterally varying lithology.

In an effort to reach a mutual agreement on nomenclature, a meeting was held at Grand Forks at which Dr. David R. Francis, Chief Geologist, Department of Mineral Resources, Province of Saskatchewan, and staff, and Dr. Wilson M. Laird, State Geologist of North Dakota and his staff discussed the nomenclature problems. At a subsequent meeting in Grand Forks, representatives of the United States Geological Survey, headed by Mr. Thomas A. Hendricks, Chief of the Fuels Section at Denver; Dr. Allan Agnew, State Geologist of South Dakota; Mr. O. D. Blake, geologist of the Montana Oil and Gas Commission; and Dr. Hugh R. McCabe, geologist of the Manitoba Department of Mines and Natural Resources, were also present. No final agreement was reached, but the problems of the individual areas were presented in detail and the groundwork was laid for possible future agreement on stratigraphic nomenclature of the Williston Basin.

The method of subdivision used and many of the unit names are from studies of areas in southeastern Saskatchewan by Porter (1955), Fuller (1956), and the Saskatchewan Geological Society (1956).

The names and units used in this report are the result of investigations by the North Dakota Geological Society under the chairmanship of Smith (1960). The writers feel that the units as defined herein are useful for study of the Madison of the entire Williston Basin. Figure 3 shows the units used in this report and their correlation with units used in Canada.

STRATIGRAPHIC SECTION

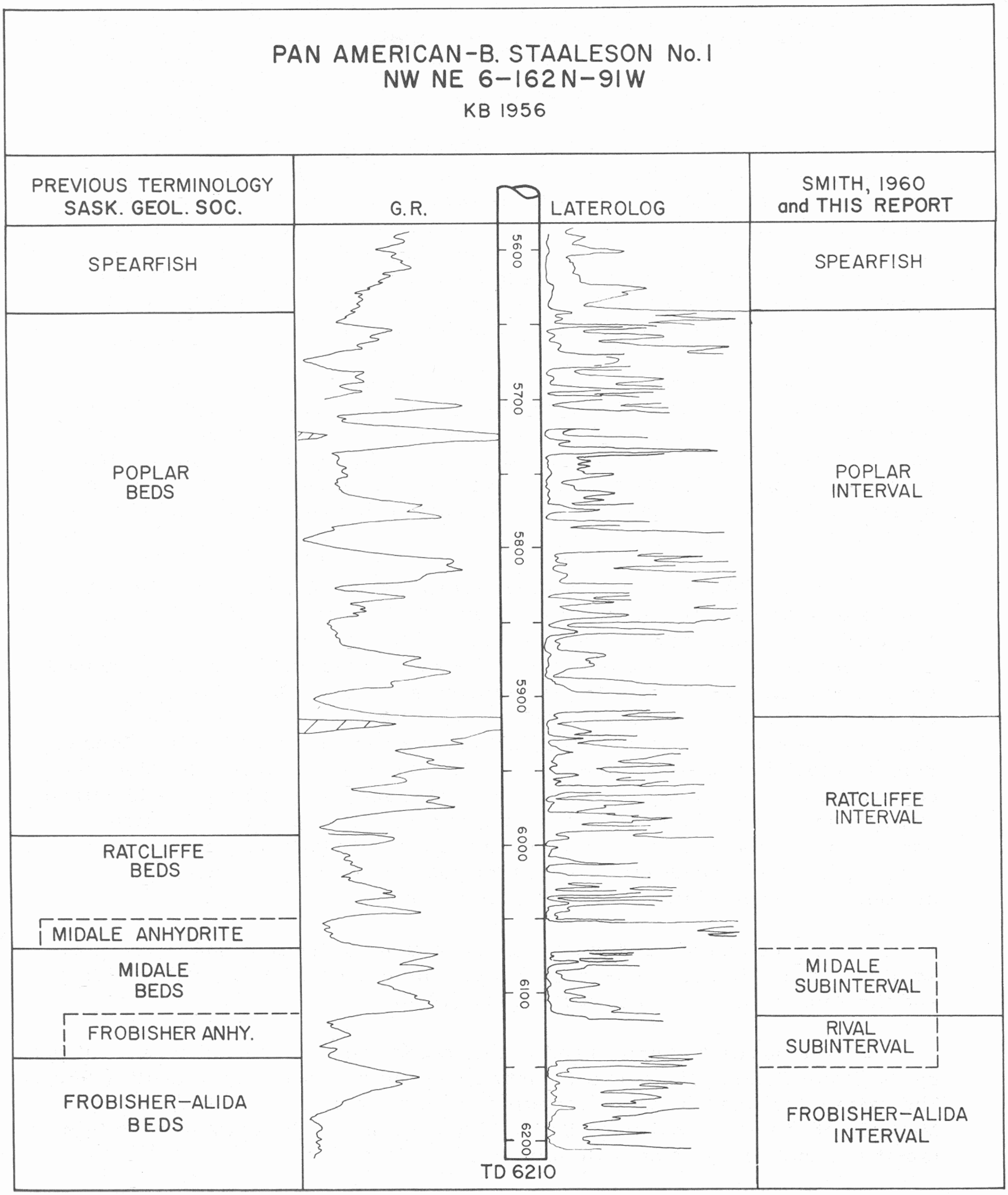


FIGURE 3.

The intervals are defined by mechanical log markers which are prominent on the gamma ray and spontaneous potential logs. The markers have a greater lateral extent than the rock types and so are useful in defining intervals of laterally varying lithology. Because the markers are assumed to be nearly time parallel, the defined units are para-time-rock units. The resulting nomenclature is informal because para-time-rock units do not have formally recognized names. Therefore, the units are termed intervals rather than "beds" because the word "beds" implies a formal stratigraphic unit according to the American Code of Stratigraphic Nomenclature.

Five mechanical log cross sections (Figures 4, 5, 6, 7 and 8) were constructed for this report. These cross sections show the mechanical log characteristics and correlations of the upper part of the Frobisher-Alida interval, Rival subinterval, Ratcliffe interval, Midale subinterval and the base of the Poplar interval.

Frobisher-Alida Interval

The name Frobisher-Alida was first used by the Saskatchewan Geological Society (1956) for the producing intervals of the Frobisher and Alida oil fields in southeastern Saskatchewan. The interval was redefined by the North Dakota Geological Society (see Smith, 1960) to include an overlying anhydrite and limestone unit (the Rival subinterval) and an underlying limestone unit, the MC-3 of Porter (1955).

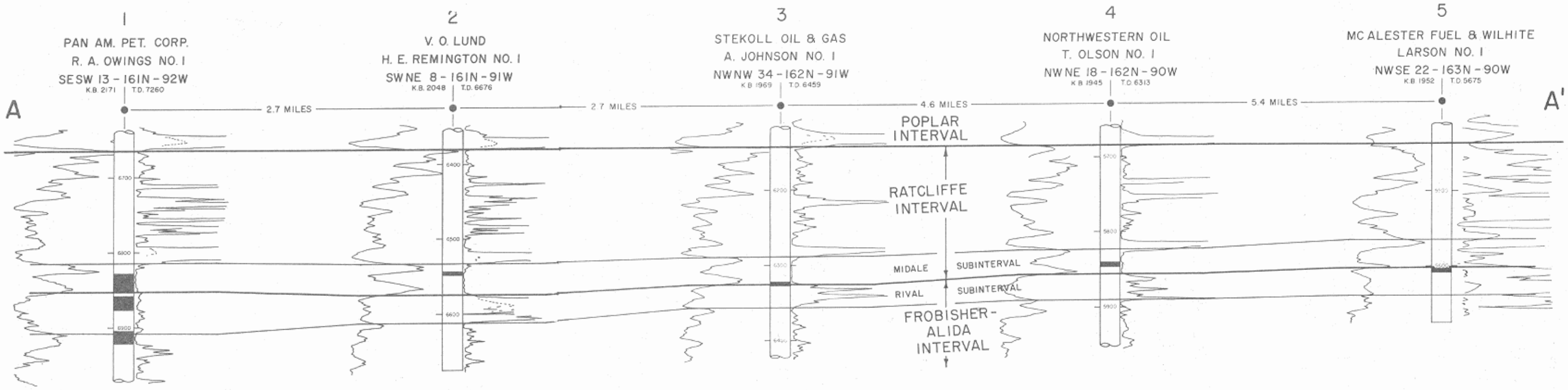
The lower boundary of the Frobisher-Alida interval cannot be determined with certainty in the area because few wells have penetrated to that depth. The upper boundary of the Frobisher-Alida is picked at a prominent gamma-ray log marker which also marks the top of the Rival subinterval.

Two prominent porosity zones occur in the upper part of the Frobisher-Alida interval in this area. The first or upper zone is the Rival subinterval with the second zone occurring immediately below. Both zones produce oil in northern Burke County; however, only a few wells are completed in the lower zone.

In general, the Frobisher-Alida interval of northern Burke County consists of brownish gray, fragmental and pelletoidal limestones; minor amounts of light gray to brownish gray argillaceous sucrosic dolomitic limestone, and rare anhydrite.

Rival subinterval. The Rival subinterval is the uppermost part of the Frobisher-Alida interval. It was named by the North Dakota Geological Society (see Smith, 1960) from the producing interval in the Rival field of Burke County, North Dakota. It corresponds to the lower part of the Midale beds as redefined by the Saskatchewan Geological Society (1956).

FIGURE 4.



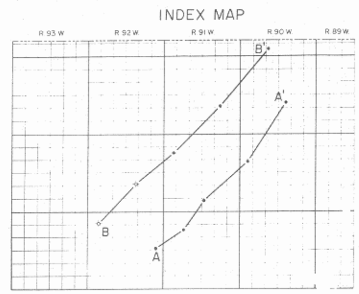


FIGURE 5.

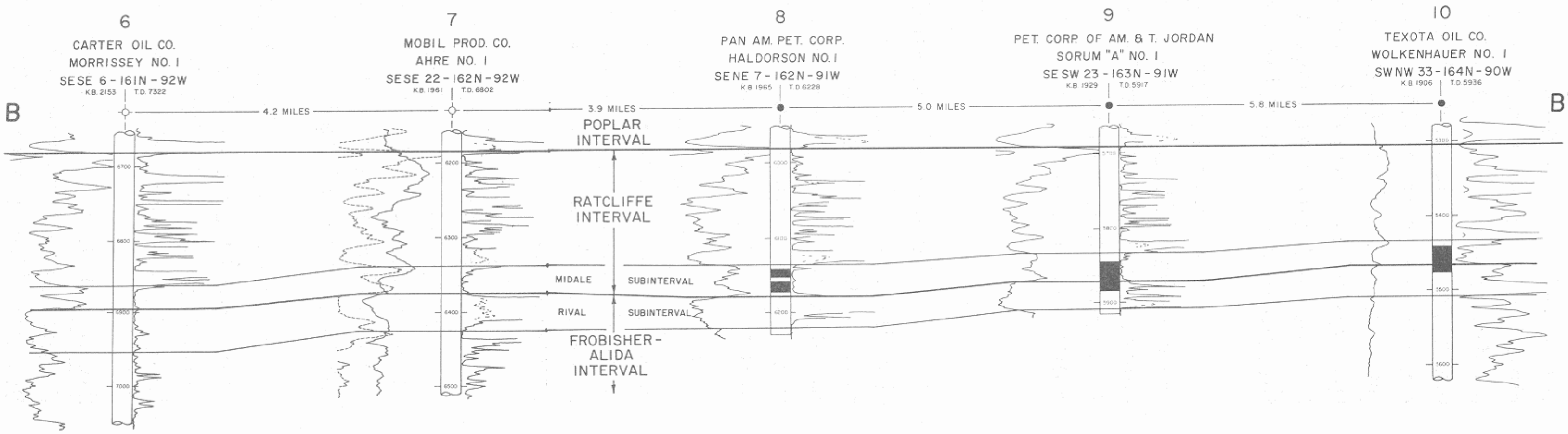
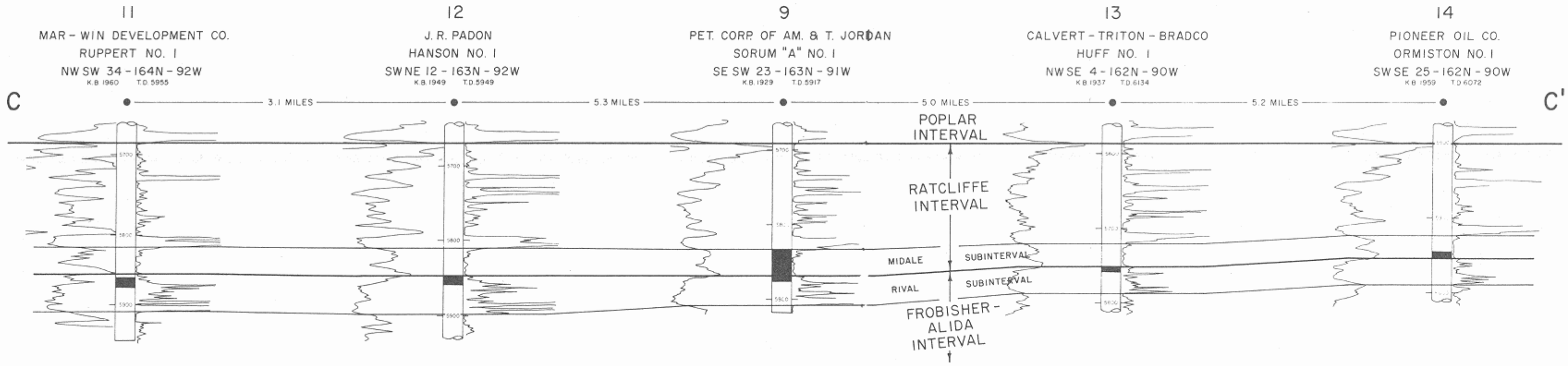


FIGURE 6.



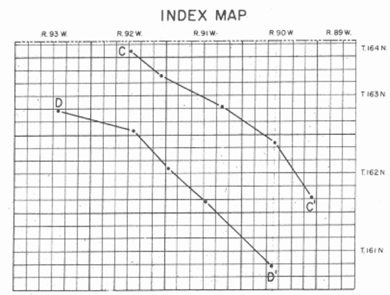


FIGURE 7.

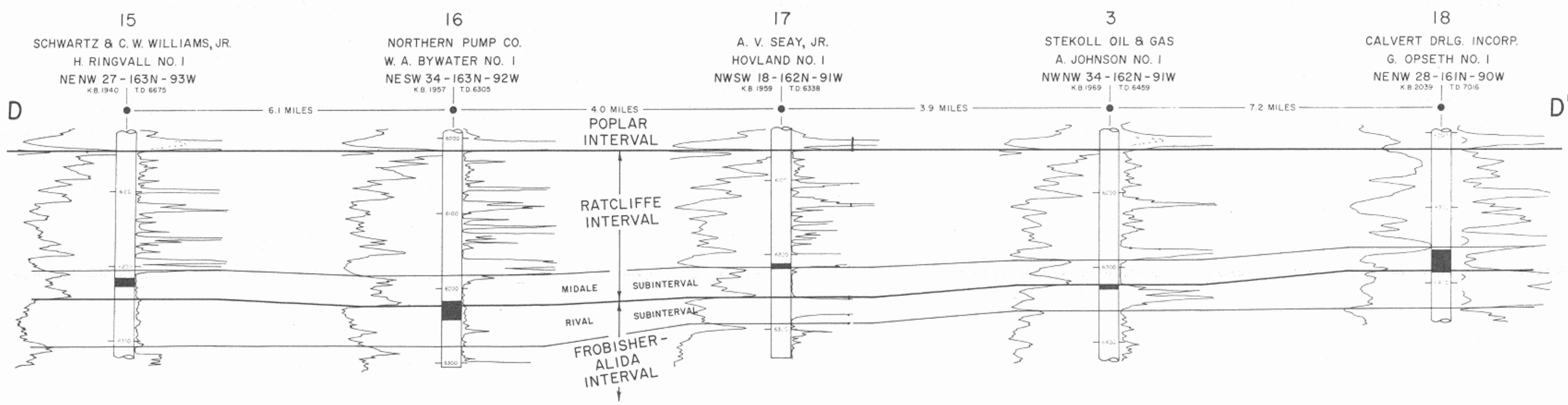
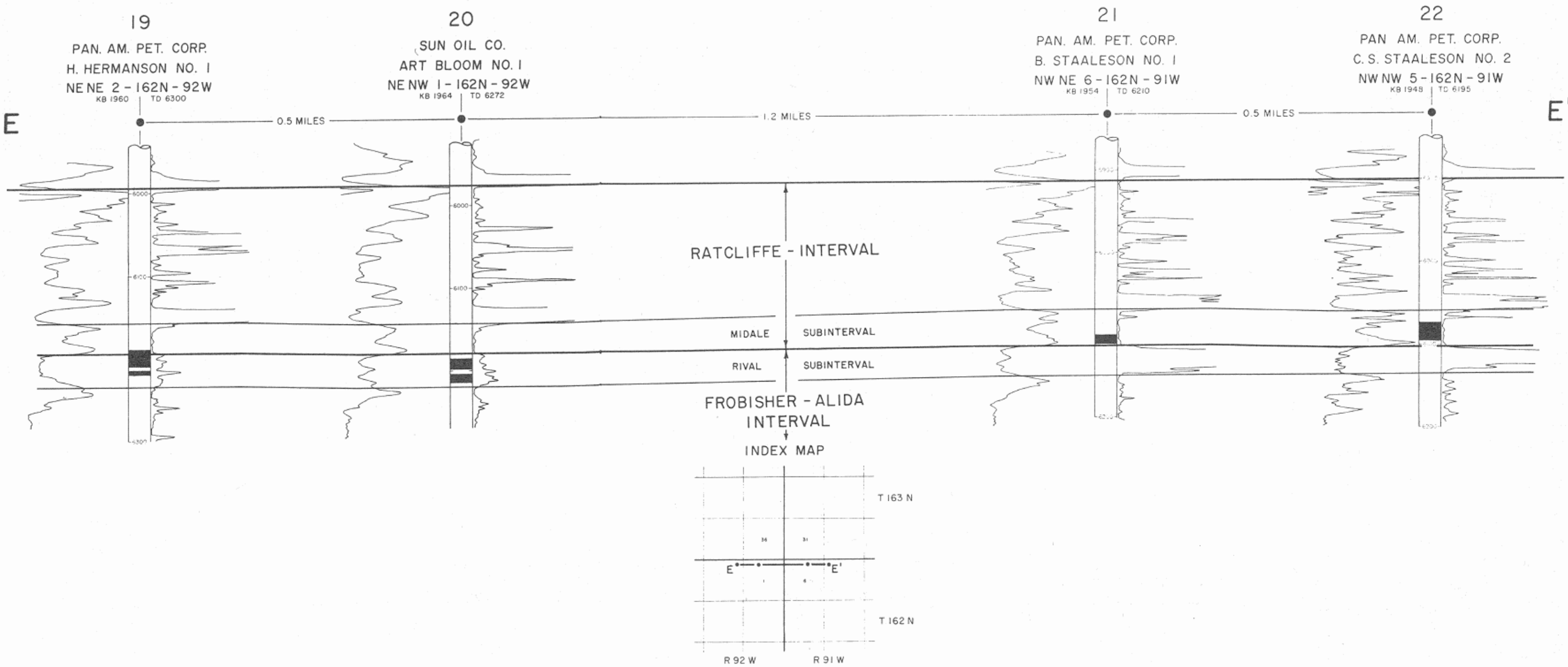


FIGURE 8.


19
PAN. AM. PET. CORP.
H. HERMANSON NO. I
NE NE 2 - 162N - 92W
KB 1960 | TD 6300
20
SUN OIL CO.
ART BLOOM NO. I
NE NW I - 162N - 92W
KB 1964 | TD 6272
21
PAN. AM. PET. CORP.
B. STAALESON NO. I
NW NE 6 - 162N - 91W
KB 1954 | TD 6210
22
PAN AM. PET. CORP.
C. S. STAALESON NO. 2
NW NW 5 - 162N - 91W
KB 1948 | TD 6195
E
E'
0.5 MILES
1.2 MILES
0.5 MILES
RATCLIFFE - INTERVAL
MIDALE SUBINTERVAL
RIVAL SUBINTERVAL
FROBISHER - ALIDA INTERVAL
INDEX MAP
T 163 N
T 162 N
R 92 W
R 91 W

Thickness of the Rival in this area of study averages about 40 feet, ranging from slightly more than 30 feet on the east side of the area to slightly more than 50 feet on the west side (Figure 9). The increase in thickness from east to west is interrupted by local thickening and thinning. There is a thickening of the Rival in the north-central part of Burke County in the Portal field. In the extreme southwestern part of the map area, the anhydrite bed at the base of the Rival has pinched out and the true base cannot be picked; in this area the top of the Madison undifferentiated is picked at the base of the Midale subinterval.

Cores and core chips were examined and those from four wells were selected to illustrate lithologic changes. The Ohio Oil Company - John Robe #1, the Stekoll Oil and Gas - Roos #1, the Pan American - Staaleson #1, and the Calvert - Huff #1 were chosen because their cored intervals were nearly complete in the Midale and Rival subintervals. The lithologic descriptions from these wells are based on the examination of core chips.

Thin sections were made from approximately one-foot intervals from cores of the following wells: Calvert - Jens Ness #1 - interval 6129-6166, Northern Pump - Bywater #1 - interval 6199-6229, and the Northern Pump - State #1 - interval 6160-6162.5. The results of the thin section study have been incorporated into the lithologic description of the other wells.

In the Stekoll #1 Roos (NW, SE, Sec. 1, T. 162 N., R. 92 W.) in the Rival field, the Rival subinterval consists of, from the base upwards, 2 feet of white anhydrite containing inclusions of oolitic limestone at the top, 6 feet of alternating beds of white limy anhydrite and pelletoidal and fragmental anhydritic limestone, and 30 feet of moderate yellowish brown oolitic, pelletoidal and fragmental anhydritic limestone. The anhydrite in the limestone occurs both as scattered masses and as cement and ranges in color from light gray to white to colorless. The amount of anhydrite decreases upward and the upper 15 feet of limestone contains very little anhydrite. Other cementing materials are clear calcite and very fine crystalline limestone. The calcite is the more common cement and occurs mainly in the oolitic and fragmental limestone. The limestone cement occurs mostly in the pelletoidal limestone. Pores and small fractures are more common in the upper part of the Rival.

The oolites range up to 0.10 inch in diameter with an average size of about half of this. Thin sections from the Calvert #1 Ness and the Northern Pump #1 State show that the nuclei of these oolites are small fragments of fine crystalline to sublithographic limestone and usually have two to three coats of very fine crystalline limestone.

ISOPACH OF RIVAL SUBINTERVAL.

