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Peter F. Bjorlie

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STRATIGRAPHY AND DEPOSITIONAL SETTING OF THE 
CARRINGTON SHALE FACIES (MISSISSISSIPPIAN) 
OF THE WILLISTON BASIN

by
Peter F. Bjorlie
Bachelor of Science, University of North Dakota, 1976

A Thesis
Submitted to the Graduate Faculty 
of the
University of North Dakota
in partial fulfillment of the requirements 
for the degree of
Master of Science

Grand Forks, North Dakota

May
1978
This Thesis submitted by Peter F. Bjorlie in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

(Dean of the Graduate School)

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Title  Stratigraphy and Depositional Setting of the Carrington Shale Facies (Mississippian) of the Williston Basin

Department  Geology

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ABSTRACT

The Carrington shale facies is a radioactive illitic lagoonal shale, apparently deposited behind lime mudstone banks (Waulsortian bioherms), along the eastern margin of the Williston basin during Early Mississippian time.

The Scallion subinterval, which is the basal subunit of the Bottineau interval of the Madison Formation in North Dakota, is divisible into six lithologic facies, one of which is the Carrington shale facies. West of the shale facies, on the basin-shelf hinge line, is the lime mudstone facies. Basinward of this facies is the interbedded shale-limestone facies. Stratigraphically above the latter two facies is the sand-silt-shale facies. Overlying a portion of this facies and the Carrington shale facies is the crinoid packstone-grainstone facies. Overlying the remaining portion of the sand-silt-shale facies is the wacke-packstone facies.

Following a period of erosion during the latest Devonian-earliest Mississippian time, Waulsortian mounds formed along the basin-shelf hinge line. These mounds and associated sediments (lime mudstone facies) created a barrier which allowed the deposition of the Carrington shale facies in a restricted environment. The source of the shale was the weathered Precambrian shield to the east. The sand-silt-shale facies was deposited on the basin slope during the deposition of the Carrington shale facies. After the deposition of these two clastic facies, carbonate deposition occurred on the basin shelf and slope in the form of the crinoid packstone-grainstone and wacke-packstone facies respectively.
Possible petroleum traps exist where; the Carrington shale facies overlies erosionally truncated Devonian strata, abrupt facies changes occur within the Scallion subinterval, and along the pre-Mesozoic subcrop of the Scallion. Conditions necessary for the concentration of uranium beneath or within the Carrington shale facies may have occurred after the deposition of the shale facies.
INTRODUCTION

General Statement

The basal shale facies of the Bottineau interval of the Madison Formation have been described and named in Manitoba, North Dakota, and South Dakota, as the Routledge Shale, Carrington shale facies and the Englewood facies respectively. The relationships between these units and the limestone units which surround them have not been studied in detail nor are their origins fully understood.

Purpose

The purpose of this study is to provide a regional picture of the history of sedimentation, during the deposition of the basal shale units of the Bottineau interval, along the eastern margin of the Williston basin. The economic potential of these units will also be evaluated.

Area of Study

The area of study includes approximately 40,000 square miles in southwestern Manitoba and east-central North Dakota (figure 1). This area includes the eastern limit of Mississippian strata in the Williston basin.

All of the units studied in this report are known only in the subsurface and were studied by the use of well cuttings, cores and mechanical logs from wells drilled in Manitoba and North Dakota.
Fig. 1. Location of study area in map view and cross section. Modified from Carlson and Anderson (1970).
A list of wells used and lithologic descriptions of the samples studied appear in the appendices of this report.

Regional Setting

The Williston basin is an intracratonic basin with a depocenter near Williston, North Dakota (Carlson and Anderson, 1970). During the latest Devonian and earliest Mississippian time, uplift occurred along the basin margins exposing Devonian strata (Sandberg, 1964). The resulting erosion created an angular unconformity around the eastern margin of the basin. At this same time deposition continued in the deeper or more central portions of the basin. Minor structural features within the eastern margin of the basin, in North Dakota, have been described by Ballard (1963).

These minor features include, the Burleigh, Cavalier, Foster, and Stutsman Highs (figure 2). These highs were identified by Ballard on the basis of structure contour and isopachous maps. They are most prominent in the lower parts of the Paleozoic section. Their prominence decreases upward in the section. The causes of these structural highs were related to topographic highs on the Precambrian surface. Further discussion of the importance of these highs will be included in later sections.

