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UPPER ORDOVICIAN AND SILURIAN ROCKS OF NORTH DAKOTA

by

C. G. Carlson and W.P. Eastwood

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UPPER ORDOVICIAN AND SILURIAN ROCKS OF NORTH DAKOTA

ABSTRACT

The Upper Ordovician and Silurian rocks of North Dakota are comprised of three formations which in ascending order are the Stony Mountain, Stonewall and Interlake Formations.

The Stony Mountain Formation of Upper Ordovician age is divided into two members, a lower or Stoughton Member and an upper or Gunton Member. The Stoughton Member is thickest in the southeastern part of the state where it consists of about 110 feet of calcareous, silty shale and silty, shaly limestone. It thins to about 30 feet of interbedded shaly limestone and calcareous shale in the northwestern part of the state. The Gunton Member is thickest in the northwestern part of the state where it consists of about 100 feet of dolomitic limestone, limy dolomite, and one thin bed of anhydrite. It thins southeastward where it consists of about 45 feet of dolomite near the erosional limit of the Stony Mountain Formation.

The Stonewall Formation of Upper Ordovician to Lower Silurian (?) age consists of about 120 feet of finely crystalline limestone and dolomite with two thin anhydrite beds near the base in the central basin area. The anhydrites pinch out towards the margins of the basin where the Stonewall Formation consists of light colored dolomites.

The Interlake Formation of Silurian age ranges in thickness from about 1,100 feet in northwestern North Dakota to an erosional edge in eastern North Dakota. It has been divided into three intervals on the basis of fine grained clastic marker horizons which mark interruptions in the predominantly carbonate deposits. The lower two intervals are mostly finely crystalline dolomites while the upper interval consists of limy dolomite and dolomitic limestone.

The upper interval of the Interlake Formation has produced oil from three fields along the Nesson Anticline and shows have been reported from the Stony Mountain Formation in the same area of North Dakota. Both of these formations are productive in the Montana portion of the Williston Basin and should be prospective horizons in other areas of North Dakota.

SILURIAN AND UPPER ORDOVICIAN ROCKS OF NORTH DAKOTA

INTRODUCTION

General Introduction

Oil and gas in commercial quantities have previously been found in rocks of Silurian age in the Williston Basin in three pools along the Nesson Anticline in northwestern North Dakota, along the Cedar Creek Anticline in southeastern Montana, and the Outlook area in northeastern Montana. The purpose of this study is to present information about the Silurian and Upper Ordovician rocks of North Dakota, thus making this information more readily available and perhaps encouraging further exploration of the petroleum potentials of these rocks in North Dakota.

The stratigraphic nomenclature for the interval of study has been derived from the outcrop areas of southern Manitoba and extended into the subsurface of the Williston Basin with some modifications. The Ordovician-Silurian systemic boundary has not been satisfactorily established in the Williston Basin, because deposition was probably continuous, or nearly continuous, from the Upper Ordovician through the Lower Silurian epochs. Therefore, for convenience of study, the studied interval includes the Stony Mountain Formation of Upper Ordovician age, the Stonewall Formation of Upper Ordovician to Lower Silurian (?) age, and the Interlake Formation of Silurian age.

A location map (Fig. 1) shows most of the wells which have penetrated Silurian or older rocks in North Dakota. Wells omitted are some field wells along the Nesson and Cedar Creek Anticlines and a few wells south and east of the erosional limit of the Stony Mountain Formation in southeastern North Dakota.

Sample cuttings, cores and mechanical logs from the wells penetrating Silurian rocks furnished the basis for the present study. The lithologic studies included examination of cuttings and cores with a binocular microscope, thin section and insoluble residue studies. Descriptions of cuttings were available from North Dakota Geological Survey Circulars for a number of wells and some of these descriptions were used on the cross sections (Figs. 3 to 6). Some of these samples were also restudied by the writers.

MANITOBA OUTCROP AREA (VARIOUS WRITERS)	PORTER & FULLER 1958, 1959	SASKATCHEWAN GEOLOGICAL SOCIETY 1958	KENT 1960	THIS PAPER
INTERLAKE GROUP: CEDAR LAKE FM. EAST ARM FM. ATIKAMEG FM. MOOSE LAKE FM. INWOOD FM. FISHER BRANCH FM.	INTERLAKE GROUP: UPPER INTERLAKE BEDS MIDDLE INTERLAKE BEDS LOWER INTERLAKE BEDS	INTERLAKE GROUP: RISSER BEDS HANSON BEDS RUPERT BEDS		INTERLAKE FORMATION: UPPER INTERVAL MIDDLE INTERVAL LOWER INTERVAL
STONEWALL FORMATION	STONEWALL FORMATION	STONEWALL BEDS	STONEWALL FORMATION	STONEWALL FORMATION
STONY MOUNTAIN FORMATION: GUNTON MEMBER PENITENTIARY MEMBER GUNN MEMBER	STONY MOUNTAIN FORMATION: GUNTON MEMBER STONY MOUNTAIN SHALE MEMBER	STONY MOUNTAIN BEDS: GUNTON BEDS STOUGHTON BEDS	STONY MOUNTAIN FORMATION: GUNTON MEMBER STOUGHTON MEMBER	STONY MOUNTAIN FORMATION: GUNTON MEMBER STOUGHTON MEMBER

Figure 2 - Chart showing previous and present stratigraphic nomenclature applied to the Upper Ordovician and Silurian rocks of the Williston Basin.

Previous Work

Prior to 1951, nine oil exploration wells and a few water wells in the northeastern part of the state had penetrated Silurian rocks, but the character and distribution of Silurian rocks in North Dakota was still a matter of conjecture. Laird (1941) published sample descriptions for a few of these wells and Kline (1942, p. 347) summarized briefly the lithology and distribution of Upper Ordovician and Silurian rocks in North Dakota. However, Seager, et al (1942, p. 1421), in a discussion of Kline's paper, expressed a difference of opinion as to the areal extent of the Silurian rocks in North Dakota.

Exploration activity in 1951 and 1952 furnished much new information and provided a basis for reliable correlations and a better understanding of the areal distribution of the Silurian and Upper Ordovician rocks in the Williston Basin. Thus, Rader (1952, p. 52-54) described the general lithology and distribution of the Stony Mountain and Interlake + Gunton Formations in the central Williston Basin and Towse (1952, p. 8) briefly described the Upper Ordovician and Silurian rocks of south-central North Dakota. Laird and Towse (1953) described the Stony Mountain Formation and the Silurian rocks of North Dakota and mapped the areal distribution of these rocks. Present concepts of the areal distribution of these rocks agree with their maps except for minor revisions along the southeastern erosional margin. General descriptions of the lithology of the Upper Ordovician and Silurian rocks of North Dakota have also been published by the North Dakota Geological Society (1954), Folsom and Anderson (1955), Hainer (1956), Middleton and Kennedy (1956), and Carlson, et al (1960).

Porter and Fuller (1958, 1959) published detailed studies of the Lower Paleozoic rocks of the northern part of the Williston Basin which included the northern part of North Dakota. Andrichuk (1959) published a detailed study of the Ordovician and Silurian stratigraphy of southern Manitoba and Fuller (1961) discussed the Upper Ordovician and Silurian rocks throughout the Williston Basin. These papers pertaining to detailed subsurface stratigraphy and the relationships of the subsurface and surface sections in Manitoba are of particular value to any study of the Upper Ordovician and Silurian strata in North Dakota because of the demonstrable physical equivalence of the North Dakota and Manitoba subsurface sections and the extension of the stratigraphic nomenclature from the surface sections of Manitoba to the subsurface of the Williston Basin.

Porter and Fuller (1959, p. 131-133) demonstrated the physical equivalency of the subsurface and surface sections of the Lower Paleozoic rocks of Manitoba. Then, they traced subdivisions of the

Lower Paleozoic rocks through the subsurface of the Williston Basin by the use of marker horizons. These marker horizons were found to be useful in the present study and we have attempted to extend them throughout the areal extent of these rocks in North Dakota.

However, this approach leads to a problem of nomenclature because the Saskatchewan Geological Society (1958) proposed formal names for the subdivisions of the Lower Paleozoic rocks as defined by Porter and Fuller. Since the basis for subdivision was marker horizons, which they believed to be time-parallel markers, rather than based on lithology, they called these subdivisions Beds (i. e., para-time rock units) rather than Members (i. e., rock units). The American Code of Stratigraphic Nomenclature makes no provision for para-time rock units. It provides that key or marker beds may be named, but such names are usually considered as informal. Therefore, if one is to follow the Code, the problem is resolved to one of whether these subdivisions are considered as time-stratigraphic or rock-stratigraphic units.

The subdivisions of the Stony Mountain Formation in North Dakota based on lithology coincide with the subdivisions based on marker horizons. Therefore, the terms proposed by the Saskatchewan Geological Society as para-time rock units are herein accepted for these rock-stratigraphic units in North Dakota.

Their subdivisions of the Interlake Formation are based on clastic horizons marked by characteristic deflections on Gamma Ray logs in an otherwise quite similar carbonate sequence rather than on lithologic differences above and below these marker horizons. Therefore, we have used their marker horizons for subdivision of the Interlake Formation, but since these are not rock-stratigraphic units, we prefer to call these subdivisions intervals rather than Beds or Members.

STRATIGRAPHY

Stony Mountain Formation

Name and Definition:

The Stony Mountain Formation was defined by Dowling (1901, p. 46) as the Ordovician rocks lying between the top of the Trenton and the base of the Silurian rocks in the Stony Mountain, Manitoba area. Okulitch (1943, p. 60) determined a thickness of about 110 feet for the Stony Mountain Formation in the type area and divided it into four members which in ascending order were: Stony Moun-

tain Shale, Penitentiary, Gunton and Birse Members. Baillie (1952, p. 8) accepted Okulitch's lower two members, but included the Birse in his Gunton Member. Baillie's three member subdivision has generally been accepted for the outcrop area of Manitoba, but Sinclair and Leith (1958, p. 244) proposed that the term Gunn Member be applied to the lower member (Stony Mountain Shale) so as to abide by the Stratigraphic Code (Art. 16, d) which states that the same names should not be applied to a unit as a whole and to a part of that unit.

The relationships of the surface and subsurface sections of the Stony Mountain Formation in southern Manitoba have been presented by Porter and Fuller (1959, p. 131, Fig. 4). They divided the Stony Mountain Formation of the subsurface into two units, the lower or Stony Mountain shale Member which they believed to be equivalent to Sinclair and Leith's Gunn and Penitentiary Members of the outcrop section and an upper or Gunton Member equivalent to the Gunton Member of the outcrop section. The Saskatchewan Geological Society (1958) used the same twofold subdivision as Porter and Fuller, but they introduced the term Stoughton Beds for the lower or Stony Mountain Shale Member. The writers have accepted this twofold subdivision of the Stony Mountain Formation in North Dakota and have accepted the terms Gunton and Stoughton for the upper and lower members respectively.

Age:

Fragments of brachiopods, bryozans and other invertebrates are relatively common in cuttings of the Stony Mountain Formation. Most of these are fragmentary and would be difficult to identify but cores of the Stoughton Member from the Union Oil Company – Aanstad No. 1 well (NDGS No. 20) in northeastern North Dakota are quite fossiliferous and might provide a representative fauna. These paleontological studies were not included in this study however, and the age of the Stony Mountain in North Dakota is based on lateral continuity to adjacent areas where its age has been established.

The Stony Mountain Formation is quite fossiliferous in the outcrop sections in southern Manitoba where it has been established that it is of Upper Ordovician age (Dowling, 1900, Okulitch, 1943). Subsurface studies of the Stony Mountain Formation in eastern Montana (Ross, 1957) and the Stoughton Member in Saskatchewan (Brindle, 1960) have shown that these subsurface sections are also of Upper Ordovician age. Since the Stony Mountain Formation of North Dakota is laterally continuous to these areas and is relatively uniform in thickness throughout these areas it must also be of Upper Ordovician age in North Dakota.

Lithology:

The Stoughton Member consists of medium dark gray (N 4), fossiliferous limestone interbedded with dark gray, (N 3), calcareous, fossiliferous shale in the central part of the Williston Basin. Insoluble residue studies of this member show the shale content generally increasing downward from about 20 per cent in the upper ten feet to from 45 to nearly 50 per cent in the lower part of this member in the central Basin area based on core chips from the Amerada Petroleum Corporation – Boe, Olson No. 1 well (NDGS No. 1403). Cores from the Amerada Petroleum Corporation – Antelope Unit No. 1 well (NDGS No. 2373) show generally similar results but one ten foot interval (13,082 to 13,092) had about 55 to 60 per cent insoluble residue.

In the eastern and southern parts of North Dakota the Stoughton Member consists of light gray (N 7), argillaceous, fossiliferous limestone and light gray (N 7) to light greenish gray (5 G 8/1) and grayish red purple (5 RP 4/2), calcareous, fossiliferous shale. The shale and silt content gradually increases to the east and south. Cores from the Union Oil Company – Aanstad No. 1 well (NDGS No. 20) in northeastern North Dakota have about 40 per cent insoluble residues for the middle part of the Stoughton Member and 55 to 60 per cent insoluble residues for the lower part of this member. No cores of this member are available for the south-central part of the state, but cuttings and mechanical logs indicate that the percentages for that area would be similar to those found in the northeastern part of the state.

The Gunton Member consists of brownish gray (5 YR 4/1) to yellowish brown (10 YR 6/2), finely crystalline, limy dolomite and dolomitic, fossiliferous limestone with a thin bed of anhydrite in its upper part in the northwestern part of the State. The anhydrite pinches out rapidly toward the margins of the Basin and the carbonates become more dolomitic so that the Gunton Member is predominantly yellowish gray (5 Y 7/2), fine grained dolomite in the southern and eastern parts of North Dakota. Sandy zones have been noted in cores of the upper part of the Gunton Member of the central Basin area, but they are often difficult to note in sample cuttings. However, the sand content increases towards the east and south and the sandy zones are usually noted in cuttings from those areas.

Thickness:

In that part of North Dakota where the depositional thickness has been preserved the Stony Mountain Formation ranges in thickness from about 115 to 180 feet (Fig. 7). However, beyond the cover

of the overlying Stonewall Formation, the Stony Mountain Formation thins rapidly due to post-Silurian erosion and is absent from the southeastern part of the State.

Isopachs of the two members of the Stony Mountain Formation show quite dissimilar patterns (Figs. 8 & 9). The Stoughton Member thins continuously and gradually from about 110 feet in southeastern North Dakota to about 30 feet in the northwest. Conversely the Gunton Member, about 100 feet thick in the northwest corner, thins to about 45 feet near its erosional limit in the southeast. This regional thinning of the Gunton is interrupted by a slight basinal thickening in west-central North Dakota. Thus the thickest section of the Stony Mountain Formation lies in west-central North Dakota where it coincides with the area of greatest thickness of the underlying Red River Formation. This suggests little change in basinal subsidence patterns from the Middle Ordovician epoch to the beginning of the Upper Ordovician epoch in the Williston Basin.

Relation to Adjacent Strata:

The Stony Mountain Formation conformably overlies the Red River Formation and is conformably overlain by the Stonewall Formation except where the Stonewall Formation has been removed by erosion near the erosional limit of the Stony Mountain Formation. The Stony Mountain Formation is unconformably overlain by rocks of Devonian age in southeastern North Dakota and by rocks of Jurassic or Cretaceous age in the northeast.

Stonewall Formation

Name and Definition:

Kindle (1914, p. 249) proposed the term Stonewall Formation to include all of the Silurian rocks of southern Manitoba, naming them for a quarry near Stonewall, Manitoba, which exposes the lowermost Silurian beds. This usage was generally accepted until Baillie (1951, p. 9) proposed that the Stonewall Formation be restricted to include only the lowermost Silurian strata of southern Manitoba and proposed a new name (Interlake Group) for the entire Silurian section of southern Manitoba. Stearn (1956, p. 10) accepted Baillie's definition of the Stonewall Formation, but on the basis of faunal studies excluded it from the Interlake Group and assigned an Upper Ordovician age to the Stonewall Formation. Most subsequent workers have followed Stearn's interpretation and considered the Stonewall to be a separate formation of probable Upper Ordovician age, but this interpretation has not been unchallenged. Andrichuk (1959, p. 2381) discussed the age and correlation of the Stonewall Formation and concluded that the main sedimentary break in the subsurface occurs at the base of the Stonewall Formation. Therefore he included the Stonewall Formation in the Interlake Group. However, since the Stonewall Formation can be separated from the rest of the Interlake Group with a fair degree of accuracy and most writers have favored treating it as a separate formation it is herein considered as a separate formation and its subsurface usage is as defined by Porter and Fuller (1961, p. 131, Fig. 4).