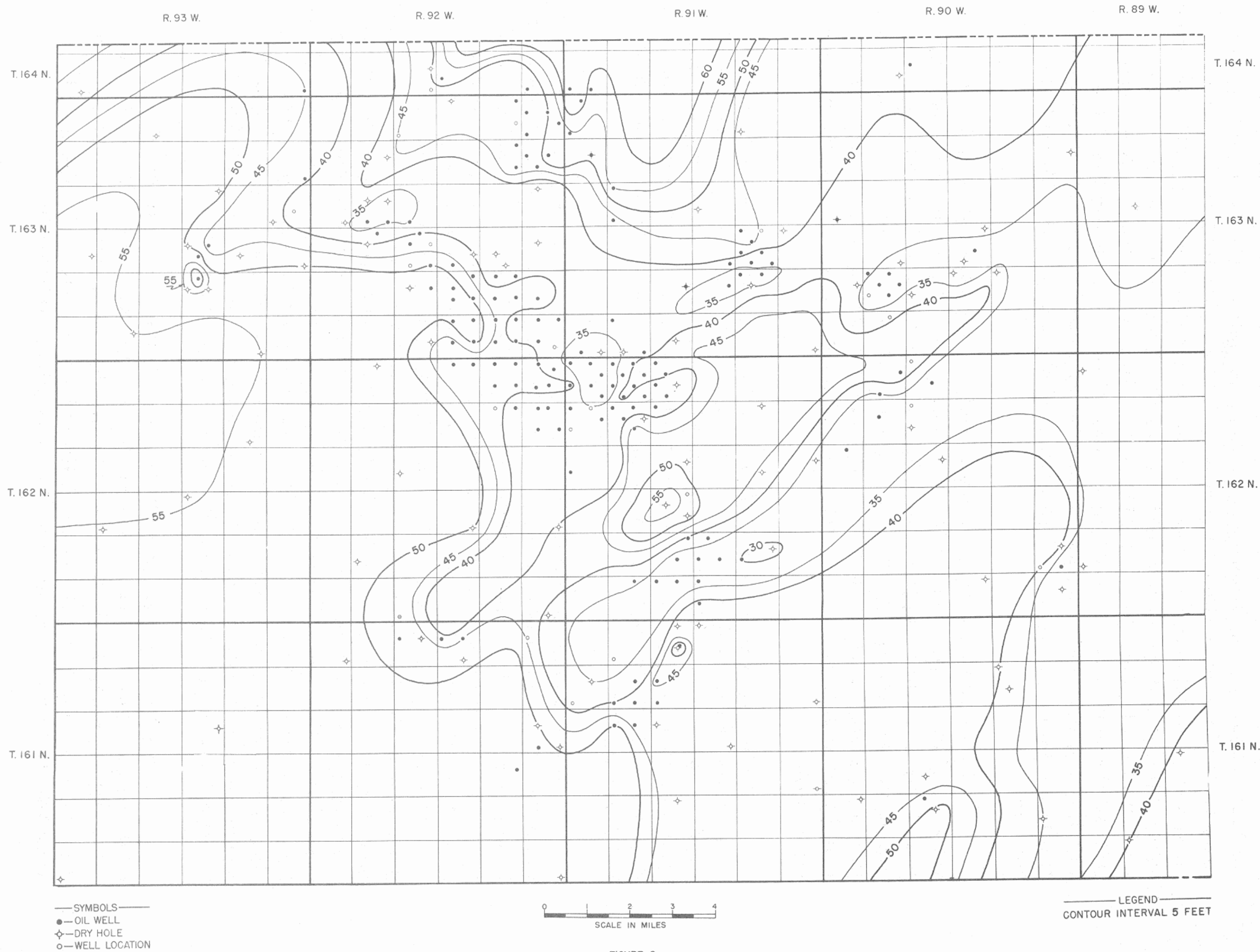


FIGURE 9.

The fragments are subrounded, generally subspherical, pieces of pre-existing limestone. The most common type is a piece of pelletoidal limestone with a sublithographic cement. The fragments may have a single coating of very fine crystalline limestone. Where oolites and fragments occur together, they are of about the same size.

The pellets are small well-rounded and subspherical particles of dark to moderate yellowish brown sublithographic limestone. The most common cement for the pelletoidal limestones is a moderate yellowish brown sublithographic limestone with clear calcite being less common. Pellets, fragments and oolites do occur together; in those cases the sublithographic limestone cement again is predominant over the clear calcite.

In summary, the Rival subinterval in the Rival field consists of a few feet of anhydrite overlain by anhydritic clastic limestone which becomes progressively less anhydritic toward the top.

The Pan American #1 Staaleson (NW, NE, Sec. 6, T. 162 N., R. 91 W.) is located in the Lignite field about a mile northeast of the Stekoll #1 Roos. In the Staaleson well the Rival subinterval consists of, from the base upwards, 10 feet of white to light gray slightly limy anhydrite containing thin shale and limestone laminae, overlain by 16 feet of very anhydritic oolitic and fragmental limestone, which in turn is overlain by 11 feet of alternating anhydrite and anhydritic oolitic limestone. The anhydrite in the limestone occurs mostly as cement with a few large masses of anhydrite. Many of the masses and beds of anhydrite contain oolites and fragments similar to those in the limestone. This may indicate that the anhydrite has replaced the limestone, starting first with the cement and then replacing the fragments and oolites.

The Calvert #1 Huff (NW, SE, Sec. 4, T. 162 N., R. 90 W.) is located in the Woburn field. In this well the Rival consists of 26 feet of white to dark gray anhydrite with rare laminae of medium to fine crystalline, slightly dolomitic limestone and with inclusions of the fine crystalline limestone. Next above are 4 feet of fine crystalline slightly dolomitic limestone, oil stained and containing inclusions of white anhydrite. This is overlain by 5 feet of pale yellowish brown limestone consisting of pellets and fragments in a matrix of sucrosic limestone.

The Ohio #1 Rolie (NW, SW, Sec. 4, T. 162 N., R. 94 W.) is located about 4 miles west of the area studied. In that well the Rival consists of 14 feet of anhydritic pelletoidal limestone at the base with the cement alternating between sublithographic limestone and sucrosic limestone. The anhydrite occurs as scattered small white inclusions or as partial replacement of the sucrosic cement.

This lower part of the Rival is overlain by 41 feet of pelletoidal limestone consisting of pellets and rare to common small oolites in a cement which is mostly clear calcite and rarely sublithographic limestone. Anhydrite is very rare in this upper part, occurring mostly as a few scattered pore fillings at the base. Pinpoint porosity and intergranular pores are common throughout the entire section of the Rival in this well and the porosity, as indicated by the mechanical logs, is quite good.

In summary, the Rival subinterval changes from a pelletoidal porous limestone in the extreme western and southwestern part of the area to an oolitic and fragmental limestone with a basal anhydrite in the Rival field area. The general lithology of the Rival subinterval is not greatly different in the Lignite field, but there the pores and fractures have been filled with anhydrite. East of the Lignite field, the Rival becomes an interval of anhydrite interbedded and interlaminated with sucrosic slightly dolomitic limestone.

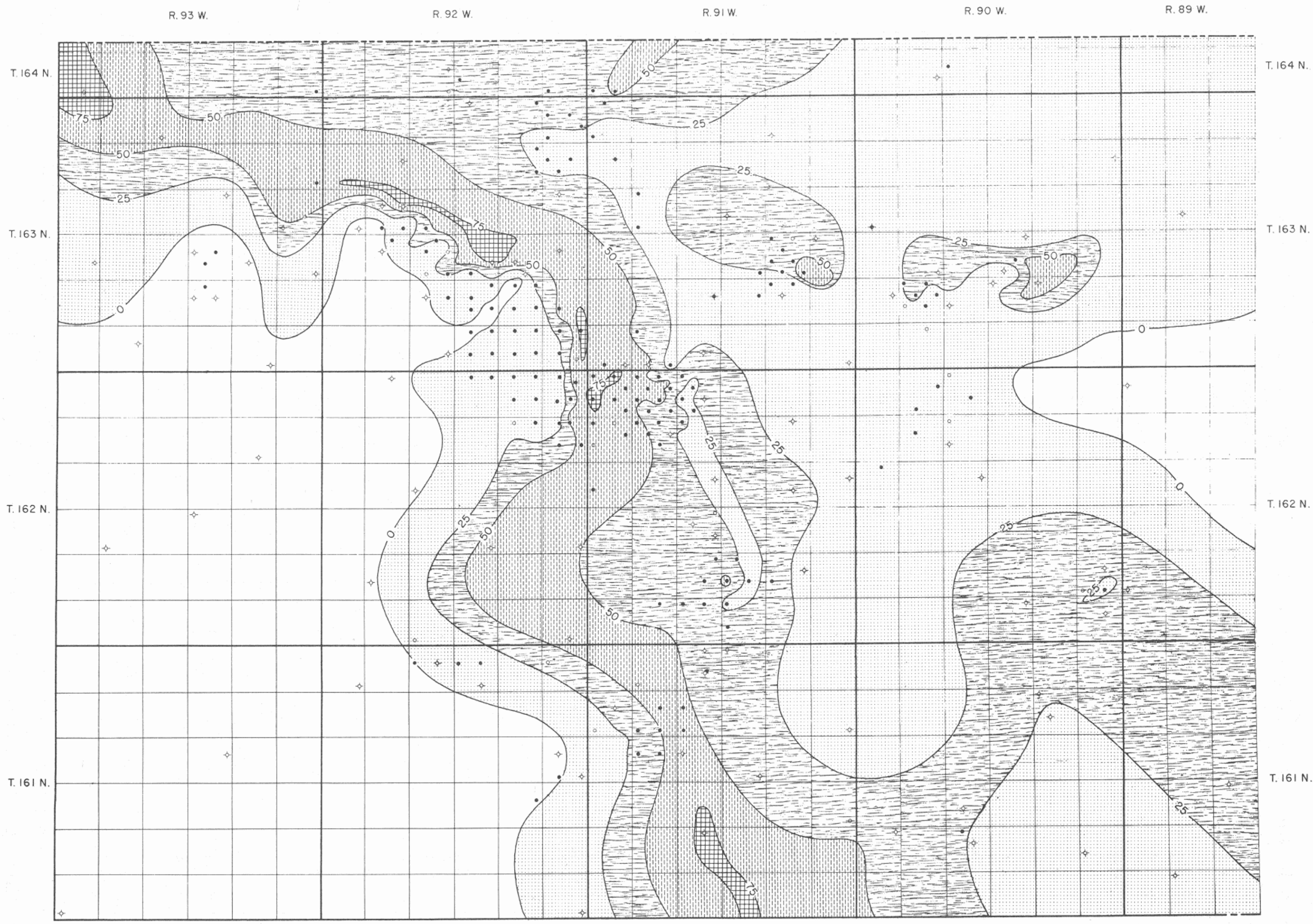
Therefore, while there is a gradual facies change in the Rival subinterval across the map area, the important physical change is the result of an increase in anhydrite content between the Rival and Lignite fields. This change is shown on the map of the percentage of non-porous section in the Rival subinterval (Figure 10) which was prepared from both laterologs and sonic logs. The section was considered non-porous if a resistivity greater than 250 ohm-meters appeared on the laterolog. In using sonic logs the readings were chosen by comparison with readings on the anhydrite bed overlying the Midale subinterval. Readings on this anhydrite bed ranged from 55 to 58 milliseconds and when comparable readings were encountered in the Rival, that portion of the section was considered non-porous. Westward from this area, anhydrite is rare in the Rival and the subinterval is quite porous. Eastward from the tight area, anhydrite is common but it is interbedded and interlaminated with porous sucrosic limestone which gives a low resistivity reading.

Ratcliffe Interval

The Ratcliffe Interval was named by Fuller (1956, p. 36) from the Ratcliffe area in southern Saskatchewan. This interval was redefined by the North Dakota Geological Society (see Smith, 1960) who picked the lower boundary at the base of the Midale subinterval and the top at a prominent gamma-ray marker overlying the lowest Madison salt bed (see Figure 3). In Burke County, the Ratcliffe consists of light brownish gray fragmental limestone (in part pelletoidal) and anhydrite with minor amounts of salt and gray shale.

An isopach map (Figure 11) of the Ratcliffe interval was constructed for this report. This map shows areas of thickening and thinning that are aligned in general northeast to southwest trends.

REDUCED POROSITY IN THE RIVAL SUBINTERVAL
DUE TO ANHYDRITE CONTENT



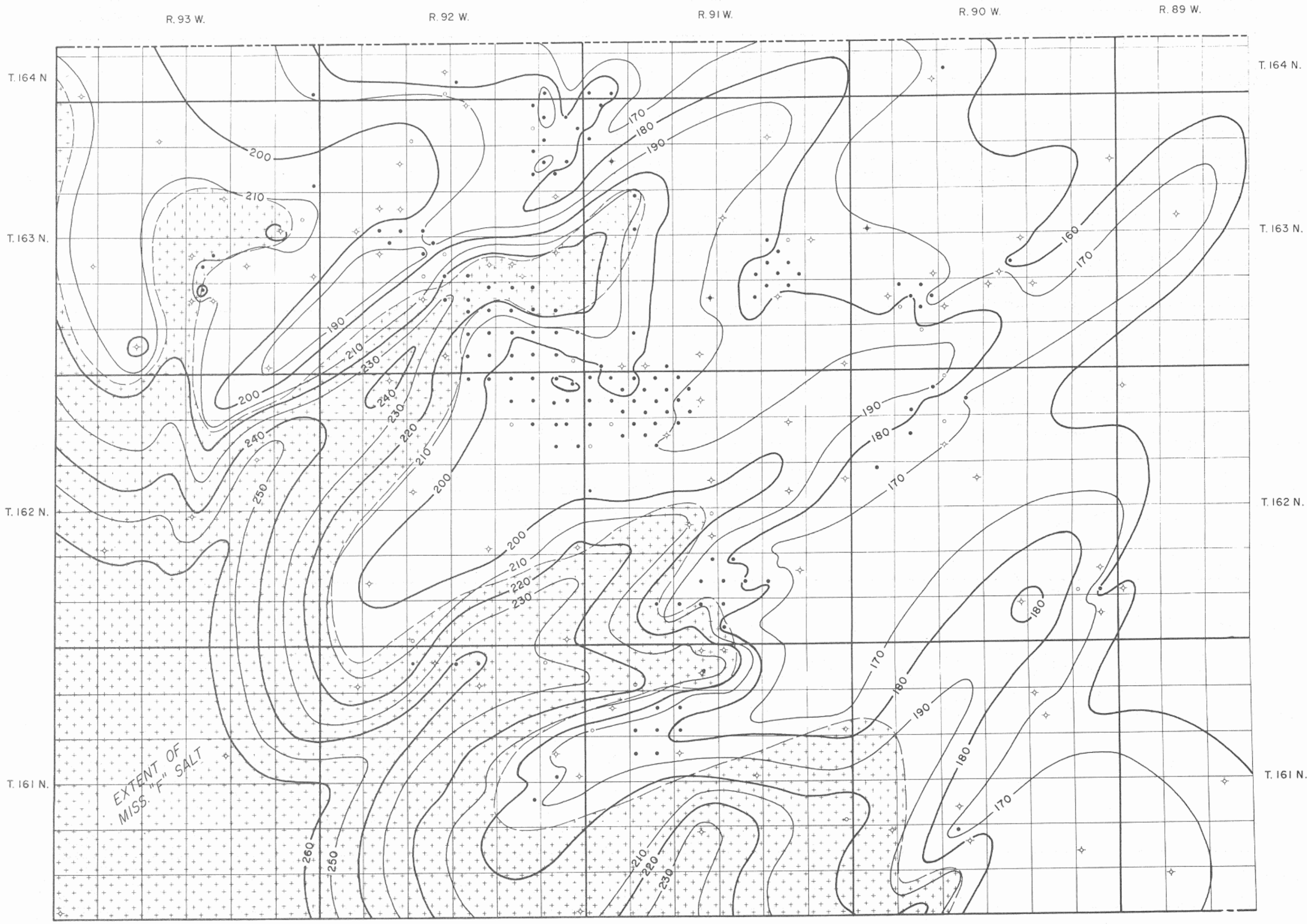
SYMBOLS
● — OIL WELL
✧ — DRY HOLE
○ — WELL LOCATION

0 1 2 3 4
SCALE IN MILES

LEGEND
CONTOUR INTERVAL 25% RESTRICTION OF POROSITY
ZONES OF NO RESTRICTION
ZONES OF LESS THAN 25% RESTRICTION
ZONES OF 25%—50% RESTRICTION
ZONES OF 50%—75% RESTRICTION
ZONES OF GREATER THAN 75% RESTRICTION

FIGURE 10.

ISOPACH OF RATCLIFFE INTERVAL
and
EXTENT OF MISSISSIPPIAN "F" SALT



—SYMBOLS—
●—OIL WELL
✧—DRY HOLE
○—WELL LOCATION

SCALE IN MILES (0 1 2 3 4)

—LEGEND—
CONTOUR INTERVAL 10 FEET
+ + MISSISSIPPIAN "F" SALT

FIGURE 11.

The areas of thinning generally coincide with the slight nosing shown on the structure map (Figure 12) drawn on top of the Rival subinterval.

Another feature of this map is the extent of the Mississippian F salt (Anderson and Hansen, 1957) or lower Mississippian salt. The outline of the salt corresponds very closely with the isopach map in that the salt extends further into the areas of thickening and thereby appears to outline the northeast southwest trends. It appears that the areas of thinning were structurally high at the time of the deposition of the salt.

Midale subinterval. The midale subinterval is the basal portion of the Ratcliffe interval. The name Midale was applied by Fuller (1956) to a sucrosic and granular limestone between two anhydrite beds in the Midale field of Saskatchewan. The Saskatchewan Geological Society (1956) redefined the unit to include the underlying anhydrite and its laterally equivalent limestone. The North Dakota Geological Society (see Smith, 1960) returned to the original definition of the Midale.

At the base of the Midale subinterval is a thin (6-8 feet) bed of dark gray, argillaceous, fossiliferous-fragmental limestone. Brachiopods are abundant in this bed and fragments of bryozoans and crinoids are present. This bed is best developed in the central and eastern parts of the map area and grades into purer limestone toward the west. In the Ohio #1 Rolie (NW, SW, Sec. 4, T. 162 N., R. 94 W.) this part of the interval is composed of slightly silty sucrosic and granular limestone containing rare oolites and pellets along with common small fossil fragments.

The Midale is a finely granular to sucrosic, light to moderate yellowish brown dolomitic limestone or limy dolomite. Oil staining is common, especially in the central part of the area of study. Fossils, mostly ostracod valves, and remnants of previous texture indicate that the dolomitization is secondary. Etching or dissolving a chip of the rock shows that it is quite argillaceous. Commonly, the rock is mottled dark gray or bluish gray. The mottles suggest the shape of worm burrows and/ or some type of plant. Brownish medium-sized anhydrite crystals are scattered throughout the Midale subinterval but are most common near the top.

In thin section the rock is seen to consist of fine calcite crystals and common small euhedral dolomite crystals. The original texture before dolomitization appears to have been a fine crystalline limestone with common small pellets or rounded fragments of limestone.

STRUCTURE CONTOURS ON TOP
OF THE RIVAL SUBINTERVAL.

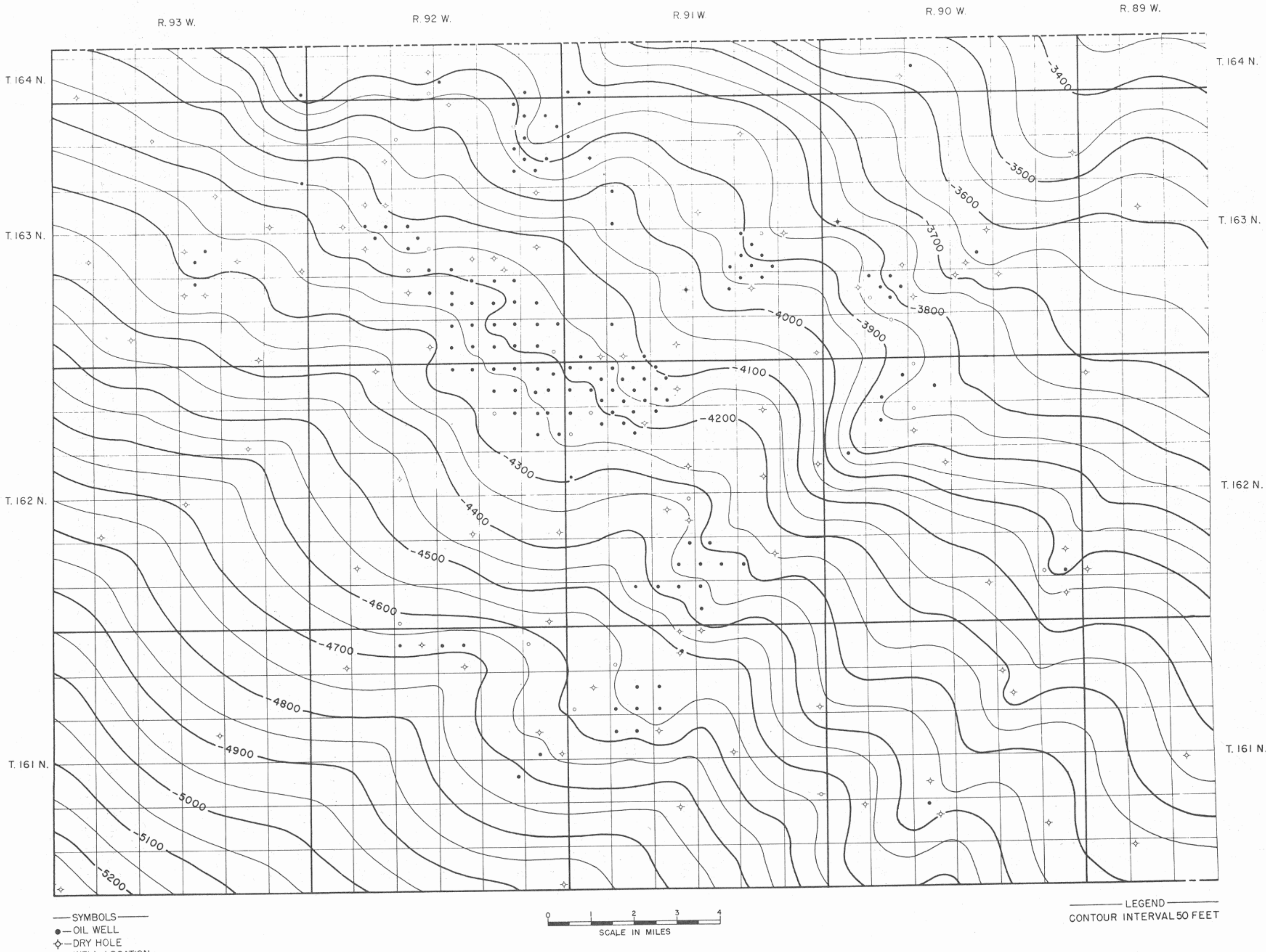


FIGURE 12.

The porosity of the upper Midale is of the intergranular and intercrystalline type and ranges from 10 to 20 percent. The permeability is low; Mitchell and Petter (1958) state that it averages two millidarcies in the Lignite field area. The intervals where dolomitization has not proceeded so far and the original texture is still preserved are less porous than the rest of the section. These intervals appear as tight streaks on the mechanical logs. One very prominent tight streak occurs in the middle of the Midale, according to Mitchell and Petter (1958). The porosity of these tight streaks is as low as 4 percent and the permeability as low as 1/2 millidarcy.

The thickness of the Midale subinterval increases from slightly less than 25 feet on the east side of the area to a little over 45 feet on the west side (see Figure 13). An area of slight thinning from this regional trend passes through the Columbus, Rival, and Black Slough fields.

Environment of Deposition

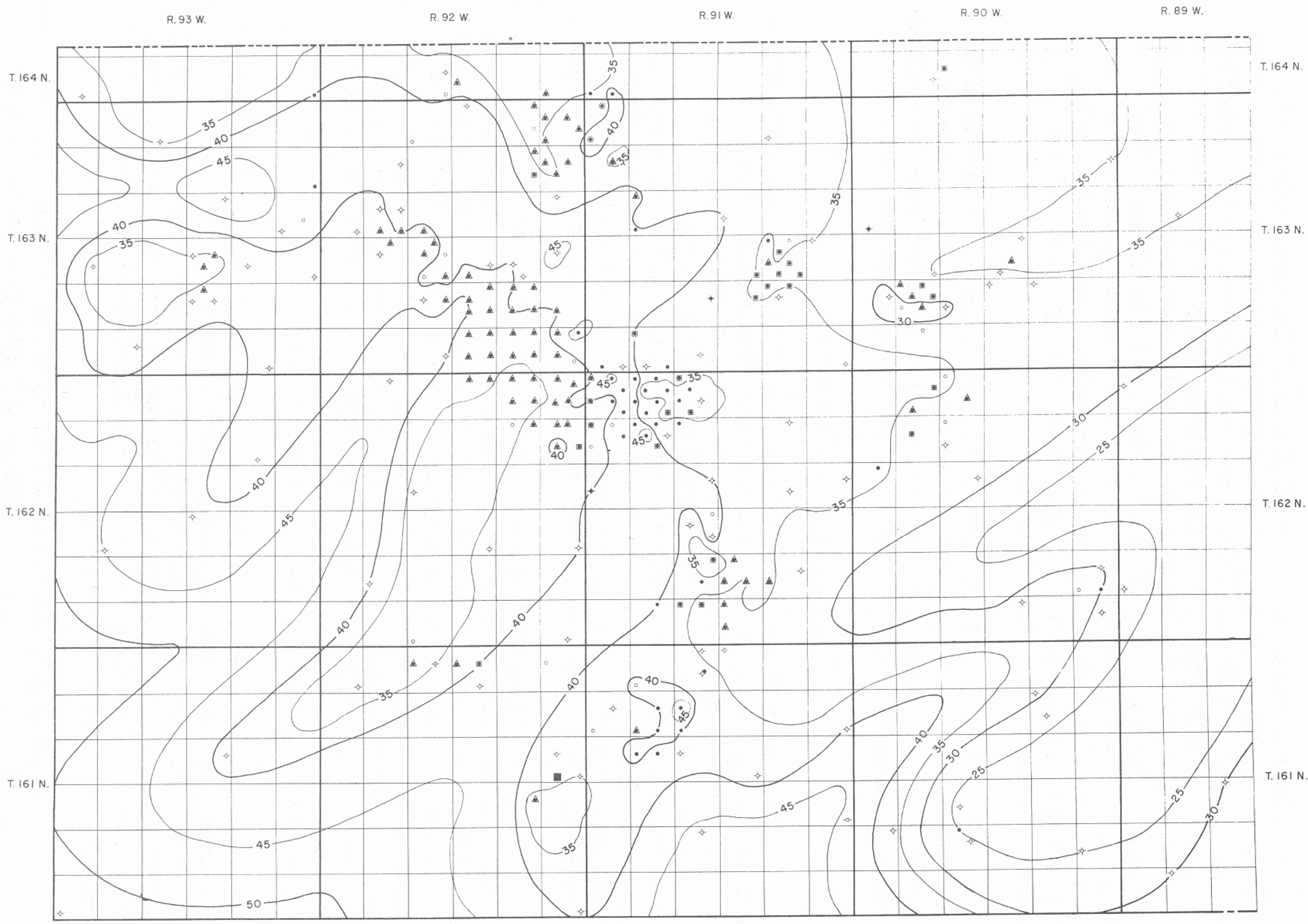
The upper Madison epoch in the Williston Basin was a time of gradual change from open marine to evaporite deposition. This is illustrated in the contrast between the Mission Canyon facies (open marine, near-shore or shelf carbonates) and the Charles facies (penesaline and saline evaporites). The evaporitic conditions began on the basin edges before Rival and Midale time and the facies boundary transgresses upward with time toward the center of the basin. In Burke County, this facies boundary transects the Rival and Midale subintervals.