Structural features evident on the Pre-Mississippian surface (figure 2) are quite subtle. The basin hinge line, located at approximately 100° west longitude, is shown by a slight compression of the contour lines. Widened contour lines to the east reflect the gentler sloping surface of the basin margin area. Irregularities in this area are numerous, the cause of which will be discussed in later sections.
Fig. 2. Structure contour map of the base of Mississippian Strata. Location of structural highs after Ballard (1963).
Stratigraphy

Figure 3 shows the relationship between the underlying and overlying units with the shale units of this study. All of these units will be discussed in greater detail (with the exception of the upper two) in later sections.

The subdivisions of the Lodgepole Formation were first proposed by Stanton (1955). He described and named the Routledge shale, Scallion, Virden and Whitewater Lake Members, as subdivisions of the Lodgepole in southwestern Manitoba. McCabe (1963) added one member to the top of the Lodgepole by naming the Flossie Lake Member. This terminology is accepted by the Manitoba Geological Survey.

Smith (1960) proposed that the Madison Group be subdivided into intervals. From base to top these intervals are the Bottineau, Tilston, Frobisher-Alida, Ratcliff and Poplar intervals. Carlson and Anderson (1970) demoted the Madison to formation status within the confines of the North Dakota portion of the Williston basin.

In order to remain consistent with accepted North Dakota terminology and also to use the subdivisions of the Lodgepole formation, the author proposes to refer to them as subintervals of the Bottineau interval.

Methods of Study

During the summer of 1977 the author examined well cuttings from North Dakota and cores from Manitoba and North Dakota. These samples are the property of the respective Geologic Surveys, having been obtained from companies and individuals that drilled oil or stratigraphic tests in the area of this study. Cores were available from only
Fig. 3. Stratigraphic column of interval studied.
a few wells and from limited intervals within these wells. Cores were examined by means of hand lens, acetate peels and thin sections. Cuttings were available for most of the wells in the area at five to ten foot intervals. Cuttings were examined by laying out approximately 200 foot intervals of the samples in sample trays. Samples were then examined for color or lithologic breaks, samples were next examined using a binocular microscope under reflected light. In the case of carbonate rock chips transmitted light was used. This was done by wetting the rock chip on a clear plastic tray. Alizarin red was used to differentiate calcite from dolomite. Particular attention was given to the fabric and fauna of the carbonate rocks. Dunham's (1962) classification of carbonate rocks was used.

Determination of Shale Mineralogy

To determine the mineralogy of the clay and silt in core samples, X-ray diffraction was used. Clay, silt and sand sized fractions were separated from the shale using the procedure outlined by Brekke (1978). The clay size fraction was then placed on porous ceramic tiles and suction used to produce a durable oriented sample. Silt size fractions were prepared for X-ray analysis by backfilling an aluminum sample holder and exerting pressure to obtain an unoriented backloaded sample. Specific X-ray diffraction procedures are outlined in Appendix D. The sand sized fraction was examined using a binocular microscope.

Size analysis of the shale unit was attempted but abandoned for the following reasons:

1. Difficulty in disaggregating the shale.
2. Flocculation of clays.
3. Small number of cores available, making it difficult to extend results beyond control points. Estimates of grain size were made during examination of well cuttings, however, the reliability of well cuttings in size analysis is very questionable.

No attempt was made to systematically study the fauna of the units in this study. Many fossils were noted during the lithologic study. Identifications of these fossils were attempted in most cases and the results utilized in the environmental analysis of the units.

Mapping

Wells used, along with the author's mechanical log picks, are listed in the appendices. Log characteristics used in correlating the units in the study are described in a later section. A computer program (SYMAP, Dougenik and Sheehan, 1975) was used in all structure contour and isopachous mapping. After the computer constructed maps were completed, the author altered the maps before drafting them. In several cases the computer program interpolated beyond reasonable limits. In these cases the author contributed to the final product in an attempt to provide a more realistic map. Plates 1-4 are the altered maps from the original computer constructed maps.