Age:

The Stonewall Formation was generally considered to be of Silurian age until Stearn (1956) in a report on the outcrop area of southern Manitoba separated the Stonewall Formation from the Interlake Group and assigned an Upper Ordovician age to the Stonewall Formation. This interpretation has been questioned by others (Porter and Fuller, 1959; Andrichuk, 1959). Porter and Fuller (1959, p. 178) noted that the Upper Ordovician fauna comes from the lower part of the Stonewall Formation and suggested that the upper part of the Stonewall Formation might be of Silurian age. Andrichuk noted that the main lithologic break is below the Stonewall Formation and considered the faunal evidence to be inconclusive.

No fossils were noted in cuttings or cores of the Stonewall Formation in North Dakota. Brindle (1960, p. 18-19) reported a few fossils from wells in Saskatchewan which tend to support the suggestion that the Ordovician-Silurian systemic boundary might lie within the Stonewall Formation but the evidence is not conclusive as yet. Therefore in this report, the Ordovician-Silurian boundary is tentatively placed within the Stonewall Formation.

Lithology:

In northwestern North Dakota, the lower part of the Stonewall Formation consists of a thin bed of anhydrite at the base overlain by about 20 feet of light (N 7) to medium dark gray (N 4), finely crystalline limestone. Next above is another thin anhydrite bed overlain by 20 to 25 feet of medium gray (N 5) to brownish gray (5 YR 4/1), finely crystalline, dolomitic limestone. The upper part of the Stonewall Formation consists of light brownish gray (5 YR 6/1), finely crystalline dolomite in this same area. Toward the margins of the Basin the anhydrites pinch out, the entire section becomes dolomitic and the dolomites are lighter colored, being yellowish gray (5 YR 8/1) to moderate orange pink (10 R 7/4) except where weathering has introduced pink and reddish alteration near the erosional limits of the Interlake and Stonewall Formations.

Thickness:

The isopach map of the Stonewall Formation (Fig. 10) shows a typical Williston Basin pattern with the area of greatest accumulation of sediments in the northwestern part of the state and a gradual depositional thinning toward all flanks of the Basin. Thus it reflects a change in depositional patterns and resembles the isopach of the overlying Interlake Formation rather than the underlying Stony Mountain and Red River Formations. This map also shows a reflection of the Nesson Anticline structure with a thinning of the Stonewall Formation in that area. The Stonewall Formation is absent from the southeastern part of the state where it thins rapidly beyond the cover of the overlying Interlake Formation due to post-Silurian erosion.

Relations to Adjacent Strata:

The Stonewell Formation conformably overlies the Stony Mountain Formation of Upper Ordovician age. It is conformably overlain by the Interlake Formation of Silurian age except near its erosional edge where it is unconformably overlain by rocks of Devonian age in the southeastern part of the State and by rocks of Jurassic and Cretaceous age in the northeast.

The upper contact has been placed at a clastic zone which marks a slight interruption or diastem in carbonate deposition. This clastic zone is no more prominent than other clastic zones in the lower interval of the Interlake Formation, but Stearn believed that this clastic zone marked the Ordovician-Silurian systemic boundary and this is perhaps the main reason that the Stonewall Formation has continued to be recognized as a separate formation. The lower contact is placed at the base of an anhydrite bed in the central Basin area which grades laterally to a fine grained clastic zone toward the margins of the Basin.

Interlake Formation

Name and Definition:

Baillie (1951, p. 6) proposed the term Interlake Group to include all "the strata that overlie the Stony Mountain Formation of Ordovician age and underlie the Ashern Formation of Silurian or Devonian age" in the Interlake area of Manitoba. As has been noted earlier, Stearn (1956, p. 6) removed the Stonewall Formation from the Interlake Group, but Andrichuk (1959, p. 2381) again included the Stonewall Formation in the Interlake Group. Baillie's original definition and Andrichuk's revision of the Interlake Group have some merit, because the marker horizon at the top of the Stonewall Formation is no more prominent than some other markers in the Silurian strata. Nevertheless the majority of workers have recognized the Stonewall as a distinct formation of possible Ordovician age and since the marker bed by which the Interlake is separated from the Stonewall in the subsurface can be traced throughout the area of study the Interlake Formation is herein used as defined by Stearn and extended to the subsurface by Porter and Fuller (1959).

Stearn (1956, p. 6) divided the Interlake Group of the Manitoba outcrop area into six formations. However, these subdivisions of the surface sections cannot be traced into the subsurface and a more satisfactory subdivision for the subsurface is the three unit subdivision of Porter and Fuller (1958, p. 35). Here a problem of nomenclature arises since they used the para-time rock term "Beds" for their subdivisions and the Saskatchewan Geological Society (1958, p. 12-17) proposed formal names for these Beds. We have accepted Porter and Fuller's marker horizons as the basis for subdivision of the Interlake Formation in North Dakota, but since these are para-time rock units we prefer to call these subdivisions intervals rather than Members or Beds. Since intervals are informal units and since the Saskatchewan Geological Society chose lease names rather than geographic names for their subdivisions, we have used upper, middle and lower for our subdivisions of the Interlake Formation in North Dakota rather than formal names.

Age:

The Interlake Formation is considered to be of Silurian age by all writers, but there has been some dispute as to what part of the Silurian System it represents. Stearn (1956, p. 8) considered the entire Interlake Group of the outcrop area of southern Manitoba to be of Middle Silurian age with a disconformity between the Interlake Group and the Stonewall Formation representing the entire Lower Silurian Series. This interpretation has been questioned by Porter and Fuller (1959, p. 178) on the basis of the reported fauna and on a depositional basis since on a regional scale there is no evidence of a sedimentary break between the Stonewall and Interlake formations.

The Interlake Formation is very sparsely fossiliferous and no fossils were noted in cuttings, cores, or in the insoluble residues in the present study. Brindle (1960, p. 22) reported paleontological studies of the Interlake Formation in Saskatchewan and on the basis of these studies agreed with Porter and Fuller's suggestion that the Interlake Formation represents Lower and Middle Silurian deposition. He further suggested that the boundary between the Lower and Middle Silurian might lie within the lower interval of the Interlake Formation.

Lithology:

The lower interval consists of light brownish gray (5 YR 6/1) to brownish gray (5 YR 4/1), very finely crystalline dolomite interbedded with three thin beds of anhydrite in the central basin area.

The uppermost anhydrite bed is the marker horizon which separates the lower and middle intervals of the Interlake Formation. The anhydrite beds pinch out rapidly toward the margins of the basin and the lower interval consists of very pale orange (10 YR 8/2) to light yellowish gray (5 Y 8/1) and white (N 9), very finely crystalline dolomite in those areas.

In the central basin area, the middle interval consists of light yellowish gray (5 Y 8/2), very light brownish gray (5 YR 7/1), and very pale orange (10 YR 8/2), fine to medium crystalline dolomite containing some white and very light gray chert. The chert has been noted only in cuttings, so it is not known whether it occurs as bedded chert or as nodules. Toward the margins of the basin, the middle interval consists of white (N 9) to very pale orange (10 YR 8/2), very finely crystalline dolomite which is very similar to the lithology of the lower interval in that area. Since the anhydrite beds of the lower interval are absent toward the margins of the basin the lower and middle intervals become inseparable in those areas.

The upper interval consists of light brownish gray (5 YR 6/1) to very light gray (N 8), limy dolomite and dolomitic limestone with a red clastic zone at its base which may mark a disconformity within the Interlake Formation. Carbonate textures vary from finely crystalline to pelletoidal, fragmental and microgranular. Vuggy porosity is common. The basal beds consist of pale red (5 R 6/2) to grayish pink (5 R 8/2), silty, sandy, dolomite which in some wells grades to a fine to medium grained, dolomitic sandstone.

Thickness:

The Interlake Formation ranges in thickness from about 1100 feet in northwestern North Dakota to 0 at its erosional margin in eastern North Dakota. The cross sections (Figs. 3 to 6) and the isopach of the upper interval of the Interlake Formation (Fig. 12) show that most of the thinning is due to post-Silurian – pre-Devonion erosion. Thus it can be seen that most of the increased thickness of the Interlake Formation in the central part of the Williston Basin is due to an increased thickness of the upper interval in that area. The lower and middle intervals thin from about 550 feet in the central part of the basin to about 450 feet near the erosional limit of the overlying upper interval, whereas the upper interval varies in thickness from a maximum of about 570 feet in the central part of the basin to 0 at its erosional limit. Beyond the cover of the upper interval the middle and lower intervals also thin markedly due to pre-Devonian erosion.

In the central part of the Williston Basin the upper and middle intervals of the Interlake Formation are separated on the basis of a prominent gamma ray marker associated with a clastic zone which seems to have a quite wide-spread distribution. However, a problem of correlation of the upper and middle intervals arises on cross section B-B' in northcentral North Dakota, where a reddish zone with a prominent gamma ray deflection was encountered at a depth of 8713 to 8745 in the Wanete Oil Company — M. O. Lee No. 1 well (NE NE Sec. 24, T. 156 N., R. 85 W.). The total section of Interlake Formation is thick enough so that some upper Interlake should be present in this well, but whether this marker horizon is the same marker horizon as the one used to separate the middle and upper intervals in the central part of the Basin is uncertain because there is a distance of 60 miles between these wells with no subsurface control. If this is the same marker it indicates a slight unconformity between the middle and upper intervals on the northeast flank of the Basin, and, although this interpretation cannot be proved, it was used for the isopach maps. The basis for using this interpretation are; (1) a reddish zone is also found in the California Company — B. Thompson No. 1 well (SW SE Sec. 31, T. 160 N., 81 W.) at a depth of 6770 to 6797 feet and (2) in both of these wells the lithology is predominantly dolomitic limestone above the reddish zone and predominantly dolomite below the reddish zone, a lithologic pattern similar to that of these intervals in the central part of the Basin.

Relations to Adjacent Strata:

The lower contact is conformable and gradational with the underlying Stonewall Formation. The upper contact is marked by the pre-Middle Devonian unconformity with the Interlake Formation unconformably overlain by rocks of Devonian age except in northeastern North Dakota where it is unconformably overlain by rocks of Jurassic and Cretaceous age.

CONDITIONS OF DEPOSITION

Silurian deposition in the Williston Basin is characterized by rather quiet conditions with relatively few tectonic disturbances and generally continuous, slow, subsidence, modified by minor epeirogenic movements around the edge of the Basin and by discontinuous movements along the Nesson Anticline. The period was ended by pre-Middle Devonian uplift and erosion. Even this last uplift was of epeirogenic nature as it was a regional uplift of the whole Williston Basin which produced few major folds or faults.

The upper Red River, Stony Mountain and Stonewall Formations are a succession of rhythmic carbonate and evaporite deposits interrupted by thin, but widespread, argillaceous and sandy beds (Porter & Fuller, 1959, p. 173). The alternating beds of eva-

porites and normal marine carbonates are a record of deposition in a shallow basin which was restricted from time to time by slight movements. The thin anhydrites were probably deposited in shallow evaporitic seas in the center of the depositional basin and represent intervals of standstill at the ends of periods of epeirogenic uplift (Kent, 1960). After deposition of the anhydrite, normal marine conditions were re-established and another cycle began.

The argillaceous and sandy marker beds in the Upper Ordovician strata generally are considered as clastic incursions interrupting the dominant carbonate and evaporite cycles. The shale beds of the Stoughton are the most prominent of these incursions. Porter and Fuller (1959) formerly believed that these beds had their source area to the southeast, probably from the Transcontinental Arch or Sioux Uplift Area. Increase in subsurface information and reinterpretation of previous data (Fuller, 1961, Patterson, 1961) have shown that this theory of origin is wrong. The Stoughton and analagous beds do increase in argillaceous content to the southeast but no unconformity exists in the Sioux Uplift area to demonstrate uplift and erosion. Fuller (1961, p. 1351) now believes that the source area was to the southeast but much more distant than the Sioux area.

Therefore, the Upper Ordovician beds of the Williston Basin show a record of carbonate deposition in a shallow marine basin. Conditions alternated from normal marine to penesaline and limestone, primary dolomites, and anhydrites were deposited. This carbonate and evaporite succession was interrupted by argillaceous beds, probably derived from the southeast.

Apparently no unconformity or diastem exists between Ordovician and Silurian deposits of the Williston Basin. A gradual change in basin orientation and depositional patterns occurred near the end of the Ordovician since the isopach of the Stonewall formation resembles that of the Interlake more than that of the Stony Mountain or Red River. The Stonewall thins over the Nesson Anticline, indicating shoaling of the sea which leads one to suggest that movement of that structure occurred during Stonewall time.

Depositional conditions during Interlake time were similar to that of the Upper Ordovician beds. Anhydrite beds exist in the lower Interlake but are not so widespread nor cyclical as in the Ordovician. The sea was probably more saline than normal marine and the fine-grained dolomites of the Lower Interlake probably are primary.

On the margins of the basin, the lower and middle Interlake intervals have a similar lithology and, in the absence of marker beds, or paleontologic evidence, are not separable at the present time. In the center of the basin, the middle interval contains dolomite which is more coarsely crystalline and of a different color than the lower interval. Also, unlike the lower interval, the middle Interlake contains chert but no anhydrite.

From this evidence, the middle Interlake carbonates were probably deposited in a sea slightly more saline than normal marine but which never approached the conditions necessary to precipitate anhydrite.

Chert has been found to date only in the middle Interlake in the center of the basin. The chert has been observed in cuttings only and the authors have seen no evidence to support a conclusion as to whether the chert is primary or secondary.

The lower and middle Interlake intervals appear to be conformable except locally in the Beaver Lodge area of the Nesson Anticline. In that area (see Figure 3) a few beds at the base of the middle Interlake are missing over a high in the Lower Interlake. There is no change in thickness of the lower Interlake so the high is not the result of carbonate build-up. This suggests that there was slight upward movement of the Nesson Anticline at the beginning of middle Interlake time.

The upper Interlake consists of pelletoidal and fragmental dolomitic limestone. It was probably deposited in a shallow sea near wave base or in a similarly high-energy environment which formed the pellets and pseudo-oolites.

It is not known how much or what kind of sediments may have been deposited after the upper Interlake interval. Uplift followed upper Interlake deposition and this could have led to the formation of a restricted evaporitic sea in the Williston Basin and the dolomitization of the upper Interlake beds by the reflux mechanism (Adams & Rhodes, 1960). The dolomite could have been introduced during the pre-Middle Devonian erosion or during deposition of the Middle Devonian sediments.

In the absence of fossils, the upper Interlake is assumed to be Middle Silurian in age (Fuller, 1961, p. 1361; Brindle, 1960, p. 22). At some time between the Middle Silurian and the Middle Devonian the entire area was uplifted and any Upper Silurian rocks that may have been present were removed by erosion. Even though the control points are widespread, there does not appear to be much topographic relief on the pre-Devonian surface, and the area was probably eroded to base-level. The Upper Interlake is thin over the Nesson Anticline indicating uplift either before or during the period of erosion.

During Interlake time thin, sandy, argillaceous beds were deposited in the Williston Basin intercalated with the carbonates. These are analagous to similar deposits in the Upper Ordovician strata but are not so prominent. They probably had the same origin as the marker beds of the Upper Ordovician formations.

In summary, the Interlake Formation was deposited in a shallow sea slightly more saline than normal marine waters. Carbonates were by far the dominant sediments deposited. In the center of the basin, anhydrite and evaporitic dolomites were deposited during lower Interlake time and chert was formed during middle Interlake time. The upper Interlake was deposited under high-energy conditions which produced pellets and pseudo-oolites. Occasionally during the Interlake thin argillaceous and sandy beds were deposited. The Nesson Anticline was uplifted slightly during the first part of middle Interlake time and at sometime after deposition of the upper Interlake. Between Middle Silurian and Middle Devonian time the area was uplifted and eroded.

ECONOMIC GEOLOGY

Introduction

The original discovery of oil in North Dakota was from Silurian rocks in the Beaver Lodge field at the Amerada Petroleum Corporation – Clarence Iverson No. 1 well (SW SW Section 6, T. 155 N., R. 95 W.) on April 4, 1951. However, with the subsequent discovery of oil in the Madison Group (April 26, 1952) in the Beaver Lodge field the original well was plugged back to the Madison reservoir and there was no further development of the Silurian pool until 1957, when a development program began. The limits of the Beaver Lodge-Silurian pool had been defined by 1959 with 20 wells capable of production, although because of high gas-oil ratios these wells have been shut in.

