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The upper Red River Formation (Ordovician) in western North Dakota

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THE UPPER RED RIVER FORMATION (ORDOVICIAN) IN WESTERN NORTH DAKOTA

by

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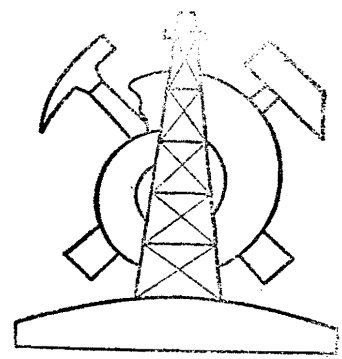

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The Nesson anticline and the basin hinge line were the most active structural areas affecting the deposition of upper Red River sediments. A knob of high relief on the anticline had a localized effect on sedimentation. Rapid thinning in all intervals of the Red River near the central part of the state indicate the effect of the hinge line. Other structural features defined on isopachous maps include the Mercer High, Divide Low, Ward High, and Billings Nose.

X-ray and microscopic analysis of selected samples of cores from the upper Red River Formation indicate that the main porosity zones consist primarily of secondary dolomite.

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Oil accumulations in the Red River Formation are primarily in structural traps, but local changes in lithology and grain size

which probably cause permeability barriers, also affect the traps. Favorable areas in western North Dakota appear to be in relatively unexplored McKenzie and Billings Counties, just east of the prolific Red River fields in Montana.

INTRODUCTION

General

New oil discoveries in the past two years in the Ordovician Red River Formation have spurred extensive drilling to that rock unit throughout the Williston Basin. Four new fields in North Dakota and a very prolific field in eastern Montana have greatly increased the economic importance of the formation. Increased drilling has resulted in an abundance of new information on the Red River Formation and has facilitated the present study of the upper rock units that contain the main productive zones.

The purpose of this study was to map the upper units in the Red River Formation in western North Dakota and to determine the composition and texture of the main porosity zones. An attempt was made to determine the major factors controlling sedimentation in the Red River that could possibly have affected oil accumulation. Also, it is the intent of this paper to present all pertinent information regarding the producing horizons of the Red River Formation in North Dakota.

Prior to 1966, only pools in the Cedar Creek and Beaver Lodge Fields produced major quantities of oil and gas from the Red River Formation. The distribution of all Red River pools, the area of study, and the areal extent of the upper Red River Formation is shown in Figure 1. The area of study was the western portion of North Da-

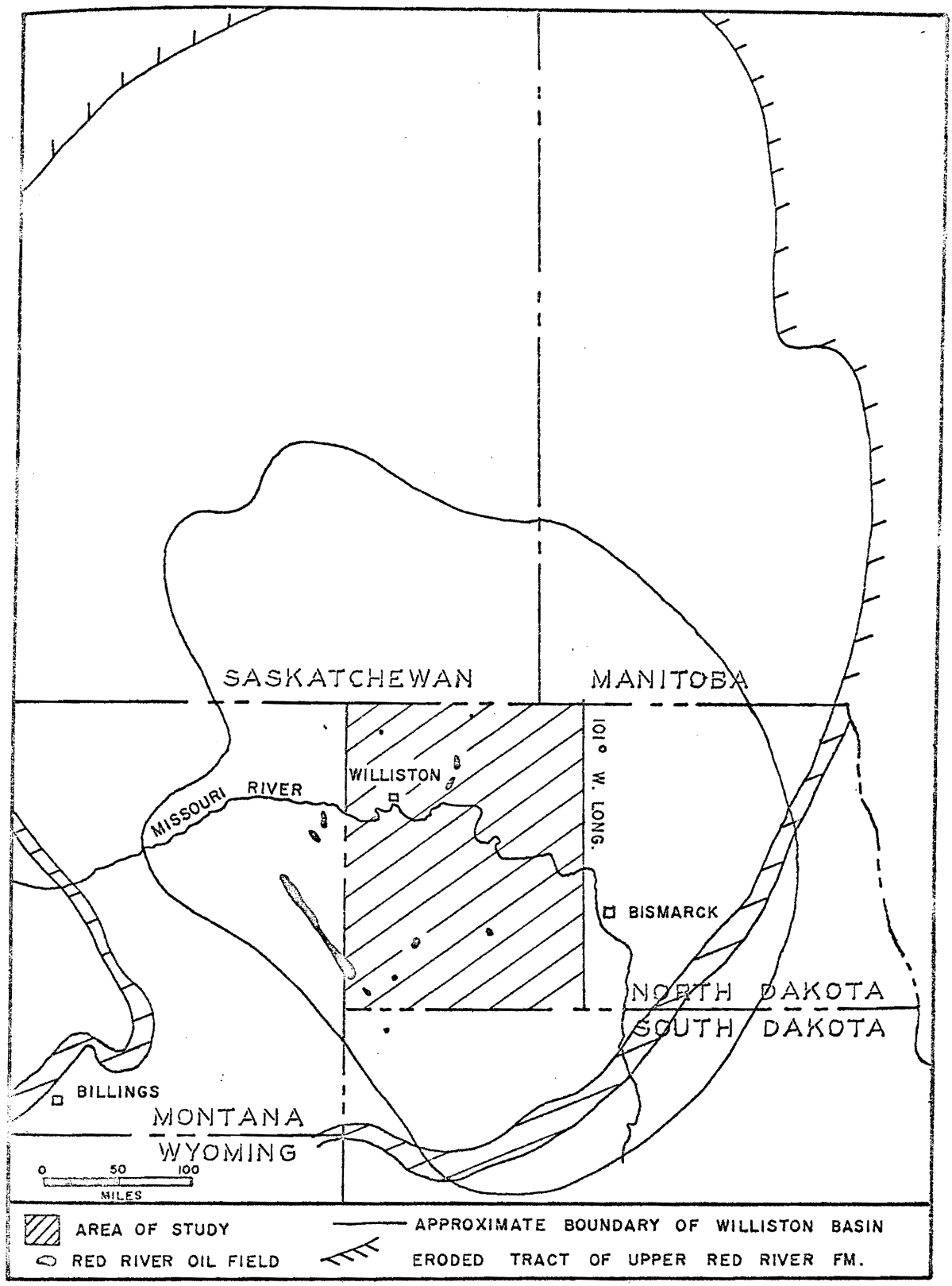


FIGURE 1.- INDEX MAP SHOWING AREAL EXTENT OF UPPER RED RIVER BEDS AND LOCATION OF RED RIVER OIL FIELDS.

kota, approximately from the 101° W. longitude line, with the exception of a few wells in Bottineau County extending east of that line, to the Montana border. Plate 1 shows the well control used in this study.

Methods of Study

Mechanical logs of approximately 90 wells that penetrated the Ordovician Red River Formation in western North Dakota were used in this study. Gamma ray and laterologs were used where possible because they provide the best definition of the strata; they were available for most wells. Other logs used were the spontaneous potential, electrical, neutron, sonic, induction, and microlaterologs.

Six cross sections using the top of the Red River Formation as the datum were constructed to show the correlation of the unit throughout western North Dakota. A structural cross section through the Tioga and Beaver Lodge Fields was also prepared, using sea level as datum. A structure contour map was constructed on the top of the Red River Formation. Isopachous maps were made of each of three intervals, as well as of the complete upper Red River.

Cored sections from six wells were described using a binocular microscope and descriptions of these sections are included in the appendix. Using the lithologic information from the cores, well completion cards, and mechanical logs, a fence diagram of the upper Red River Formation was constructed (Plate 16).

Sixty thin sections were prepared from cores of twenty wells to study the texture and composition of the various units. Photo-

micrographs of selected thin sections were made to illustrate some of these properties.

X-ray analyses of 180 selected samples provided a description of the mineralogic composition of the upper Red River units. Sample depths of the cores were selected from gamma ray-laterologs. Approximately 30 samples from well cuttings and 150 samples from cores were used in this analysis.

PREVIOUS WORK

The name, "Red River Formation," was applied by Foerste (1929) to the carbonate rocks between the underlying Winnipeg Formation and the overlying shale of the Stony Mountain Formation. Foerste subdivided the formation into three members called the Dog Head, Cat Head, and Selkirk, in ascending order. These terms are still used in outcrop areas of Manitoba (Andrichuk, 1959, p. 2357). However, in the subsurface of the Williston Basin, the Red River Formation is divided (Fuller, 1961, p. 1347) into two major units: a lower dolomitic limestone unit and an upper evaporitic, cyclic unit of dolomite, limestone, and anhydrite.

After 1928, most literature has proposed that the limestones and dolomites in the continental interior, variously called Bighorn, Fish Haven, Fremont, Red River (formerly Trenton) and Whitewood belonged to the Upper Ordovician (Cincinnati Series, Richmondian Stage).

Andrichuk (1959) described in detail the Red River Formation in the subsurface of southern Manitoba. He divided it into three main lithologic units: a basal limestone, an intermediate dolomitic limestone and secondary dolomite and an upper dolomite.

Porter and Fuller (1959), in their paper on the lower Paleozoic rocks of the Williston Basin, subdivided the upper Red River Formation into three cyclic units. They recognized three phases

within each unit, which are, in ascending order: (1) fragmental limestone, (2) argillaceous dolomite, and (3) anhydrite. They stressed the importance of the argillaceous marker beds in correlation since they can be traced throughout a large part of the Williston Basin. They are thus useful in subdividing the formation and in tracing its various units.

Fuller (1961) separated the lower from the upper Red River, using an argillaceous bed which has a distinctive "kick" on the gamma ray log. This marker bed separates two different sequences of sedimentation, marine limestones below and evaporitic rocks above.

The beds of the Red River had long been considered to be Upper Ordovician, based on work by Foerste (1929) and Okulitch (1943). However, Fuller (1961, p. 1362) considers it to be Middle Ordovician based on its correlation and continuity with the Viola Formation in Nebraska, which is accepted as Middle Ordovician in age. He regards the conformably overlying Stony Mountain Formation as Upper Ordovician and, referring to the contact between the two, he states:

> The successively thinner deposits of the sedimentary rhythms and the shrinking spread of evaporite both point to a decline in the rate of basin subsidence, and the abrupt incursion of Stony Mountain shale seems to have halted, at any rate temporarily, the recurrence of evaporite. This junction is important because it separates Middle Ordovician (Viola-Trenton) from Upper Ordovician (Cincinnati-Sylvan).

Fuller (1961, p. 1354) constructed cross-sectional diagrams to demonstrate graphically the continuity of Red River strata from South Dakota to the Manitoba outcrop area. He demonstrated the continuity of the Red River strata between these areas and concluded that it is the same stratigraphical age at both places.

Extending the Red River Formation in the opposite direction from South Dakota to Nebraska over the Sioux arch, he showed by facies distribution and gradients of depositional thickening that the Red River of South Dakota was in the past stratally continuous with and limited by the same boundaries as the Viola of Nebraska. Thus, he also concluded that the Red River and Viola are alternative names for the same deposit.

STRATIGRAPHY

Lower Red River Formation

Approximately forty wells in western North Dakota have been drilled through the lower Red River Formation and only a few have been cored in that interval. The lower Red River was not studied in detail for this report, but a brief description of its thickness and lithology is given here. Porter and Fuller (1959, p. 146) described that interval as ". . . several hundred feet of fragmental, dolomitic, marine limestone containing numerous fossils in the central part of the basin." Fuller (1961, p. 1345) constructed an isopach map of that unit which showed the thickest development to be in central and west-central North Dakota. It thins very gradually eastward until truncated by post-Silurian erosion. To the northwest it thins much more rapidly and in Divide County, the total Red River is only 430 feet thick.

Fuller separated the lower Red River from the upper at the top of the evaporite bed which he called the "Q" horizon. This horizon is easily picked on gamma ray logs because of its high radioactivity compared to the rest of the formation. However, in this paper, the division between the upper and lower Red River beds is made at the base of the lowest main porosity zone in the central part of the Williston Basin. The formation was divided here because it is the base of the P-cycle rocks which will be defined in the

next section. The base of the porosity zone can also be correlated reasonably well throughout western North Dakota. All the major producing zones in the formation are included in the upper part, so most Red River wells are drilled just below the base of the P-cycle rocks, or upper Red River as here defined.

Despite the generally dense character of the lower beds, two distinct porosity zones are present in that interval in western North Dakota. In the Tioga and Beaver Lodge Fields, one porous zone informally termed the "F" zone, occurs at a depth of 270-300 feet below the top of the Red River (Plate 15). It is 25-40 feet thick and produces oil in the Tioga Field, the first production from that zone in the state. The "F" zone can be traced into the southwestern part of the state where it is defined only by a slight decreased in resistivity on the laterolog curve. Where relatively porous, it consists primarily of dolomite, but more commonly is a dense dolomitic limestone.

The other porous zone in the lower Red River, termed the "E" zone, occurs approximately ten feet below the base of the upper Red River beds (Plate 2). Where porous, it also consists of dolomite and is best developed in the southwestern portion of the state.

Upper Red River Formation

General

The upper Red River Formation can be divided into three major cyclic units called the P, R, and F cycles, in ascending order. In this paper, they will be referred to as intervals. These

cycles were originally described and defined by Porter and Fuller (1959, p. 153). They subdivided each cycle into three phases, which are, in ascending order: (1) fragmental limestone, (2) argillaceous dolomite, and (3) anhydrite. These units are also recognized in this paper, but log tops of each unit may not correspond identically with those of Porter and Fuller. Within the P, R, and F units, four principal porosity zones are recognized. They are termed the "A," "B," "C," and "D" zones, in descending order, and were originally used and defined by geologists of the Amerada Petroleum Corporation. The terms "E" and "F" were named by the author for the porosity zones in the lower Red River Formation. A typical log of these units and the porosity zones are shown in Plate 2.

The thickness of the combined units of the upper Red River ranges from 120 feet in northeastern Bottineau County to 264 feet in northeastern Dunn County (Plate 4). A cross section illustrates the rapid thinning of the upper Red River beds to the northeast (Plate 14). An isopach map (Plate 4) of these units shows a gradual thickening toward the central part of the Williston Basin, but marked thinning over the Nesson anticline. Near the eastern edge of the study area, it thins rapidly eastward along a north-south trending wedge edge through the central part of the state.

A fence diagram of the upper Red River Formation was constructed to show the stratigraphic relationships in western North Dakota (Plate 16). It illustrates the uniform and persistent nature of most of its units.

P Interval

The P interval can be divided conveniently into two major units on mechanical logs. The lower unit is the Pu (undifferentiated), which consists of interbedded dolomite, dolomitic limestone, and limestone. It is the most variable of the upper units, typically changing facies over very short distances in some areas. The upper unit, called the P_3, is an evaporitic bed consisting of anhydrite and dolomitic anhydrite.

A lithologic description of the P interval rocks is given here. The rocks are described from core chips from one-foot intervals in the Phillips #A-1 Hoehn well, NE SE Sec. 13, T. 152 N., R. 102 W., McKenzie County, North Dakota. A log of this well is shown in Figure 2. Sample depths are adjusted to mechanical log depths.

Cores:

P interval

13646-49	Dolomite, dark gray brown, cyrptocrystalline, anhydritic, dense.
13649-51	Anhydrite, dark gray, cryptocrystalline, dolomitic.
13651-62	Dolomite, medium brown, microcrystalline, dense, anhydritic.
13662-69	Dolomite, dark gray brown, microcrystalline to cryptocrystalline, anhydritic, algal structures.
13669-84	Dolomite, tan to medium gray brown, microcrystalline, finely bedded, dark layers of carbonaceous material, calcareous oolitic structures, few fossils.
13684-86	Dolomite, medium brown, microcrystalline to crystalline, poor porosity, fractures fill with anhydrite crystals.
13686-90	Dolomite, dark gray, microcrystalline, algal structures, calcareous.
13690-92	Dolomite, dark gray brown, cryptocrystalline, dense, anhydritic, abundant carbonaceous material.

13692-94	Dolomite, light-medium gray brown, crystalline, poor porosity, finely bedded.
13694-701	Dolomite, tan, crystalline, fair intercrystalline porosity, oolitic, slightly calcareous, some carbonaceous material.
13701-02	Limestone, dark gray brown, microcrystalline, dense, argillaceous.
13702-03	Limestone, tan, microcrystalline, with large chert nodules.
13703-04	Dolomite, tan, crystalline, oolitic, good porosity.
13704-07	Dolomite, dark gray, crystalline, dense, with scattered vugs filled with carbonaceous material.
13707-10	Limestone, tan, crystalline, to granular, fair to good porosity, black carbonaceous material, appears to be dead oil, becoming dolomitic at 09 feet.
13710-16	Dolomite, tan-medium brown, granular to microcrystalline, fair to good porosity.
13716-22	Dolomite, medium gray brown, crystalline, fair porosity.
13722-24	Dolomite, medium to dark gray, coarsely crystalline, large oolite-pisolite of dolomite, calcareous cement.
13724-33	Dolomite, dark gray, crystalline to granular, fair porosity, fractures filled with carbonaceous material and calcite crystals.
13733-36	Dolomite, black, microcrystalline, quite dense, becoming very shaly.
13736-46	Dolomite, medium to dark gray brown, microcrystalline, fairly dense.
13746-50	Dolomite, dark gray, microcrystalline, mottled with light gray dolomite, some pyrite and anhydrite crystals at 47 feet.
13750-54	Dolomite, dark gray, crystalline, calcareous, with pieces of woody material.
13754-59	Dolomite, dark gray, crystalline, mottled, anhydrite crystals.
13759-60	Limestone, dark gray, microcrystalline, with large crystals of calcite.

13760-61 Dolomite, medium brown, crystalline, mottled.

13761-65 Limestone, dark gray to black, microcrystalline, dense.

Fuller (1961, p. 1348) placed an arbitrary lower boundary on the P rhythm carbonates but stated that they were about 130 feet thick near Williston, North Dakota, which corresponds to this writer's thickness (Plate 5). In this report the base of the P interval was chosen at the Phillips #A-1 Hoehn well on the lowest porosity zone on the laterlog (Figure 2). Surrounding wells were correlated with it and the lower boundary of the P interval was then traced throughout western North Dakota.

Fuller, p. 1348, described the P rocks as follows:

> . . . in the central part of the basin they contain an abundance of fragmented organic material, mainly remains of bryozoans, corals, crinoids, and brachiopods in a strongly mottled dolomitic limestone matrix . . . . Mudstone and pseudo-oolitic rocks are increasingly numerous nearer the top of the section and seem to represent a phase of precipitation close to the final deposit of compact, very finely crystalline bedded anhydrite, much of which is interlaminated with dense anhydritic dolomite.

The Pu interval in the eastern portion of the study area consists of a fine grained dolomite which has a low resistivity on electric logs. Cross sections E-E' (Plate 13) and F-F' (Plate 14) show the transition from an interbedded dolomite-limestone sequence to a fine grained dolomite on the east flank of the basin. All wells east of a line trending parallel to the periphery of the basin, approximately 40 miles west of the basin hinge line (Figure 3), contain this type dolomite in the Pu unit (Plates 13 and 14).

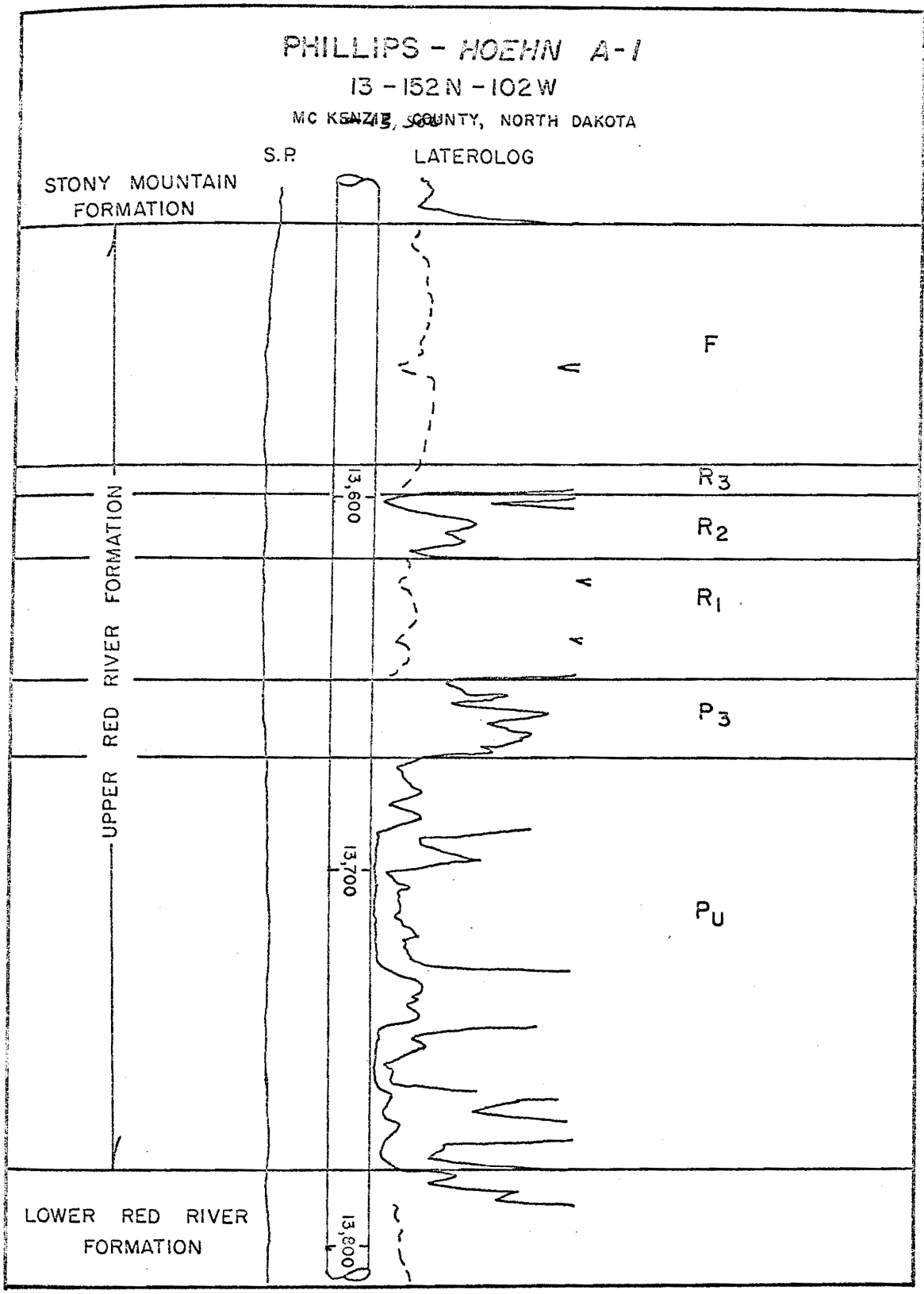


FIGURE 2. — SELF POTENTIAL AND LATEROLOG SHOWING UNITS OF UPPER RED RIVER FORMATION DESCRIBED FROM CORE CHIPS IN TEXT.