Previous Work

The first published mention of a basal Mississippian shale (in the eastern portion of the Williston basin), separate from the Bakken Formation, was by Stanton (1955, 1956, 1958) in reports on the stratigraphy of the Lodgepole Formation in Manitoba. He named the Routledge shale as a basal member of the Lodgepole Formation, reporting it to be
conformable on the Bakken Formation and probably a continuation of Bakken deposition. Stanton (1956) considered it to be equivalent to the lower portion of the Scallion member. The shale in the type section (Calstan Routledge Prov. 13-29, 13-29-9-25 WPM, 2230 to 2307 feet) was black and dark brown to gray.

McCabe (1959) mapped the occurrence of the Routledge shale in Manitoba and north-central North Dakota. He presented two hypotheses for its formation. The first, deposition behind a barrier of some type. The second, local thickening of the Bakken Formation caused by collapse of salt formations in the underlying strata.

Sandberg and Hammond (1958) mentioned the occurrence of discontinuous shales located stratigraphically above the Bakken Formation on the south and east margins of the Williston basin. These shales were considered to be a facies of the Englewood Formation (Darton, 1901) which was believed to be of Early Mississippian age.

Work by Klapper and Furnish (1962), based on conodont studies, gave the Englewood Formation a Late Devonian-Early Mississippian age, making it more closely related to the Bakken Formation which had been recognized by Christopher (1961) to be a transitional Devonian-Mississippian formation.

Based on this time correlation of the Englewood Formation with the Bakken Formation, Sandberg (1962) questioned the correlation of the Englewood (shale) facies with the Englewood Formation. He considered the Englewood facies to be a portion of the Lodgepole Formation and described the shale facies as a dark gray shale interbedded with highly argillaceous limestone and calcareous shale or siltstone or a gray red or greenish gray shale speckled with grayish red. He noted that
laterally it graded abruptly into a less argillaceous limestone. This fact had also been noted by investigators of the Routledge shale (Stanton, 1958; McCabe, 1959).

Ballard (1963) isopached the basal shale facies of the Bottineau interval in North Dakota and named it the Carrington shale facies. He recognized it as distinct from the Bakken Formation, describing it as a bentonitic red brown calcareous shale. He recognized the similarity in the stratigraphic positions of the Carrington shale facies and the Routledge Shale. However, he interpreted the Carrington shale facies to be an isolated occurrence due to the formation of a basin behind the Burleigh High, a north-south low relief structural feature discovered in his study of the Paleozoic rocks of eastern North Dakota. The location of this high can be seen on figure 2.
STRATIGRAPHY

Mechanical Log Characteristics

Spontaneous potential and gamma ray logs were used in the determination of thicknesses and correlation of units in the study area. Figure 4 is a reproduction of a typical log pattern and the log characteristics of the units shown on this figure are similar to that of the other wells in the study area.

The Duperow and Birdbear Formations typically show intermediate resistivity and negative going spontaneous potential. This pattern is interrupted by thin streaks of lower resistivity and increased gamma ray counts. The former represent limestone and dolomite and the latter thin shale beds.

The Carrington shale facies exhibits very low resistivity, positive going spontaneous potential and high to very high gamma ray counts. It is usually consistent vertically, giving a smooth log appearance. In some cases a thin zone of high resistivity, a negative going spontaneous potential and lower gamma ray counts occurs in the upper one third of the shale section. This is probably the result of a thin limestone bed.

The Scallion subinterval has a fairly smooth negative going spontaneous potential, low gamma ray intensity and high resistivity. Some logs do show a zone of increased radioactivity and positive going spontaneous potential near the center of the subinterval. This log pattern occurs only to the west of the Carrington shale facies. It
Fig. 4. Typical mechanical log from the area of study.
represents a shaley bed that appears to form a boundary between two distinct carbonate units in the Scallion subinterval. The mechanical log patterns of these two units are very similar (see well no. 207, cross section B-B', plate 6). The top of the Scallion subinterval was usually picked at the first consistent increase in radioactivity and increasingly positive spontaneous potential.

The Virden subinterval has an irregular spontaneous potential and a higher radioactivity than the underlying Scallion subinterval. In some cases the Scallion subinterval or the units stratigraphically beneath it to the east are directly overlain by rocks of Mesozoic age. These rocks exhibited a high positive going spontaneous potential, high radioactivity and very low resistivity. The beds also appeared to be more massive and lacked the many thin shale beds common to the Mississippian and Devonian rocks.