The second Silurian pool (North Fork Field) was discovered by the Amerada Petroleum Corporation – H. H. Shelvik,, Tract 1, No. 1 well (NE SW Section 35, T. 150 N., R. 97 W.) near the south end of the Nesson Anticline on March 1, 1958. However, this proved to be a marginal well and it was plugged and abandoned after producing 3,029 barrels of 53.6° API gravity oil and 2,914 barrels of water in an eight month period.

The Antelope-Silurian pool was discovered by the Amerada Petroleum Corporation at the Antelope Unit "A" No. 1 well (NE SE Section 1, T. 152 N., R. 95 W.) on February 16, 1960, and the cumulative production of this well to January 1, 1962, was 69,781 barrels of 44.9° API gravity oil. A northwest extension was completed by the Amerada Petroleum Corporation at the Oleson Unit No. 1 well (NW SE Section 30, T. 153 N., R. 94 W.) in August, 1960, and cumulative production from this well to January 1, 1962, was 97,901 barrels of oil. Six wells penetrating Silurian rocks were drilled either within or offsetting the Antelope field limits as of January 1, 1962, however four of these have been abandoned. Information from these wells indicates that the Antelope-Silurian pool has at least as much closure as the Antelope-Sanish pool (Devonian). However, the Silurian oil accumulations in this area seem to be controlled by porosity and permeability variations as well as structure, so some of the early development has been discouraging and the limits of the Antelope-Silurian pool must await further development.

Beaver Lodge – Silurian Field Study

Development:

The Beaver Lodge field is the only Silurian pool which has been completely developed in North Dakota to date. It was developed on a spacing pattern of 320 acres with 20 producing wells for a total area of 6400 proven acres. The producing horizons are at depths of about 11,350 to 11,750 feet with a net pay of about 180 feet. No production history is available, but the initial potentials ranged from 42 to 609 barrels of 50.1° API gravity oil and averaged about 196 barrels per day. Initial reservoir pressure was 5350 psi and gas-oil ratios ranged from 2817 to 1 to 15,463 to 1. Since this is a condensate reservoir the State Industrial Commission has shut in the Beaver Lodge-Silurian pool with the hope that the field would prove to have enough reserves to warrant construction of a re-cycling plant for the gas production. However, no such plant has been built to date and the pool is still shut in.

Structure:

A structure map on the Interlake Formation in the Beaver Lodge Field (Fig. 14) is very similar to structure maps of the Beaver Lodge-Madison reservoir but differs inasmuch as the Silurian reservoir has a slightly greater closure in the southwestern part of the field and the closures in the northeastern and southwestern part of the field are separated on the Interlake structure map, whereas they are connected on the Madison structure map. Thus the Silurian reservoir covers a greater area than the Madison reservoir in the southwestern part of the field, but is non-productive in the northeastern part of the field. The cross section (Fig. 15) shows mechanical log characteristics of the upper part of the Interlake Formation and the producing horizons in the Beaver-Lodge-Silurian pool.

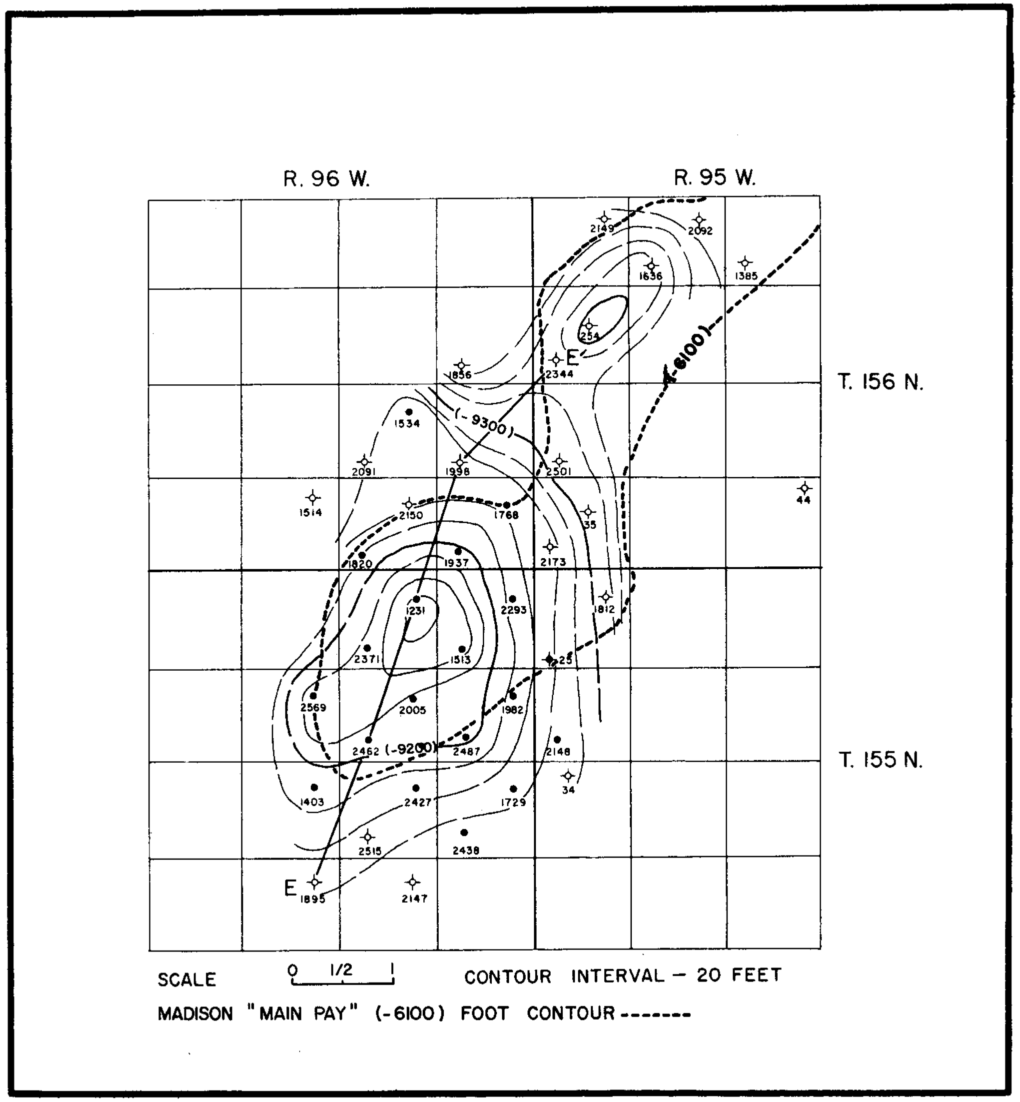

Figure 14 - Structure map of Beaver Lodge field; datum - top of Interlake Formation.

Producing zones:

Production in the Beaver Lodge-Silurian pool is from the upper Interlake interval. Nearly three-fourths of this interval was cored during the drilling of the Amerada-Iverson, Nelson Unit No. 1 well (NE 1/4, Sec. 2, T. 155 N., R. 96 W.) and thin sections of this core were made in order to gain a better understanding of the characteristics of this interval.

Petrography:

The classification of carbonate rocks proposed by Folk (1959, p. 14) seems to be most useful for the upper interval of the Interlake and was used for the petrographic descriptions. Grain size terms for the allochems are also used as defined by Folk (1959, p. 16).

The cored portion of the upper Interlake can be divided into three lithologic units. The upper lithologic unit extends from the top of the Interlake at 11,453 feet down to about 11,565 feet (9,137-9, 249 feet below sea level). The middle lithologic unit of the upper Interlake interval extends from about 11,565 feet to about 11,600 feet (9,249-9,284 feet below sea level) and the lower lithologic unit of the upper Interlake extends from about 11,600 feet to the base of the core at 11,785 feet. Cuttings and mechanical logs indicate that similar rocks are present down to the base of the upper Interlake interval at 11,910 feet.

The most prominent rock type of the upper unit consists of medium, round to subround intraclasts, closely to loosely packed in a matrix ranging from sublithographic limestone with scattered fine dolomite crystals to a very finely crystalline carbonate containing common to abundant dolomite crystals (Plate I, Figs. 1-4). Some beds contain common fine pellets which are mostly structureless, sublithographic limestone and are generally round to subround. Large fragments are rare, generally angular to subangular and may themselves contain smaller fragments. Oolitic coatings are very rare.

The matrix is generally either a very finely crystalline to sublithographic limestone with scattered dolomite crystals or a finely crystalline calcareous dolomite. Only one specimen was seen in which the cementing material was sparry calcite. (Plate II, Fig. 1). The dolomite is probably secondary so this rock type can be classified as a dolomitized intramicrite-microsparite under the system of Folk (1959) or as a fine to medium calcarenite under the system of Beales (1958). It is by far the most common rock type in the upper unit, making up 60-70% of the beds.

Interbedded with the intramicrite-microsparite are beds of finely crystalline calcareous dolomite containing rare intraclasts or the

ghosts of intraclasts (Plate II, Figs. 2-3). In some cases there can be seen a gradation from intramicrosparite, containing loosely packed to scattered round intraclasts, to dolomitic microsparite containing a few remnants of intraclasts.

A minor rock type in this unit is a sublithographic to very finely crystalline dolomitized limestone (dismicrite-microsparite of Folk, 1959). This type contains irregular-shaped, smooth-walled pores which are usually filled with coarsely crystalline calcite or anhydrite.

Fine to very fine angular anhedral quartz grains are scattered throughout the upper lithologic unit of the upper Interlake interval. While they are found in all the different rock types they are more common and slightly larger in the intramicrite-microsparite.

Interstices in the intramicrite and the pores in the dismicrite are generally filled with calcite and/or anhydrite or rarely with what is questionably identified as celestite. Fair to poor porosity is developed in local zones where these interstices have not been filled. Vertical fractures, which are common, are also an important part of the porosity and permeability of this unit. Black to brown live oil staining is present in the pores (Plate I, Fig. 3), on the fracture surfaces, and in large spots in the finely crystalline dolomite.

Definite fossils or fossil fragments were not seen. Possible laminated algal growths are present in a few beds (Plate I, Fig. 5).

The middle lithographic unit is mainly interbedded sublithographic dolomitized limestone and finely crystalline calcareous dolomite. Closely packed medium to fine intraclasts are present in a few thin beds and the finely crystalline dolomite commonly contains remnants and ghosts of intraclasts (Plate II, Fig. 4 and Plate III, Figs. 1 & 2).

Anhydrite is present as pore fillings in the intraclast parts of the rock and as rare lath-shaped crystals in the finely crystalline dolomite, but is not as common as in the upper lithographic unit. Calcite and rare celestite (?) are also present but likewise are not as common as in the upper unit. Fine quartz grains are present but are very rare. No fossils were seen.

Pinpoint and vuggy porosity is present in local zones where the interstices of the intraclast rock have not been filled, and where pores are present in the dismicrite. Fractures are common and are the most important part of the effective porosity. Oil staining is present on fractures, in the local porous zones, and in the finely crystalline dolomite.

The most prominent lithology of the lower lithologic unit of the upper Interlake is fine to very finely crystalline dolomite which in places contains remnants and ghosts of intraclasts (Plate III, Figs.

3 & 4). This is interbedded intramicrite-microsparite consisting of pellets and fine to medium intraclasts closely to loosely packed in a matrix ranging from dolomitic, sublithographic limestone to finely crystalline, calcareous dolomite (Plate IV, Figs. 1-3).

An interesting rock type in this unit is one which is apparently made up of recrystallized and dolomitized intracasts (Plate IV, Fig. 4). The rock consists of finely crystalline calcareous dolomite with common open or anhydrite-filled pores which are arranged so that parts of the rock appear to be remnants of intraclasts.

A few fine quartz grains are present and are generally confined to the intraclast beds. Very rare dolomitized fossil fragments were seen in the dolomitized microsparite. Coarsely crystalline calcite is present as pore fillings. Anhydrite is present in the intramicrosparite and dismicrosparite as pore fillings and in the dolomitized microsparite as lathshaped crystals and as fine disseminated crystals.

Porosity is confined to local zones of pinpoint and vuggy pores and to rare vertical and horizontal fractures. It is fair to poor at the top of this unit and decreases downward. Oil staining is generally confined to the pores and fracture surfaces and also decreases downward.

In summary, the upper Interlake interval of the Beaver Lodge area consists of three lithologic units. The upper one is a very dolomitic, fragmental limestone with fair to poor intergranular and fracture porosity and with good oil staining.

The middle lithologic unit consists mainly of finely crystalline limy dolomite. Effective porosity is mostly confined to fractures. Oil staining is good.

The lower unit is similar to the upper one but in general contains smaller fragments, more dolomite and less porosity and staining.

Future Possibilities

The Silurian pools which have been found in North Dakota to date have all been found along the Nesson Anticline in northwestern North Dakota (see Fig. I) associated with minor folds along the major anticlinal trend and just beneath the pre-Middle Devonian unconformity. The production comes from the uppermost part of the upper interval of the Interlake Formation which in this area is encountered at depths of about 11,500 to 12,500 feet. Exploration will undoubtedly locate more of these minor folds, many of which are productive in the Madison group, to also be productive from the upper interval of the Interlake Formation.

Commercial production has also been found in Silurian rocks associated with structure and just beneath the pre-Middle Devonian unconformity in the Outlook area of northeastern Montana and along the Cedar Creek Anticline in southeastern Montana. However, the upper interval and part of the middle interval of the Interlake Formation has been removed by erosion and the middle or middle and lower intervals of the Interlake Formation are productive in those areas. Thus, wherever structure can be found in Lower Paleozoic rocks the Interlake Formation is a prospective horizon in the Williston Basin.

The depth of the Silurian rocks in most areas of North Dakota has discouraged exploration for stratigraphic traps except in the eastern part of the state where these rocks are penetrated at depths ranging from about 1,500 to 3,000 feet. Although no shows have been reported from Silurian rocks in that area the number of wells drilled to date is not sufficient to condemn it as a prospective area. However, the upper interval and most of the middle interval of the Interlake Formation has been removed by pre-Devonian erosion so any prospect must be developed on the basis of an updip pinchout in the lower interval of the Interlake Formation.

Perhaps the most favorable prospective horizon for stratigraphic traps is the upper interval since this is the productive horizon in the Nesson Anticline area and this interval displays more facies changes than the other two intervals of the Interlake Formation. However, this interval is present only in the deeper parts of the basin (see Fig. 12) where well control outside of the field areas is sparse, thus the location of stratigraphic prospects is difficult at this time. Since the prospect of finding structural traps is also more favorable, stratigraphic information is gradually accumulating in this area. The combination of favorable structural and stratigraphic aspects should complement each other and as the search for oil in North Dakota turns more toward Lower Paleozoic rocks the upper interval of the Interlake Formation should become an important producing horizon in the central part of the Basin.

There has been no commercial production of oil or gas from the Stony Mountain Formation in North Dakota but shows have been tested at the Amerada Petroleum Corporation — Iverson, Nelson Unit No. 1 well (NE Sec. 2, T. 155 N., R. 96 W.) in the Beaver Lodge field. A seven hour swabbing test of the Gunton Member in this well recovered one barrel of condensate, 26 barrels of water and 48 MCF of gas. The well was then plugged back to test upper horizons.

In southeastern Montana, along the Cedar Creek anticline, several fields which produce from the Interlake and Red River Formations are also productive from the Gunton Member of the Stony

Mountain Formation. These fields are located on faulted anticlines where structure is apparently the trapping mechanism.

Since the Gunton Member is relatively uniform in thickness and lithology over wide areas of the Basin the most promising prospects for commercial production are structural traps. However, in the area of the State where most of the structures have been found to date, the Stony Mountain Formation lies at depths of around 13,000 feet. Thus the depth of the Stony Mountain Formation has discouraged exploration up to this time.