In the central portion of the basin, the Pu interval typically consists of a basal dolomite averaging 30 feet thick with thin interbeds of limestone. This unit is characteristically porous and is termed the "D" zone. It is a major producing horizon in the Red River Formation in Tioga and Beaver Lodge Fields. Minor amounts of oil in the Fryburg and Eleven Bar Fields produce from this zone.

Overlying the "D" zone is a dense limestone which varies from 25 to 45 feet in thickness. This unit can be observed on Plate 13 in the three wells 3588, 4280, and 4075, in the western part of the cross section, as a highly resistive bed on the laterolog. However, within this unit, rapid facies changes occur in some areas, such as in the Eleven Bar Field. In the Hunt #1 N.P.R.R., the "D" zone consists of dense, microcrystalline limestone but in the Hunt #3 N.P.R.R., just 2 1/2 miles southeast, it consists of a porous, granular dolomite (Plate 13, wells 4075 and 4241). This dense limestone probably acts as an upper seal for oil in the "D" zone below, in the producing wells.

The upper part of the Pu unit consists of alternating dolomites and variably dolomitized limestones, which vary in thickness and porosity. It is termed the "C" zone and is the major producing zone in the Ordovician-Tioga discovery well, Amerada #2 Lalim, NE NE Sec. 35, T. 158 N., R. 95 W.

Overlying the Pu unit is the P_3 anhydrite, which is an effective seal for oil in the Pu unit. At the top of this unit is the argillaceous bed with its distinctive "kick" on the gamma ray log, making it an easy correlation point throughout most of the Williston

Basin. This anhydrite unit is present in all of western North Dakota but pinches out near the eastern edge of the study area (Plate 14). Its average thickness is 18 feet but reaches a maximum of 25 feet.

In the southwestern part of the state, the P_3 unit consists of two thin anhydrite beds separated by a dolomite bed (Plate 13, wells 3588, 4280, and 4075). Porter and Fuller (1959, p. 152) called the lower anhydrite P, and the upper, Q. North and east of this area, the two anhydrite beds merge, forming one single unit of anhydrite. However, near the central part of the basin, the P_3 is predominantly a dense, anhydritic dolomite interlaminated with dense, microcrystalline anhydrite.

Plate 5 is an isopachous map of the P interval in western North Dakota. It shows that this interval thins more rapidly in the eastern part of the study area and has been affected by numerous high areas. In the central portion of the basin, its thickness is very uniform over a wide area.

Depositional environment of the Pu rocks was similar to that of the lower Red River which was a shallow sea occupying a steadily subsiding basin. It is suggested that the fine grained dolomites of the Pu unit in the eastern part of the study area represent a shelf type, penesaline environment. Sloss (1955, p. 145) said this environment is characterized by deposition of evaporitic carbonates, chiefly primary dolomite, interbedded with anhydrite. The dolomite is typically dense, unfossiliferous, light in color, and finely laminated. This appears to correspond to the Pu dolomite in the eas-

tern portion of the Williston Basin. The Pu unit in the central portion of the basin was deposited in epicontinental marine areas of normal salinity with unrestricted circulation. The rock types are typically fossiliferous and fragmental limestones and their dolomitized equivalents.

Cumming, et al., (1959), stressed the environmental importance of the persistent, argillaceous marker beds that occur above and below the anhydrites and termed them non-sequential beds. They interpreted them to represent clastic interruptions in a rhythmic carbonate and sulfate succession, caused possibly by diastrophic pulses which terminated widespread standstill in sedimentation. The clastic materials found in this very thin zone consist of shale chips, dolomite pebbles, chert, and sand grains. Cummings, et al., (p. 729) stated: ". . . without perceptible change the clastic seams cross the facies boundaries of the preceding sequences and behave as microbasal conglomerates to the succeeding sequences. For these reasons they are termed non-sequential."

Porter and Fuller (1959, p. 173) suggested that the possible source of the argillaceous material, which was spread persistently over a very wide area in the basin, was the Sioux upwarp, along the southeastern margin of the basin.

R Interval

The R interval consists of three cyclic units called the R_1, R_2, and R_3 units. The thickness of the interval is relatively uniform in the central portion of the basin, averaging 60 to 65 feet (Plate 6). Its center of accumulation is near the Dunn-Mercer County

border, with a maximum thickness of 68 feet. In western McKenzie County, the R interval also reaches 68 feet, which appears anomalous for that area (Plate 9).

The following is a lithologic description of core chips in the R interval at one-foot intervals in the Phillips #A-1 Hoehn well, McKenzie County:

Cores:

R interval

R_3:	13591-98	Anhydrite, dark gray, microcrystalline, dolomitic, becoming pure anhydrite at 94.
	13598-600	Anhydrite, dark gray, microcrystalline, finely interbedded with dolomite, pure anhydrite at 99.
	13600-02	Limestone, dark gray, crystalline, fair intercrystalline porosity.
R_2:	13602-10	Dolomite, tan, finely crystalline, finely bedded, fair intercrystalline porosity.
	13610-17	Dolomite dark gray brown to black, microcrystalline to cryptocrystalline, scattered with black organic material, lithographic at 12.
R_1:	13617-19	Limestone, dark gray brown to black, microcrystalline, very carbonaceous.
	13619-27	Limestone, dark gray brown, cryptocrystalline, with calcite crystals.
	13627-42	Limestone, medium to dark gray brown, microcrystalline, abundant calcite crystals filling vugs, fossil brachiopods at 29.
	13642-48	Dolomite, dark gray brown, dense, microcrystalline, calcareous.

The average thickness of the R_1 unit is 35 feet, but decreases anomalously to 22 feet in central McKenzie County (Plate 10). In the central part of the basin, the R_1 unit consists of dense, fossiliferous, fragmental limestone which is very carbonaceous. It has

a distinctively high, uniform resistivity on the laterolog curve in most areas of western North Dakota (Plates 11 and 13). However, in Divide County, the R_1 unit thins to less than 20 feet and changes in lithology to a more porous unit (Plate 10, wells 2010 and 1546). It is rather difficult to correlate all R and P units in these wells with other wells in western North Dakota.

Overlying the dense limestones of the R_1 unit is a porous dolomite bed called the R_2 unit, also referred to as the "B" zone. It consists of predominantly recrystallized, secondary dolomite having relatively high porosity. It can be traced consistently throughout all of western North Dakota, varying in thickness from 10 to 15 feet, as seen on all cross sections. Its comparatively low resistivity, uniform thickness, and stratigraphic position above the dense R_1 limestones makes it easy to correlate. In the Cedar Creek (Bowman County), Eleven Bar (Slope County), and Buffalo Creek (Stark County) Fields, it is the major producing horizon and has produced more oil in North Dakota than all other Red River zones.

The R_3 unit is an anhydrite bed that overlies the porous R_2 dolomites and acts as the upper seal for any oil occurring in that zone. It also is quite uniform in thickness, averaging 10 feet, but reaches a maximum of 20 feet in southern McKenzie County. Apparently this thickening occurs where the R_1 unit thins, as in the Shell-State #32-16-1, well 2584 (Plate 10). The R_3 anhydrite is not as extensive as the P_3 anhydrite and pinches out in the eastern edge of the study area (Plate 13). Its eastern limit is approximately along a north-south line from Canada to South Dakota passing through Minot, North Dakota.

F Interval

The F interval is the uppermost unit of the Red River Formation. The isopach map of that interval (Plate 7) shows that it uniformly thickens toward the center of the basin. In the easternmost edge of the study area it thins to only 9 feet from a maximum of 69 feet on the east flank of the Nesson anticline.

A lithologic description of the F interval from the Phillips #A-1 Hoehn well is given here:

Cores:

F interval

13520-30	Limestone, dark brown to black, microcrystalline to cryptocrystalline, very argillaceous, platy, fossil brachiopods, pyritic.
13530-46	Limestone, dark gray brown, cryptocrystalline, very dense, fossil brachiopods at 32, chert at 45.
13546-65	Limestone, dark brown. microcrystalline, fractures filled with anhydrite, pyritic at 49, very carbonaceous at 63.
13565-67	Anhydrite, dark gray, dense, cryptocrystalline, becoming dolomitic at 66.
13567-70	Dolomite, medium brown, microcrystalline, poor intercrystalline porosity, finely laminated.
13570-91	Limestone, dark brown to black, cryptocrystalline, calcite crystals.

The F interval consists of predominantly dense, carbonaceous dark brown to black limestone with abundant brachiopods near the top. In west-central North Dakota (Plate 11), a thin argillaceous dolomite bed, 3 to 5 feet thick, occurs at the base of the interval followed by the dense limestones. Approximately in the middle of the interval, a dolomite bed, 5 to 10 feet thick, is marked by a

decrease in resisitivty on the laterolog curve. It is called the "A" zone, the uppermost porosity zone in the Red River Formation. This zone is best developed away from the center of the basin and is most important in the Cedar Creek Field where it is a major oil producing horizon (Plate 9).

In the eastern portion of the study area, the "A" zone migrates upward in an easterly direction, occurring at the top of the formation in the Cardinal #1 Bierwagen, SW NE Sec. 1, T. 133 N., R. 90 W., Grant County. The upward migration of this zone can be traced from west to east on cross section C-C', Plate 11.

A thin anhydrite bed, 2 to 5 feet thick, is also present in the F interval as seen in cores, but is not traceable on mechanical logs. Fuller (1961, p. 1350) outlined its areal extent, which is limited to the northwestern corner of North Dakota.

The uppermost part of the interval is dense limestone overlain conformably by the Stony Mountain Formation. In the interior part of the Williston Basin, the Stony Mountain consists of about 75 feet of very dark gray and brown, argillaceous limestone with interbedded shale (Fuller, 1961, p. 1349). The high radioactivity shown on the gamma ray curve provides a good marker for the two formations.

The range of rock types in the R and F intervals is similar to those in the P interval, but deposits are thinner. It is likely that the F interval pinches out a short distance east of the study area in central North Dakota. Fuller (1961) suggests that the successively thinner deposits of the sedimentary rhythms and the shrinking evaporites indicate a decline in the rate of basin subsidence.

STRUCTURAL ELEMENTS

General

The major structural element in North Dakota is the Williston Basin, which had its inception in Middle Ordovician time (Sandberg, 1964, p. 37). In Red River time, it was a rapidly subsiding, intracratonic basin surrounded by a wide stable shelf, covered by shallow waters of a huge epicontinental sea. According to Sandberg (1962, p. 116), the dominant structural grain trends N. 30° W., and secondary structural grains trend N. 55° to 60° E. and N. 2° E. Many linear structural features within the Williston Basin trend roughly in one of these directions.

Other major structural elements affecting Red River sedimentation in western North Dakota were the Nesson anticline and the basin hinge line defined by Ballard (1963, p. 32). Minor structural features included the Mercer High, the Ward High, the Divide Low, and the Billings Nose. Figure 3 shows the location of these structural features in western North Dakota.

The structure contour map drawn on top of the Red River Formation (Plate 8) indicates a gradual dip of approximately 60 to 80 feet per mile toward the center of the basin. Dips appear to be slightly greater on the eastern flank of the basin than elsewhere inside the hinge line.

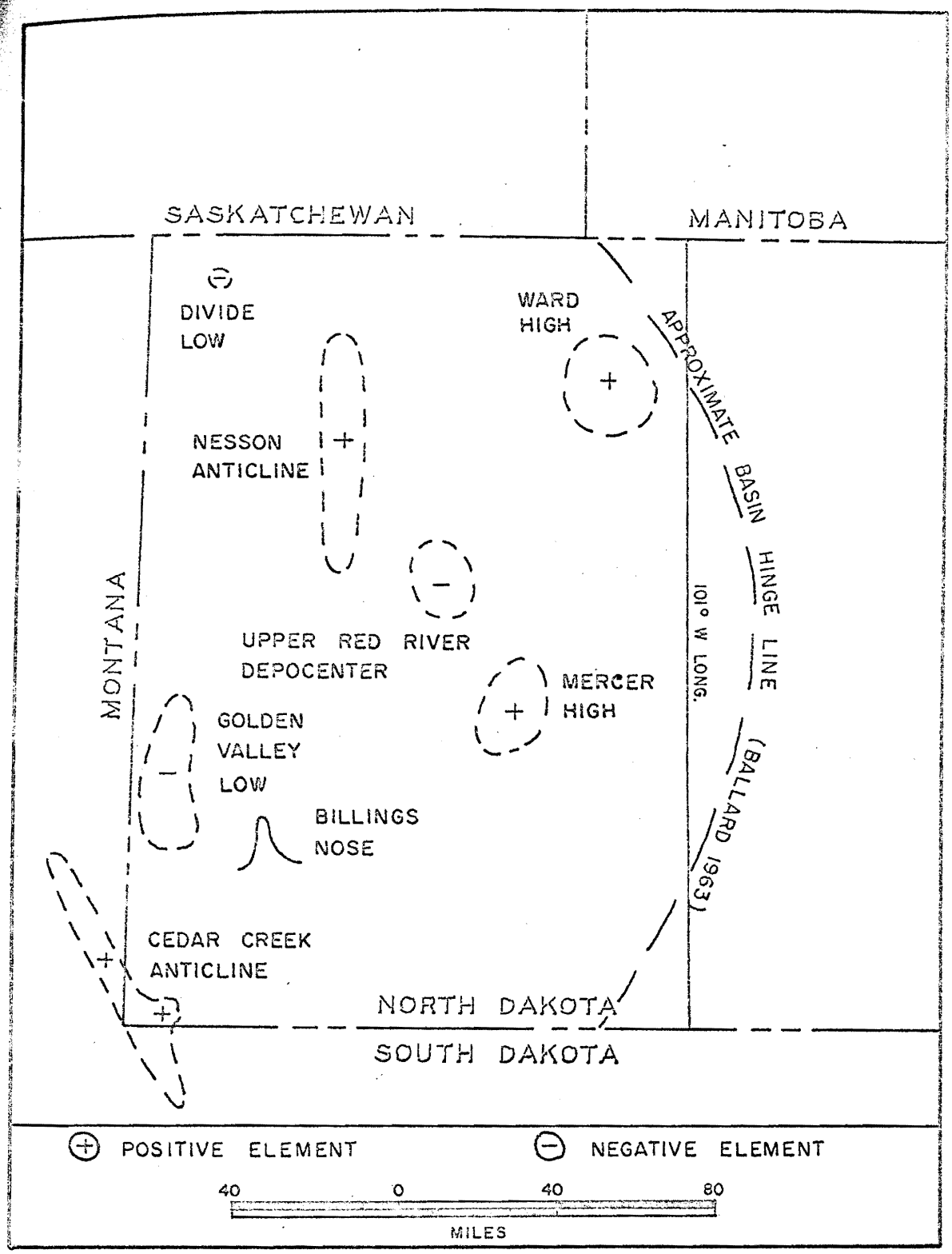


FIGURE 3. – LOCATION MAP SHOWING POSITIVE AND NEGATIVE STRUCTURAL FEATURES THAT AFFECTED UPPER RED RIVER SEDIMENTATION IN WESTERN NORTH DAKOTA.

The depocenter of the upper Red River Formation was in a broad area in northeastern Dunn County, where it reaches a maximum thickness of 264 feet in the Mobil Birdbear, SE NW Sec. 22, T. 149 N., R. 91 W. This was also the center of maximum accumulation during lower Red River time (Fuller, 1961, p. 1345). However, the structure map of the Red River (Plate 8) shows that the present structural center is located just a few miles east of Williston. This indicates that the basin center has migrated back to the west where it was during Winnipeg (Middle Ordovician) time. Ballard (1963, p. 35) shows the basin depocenter almost continuously migrating northwestward from Red River until Duperow (Upper Devonian) time, when it began migrating eastward.

Nesson Anticline

The Nesson anticline was apparently active during deposition of most of the upper Red River sediments. Thinning over the anticline in the P interval indicates that it was either undergoing slight uplift or retarded subsidence. A north-south structural cross section through Tioga and Beaver Lodge Fields of the Red River Formation illustrates the dramatic changes in both structural position and stratigraphy of that formation (Plate 15). The Tioga Field is the structurally highest field on the Nesson anticline, and the fields south of it are at progressively lower structural positions (personal communication, C. B. Folsom). It is interesting to observe in the Amerada #9 N. D. "A", well 1385, which is structually 162 feet low to the Amerada #1 Peterson-Davidson, the great change in facies of the P interval.

A cross section of two wells in Beaver Lodge Field illustrates the changes in thickness of the upper Red River intervals (Figure 4). It is suggested that the rapid facies change in the P interval and the thinned section in the Amerada #1 Iverson-Nelson well, reflect a very localized structural feature in the Precambrian basement rocks. The presence of a knob of high relief is evidence by the thinning of 600 feet in the sequence from the base of the Red River Formation to the top of the Precambrian in this well. This feature probably trends northeastward, which is the trend of both Red River and Madison-producing wells in the field. This knob or lineament has been periodically active throughout geologic time. However, the R interval thickens over this knob, indicating that uplift was temporarily halted, and the entire anticline appeared to be relatively inactive since there is only slight thinning over it. Renewed uplift occurred in the F interval, especially on the above localized structure where the interval thins 18 feet in only 1 1/2 miles.

Cedar Creek Anticline

The Cedar Creek anticline was apparently inactive during the deposition of all upper Red River sediments, as shown by the uniform thickness on all isopach maps. Sandberg (1964, p. 37) also suggests that the ancestral Cedar Creek anticline was inactive from Middle Ordovician until Late Silurian time and subsided with the rest of the basin during that time.

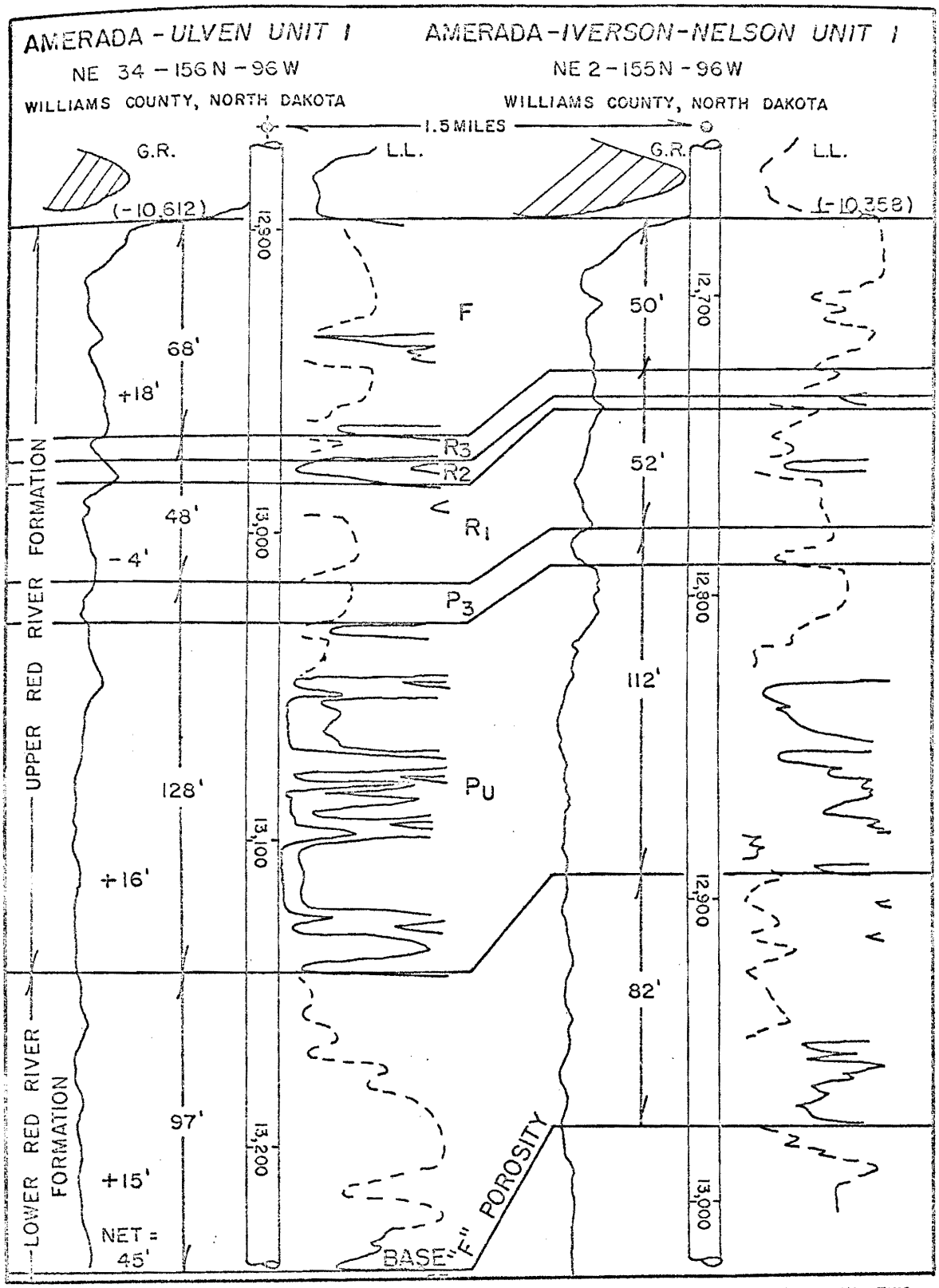


FIGURE 4. - CROSS SECTION SHOWING CORRELATION OF RED RIVER FORMATION IN TWO WELLS OF BEAVER LODGE FIELD. STRUCTURALLY HIGH PRODUCING WELL THINS IN ALL INTERVALS EXCEPT R WHICH THICKENS SLIGHTLY.

Basin Hinge Line

The basin hinge line defined by Ballard (1963, p. 32) possibly represents the junction between two Precambrian provinces which trend north-south through the central part of North Dakota. He noted that changes of facies commonly occur over the hinge line in several of the pre-Mississippian formations. This is apparently the case in the upper Red River. In the P interval, the limestones, dolomites, and evaporites in the deeper basin change facies updip to fine grained, dense dolomite. This change occurs in a line that roughly parallels the hinge line, but is west of it. Closer spacing of the contour lines on the isopachous maps of the three intervals and of the combined upper Red River suggests the effect of the hinge line on sedimentation. However, a study of the formation in central and eastern North Dakota would give a clearer indication of its effect at that time.

Laird (1964, p. 40) noted that structural trends west of the hinge line are generally north or northwesterly; east of that line they are northerly, northeasterly or almost east-west. He also suggested that these are lines of weakness that may have been reactivated periodically over much of geologic time. A possible example of this is the recent earthquake in south-central North Dakota in July, 1968, which had an intensity of 4.5 on the Richter scale.