**Underlying Units**

The Scallion subinterval is underlain by formations ranging in age from Ordovician to Mississippian. This is the result of erosion that occurred in the latest Devonian-earliest Mississippian time. Figure 5 is a diagramatic east-west cross section showing the relationship between these units and the overlying Scallion subinterval.

Of the units shown on the cross section, the Duperow, Birdbear, Three Forks and Bakken Formations will be discussed briefly. The older units were not examined during the sample study and will not be discussed further in this section. Isopachous maps and a discussion of the Paleozoic section of eastern North Dakota can be found in Ballard (1963).
Pre-Mesozoic Geologic Map

North Dakota

MESOZOIC AGE STRATA

TILSTON INTERVAL
Flossie Lake Subinterval
Whitewater Lake Subinterval
Virde Subinterval
Scallion Subinterval
Carrington Shale Facies

BOTTINEAU INTERVAL UNDIFFERENTIATED

BAKKEN FM. THREE FORKS FM. BIRDBEAR FORMATION DUPERON FORMATION

Fig. 5. Diagrammatic cross section through the area of study.
Duperow Formation

The Duperow Formation (Devonian) is composed of limestone, dolomite and interbedded shales and siltstones. It conformably overlies the Souris River Formation throughout the Williston basin except on the eastern margin where it rests unconformably on rocks of Silurian and Ordovician age. It is conformably overlain by the Birdbear Formation except where this unit has been removed by early Mississippian erosion. In these areas the Duperow is unconformably overlain by the Bottineau interval or in areas further to the east by Mesozoic age rocks. These relationships are illustrated on cross-section B-B' on plate 6.

In the area of study the Duperow ranged in thickness from 0 feet along the erosional edge to 400 feet in Bottineau and Rolette counties, North Dakota.

Birdbear Formation

The Birdbear Formation is composed of porous limestone and dolomite. It conformably overlies the Duperow Formation and is conformably overlain by the Three Forks Formation in the central basin area. On the Basin margin it is unconformably overlain by the Bottineau interval of Mississippian age or by Mesozoic age rocks. In the area of study the Birdbear Formation ranges in thickness from 0 feet on its erosional edge to 100 feet in Bottineau County.

Three Forks Formation

The Three Forks Formation is composed of red dolomitic shales and siltstones. It conformably overlies the Birdbear Formation. The Bakken Formation overlies the Three Forks in the central basin area. In some cases the Three Forks extends beyond the limit of the Bakken
and is unconformably overlain by the Bottineau interval. This case is illustrated on cross-section C-C' on plate 6. Thickness of the Three Forks Formation ranges from 0 to 100 feet in the study area.

Bakken Formation

The Bakken is composed of three separate units. The lower is a fissile organic black shale. The middle unit is composed of dolomitic siltstone and sandstone. The upper member is composed of a black shale similar to the lower member but not as dark in color. The Bakken unconformably overlies the Three Forks Formation and is conformably overlain by the Bottineau interval. In the area of study the Bakken ranges in thickness from 0-60 feet.

Bottineau Interval

The Bottineau interval is composed of several different shale and limestone units. The limestone units may be separated based on fabrics and faunal constituents. Four separate members have been proposed by Stanton (1958) and McCabe (1963) for this formation (figure 3). These units are easily identifiable based on electric log characteristics. However, they do not necessarily represent a single lithologic facies. The Scallion subinterval has been divided into six lithologic facies in the report.

Scallion subinterval

The Scallion subinterval as described by Stanton (1958) is a crinoidal cherty limestone to argillaceous limestone, fine to coarse grained, compact to chalky, becoming oolitic in the upper portions. It varies from 0-245 feet in thickness in the area of study. On the
east it is bounded by the erosional limit of Mississippian rocks. On
the west the unit looses its typical electric log character and becomes
indistinguishable from the overlying units. This problem was also
mentioned by Stanton (1958).

Plate 2 is an isopachous map of the Scallion subinterval in
North Dakota. The Scallion is also shown on the stratigraphic cross-
section on plate 6. The subinterval has been divided into six separate
lithologic facies on the basis of sample and log studies. These facies
will each be discussed separately in the section on facies analysis.
The stratigraphy of the Carrington and Routledge shale facies will be
discussed in more detail in this section.