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Plate I

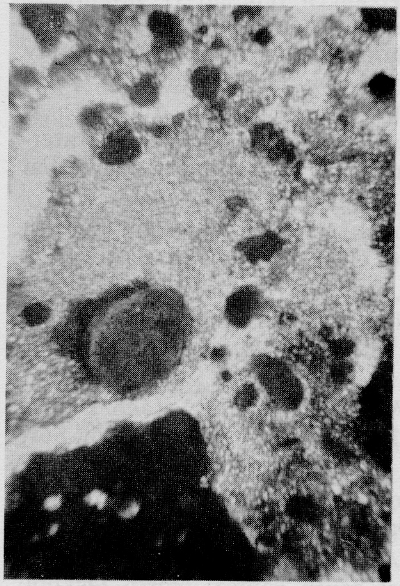


Figure 1

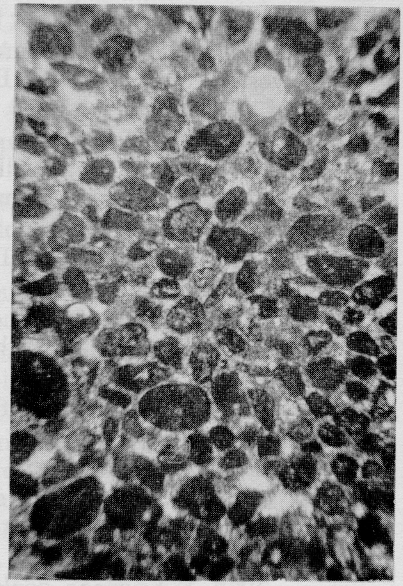


Figure 2

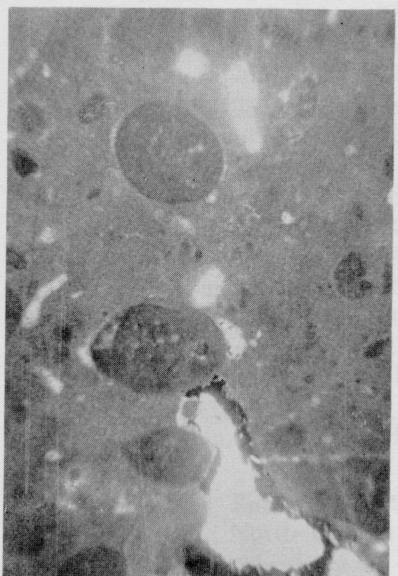


Figure 3

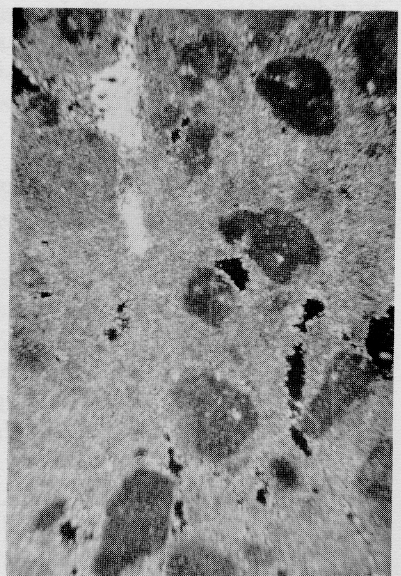


Figure 4

PLATE 1

EXPLANATION

Figure 1
(11,457) Pelintramicrosparite. Pellets and fine intraclasts loosely packed to scattered in a partially dolomitized sublithographic to fine crystalline calcite matrix. (X46)

Figure 2
(11,490) Intramicrite. Fine to medium intraclasts closely to tightly packed in a sublithographic matrix with rare areas of fine crystalline limestone. (X46)

Figure 3
(11,494) Intradismicrite. Medium sized intraclasts scattered in a sublithographic matrix. Many irregular medium to coarse pores generally having a drusy calcite lining and some filled with coarsely crystalline calcite. Oil staining in the pores. (X46)

Figure 4
(11,495) Intramicrosparite. Medium to coarse intraclasts loosely packed to scattered in microsparite. Borders of some of the intraclasts indistinct. Common small irregular pores generally filled by anhydrite. (X46)

Plate II

Figure 1

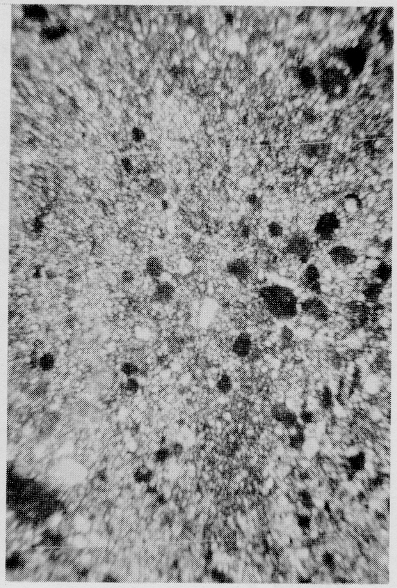


Figure 2

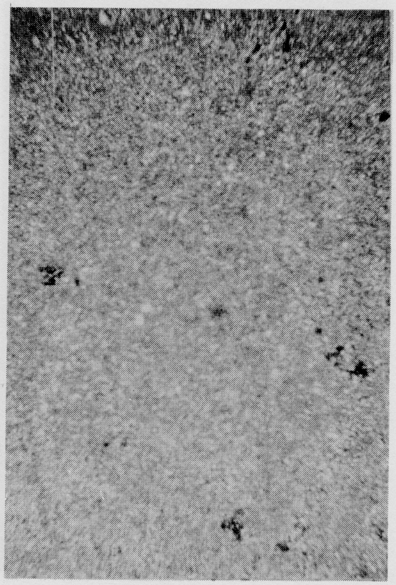


Figure 3

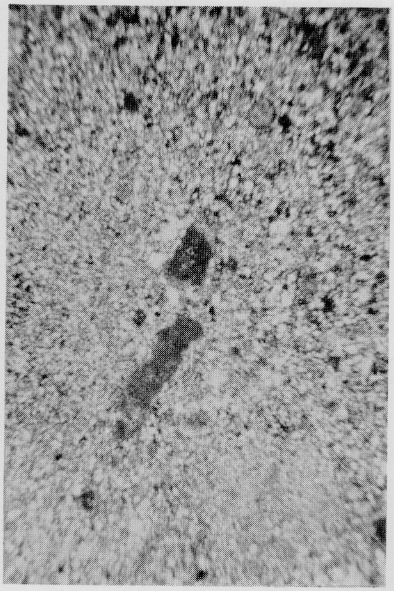


Figure 4

PLATE II

EXPLANATION

Figure 1
(11,490) Intrasparite, with a liminated algal (?) growth. (X46)

Figure 2
(11,476) Dolomitized pelmicrosparite. Pellets and fine intraclasts scattered in microsparite. Common fine quartz grains. Rare fine pores. (X46)

Figure 3
(11,477) Microsparite; with rare small pores. (X46)

Figure 4
(11,567) Dolomitized microsparite; with rare fine intraclasts and quartz grains. (X46)

Plate III

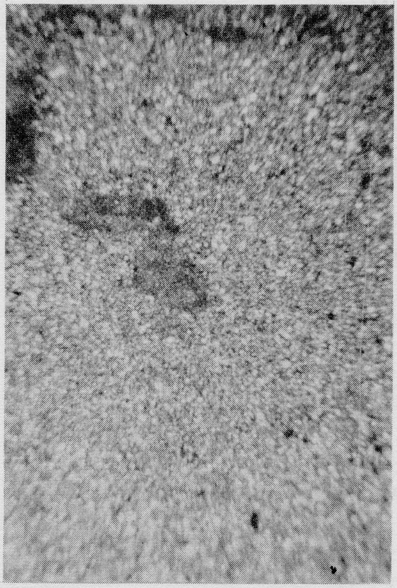


Figure 1

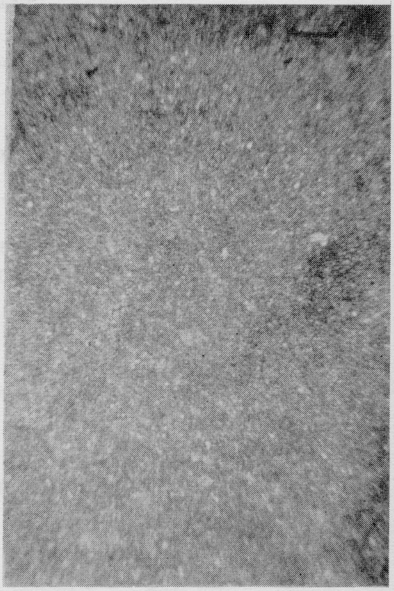


Figure 2

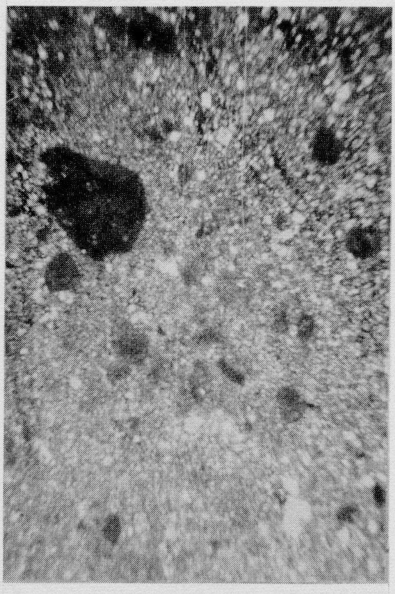


Figure 3

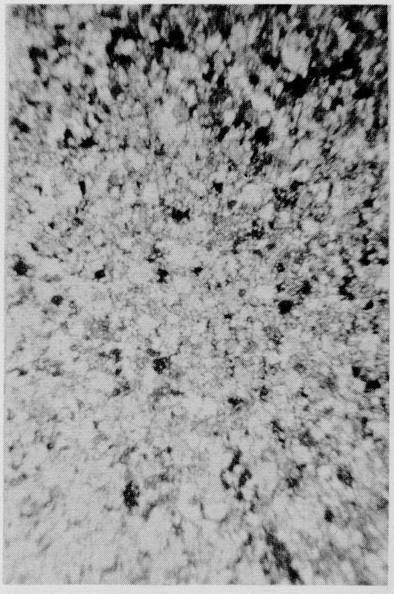


Figure 4

PLATE III

EXPLANATION

Figure 1
(11,568) Dolomitized microsparite; with small remnants of micrite. (X46)

Figure 2
(11,590) Microsparite; very finely crystalline. (X46)

Figure 3
(11,635) Dolomitized microsparite; with scattered intraclasts. (X46)

Figure 4
(11,769) Dolomitized microsparite. Mainly medium to fine dolomite crystals. (X46)

Plate IV

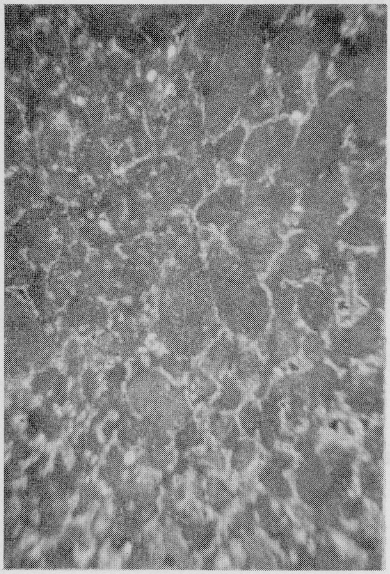


Figure 1

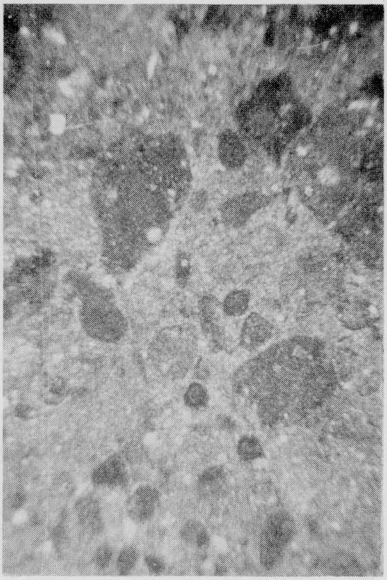


Figure 2

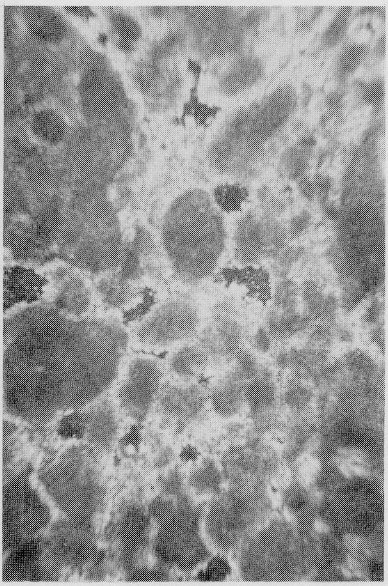


Figure 3

Figure 4

PLATE IV

EXPLANATION

Figure 1
(11,640) Intramicrosparite. Fine to medium intraclasts tightly packed with finely crystalline sparry cement. (X46)

Figure 2
(11,720) Intramicrosparite. Very finely crystalline slightly dolomitic microsparite with loosely packed fine to medium and a few coarse intraclasts. (X46)

Figure 3
(11,764) Intramicrite grading to microsparite. Medium intraclasts with microsparite coating closely packed in micrite. (X46)

Figure 4
(11,685) Intramicrosparite, Medium to coarse intraclasts and ghosts intraclasts loosely packed to scattered in dolomite microsparite. (X46)