Mercer High

A structural high of unknown size in south-central Mercer County, called the "Mercer High" is defined on the isopach of the P interval. The Kelly #1 Leutz, NW NE Sec. 28, T. 142 N., R. 89 W.,

Mercer County, shows a thinning of about 20 feet in the P interval. Dow (1967, p. 24) also found a positive area in western Mercer County that was defined by the presence of a "fenster" in the Minnekahta Limestone. Salisbury (1966, p. 37) found a thinning in west-central Mercer County in the Poe and Morrison Formations. Apparently, this structural high was periodically active during geologic time and may be related to movement in the basement rocks. Laird (1964, p. 41) showed numerous linear trends in south-central Mercer County and believes that these trends, regardless of age, reflect structural conditions in the Precambrian basement .

Ward High

The Ward High is located in northern Ward County and is best defined on the P interval isopach (Plate 5) by thinning of 20 to 30 feet. It is also reflected in the F interval and total upper Red River isopachs by a structural nose trending southwest-northeast. Fuller's isopach (1961, p. 1351) of the combined upper Red River and lower Stony Mountain Formation also shows a prominent structural nose in this area.

Divide Low

In western Divide County a small structural low is marked by thickened sections in the R and F intervals in the Pan American #1 Raum, NW SW Sec. 26, T. 162 N., R. 101 W. This well is also structurally 60 feet low to the well less than a mile from it. Apparently, it is a localized feature and was not active until after deposition of the P sediments.

Billings Nose

A prominent structural nose trending north-south through Fryburg and Eleven Bar Fields is present in southern Billings County. It is possible that this broad anticlinal structure extends into southern McKenzie County, as shown on the isopach of the upper Red River Formation (Plate 4). Anderson (1966) also noted a northward plunging anticlinal trend based on structure maps on the Fryburg Pay (Mississippian), Minnekahta Formation (Permian), and Mowry Shale (Cretaceous), extending through western Billings County. Salisbury (1966) found this trend reflected in structure maps of the Jurassic System. He informally termed it the "Anderson High." It appears that this anticlinal structure was most active during deposition of the R and F sediments (Plates 4, 6, and 7).

MINERALOGY

X-ray Analysis

Selected samples from the various units of the Red River Formation were X-rayed by the diffraction method to determine their approximate mineralogical composition. Using the gamma ray-laterolog as a guide, 150 core samples from 17 Red River wells were analyzed. One of these wells, the Amerada #1 Boe-Olson Unit, was cored through the complete upper Red River section. Results of the analyses for this well are shown on Plate 3, plotted opposite the zone sampled on the gamma ray-laterolog curve. Mineral composition is expressed in parts per ten since they were evaluated by an approximate, rapid, X-ray method (F. R. Karner, Dept. of Geology, Univ. of N. Dak.). Only minerals typically found in a carbonate section were analyzed, but did not give a representative composition due to the wide interval included in the sample as well as cavings; these results were omitted. Abundance of each constituent was calculated by comparing the relative height of the major peak of a mineral to that of a pure sample. All minerals present were then recalculated to total of approximately 100%.

From this study, the approximate composition, as well as the variation in composition of the upper Red River units was obtained. These results are shown in Table 2.

TABLE 1

MINERAL COMPOSITION OF UPPER RED RIVER
UNITS ANALYZED BY X-RAY METHODS

Well Name, Depth, Unit	Composition* Anhy.	Calc.	Dol.	Qtz.	Feld.
Amerada #1					
Iverson-Nelson					
12690 F		6	4	T	
12700 F	1½	2½	1½	4½	
12715 F	T	9	1		T
12735 R_2	T		10		T
12756 R_1		10	T	T	
12775 Base R_1	5½		4½		
12786 P_3	4		6		
12800 Pu	1½		8½		T
12830 Pu		T	9½	T	T
12850 Pu		T	9½	T	T
12875 Pu		½	9		T
12950 Low R.R.		1	9		T
Amerada #9					
N. D. "A"					
13176 F	T		10	T	T
13185 F		9½	½		
13194 R_3	6	2	½	1	
13215 R_2	T		9½		T
13230 R_1	½	8½	1	T	

Well Name, Depth, Unit	Composition* Anhy.	Calc.	Dol.	Qtz.	Feld.
Amerada #9					
N. D. "A"					
13250 R_1		8½	1	½	
13275 Pu	½		9½		T
13285 Pu			9½	T	T
13300 Pu	T	T	9½		T
Amerada #1					
Ulven Unit					
13040 Pu	2½		7½		T
13048 Pu			9½		½
13055 Pu			10	T	T
13065 Pu	T	T	9½	T	T
13073 Pu		4½	5½	T	T
13080 Pu		9	1	T	
13090 Pu	T	1	9	T	T
13100 Pu	T	T	9½		T
Amerada #1					
Bakken					
12980 Pu		½	9½		T
13000 Pu			9½	T	T
13020 Pu		T	9½	T	T
13034 Pu		6	4	T	

*Expressed in parts per ten
T = trace, less than 5%

TABLE 1--Continued

Well Name, Depth, Unit	Composition Anhy.	Calc.	Dol.	Qtz.	Feld.
Texas #1 Garland					
12997 R_2			9½	T	½
13020 R_1^2		10	T	T	
13040 P_3^1	8		1	T	
Amerada #1 Antelope A					
13110 F		7½	2½	T	
13130 F		5	3	T	
13145 F		10		T	
13150 F	T	9½	T	T	
13160 F	10				
13174 F	T	2	8		T
13180 R_2			9½		½
13195 R_2		9	1	T	
13225 R_1		6	4	½	
13240 P_3^1	9½	T		T	
13250 P_3^1	7		3		
13258 Pu			10		T
Texas #1 Donahue					
13860 F		9	½	½	
13880 F		7	2½	½	
13890 F	½	9½	T	T	
13898 F	9	T	1		
13920 F		7		T	

Well Name, Depth, Unit	Composition Anhy.	Calc.	Dol.	Qtz.	Feld.
Texas #1 Donahue					
13930 R_3	10				
13940 R_3	9				1
13960 R_1		10		T	
13975 R_1	1½	8	T	T	
13990 P_3	1		8½		T
14010 Pu	T		9½	T	
14020 Pu		9	½	½	
Shell #14-13-14					
8240 F	½	5	4½	T	
8275 R_2	T		9½	T	½
8290 R_1		8½	1	½	
8310 R_1	½	2	7½	T	T
8328 R_1	1	½		9	
8344 Pu	T		9½	T	T
8355 Pu			9½	T	T
8368 Pu		2	7½	½	T
8385 Pu	1	8½	½	T	
8410 Pu		10	T	T	
8451 Pu	T	5	5	T	
8464 Pu	½	6	3½	T	
Shell #42-3A-9					
8170 F		3	2	3	2
8180 F	T	1½	8	½	T
8195 R_3	3		5	½	1

TABLE 1--Continued

Well Name Depth, Unit	Composition Anhy.	Calc.	Dol.	Qtz.	Feld.
Shell #42-3A-9					
8235 R_1	½	2	7	T	½
8252 P_3	1	5	3½	½	
8280 Pu	4		5½	T	½
8300 Pu			10	T	T
8320 Pu	T		9½	T	T
8335 Pu	T	7	3	T	
8356 Pu	T	4	4½	T	1½
8378 Pu		4½	5	T	½
Samples analyzed by detailed X-ray method					
	Composition (100%)**				
Hunt #1					
USA-8					
11247 R_1		96	3	1	
11286 P_3	90		10		
11300 P_3	19		72	9	1
11332 Pu		88	9	3	
11370 Pu		84	14	2	T
11395 Pu		17	80	1	2
11400 Pu	T	1	89	4	6
11405 Pu		2	94	2	2
Hunt #3					
NPRR					
11375 R_2	4	1	91	1	3
Hunt #3					
NPRR					
11430 P_3	49		51		
11470 Pu			95	3	2
11525 Pu			96		3
11535 Pu			95		3
Carter #1					
N. Dak.					
6510 F	1	77	21	1	
6530 R_2	6	74	26	2	2
6560 R_1	2	91	5	2	
6640 Pu	3	2	87	6	2
6910 Low R. R.		56	41	1	2
Gulf #1					
B. Pierre					
12841 R_2	7		89	1	3
12939 Pu			99		1
12960 Pu		2	96	1	1
13000 Pu			95	1	4

**Composition (100%) X-ray analyses only

TABLE 2

APPROXIMATE MINERAL COMPOSITION OF
THE UPPER RED RIVER UNITS

Unit	Composition		
	Anhydrite	Dolomite	Calcite
F	0-5	30-35	55-60
R_3	70-75	15-20	0-5
R_2	0-5	90-95	0
R_1	0-5	20-25	65-70
P_3	85-90	5-10	0
Pu	0	75-80	15-20

A relationship can be seen between mineral composition and porosity (laterolog resistivity) in the Red River section (Plate 3). Zones of high porosity (low resistivity) are generally composed of a high percentage of dolomite; those with low porosity (high resistivity) are either limestone or anhydrite. The anhydrite can be distinguished by its stratigraphic position and the presence of marker beds above and below it on the gamma ray log.

Table 2 indicates that the anhydrite beds are typically associated with dolomites, which is a common relationship. The two major limestone units, the F and R_1, are typically of dolomitic limestone, containing 20-35 percent dolomite. However, the F interval contains the A zone, which is commonly a pure dolomite.

Microscopic Analysis

Sixty thin sections were prepared from cores of the upper Red River Formation to determine the texture and composition of these units. The X-ray analyses were used to aid in identifying

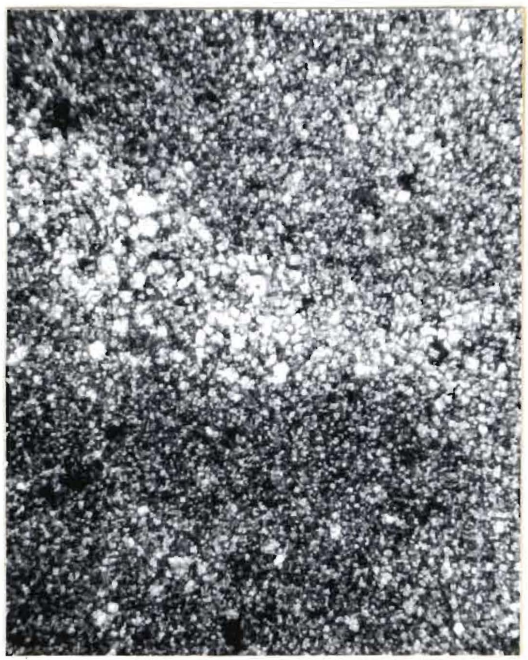
minerals in thin section. Selected thin sections were then photographed and are illustrated in Figure 5 and 6.

Porosity Development

From X-ray, microscope and sonic log studies, it is concluded that the greatest porosity in the Red River Formation occurs where secondary, rhombic dolomite has been formed. Values of porosity in some zones reach 25 percent, determined from the sonic log, but rarely exceed 20 percent. The "B" zone typically has the highest porosity of any zone and consists of 90-100 percent dolomite.

Murray (1960, p. 66) stated that, quantitatively the most important North American carbonate pore type in terms of oil and gas production is found in sucrosic dolomite. However, the origin of dolomite and the process of dolomitization has been a mystery of geology and is little understood. Deffeyes, et al. (1965) found dolomite being formed today in supratidal flats of arid climates in association with waters that have been evaporated to the stage of precipitation of gypsum. The significance of this is that the precipitation of gypsum causes a significant rise in the magnesium to calcium ratios of the waters, thus favoring the replacement of calcium carbonate minerals by dolomite. Thus, the common association of dolomite and anhydrite results.

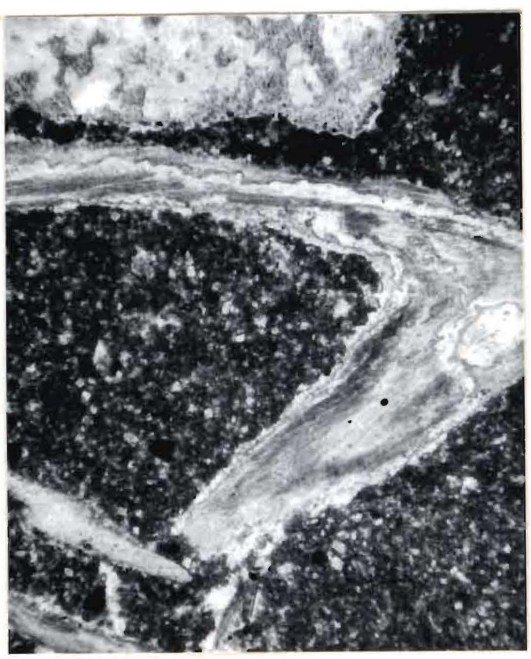
Weyl (1960) suggested that sucrosic dolomite is formed by the growth of randomly oriented, uniformly-sized dolomite euhedra, followed by dissolution of the nonreplaced calcite. Rocks that are undergoing dolomitization initially show a slight decrease in porosity until the dolomite crystals form a space-supporting framework.



1 mm

A.

B.



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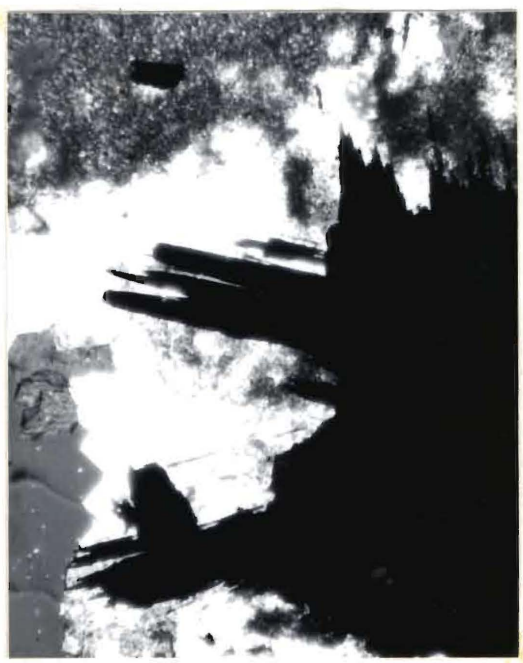
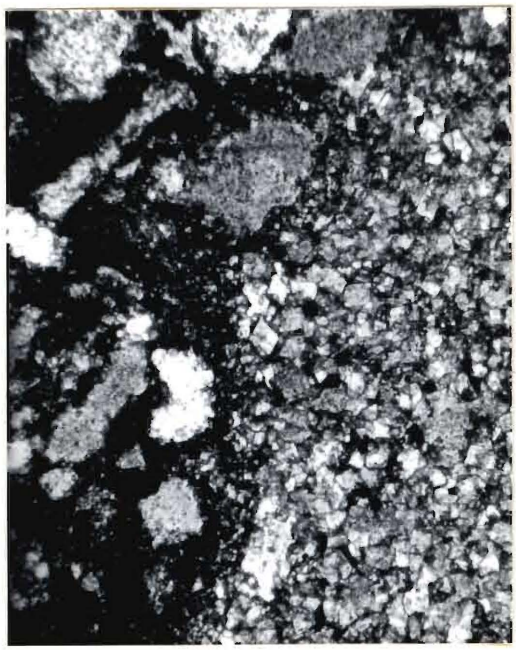
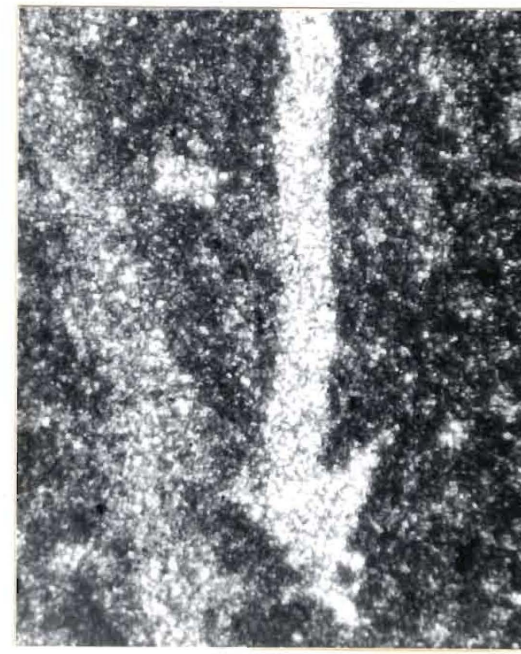


D.

Figure 5.--Photomicrographs of upper Red River cores.
A. Fine grained dolomite (Pu unit, A.P.C.-Ulven, 13,048').
B. Fossiliferous limestone (R_1 unit, Texas-Donahue, 13,975').
C. Anhydrite replacing fossil in dolomitic limestone (R_1 unit, Socony-Jacobs, 10,257').
D. Galena inclusion associated with anhydrite (white) in fine grained dolomite (Pu unit, Shell 42-3A-9, 8280').

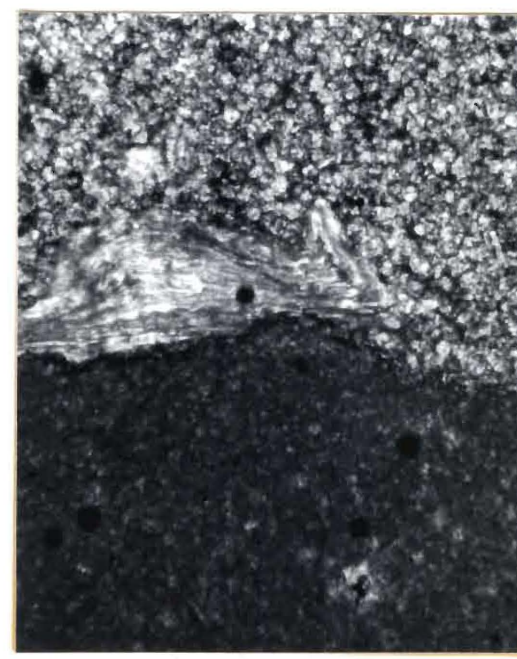


A.



B.

C.



D.

Figure 6.--Photomicrographs of upper Red River cores.

A. Coarse rhombic dolomite in contact with partially dolomitized fossiliferous limestone (Pu unit, A.P.C.-Ulven, 13,100').

B. Stringer of coarse dolomite in finer grained dolomite matrix (Pu unit, A.P.C.-Antelope A, 13,258').

C. Contact of dolomite and fossiliferous limestone (Pu unit, Shell 42-3A-9, 8378').

D. Contact of dolomite and limestone separated by anhydrite (Pu unit, Shell 14-13-14, 8410').

As the dolomite content increases, the porosity and permeability show a marked increase.

It is believed that the process of dolomitization is the most important process that formed the porous, secondary dolomite zones in the upper Red River Formation.

PRODUCTION HISTORY

General

There are presently eight oil fields producing from the Red River Formation in North Dakota and a ninth that was abandoned. The Red River discovery well was the Amerada #1 Iverson-Nelson Unit, NE Sec. 2, T. 155 N., R. 96 W., in Beaver Lodge Field, discovered on December 3, 1957, but originally completed as a dual producer in the Devonian and Silurian. The largest Red River oil field in North Dakota, the Cedar Creek, in Bowman County, was discovered in 1960 and has produced approximately 80 percent of the Red River oil in the state to date. However, with the discovery of four new fields in the past two years, their total monthly production now exceeds the monthly production from the Cedar Creek Field. The newly discovered Red River pool in Tioga Field, which is still being developed, could possibly surpass the Cedar Creek monthly production in the near future. Table 3 shows the production statistics for all Red River pools in North Dakota through May, 1968.

Total cumulative gas production from the Red River Formation through January 1, 1968, was 22,206,645 MCF, with 96 percent of that total produced from the Beaver Lodge Field.

TABLE 3

PRODUCTION STATISTICS FOR RED RIVER POOLS
IN NORTH DAKOTA THROUGH MAY, 1968*

Field	Wells	Discovery date	API Gravity	Approx. daily average/well	Total cumul. oil prod. (bbls.)
Beaver Lodge	3	Dec., 1957	54.2°	---------	644,216
Little Missouri	1	Jan., 1958	31.3°	20 BOPD	103,047
Writing Rock	1	Feb., 1958	34.0°	P & A	16,008
Cedar Creek	35	Feb., 1960	29.0°	50 BOPD	5,500,142
Fryburg	1	Apr., 1963	50.9°	16 BOPD	39,190
Eleven Bar	2	July, 1966	47.5°	130 BOPD	216,828
Buffalo Creek	1	Oct., 1966	49.0°	130 BOPD	86,669
Medicine Pole Hills	1	May, 1967	45.0°	28 BOPD	11,988
Tioga	3	Aug., 1967	50.1°	365 BOPD	135,862
TOTALS	48				6,753,947

*Information from Official Oil in North Dakota, May, 1968, North Dakota Geological Survey

Producing Zones

Lower Red River Formation

The first oil production from lower Red River beds in North Dakota was in the Amerada #B-1 Ives, in the Tioga Field, completed on January 2, 1968. It flowed 225 barrels of oil in 12 1/4 hours after being perforated and acidized in the "F" zone. The only other well that has been tested in this zone was the Amerada #1 Boe-Olson in Beaver Lodge Field, 15 miles south of the Ives well. It flowed 331 barrels of salt water with a trace of oil in 8 hours.

Most Red River wells in the state are not drilled to this zone because the lower Red River is typically dense and had no production until 1968. However, along the Nesson anticline, several wells have good porosity developed in the "F" zone (Plate 15).

The "E" zone (Plate 2) does not produce oil in the state but was tested in the Hunt #1 USA-8, NE SW Sec. 8, T. 136 N., R. 101 W., Eleven Bar Field, Slope County. On drill stem test, 15 barrels of oil and 23 barrels of water were recovered after 3 hours of swabbing, but it was not completed in that zone.

Upper Red River Formation

The four porosity zones in the upper Red River, "A," "B," "C," and "D" are all productive in various parts of the state. Table 4 shows the producing zones in various wells from Red River pools in North Dakota. It indicates that the "A" and "B" zones are the most productive along the Cedar Creek anticline, and the "C" and "D" are more productive along the Nesson anticline. In general,

the "B," "C," and "D" zones produce in a wide area of the state, but the "A" zone is limited to the Cedar Creek area.

TABLE 4

POROSITY ZONES IN THE RED RIVER FORMATION
THAT PRODUCE OIL IN NORTH DAKOTA

Field	County	Well Name	Producing Zones
Beaver Lodge	Williams	Amerada #1 Iverson-Nelson	C,D
		Amerada #3 B.L.O.U.	D
Little Missouri	Bowman	Carter #1 Johnson	A,B
Writing Rock	Divide	Kerr-McGee #1 Johnson	C,D
Cedar Creek	Bowman	Shell #23-35B-21	A,B,C
		Shell #43-10A-4	B,C,D
		Shell #42-3A-9	A,B
		Shell #14-13-14	B,C
Fryburg	Billings	Amerada #8 Scoria	C,D
Eleven Bar	Slope	Hunt #1 USA-8	B
		Hunt #1 N.P.R.R.	B,D
Buffalo Creek	Stark	Texaco #1 NCT-Schank	B
Medicine Pole Hills	Bowman	Hodges #1 Hestekin	B
Tioga	Williams	Amerada #2 Lalim	B,C,D
		Amerada #B-1 Ives	B,C,D,F

ECONOMIC GEOLOGY

Known Oil Fields

The Red River Formation produces oil in eight fields throughout western North Dakota. Most of the known oil occurrences are located along the two major anticlines in the state, the Cedar Creek in Bowman County and the Nesson in Williams County.