The alternations of carbonates and evaporites have been described by Fuller (1956, p. 37-42) as cyclic deposits caused by rhythmic advance and retreat of the sea. His theory calls for an advance of the strand line or a rise in sea level during deposition of the oolitic and algal limestone, then a gradual lowering of sea level causing deposition of argillaceous limestone (later dolomitized) and ending in the formation of an anhydrite bed. Fuller did not discuss lateral equivalents of these three lithologies but, ideally, the oolitic limestone should grade shoreward into an argillaceous limestone and then an anhydrite bed.

In Burke County, these three lithologies are easily distinguished in vertical sequence, but the lateral equivalents are not so easily discerned. For example, in the Rival subinterval of eastern Burke County, the argillaceous limestone that would be expected to occur between the areas of oolitic limestone and anhydrite is represented by interbedded and interlaminated limestone and anhydrite.

This implies a sharp change from open sea to evaporitic conditions during Rival deposition. For this reason, a barrier is postulated which restricted circulation to the east.

ISOPACH MAP OF THE MIDALE SUBINTERVAL
ALSO SHOWING PERFORATED SECTIONS



0 1 2 3 4
SCALE IN MILES

FIGURE 13.

SECTIONS PERFORATED
- • — MIDALE SUBINTERVAL
- ▲ — RIVAL SUBINTERVAL
- ▣ — RIVAL and MIDALE SUBINTERVAL
- ◉ — SECOND FROBISHER — ALIDA POROSITY
- ■ — SECOND FROBISHER — ALIDA POROSITY, & RIVAL and MIDALE SUBINTERVALS

Supporting evidence is found in the thickening of the oolitic limestone, just east of the area where the Rival thins in the central part of the area of study. Figure 14 is a schematic cross section showing these relationships.

The oolitic and pelletoidal limestone was formed in an open marine environment probably near wave base or in a zone of strong currents. Illing (1954) found that oolites were formed only on the edges of the Bahama banks where wave and current action was greater than over the shallower portion of the banks.

During deposition of the oolitic limestone, the evaporite of the Rival subinterval was being deposited in a penesaline environment behind the barrier. From time to time the water in this lagoonal area was diluted either by sea water coming over low places in the barrier during storms, or by exceptionally heavy rainfall and runoff from the land. These dilutions of the water allowed deposition of the thin limestone and limy laminae in the anhydrite.

A slight rise in sea level and a consequent flooding of the lagoonal area through lows in the barrier initiated deposition of the argillaceous carbonate unit of the Midale subinterval. Argillaceous material was incorporated into the sediments to such an extent that the algae producing the pellets of the Rival limestone were killed and further development of the clastic barrier ceased. The argillaceous limestone was deposited in a shallow-water shelf environment, perhaps at a similar depth as the underlying anhydrite, but not under conditions of restricted circulation.

Progressive lowering of sea level took place after an initial advance at the beginning of deposition of the argillaceous limestone. This continued until restricted conditions were renewed, resulting in the deposition of the laterally extensive evaporite immediately overlying the Midale subinterval.

Diagenesis

Fuller (1956) has described the diagenetic changes active in the Mississippian rocks. The most important of these in Burke County are dolomitization in the Midale and secondary anhydrite filling in a portion of the Rival.

Dolomitization was most active in the beds immediately below primary anhydrites. While this could have been caused by circulation of saline waters at the time of deposition of the anhydrite, Fuller (1956, p. 33) points out that the more dolomitic parts of the upper unit are also the most argillaceous. Therefore, original composition probably influenced the amount of alteration.

SCHEMATIC CROSS SECTION OF THE PRODUCING INTERVALS
IN RIVAL, LIGNITE & WOBURN FIELDS

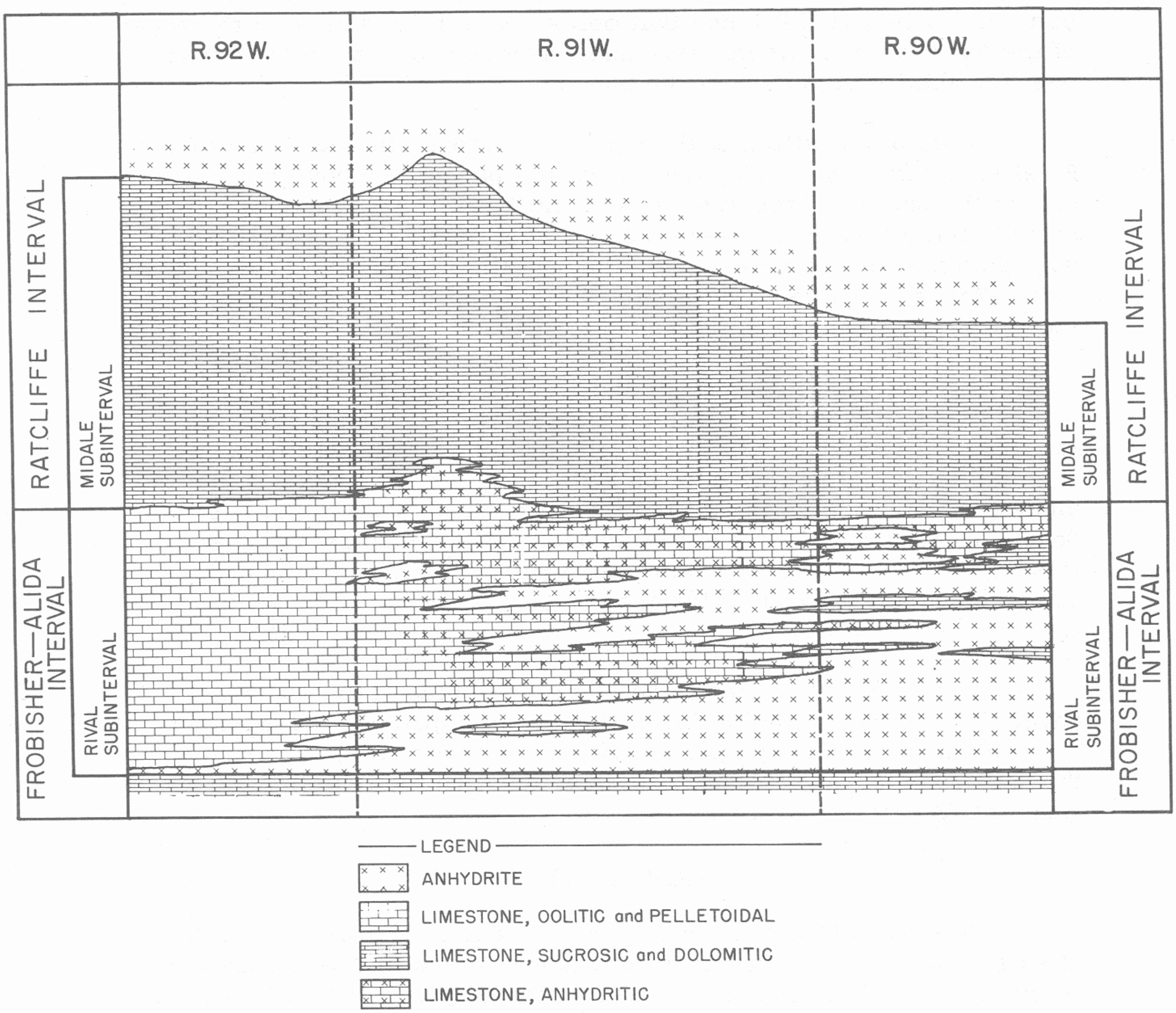


FIGURE 14.

In any case, dolomitization of the Midale subinterval resulted in almost complete obliteration of primary sedimentary structures and an increase in porosity. Dolomitization resulted in a finely granular argillaceous dolomite with limy streaks and average permeability is low.

Several forms of anhydrite are present in the carbonate portion of the Rival and Midale subintervals. Relatively rare brownish anhydrite crystals are most common in the Midale, but also occur sporadically in the Rival. Rarely, the crystals contain inclusions of the original texture of the limestone and thus must have formed before dolomitization. The crystals were probably deposited from sulfate solutions at the time of formation of the overlying anhydrite bed. Fuller (1956, p. 33) believes the brown color of the crystals to be caused by minute quantities of hydrocarbons.

Gray to white to colorless fine-crystalline anhydrite is found in the Rival subinterval. To the east, the anhydrite is interbedded and interlaminated with brown sucrosic limestone. Contorted bedding is common and could have been produced by the alteration from gypsum to anhydrite. No definite evidence of replacement of limestone by anhydrite can be seen.

In the central part of the area much of the anhydrite appears to be a replacement of the oolitic limestone of the Rival. This secondary anhydrite was deposited from solutions derived from the primary evaporite, perhaps during the alteration of the gypsum to anhydrite.

Porosity in the Rival is due to voids between the pellets and oolites, and the pore size varies accordingly. Most of the oolites are about 1 millimeter in diameter as stated previously. As pointed out by Fuller (1956, p. 34), many of these appear to be of primary origin. There is some evidence of secondary porosity due to minor solution and etching.

Structure

A structure map was contoured on the top of the Rival subinterval (see Figure 12). This structure map shows several noses occurring in generally parallel northeast southwest trends and a terrace-like structure in the Rival field. A structure map on the top of the Ratcliffe interval reflects the structure on the Rival very closely and, therefore, was not included in this report. Apparently, the regional dip masks any closure that could be shown by the 50 foot contour interval.

Probable closure in the northern Burke County area was found by constructing a structure map on the Rival subinterval with the regional dip removed (see Figure 15).

STRUCTURE CONTOURS ON TOP OF THE RIVAL SUBINTERVAL
WITH REGIONAL DIP REMOVED.

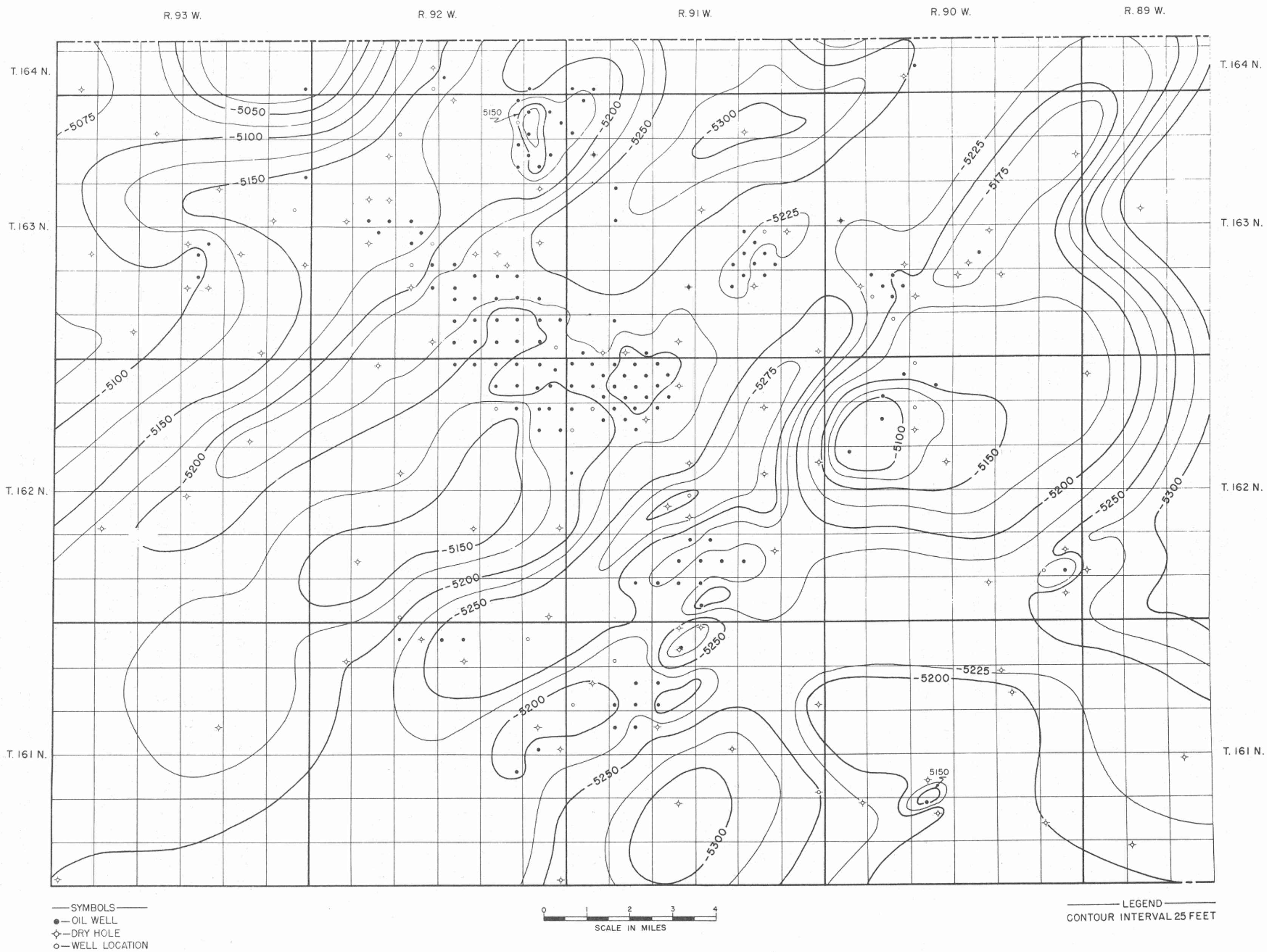


FIGURE 15.

This map was prepared by determining the regional dip from the subsea data used to make the structure map on the upper surface of the Rival subinterval. The regional dip was found to be about 66 feet per mile to the southwest and the strike N 54° W. The next steps then consisted of constructing a grid of the same scale as the Rival subinterval structure map, constructing equal grid spaces with each space denoting a dip of 66 feet per mile, and, finally, orienting the grid lines N 54° W, the strike of the strata involved. The datum to which the regional dip was adjusted is -5200 feet, so that the zero line of dip removal occurs in the southwestern or structurally deeper portion of the area studied. The removal of the regional dip in a northeast direction then consisted of an addition of the accumulative 66 foot increments to the numerical position of the top of the Rival subinterval corrected to sea level. For example, in the Mobil Producing Company - Ahre #1 well, SE, SE, Sec. 22, T. 162 N. R. 92 W., the top of the Rival subinterval occurs at a depth of -4414 feet corrected to sea level. According to the grid an accumulative total of 733 feet was added to correct to the -5200 foot datum. The resulting depth with the dip removed was found to be a -5147 feet or 53 feet above the new datum.

The structure map on the Rival subinterval with the regional dip removed (see Figure 15) shows structural highs in the Lignite, Foot Hills, Northeast Foot Hills, Portal, Flaxton, Woburn, Bowbells, Rennie Lake, and Coteau fields. The Woburn field has closure of over 75 feet; the Portal field has closure greater than 50 feet; Coteau and Bowbells fields have closure greater than 25 feet; and the magnitude of closure in the Lignite, Foot Hills, Northeast Foot Hills, Rennie Lake, and Flaxton fields is less than 25 feet. In the fields with closure, the production of petroleum is for the most part from the Midale subinterval. In other fields of Burke County, the production is for the most part from the Rival subinterval in areas that are structurally low or that have little or no closure.

Trapping Mechanisms

No one factor can be definitely cited as the trapping mechanism in northern Burke County. As mentioned elsewhere in this report, variations from regional dip may be responsible for some of the accumulations, especially in the fields producing from the Midale. Variations in porosity and permeability caused by different degrees of dolomitization may be important factors.

In the Rival subinterval the important part of the trapping mechanism appears to be the anhydrite-limestone facies change. Cementation by secondary anhydrite is illustrated in Figure 14, a mechanical log cross section across the Rival and Lignite fields.

A comparison of the samples and mechanical logs enabled the writers to outline an area where secondary anhydrite deposition is sufficient to form traps. This area (see Figure 10) trends east and west between the fields of Columbus, Rival and South Rival, and the Short Creek and Portal fields. From there it swings south and west between South Rival and Lignite, turns northeast of the Black Slough field and passes through the Northeast Foot Hills field. To the south and west secondary and primary anhydrites are rare or lacking and pores in the oolitic limestone are common. North and east of the mapped area, the limestone pinches out and anhydrite occupies the Rival subinterval.

In the Rival and Black Slough fields, oil accumulates down dip from the anhydrite barrier and no production is now obtained from the more porous Midale above. Mitchell and Petter (1958, p. 66) consider the intervening shaly zone an impervious seal between the Rival and the Midale. Sonic logs from wells in Section 12, T. 162 N., R. 92 W., in the southeastern part of the Rival field indicate a zone of low transit time and, therefore, of high density in the position of this shaly zone.

Future Possibilities

Some of the better possibilities for future oil production in this area appear to be on the west side of the anhydrite filled barrier in the Rival subinterval. As previously mentioned, this barrier appears to have been the major factor in trapping the oil in the Rival and Black Slough fields. Consideration should be given in future exploration for similar conditions along the barrier.

To the east and north of the barrier, production comes largely from the Midale subinterval, occurring in northeast-southwest trends on areas of thinning in the Ratcliffe isopach map (see Figure 11). The thin areas coincide with the trends on the Rival structure map (see Figure 12). It is probable that more oil will be found on similar trends in this and in adjacent areas.

There has been little drilling below the top of the Frobisher-Alida interval, and no well in the area has penetrated the entire Mississippian section.

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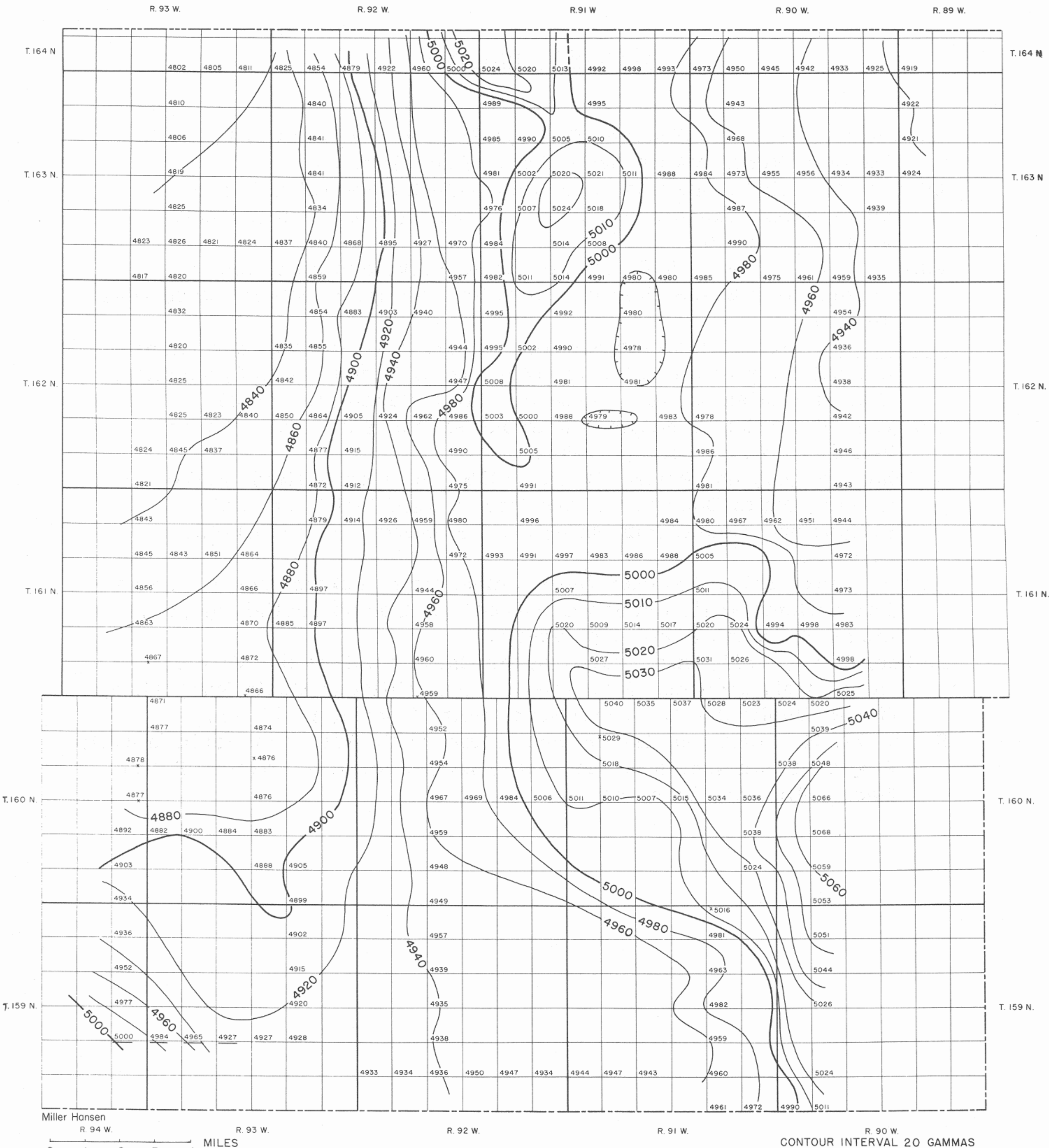

OBSERVED VERTICAL MAGNETIC INTENSITY
BURKE COUNTY AREA, NORTH DAKOTA

FIGURE 16

MAGNETIC MAP

by Miller Hansen

Field work on this map was begun during the 1956 field season to determine values of vertical magnetic intensity near Lignite, North Dakota. Townsend (1950) had reported evidence of surface structure in the vicinity of Lignite. His investigation covered an area which includes what is now the Black Slough oil field, in the west-central portion of this map.

Four stations in the extreme southwestern part of the map are underlined. These four stations are shown also on the magnetic map of the Tioga area (Hansen, 1956) and this survey is thus tied to the same magnetic base used in the Tioga area investigation.

The highest magnetic readings observed are located in T. 160 N., R. 90 W., and the magnetic high extends over an appreciable area to the east. Work was suspended due to extremely high diurnal variations before the entire anomaly could be defined.

In the Columbus area, the trend of the magnetic contours corresponds to the trend of contours on a gravity map of an adjoining area to the west, which has been published as North Dakota Geological Survey Report of Investigation 35.

References

Townsend, R. C., 1950, Deformation of the Fort Union near Lignite, North Dakota: Am. Assoc. Petrol. Geol. Bull., v. 34, p. 1562-1564.