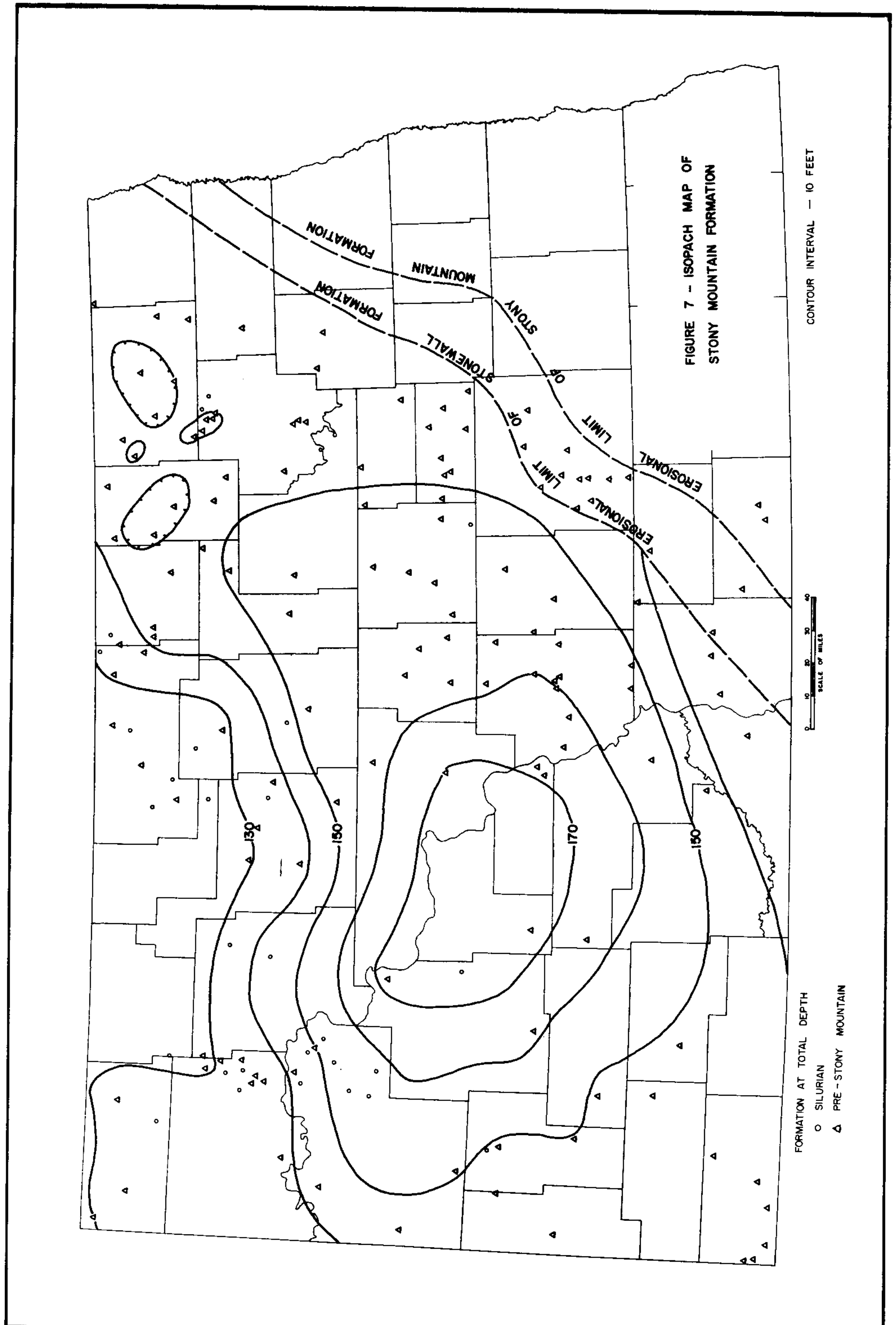


FIGURE 7 - ISOPACH MAP OF STONY MOUNTAIN FORMATION

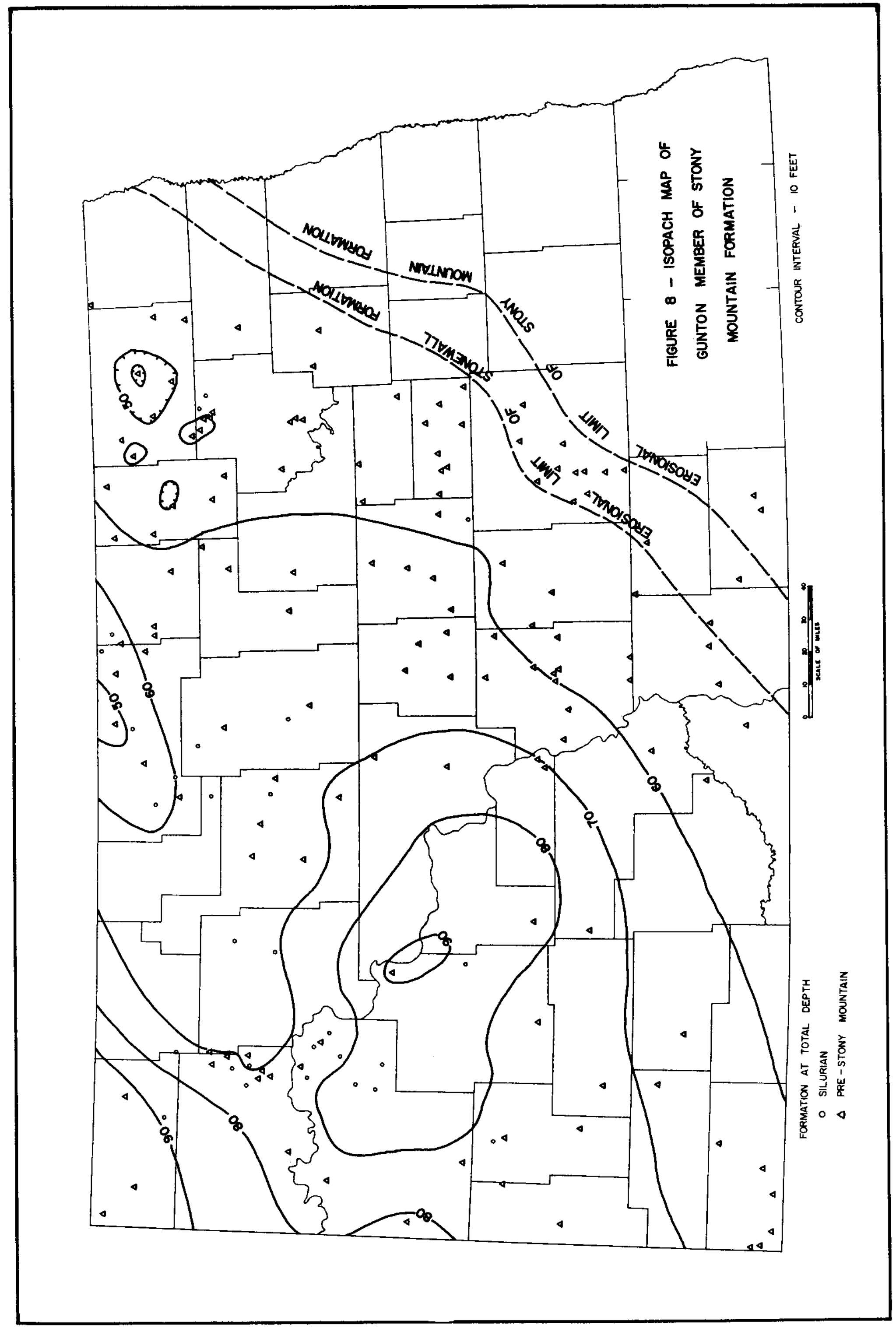


FIGURE 8 - ISOPACH MAP OF GUNTON MEMBER OF STONY MOUNTAIN FORMATION

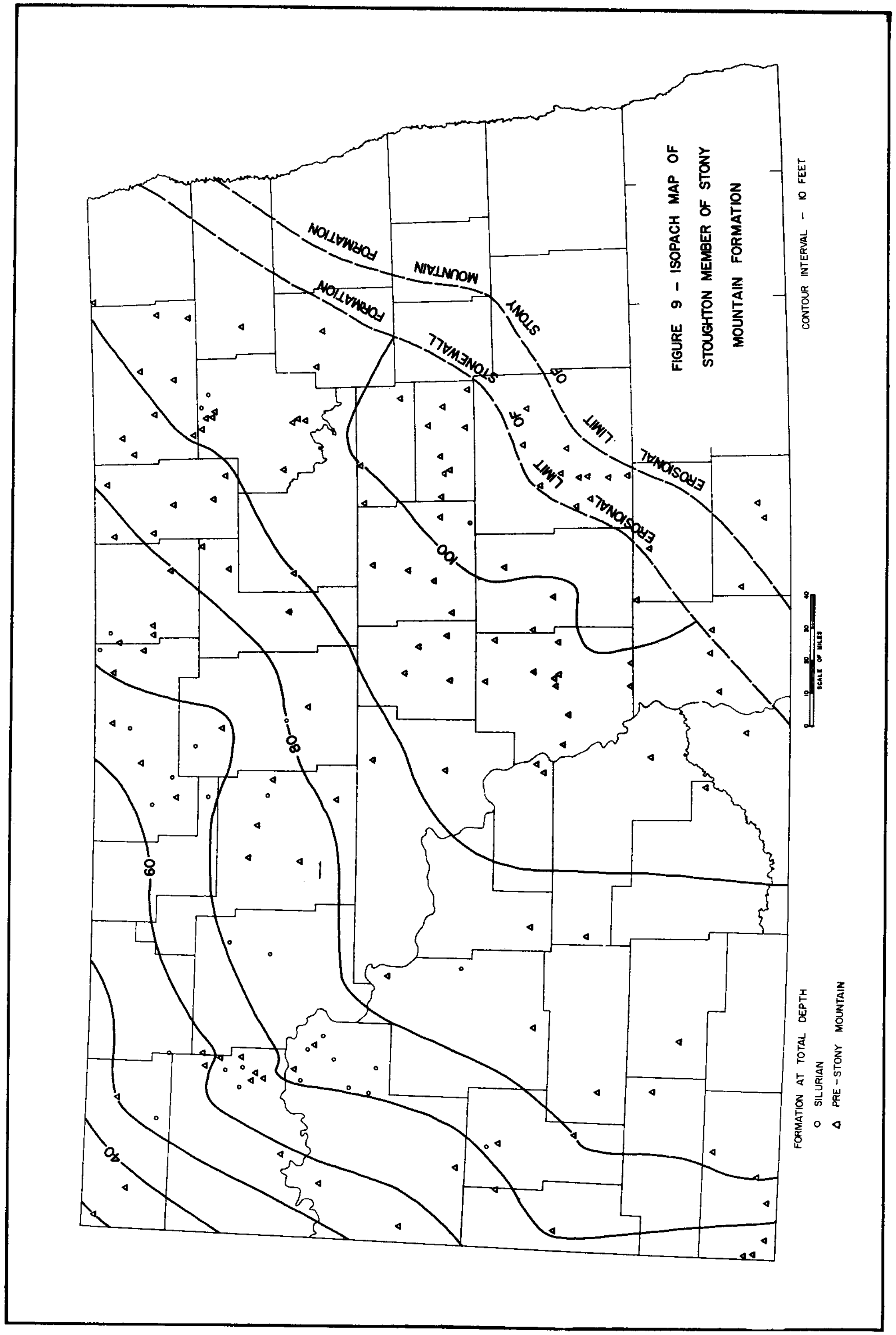


FIGURE 9 - ISOPACH MAP OF STOUGHTON MEMBER OF STONY MOUNTAIN FORMATION

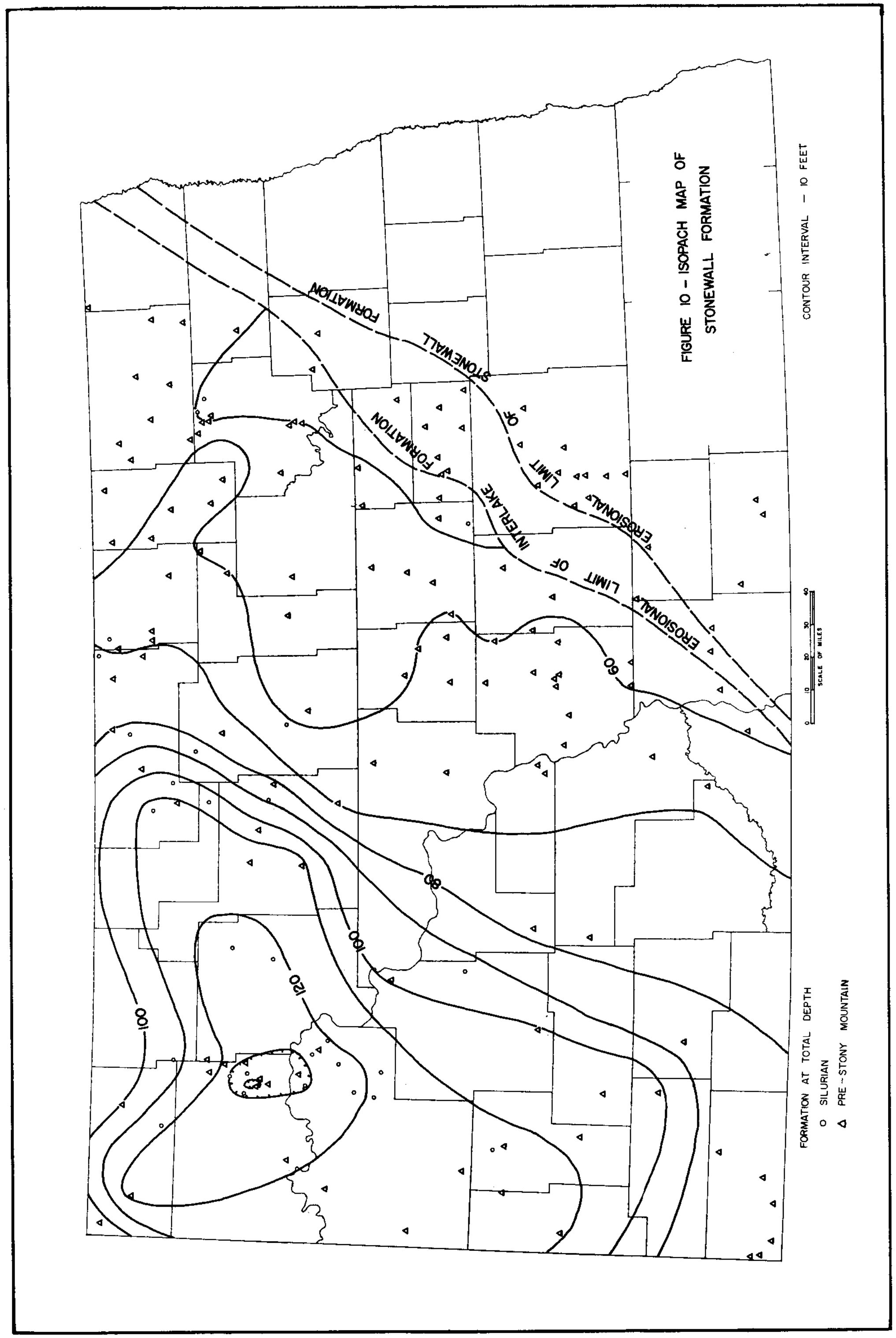


FIGURE 10 - ISOPACH MAP OF STONEWALL FORMATION

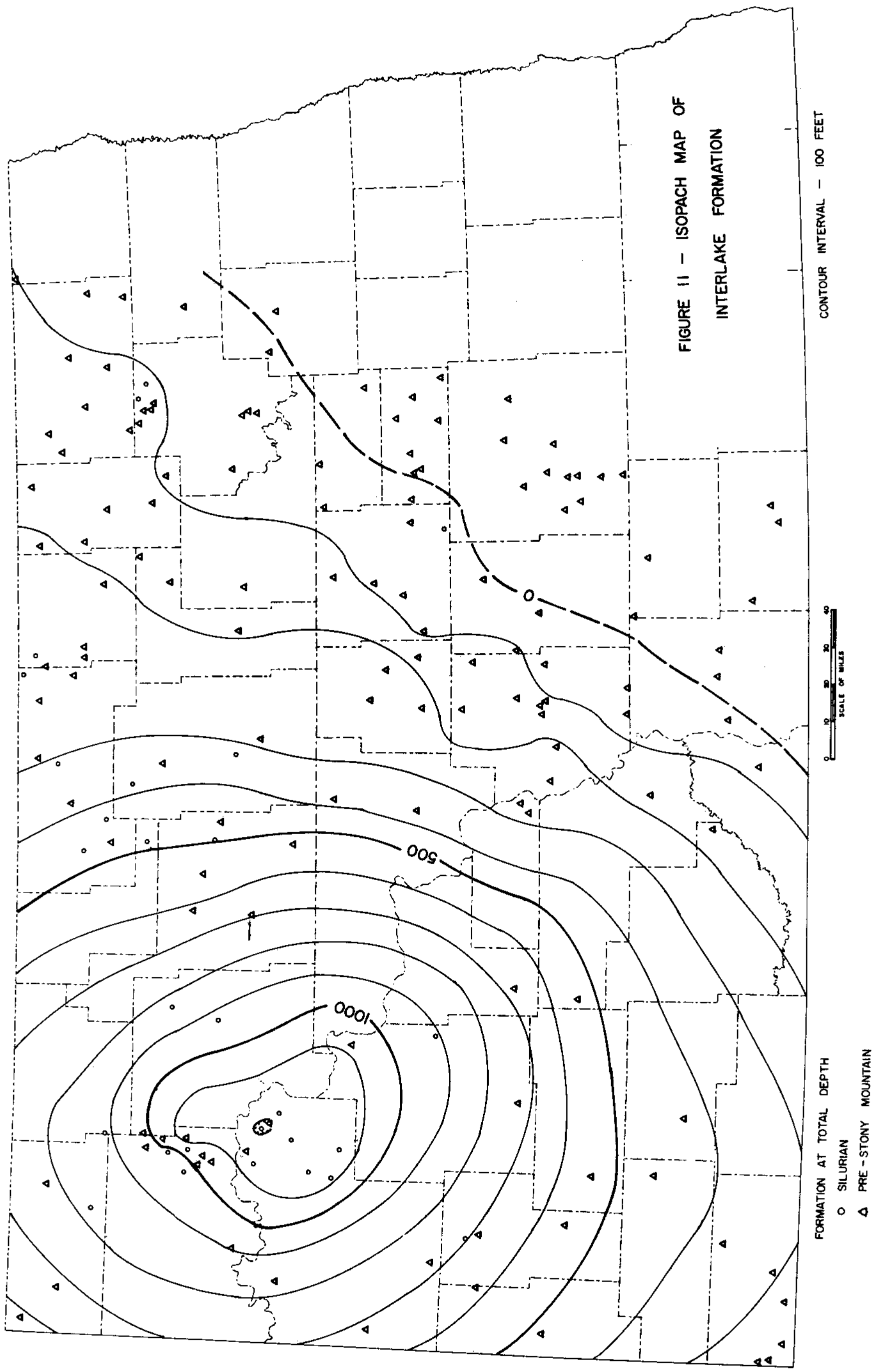


FIGURE 11 - ISOPACH MAP OF INTERLAKE FORMATION

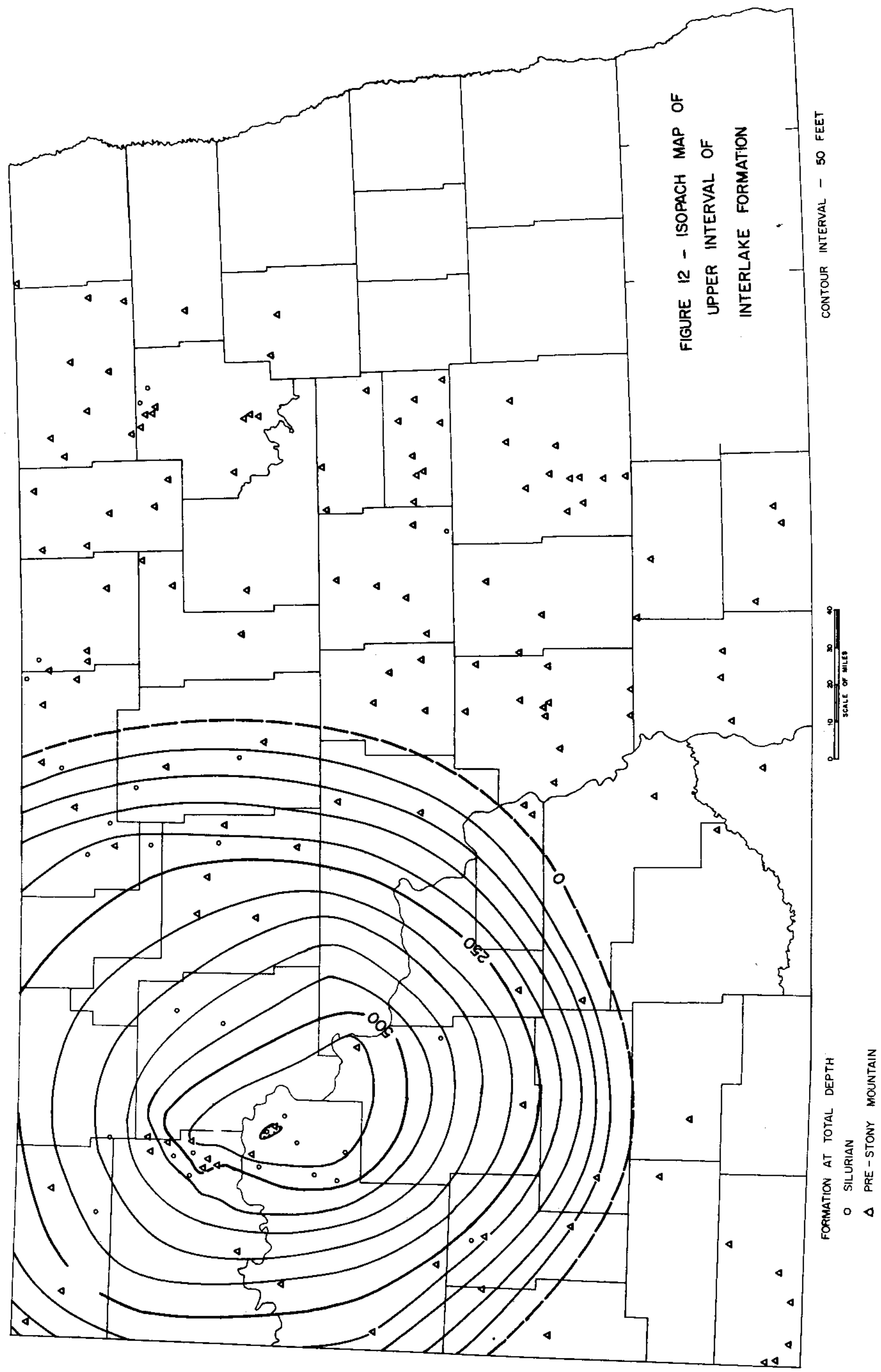
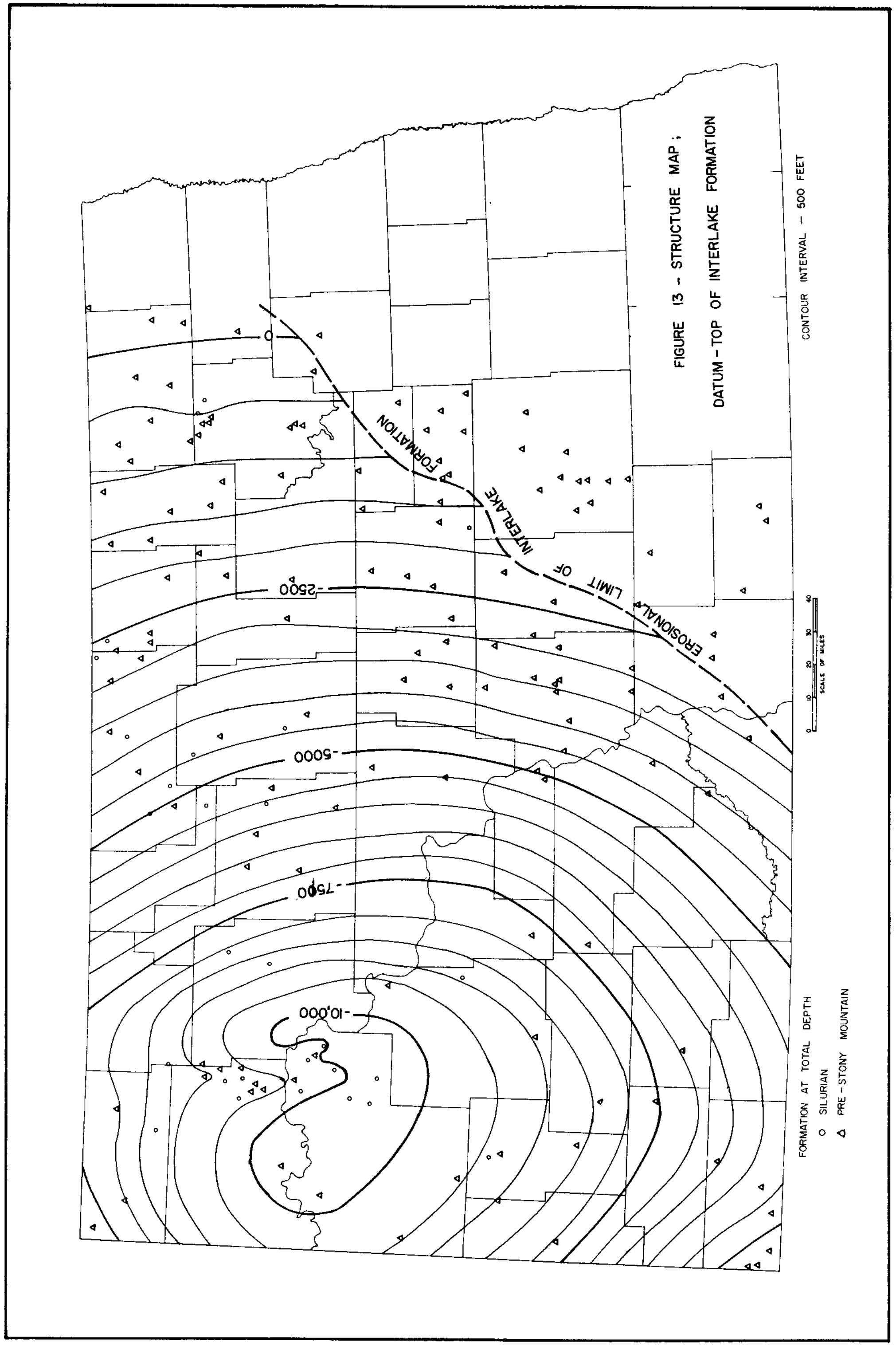


FIGURE 12 - ISOPACH MAP OF UPPER INTERVAL OF INTERLAKE FORMATION



APPENDIX

Descriptions of cuttings and cores giving detailed lithology of the Stony Mountain, Stonewall and Interlake Formations.

Stony Mountain Formation

Stoughton Member

Phillips Petroleum Company – Hoehn No. 1-A; NE SE Sec. 13, T. 152 N., R. 102 W., McKenzie County.

Cores

13,480-13,482	Limestone, light brownish gray (5 YR 6/1), fine to medium crystalline, few fossil fragments.
13,482-13,497	Limestone, light to medium gray (N 7, N 5), finely crystalline matrix, fossiliferous, fragmental.
13,497-13,510	Limestone, light to medium gray, (N 7, N 5) fine to medium grained, fragmental, fossiliferous, slightly argillaceous.
13,510-13,523	Limestone, light gray to medium gray, (N 7, N 5) fine to medium grained, fragmental, fossiliferous; some limestone, medium gray, (N 5), fine grained, argillaceous, fossiliferous.
13,523-13,524	Limestone, light to medium gray, (N 7, N 5) very finely crystalline.
13,524-13,530	Limestone, light to medium gray, (N 7, N 5) fine to medium grained, fossiliferous, fragmental; limestone, medium gray, (N 5), fine grained, argillaceous.

Amerada Petroleum Corporation - Antelope Unit "A" No. 1 NE SE Sec. 1, T. 152 N., R. 95 W., McKenzie County.

Samples

13,032-13,053	Limestone, dark yellowish brown (10 YR 4/2) to dark gray, (N 3) micrite with common masses of sparry calcite.

Cores

13,053-13,070	Shale, very limy, waxy, non-fissile, dark gray (N 3). Interbedded and interlaminated with dark to moderate yellowish brown (10 YR 4/2 to 5/4) microsparite and sparry limestone (coarsely crystalline) containing abundant fossil fragments.
13,070-13,074	Limestone, dark yellowish brown, (10 YR 4/2(micrite, with very rare small pellets and rare small fossil fragments. Contains numerous small black fragments of unknown affinity and common masses of fine crystalline pyrite.

13,074-13,108	Shale, limy, dark gray (N 3); interbedded with micrite and sparry limestone; common whole and fragmentary brachiopods and colonial corals.
13,108-13,110	Limestone, moderate to dark yellowish brown (10 YR 4/2 to 5/4), pelmicrosparite with small patches of white calcite. Rare to common small pellets and fossil fragments in a microsparite matrix.

Union Oil Company – Restad No. 1 SW NW Sec. 26, T. 162 N., R. 64 W., Cavalier County.

Cores

2,733- 2,780	Dolomite, yellowish gray (5 Y 8/1), mottled with pink and lavender, dense, sucrosic.
2,780- 2,800	Limestone, pale greenish gray (5 G 8/1), argillaceous, earthy.
2,800- 2,805	Dolomite, yellowish gray (5 Y 8/1) with purple mottling, dense.
2,805- 2,835	Limestone, light gray to olive gray (N 7, 5 Y 4/1), purple mottlings, fossiliferous.
2,835- 2,840	Shale, greenish gray (5 G 6/1), calcareous.
2,840- 2,862	Limestone, medium gray (N 5), dense, fossiliferous, interbedded with shale, greenish gray (5 G 6/1), calcareous.

Gunton Member

Mobil Producing Company – Birdbear No. F22-22-1 SE NW Sec. 22, T. 149 N., R. 91 W., Dunn County.

Cores

12,890-12,895	Dolomite, pale yellowish brown (10 YR 6/2), medium crystalline, not sandy.
12,895-12,900	Dolomite, dark gray (N 3), argillaceous.
12,900-12,907	Limestone, dark yellowish brown (10 YR 4/2), fine crystalline, slightly silty, fossiliferous, algae (?) and bryozans (?) rare fragments of brachiopod shells.
12,907-12,914	Limestone, dark yellowish brown (10 YR 4/2), fine crystalline, with common yellowish brown dolomite crystals. Sandstone, blue-gray (10 YR 5/4), fine grained rounded quartz grains.
12,914-12,924	Anhydrite, dark yellowish brown (10 YR 4/2).
12,924-12,934	Dolomite, granular, limy pale yellowish brown (10 YR 6/2), with scattered dark brown anhydrite crystals. Good porosity. No fluorescence.
12,934-12,944	Dolomite, pale, yellowish brown (10 YR 6/2), finely granular, fair porosity.

12,944-12,954	As above.