Characteristics of Red River oil fields in North Dakota are the following:

1. Most accumulations are located in structural "highs."
2. The pay zones are the four porosity zones, consisting primarily of dolomite.
3. Effective seals are present over each porosity zone; the R_3 and P_3 anhydrites provide an upper seal for oil in the B and C zones; the Stony Mountain Formation seals the A, and dense limestones seal the D zone.
4. Permeability barriers apparently surround or are adjacent to many fields. In Eleven Bar, Fryburg, and Buffalo Creek Fields, offset wells that are structurally higher than producing wells, are nonproductive. It is interpreted that the barrier is caused by either an updip change in texture or lithology.
5. Abrupt facies changes in both producing and non-producing intervals occur in several fields. An example of this is in the Eleven Bar Field, where the middle dense limestone unit of Pu in the producing well, changes to a very porous dolomite in the dry hole.
6. Some fields appear to be related to structures in the Precambrian basement rocks. An example of this is the Beaver Lodge Field.

Future Possibilities

Most of the present exploration for Red River oil is based on seismic information, since stratigraphic control is sparse. The most favorable area in North Dakota appears to be along the Montana border in McKenzie and Golden Valley Counties, just 20 miles east of the prolific Fairview and Brorson Fields. The few wells that have been drilled in that area all had either shows or small recoveries of oil in the Red River.

The most favorable area in central North Dakota appears to be in Ward County, between the Ward High and the hinge line. Periodic structural activity in this area could have produced sufficient structure to trap oil. The most favorable zone would be the "B," which is very persistent and uniform throughout western North Dakota. It is possible that oil could have migrated updip into structures in central North Dakota with the shale of the Stony Mountain Formation as an upper seal.

Structural highs, such as the one in Beaver Lodge Field, could be located anywhere in the Williston Basin and provide a trap for oil accumulation.

The Red River Formation is likely to become one of the most important producing intervals in the Williston Basin. At present, it holds the record for the highest initial production from a single well in the basin. The Miami #1 Dynneson in Richland County, Montana, discovered in 1968, had an initial flowing production of 2960 barrels of oil per day (Petroleum Information, July, 1968). Several

others in that area have recently been developed, producing over 500 barrels of oil per day.

With further drilling, new Red River fields will likely be discovered in North Dakota and increase the economic importance of that rock unit immensely.

SUMMARY

The upper Red River Formation consists of cyclic sedimentary rocks which can be divided into three distinct intervals on the basis of mechanical log studies. In ascending order they are the P, R, and F intervals, which consist of alternating sequences of dolomites, limestones, and anhydrites. Four principal porosity zones are recognized in the upper Red River Formation. Based on X-ray and thin section studies, the porosity zones consist predominantly of secondary, recrystalized dolomite. All zones produce oil in various parts of western North Dakota. The "A" and "B" zones are most productive along the Cedar Creek anticline, and the "C" and "D" zones are most productive along the Nesson anticline. Correlation of these zones throughout western North Dakota illustrate the uniform sedimentation during Red River time.

Facies changes occur mostly within the P interval and are of two types. One type is an updip change from the limestones and dolomites away from the basin center. The other facies type is an abrupt change from dense limestones to porous dolomites apparently near structural highs.

The Nesson anticline was the major structural feature affecting Red River sedimentation. Other positive areas defined from isopach data are the basin hinge line, the Ward and Mercer Highs, and the Billings Nose. A knob of high relief in Beaver Lodge Field

with relief exceeding 600 feet on the Precambrian was periodically active and is indicated by thinning in the P and F intervals and thickening in the R interval over the knob. The depocenter in upper Red River time was in northeastern Dunn County where the unit reaches a maximum thickness of 264 feet.

Future exploration of the Red River Formation in western North Dakota will undoubtedly increase in the future because of the recent prolific discoveries in that area. The most promising area appears to be in western McKenzie and Golden Valley Counties, just east of the prolific producers in Montana. The shallower areas near the hinge line in central North Dakota, with drilling depths of 7500-8500 feet, should not be overlooked for Red River oil production.

APPENDIX

Wells are listed by counties and by North Dakota Geological Survey numbers. All drill stem test and core information is from the Red River Formation. Core descriptions are given only for wells used in the fence diagram but all cored intervals are listed. The tops of the strata are given as depth in feet from the Kelly Bushing.

ABBREVIATIONS

D & A:	dry and abandoned
IPP:	initial production pumping
IPF:	initial production flowing
DST:	drill stem test
WC:	water cushion
SW:	salt water
MW	muddy water
OC:	oil cut
GC:	gas cut
MC:	mud cut
HOC:	heavily oil cut
HGC:	heavily gas cut
SGC:	slightly gas cut
GTS:	gas to surface
OTS:	oil to surface
WCTS:	water cushion to surface
BOPD:	barrels oil per day
BWPD:	barrels water per day
WLT:	wire line test
rec.:	recovered
DR	does not reach
R R	Red River Formation
R	R interval of upper Red River Formation
P	P interval of upper Red River Formation
K.B.:	Kelly Bushing
T.D.:	Total Depth
Comp.:	Completed

BILLINGS COUNTY

Well Number: N.D. 291
Well Name: Amerada Petrol. Corp. #1 H. May
Location: NW NE 9-139-100 Comp.: 9-24-53
K.B.: 2774 T.D.: 13325 Status in R R: D & A
DST: (1) 12375-12444, packer failed.
(2) 12368-12446, packer failed, rec. 1860' WC, 460' GCWC, reversed out 1755' GCWC with light scum and rainbow oil, 585' GCWC, no oil, 585' gray GCW with slight salty taste and slightly OC, 936' GCSW, 234' GCM, 507' M.
(3) 12354-12446, rec. 1600' HGCWC, reversed out 3400' HGC WC, 900' MGCW with scum oil, salty, 1069' GCSW, 100' GCM, 590' SM.
Cores: 12300-318; 12386-444.
Tops: R R: 12212 R: 12250 P: 12314 Base P: 12438

Well Number: N.D. 555
Well Name: Stanolind #1 Northwest Improvement Co.
Location: SE SE 17-143-100 Comp.: 8-28-54
K.B.: 2815 T.D.: 13888 Status in R R: D & A
DST: (1) 13489-528, rec. 1674' M.
Cores: None
Tops: R R: 12018; others not picked.

Well Number: N.D. 1678
Well Name: Amerada Petrol. Corp. #2 Scoria Unit
Location: SW SW 2-139-101 Comp.: 8-26-63
K.B.: 2634 T.D.: 12223 Status in R R: D & A
DST: (1) 12176-233, tool stuck, left 700' drill collar and test tool in hole.
Cores: 12178-233
Tops: R R: 12018; others not picked, not logged.

Well Number: N.D. 2853
Well Name: Shell-N.P. 41X-5-1 Fed.
Location: NE NE 5-143-101 Comp.: 7-26-61
K.B.: 2578 T.D.: 13018 Status in R R: D & A
DST: (1) 12812-920, misrun.
(2) 12684-920, rec. 188' WCM, 354' sul. water, no oil.

Cores: None
Tops: R R: 12774 T: 12822 P: 12880 Base P: 13008

Well Number: N.D. 3268
Well Name: Amerada Petrol Corp. #8 Scoria Unit
Location: NE SW 10-139-101 Comp.: 9-26-63
K.B.: 2540 T.D.: 13750 Status in R R: Oil
Prod. zones: C & D IPF: 101 BOPD, 14 1/2 BWPD; R R perfs: 12070-086
DST: (1) 11914-967, rec. 1636' SW.
(2) 12017-116, WTS 75 min., GTS 82 min., gauged 3-5 MMCF GPD with good spray oil, rec. 1286' oil, 47.7°, 60' HOC MW, 30' SW.
Cores: None
Tops: R R: 11901 R: 11944 P: 12005 Base P: 12132

Well Number: N.D. 3746
Well Name: Davis-Kevin Federal #1
Location: SW SW 10-138-100 Comp.: 2-6-65
K.B.: 2814 T.D.: 12270 Status in R R: D & A
DST: None
WLT: (1) 12161-164, rec. 12000 c.c. SW with scum dull yellow white fluorescence.
Cores: None
Tops: R R: 12000 R: 12040 P: 12102 Base P: 12228

Well Number: N.D. 3927
Well Name: Amerada Petrol. Corp. #1 USA-Hodge
Location: NW NE 21-139-101 Comp.: 12-6-65
K.B.: 2548 T.D.: 12141 Status in R R: D & A
DST: (1) 11872-960, rec. 840' black sulfur water.
(2) 12015-041, rec. 105' GCM with trace gas.
(3) 12041-092, rec. 510' MSW.
Cores: None
Tops: R R: 11877 R: 11920 P: 11978 Base P: 12106

Well Number: N.D. 4254
Well Name: Pan American-USA McCauley "B"
Location: SE NW 28-137-100 Comp.: 7-10-67
K.B.: 2864 T.D.: 11865 Status in R R: D & A

DST: (1) 11647-687, rec. 465' G & MCSW, 3162' GCSW.
Cores: None
Tops: R R: 11628 R: 11660 P: 11721 Base P: 11852

BOTTINEAU COUNTY

Well Number: N.D. 38
Well Name: California - #1 B. Thompson
Location: SW SE 31-160-81 Comp.: 2-6-52
K.B.: 1526 T.D.: 8272 Status in R R: D & A
DST: None
Cores: 7286-7336; 7685-7735
Tops: R R: 7244 R: 7289 P: 7351 Base P: 7446

Well Number: N.D. 64
Well Name: Hunt #1 Olson
Location: SW NW 18-163-77 Comp.: 6-19-52
K.B.: 1520 T.D.: 6420 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 5610 R: 5626 P: 5665 Base P: 5756

Well Number: N.D. 110
Well Name: Lion #1 Huss
Location: NW NW 23-163-75 Comp.: 9-8-52
K.B.: 2205 T.D.: 6644 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 5660 R: 5676 P: 5712 Base P: 5780

Well Number: N.D. 286
Well Name: Lion #1 H. Erickson
Location: SW SE 32-164-78 Comp.: 5-3-53
K.B.: 1539 T.D.: 5824 Status in R R: D & A
DST: None
Cores: 5753-5803; 5809-5824
Tops: R R: 5732 R: 5754 P: 5798 Base P: DR

Well Number: N.D. 1968
Well Name: Calvert #1 Hanson
Location: SW NW 30-163-78 Comp.: 9-2-58
K.B.: 1513 T.D.: 6064 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 5888 R: 5908 P: 5950 Base P: 6050

Well Number: N.D. 2219
Well Name: California #4 Bert Henry
Location: C SE SW 6-161-79 Comp.: 5-7-59
K.B.: 1494 T.D.: 7295 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 6370 R: 6408 P: 6448 Base P: 6550

BOWMAN COUNTY

Well Number: N.D. 485
Well Name: Hunt-Brooks #1 State
Location: C NW NW 16-129-104 Comp.: 4-2-54
K.B.: 3212 T.D.: 10016 Status in R R: D & A
DST: (1) 9175-9220, rec. 3870' gas, 15' dark brown free oil; 175' VHOCM, 990' OCWC, 570' SOCSW.
(2) 9270-9332, rec. 60' SO & GCMW, 270' SMW with trace oil, 270' SMW.
(3) 9350-9402, GTS, 2 hrs. 25 min., rec. 90' free oil, 180' G & MCO, 150' O & GCM, 90' HO & GCMW, 270' SO & GCSW, 540' SW with some oil, 90' SW.
(4) 9400-9460, rec. 240' MSW, 780' SW.
Cores: None
Tops: R R: 9158 R: 9190 P: 9240 Base P: 9360

Well Number: N.D. 516
Well Name: Western Natural Gas-Truax Traer
Location: NW SW 13-132-102 Comp.: 4-9-54
K.B.: 3074 T.D.: 10635 Status in R R: D & A
DST: (1) 10417-445, rec. 270' very slightly SWCM, 1980' SOCSW.
(2) 10584-628, rec. 180' SW

Cores: 10415-445; 10492-525; 10582-628
Tops: R R: 10400 R: 10434 P: 10487 Base P: 10612

Well Number: N. D. 1446
Well Name: Snowden-#1 Morrison
Location: SE SW 34-130-103 Comp.: 7-11-57
K.B.: 3028 T.D.: 9552 Status in R R: D & A
DST: (1) 9268-350, rec. 1440' SGCWC, 370' G & SOCM.
(2) 9273-352, rec. 475' SG & WCM with trace oil, 650' SG & MCW with trace of oil.
Cores: None
Tops: R R: 9277 R: 9310 P: 9366 BaseP: 9478

Well Number: N. D. 1575
Well Name: Carter-Shell #1 Johnson
Location: NW SW 9-129-106 Comp.: 1-6-58
K.B.: 2953 T.D.: 8980 Status in R R: Oil
Prod. zones: A, B IPP: 195 BOPD, 19 BWPD Perfs: 8206-8221; 8231-8248
DST: (1) 8189-211, rec. 10' free oil.
(2) 8229-244, rec. 900' gas, 240' HO & GCM.
(3) 8290-332, rec. 660' SM & GCW (rainbow of oil).
(4) 8360-410, rec. 4750' SM & GCW with trace oil.
Cores: (1) 8211-221; 8226-244; 8305-332
Tops: R R: 8198 R: 8232 P: 8288 Base P: 8400

Well Number: N. D. 2761
Well Name: Shell 43X-10A-4 Gov't.
Location: NE SE 10-130-107 Comp.: 3-7-61
K.B.: 3025 T.D.: 8397 Status in R R: Oil
Prod. zones: B, C, D IPP: 121 BOPD, 21 BWPD Perfs: 8215-217; 8267-269; 8295-297; 8356-358
DST: None
Cores: 8175-8397
Tops: R R: 8170 R: 8198 P: 8264 Base P: 8387

Well Number: N. D. 2961
Well Name: Shell-Gov't Unit #42-3A-9
Location: SE NE 3-130-107 Comp.: 9-6-61
K.B.: 2962 T.D.: 8450 Status in R R: Oil

Prod. zones: A, B IPP: 282 BOPD, 1 BWPD Perfs: 8177-179; 8207-209

DST: None

Cores: 8157-172, rec. 1' shale, 11' dol., poor spotty oil stain, 2 1/2' dol.
8174-234, rec. 5' ls., 4 1/2 dol., vertical fracs. 80-82, 4' dol., oil stain; 1 1/2' dol., shale lams., 3' dol., oil stain, 3' dol., 12' dol., with good oil stain, 4' dol., oil stain, 3' dol. with oil stain, 5' dol., oil stain, 10' dol., med-large vugs and fracs, 3' ls., large vugs, trace pin point porosity, oil stain.
8234-294, rec. 5' ls., vuggy with trace of oil stain, 1 1/2' ls., 4 1/2' ls., vuggy, trace oil stain, 11' dol., trace oil stain, 7 1/2' dol., oil stain, 7' anhydrite, 5 1/2' dol., 100% oil stain, 5 1/2' dol., few vertical fracs, oil stained, 1 1/2' anhydrite, 1' dol., oil stained, 3 1/2' dol., 90% oil stained, 5 1/2' dol., oil stained.
8294-354, rec. 21' dol., with spotty oil stain, 6' dol., 70% oil stain, 2' dol., 6' ls., oil stain, 10' ls., 7' dol., oil stain, slightly vuggy at 344-46, 8' dol., trace pin point porosity, good oil stain.
8354-379, rec. 1' ls., 3' dol., oil stained, 5' dol., mottled with ls., spotty shows, bleeding at 8360, 3' dol., oil stained, SW, 10' dol., oil stained, SW, 2' ls., mottled with dol., slightly oil stained, bleeding.

Tops: R R: 8158 R: 8200 P: 8252 Base P: 8370

Well Number: N.D. 3046
Well Name: Shell-Crawford Gov't Unit 14-13A-14
Location: SW SW 13-130-107 Comp.: 1-7-62
K.B.: 3008 T.D.: 8490 Status in R R: Oil
Prod. zones: B, C IPP: 72 BOPD, 9 BWPD Perfs: 8269-271; 8274-276; 8366-368
DST: None
Cores: 8221-8471
Tops: R R: 8228 R: 8262 P: 8322 Base P: 8436

Well Number: N.D. 3144
Well Name: Shell-Antelope Butte #23-35B-21
Location: NE SW 35-131-107 Comp.: 8-9-62
K.B.: 2993 T.D.: 8556 Status in R R: Oil

Prod. zones: A, B, C IPP: 200 BOPD, 74 BWPD Perfs: 8342-344; 8346-348; 8369-372; 8377-379; 8466-468
DST: None
Cores: 8322-423
Tops: R R: 8325 R: 8364 P: 8418 Base P: 8536

Well Number: N. D. 3514
Well Name: Shell-Gov't 43-30C-43
Location: NE SE 30-130-106 Comp.: 3-13-64
K.B.: 2950 T.D.: 8525 Status in R R: D & A
DST: (1) 8276-330, rec. 101' watery mud with trace oil.
Cores: 8296-357
Tops: R R: 8266 R: 8293 P: 8358 Base P: 8468

Well Number: N. D. 4143
Well Name: Hodges Inc. #1 Hestekin
Location: NE NE 15-130-104 Comp.: 7-17-67
K.B.: 3179 T.D.: 9735 Status in R R: Oil
Prod. zones: B IPP: 120 BOPD, 12 BWPD Perfs: 9503-505
DST: (1) 9490-510, GTS 1 hr. 45 min., rec. 2500' O & GCWC (30% oil), 90' gassy oil, 270' SOCSW.
(2) 9639-659, rec. 626' M & GCSW.
Cores: 9422-482
Tops: R R: 9462 R: 9500 P: 9550 Base P: 9663

DIVIDE COUNTY

Well Number: N. D. 1443
Well Name: Dakamont #1 Jacobson
Location: SW NE 6-162-96 Comp.: 1-10-58
K.B.: 1949 T.D.: 11515 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 10828 R: 10885 P: 10934 Base P: 11056

Well Number: N. D. 1546
Well Name: Kerr McGee-#1 Johnson Estate
Location: NE NW 34-162-101 Comp.: 4-26-58
K.B.: 2259 T.D.: 11782 Status in R R: Originally Oil, now P & A

Prod. zones: C, D IPP: 152 BOPD, 102 BWPD Perfs: 11256-280; 11312-326

DST: (1) 11262-280, rec. 4 gals. free oil, 180' OCWC, 240' MCSW.
(2) 11236-300, rec. 1760' gas in pipe, 50' free oil, 90' HO & GCWC, 90' SO & GCWC, 1320' GCWC, 720' GCDF.
(3) 11363-417, rec. 315' mud.

Cores: (described by author)
11130-35, Limestone, dark brown, cryptocrystalline, dense, brachiopods abundant, few calcite crystals in vugs.
11135-37, Limestone, medium-dark brown, microcrystalline, fossils present.
11137-43, Limestone, medium brown, fine-med. crystalline, brachiopods abundant, calcite inclusions.
11280-83, Dolomite, granular, light-medium brown, some vuggy porosity, bryozoans, dead oil stain, mottled at 82.
11283-87, Dolomite, dark brown, microcrystalline, few fossils, large fractures filled with white granular dolomite, very porous, dead oil stain, some vuggy porosity.
11287-88, Dolomite, medium brown, becoming limy.
11288-91, Limestone, dark brown, microcrystalline, vugs filled with calcite.
11291-93, Limestone, medium brown, microcrystalline, dense, no porosity.
11293-94, Dolomite, medium brown, microcrystalline, vugs filled with white earthy dolomite, very good intergranular porosity.
11294-96, Limestone, medium brown, microcrystalline.
11296-300, Dolomite, medium to dark brown, crystalline, sandy texture, friable, vugs filled with calcite crystals.
11359-62, Limestone, light to medium brown, microcrystalline, mottled, fossils, calcite crystals present.
11362-65, Limestone, light brown, microcrystalline, earthy, mottled with dark blotches of dolomite, microcrystalline.
11365-69, Limestone, as above, becoming more dolomitic.
11369-71, Limestone, medium brown, crystalline, very dolomitic, breaks in subspherical, massive pattern, grumulose (?).
11371-80, Limestone, light-medium brown, granular, dolomitic with good intergranular porosity.
11380-90, Limestone, light brown, crystalline, dolomitic, earthy at 85, some vugs filled with calcite.
11390-96, Limestone, light to medium brown, finely crystalline to earthy, fair intergranular porosity.
11396-97, Dolomite, light to medium brown, cryptocrystalline, vugs filled with shite earthy dolomite.

11397-402, Limestone, medium to dark brown, dense, dolomitic.
11402-407, Limestone, light to medium brown, crystalline, slightly mottled, vugs filled with calcite, slightly dolomitic, some blotches of dark dolomite, dense.
11407-411, Limestone, medium brown, granular, slightly dolomitic.
11411-417, Limestone, light to medium brown, crystalline, becoming dolomitic at 17, vugs filled with white granular dolomite.