Carrington shale facies

The type section of the Carrington shale facies is North Dakota
Geological Survey Well No. 403, Pure Carr No. 1, Section 15, Township
146 North, Range 66 West, Foster County, near the town of Carrington,
North Dakota. Core from this section and samples from other wells in
eastern North Dakota reveal the shale to be a distinct lithologic unit
within the Scallion subinterval. Its log character as described earlier
also separates it from the adjoining carbonate units.

As a separate stratigraphic unit the Carrington shale facies
is traceable over an area equal to approximately 10,000 square miles
in eastern North Dakota. Its western limit extends to the basin hinge
line mentioned earlier. Its eastern limit is bounded by the erosional
limit of Mississippian strata. To the north the unit is bounded by
the Scallion subinterval. To the south the unit probably extends into
South Dakota, following the outline of the Williston basin, but the
extent of the Carrington shale facies in South Dakota is not known. Correlation of the Carrington shale into South Dakota is greatly hampered by lack of well control in north central South Dakota. For the above reason South Dakota has been excluded from the major portion of this study.

Plate 6 has four cross sections, all of which show portions of the Carrington shale facies. A-A', the north-south section shows the correlation of the unit from Pierce to Sioux County, North Dakota. The east-west cross sections show the abrupt change from the limestone unit to the Carrington shale. These sections best illustrate the facies relationship of the shale unit. It can be seen that the shale unit is a lateral equivalent of the basinward limestone. Isopachous maps of the Scallion subinterval also illustrate this relationship. Plate 2 shows the total thickness of the Scallion which includes the shale unit. While Plate 3 shows the thickness of the Scallion minus the shale units. It is apparent that the Carrington shale is an integral part of the Scallion, a lithologic facies of it, not a separate stratigraphic unit of equal status.

 Thickness of the Carrington shales varies from 0 to 90 feet. The thickest portion is along the western margin of the shale body. It can be seen on plate 1 that the thickness decreases more rapidly to the west and less rapidly to the east.

Variations in thickness occur in several locations. Most notable are two indentations along the western margin of the shale, located in Burleigh and Benson Counties. The thickness of the shale decreases rapidly in these areas. Reasons for the thinning of the shale in these areas will be discussed later.
Correlation of the unit was relatively easy, with a few notable exceptions. The shale section in well no. 631 in Sioux County displayed a slightly different log pattern as seen on cross section A-A', Plate 6. Lack of well control in that area also makes the correlation difficult. If it is not part of the Carrington shale facies, the possibility exists that the Three Forks Formation extends that far to the south and east. However, the shale interval does occupy the proper place in the section. Also the thickness of the limestone portion of the Scallion subinterval is normal in well no. 631 for wells which penetrate the Carrington shale facies. As noted earlier the presence of the Carrington shale facies decreases the total thickness of the limestone in the Scallion subinterval. For these reasons the author has continued to extend the Carrington shale facies into Sioux County, following Ballard (1963).

The Carrington shale facies has been extended further to the north than it had been previously by Ballard (1963). This was done on the basis of sample and mechanical log characteristics and stratigraphic position. On cross section A-A' wells numbered 435 and 683 were not included in the Carrington shale facies by Ballard. Although 683 has an abundance of sand and rock fragments, which is atypical of a Carrington shale section, it is bounded to the north by a typical shale section (well no. 435) and does display a fairly typical mechanical log character. For these reasons and its stratigraphic position it has been included within the Carrington shale facies.

Routledge shale facies

This shale unit is located in southwestern Manitoba and extends into north-central North Dakota. Two separate bodies of shale exist.
Figure 1. illustrates the locations of these two shale bodies. The Routledge shale can also be considered a facies of the Scallion sub-interval, for the same reasons given for the Carrington shale facies. Cross section A-A' illustrates this relationship as does plates 2 and 3.