12,954-12,964	Dolomite, medium gray (N 5), fine crystalline, common horizontal fractures.
12,964-12,974	As above, dark gray (N 3) shaly partings.
12,974-12,981	Limestone, medium to light gray to grayish green (N 5, N 7, 5 G 5/2) with finely disseminated pyrite. Common brachiopods.

Phillips Petroleum Company – Hoehn No. 1-A NE SE Sec. 13, T. 152 N., R. 102 W., McKenzie County.

Cores

13,403-13,408	Limestone, light brownish gray (5 YR 6/1), finely crystalline, with some medium to coarse crystals.
13,408-13,409	Limestone; light gray (N 7), finely crystalline.
13,409-13,411	Anhydrite; medium gray (N 5).
13,411-13,418	Limestone; medium gray to brownish gray (N 5, 5 YR 4/1), very finely crystalline.
13,418-13,421	Limestone; light gray to medium gray (N 7, N 5), finely crystalline, thinly laminated slightly argillaceous.
13,421-13,423	Limestone; light gray (N 7), fine to medium crystalline.
13,423-13,425	Dolomite; very light brownish gray (5 YR 7/1), fine grained, limy.
13,425-13,434	Limestone; light to medium gray (N 7, N 5), finely crystalline, and fine grained.
13,434-13,438	Limestone; light gray (N 7), fine grained, fragmental, fossiliferous.
13,438-13,442	Limestone, light gray to light brownish gray (N 7, 5 YR 7/1), fine to medium crystalline, a few shell fragments.
13,442-13,451	Dolomite, light brownish gray (5 YR 6/1), fine grained, granular, limy, with stylolites.
13,451-13,468	Limestone, light brownish gray (5 YR 6/1), finely crystalline, with a few fossil fragments and a few stylolites.
13,468-13,480	Limestone, light brownish gray (5 YR 6/1), fine to medium crystalline, few fossil fragments.

Union Oil Company – Restad No. 1 SW NW Sec. 26, T. 162 N., R. 64 W., Cavalier County.

Samples

2,710- 2,720	Dolomite, pale red (5 R 6/2) to yellowish gray (5 Y 8/1), fine grained, dense, with little mottled red and gray shale interbedded.

2,720- 2,735	Dolomite, pale red (5 R 6/2), sandy, limy, with little interbedded mottled red and gray shale.
2,735- 2,745	Dolomite, as above, becoming very sandy, with yellowish gray (5 Y 8/1) very sandy dolomite.
2,745- 2,773	Core #11. Dolomite, yellowish gray (5 Y 8/1), mottled with pink and lavender, dense, sucrosic.

STONEWALL FORMATION

Phillips Petroleum Company – Hoehn No. 1-A NE SE Sec. 13, T. 152 N., R. 102 W., McKenzie County.

Samples

13,286-13,300	Dolomite; light brownish gray (5 Y 6/1), finely crystalline.
13,300-13,310	Dolomite; as above; some white anhydrite.
13,310-13,348	Dolomite; brownish gray (5 YR 4/1), finely crystalline.

Cores

13,348-13,352	Dolomite; brownish gray (5 YR 4/1), finely crystalline, dense, limy.
13,352-13,361	Limestone; brownish gray (5 YR 4/1), very finely crystalline, dense with dark gray (N 3) shaly stringers.
13,361-13,366	Limestone; brownish gray (5 YR 4/1), fine to medium crystalline, fragmental with a few shell fragments, slightly shaly.
13,366-13,373	Limestone; brownish gray (5 YR 4/1), finely crystalline with a few medium crystals, a few shell fragments.
13,373-13,377	Limestone, light gray (N 7), finely crystalline, dolomitic.
13,377-13,379	Anhydrite, white (N 9) massive.
13,379-13,381	Limestone; light gray and medium dark gray (N 7, N 4), finely crystalline, slightly shaly; anhydrite white (N 9), massive.
13,381-13,383	Limestone; medium gray (N 5), finely crystalline, argillaceous.
13,383-13,388	Limestone; dark gray (N 3), finely crystalline, with a few medium crystals slightly argillaceous, few shell fragments.
13,388-13,398	Limestone; light to medium gray (N 7, N 5), finely crystalline, with some medium crystals, few shell fragments.
13,398-13,399	Limestone; dark gray (N 3), finely crystalline, dense; anhydrite, white (N 9) massive.

13,399-13,401	Limestone; light gray (N 7), fine to medium crystalline fossiliferous, fragmental.
13,401-13,402	Limestone; medium gray (N 5), finely crystalline, thinly laminated with medium gray shale partings.
13,402-13,403	Anhydrite; medium gray (N 5), massive.

Calvert Exploration Company – Stadum No. 1, NW SE Sec. 31, T. 154 N., R. 70 W., Benson County.

Samples

4,085- 4,090	Limestone, white to pinkish gray (N 9, 5 YR 8/1), sublithographic to very fine grained.
4,090- 4,100	Limestone, pinkish gray (5 YR 8/1), sublithographic, slightly dolomitic.
4,100- 4,130	Dolomite, white to very light gray (N 9, N 8), sublithographic slightly limy.
4,130- 4,138	Dolomite, as above and pinkish gray (5 YR 8/1), fine grained, limy dolomite.