Tops: R R: 11130 R: 11183 P: 11227 Base P: 11344

Well Number: N. D. 2010
Well Name: Carter #1 Moore
Location: NW NE 7-163-102 Comp.: 12-30-58
K.B.: 2207 T.D.: 11040 Status in R R: D & A
DST: (1) 10250-492, rec. 800' mud.
(2) 10492-550, rec. 260' MCWC, 740' M, 210' SMCSW.
(3) 10550-585, rec. 3330' M, 990' SW with scum of oil.
Cores: 10532-550; 10561-585
Tops: R R: 10390 R: 10446 P: 10488 Base P: 10596

Well Number: N. D. 4423
Well Name: Pan American #1 Raaum
Location: NW SW 26-162-101 Comp.: 7-2-68
K.B.: 2236 T.D.: 11500 Status in R R: D & A
DST: (1) 11315-355, rec. 1676' SW, 370' MSW.
Cores: None
Tops: R R: 11168 R: 11228 P: 11274 Base P: 11391

Well Number: N. D. 505
Well Name: Socony Vacuum-Dvorak F-42-6-P
Location: SE NE 6-141-94 Comp.: 5-22-54
K.B.: 2296 T.D.: 12556 Status in R R: D & A
DST: None
Cores: 12298-356, rec. 14' dark gray, argillaceous, dense, dol. ls., highly fossiliferous, some fracs, 20' dark brown and tan, dense, dol. ls., with irregular fracs., calcareous, crystalline, algal fracs, some black residue, 7' light brown, dense, dol., with trace fracs., good show of oil and good fluorescence and cut on algal fracs., some styloites filled with black residue, 7' very hard, dark brown, dense dol. ls., with dead oil residue,

algal stylolites, last 6" brown-black anhydrite, crystalline to dense dol. ls., bleeding oil with good fluorescence and cut.
12356-371, rec. 15'; 1/2' brown, fine crystalline ls., with gray yellow fluorescence and cut, bleeding oil, 2' gray brown dense anhydrite, 2' gray, dense, argillaceous dol., 10 1/2' gray, brown, dense anhydrite.
12371-429, rec. 58'; 2' gray brown, dense anhydrite, 3' brown, very fine crystalline, earthy dol., 1' brown, fine sucrosic dol., 7' brown very fine crystalline ls., with tan anhydrite, 2' brown, very fine crystalline, earthy dol., 6' brown, cryptocrystalline ls., with much dead, black residue, trace live, spotty, good fluorescence, good cut, very slight porosity, 2' brown, cryptocrystalline ls., 6' brown, cryptocrystalline ls., with good scattered fluorescence, 3' light brown, dense anhydrite.
12499-466, rec. 37'; 3 1/2' brown, dense, anhydrite, little cryptocrystalline ls., 1 1/2' light brown, dense, earthy dol., 1' brown, very fine to cryptocrystalline ls. with some dead black residue, 4' light brown, dense, earthy dol., 4' brown, cryptocrystalline ls., with some dead black residue, 3' brown, dense anhydrite, 2' brown, dense anhydrite with interbedded cryptocrystalline ls., 6' brown, dense, earthy dol., 2' light tan, very soft ls. with little dull fluorescence and cut.
12466-513, rec. 45'; 1' brown, dense, dol., 5' brown, lithographic ls., 3' brown, lithographic ls. with spotty fluorescence, 11' brown, lithographic ls., with yellow fluorescence on algal fracs., 11' as above with dead black residue, 5' brown, lithographic ls., with little very spotty fluorescence and cut, 2' brown, lithographic ls., with scattered dead black residue, 1' brown lithographic ls. with some fluorescence, fair to good cut, 3' brown, lithographic crumbling ls.

Tops: R R: 12312 R: 12358 P: 12422 Base P: DR

Well Number: N. D. 793
Well Name: Mobil-#F-22-22-1 Birdbear
Location: SE NW 22-149-91 Comp.: 5-8-55
K.B.: 2103 T.D.: 13481 Status in R R: D & A
DST: (1) 13075-170, rec. 20' M.
Cores: 12994-13084, rec. 90', semifragmental ls., tight, with dead oil residue.
13084-170, rec. 86'; 12' ls., cryptocrystalline, tight, 2' fine crystalline ls., with spotty shows of oil, 2' anhydrite, 4' dol., 1' anhydrite, 11' ls., crystalline, tight, 8' tight ls. with show of oil, 2' anhydrite, 2' crystalline tight dol. with trace of oil, 9' anhydrite, 4' tight ls., 1' fine dol., wet, salty

with anhydrite inclusions, 4' dol. with poor porosity, 8', as above with slight bleeding of oil, 6' as above, but no porosity, 10' cryptocrystalline tight ls.
13170-248, rec. 17' crystalline ls., 18' anhydrite, 17' crystalline tight, hard dol., anhydrite at top, slight trace of oil, 26' crystalline ls.
13248-310, rec. 31' crystalline ls., no porosity, 5' dol. with ls. pebbles, 10', as above with no porosity, 15' crystalline ls.
13310-396, rec. 12' crystalline ls., few anhydrite inclusions, spotty yellow fluorescence on fractures, 13' crystalline ls., with yellow oil in thin zones at 13322, 28, and 32, 61' crystalline ls., weak fluorescence on breaks.
13396-481, rec. 1' hard, crystalline ls., tight, 4' mixed dol., crystalline ls., slight porosity, faint fluorescence, 64' hard, tight, crystalline ls.

Tops: R R: 13064 R: 13130 P: 13190 Base P: 13328

Well Number: N.D. 4220
Well Name: Sinclair #1 Knudsvig
Location: SW NE 13-145-94 Comp.: 4-5-67
K.B.: 2210 T.D.: 13283 Status in R R: D & A
DST: (1) 13070-167, rec. 90' WCM, 270' SWCM, 270' SMCW.
(2) 13156-283, rec. 5091' SGCWC, 196' GCM.
Cores: None
Tops: R R: 13014 R: 13074 P: 13140 Base P: 13274

Well Number: N.D. 3044
Well Name: Amerada Petrol. Corp.-#1 Selle T-1
Location: NE NE 27-143-92 Comp.: 2-6-62
K.B.: 2200 T.D.: 12168 Status in R R: D & A
DST: (1) 12068-157, rec. WC with thin scum dead oil on top, 1037' MSW.
Cores: None
Tops: R R: 12021 R: 12078 P: 12140 Base P: DR

GOLDEN VALLEY COUNTY

Well Number: N.D. 410
Well Name: Gulf-#1 Dorough Gov't
Location: NE SW 24-143-103 Comp.: 4-7-54

K.B.: 2515 T.D.: 13374 Status in R R: D & A
DST: (1) 12607-646, rec. 7200' gas, 300' O & GCSM, 4000' O & GC WC, 325' very gassy SW.
Cores: 12528-553; 12626-646
Tops: R R: 12404 R: 12452 P: 12509 Base P: 12643

Well Number: N.D. 470
Well Name: Blackwood & Nichols #1 Gilman
Location: NE SE 15-140-105 Comp.: 3-21-54
K.B.: 2867 T.D.: 12690 Status in R R: D & A
DST: (1) 11728-779, rec. 2740' GC salty sulfur water.
(2) 11830-860, rec. 690' M.
(3) 11826-860, rec. 123' SG & WCM.
(4) 11915-975, rec. 1000' SO & GCWC, 240' SO & GCM, 770' SGCMSW with rainbow dark brown oil.
Cores: None
Tops: R R: 11707 R: 11748 P: 11806 Base P: 11934

Well Number: N.D. 4130
Well Name: Amerada Petrol. Corp. #1 Waldron
Location: SW NW 9-138-105 Comp.: 9-30-66
K.B.: 2867 T.D.: 11363 Status in R R: D & A
DST: (1) 11068-108, rec. 35' M, 4690' SW.
(2) 11145-182, rec. 90' GCM.
(3) 11180-270, rec. 430' M.
Cores: None
Tops: R R: 11032 R: 11076 P: 11134 Base P: 11265

GRANT COUNTY

Well Number: N.D. 232
Well Name: Youngblood #1 Kelstrom
Location: SW SW 26-133-83 Comp.: 1-15-53
K.B.: 1997 T.D.: 6800 Status in R R: D&A
DST: None
Cores: None
Tops: R R: 6364 R: 6385 P: 6453 Base P: 6576

Well Number: N.D. 3636
Well Name: Cardinal #1 Bierwagen
Location: SW NE 1-133-90 Comp.: 8-20-64
K.B.: 2351 T.D.: 8860 Status in R R: D & A
DST: (1) 8694-8915, rec. 745' M, 2690' SW.
Cores: None
Tops: R R: 8662 R: 8700 P: 8761 Base P: 8866

HETTINGER COUNTY

Well Number: N.D. 511
Well Name: Socony #1 Jacobs
Location: SW SW 24-134-96 Comp.: 4-13-54
K.B.: 2606 T.D.: 10435 Status in R R: D & A
DST: (1) 10199-300, rec. 180' SMGCWC, 450' MSW, 1290' SW with sulfur trace.
(2) 10318-375, rec. 180' WSGCM, 90' SO & GCM, 360' MSW.
Cores: 10195-212, rec. 17' ls., gray and dense, to vuggy with vertical fractures, very argillaceous, brittle ls., very fossiliferous.
10212-226, rec. 14' ls., with vertical fractures, 1/2' dol., with very good fluorescence and good cut at 10214, 3' same at 10218-21.
10226-241, rec. 15' brown ls., with fluorescence in vertical fractures.
10241-256, rec. 15' ls., with bleeding oil, stain and fluorescence to dolomite, with pin point porosity and dead stain.
10256-270, rec. 15'; 4 1/2' dol., with vuggy porosity and fluorescence, 8 1/2' ls., with dead stain, scattered intercrystalline porosity and fluorescence.
10270-285, rec. 15' ls., with tight vertical fractures throughout, spotted fluorescence and stain with bleeding oil at 10285.
10285-300, rec. 1' brown, very fine crystalline ls., with little spotty fluorescence, 4' same, no fluorescence, 2' brown, very fine crystalline, fossiliferous ls., with fluorescence, algal fracs., little brown stain, trace bleeding oil, 4' brown, crystalline, fossiliferous ls., with dead black stain, 2 1/2' brown, crystalline ls., with brown stain and good fluorescence on fractures.
10300-315, rec. 12'; light tan-brown, gray, dense anhydrite.
10315-327, rec. 12'; 1 1/2' anhydrite, as above, 4' light tan crystalline, dense dolomite, pseudo-oolitic in part, dull yellow fluorescence, no porosity, 1 1/2' anhydrite, crystalline,

dense anhydritic ls., 1' tan, dense, argillaceous dolomite with blobs white anhydrite, dull yellow fluorescence, 4' light brown dol., dark brown ls., black dead residue.
10327-344, rec. 16'; 3' brown and dark gray, hard, dense, calcareous anhydrite, 3' light tan to brown, very fine sucrosic dolomite banded with light and dark streaks, dull yellow fluorescence, streaks, dead carbonaceous residue, very slight cut and sulfur odor, 1 1/2' dark brown, dense dol., with trace fluorescence, 7 1/2' light tan, very fine sucrosic dolomite, pseudo-oolitic in part, dull yellow fluorescence, 1' medium brown crystalline dol., with trace fluorescence.
10344-55, rec. 7 1/2'; 3' tan, dense ls., with spotty fluorescence and light stain along fractures, 2' ls., mottled with tan and light brown, dense, sucrosic ls. and dol. ls., 1' dense ls., stylolitic with dead stain and trace fluorescence along vertical fractures.
10355-60, no recovery.
10360-365, rec. 3 1/2' gray, tan, very hard, dense ls., bottom 1 1/2' fractured, fairly good fluorescence and cut in fractures.
10365-375, no recovery.
10375-433, rec. 58' brown, dense ls., with large patches of sucrosic ls. having fractures with spotty fluorescence, good to poor cut, gas at 10414-433.

McCLEAN COUNTY

Well Number: N. D. 22
Well Name: Samedan #1 Hanson
Location: C NE 10-146-81 Comp.: 9-15-50
K.B.: 1994 T.D.: 9031 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 8090 R: 8128 P: 8170 Base P: 8295

Well Number: N.D. 49
Well Name: Stanolind #1 McClean County
Location: SW SW 28-150-80 Comp.: 1-30-53
K.B.: 2100 T.D.: 8900 Status in R R: D & A
DST: (1) 8035-087, rec. 180' M, 600' SW.
(2) 8090-127, rec. 100' M, 350' MCSW.

Cores: 8066-87
Tops: R R: 7997 R: 8037 P: 8094 Base P: 8204

McKENZIE COUNTY

Well Number: N.D. 545
Well Name: Phillips, Gulf, Skelly #1 Hoehn
Location: NE SE 13-152-102 Comp.: 12-2-54
K.B.: 2278 T.D.: 13853 Status in R R: D & A
DST: None
Cores: 13515 1/2-13853
Tops: R R: 13526 R: 13591 P: 13648 Base P: 13778

Well Number: N.D. 956
Well Name: Gulf #1 B. Pierre Fed. Unit
Location: NW SW 28-148-104 Comp.: 3-20-56
K.B.: 2339 T.D.: 13503 Status in R R: D & A
DST: (1) 12905-950, rec. 540' SW.
(2) 12961-13006, rec. 1030' SW.
Cores: 12795-929; 12950-13007 (described by author)..
12795-97, Limestone, medium brown, microcrystalline, dense, tight, few brachiopod fragments.
12797-800, Dolomite, light to medium brown, finely crystalline, finely bedded.
12800-815, Limestone, dark brown to black, cryptocrystalline, dense, carbonaceous, trace of brachiopods with several small fractures filled with anhydrite.
12815-821, Limestone, medium to dark brown, microcrystalline, dense, no porosity.
12821-825, Dolomite, gray, microcrystalline, slight intercrystalline porosity, finely bedded.
12825-835, Anhydrite, white to cream, cryptocrystalline, dense becoming slightly dolomitic at 30.
12835-838, Dolomite, medium brown, microcrystalline, fair intercrystalline porosity, finely bedded.
12838-39, Anhydrite, gray cryptocrystalline.
12839-843, Dolomite, medium brown, microcrystalline, dense, no porosity.
12843-850, Dolomite, medium to dark brown, microcrystalline, fractured in places, filled with anhydrite.

12850-852, Dolomite, tan, microcrystalline, dense, vugs filled with anhydrite.
12852-858, Limestone, dark gray, brown to black cryptocrystalline, dense, cephaloped fragments.
12858-860, Dolomite, tan crystalline.
12860-893, Limestone, dark gray brown to black, cryptocrystalline, dense, very carbonaceous, calcite crystals filling vugs in places.
12893-895, Dolomite, dark gray brown, microcrystalline, dense.
12895-899, Anhydrite, dark brown, dense, dolomitic at 896, pyrite crystals at 95.
12899-900, Dolomite medium brown, dense, no porosity.
12900-907, Anhydrite, dark gray brown, microcrystalline, becoming lighter at 902.
12907-915, Dolomite, light to medium brown, microcrystalline, dense, no porosity, some dead black oil stain at 910.
12915-924, Dolomite, medium brown, crystalline, some intercrystalline porosity, dead black oil at 915.
12924-28, Dolomite, dark brown, dense, mottled, becoming vuggy at 927.
12928-930, Dolomite, dark gray brown, sucrosic, carbonaceous, anhydrite crystals, vuggy in places.
12930-939, Dolomite, light to medium brown, microcrystalline to sucrosic, poor to fair porosity, streaks of black carbonaceous material.
12939-948, Dolomite, light to dark brown, some good intercrystalline porosity, algal structures.
12948-953, Limestone, medium to dark brown, microcrystalline, dense, fractures filled with carbonaceous material.
12953-954, Dolomite, medium gray brown, microcrystalline, dense.
12954-959, Limestone, medium to dark brown, dense, becoming granular at 955 with fair porosity, fossiliferous.
12959-967, Dolomite, medium to dark brown, granular, fair porosity, calcite crystals filling vugs, carbonaceous woody material.
12967-975, Dolomite, medium to dark brown, sucrosic, large dolomite crystals at 968.
12975-990, Dolomite, dark gray brown, microcrystalline to sucrosic, mottled in places.
12990-13003, Dolomite, dark gray brown, sucrosic, fair porosity in places, some vuggy porosity.

Tops: R R: 12770 R: 12824 P: 12892 Base P: 13022

Well Number: N.D. 1606
Well Name: Amerada Petrol. Corp. #1 Shelvik Tr-1
Location: NE SW 35-150-97 Comp.: 3-7-58
K.B.: 2334 T.D.: 13305 Status in R R: D & A
DST: None
Cores: 13190-305
Tops: R R: 13165 R: 13227 P: 13284 Base P: DR

Well Number: N.D. 2373
Well Name: Amerada Petrol. Corp. #1 Antelope Unit "A"
Location: NE SE 1-152-95 Comp.: 3-10-60
K.B.: 2117 T.D.: 15135 Status in R R: D & A
DST: (1) 13164-304, rec. 3120' GCWC, 190' HGC & MCWC, 110' HGCM.
Cores: 13111-169; 13227-282
Tops: R R: 13109 R: 13176 P: 13241 Base P: 13367

Well Number: N.D. 2584
Well Name: Shell #32-16-1 State
Location: SW NE 16-145-101 Comp.: 7-8-60
K.B.: 2463 T.D.: 13280 Status in R R: D & A
DST: (1) 13205-280, rec. 675' G & MCW.
Cores: None
Tops: R R: 13023 R: 13074 P: 13126 Base P: 13253

Well Number: N.D. 2602
Well Name: Texas-Amerada #5 Garland
Location: NE 6-153-95 Comp.: 1-25-61
K.B.: 1983 T.D.: 13860 Status in R R: D & A
DST: None
Cores: 12996-13041
Tops: R R: 12918 R: 12980 P: 13040 Base P: 13163

Well Number: N.D. 3645
Well Name: Quintana #1 U.S.A.
Location: SE SE 24-145-105 Comp.: 10-26-64
K.B.: 2379 T.D.: 12521 Status in R R: 12184
DST: (1) 12390-438, rec. 900' SMCWC, 133' M & SOCWC.
Cores: None
Tops: R R: 12184 R: 12236 P: 12300 Base P: 12426

Well Number: N.D. 4062
Well Name: Shell #22X-28-1 Gov't
Location: SE NW 28-148-101 Comp.: 7-5-66
K.B.: 2214 T.D.: 13650 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 13337 R: 13398 P: 13450 Base P: 13574

Well Number: N.D. 4304
Well Name: Helmerich & Payne #1 Federal-McKenzie
Location: SE NW 28-148-101 Comp.: 7-5-66
K.B.: 2515 T.D.: 12870 Status in R. R: D & A
DST: (1) 12600-659, rec. 4500' SGCWC, 176' GCM.
(2) 12640-772, rec. 65' G & WCM.
(3) 12766-826, rec. 148' SGCSW w/trace oil.
Cores: None
Tops: R R: 12576 R: 12626 P: 12688 Base P: 12816

MERCER COUNTY

Well Number: N.D. 21
Well Name: Kelly-Plymouth #1 Leutz
Location: NW NE 28-142-89 Comp.: 9-28-50
K.B.: 2284 T.D.: 12526 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 11160 R: 11220 P: 11288 Base P: 11392

MORTON COUNTY

Well Number: N.D. 26
Well Name: Carter-Phillips #1 North Dakota
Location: NW 29-136-81 Comp.: 6-4-51
K.B.: 2005 T.D.: 7790 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 6494 R: 6520 P: 6578 Base P: 6675

Well Number: N.D. 1620
Well Name: Pan American #1 Vetter
Location: NE SW 27-139-90 Comp.: 2-11-58
K.B.: 2426 T.D.: 11212 Status in R R: D & A
DST: (1) 10346-387, rec. 300' MCSW
Cores: None
Tops: R R: 10342 R: 10389 P: 10456 Base P: 10580

Well Number: N.D. 3859
Well Name: Amerada Petrol. Corp. #1 Meyer
Location: SE NE 34-135-83 Comp.: 6-8-65
K.B.: 2125 T.D.: 8229 Status in R R: D & A
DST: (1) 6918-6961, rec. 180' M, 2995' MCSW.
(2) 7023-7060, rec. 270' MSW, 4195' SW.
Cores: None
Tops: R R: 6922 R: 6952 P: 7008 Base P: 7134

Well Number: N.D. 3978
Well Name: Austral #1 Leingang
Location: SE NW 34-137-83 Comp.: 11-30-65
K.B.: 2281 T.D.: 7614 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 7436 R: 7462 P: 7528 Base P: DR

MOUNTRAIL COUNTY

Well Number: N.D. 355
Well Name: Amerada Petrol. Crop. #3 C. Hanson
Location: C SW NW 18-158-94 Comp.: 2-11-54
K.B.: 2339 T.D.: 12806 Status in R R: D & A
DST: None Perf.: 12670-720, formation would not take acid.
Cores: 12570-806
Tops: R R: 12557 R: 12608 P: 12655 Base P: 12784

OLIVER COUNTY

Well Number: N.D. 95
Well Name: Youngblood #1 Wachter
Location: SE SW 3-141-81 Comp.: 9-8-52
K.B.: 1924 T.D.: 7850 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 7397 R: 7426 P: 7476 Base P: 7570

SIOUX COUNTY

Well Number: N.D. 631
Well Name: Ohio #1 Standing Rock
Location: NE SW 29-131-80 Comp.: 8-6-54
K.B.: 1731 T.D.: 5906 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 5048 R: 5064 P: 5120 Base P: 5215

SLOPE COUNTY

Well Number: N.D. 91
Well Name: Deep Rock #1 Brusich
Location: SE SE 8-135-98 Comp.: 1-18-53
K.B.: 2803 T.D.: 11521 Status in R R: D & A
DST: (1) 11096-11194, rec. 630' MCSW, 2070' blk sulf. SW, 540' M.
Cores: None
Tops: R R: 11054 R: 11090 P: 11146 Base P: 11276

Well Number: N.D. 3383
Well Name: Pan American #1 Foreman
Location: SW SE 23-133-106 Comp.: 6-24-63
K.B.: 2801 T.D.: 9416 Status in R R: D & A
DST: (1) 9164-9201, rec. 200' MCW, 724' HGCW with trace of oil, 470' HGCW.

(2) 9250-9286, rec. 650' gas, 270' O & GCM.
(3) 9286-9416, rec. 282' GCM, 548' GCW, 134' SGCW, 89' G & WCM.

Cores: None
Tops: R R: 9147 R: 9184 P: 9242 Base P: 9370

Well Number: N. D. 3588
Well Name: Sun #1 Greer Federal
Location: SE SE 21-134-105 Comp.: 7-9-64
K.B.: 2896 T.D.: 10128 Status in R R: D & A
DST: (1) 9928-9940, rec. 5' oil, 1866' OCWC, 180' GO & MCSW, 515' SW.
(2) 10054-10087, rec. 47' M.
(3) 10067-10129, rec. 25' M.
Cores: 9982-10032
Tops: R R: 9894 R: 9926 P: 9984 Base P: 10006

Well Number: N. D. 4075
Well Name: Hunt #1 NPRR "A"
Location: NE SW 9-136-101 Comp.: 7-26-66
K.B.: 2774 T.D.: 11566 Status in R R: Oil
Prod. zones: B, D IPF: 640 BOPD Perfs.: 11286-297; 11439-446
DST: (1) 11286-326, WCTS 50 min., G & OTS 60 min. closed after 5 min.
(2) 11336-388, rec. 40' M.
(3) 11257-335, WCTS 85 min., clean oil to surface 3 hrs., rec. 29 BOPD in 1 hr.
Cores: None
Tops: R R: 11241 R: 11276 P: 11336 Base P: 11457

Well Number: N. D. 4119
Well Name: Hunt #1 U.S.A.-8
Location: NE SW 8-136-101 Comp.: 10-7-66
K.B.: 2725 T.D.: 11506 Status in R R: Oil
Prod. zones: B IPF: 195 BOPD, 78 BWPD Perfs: 11246-254; 11328-357, gross, acidized/1000 gals, swabbed 70% W, 30% oil, swzd.; 11395-400, acidized/400 gals, swabbed 30 BSW, squeezed; 11428-438, acidized/1500 gals, swabbed 15.4 BO & 23 BSW, 3 hrs. squeezed.
DST: (1) 11210-340, WCTS 4 hrs., O & GCMTS 5 3/4 hrs., F 9 BO/ 15 min.