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STATISTICAL ANALYSIS OF LINEAMENTS
REPRESENTED BY ROSE DIAGRAM

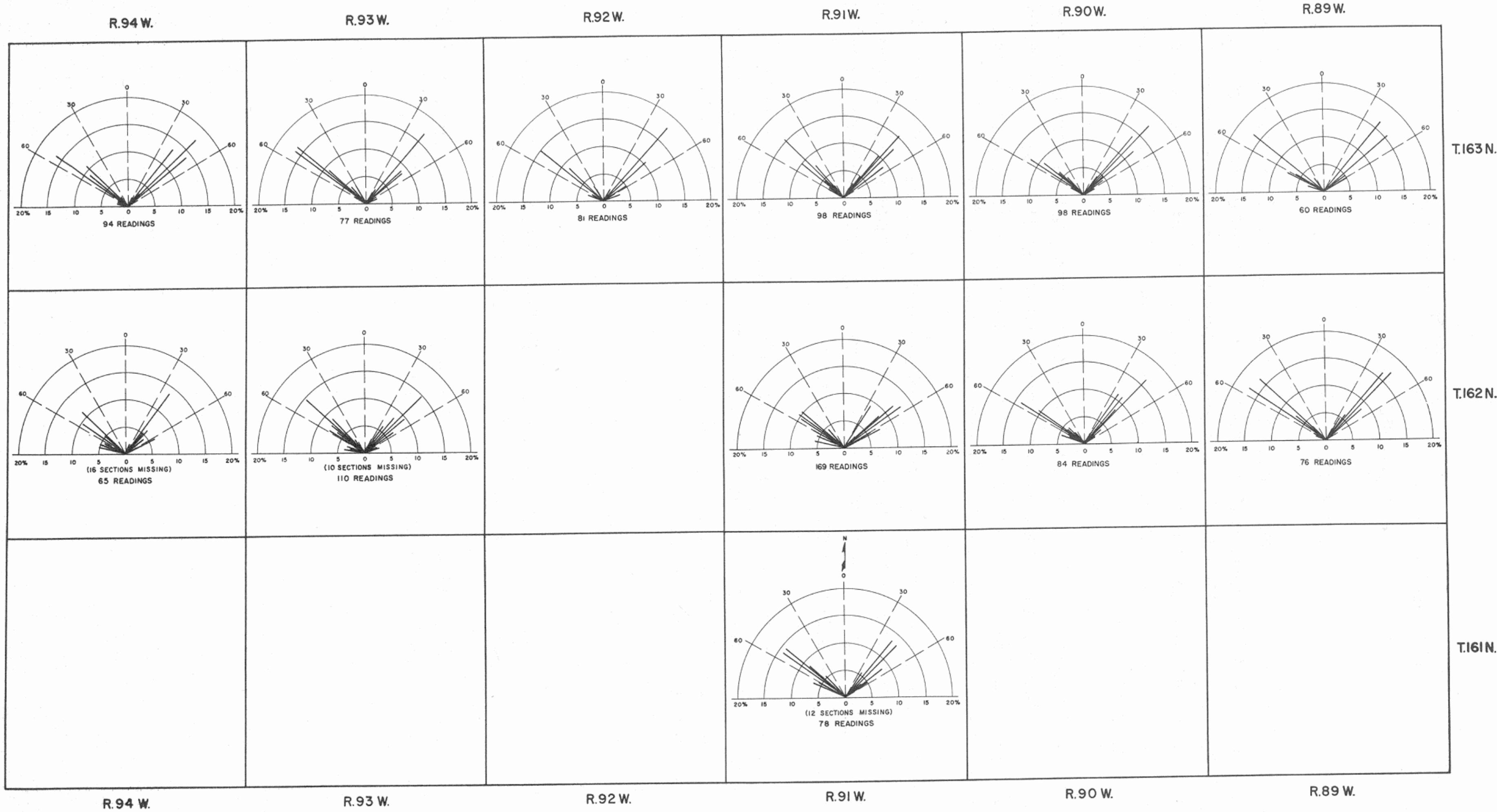

FIGURE 17

LINEAMENTS AND FRACTURE TRACES

by David S. Johnson

Introduction

Lineaments and fracture traces were observed on aerial photographs and aerial mosaics. A surface study of bedrock is not possible because of glacial drift cover.

Structure and isopach maps, profiles, a base map showing drilling and development, and a structure map on the top of the Rival subinterval with regional dip removed were used in this investigation. Lineaments are defined as broad vegetational, soil tonal, or drainage alignments which are commonly several miles long and may be up to 50 miles long, while fracture traces are defined as thin lines of vegetational, soil tonal, or drainage alignments less than 1 mile long according to Lattman (1959, p. 234). The relative intensity of lineaments and fracture traces per township and their direction in percentage is shown by rose diagrams. This systematic pattern of lineaments and fracture traces, anomalous profiles, an earthquake, general location, permeability, and the flexing action of cyclic earth tides are advanced as evidence of fracturing and faulting, probably at depth, in Burke County, North Dakota.

This report is intended to stimulate further interest in photo interpretation as a tool in explaining the subsurface geology. A detailed study of geomorphology is suggested along with a geochemical program with respect to escaping hydrocarbons.

Method of Study

One mosaic map on a scale of 1" = 1 mile was used for this study along with aerial photographs on a scale of 6" = 1 mile. No field work has been done in this area by the writer.

The aerial photographs were studied and the lineaments and fracture traces observed by sight were plotted on a base map. These fracture traces and lineaments were analyzed by townships, and the findings are represented on rose diagrams (see Figure 17). The lineaments as viewed from the aerial mosaic were also plotted on a Burke County field map, scale 1" = 1 mile (see Figure 18).

The locations of the north-south and east-west profiles are shown in Figure 18. The profiles were drawn from a structure map on the top of the Rival subinterval with the regional dip removed (see Figure 15) and isopach maps of the Ratcliffe interval (see Figure 11) and the Rival subinterval (see Figure 9).

LINEAMENTS FROM AERIAL MOSIAC

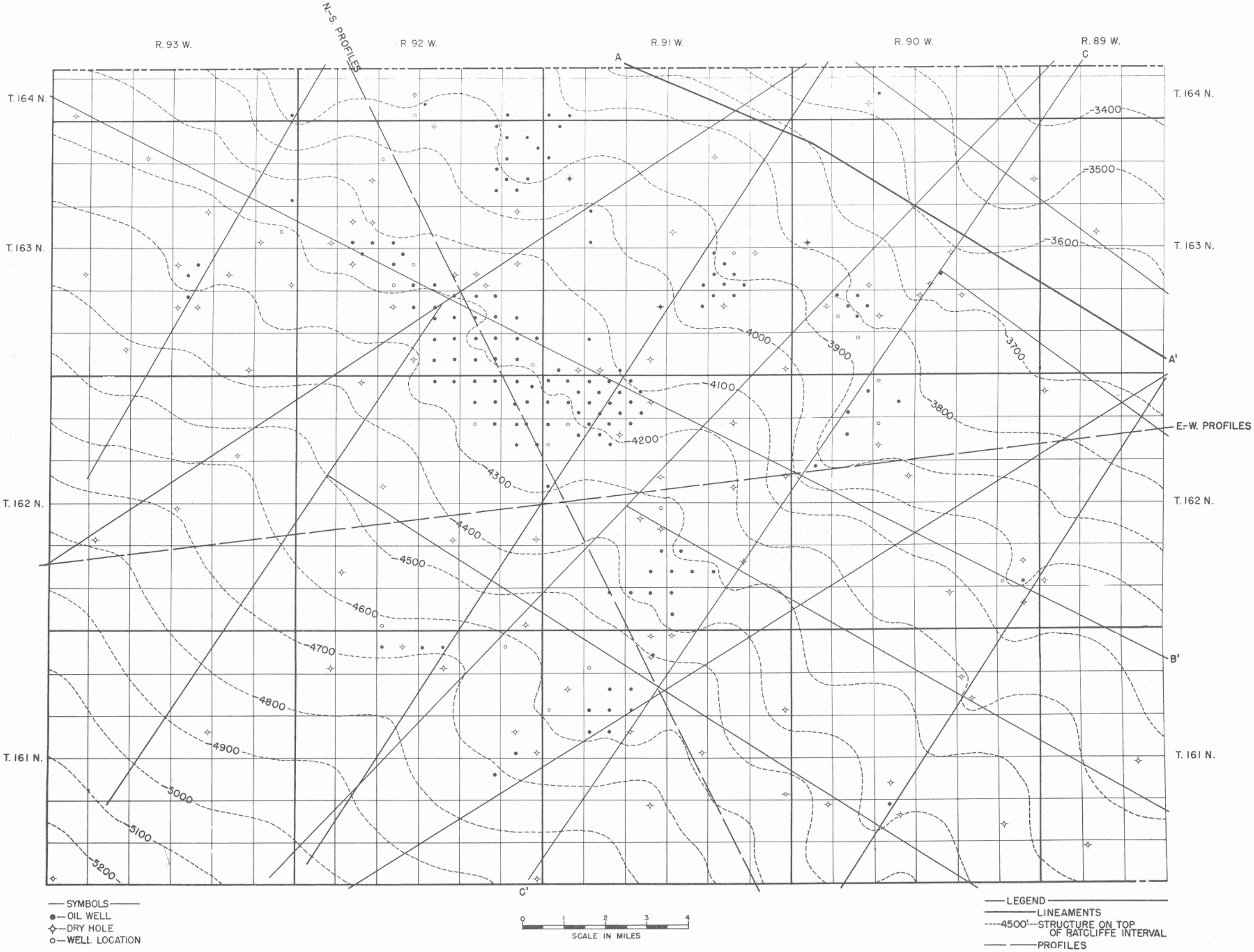

FIGURE 18

Objective of Finding Anomalies

The objective in recording lineaments and fracture traces is to locate shallow to deep seated structures and stratigraphic anomalies. These lineaments and fracture traces are theorized to be the surface expression of fractures in the earth's crust. The continuous seismic activity of the earth's crust acts as a means of propagations upwards of fracture zones. It cannot be demonstrated that the patterned linear features are all the product of the same mechanism until further work is done. On the other hand, it does seem reasonable to suspect that lineaments and fracture traces as seen in the glacial drift correspond to zones of fundamental crustal weakness and that recurrent instability, however small in magnitude, may be responsible in part for the oil traps found in Burke County, North Dakota. There is a remarkable coincidence between the lineaments as seen on Figure 18 and the anhydrite "barrier" spoken of in the first section of this report. It may well be that if these lineaments are surface expressions of fractures that anhydrite was deposited along these lines of weakness and reduced the porosity and effective permeability, thus in part forming the trap for the Rival field.

Report of Lineaments in Burke County, North Dakota

Blanchet (1957, p. 1748) states, "The crust of the earth is fractured. It is abundantly and systematically fractured, and it is fractured in four principal directions." Lineaments as viewed by this writer on an aerial mosaic of Burke County (U. S. Dept. of Agriculture, Symbol BAK PMA 38.53 DC, 1953, Plate #2) run in 3 principal directions. One set runs N 34° E, another at N 58° E, and still another at N 65° W.

The lineaments on the structure map (see Figure 18) are observable from the aerial mosaic map mentioned above. Lineament A-A' is especially well developed. On Figure 17, a greater intensity of lineaments and fracture traces as recorded on rose diagrams correspond in most cases with areas of known production, and would appear to be of value in an exploration program.

Evidence Postulated for Fracturing

Although no actual faulting has been seen in the field by this writer, certain evidences which are presented below would tend to indicate that some movement, probably of tectonic origin, has taken place in Burke County, North Dakota.

(a) Lineaments and Fracture Traces -- Recognizable on air photos and aerial mosaics. They are systematic in direction as shown on Figure 17. Lattman (1959, p. 234) states that, "They are believed to represent major zones of fracture concentration at the surface of the earth and to be related to deep faulting, perhaps involving the basement rocks."

(b) Visible Folding and Fracturing -- Folds and fractures in the Fort Union beds have been viewed in coulees south of Lignite, North Dakota by Townsend (1950). He has observed high angle thrust faults with 1 foot to 10 foot displacement in these Fort Union beds. He further states, "The general trend of the strike of both folds and faults is approximately N 74° W, or nearly parallel to the Missouri Coteau. Locally the dips of two parallel resistant sandstone beds forming one limb of an anticline are so different that faulting must be inferred to be of a magnitude greater than the 1 foot to 10 foot displacement elsewhere. The thickness of folded and faulted beds eroded from above the present surface cannot be estimated, but it may be assumed on the basis of the generally steep dips that the deformation does not end a few feet below the surface but extends downward for several hundred feet."

(c) Earthquake -- May 15, 1909 (rating of 9 on the Rossi-Forel Scale). The epicenter of the quake was 105° W Longitude, 50° N Latitude (Heck, 1928). The shock was felt over an area of 500,000 square miles which would encompass a circle with a radius of 400 miles. Burke County is only 150 miles southeast of the epicenter. "It is commonly held that tensile fractures and strike-slip faults occur in the vicinity of earthquake foci." (Mollard, 1957, p. 8.)

(d) Structure Overlay -- When a structure map of Burke County is laid over a map showing lineaments, the noses of the structures and the lineaments coincide (see Figure 18).

(e) Permeability -- Permeability of the matrix is not sufficient to account for the quantities of oil being produced. From this the presence of fractures is postulated (Folsom, 1959).

(f) Anomalous Profiles -- If a careful study is made of the profiles (see Figures 19a and 19b) it is noticed that in most cases the isopach maps will correspond with each other and will thicken and thin over the lows and highs respectively as drawn from a structure map on the top of the Rival subinterval with regional dip removed.

There are three anomalous conditions which are shown on the profiles by circled numbers. Anomalous conditions 1 and 2 on Figures 19a and 19b correspond exactly with lineaments C-C' and B-B' respectively, whereas anomalous condition 3 shows a thickening of the Ratcliffe interval which is not present in the Rival subinterval. From this evidence and from that mentioned above, it is postulated that during and after Ratcliffe deposition, movement occurred in eastern Burke County, North Dakota and some structural anomaly was present in the Ratcliffe interval in the Rival field area.

E—W PROFILES

LINE OF PROFILES SHOWN ON FIGURE 18

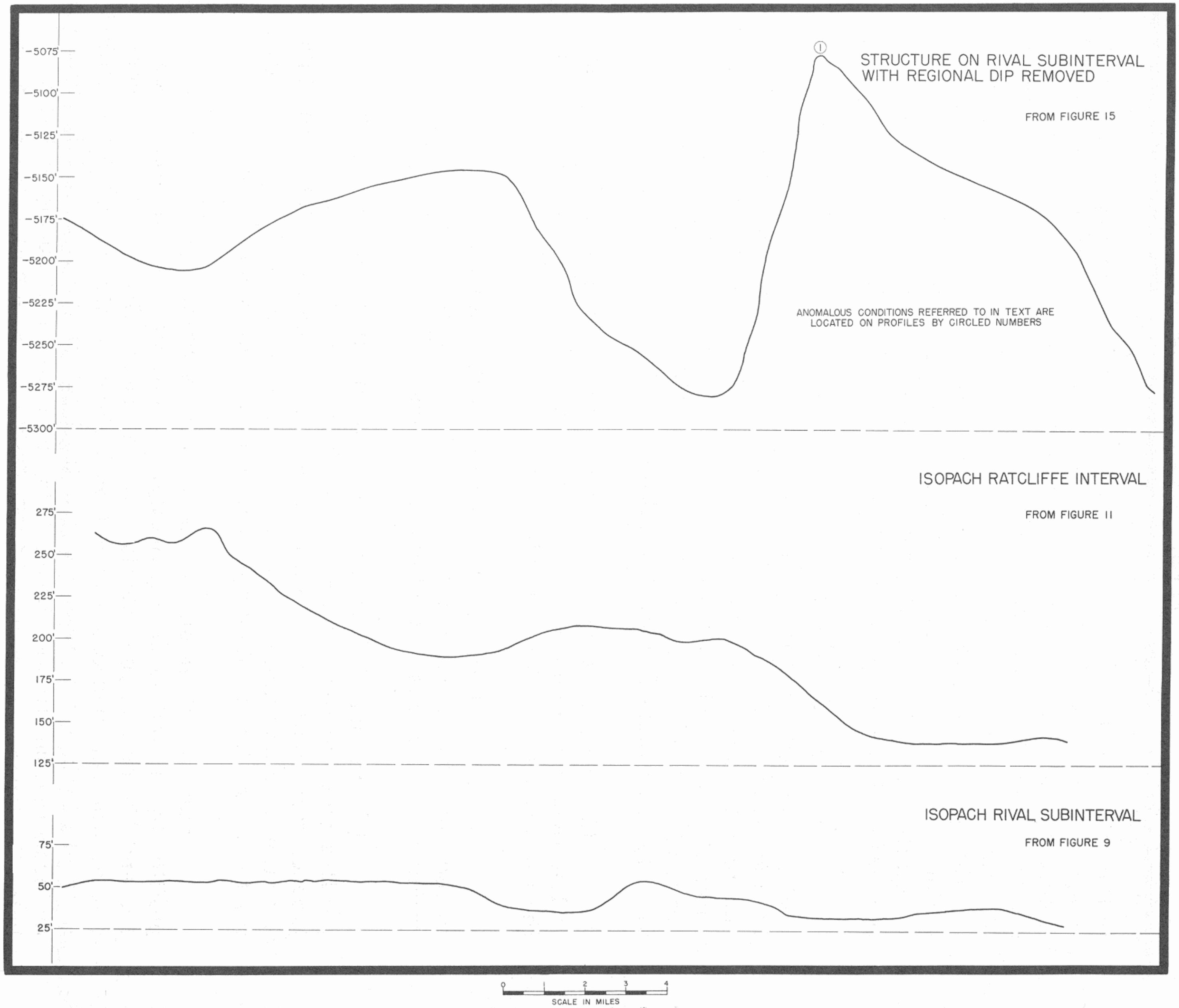

FIGURE 19a

N—S PROFILES

LINE OF PROFILES SHOWN ON FIGURE 18

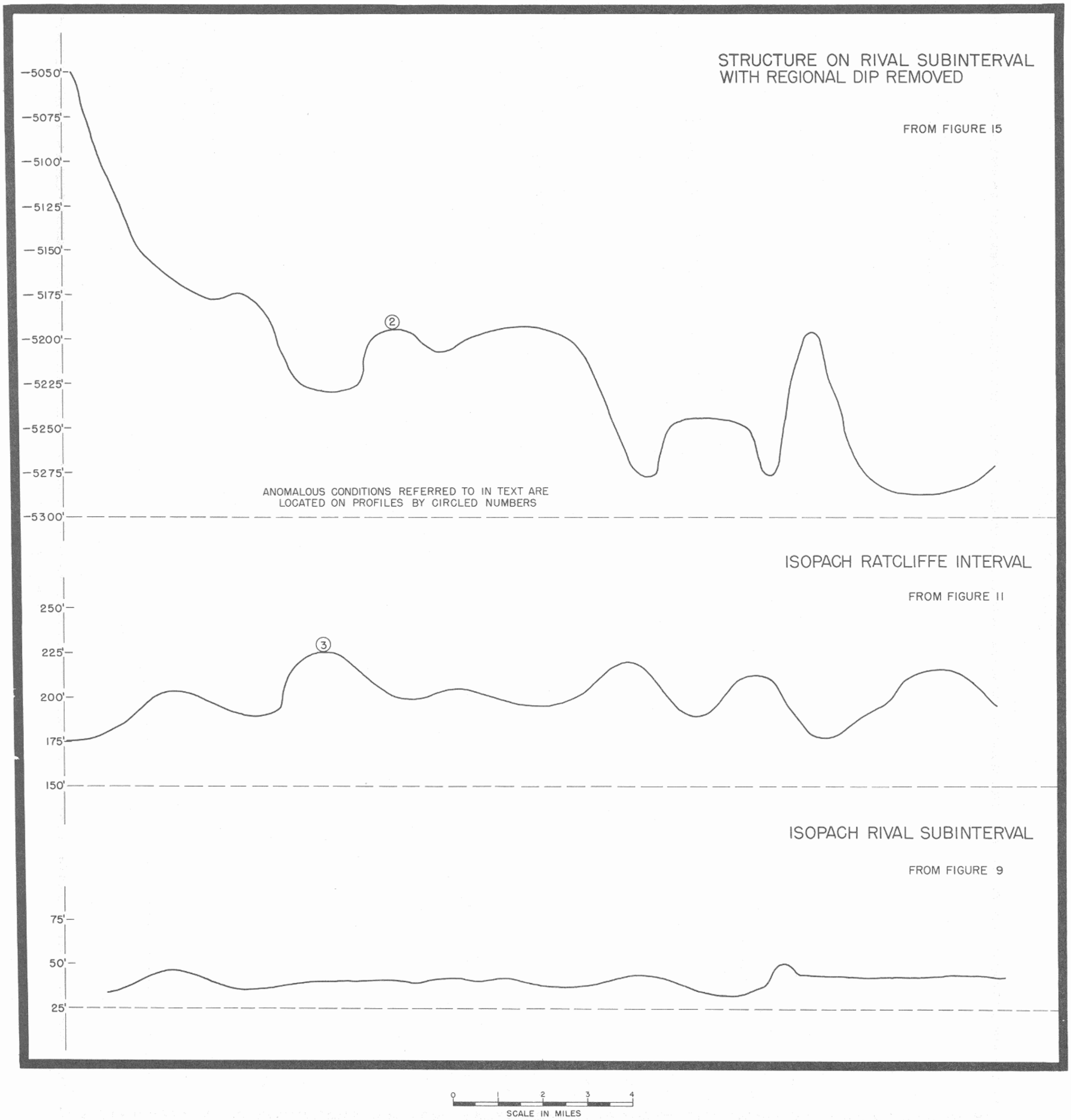

FIGURE 19b

(g) Other features which were noticed on aerial photographs were tonal halos. These are relatively circular tonal anomalies. Specifically, a tonal halo was found in April, 1959 by this writer in Section 29, Township 163, Range 90. This tonal halo was approximately 1 mile in diameter, and was confirmed as a definite productive area as evidenced by the 5 producing wells located within the halo.

Probable Causes of Fracturing

The writer theorizes that the fracturing, so much in evidence on the aerial photos of Burke County, was greatly dependent on tectonic forces. One of the principle causes of the systematic fracture system is probably in the rhythmic action of tides in the crust of the earth.

Blanchet (1957, p. 1754-1755) states, "The amplitude of such earth tides, though only 9-14 inches, is, as a matter of fact, as much as two-thirds of the amplitude of the hydrospheric tides on the free ocean surface beyond the continental shelves where their amplitude is only 18 inches. It is the cumulative effect, in shallow water, which gives the ocean tides their relatively great amplitude and considerable potential energy. In a similar manner the earth tides gain their power from cumulative build up." There are other external forces which help in the process of propagation and generation. One example of the external forces would be the earthquake in 1909.

The fractures in Burke County are probably in part generated and propagated upwards to the surface by the process of fatigue, better shown in metals by rupture caused by often repeated stresses, such as vibration. It is the cumulative effect of rhythmic motion of earth tides acting through long periods of time which set up these often repeated stresses as mentioned above. On earth there are 4 half-cycles per day, repeated 1,460 times per year and 1 1/2 billion times every million years.

Blanchet (1957, p. 1755) states, "The propagation of fractures upward to the surface even through soils and overburden, is considered to take place as a result of the flexing action of the earth tides within the layers of sediments. As a crustal stress, earth tides acting alone, are considered to be sufficient to have caused generation and propagation of fractures, especially in deep sedimentary basins."

The magnitude of this flexing action is indicated by variable flow of water from certain deep springs in various parts of the world. In the Belgian Congo in certain hot springs the flow of water varied from 8.5 gpm to 16.1 gpm in sympathy with earth tides (Vorster, 1956).

Significance of Lineaments and Fracture Traces in Burke County, North Dakota

There is no way at the present time of knowing if all lineaments and fracture traces in Burke County are of the same origin. The probable causes already mentioned played an important part, but other phenomena probably are in part responsible for the fracturing and propagation upward.

It does appear significant that a greater intensity of fracture traces and lineaments correspond in part with known producing areas. The Lignite field area can be said to be abundantly fractured as viewed from Figure 17. No aerial photos were available for the Rival field areas.

Summary

This report is meant to stimulate interest in photogeology and to advance hypotheses of what lineaments probably represent and the forces that could produce them. When used in conjunction with other methods of exploration, a study of fracture traces and lineaments may be of value. Another possibility for future petroleum exploration is the chemical analysis of soils for detection of escaping hydrocarbons.