INTERLAKE FORMATION

Amerada Petroleum Corporation – North Dakota "A" Unit No. 9; SE SW Sec. 16, T. 156 N., R. 95 W., Williams County.

Samples

11,710-11,720	Limestone, pale red to grayish orange red (5 R 6/2, 10 R 8/2), fine to medium crystalline, granular, argillaceous.
11,720-11,744	Limestone, light gray to very light brownish gray (N 7, 5 YR 7/1), finely crystalline, dense, argillaceous.

Cores

11,744-11,769	Dolomite, pale reddish brown (10 R 5/4), very finely crystalline.
11,769-11,774	Dolomite, very light gray (N 8), finely crystalline, slightly vuggy; some salt crystals.
11,774-11,784	Dolomite, very light gray (N 8), very fine to finely crystalline, traces of pseudo-oolitic structure, some filling of small vugs with colorless calcite.
11,784-11,799	Dolomite, very light brownish gray (5 YR 7/1), finely crystalline with colorless calcite filling vugs and pores.
11,799-11,807	Dolomite, very light gray (N 8), finely crystalline.
11,807-11,812	Dolomite, medium light gray (N 6), finely crystalline.
11,812-11,817	Dolomite, very light gray (N 8), finely crystalline.

11,817-11,832	Dolomite, very light gray (N 8), finely crystalline, vuggy, traces of oolitic or pelletoidal structure, limy; some black residue and colorless calcite infilling.
11,832-11,842	Dolomite, very light gray (N 8), finely crystalline, limy.
11,842-11,860	Dolomite, very light gray (N 8), finely crystalline, vuggy, limy, traces of pelletoidal texture, some calcite infilling.
11,860-11,865	Dolomite, very light gray (N 8), finely crystalline, limy.
11,865-11,890	Dolomite, very light gray (N 8), finely crystalline, vuggy, limy, traces of pelletoidal textures, some calcite infill.
11,890-11,895	Dolomite, light yellowish gray (5 Y 9/1), very finely crystalline.
11,895-11,900	Dolomite, light gray (N 7), very finely crystalline to slightly granular, vuggy, oil stain.
11,900-11,905	Dolomite, very light gray (N 8), finely crystalline, earthy.
11,905-11,923	Dolomite, light yellowish gray (5 Y 9/1), fine to medium crystalline, vuggy, slight oil stain; oolitic to pelletoidal texture 918-923.
11,923-11,928	Dolomite, very light gray (N 8), finely crystalline, oil stain.
11,928-11,938	Dolomite, mottled light yellowish gray and very light gray (5 Y 9/1, N 8), finely crystalline, oolitic to pelletoidal texture limy, vuggy.
11,938-11,948	Dolomite, very light gray (N 8), finely crystalline, limy.
11,948-11,953	Dolomite, as from 928 to 938.
11,953-11,958	Dolomite, light gray (N 7), very finely crystalline.
11,958-11,963	Shale, medium gray (N 5), dolomitic, pyritic.
11,963-11,968	Dolomite, medium light gray (N 6), finely crystalline.
11,968-11,976	Dolomite, light gray (N 7), very fine to finely crystalline, vuggy, limy, some calcite infill.
11,976-11,981	Dolomite, light gray (N 7), finely crystalline, slightly silty.
11,981-12,015	Dolomite, light yellowish gray (5 Y 9/1), finely crystalline, limy, slight oil stain.

Samples

12,015-12,060	Dolomite, light yellowish gray (5 Y 9/1), finely crystalline, some with traces of fragmental texture, limy.

12,060-12,070	Dolomite, light yellowish gray (5 Y 9/1), fine to medium crystalline, limy, fragmental to pelletoidal, vuggy.
12,070-12,090	Dolomite, light yellowish gray (5 Y 9/1), fine crystalline; some Dolomite, as above.
12,090-12,140	Dolomite, very light brownish gray (5 YR 7/1), very fine to finely crystalline, limy, vuggy, traces of pelletoidal texture.
12,140-12,190	Dolomite, very light gray (N 8), very finely crystalline, dense.
12,190-12,200	Dolomite, very light gray (N 8), very fine to finely crystalline, slightly vuggy.
12,200-12,220	Dolomite, very light gray to light yellowish gray (N 8, 5 YR 9/1), very finely crystalline in part, fragmental in part.
12,220-12,260	Dolomite, light yellowish gray to very light gray (5 Y 9/1, N 8), very finely crystalline, dense.
12,260-12,280	Dolomite, pale red to grayish pink (5 R 6/2, 5 R 8/2), fine to medium crystalline, granular, silty.
12,280-12,300	Dolomite, as above; some Shale, pale reddish brown (10 R 5/4), calcareous.
12,300-12,330	Dolomite, pale red to grayish pink (5 R 6/2, 5 R 8/2), finely crystalline, silty to sandy grading to dolomitic sandstone in part, fine to medium, rounded frosted grains.

Top of Middle Interval

12,330-12,370	Dolomite, very light gray (N 8), very fine to finely crystalline, some colorless quartz and white chert.
12,370-12,430	Dolomite, light yellowish gray to very light gray (5 Y 9/1, N 8), fine to medium crystalline, slightly vuggy.
12,430-12,480	Dolomite, very light gray to light yellowish gray (N 8, 5 Y 9/1), fine to medium crystalline, granular in part, dense in part.
12,480-12,490	Dolomite, light yellowish gray (5 Y 9/1), finely crystalline, dense.
12,490-12,530	Dolomite, as above; Chert, white and light yellowish gray (N 9, 5 Y 9/1).
12,530-12,560	Dolomite, very light gray to light yellowish gray (N 8, 5 Y 9/1), very fine to finely crystalline, dense.
12,560-12,570	Dolomite, very light brownish gray (5 YR 7/1), fine to medium crystalline, granular, slight intergranular pinpoint porosity.

12,570-12,590	Dolomite, as above in part, finely crystalline, dense in part.
12,590-12,620	Dolomite, very pale orange to light gray (10 YR 8/2, N 7), very fine to finely crystalline, dense.
12,620-12,680	Dolomite, light brownish gray (5 YR 6/1), medium to coarsely crystalline.
12,680-12,700	Dolomite, light brownish gray (5 YR 6/1), very fine to finely crystalline.

Top of Lower Interval

Cores

12,700-12,705	Anhydrite, medium gray (N 5).
12,705-12,710	Intermingled Dolomite, light brownish gray (5 YR 6/1), very finely crystalline and anhydrite, medium gray.
12,710-12,715	Dolomite, light brownish gray (5 YR 6/1), very fine to finely crystalline, dense.
12,715-12,720	Dolomite, as above and anhydrite, medium gray (N 5).
12,720-12,725	Anhydrite, white (N 9).
12,725-12,730	Anhydrite, medium gray to light brownish gray (N 5, 5 YR 6/1).
12,730-12,735	Anhydrite, medium gray to white (N 5, N 9).
12,735-12,740	Dolomite, brownish gray (5 YR 4/1), very finely crystalline, dense.
12,740-12,745	Dolomite, light brownish gray (5 YR 6/1), finely crystalline, slightly vuggy.
12,745-12,755	Dolomite as above and anhydrite, medium gray (N 5).
12,755-12,760	Dolomite, light brownish gray (5 YR 6/1), finely crystalline, oil stain.
12,760-12,765	Dolomite, brownish gray (5 R 4/1), very finely crystalline.
12,765-12,770	Limestone, medium light gray (N 6), finely crystalline.
12,770-12,815	Dolomite, light brownish gray (5 YR 6/1), finely crystalline, dense.
12,815-12,825	Anhydrite, medium gray (N 5), dolomitic.
12,825-12,869	Dolomite, brownish gray (5 YR 4/1), very finely crystalline.

Samples

12,870-12,875	Limestone, very light brownish gray to brownish gray (5 YR 6/1, 5 YR 4/1), fine to medium crystalline, anhydritic.

12,875-12,880	Dolomite, light brownish gray (5 YR 6/1), finely crystalline, slight pinpoint porosity, limy.

California Oil Company – Blanche Thompson No. 1; SW SE Sec. 31, T. 160 N., R. 81 W., Bottineau County.

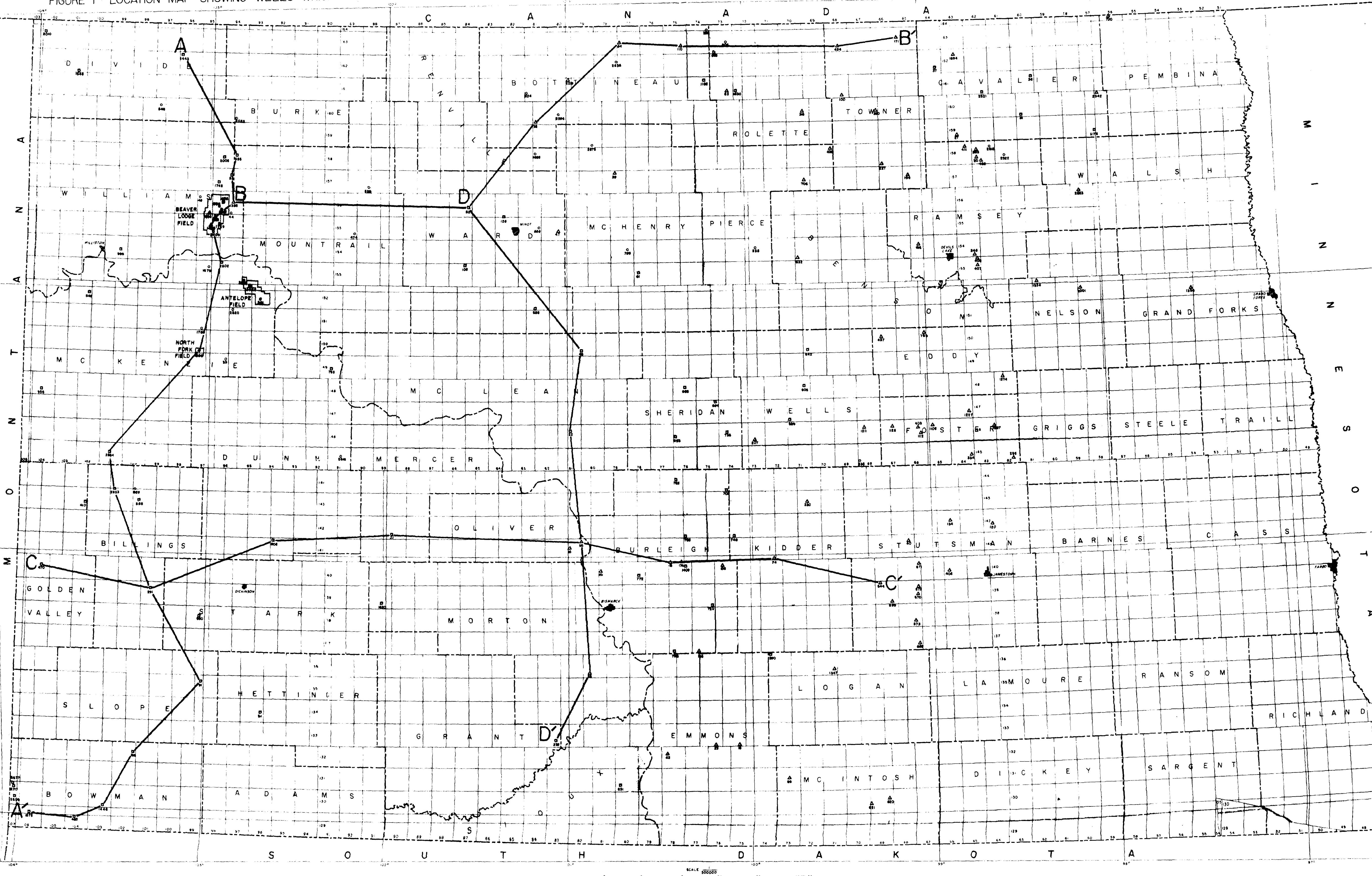
Cores

6560- 6570	Dolomite, very light gray (N 8), finely crystalline.
6570- 6579	Anhydrite, white to colorless (N 9) with intercalated dolomite, as above.
6579- 6586	Dolomite, pale red (5 R 6/2), finely crystalline and dolomite, very light gray (N 8), finely crystalline, anhydritic.
6586- 6595	Dolomite, mottled grayish orange pink (5 YR 7/2), fine to coarsely crystalline with some fillings of vugs with light greenish gray shale.
6595- 6600	Dolomite, pinkish gray (5 YR 8/1), finely crystalline.
6600- 6611	Dolomite, very light gray (N 8), fine to coarsely crystalline, slightly vuggy.
6611- 6623	Dolomite, white to light yellowish gray (N 9, 5 Y 9/1), finely crystalline, limy.
6625- 6639	Dolomite, white to very light gray (N 9, N 8), fine to coarsely crystalline, vuggy, remnants of pelletoidal texture, limy.
6639- 6658	Dolomite, very pale orange (10 YR 8/2), finely crystalline, limy, traces of remnant pelletoidal texture.
6658- 6660	Dolomite, very light gray to white (N 8, N 9), fine to coarsely crystalline, vuggy.
6660- 6670	Dolomite, white (N 9), finely crystalline, limy.
6670- 6680	Dolomite, as above and Dolomite, very light gray (N 8), fine to coarsely crystalline, slightly vuggy.
6680- 6690	Dolomite, very pale orange (10 YR 8/2), finely crystalline.
6690- 6701	Dolomite, very light gray (N 8), finely crystalline, limy, remnants of pelletoidal or oolitic structure; Dolomite, as above.
6701- 6708	Dolomite, very light gray to very pale orange (N 8, 10 YR 8/2), fine to medium crystalline, slightly vuggy.
6708- 6711	Dolomite, very pale orange (10 YR 8/2), fine to medium crystalline.
6711- 6718	Dolomite, white (N 9), fine to medium crystalline, vuggy in part, remnants of pelletoidal texture in part.

6718-	6750	Dolomite, very pale orange (10 YR 8/2), fine to medium crystalline, slightly vuggy.
6750-	6757	Dolomite, white to very light gray (N 9, N 8), fine crystalline, mottled with patches of very pale orange dolomite, slightly limy.
6757-	6762	Dolomite, mottled pale red (5 R 6/2), hematitic stain, fine to coarsely crystalline.
6762-	6780	Limestone, grayish orange pink (10 R 8/2), very fine to finely crystalline, with some reddish brown stain and argillaceous material.
6780-	6797	Limestone, as above; Shale, pale reddish brown (10 R 5/4), lumpy, slicken-sided, calcareous.
6797-	6820	Limestone, grayish pink (5 R 8/2), very finely crystalline, in part, medium to coarsely crystalline in part, some reddish stain some grayish red (5 R 4/2) argillaceous material filling vugs which are lined with medium to coarse crystals of calcite.
6820-	6830	Limestone, light yellowish gray (5 Y 9/1), very finely crystalline.
6830-	6833	Limestone, moderate orange to grayish pink (10 R 7/4, 5 R 8/2), medium to coarsely crystalline with thin lenses of purplish shale, slicken-sided.
6833-	6836	Limestone, very light gray to light yellowish gray (N 8, 5 Y 9/1), very finely crystalline.
6836-	6839	Limestone, grayish orange pink (10 R 8/2), very fine to finely crystalline, some hematitic stain and some stringers or infilling with light greenish gray and grayish red (5 GY 8/1, 5 R 4/2), shale.
6839-	6846	Dolomite, very light gray (N 8), very fine to medium crystalline, dense with thin layers of purplish and light greenish gray shale.
6846-	6860	Dolomite, moderate orange to pinkish gray (10 R 7/4, 5 R 8/2), very finely crystalline.
6860-	6870	Dolomite, moderate orange pink (10 R 7/4), very fine to medium crystalline and some coarsely crystalline, some greenish gray (5 GY 6/1), shale layers and lenses.
6870-	6892	Dolomite, light pinkish gray (5 YR 8/1), medium to coarsely crystalline, some vuggy porosity.
6892-	6900	Dolomite, as above with some greenish gray (5 GY 6/1) shale lenses.
6900-	6910	Dolomite, very light gray (N 8), very finely crystalline.

6910-	6920	Dolomite, grayish orange pink (10 R 8/2), very fine to finely crystalline.
6920-	6922	Dolomite, grayish orange pink (10 R 8/2), very fine to medium crystalline, slightly vuggy; a little greenish gray (5 GY 6/1) shale.
6922-	6935	Dolomite, grayish pink (5 R 8/2), fine grained.
6935-	6941	Dolomite, very light gray (N 8), fine to medium crystalline, granular, slightly vuggy.
6941-	6969	Dolomite, very light yellowish gray (5 Y 9/1), very finely crystalline, slight intergranular porosity.
6969-	6973	Dolomite, very pale orange (10 YR 8/2), finely crystalline, granular, tight; Dolomite, very light gray (N 8), very fine to medium and coarsely crystalline.
6973-	6979	Limestone, light yellowish gray (5 Y 8/1), sublithographic.
6979-	7000	Dolomite, light yellowish gray (5 Y 8/1), finely crystalline, granular to very finely crystalline, dense.