Cores: 11221-226, rec. 5' ls., dense, slight bleeding of oil from fractures at 222 & 223.
11226-248, rec. 22'; 1' ls., dense, 7' anhydrite, 1' ls., poor to fair porosity, oil stained, 2' ls., fair to good porosity, scattered vugs, oil stained, 4' dol., scattered oil stain, 7' ls., dense.
11286-340, rec. 54'; 1' anhydrite, 1' dol., very anhydritic and dense, 2' anhydrite, 12' dol., brown-gray brown, tan, crystalline, mostly dense, slight trace oil stain from 91-93, highly fractured, 5' anhydrite, 20' dol., brown to gray brown, tan, crystalline, subearthy, argillaceous, 2' ls., gray brown, crystalline, fragmental, dense, no show, 3' dol., tan to gray, subearthy, fragmental, granular porosity, argillaceous in part, with scattered fair oil stain, few hairline fractures, 2' dol., scattered vugs, trace oil stain, 3' ls., 14' dol., earthy, with good intergranular and vuggy porosity, good oil stain, 5' ls., tight, no show, 5' dol., earthy with scattered oil stain, 2' ls., fragmental, tight, 8' dol., sucrosic to crystalline, mostly dense, 7' ls., fragmental, fossiliferous, mostly dense, no show.
Tops: R R: 11197 R: 11234 P: 11296 Base P: 11417

Well Number: N. D. 4124
Well Name: Hunt #1 Hayden
Location: NW SE 4-136-101 Comp.: 11-14-66
K.B.: 2740 T.D.: 11510 Status in R R: D & A
DST: (1) 11300-330, rec. 5282' SW.
(2) 11368-438, rec. 1125' SW.
(3) 11442-510, rec. 632' SW.
Cores: None
Tops: R R: 11273 R: 11308 P: 11367 Base P: 11490

Well Number: N. D. 4164
Well Name: Hunt #2 NPRR "A"
Location: SW NE 17-136-101 Comp.: 11-28-66
K.B.: 2783 T.D.: 11530 Status in R R: D & A
DST: (1) 11294-346, rec. 4516' SW.
(2) 11362-430, rec. 290' SW & GCM.
(3) 11444-530, rec. 5566' SW.
Cores: None
Tops: None - not logged.

Well Number: N. D. 4241
Well Name: Hunt #3 NPRR "A"
Location: NE NW 23-136-101 Comp.: 5-4-67
K.B.: 2865 T.D.: 11588 Status in R R: D & A
DST: (1) 11366-384, rec. 6019' SGCSW.
(2) 11426-487, rec. 483' SGCM.
(3) 11498-567, rec. 7067' SW with slight trace oil.
Cores: 11368-384; 11430-487; 11510-567
Tops: R R: 11325 R: 11358 P: 11424 Base P: 11547

Well Number: N. D. 4280
Well Name: Amerada Petrol. Corp. #1 Mitchell
Location: NE SW 18-135-103 Comp.: 8-8-67
K.B.: 2971 T.D.: 11080 Status in R R: D & A
DST: (1) 10816-845, rec. 101' WCM, 7457' SW.
(2) 10884-994, rec. 400' WCM.
(3) 10854-11030, rec. 400' WCM.
Cores: None
Tops: R R: 10786 R: 10820 P: 10880 Base P: 11010

STARK COUNTY

Well Number: N. D. 850
Well Name: Hunt #1 Privratsky
Location: NW NW 15-138-98 Comp.: 6-22-55
K.B.: 2652 T.D.: 12205 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 11894 R: 11938 P: 11995 Base P: 12123

Well Number: N. D. 3515
Well Name: Continental #1 Stoxen
Location: NW NW 9-140-93 Comp.: 4-15-64
K.B.: 2291 T.D.: 11750 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 11420 R: 11465 P: 11528 Base P: 11660

Well Number: N. D. 4134
Well Name: Texaco #1 Schank (NCT-1)
Location: C NW SE 15-137-92 Comp.: 11-9-66
K.B.: 2341 T.D.: 10425 Status in R R: Oil
Prod. zones: B IPF: 265 BOPD, 30 BWPD Perfs: 10216-226
DST: (1) 10180-230, GTS 1 hr. 12 min., rec. 1233' HG & MCO, 50' oil, 150' HGCO, 192' SW.
(2) 10232-292, rec. 100' WM.
(3) 10296-392, rec. 186' WCM, 539' GCM.
Cores: None
Tops: R R: 10164 R: 10204 P: 10266 Base P: 10392

Well Number: N. D. 4182
Well Name: Texaco #2 Schank (NCT-1)
Location: C SW 23-137-92 Comp.: 12-31-66
K.B.: 2345 T.D.: 10429 Status in R R: D & A
DST: (1) 10150-192, rec. 486' M.
(2) 10198-230, rec. 180' G & WCM, 2295' SW.
Cores: 10150-230.
Tops: R R: 10160 R: 10200 P: 10264 Base P: 10394

Well Number: N. D. 4311
Well Name: Union #1 Kudrna
Location: NE SW 20-139-97 Comp.: 11-21-67
K.B.: 2560 T.D.: 12180 Status in R R: D & A
DST: (1) 11970-987, rec. 30' M.
(2) 12016-037, rec. 2267' SW.
Cores: 11969-989; 12021-037; 12095-136 (described by author)
11969-985, Limestone, dark gray brown, cryptocrystalline, dense, brachiopods abundant.
11985-989, Dolomite, medium gray brown, crystalline, fair porosity, finely laminated.
12021-26, Dolomite, medium gray brown, granular, fair intercrystalline porosity, finely, laminated.
12026-032, Dolomite, medium gray grown, granular, good intercrystalline and vuggy porosity, abundant black carbonaceous material (oil?).
12032-037, Limestone, dark gray to black, microscrystalline, dense, scattered crystals of anhydrite, carbonaceous material in fractures.
12095-096, Dolomite, dark gray brown, microcrystalline.
12096-098, Limestone, medium gray, dense, with inclusions of dark spherical bodies.

12098-103, Dolomite, dark gray brown, microcrystalline, finely bedded, fractures filled with anhydrite.
12103-105, Anhydrite, dark gray brown, dense, dolomitic.
12105-109, Dolomite, light to medium brown, crystalline, finely bedded.
12109-110, Limestone, dark gray, dense, platy, oolitic.
12110-117, Dolomite, medium brown, microcrystalline, fair porosity, finely bedded.
12117-125, Limestone, dark gray brown, fragmental, with abundant fossil bryozoans and brachiopods, scattered inclusions of anhydrite.
12125-132, Limestone, medium to dark brown, cryptocrystalline, inclusions of anhydrite, finely laminated with layers of dark carbonaceous material.
12132-136, Dolomite, dark gray brown, dense, finely laminated.

Tops: R R: 11969 R: 12014 P: 12074 Base P: DR

WARD COUNTY

Well Number: N. D. 47
Well Name: Hunt #1 Wald
Location: SE SW 23-155-81 Comp.: 4-25-52
K.B.: 1596 T.D.: 8652 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 7558 R: 7600 P: 7660 Base P: 7768

Well Number: N. D. 52
Well Name: Wanete #1 Lee
Location: NE NE 24-156-85
K.B.: 1840 T.D.: 10134 Status in R R: D & A
DST: (1) 9315-341, rec. 10' SO & GCM.
(2) 9398-409, rec. 210' GCSW.
Perfs.: 9320-336, rec. 120' sulfur water; 9401-408
Cores: 9320-74; 9389-447; 9463-633; 9635-807
Tops: R R: 9287 R: 9347 P: 9410 Base P: 9497

Well Number: N.D. 105
Well Name: Stanolind #1 Wasick
Location: C SW NE 2-153-85 Comp.: 10-31-52
K.B.: 2155 T.D.: 11009 Status in R R: D & A
DST: (1) 10130-177, rec. 120' M.
(2) 10171-347, rec. 3800' MCSW.
Cores: 10157-177
Tops: R R: 10090 R: 10144 P: 10205 Base P: 10324

Well Number: N.D. 588
Well Name: Hunt #1 Neumann
Location: SW SE 33-152-82 Comp.: 7-13-54
K.B.: 2087 T.D.: 9653 Status in R R: D & A
DST: None
Cores: None
Tops: R R: 8813 R: 8856 P: 8920 Base P: 9026

WILLIAMS COUNTY

Well Number: N.D. 32
Well Name: Amerada Petrol. Corp. #1 Bakken
Location: SW NW 12-157-95 Comp.: 4-25-52
K.B.: 2458 T.D.: 13709 Status in R R: D & A
DST: (1) 12966-13034, rec. 5420' SO & GCSW, 180' salt crystals.
Cores: 12976-13034, salt filled
Tops: R R: 12817 R: 12874 P: 12924 Base P: 13046

Well Number: N.D. 35
Well Name: Amerada Petrol. Corp. #1 P. Dilland
Location: SW NE 31-156-95 Comp.: 5-30-52
K.B.: 2329 T.D.: 13325 Status in R R: D & A
DST: (1) 13200-325, rec. 469' M.
(2) 13188-325, rec. 16' M, tool stuck, left tool in hole.
Cores: None
Tops: None - R R not logged.

Well Number: N.D. 235
Well Name: Amerada Petrol. Corp. #2 Lalim (OWDD)
Location: NE NE 35-158-95 Comp.: 8-23-67
K.B.: 2469 T.D.: 12800 Status in R R: Oil
Prod. zones: B, C, D, C IPF: 390 BO/23 hrs., no water
Perfs: 12669-675; 12766-779; 12783-787; 12789-796; 12806-817
DST: (1) 12666-700, GTS 1 hr. 57 min., rec. 1053' oil, 46°, 100' MCW.
(2) 12762-830, WCTS 24 min., rec. 2158' free oil, 45°, 90' OCM.
Cores: None
Tops: R R: 12605 R: 12662 P: 12713 Base P: 12830

Well Number: N.D. 254
Well Name: Amerada Petrol. Corp. #2 L. Kvam
Location: SW NE 19-156-95 Comp.: 3-7-54
K.B.: 2397 T.D.: 14066 Status in R R: D & A
DST: (1) 13057-090, GTS 4 hrs., pulled up to 8228' and well unloaded 35 bbls. GCWC.
Cores: None
Tops: R R: 13006 R: DR P: DR Base P: DR

Well Number: N.D. 999
Well Name: Texas #1 Donahue
Location: SW NE 23-154-100 Comp.: 6-10-56
K.B.: 2253 T.D.: 14035 Status in R R: D & A
DST: None
Cores: 13867-14035
Tops: R R: 13856 R: 13920 P: 13977 Base P: DR

Well Number: N.D. 1231
Well Name: Amerada Petrol. Crop. #1 Iverson-Nelson Unit
Location: SE NE 2-155-96 Comp.: 12-10-57
K.B.: 2316 T.D.: 13615 Status in R R: Oil
Prod. zones: C, D IPF: 332 BC in 24 hrs. Perfs: 12696-12784
DST: None
Cores: 12676-734; 12792-966
Tops: R R: 12674 R: 12724 P: 12776 Base P: 12888

Well Number: N.D. 1385
Well Name: Amerada Petrol. Corp. #9 N.D. "A"
Location: SE SW 16-156-95 Comp.: 9-27-57
K.B.: 2360 T.D.: 14828 Status in R R: D & A
DST: None
Perfs: 13292-360, swabbed 66 BSW in 5 hrs., 86.5 BSW in 8 hrs., squeezed.
Cores: 13176-350
Tops: R R: 13125 R: 13194 P: 13249 Base P: 13373

Well Number: N.D. 1403
Well Name: Amerada Petrol. Corp. #1 Boe-Olson Unit
Location: NE 15-155-96 Comp.: 11-19-57
K.B.: 2165 T.D.: 14154 Status in R R: D & A
DST: None
Perfs.: 12945-985, F 331 BSW with trace of oil in 8 hrs., F 87 BSW, trace of oil in 5 hrs.; 12810-885, F 3.62 BSW in 8 hrs.; 12710-735, swabbed 19 bbls. black sulfur water in 14 hrs., swabbed 0.8 bbls. cond., 6.34 bbl. SW in 6 hrs., reacidized, F 24 BC and 340 BSW in 12 hrs., squeezed perfs.; 12810-840, swabbed 61 bbls. load water and 13 bbls. acid water in 12 1/2 hrs., reacidized, swabbed and flowed 60 BMSW, squeezed perfs. 12710-735.
Cores: 12637-917
Tops: R R: 12656 R: 12720 P: 12773 Base P: 12895

Well Number: N.D. 1514
Well Name: Amerada Petrol. Corp. #1 Ulven Unit
Location: NE 34-156-96 Comp.: 2-15-58
K.B.: 2286 T.D.: 14510 Status in R R: D & A
DST: None
Cores: 13038-101
Tops: R R: 12898 R: 12966 P: 13014 Base P: 13142

Well Number: N.D. 1636
Well Name: Amerada Petrol. Corp. #1 Peterson-Davidson Unit
Location: C SW 17-156-95 Comp.: 5-11-58
K.B.: 2401 T.D.: 14095 Status in R R: Oil
Prod. zones: D IPF: 162 BC, 33 BSW in 13 hrs. (nor completed originally in R R). Perfs.: 13164-214
DST: None

Cores: None
Tops: R R: 13004 R: 13066 P: 13118 Base P: 13240

Well Number: N.D. 1745
Well Name: Hunt #1 Odegaard
Location: NW 21-157-95 Comp.: 6-11-58
K.B.: 2361 T.D.: 13045 Status in R R: D & A
DST: (1) 12842-890, rec. 140' SW.
(2) 12904-955, rec. 586' salt crystals, 6004' SW.
Cores: None
Tops: R R: 12722 R: 12784 P: 12836 Base P: 12957

Well Number: N.D. 2009
Well Name: Amerada Petrol. Corp. #2-A N.D. "C"
Location: C NE NW 16-158-95 Comp.: 12-31-58
K.B.: 2446 T.D.: 12840 Status in R R: D & A
DST: (1) 12742-790, rec. 510' GCSW.
Cores: None
Tops: R R: 12607 R: 12664 P: 12714 Base P: 12832

Well Number: N.D. 3844
Well Name: Amerada Petrol. Corp. #3 B.L.O.U.
Location: SE SE 1-155-96 Comp.: 10-9-65
K.B.: 2370 T.D.: 14600 Status in R R: Oil
Prod. zones: D IPF: 341 BCPD, 53.2°, plus 5799 MCF6PD.
Perfs.: 13126-156
DST: None
Cores: None
Tops: R R: 12923 R: 12986 P: 13042 Base P: 13167

Well Number: N.D. 4323
Well Name: Amerada Petrol. Corp. #B-1 Ives
Location: NE SW 26-158-95 Comp.: 1-2-68
K.B.: 2460 T.D.: 13757 Status in R R: Oil
Prod. zones: B, C, D, F IPF: Unknown Perfs.: 12654-665; 12730-738; 12762-764; 12779-801; 12817-821, F 136.8 BO in 7 hrs.; 12874-890, F 225 BO in 12 1/4 hrs.
DST: (1) 12628-670, GTS 30 min. after closing tool, rec. 51 bbls. WC, 3.2 BO & 4.8 BM.
(2) 12715-815, WCTS 25 min., GTS 25 min., reversed out 30 BO.

Cores: 12628-670; 12720-780; 12780-815
Tops: R R: 12587 R: 12650 P: 12 700 Base P: 12816

REFERENCES

Andrichuk, J. M., 1959, Ordovician and Silurian stratigraphy and sedimentation in southern Manitoba, Canada: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 10, p. 2333-2398.

Ballard, F. V., 1963, Structural and stratigraphic relationships in the Paleozoic rocks of Eastern North Dakota: N. D. Geol. Survey Bull. 40, 42 p.

Cumming, A. D., Fuller, J. G. C. M., and Porter, J. W., 1959, Separation of strata: Paleozoic limestones of the Williston Basin: Am. Jour. Sci., vol. 257, p. 722-733.

Dow, W. G., 1967, The Spearfish Formation in the Williston Basin of western North Dakota: N. D. Geol. Survey Bull. 52, 28 p.

Fuller, J. G. C. M., 1961, Ordovician and continuous formation in North Dakota: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 8, p. 1334-1363.

Laird, W. M., 1964, Resume of the stratigraphy and structure of North Dakota: Third Internat. Williston Basin Symposium, p. 39-44.

Murray, R. C., and Lucia, F. J., 1967, Cause and control of dolomite distribution by rock selectivity: Geol. Soc. America Bull., v. 78, no. 1, p. 21-36.

Murray, R. C., 1960, Origin of porosity in carbonate rocks: Jour. Sed. Petrology, v. 30, no. 1, p. 59-84.

North Dakota Geological Survey, 1968, Official Oil in North Dakota (second half, 1967): 155 p.

Porter, J. W., and Fuller, J. G. C. M., 1959, Lower Paleozoic rocks of Northern Williston Basin and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 124-189.

Salisbury, R. A., 1966, Jurassic stratigraphy of the southern two-thirds of North Dakota: Unpublished Masters Thesis, Univ. of N. Dak., Grand Forks, 124 p.

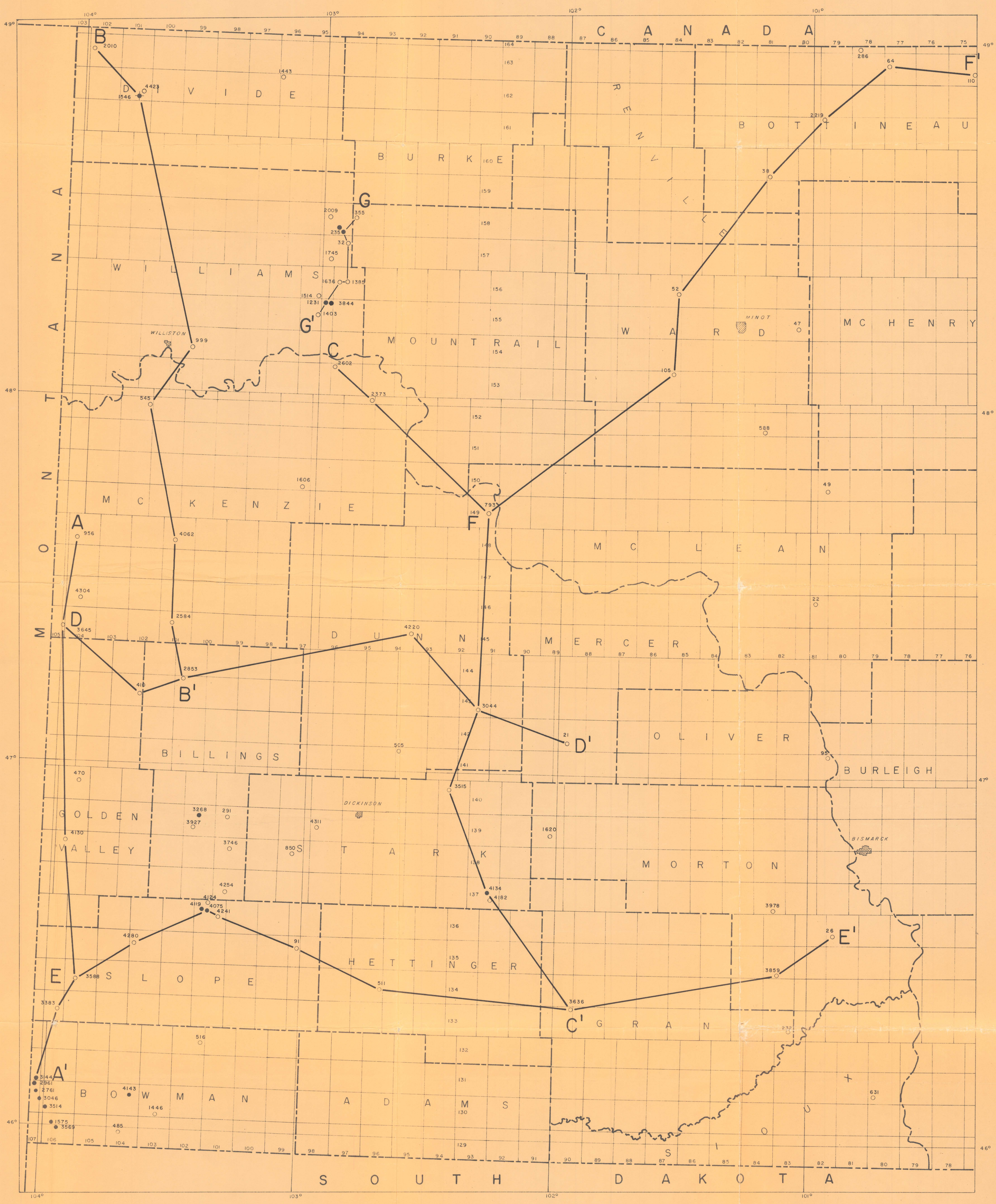
Sandberg, C. A., 1962, Geology of the Williston Basin, North Dakota, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes: U. S. Geol. Survey Prel. Report TEI-809.

_____, 1964, Precambrian to Mississippian paleotectonics of the southern Williston Basin: Third Internat. Williston Basin Symposium, p. 37-38.

Scruton, P. C., 1953, Deposition of evaporites: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 11, p. 2498-2512.

Sloss, L. L., 1953, The Significance of evaporites: Jour. Sed. Petrology, v. 23, no. 3, p. 143-161.

Weyl, P. K., 1960, Porosity through dolomitization: conservation of mass requirements: Jour. Sed. Petrology, v. 30, p. 85-90.