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ISOPORE MAP
MIDALE *SUB*INTERVAL

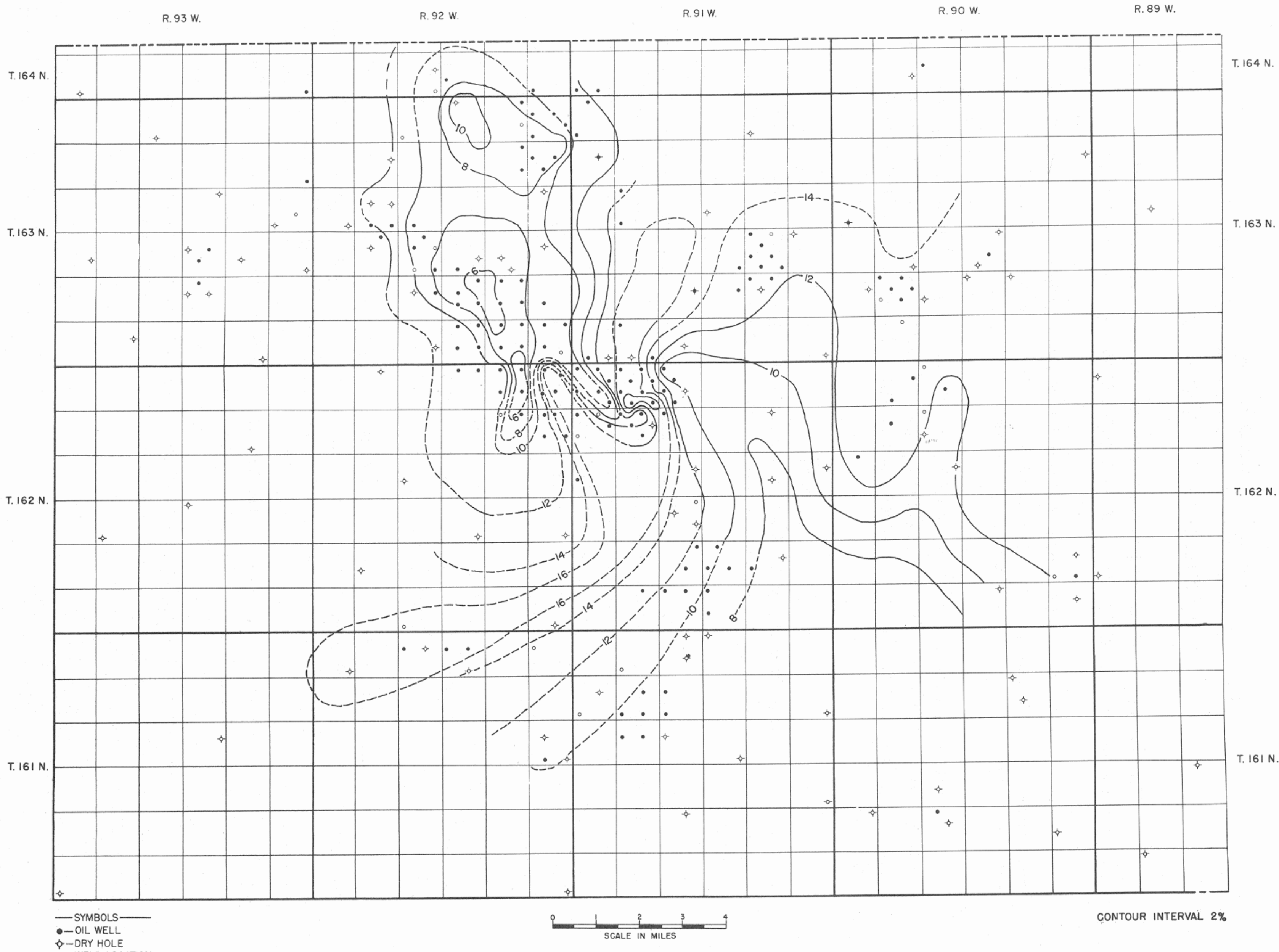


FIGURE 20

ENGINEERING DATA

by Clarence B. Folsom, Jr.

On the following pages will be found Engineering and Statistical Data for each field in the area covered by this report.

Performance curves are shown for each reservoir and typical well drilling and completion programs, together with data on the discovery well and an analysis of crude oil produced.

The crude oil analyses were furnished by the United States Geological Survey at Casper, Wyoming. All other data has been taken from the files of the North Dakota Geological Survey and the State Industrial Commission.

Figures 20 and 21 are isopore maps of the area giving the weighted average porosity of the Midale and Rival "subintervals" respectively. The data for these maps was obtained from core analysis reports.

Figure 22 is a cross-section, through the Rival and Lignite fields, on which the porosity from the core analysis has been plotted. Recognizable porosity developments have been connected by dashed lines to indicate the continuity of the porous intervals and to demonstrate that the intervals vary in position within the subinterval. An insert map shows the locations of the wells used.

Also shown on the insert are Mobil Producing Company's #1 H. K. Noren, in the Lignite field (#1) and the Arrowhead Exploration Company's #1 Bley, in the Rival field (#2).

Pressure build-up tests were taken on these wells in June and July of 1958. The Noren well was shut-in for 104 hours (June 26-30) and the Bley well was shut-in for 120 1/2 hours (July 7-13), the curves were extrapolated by the Horner method, and the results corrected to a datum of 4150 feet below sea level. The results showed pressures of 2157 psi in the Rival pool and 2165 psi in the Lignite pool.

Cumulative production for these fields at the time of the tests was 112,764 barrels and 214,874 barrels in the Rival and Lignite fields, respectively.

ISOPORE MAP
RIVAL *SUB*INTERVAL

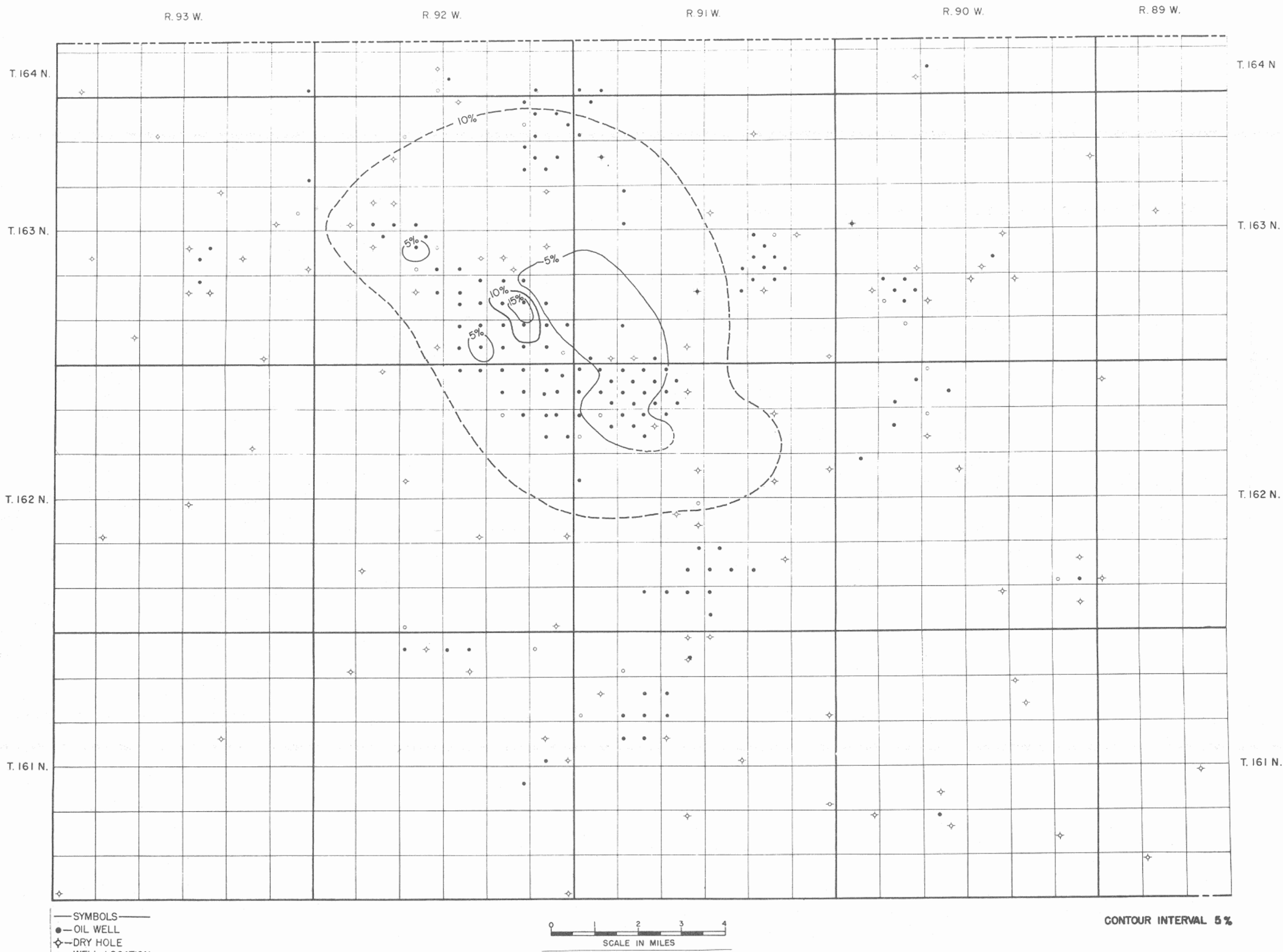
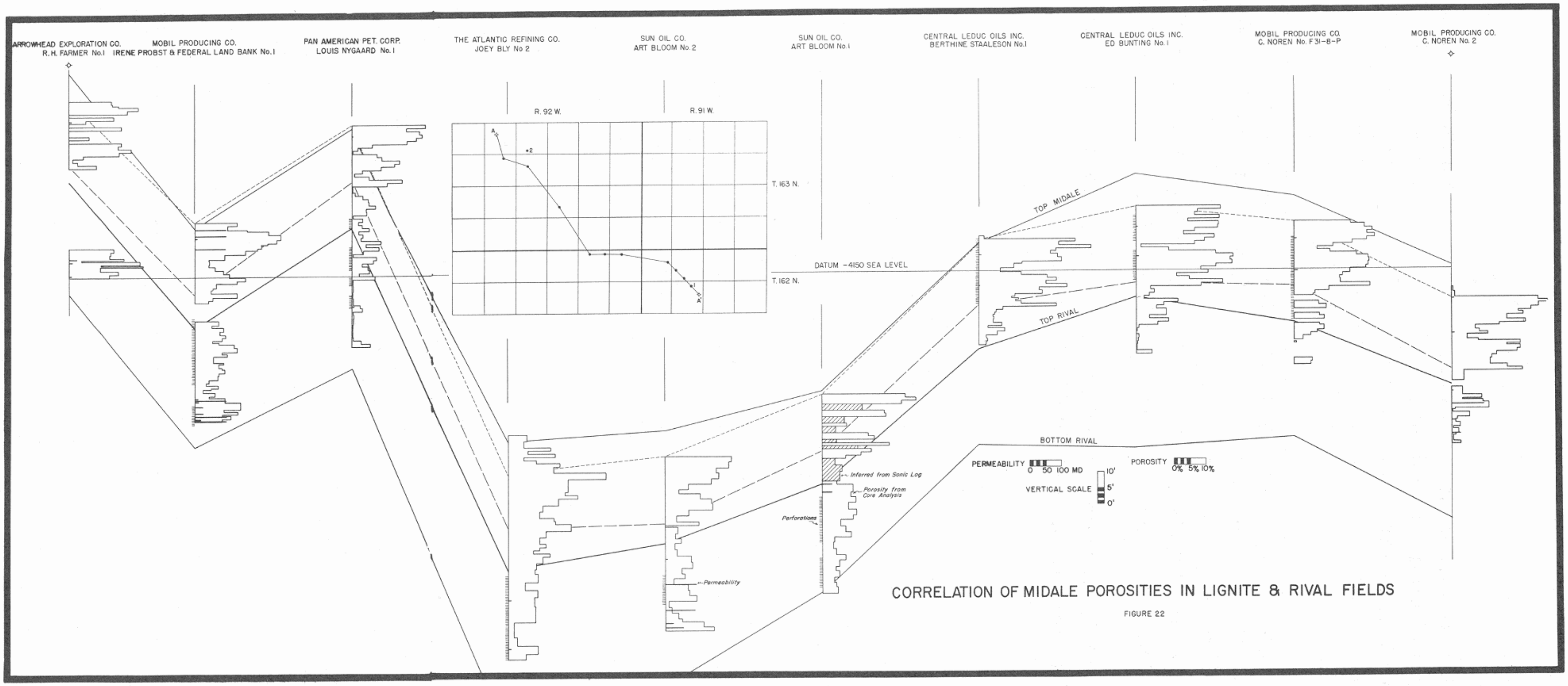


FIGURE 21



CORRELATION OF MIDALE POROSITIES IN LIGNITE & RIVAL FIELDS

FIGURE 22

The pressures used in plotting the bottom-hole pressure curves for individual fields are arithmetical averages of the 48 hour shut-in pressures taken in accordance with the various field rules. Measurements which do not conform statistically have been eliminated from the data.

Figure 23 is a plot of C.I.* versus United States Bureau of Mines fraction for the crudes produced in the Rival and Lignite fields. This plot, together with the pressure build-up tests cited above, indicates that the two reservoirs constitute a single common source of supply, although they are separated, laterally, for administrative purposes.

* C.I. (carbon index) values calculated on basis of United States Bureau of Mines Technical Publication #610.

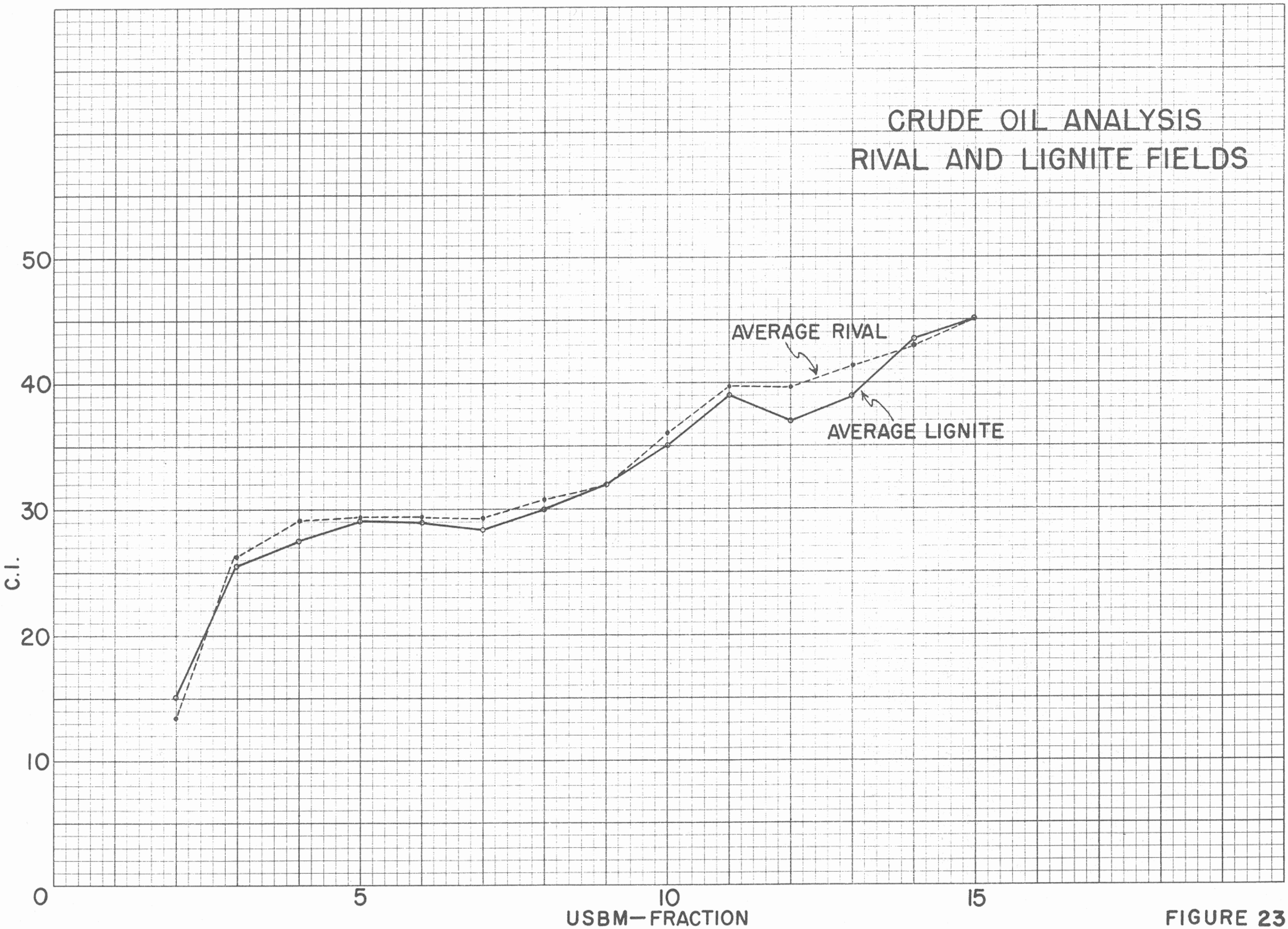

CRUDE OIL ANALYSIS
RIVAL AND LIGNITE FIELDS
AVERAGE RIVAL
AVERAGE LIGNITE
C.I.
50
40
30
20
10
0
5
10
15
USBM—FRACTION

FIGURE 23

Appendix

Field Data and Performance Curves

BLACK SLOUGH - MADISON POOL

DISCOVERY WELL
Anschutz Oil Co., Inc. - #1 Oscar Bakken
SW NW 3-161-92
Spudded - 16 March 1959
Completed - 16 April 1959
Total depth - 6858 feet

DEEPEST TEST
Anschutz Oil Co., Inc. - #1 Oscar Bakken
SW NW 3-161-92
Total depth - 6858 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6812 feet
Bits used - 17 Rock bits, 1 Diamond core bit
Mud - Salt base
Drilling time to completion - 29 days
Logs - Lateralog, Sonic, GRN, MicroLat
Casing program - 540 feet 8 5/8"/315 sax
6800 feet 4 1/2" or 5 1/2"/ 350 sax
Completion - 4 Jet shots/foot/250-2500 acid

RESERVOIR DATA
Average porosity - 8.47%
Average connate water saturation - 30%
Shrinkage factor - 1.48
Average permeability - 10 md
Orig. res. press. - 2785 psig (est)
Pressure datum - 4700 feet below sea level
Net thickness - 14 feet
Number of producing wells - 4
- flowing - 4
- pumping - 0

Number of dry holes drilled - 2
Cumulative production to 1/1/60
- Oil - 45,925 barrels
- Water - 5,247 barrels
- Gas - 58,307 SMCF

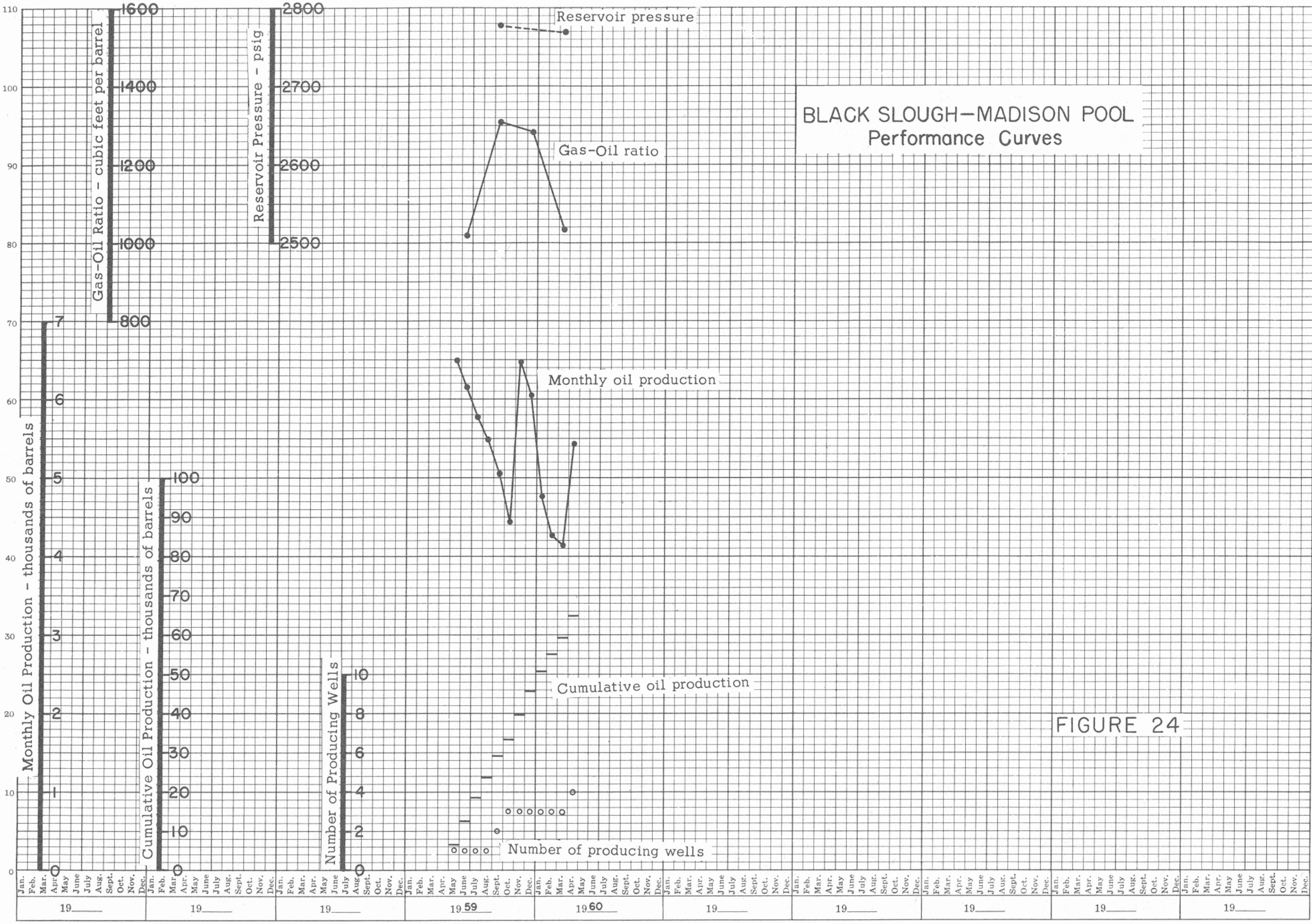
Cumulative GOR - 1270 SMCF/barrel
Cumulative WOR - 0.114 bbls/barrel
Reservoir temperature - 147° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8343
Percent Sulfur - 0.70
API gravity - 38.1°
Pour point - 30° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	4.2	
2	167	8.3	17
3	212	15.2	29
4	257	21.4	30
5	302	27.8	31
6	347	33.7	30
7	392	38.9	30
8	437	43.9	31
9	482	49.5	34
10	527	56.5	37

Carbon residue - 1.5%



BLACK SLOUGH—MADISON POOL
Performance Curves

FIGURE 24

BOWBELLS - MADISON POOL

DISCOVERY WELL
Pioneer Oil Company - B. Ormiston #1
SW SE 25-162-90
Spudded - 4 July 1958
Completed - 26 July 1958
Total depth - 6072 feet

DEEPEST TEST
Simcox Oil Company - J. Briggs #1
SW NE 25-162-90
Total depth - 6080 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6058 feet
Mud - Gyp base
Drilling time to completion - 22 days
Logs - Lateralog, MicroLat, Induction, Sonic
Casing program - 480 feet 8 5/8"/250 sax
6014 feet 5 1/2"/250 sax
Completion - 4 Perfs/foot with 1750 acid