Only the south unit of this shale, because of its location near the international border, has been mapped in this study. McCabe (1959) discussed the similar lithology and stratigraphic position of the two shale bodies and considered them to be correlative units. The Routledge shale, like the Carrington, is bounded to the west by the basin hinge line and to the east by the erosional limit of the Mississippian strata. Erosion has probably removed more of the Routledge, evidenced by its rapid thinning eastward. The Routledge (0-100 feet) is slightly thicker than the Carrington shale (0-90 feet). This difference may be the result of the author's picking of the Routledge shale-Bakken Formation contact slightly lower than it had been picked by McCabe (1959). However, it is not unusual for formations to thicken in this area of Rolette County, North Dakota. Ballard (1963) illustrated that the Bakken and Three Forks Formations are slightly thicker in this area.

Carrington and Routledge shale facies

From the preceding discussion it seems reasonable that these two shale units were deposited at the same time and most likely under similar environmental conditions. This is evidenced by their stratigraphic positions and lithologies (to be discussed in more detail in the next section). For this reason they could be considered correlative units and assume the same name, however, their physical separation makes
this difficult. The author will continue to recognize them as distinct units. For the purpose of facies analysis they will be discussed as one unit and so be called the Carrington-Routledge shale facies.

Overlying Units

Normally the Virden subinterval overlies the Scallion subinterval in the area of study. This unit is typically composed of a lower shaley oolitic and/or bioclastic limestone and an upper crinoidal limestone member. It ranges in thickness from 0 to 40 feet. (Stanton, 1958).

Where the Virden subinterval has been removed by pre-Mesozoic erosion, the Scallion is covered by the Triassic Spearfish or the Jurassic Piper Formation. The Piper extends further to the east than the Spearfish. Many irregularities occur on the upper surface of the Mississippian section due to pre-Mesozoic and Mesozoic erosion. This relationship is illustrated on the log of well no. 316 on stratigraphic cross section A-A'. Discussion of these erosional features is beyond the scope of this report.
FACIES ANALYSIS

General Statement

The Scallion subinterval has been subdivided into six facies by the author of this report. This subdivision was based on sample and mechanical log characteristics of the subinterval. It is the intention of the author for these to be lithologic facies without any generic implication in their names, although, environmental interpretations have been made of the facies, and are included in the discussion of each facies.

The facies are best documented through the center of the study area along the cross section B-B' on plate 6. The author has extended the facies throughout the study area by the use of mechanical log characteristics and the sample studies.

The naming of the carbonate units was based primarily on the dominant fabrics present, using Dunham's (1962) classification of carbonate rocks. Clastic units are named by the components of the units. Variations are common within units due to lateral and vertical variations in lithology. The fact that well cuttings were used to describe the facies necessitated that the facies be described in general terms. Minor variations in the samples could not be automatically attributed to lithologic variations within the facies.

A look ahead at this time to figure 14 will familiarize the reader with the location of the facies in cross section.
Carrington-Routledge Shale Facies

Lithology and fauna

The Carrington-Routledge shale facies is typically a dark gray or a red brown shale with green mottles. It contains approximately 60-70% clay, 30-40% silt and trace amounts of sand. The red-brown colored shale could be called a mudstone, due to its massive blocky character at times. However, the presence of faint laminations on the cored surface and its tendency to break horizontally more often than not, suggest that it is slightly fissile and therefore should be referred to as a shale. The darker shales are considerably more fissile. Some fragments of the red-brown shale showed irregular small scale disturbed bedding (Appendix C, well no. 689).

No fauna was noted within the shale itself, with the exception of a brachiopod reported by Sidney Anderson (personal communication). Lack of fauna noted is probably due to small sample size and to conditions within the shale which may not have been conducive to life at the time of deposition or to the preservation of fossils following deposition. The author made no attempt to pick samples for microfossils. The possibility exists that a conodont fauna is present in the shale facies. More core of this interval would be necessary before a study of that nature could be undertaken.

Variations in lithology

A thin limestone bed is located in the upper one third of the shale bed in several wells within the area of the Carrington shale. It is shown in cross section A-A'. This limestone bed may be present throughout the occurrence of the Carrington shale, however, it was not
found in the sample study of wells in the area. Increasing resistivity, decreasing spontaneous potential and lower gamma ray intensity on the mechanical logs is the only evidence for it. Variations noted in the sample study were anomalously large amounts of siltstone, sand and rock fragments found in wells no. 683 and 644. These clastic sediments reflect environments of increased energy over the surrounding areas. It is possible that a channel passed through these portions of the shale facies. However, lack of control prevents extending the data from these wells. Variations in the color of the shale will be discussed in the section on chemical environment.