LEGEND

- ○ DRY HOLE (RED RIVER)
- ● PRODUCER (RED RIVER)
- 1446 NORTH DAKOTA GEOLOGICAL SURVEY NUMBER

LOCATION OF CROSS SECTIONS:

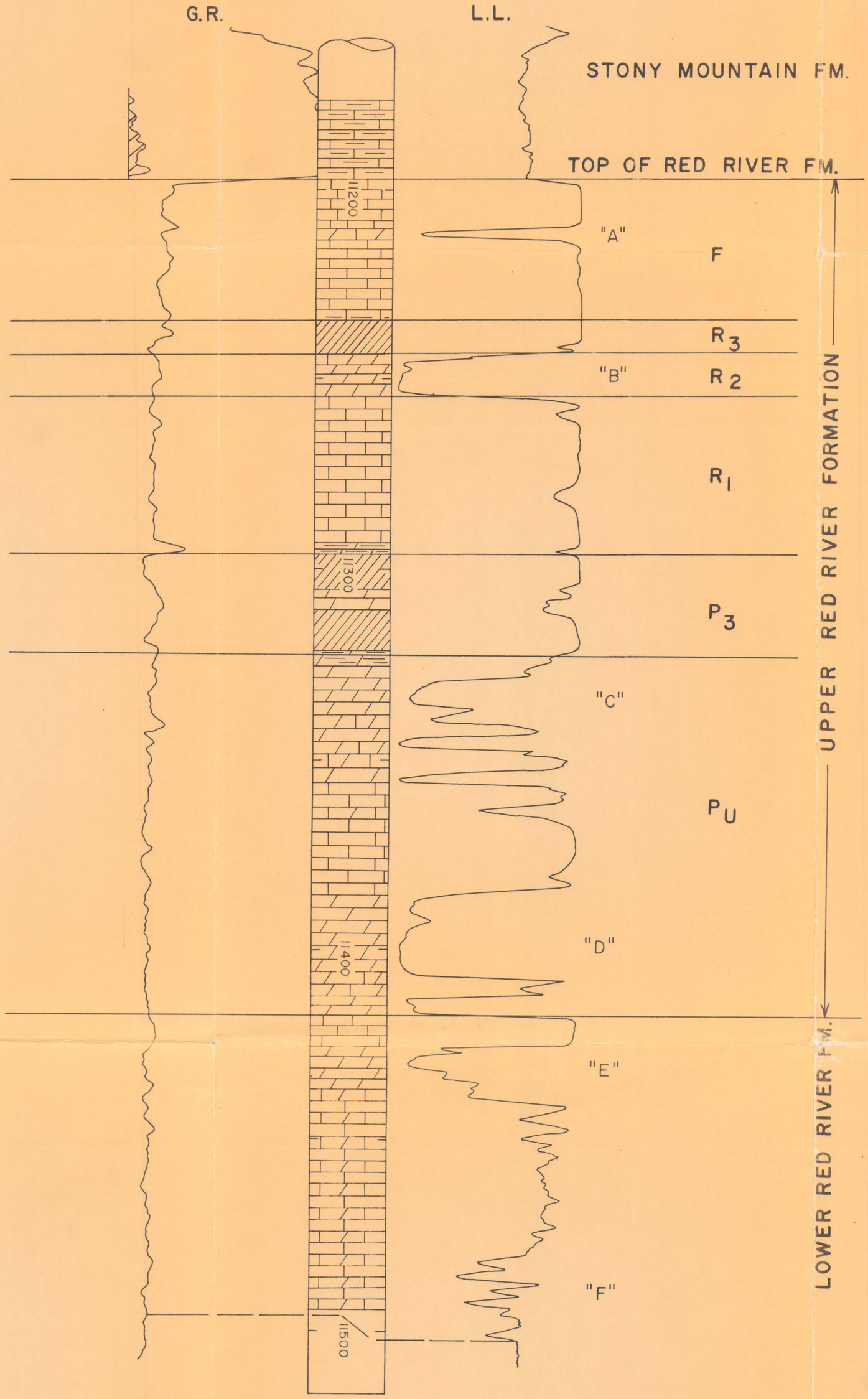
A-A'	PLATE 9
B-B'	PLATE 10
C-C'	PLATE 11
D-D'	PLATE 12
E-E'	PLATE 13
F-F'	PLATE 14
G-G'	PLATE 15

INDEX MAP
SHOWING
WELL CONTROL AND CROSS SECTIONS

SCALE 0 10 20 30 40 MILES

PLATE 1

4119
HUNT - U.S.A. 8 NO. 1
NE-SW 8-136-101
SLOPE COUNTY



LEGEND

"A", "B", ... POROSITY ZONES

P, R, F - CYCLIC UNITS (INTERVAL)

A TYPICAL LOG OF THE RED RIVER FORMATION IN WESTERN NORTH DAKOTA

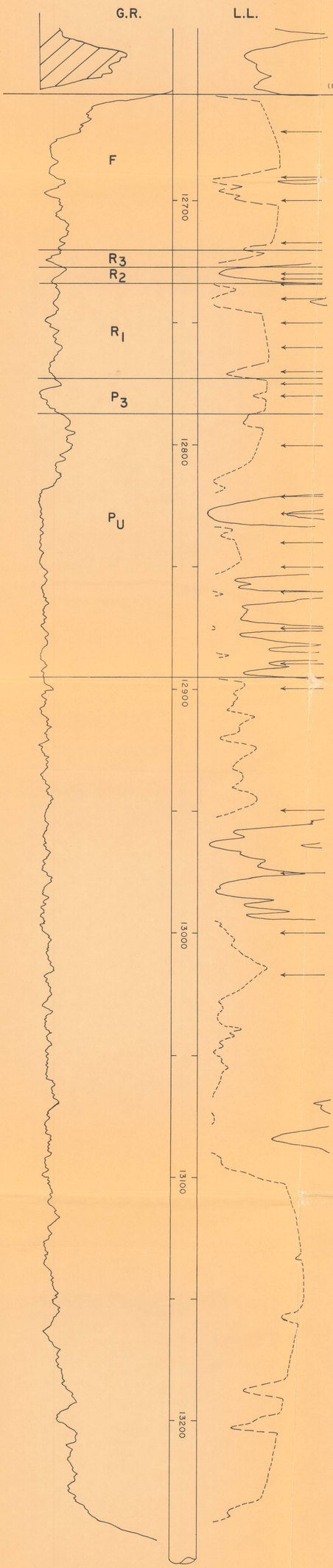
PLATE 2

1403

AMERADA-BOE OLSON UNIT NO. 1

NE-15-155-96

WILLIAMS COUNTY

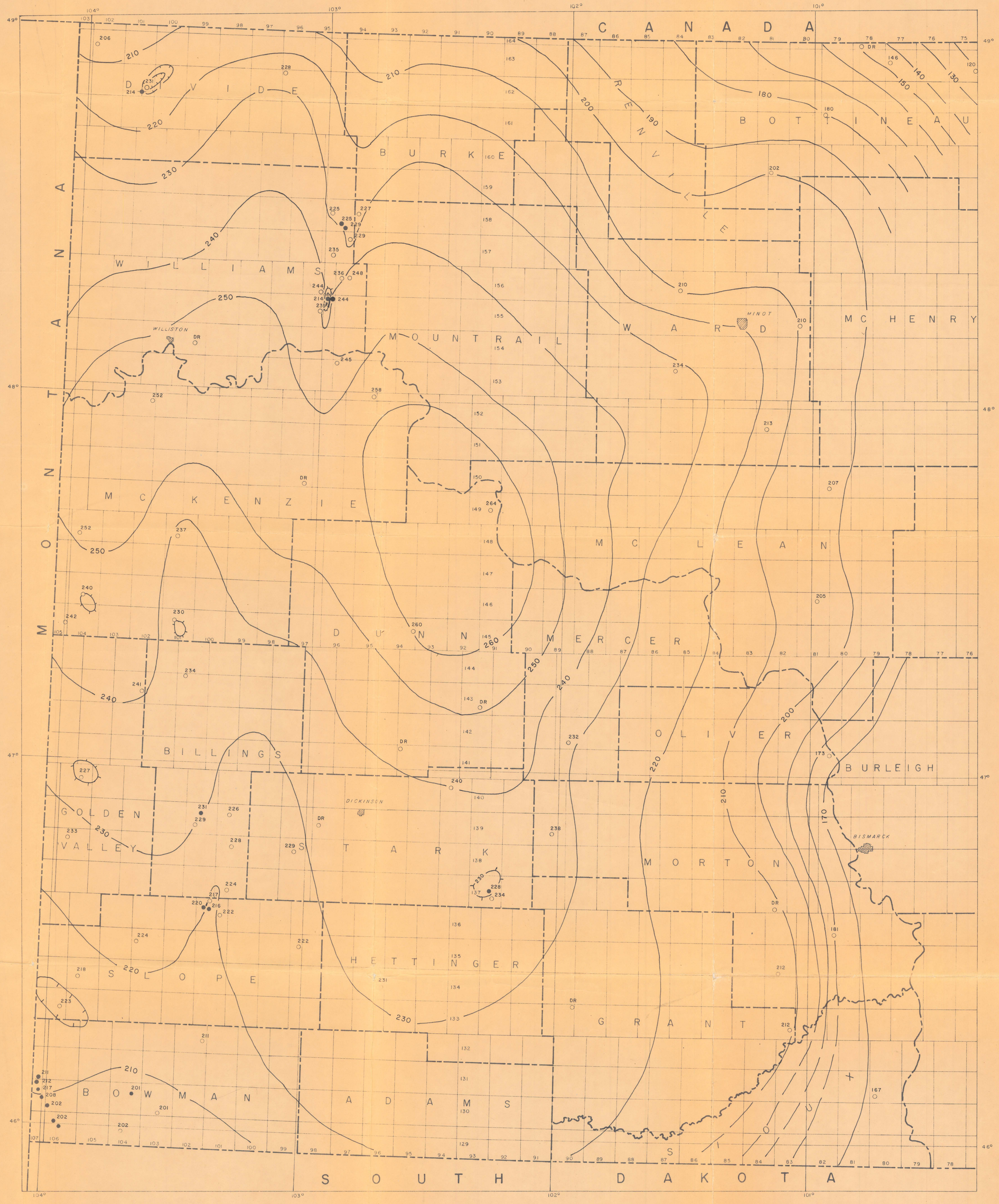


(EXPRESSED IN PARTS PER TEN)

CALCITE	DOLOMITE	ANHYDRITE	QUARTZ + FELDSPAR
8	1 1/2		1/2
6	3		TR.
	1 1/2	8 1/2	
	3	6	1
	9 1/2	1/2	TR.
	9 1/2	TR.	TR.
	9 1/2	TR.	TR.
	9	1	TR.
9	1/2		1/2
10			TR.
	1 1/2	8 1/2	TR.
		10	
		10	
	10	TR.	
	10	TR.	TR.
TR.	9 1/2	TR.	TR.
1	9		TR.
7	3		TR.
1/2	8	1 1/2	TR.
1	9		TR.
8	2		TR.
4 1/2	5 1/2		
1	8 1/2		1/2
2	7 1/2		1/2
7	3		TR.
5	5		TR.

LOG SHOWING MINERAL COMPOSITION AND LOCATION OF CORE SAMPLES ANALYZED BY X-RAY

PLATE 3



LEGEND

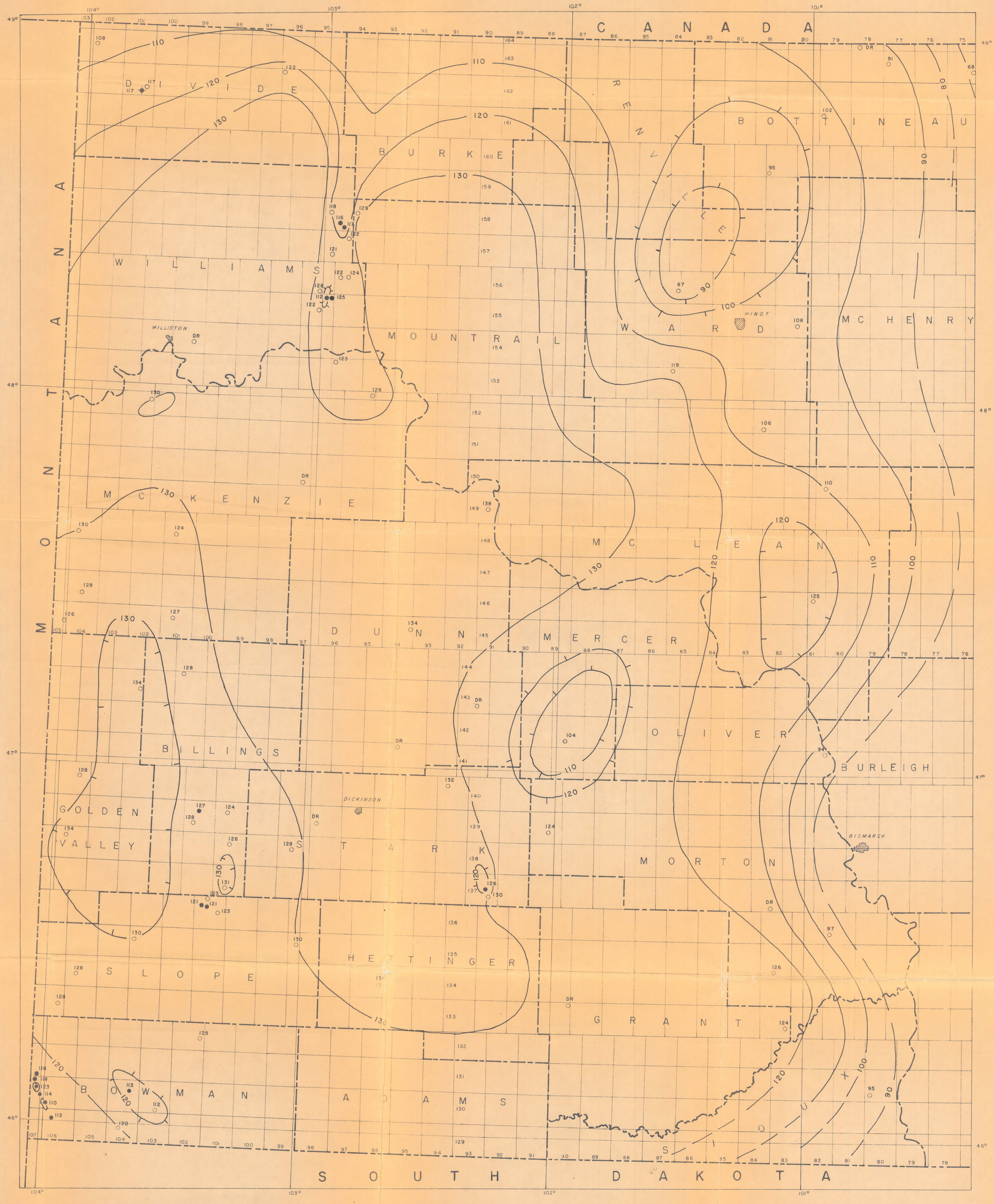
- ○ CONTROL WELL - DRY IN RED RIVER
- ● CONTROL WELL - OIL IN RED RIVER
- DR - WELL DOES NOT REACH BASE OF UPPER RED RIVER
- 231 THICKNESS IN FEET
- CONTOUR INTERVAL - 10 FEET
- THIN AREA
- THICK AREA

SCALE
0 10 20 30 40 MILES

ISOPACHOUS MAP OF THE UPPER RED RIVER FORMATION

(INCLUDES P, R, AND F INTERVALS)

PLATE 4



LEGEND

- ○ CONTROL WELL – DRY IN RED RIVER
- ● CONTROL WELL – OIL IN RED RIVER
- DR – DOES NOT REACH BASE OF "P" INTERVAL
- 130 THICKNESS IN FEET
- CONTOUR INTERVAL – 10 FEET
- THIN AREA
- THICK AREA

SCALE 0 10 20 30 40 MILES

ISOPACHOUS MAP OF THE "P" INTERVAL UPPER RED RIVER FORMATION

PLATE 5

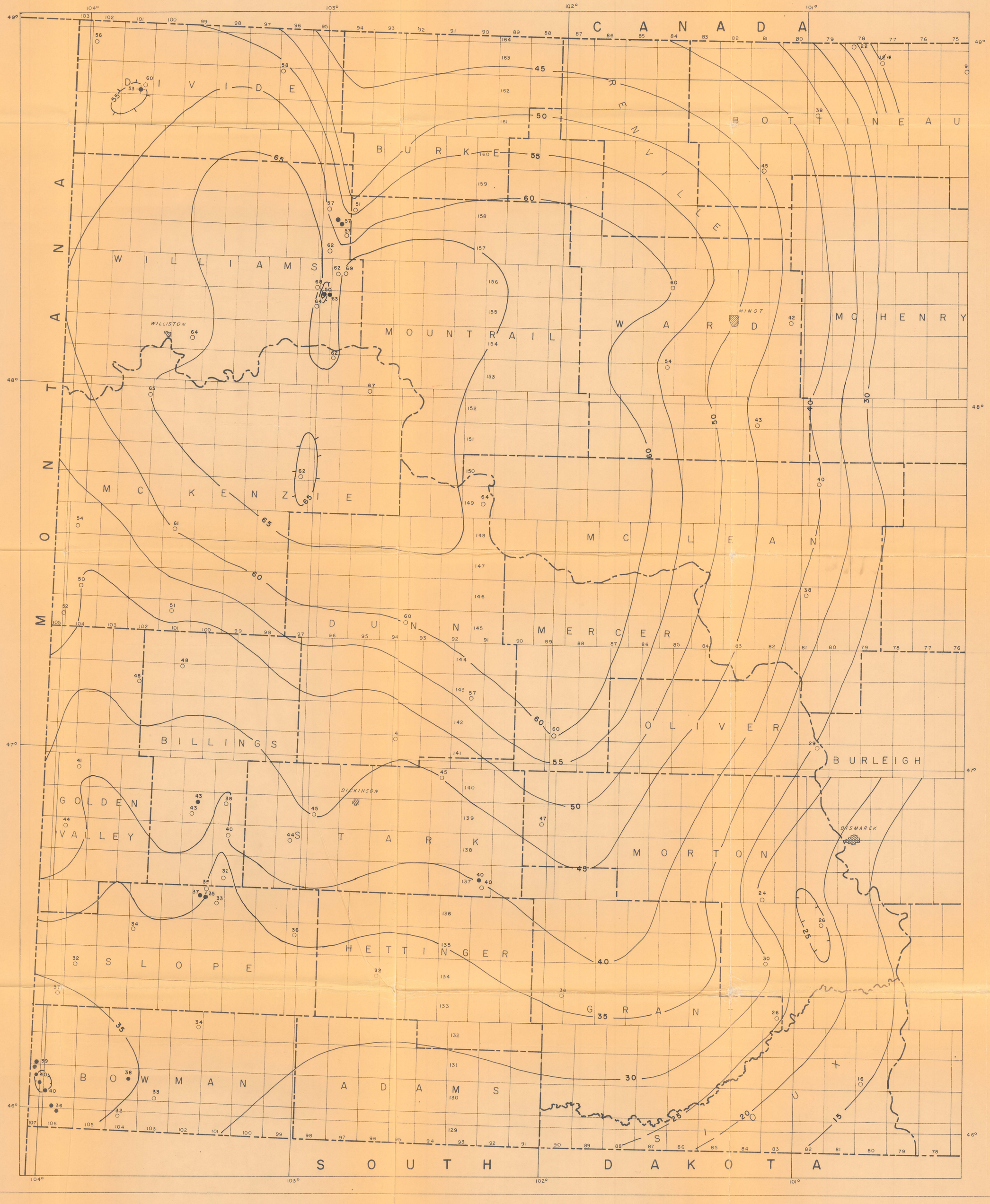
ISOPACHOUS MAP OF THE "R" INTERVAL UPPER RED RIVER FORMATION

LEGEND

- ○ CONTROL WELL - DRY IN RED RIVER
- ● CONTROL WELL - OIL IN RED RIVER
- 53 THICKNESS IN FEET
- CONTOUR INTERVAL - 5 FEET
- THIN AREA
- THICK AREA

SCALE
0 10 20 30 40 MILES

PLATE 6



LEGEND

- ○ CONTROL WELL- DRY IN RED RIVER
- ● CONTROL WELL- OIL IN RED RIVER
- 32 THICKNESS IN FEET
- CONTOUR INTERVAL- 5 FEET

THIN AREA

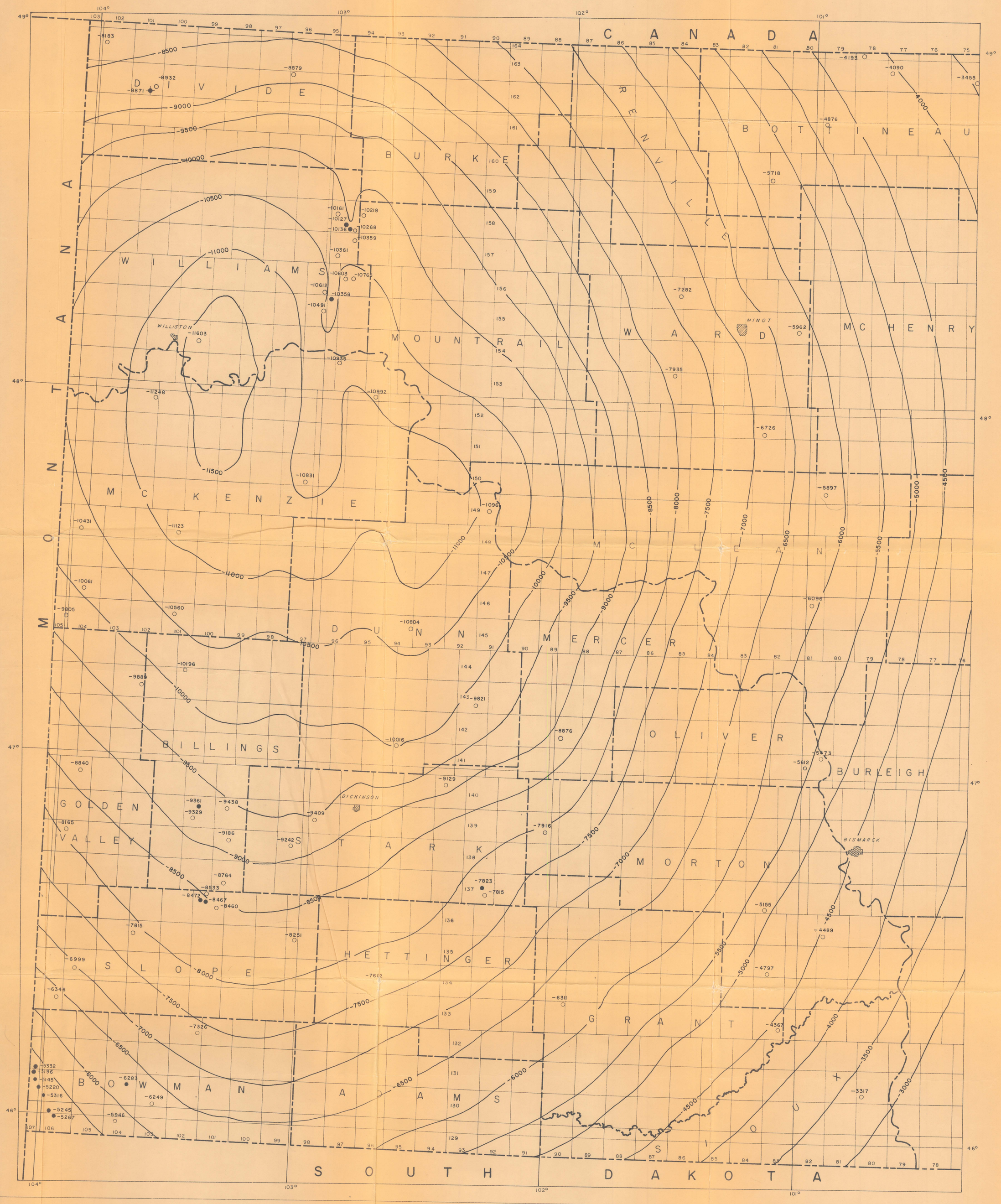
THICK AREA

SCALE

0 10 20 30 40 MILES

ISOPACHOUS MAP OF THE "F" INTERVAL UPPER RED RIVER FORMATION

PLATE 7



LEGEND

○ CONTROL WELL

−7326 DEPTH BELOW SEA LEVEL

CONTOUR INTERVAL — 500 FEET

SCALE

0 10 20 30 40 MILES

STRUCTURE CONTOUR MAP ON THE TOP OF THE RED RIVER FORMATION

PLATE 8

NORTH-SOUTH CROSS SECTION OF THE RED RIVER FORMATION IN SOUTHWESTERN NORTH DAKOTA

A

956
GULF OIL - B. PIERRE FED. NO. 1
28-148-104
MC KENZIE, COUNTY

G.R. L.L. N.