FIGURE 1 - LOCATION MAP SHOWING WELLS WHICH HAVE PENETRATED TO OR THROUGH SILURIAN ROCKS IN NORTH DAKOTA, AND LINES OF CROSS-SECTION.



EXPLANATION

SILURIAN OIL FIELD AREAS --- ▭

N.D.G.S. WELL FILE NUMBERS --- 511

KEY TO FORMATION AT TOTAL DEPTH

○ - SILURIAN

□ - ORDOVICIAN OR CAMBRIAN

△ - PRECAMBRIAN

FIGURE 3 – CROSS SECTION A-A′ SHOWING UPPER ORDOVICIAN AND SILURIAN ROCKS

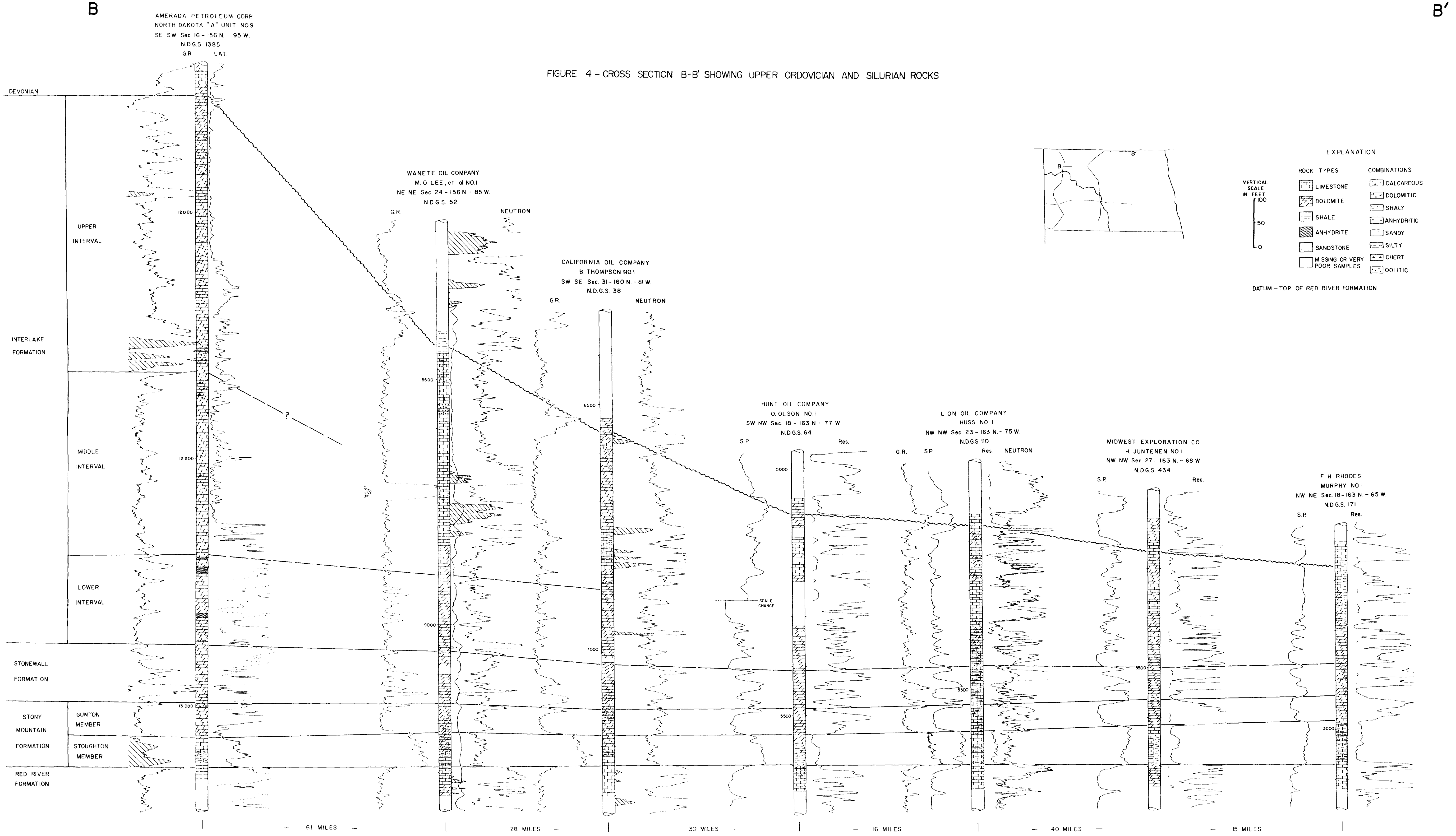
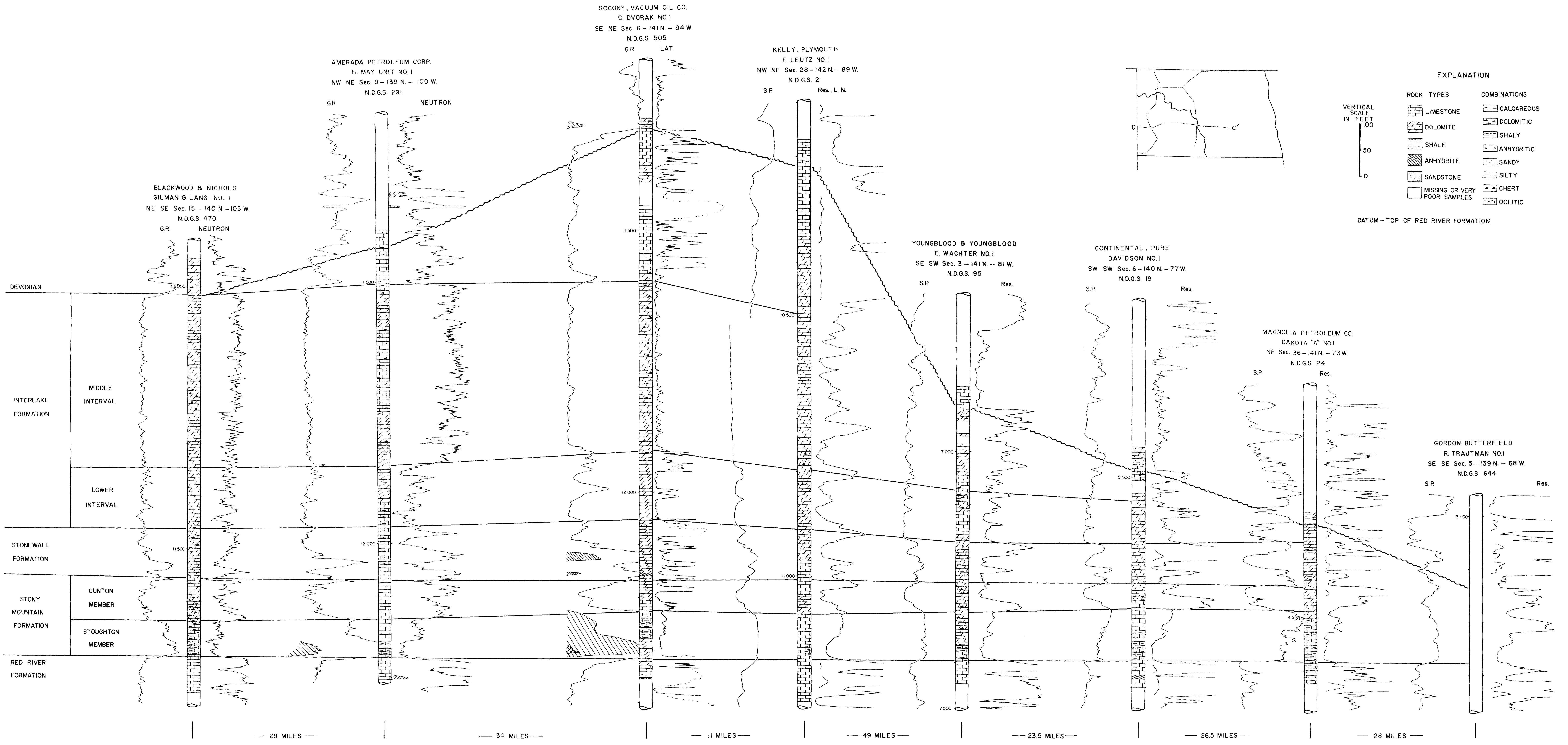


FIGURE 4 – CROSS SECTION B-B′ SHOWING UPPER ORDOVICIAN AND SILURIAN ROCKS

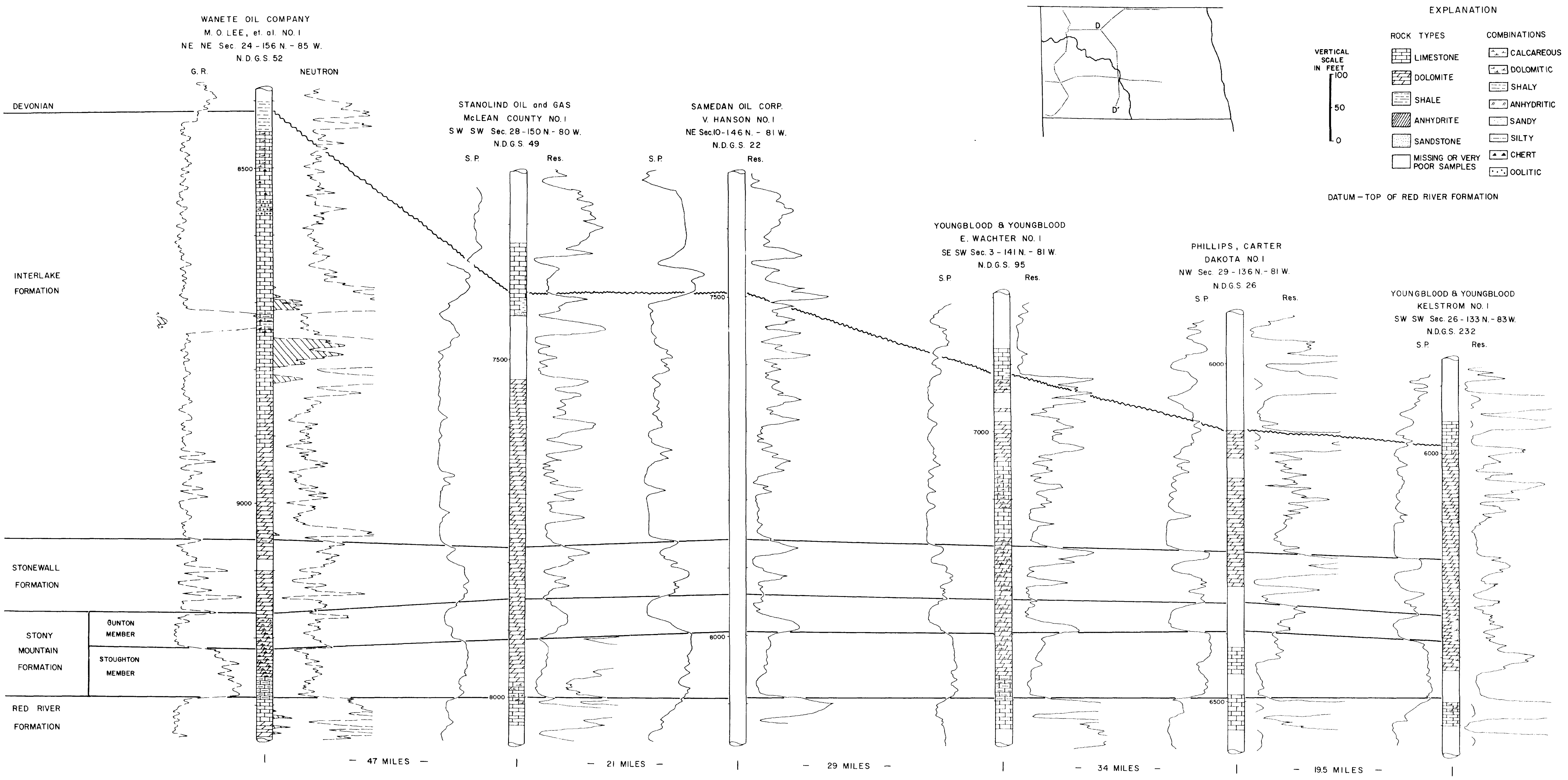
FIGURE 5 – CROSS SECTION C-C' SHOWING UPPER ORDOVICIAN AND SILURIAN ROCKS



D - NORTH

FIGURE 6 – CROSS SECTION D-D' SHOWING UPPER ORDOVICIAN AND SILURIAN ROCKS

SOUTH-D'



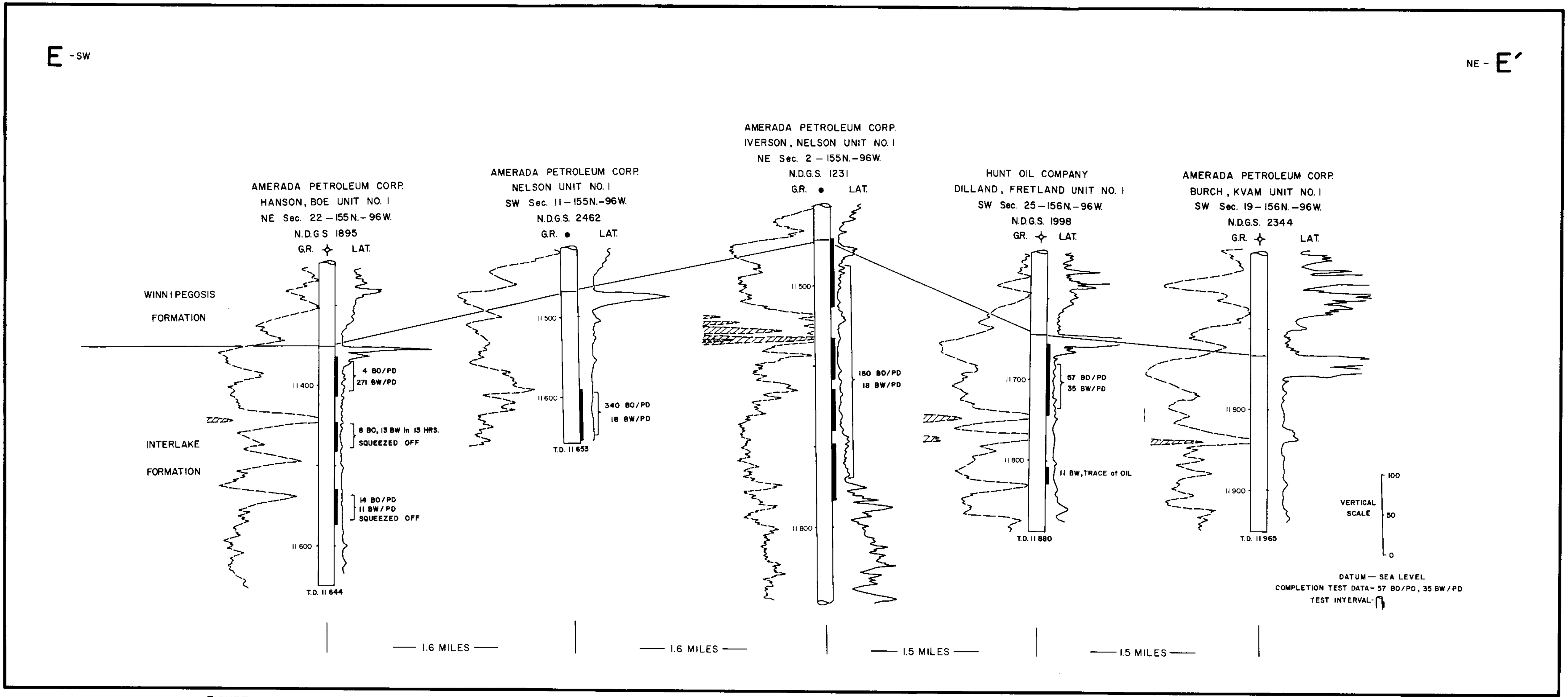


FIGURE 15 - CROSS SECTION SHOWING PRODUCING HORIZONS OF INTERLAKE FORMATION IN BEAVER LODGE FIELD.