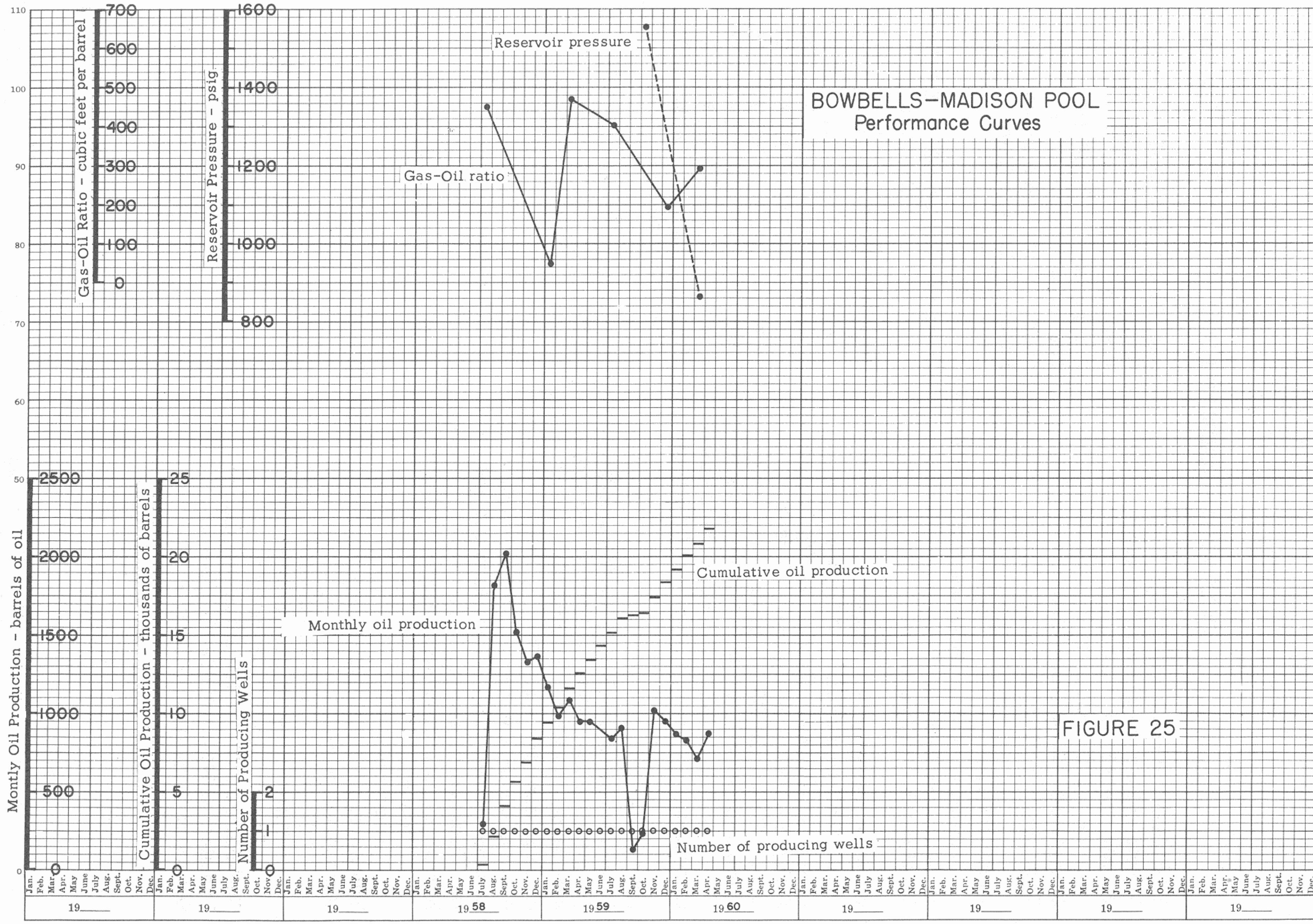
RESERVOIR DATA
Average porosity - 12.8%
Average connate water saturation - 54%
Average permeability - 10.2 md
Orig. res. press. - 450 psig
Pressure datum - 4000 feet below sea level
Net thickness - 8 feet
Number of producing wells - 1
flowing - 0
pumping - 1
Number of dry holes drilled - 4
Cumulative production to 1/1/60
Oil - 18,424 barrels
Water - 2,027 barrels
Gas - 5,168 SMCF
Cumulative GOR - 281 cubic feet per barrel
Cumulative WOR - 0.11 bbls/barrel
Reservoir temperature - 136° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8251
Percent Sulfur - 0.47
API gravity - 40°
Pour point - 35° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	3.4	
2	167	7.6	16
3	212	15.5	27
4	257	23.7	30
5	302	29.6	31
6	347	35.1	30
7	392	40.8	29
8	437	45.5	30
9	482	52.8	33
10	527	58.3	36

Carbon residue - 0.9%


BOWBELLS–MADISON POOL
Performance Curves
Reservoir pressure
Gas-Oil ratio
Monthly oil production
Cumulative oil production
Number of producing wells
Gas-Oil Ratio - cubic feet per barrel
Reservoir Pressure - psig
Montly Oil Production - barrels of oil
Cumulative Oil Production - thousands of barrels
Number of Producing Wells
0
100
200
300
400
500
600
700
800
1000
1200
1400
1600
500
1000
1500
2000
2500
5
10
15
20
25
1
2
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
19 58
19 59
19 60
FIGURE 25

COLUMBUS - MADISON POOL

DISCOVERY WELL
Texota Oil Company - S. Swenson #1
NE SW 22-163-93
Spudded - 7 December 1955
Completed - 25 January 1956
Total depth - 6507 feet

DEEPEST TEST
T. Schwartz & C. W. Williams - H. Ringvald #1
NE NW 27-163-93
Total depth - 6675 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6480 feet
Mud - Gyp base, 10#, vis 53, WL 10
Drilling time to completion - 30 days
Logs - E-SP, Lat GR, MicroLat
Casing program - 475 feet 9 5/8"/325 sax
6410 feet 5 1/2"/340 sax
Completion - 4 Jet shots per foot/750 acid

RESERVOIR DATA
Orig. res. press. - 1875 psig (reported)
Pressure datum - 4300 feet below sea level
Saturation pressure - unknown
Average porosity - 11.0%
Average connate water saturation - 50%
Average permeability - Less than 0.1 md
Net thickness - 15 feet
Number of producing wells - 3
- flowing - 1
- pumping - 2

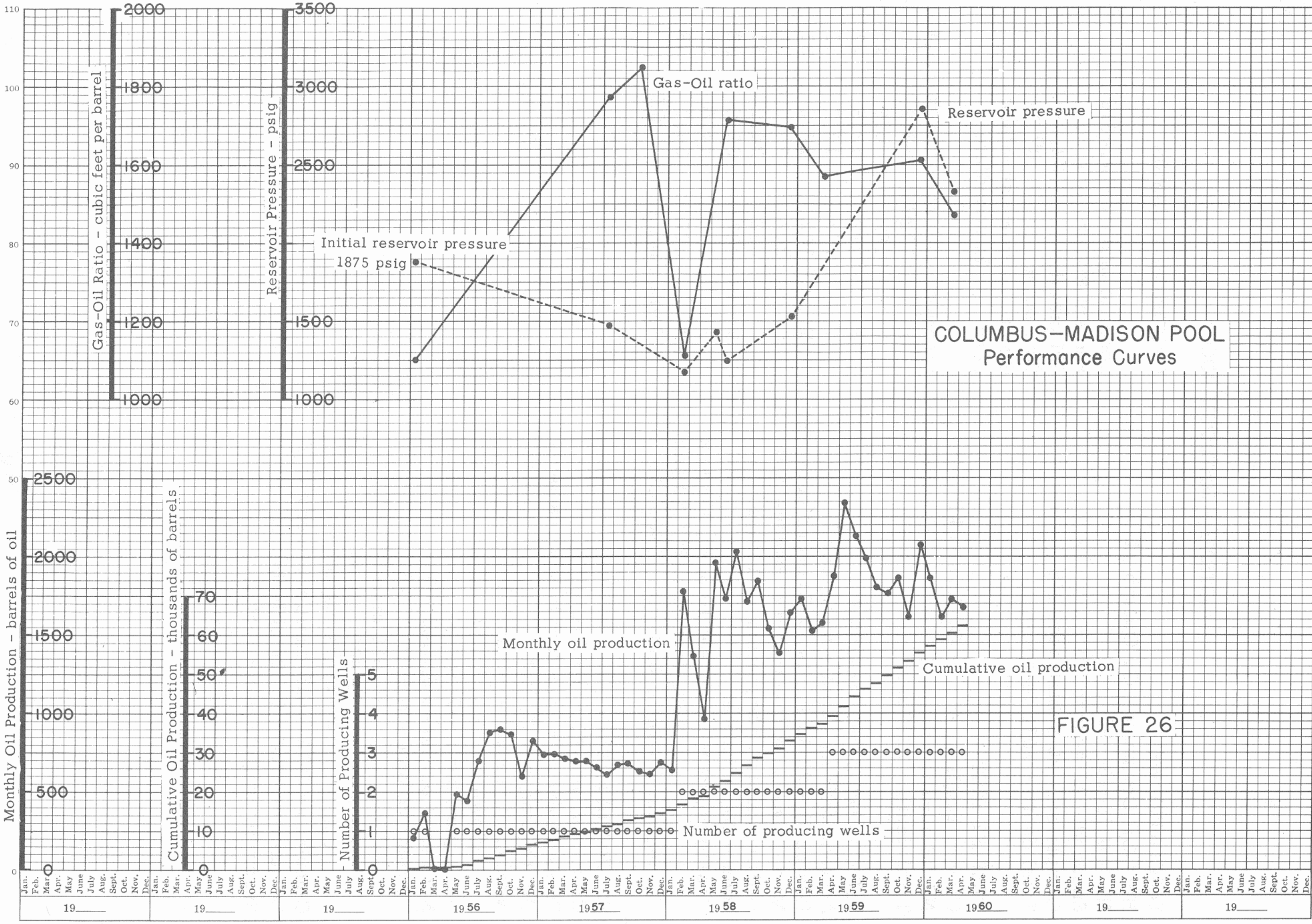
Number of dry holes drilled - 4
Cumulative production to 1/1/60
- Oil - 55,175 barrels
- Water - 3,256 barrels
- Gas - 83,669 SMCF

Cumulative GOR - 1517 cubic feet/barrel
Cumulative WOR - 0.059 bbls/barrel
Reservoir temperature - 113° F

CRUDE OIL ANALYSIS
Specific gravity - 0.8319
Percent Sulfur - 0.51
API gravity - 38.6°
Pour point - 40° F
Color Brownish-green (dark)
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	2.6	
2	167	7.0	14
3	212	13.5	26
4	257	21.2	27
5	302	28.0	30
6	347	33.7	30
7	392	38.9	30
8	437	44.8	31
9	482	50.8	34
10	527	58.5	37

Carbon residue - 1.0%


COLUMBUS–MADISON POOL
Performance Curves
FIGURE 26
Gas-Oil Ratio - cubic feet per barrel
Reservoir Pressure - psig
Monthly Oil Production - barrels of oil
Cumulative Oil Production - thousands of barrels
Number of Producing Wells
Gas-Oil ratio
Reservoir pressure
Initial reservoir pressure
1875 psig
Monthly oil production
Cumulative oil production
Number of producing wells
1956
1957
1958
1959
1960

COTEAU - MADISON POOL

DISCOVERY WELL
Hunt Oil Company - G. Opseth #1
NE NW 28-161-90
Spudded - 12 August 1955
Completed - 20 September 1955
Total depth - 7016 feet

DEEPEST TEST
Calvert Drilling, Inc. - C. Jepson #1
NE NE 30-161-90
Total depth - 7282 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6992 feet
Bits used - 22 Rock bits, 2 Diamond core bits
Mud - Gyp base/Controloid & Brinegel/oil
Drilling time to completion - 31 days
Logs - ES, MicroLat
Casing program - 600 feet 10 3/4"/335 sax
6600 feet 5 1/2"/150 sax
Completion - 4 Perfs/foot with 7000 acid

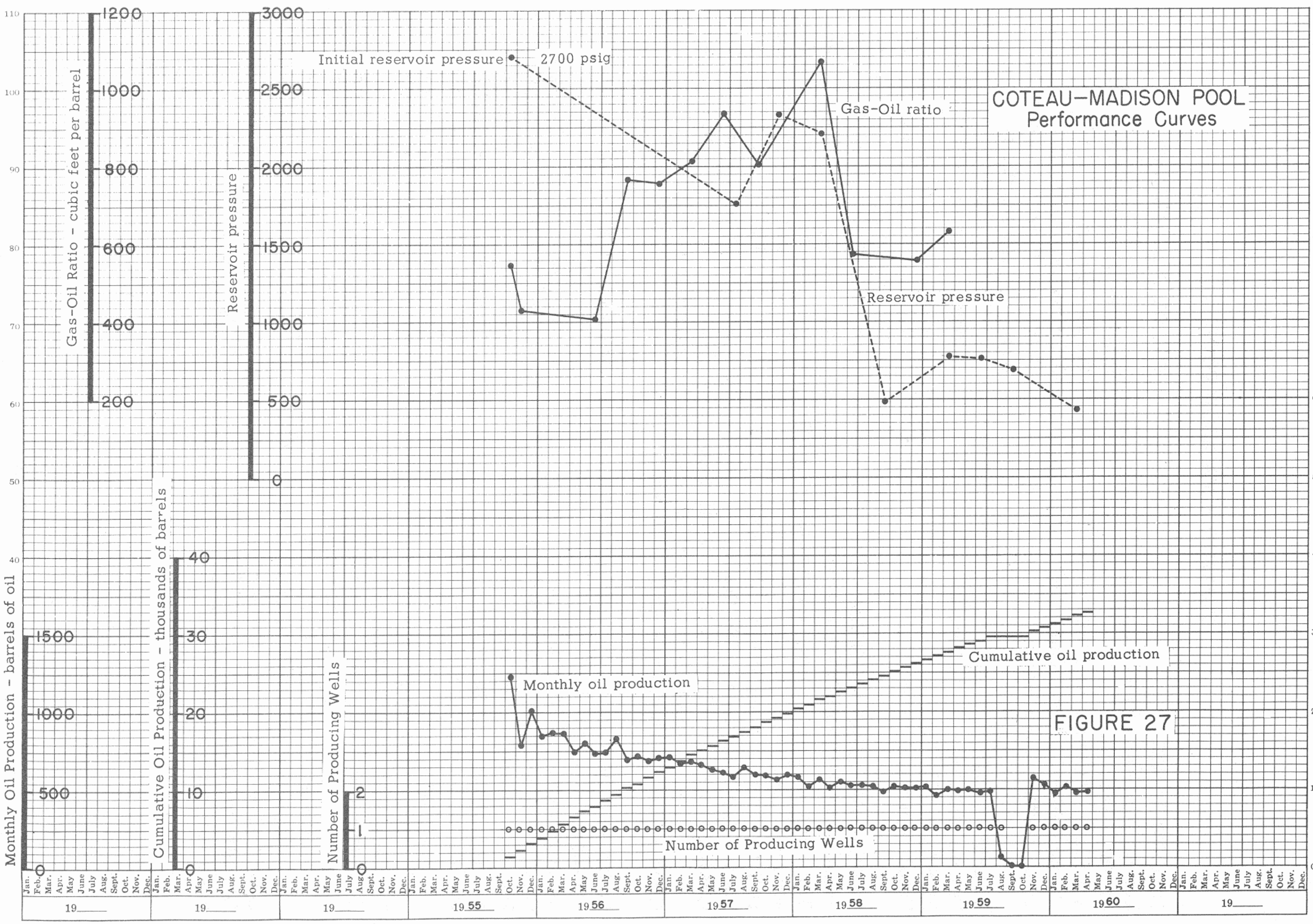
RESERVOIR DATA
Orig. res. press. - 2700 psig
Pressure datum - 4375 feet below sea level
Net thickness - 20 feet
Number of producing wells - 1
flowing - 0
pumping - 1
Number of dry holes drilled - 3
Cumulative production to 1/1/60
Oil - 30,668 barrels
Water - 9,409 barrels
Gas - 18,973 SMCF
Cumulative GOR - 619 cubic feet per barrel
Cumulative WOR - 0.306 bbls/barrel
Reservoir temperature - 135° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8612
Percent Sulfur - 1.30
API gravity - 32.8°
Pour point - 30° F
Color Brownish-black
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	3.1	
2	167	6.9	15
3	212	13.5	27
4	257	19.7	31
5	302	24.6	31
6	347	29.5	31
7	392	34.2	31
8	437	39.0	33
9	482	44.8	36
10	527	50.7	39

Carbon residue - 4.0%


COTEAU-MADISON POOL
Performance Curves
FIGURE 27
Initial reservoir pressure 2700 psig
Gas-Oil ratio
Reservoir pressure
Cumulative oil production
Monthly oil production
Number of Producing Wells
Gas-Oil Ratio - cubic feet per barrel
Reservoir pressure
Monthly Oil Production - barrels of oil
Cumulative Oil Production - thousands of barrels
Number of Producing Wells
1955
1956
1957
1958
1959
1960

FLAXTON - MADISON POOL

DISCOVERY WELL

Texota Oil Co. - #1 M. Sorum
SE SE 23-163-91
Spudded - 21 October 1956
Completed - 29 December 1956
Total depth - 6295 feet

DEEPEST TEST

Texota Oil Co. - #1 M. Sorum
SE SE 23-163-91
Total depth - 6295 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 5940 feet
Bits used - 16 Rock bits, 1 Diamond core bit
Mud - 10.3#/gallon
Drilling time to completion - 30 days
Logs - GRN, Mll, Lat, ES, Sonic
Casing program - 510 feet 8 5/8"/345 sax
5895 feet 5 1/2"/265 sax
Completion - 4 shots/foot with 4000 acid

RESERVOIR DATA

Average porosity - 9.65%
Average permeability - 0.5 md
Orig. res. press. - 2595 psig
Pressure datum - 3900 feet below sea level
Net thickness - 18 feet
Number of producing wells - 15
- flowing - 3
- pumping - 12

Number of dry holes drilled - 7
Cumulative production to 1/1/60
- Oil - 277,325 barrels
- Water - 20,011 barrels
- Gas - 406,540 SMCF

Cumulative GOR - 1466 SMCF/barrel
Cumulative WOR - 0.072 bbls/barrel
Reservoir temperature - 138° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8314
Percent Sulfur - 0.58
API gravity - 38.7°
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	2.6	
2	167	6.6	16
3	212	14.1	27
4	257	21.7	30
5	302	28.1	30
6	347	34.4	30
7	392	39.8	30
8	437	45.6	31
9	482	51.6	34
10	527	58.2	37

Carbon residue - 1.0%

GAS ANALYSIS

Nitrogen	- 17.59%
H_2S	- 0.96
CO_2	- 0.33
Methane	- 45.51
Ethane	- 14.75
Propane	- 10.45
i-Butane	- 1.50
Butane	- 4.62
i-Pentane	- 1.04
Pentane	- 1.27
Hexane	- 0.77
C_7+	- 0.25
Air	- 0.96

BTU (gross) 1322/SCF
(net) 1288/SCF
Specific gravity - 0.9716 @ 60° F

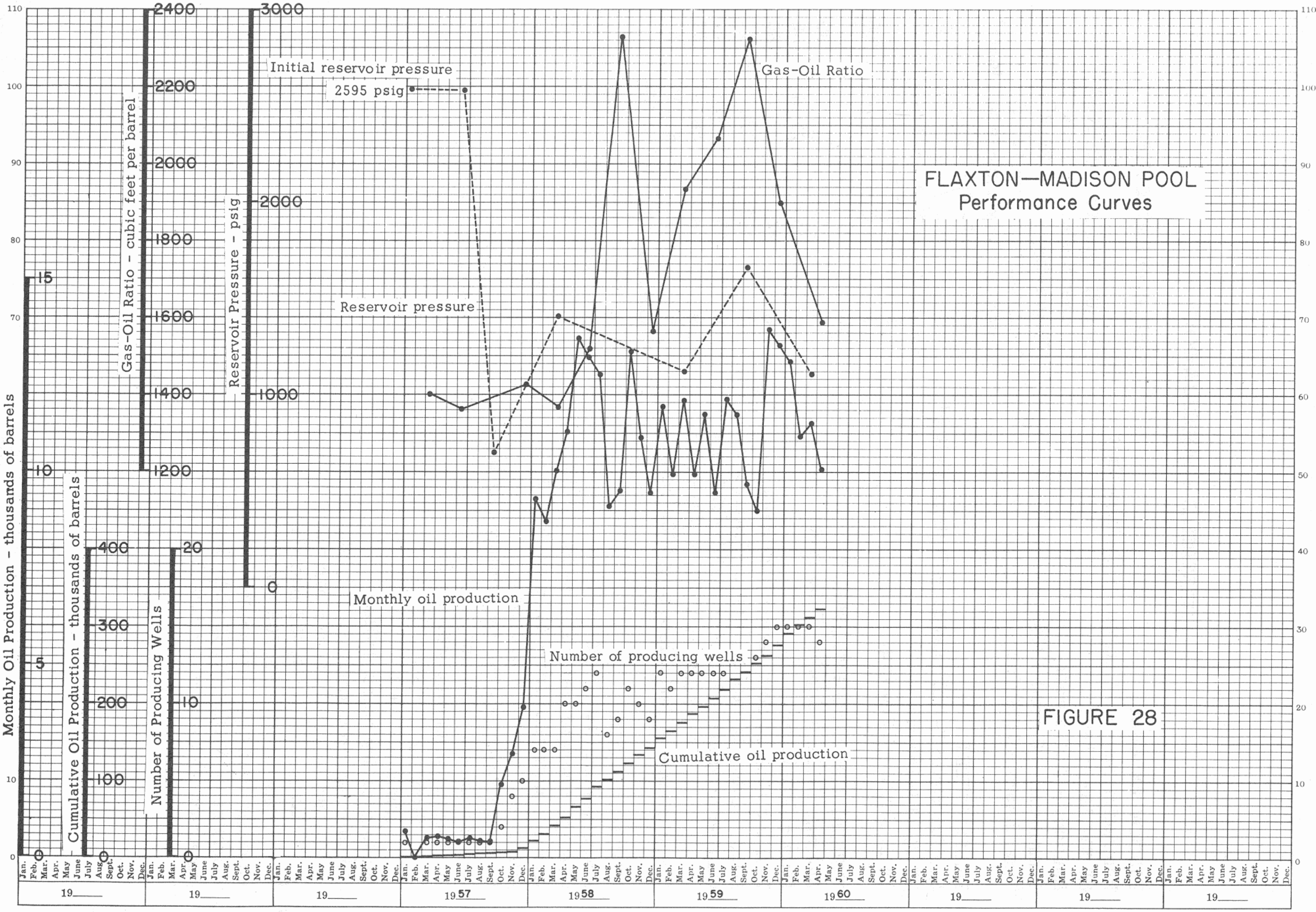

FLAXTON—MADISON POOL
Performance Curves
Initial reservoir pressure
2595 psig
Gas-Oil Ratio
Reservoir pressure
Monthly oil production
Number of producing wells
Cumulative oil production
Monthly Oil Production - thousands of barrels
Cumulative Oil Production - thousands of barrels
Gas-Oil Ratio - cubic feet per barrel
Number of Producing Wells
Reservoir Pressure - psig
1957
1958
1959
1960

FIGURE 28

FOOTHILLS - MADISON POOL

DISCOVERY WELL

Pan American Petrol. Corp. - Owings Unit #1
SE SW 13-161-92
Spudded - 25 February 1958
Completed - 6 April 1958
Total depth - 7250 feet

DEEPEST TEST

Pan American Petrol. Corp. - Owings Unit #1
SE SW 13-161-92
Total depth - 7250 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 7055 feet
Mud - Gyp base
Drilling time to completion - 29 days.
Logs - GRN, MicroLat, Sonic, Lateralog
Casing program - 525 feet 8 5/8"/375 sax
7230 feet 5 1/2"/275 sax
Completion - 4 Perfs/foot and 4000 acid

RESERVOIR DATA

Average porosity - 15%
Average connate water saturation - 46%
Average permeability - 4.16 md (radial)
Orig. res. press. - 910 psig
Pressure datum - 4700 feet below sea level
Net thickness - 18 feet
Number of producing wells - 2
- flowing - 1
- pumping - 1

Number of dry holes drilled - 1
Cumulative production to 1/1/60
- Oil - 26,436 barrels
- Water - 9,453 barrels
- Gas - 20,703 SMCF