17 MILES

3645
QUINTANA PETROL - U.S.A. NO. 1
25-145-105
MC KENZIE COUNTY

G.R. L.L. SON.

41 MILES

4130
AMERADA PETROL - WALDRON NO. 1
9-138-105
GOLDEN VALLEY COUNTY

G.R. L.L. SON.

26 MILES

3588
SUN OIL - GREER FED. NO. 1
21-134-105
SLOPE COUNTY

G.R. L.L. SON.

7 MILES

3383
PAN AMERICAN - FOREMAN NO. 1
23-133-106
SLOPE COUNTY

G.R. L.L. SON.

15 MILES

3144
SHELL - ANTELOPE BUTTE NO. 23-35B-21
35-131-107
BOWMAN COUNTY

G.R. L.L.

A'

UPPER RED RIVER FORMATION

LOWER RED RIVER FORMATION

F

R_3 R_2 (Anhydrite)

R_1

P_3

P_U

DST: 12905-12950, Rec. 540' S Wtr.
DST: 12961-13006, Rec. 1030' S Wtr.
CORE: 12795-13007

DST: 12390-12438, Rec. 900' Slt. MC Wtr. Cush.
133' Mdy. G. and Slt. OC Wtr. Cush.

DST: 11068-11108, Rec. 35'M, 4690' S Wtr.
DST: 11145-11182, Rec. 90' G C M
DST: 11180-11270, Rec. 430' M

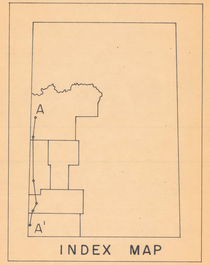
DST: 9928-9940, Rec. 5' O, 1866' O C Cush.,
180' Gsy O, 515' S Wtr.
DST: 10054-10087, Rec. 47' M.
DST: 10067-10129, Rec. 25' M.
CORE: 9982-10032

DST: 9164-9201, Rec. 200' M C Wtr.
724' H G C Wtr., Tr. O, 470' H G C Wtr.
DST: 9250-9286, Rec. 650' G., 270' G & G C M
DST: 9286-9416, Rec. 252' G C M, 548' G C Wtr.
138' Slt G C Wtr, 89' G C M.

CORE: 8322-8421
PERF: 8342-44, 8346-48, 8369-72,
8377-79, 8466-68
IPP: 200 B O & 74 BWPD

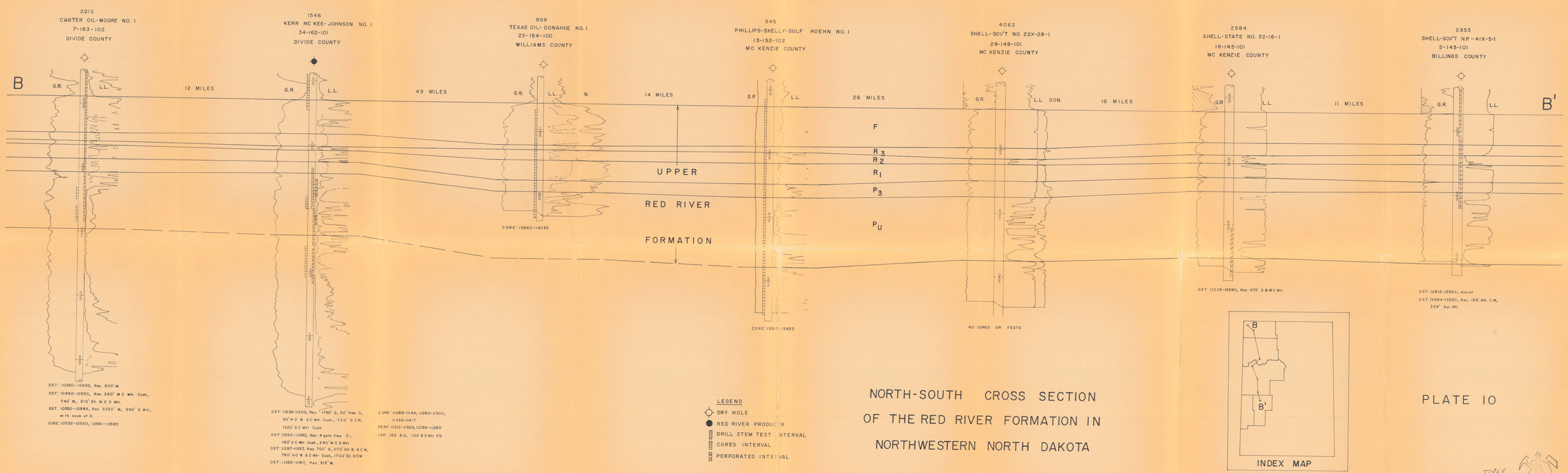
LEGEND

- DRY HOLE
- RED RIVER PRODUCER
- DRILL STEM TEST INTERVAL
- CORED INTERVAL
- PERFORATED INTERVAL



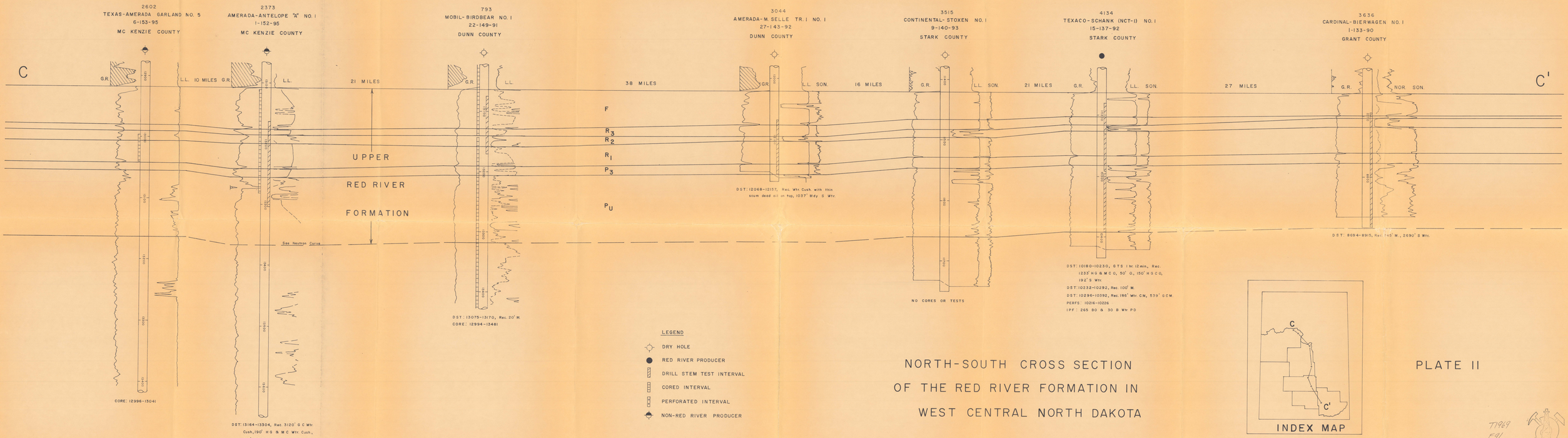
INDEX MAP

PLATE 9



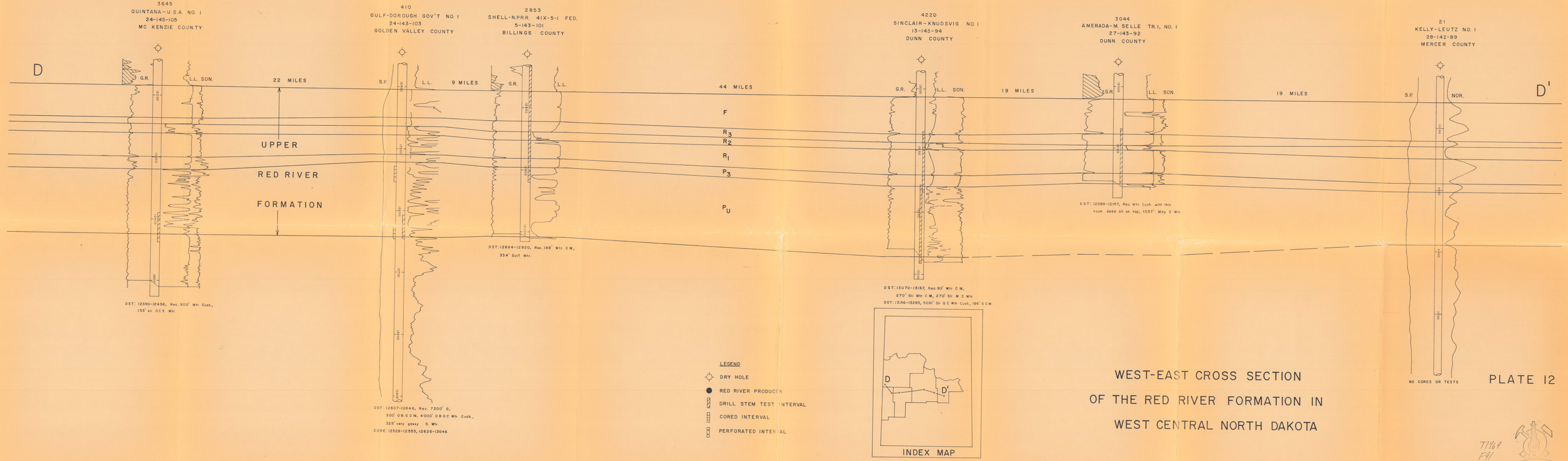
NORTH-SOUTH CROSS SECTION OF THE RED RIVER FORMATION IN NORTHWESTERN NORTH DAKOTA

PLATE 10



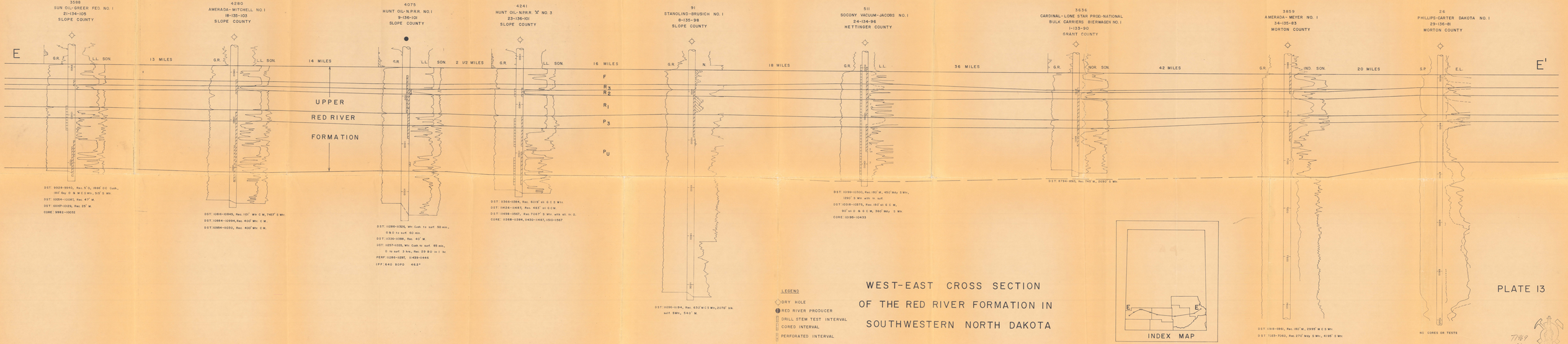
NORTH-SOUTH CROSS SECTION OF THE RED RIVER FORMATION IN WEST CENTRAL NORTH DAKOTA

PLATE II



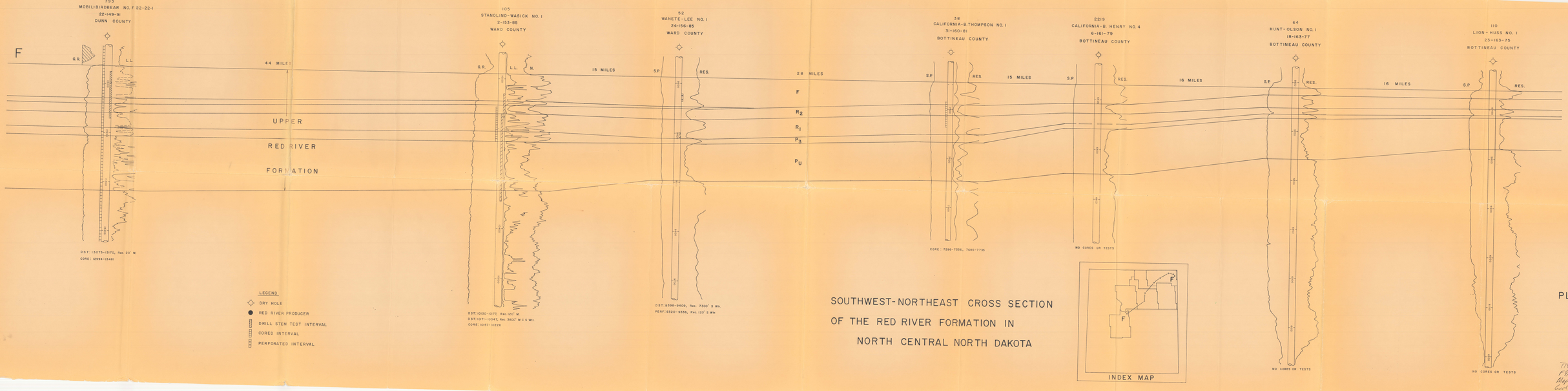
WEST-EAST CROSS SECTION OF THE RED RIVER FORMATION IN WEST CENTRAL NORTH DAKOTA

PLATE 12



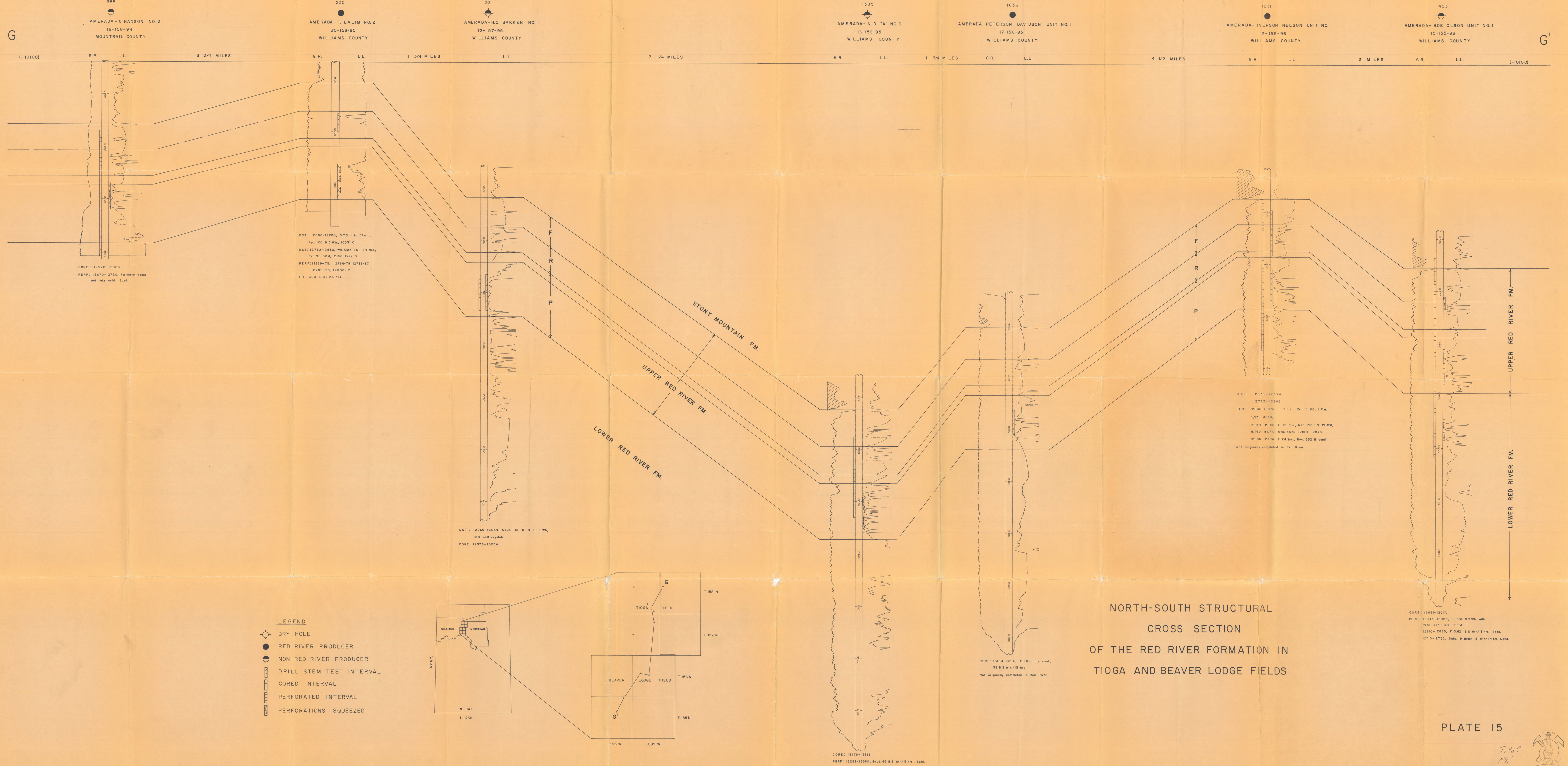
WEST-EAST CROSS SECTION OF THE RED RIVER FORMATION IN SOUTHWESTERN NORTH DAKOTA

PLATE 13



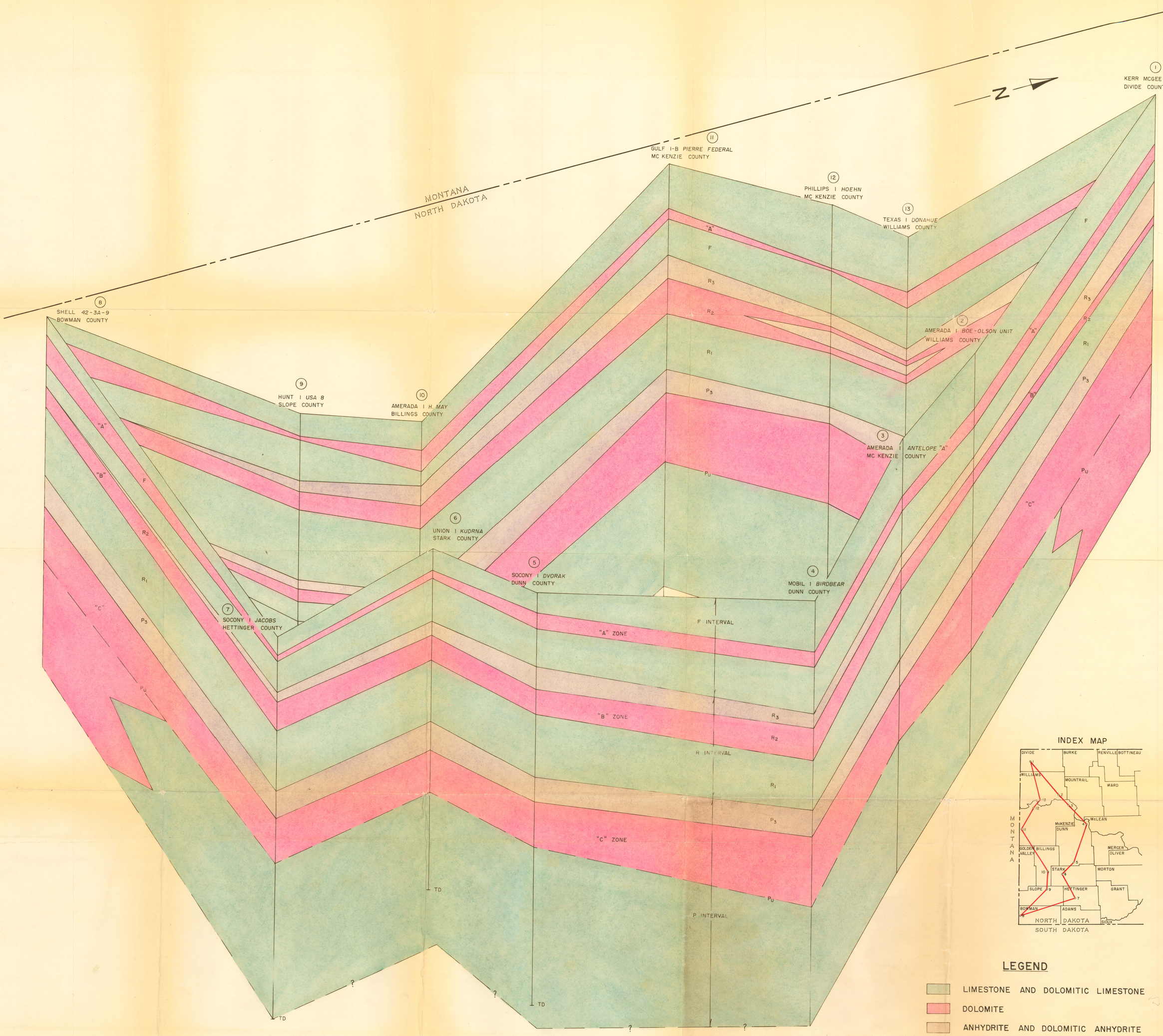
SOUTHWEST-NORTHEAST CROSS SECTION OF THE RED RIVER FORMATION IN NORTH CENTRAL NORTH DAKOTA

PLATE 14



NORTH-SOUTH STRUCTURAL CROSS SECTION OF THE RED RIVER FORMATION IN TIOGA AND BEAVER LODGE FIELDS

PLATE 15



INDEX MAP

LEGEND

- LIMESTONE AND DOLOMITIC LIMESTONE
- DOLOMITE
- ANHYDRITE AND DOLOMITIC ANHYDRITE

VERTICAL SCALE 1" = 20'
HORIZONTAL SCALE 1" = APPROX. 8 MILES

FENCE DIAGRAM
UPPER RED RIVER FORMATION
WESTERN NORTH DAKOTA

PLATE 16