Mineralogy of the Carrington-Routledge shale facies

Results of X-ray diffraction analysis of core samples of the Carrington shale show that illite is the dominant mineral in the shale. The clay size fraction is essentially 100% illite with trace amounts of quartz present. Samples of the Routledge shale gave similar X-ray diffraction patterns. Figure 6 illustrates the degree of similarity between the two. Glycolation and intense heating of samples did not alter the X-ray tracings or give evidence of other clay minerals.

Samples taken from different depths from the same wells also gave identical X-ray diffraction patterns and it can be concluded that the clay size fraction of both the Carrington and Routledge shales are pure illites. Lateral variations in mineralogy are possible, but based on existing data and uniformity of mechanical logs, lateral variations are not to be expected.

Silt size fractions that were X-rayed contained quartz, feldspar, calcite, dolomite, mica and illite in approximate order of decreasing abundance. X-ray patterns for the two facies did not vary significantly.
Fig. 6. X-ray diffraction tracings of the clay size fraction.  
(A) Routledge shale facies, Manitoba, (B) Carrington shale facies, 
Wells County, North Dakota, (C) and (C') Carrington shale facies, 
Foster County, North Dakota. See Appendix D for X-ray machine conditions.
Fig. 7. X-ray diffraction tracings of the silt size fraction of shale samples from: (A) Routledge shale facies, Manitoba, (B) Carrington shale facies, Wells County, North Dakota, (C) Carrington shale facies, Foster County, North Dakota. See Appendix D for X-ray machine conditions.
Figure 7 illustrates the similarity. The vertical variation was also not significant. Overall compositions remained the same with only slight changes in peak intensities. Sand sized grains found within the shale were composed of quartz, K-feldspar, igneous rock fragments (well nos. 644, 672, 1346), calcite (possibly the result of thin interbedded limestones incorporated within the samples), and mica. Mica flakes were very prominent in some of the well cuttings.

Significance of shale mineralogy

The presence of illite, quartz, feldspar, igneous rock fragments, and abundant mica flakes indicates that the shale was derived from a nearby weathered igneous-metamorphic terrain. Support for this statement is given by:

1. Illite is a common weathering product of an igneous-metamorphic terrain.
2. Quartz, K-feldspar, igneous rock fragments, and mica in the silt and sand sized fraction are to be expected from a weathered igneous-metamorphic terrain.
3. Abundant easily weathered K-feldspar and mica flakes indicates that the source was nearby.

Chemical Environment

Based solely on the color of the shale facies we may speculate about the chemical environment during deposition and diagenesis of the shale facies. It is known that towards the base of the unit the shale becomes darker in color and also harder. This is especially evident in Carrington shale samples from well no. 660. McCabe (1959) makes reference to the increasing hardness and consolidation of the Routledge shale towards its base, and mentions the possibility of some of the
shale being of a reddish color. The author of this report noted that one core sample of the Routledge shale (M-19, Sapphire West Blossom #1) was of a red brown color. This sample was taken from near the top of the Routledge section. Figure 8 includes a diagrammatic east-west cross section thru the Carrington shale facies showing the color relationship. There are two possible causes for this relationship:

1. The darker shale was deposited under reducing conditions and the red-brown shale was deposited under oxidizing conditions at a later time.

2. Both shales were deposited under reducing conditions and post depositional oxidation of the shale nearer the surface caused the distinction between the two, aeration of the interstitial fluids allowing the oxidation to proceed.

The presence of pyrite in samples of the red-brown shale may indicate reducing conditions during the deposition of that shale type. For this reason the author favors the second explanation.

Chemical analyses of the Carrington shale facies were obtained in the hopes of determining the cause of the increased radioactivity of the shale. Appendix E contains this information in table form. Figure 9 is a graphical comparison of some of the results.