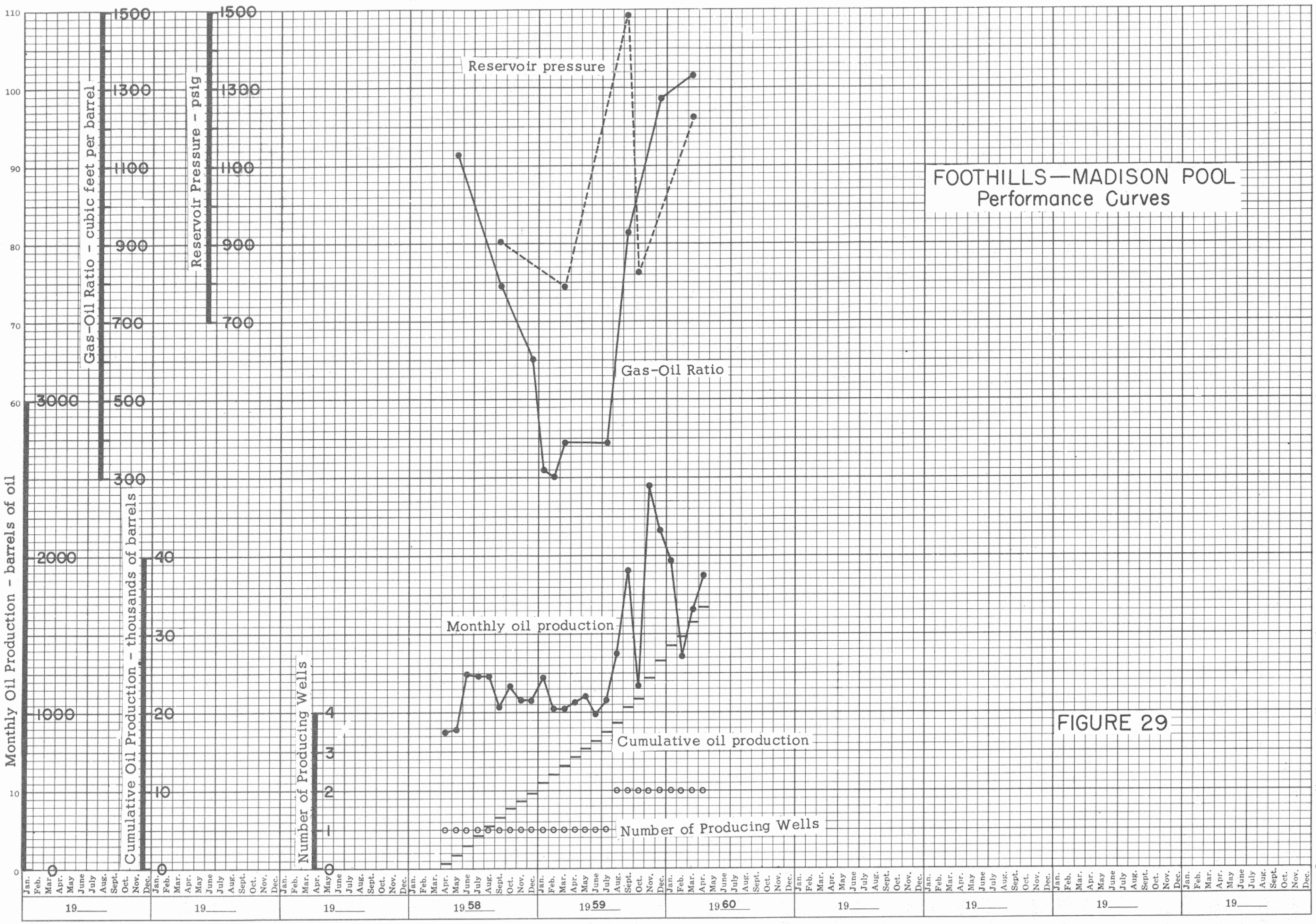
Cumulative GOR - 783 cubic feet per barrel
Cumulative WOR - 0.358 bbls/barrel
Reservoir temperature - 190° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8413
Percent Sulfur - 0.84
API gravity - 36.7°
Pour point - 10° F
Color Brownish-green (dark)
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	2.9	
2	167	7.0	16
3	212	14.6	27
4	257	21.2	30
5	302	27.0	30
6	347	33.0	30
7	392	37.7	31
8	437	43.3	31
9	482	48.9	34
10	527	55.1	37

Carbon residue - 2.3%


FOOTHILLS—MADISON POOL
Performance Curves
FIGURE 29
Reservoir pressure
Gas-Oil Ratio
Monthly oil production
Cumulative oil production
Number of Producing Wells
Gas-Oil Ratio - cubic feet per barrel
Reservoir Pressure - psig
Monthly Oil Production - barrels of oil
Cumulative Oil Production - thousands of barrels
Number of Producing Wells
19 58
19 59
19 60

55

DISCOVERY WELL

Northwest Oil Drilling Co. - #1 Ed Bunting
SE SW 5-162-91
Spudded - 7 June 1957
Completed - 11 July 1957
Total depth - 6640 feet

DEEPEST TEST

Northwest Oil Drilling Co. - #1 Ed Bunting
SE SW 5-162-91
Total depth - 6640 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 6205 feet
Bits used - 16 Rock bits, 2 Diamond core bits
Mud - Gyp or Salt base
Drilling time to completion - 25 days
Logs - SP, Mll, GRN, Sonic, Lat, Induction
Casing program - 515 feet 8 5/8"/365 sax
6185 feet 5 1/2"/315 sax
Completion - 4 Jet shots/foot with 2500 acid

RESERVOIR DATA

Average porosity - 18.7%
Average connate water saturation - 25%
Shrinkage factor - 1.47
Average permeability - 1.25 md
Orig. res. press. - 2493 psig
Saturation pressure - 1805 psig
Pressure datum - 4150 feet below sea level
Solution GOR - 825 SCF/barrel
Oil viscosity - 0.466 cp @ saturation pressure
1.310 cp @ 0 psig and 172° F
Net thickness - 18 feet
Number of producing wells - 24
flowing - 6
pumping - 18
Number of dry holes drilled - 4
Cumulative production to 1/1/60
Oil - 662,163 barrels
Water - 36,317 barrels
Gas - 1,087,184 SMCF
Cumulative GOR - 1642 SMCF/barrel
Cumulative WOR - 0.055 bbls/barrel
Reservoir temperature - 186° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8314
Percent Sulfur - 0.46
API gravity - 38.7°
Pour point - 10° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	2.5	
2	167	6.8	15
3	212	13.3	27
4	257	21.0	28
5	302	27.7	31
6	347	34.3	30
7	392	39.3	29
8	437	45.1	31
9	482	50.7	33
10	527	57.1	36

Carbon residue - 1.1%

WATER ANALYSIS

Sodium - 109,712 ppm
Calcium - 5,292
Magnesium - 1,062
Sulfate - 731
Chloride - 181,028
Carbonate - 0
Bicarbonate - 205
Resistivity @ 68° F - 0.046 ohm-meters
Total solids from resist. - 293,350 ppm
Specific gravity - 1.187 @ 60° F
pH - 6.4

GAS ANALYSIS

Nitrogen - 3.56% (air free)
H_2S - 1.27
CO_2 - 1.25
Methane - 56.73
Ethane - 17.20
Propane - 10.89
i-Butane - 1.46
Butane - 4.27
i-Pentane - 0.96
Pentane - 1.17
Hexane - 0.80
C_7+ - 0.40
BTU (gross) Air free - 1468/SCF
(net) - 1362
Specific gravity - 0.933 @ 60° F

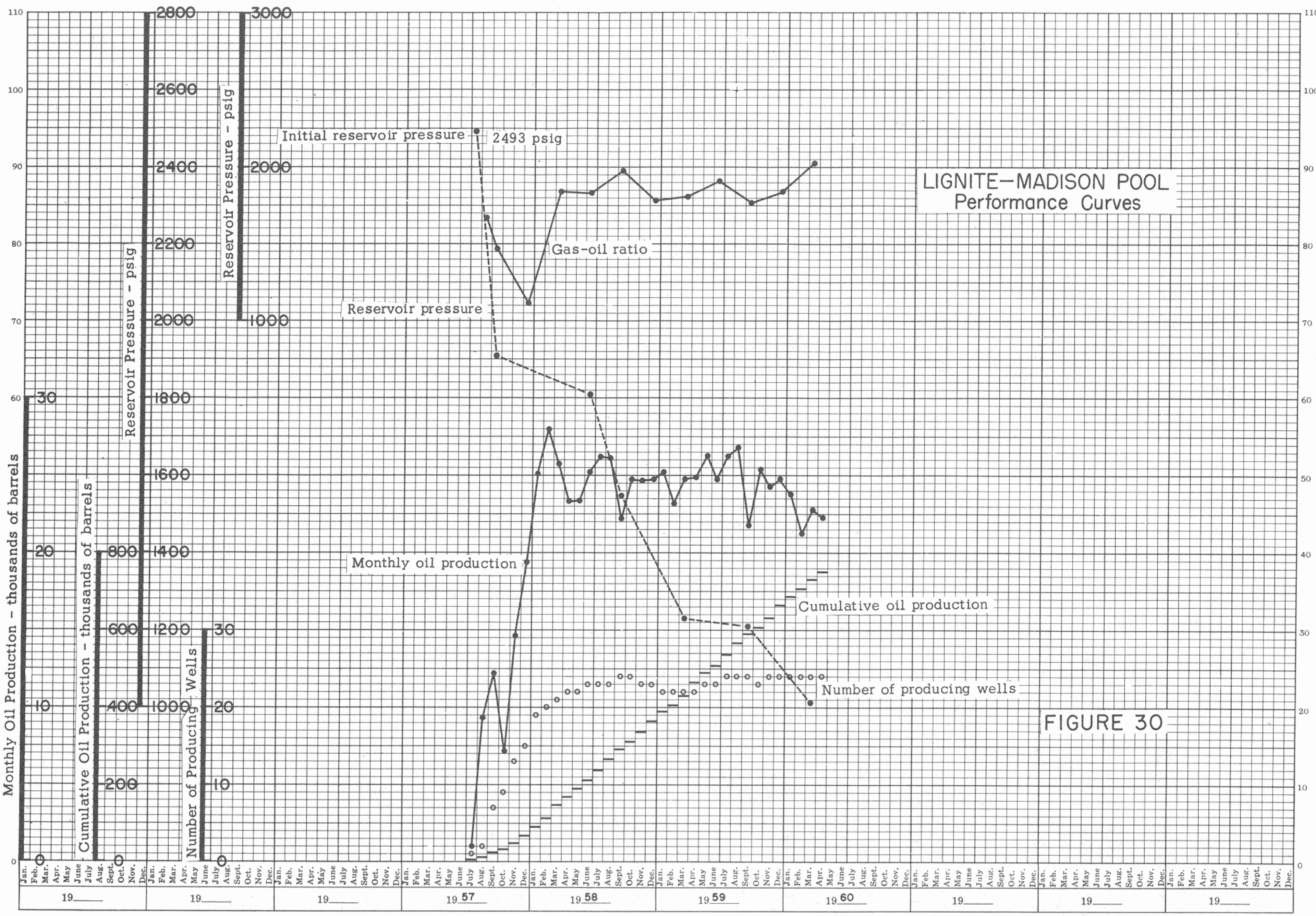

LIGNITE–MADISON POOL
Performance Curves
Initial reservoir pressure
2493 psig
Gas-oil ratio
Reservoir pressure
Monthly oil production
Cumulative oil production
Number of producing wells
Monthly Oil Production - thousands of barrels
Cumulative Oil Production - thousands of barrels
Reservoir Pressure - psig
Number of Producing Wells
19 57
19 58
19 59
19 60

FIGURE 30

NORTHEAST FOOTHILLS - MADISON

DISCOVERY WELL
Vern O. Lund - #1 Gullickson
SW SW 8-161-91
Spudded - 14 January 1959
Completed - 21 February 1959
Total depth - 6753 feet

DEEPEST TEST
Vern O. Lund - #2 Gullickson
SW NW 17-161-91
Total depth - 6778 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6670 feet
Mud - Gyp base, 9.4#, vis 50, WL 8.2, 2/32"
Drilling time to completion - 46 days
Logs - EL, Micro, Lateralog, Sonic, GRN
Casing program - 500 feet 10 3/4"/350 sax
6685 feet 5 1/2"/400 sax
(1 well has been completed with 2 7/8" tbg. set/450 sax)
Completion - 4 Perfs/foot with 1200 to 3700 gallons of acid. (Lowest water cuts have been attained with least acid.)

RESERVOIR DATA
Orig. res. press. - 2500 psig
Pressure datum - 4700 feet below sea level
Net thickness - 15 feet
Number of producing wells - 8
- flowing - 6
- pumping - 2

Number of dry holes drilled - 2
Cumulative production to 1/1/60
- Oil - 57,809 barrels
- Water - 2,612 barrels
- Gas - 66,181 SMCF

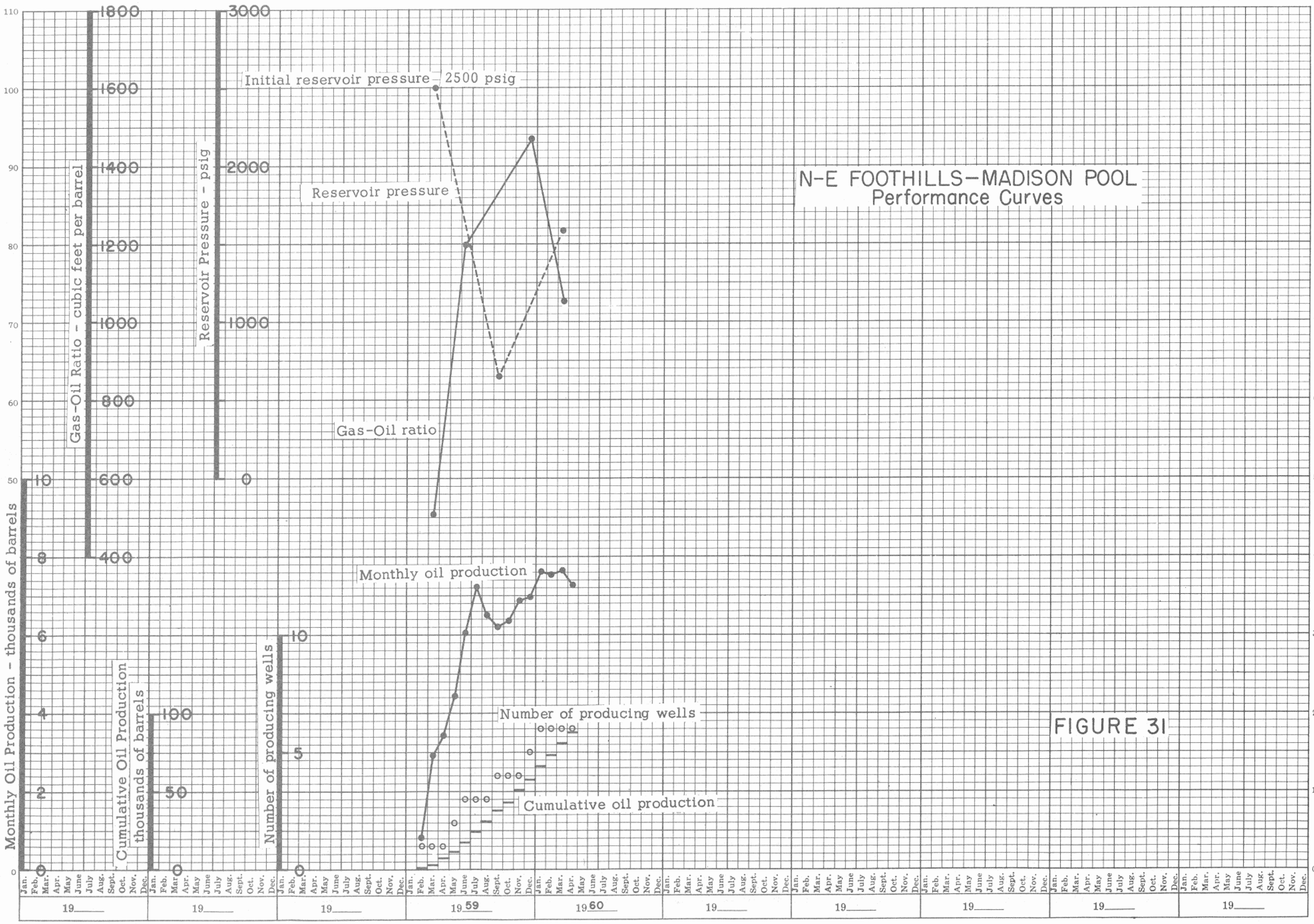
Cumulative GOR - 1145 cubic feet per barrel
Cumulative WOR - 0.045 bbls/barrel
Reservoir temperature - 147° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8509
Percent Sulfur - 0.90
API gravity - 34.8°
Pour point - 30° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	1.6	
2	167	4.4	17
3	212	10.7	27
4	257	17.2	30
5	302	23.5	30
6	347	29.2	31
7	392	34.4	31
8	437	40.3	32
9	482	45.7	35
10	527	52.7	37

Carbon residue - 2.0%


N-E FOOTHILLS–MADISON POOL
Performance Curves
FIGURE 31
Initial reservoir pressure 2500 psig
Reservoir pressure
Gas-Oil ratio
Monthly oil production
Number of producing wells
Cumulative oil production
Monthly Oil Production - thousands of barrels
Gas-Oil Ratio - cubic feet per barrel
Reservoir Pressure - psig
Cumulative Oil Production thousands of barrels
Number of producing wells
1959
1960

PORTAL - MADISON POOL

DISCOVERY WELL

Farmer's Union Central Exchange, Inc. - #1 E. Klitzke
SW SW 17-163-91
Spudded - 4 August 1957
Completed - 27 October 1957
Total depth - 6410 feet

DEEPEST TEST

Farmer's Union Central Exchange, Inc. - #1 E. Klitzke
SW SW 17-163-91
Total depth - 6410 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 5980 feet
Mud - Gyp base, 10.2#
Drilling time to completion - 25 days
Logs - Induction, ML, LL-GR, GRN, Sonic
Casing program - 430 feet 9 5/8"/300 sax
5930 feet 4 1/2" or 5 1/2"/320 sax

Completion - 5 shots per foot/3325 acid

RESERVOIR DATA

Average porosity - 9.4%
Average permeability - less than 1 md
Orig. res. press. - 2090 psig (est)
Pressure datum - 3925 feet below sea level
Net thickness - 8 feet
Number of producing wells - 21
- flowing - 15
- pumping - 6

Number of dry holes drilled - 3
Cumulative production to 1/1/60
- Oil - 120,549 barrels
- Water - 30,910 barrels
- Gas - 212,740 SMCF

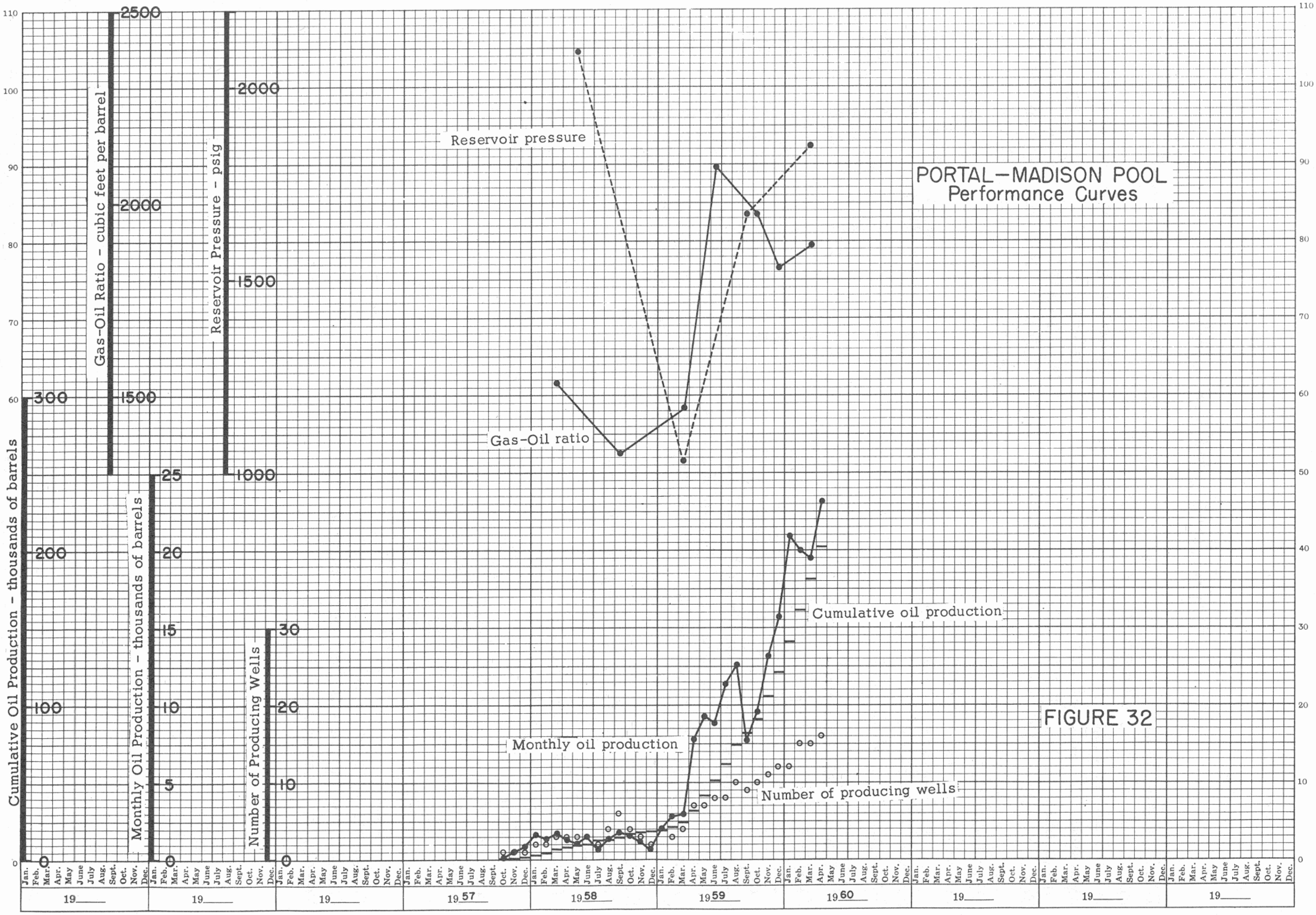
Cumulative GOR - 1765 SMCF/barrels
Cumulative WOR - 0.257 bbls/barrel
Reservoir temperature - 176° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8398
Percent Sulfur - 0.67
API gravity - 37.0°
Pour point - 40° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	1.2	
2	167	3.0	13
3	212	9.0	27
4	257	16.4	28
5	302	23.2	30
6	347	30.5	30
7	392	36.0	30
8	437	41.8	31
9	482	48.3	33
10	527	55.4	36

Carbon residue - 1.2%


PORTAL—MADISON POOL
Performance Curves
FIGURE 32
Reservoir pressure
Gas-Oil ratio
Monthly oil production
Cumulative oil production
Number of producing wells
Cumulative Oil Production - thousands of barrels
Gas-Oil Ratio - cubic feet per barrel
Monthly Oil Production - thousands of barrels
Reservoir Pressure - psig
Number of Producing Wells
1957
1958
1959
1960

RENNIE LAKE - MADISON POOL

DISCOVERY WELL

Petroleum Corp. of America - #1 M. Jorgans
NE NE 28-162-91
Spudded - 17 August 1957
Completed - 15 October 1957
Total depth - 6380 feet

DEEPEST TEST

Petroleum Corp. of America -
#1 Lindsay R. Bunting
SE NW 21-162-91
Total depth - 6603 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 6446 feet
Drilling time to completion - 31 days
Logs - SP, ML, LL, Ind.-Sonic-GRN
Casing program - 515 feet 8 5/8"/320 sax
6405 feet 2 7/8" tbg/400 sax
Completion - 1 Jet shot/3000 acid or light wash

RESERVOIR DATA

Pressure datum - 4150 feet below sea level
Net thickness - 32 feet
Number of producing wells - 11
- flowing - 9
- pumping - 2

Number of dry holes drilled - 1
Cumulative production to 1/1/60
- Oil - 106,939 barrels
- Water - 26,373 barrels
- Gas - 144,481 SMCF

Cumulative GOR - 1351 SMCF/barrel
Cumulative WOR - 0.247 bbls/barrel
Reservoir temperature - 144° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8498
Percent Sulfur - 1.10%
API gravity - 35.0°
Color Brownish-green (dark)
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	2.7	
2	167	6.0	18
3	212	11.9	28
4	257	18.6	31
5	302	24.7	31
6	347	29.9	31
7	392	34.7	31
8	437	40.1	32
9	482	46.0	35
10	527	52.8	38

Carbon residue - 2.5%

RENNIE LAKE—MADISON POOL
Performance Curves

FIGURE 33

RIVAL - MADISON POOL

DISCOVERY WELL

Arrowhead Exploration Co. - J. Probst #1
SE SE 17-163-92
Spudded - 2 September 1957
Completed - 24 October 1957
Total depth - 6425 feet

DEEPEST TEST

Arrowhead Exploration Co. - J. Probst #1
SE SE 17-163-92
Total depth - 6245 feet

TYPICAL DRILLING PROGRAM

Average drilling depth - 6270 feet
Bits used - 15 Rock bits, 2 Diamond core bits
Mud - Gyp base and/or oil emulsion
Drilling time to completion - 25 days
Logs - Induction, GRN, Sonic, Lateralog
Casing program - 515 feet 8 5/8"/360 sax
6260 feet 4 1/2" or 5 1/2"/320 sax
(7 wells have been completed with
2 5/8" tbg set/400 sax)
Completion - 4 Jet shots per foot/1500 acid

RESERVOIR DATA

Average porosity - 8.87%
Average connate water saturation - 29%
Shrinkage factor - 1.6079
Average permeability - Less than 0.1 md
Orig. res. press. - 2760 psig
Saturation pressure - 2235 psig @ 172° F
Pressure datum - 4150 feet below sea level
Solution GOR - 981 cubic feet/bbl (liber.)
Oil viscosity - 0.475 cp @ saturation point
1.24 cp @ 0 psig and 172° F
Net thickness - 18 feet
Number of producing wells - 46
flowing - 39
pumping - 7
Number of dry holes drilled - 1
Cumulative production to 1/1/60
Oil - 1,407,416 barrels
Water - 136,908 barrels
Gas - 1,246,567 SMCF
Cumulative GOR - 886 cubic feet per barrel
Cumulative WOR - 0.097 bbls/barrel
Reservoir temperature - 165° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8294
Percent Sulfur - 0.58
API gravity - 39.1°
Pour point - 35° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	4.2	15
2	167	9.2	27
3	212	16.2	31
4	257	23.9	31
5	302	30.5	31
6	347	36.1	31
7	392	41.9	31
8	437	46.3	33
9	482	52.6	35
10	527	59.3	38

Carbon residue - 1.2%

WATER ANALYSIS

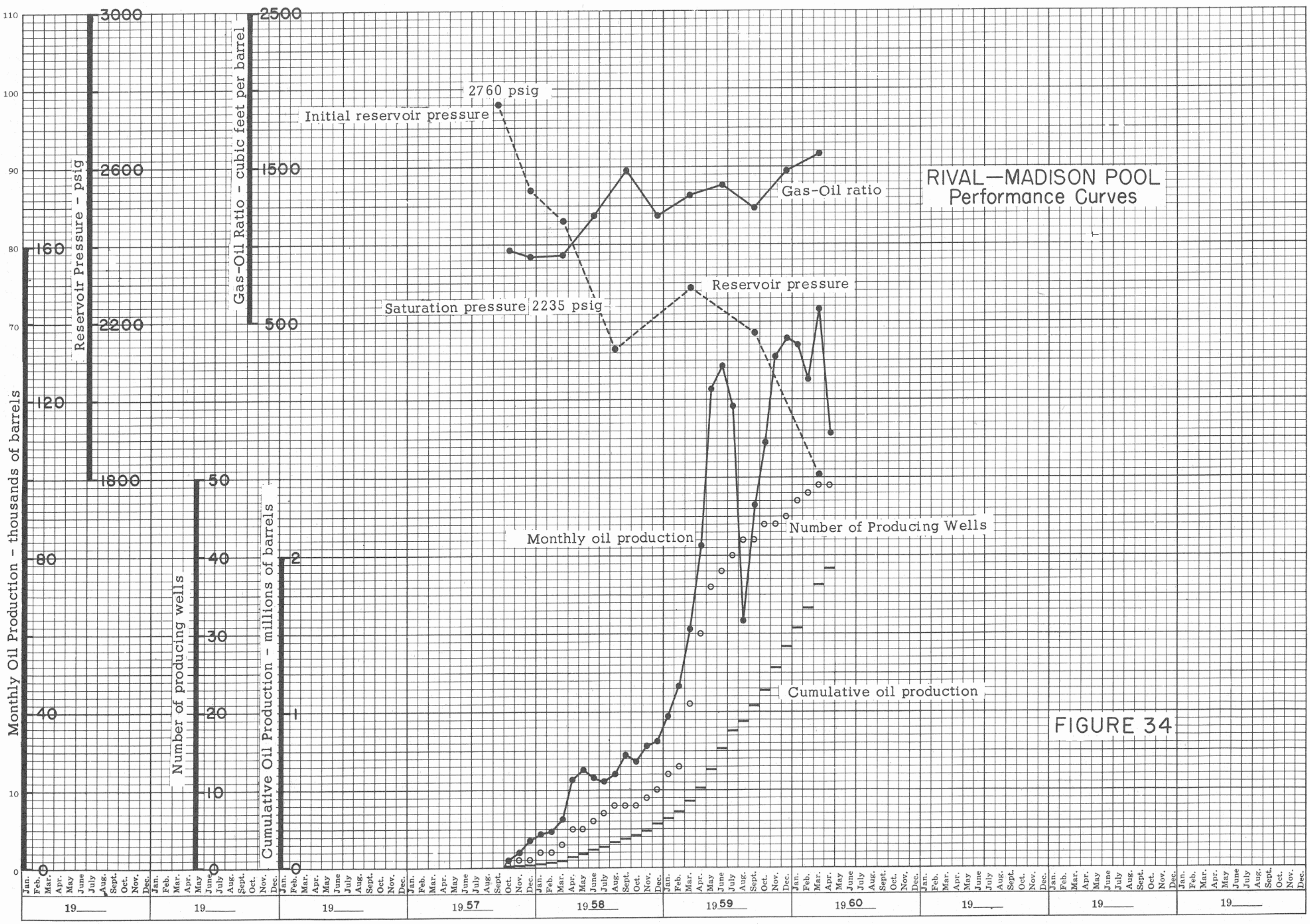
Sodium	- 108,499 ppm
Calcium	- 8,526
Magnesium	- 1,652
Sulfate	- 627
Chloride	- 186,638
Carbonate	- 0
Bicarbonate	- 270

Resistivity @ 68° F - 0.046 ohm-meters
Total solids from resist.- 306,928 ppm
Specific gravity - 1.199 @ 60° F
pH - 5.2

GAS ANALYSIS

Nitrogen	- 5.82% (Air free)
Air	
H_2S	- 2.00
CO_2	- 2.60
Methane	- 59.62
Ethane	- 16.98
Propane	- 8.61
i-Butane	- 0.89
Butane	- 2.31
i-Pentane	- 0.36
Pentane	- 0.42
Hexane	- 0.27
C_7+	- 0.12

BTU (gross) Air free - 1266
(net) - 1172
Specific gravity - 0.8527 @ 60° F


RIVAL—MADISON POOL
Performance Curves
Monthly Oil Production - thousands of barrels
Reservoir Pressure - psig
Gas-Oil Ratio - cubic feet per barrel
Number of producing wells
Cumulative Oil Production - millions of barrels
2760 psig
Initial reservoir pressure
Gas-Oil ratio
Reservoir pressure
Saturation pressure 2235 psig
Monthly oil production
Number of Producing Wells
Cumulative oil production
3000
2600
2200
1800
2500
1500
500
160
120
80
40
0
50
40
30
20
10
2
1
110
100
90
70
60
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1957
1958
1959
1960
FIGURE 34

SHORT CREEK - MADISON POOL

DISCOVERY WELL
Northwest Oil Drilling Co. - #1 Bonnie B
SE SE 36-164-93
Spudded - 6 January 1957
Completed - 7 February 1957
Recompleted - 25 November 1957
Total depth - 6394 feet

DEEPEST TEST
Northwest Oil Drilling Co. - #1 Bonnie B
SE SE 36-164-93
Total depth - 6394 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6243 feet
Mud - 10.3#, vis 75, WL 6
Drilling time to completion - 31 days
Logs - Lateralog, Sonic
Casing program - 512 feet 9 5/8"/350 sax
6111 feet 5 1/2"/350 sax
Completion - 4 Jets/foot with 5000 acid

RESERVOIR DATA
Pressure datum - 3975 feet below sea level
Net thickness - 8 feet
Average porosity - 16%
Number of producing wells - 2
- flowing - 1
- pumping - 1

Number of dry holes drilled - 2
Cumulative production to 1/1/60
- Oil - 6,789 barrels
- Water - 638 barrels
- Gas - 8,388 SMCF

Cumulative GOR - 1236 cubic feet per barrel
Cumulative WOR - 0.094 bbls/barrel
Reservoir temperature - 195° F

CRUDE OIL ANALYSIS

Specific gravity - 0.8309
Percent Sulfur - 0.60
API gravity - 38.8°
Pour point - 20° F
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	3.0	
2	167	8.5	17
3	212	14.9	27
4	257	22.7	30
5	302	29.4	30
6	347	35.5	31
7	392	40.4	31
8	437	45.8	31
9	482	51.8	34
10	527	59.1	37

Carbon residue - 1.1%

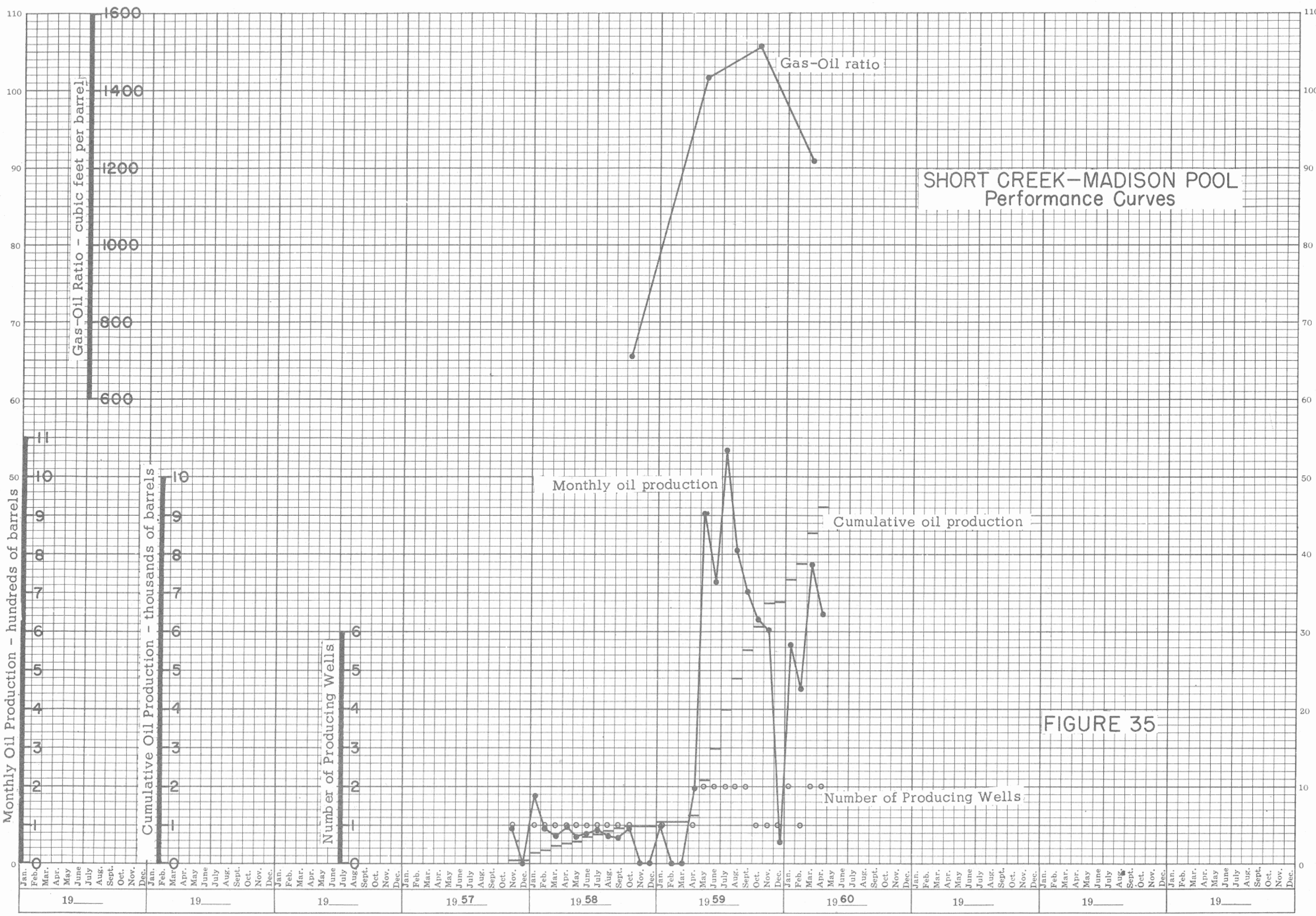

SHORT CREEK–MADISON POOL
Performance Curves
Gas-Oil ratio
Monthly oil production
Cumulative oil production
Number of Producing Wells
Gas-Oil Ratio - cubic feet per barrel
Monthly Oil Production - hundreds of barrels
Cumulative Oil Production - thousands of barrels
Number of Producing Wells
19 57
19 58
19 59
19 60

FIGURE 35

STONY RUN - MADISON POOL

DISCOVERY WELL
McAlester Fuel Company - A. Larson #1
NW SE 22-163-90
Spudded - 25 July 1958
Completed - 16 August 1958
Total depth - 5675 feet

DEEPEST TEST
Signal Drilling and Wilhite - A. Nelson #1
SE SW 22-163-90
Total depth - 6010 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 5796 feet
Bits used - 15 Rock bits, 2 Diamond core bits
Mud - Gyp base/Brinegel & Controloid
Drilling time to completion - 23 days
Logs - ML, GRN
Casing program - 500 feet 8 5/8"/375 sax
5660 feet 5 1/2"/250 sax
Completion - 4 Jet shots/foot and 4250 acid

RESERVOIR DATA
Orig. res. press. - 1630 psig
Pressure datum - 3600 feet below sea level
Net thickness - 10 feet
Number of producing wells - 1
flowing - 0
pumping - 1
Number of dry holes drilled - 4
Cumulative production to 1/1/60
Oil - 3,824 barrels
Water - 46 barrels
Gas - 5,346 SMCF
Cumulative GOR - 1398 cubic feet per barrel
Cumulative WOR - 0.012 bbls/barrel
Reservoir temperature - 134° F

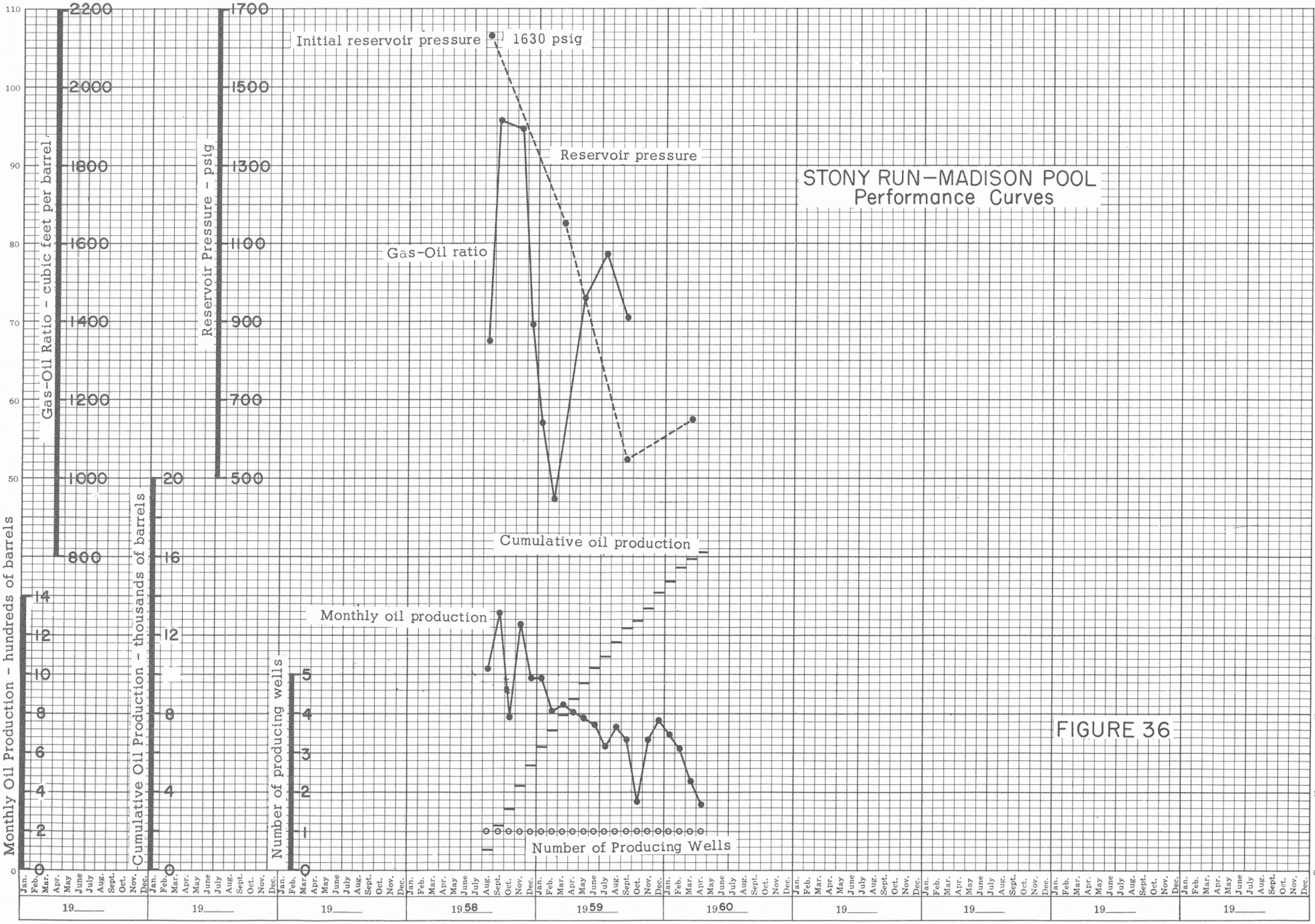

STONY RUN–MADISON POOL
Performance Curves
Initial reservoir pressure 1630 psig
Reservoir pressure
Gas-Oil ratio
Cumulative oil production
Monthly oil production
Number of Producing Wells
Gas-Oil Ratio - cubic feet per barrel
Reservoir Pressure - psig
Monthly Oil Production - hundreds of barrels
Cumulative Oil Production - thousands of barrels
Number of producing wells
1958
1959
1960

FIGURE 36

WOBURN - MADISON POOL

DISCOVERY WELL
Central LeDuc Oils, Inc. - #1 T. Olson
NW NE 18-162-90
Spudded - 2 October 1957
Completed - 23 November 1957
Total depth - 6315 feet

DEEPEST TEST
Central LeDuc Oils, Inc. - #1 T. Olson
NW NE 18-162-90
Total depth - 6315 feet

TYPICAL DRILLING PROGRAM
Average drilling depth - 6030 feet
Bits used - 19 Rock bits
Drilling time to completion - 27 days
Mud - Gyp base
Logs - GR, LL, ES, Sonic, Induction, Mll
Casing program - 487 feet 8 5/8" or 10 3/4"/300 sax
5945 feet 4 1/2" or 5 1/2"/275 sax
Completion - 4 shots/foot/2500 acid

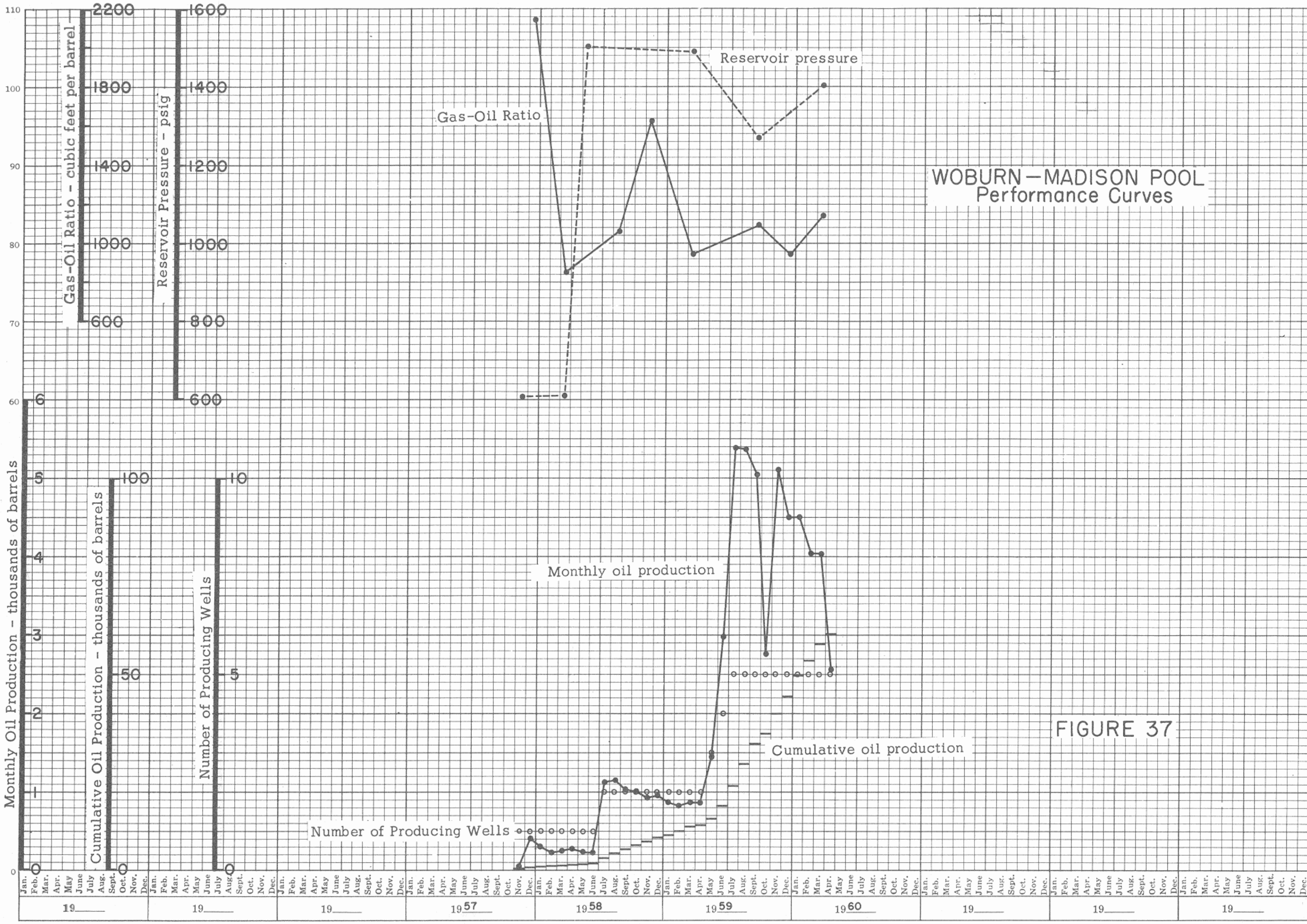
CRUDE OIL ANALYSIS

Specific gravity - 0.8251
Percent Sulfur - 0.47
API gravity - 40.0°
Color Brownish-green
Base Intermediate

Fraction	Cut at	Cum.%	C.I.
1	122° F	3.4	
2	167	7.6	16
3	212	15.5	27
4	257	23.7	30
5	302	29.6	31
6	347	35.1	30
7	392	40.8	29
8	437	45.5	30
9	482	52.8	33
10	527	58.3	36

Carbon residue - 0.9%

RESERVOIR DATA
Average porosity - 14.0%
Average connate water saturation - 58%
Average permeability - 0.4 md
Pressure datum - 3900 feet below sea level
Net thickness - 10 feet
Number of producing wells - 5
flowing - 3
pumping - 2
Number of dry holes drilled - 1
Cumulative production to 1/1/60
Oil - 44,338 barrels
Water - 7,503 barrels
Gas - 49,973 SMCF
Cumulative GOR - 1127 SMCF/barrels
Cumulative WOR - 0.169 bbls/barrel
Reservoir temperature - 138° F



WOBURN—MADISON POOL
Performance Curves

FIGURE 37