Potassium appears to be the cause of the increased radioactivity of the shale. The percentage of potassium in an average shale is approximately 3.2 (Krauskopf, 1967), whereas the Carrington shale facies has between 5 and 6% potassium. Both thorium and uranium are at normal levels according to Krauskopf. The reason for the relatively large amount of potassium is that the composition of the shale is dominantly illite which has an abundance of interlayer potassium.
Fig. 8. Lithofacies map and cross section illustrating the Carrington shale, lime mudstone, and interbedded shale-limestone facies.
Fig. 9. Graphical comparison of chemical analyses of shale samples taken from two cores of the Carrington shale facies. See Appendix E for complete analyses.
The increase of uranium in the shale samples from well no. 207 reflects the unoxidized state of that shale. The oxidized shale samples (well no. 403) have less uranium, possibly due to the mobilization of the uranium in an oxidized state and its removal from the shale. This will be discussed in more detail in the section on Economic Potential.

The significance of the other chemical analyses is not known to the author.

Slaking of the Carrington Shale facies

Ballard (1963) referred to the Carrington shale facies as bentonitic. However, X-ray data has shown that the shale is devoid of bentonite and instead composed of illite. The discrepancy was probably caused by Ballard's observance of the shales reaction with water. When a fragment of the red brown Carrington shale is placed in water it breaks apart giving off small gas bubbles. This reaction could easily be mistaken for a swelling reaction. The shale does not become sticky and hold or absorb water as montmorillonites (bentonite) do. The Carrington shale falls apart in the bottom of the beaker. This process has been referred to as slaking, as in a slaking coal. This process was noted in the red-brown shales and in a few cases in some of the darker brown shales, although these shales did not slake as readily.

Cause of the slaking

The slaking of the shale appears to be related to the chemical environment of the shale. This is evidenced by the fact that the shales which slake most readily are those which have been oxidized. It is also evident that the presence of water initiates the slaking action. Knowing
the mode of interaction between the shale and the water would undoubtedly reveal much of the cause of the slaking. What can be said, concerning this interaction, is that the water is not moving into the interlayer spaces of the clay particles. This conclusion is based on the invariance of the interlayer spacing during glycol saturation and heating. Instead, the water is apparently interacting with whole particles of the shale. Clay particles are known to be bound together by a delicate balance of attractive and repulsive forces (Olphen, 1963). It appears that the water is strongly attracted to the clay particle surfaces, readily overcoming the interparticle attractive forces.

Variations in thickness

As noted earlier in the section on stratigraphy of the Carrington shale facies, there are two areas in which the shale facies is abnormally thin. These areas occur in Benson and Emmons Counties and can be seen on the isopachous map of the Carrington and Routledge shale facies (plate 1). They are also visible on the isopachous map of the Scallion subinterval (plate 2).

It is the interpretation of the author that these thin areas formed as the result of channels (submarine or subaerial) which formed across the Carrington shale facies during and/or after its deposition. This interpretation is based on:

1. The narrow and elongate geometry of the thin areas.
2. The presence of sand in wells no. 663 and 742 directly basinward of the proposed channels.

Accumulation of sand in the areas of these proposed channels is also possible. However, it is not the intention of the author to depict
these areas as elongate bodies of sand. It is conceivable that the winnowing of the shale from these areas resulted in the formation of these thin areas. It is not necessary for the deposition of sand to have occurred. Well control in these areas is not sufficient for further discussion of this problem.

**Origin of the shale facies**

McCabe (1959) discussed two theories on the accumulation of the Routledge shale. The first, formation of a barrier (reef or shoal) which caused a local restriction of circulation and deposition of the shale. The second, the Routledge is a continuation of Bakken deposition. The author of this report has no objection to the first explanation which will be discussed in greater detail in the following section. The second explanation given by McCabe necessitated the solution of underlying salt beds. Although this theory could explain the occurrence of the Routledge shale it cannot explain the occurrence of the stratigraphically equivalent Carrington shale facies. Salt beds are lacking in the area of the Carrington shale.

Ballard (1963) proposed that the Carrington shale facies formed behind the Burleigh High. The location of which is illustrated on figure 2 and by the area within the 200 foot contours of the Scallion subinterval in Burleigh and Sheridan Counties (plate 2). By making a comparison of the location of this high with the location of the Carrington shale facies (plate 1) it can be seen that this high is located 10 to 20 miles basinward of the shale facies. It is the interpretation of the author that this high is located too far basinward to have affected the deposition of the shale itself. The depositional
slope would probably have rendered ineffective any structural relief. Also this structural high does not extend far enough to the north to account for the northern portion of the Carrington shale facies or for the stratigraphically equivalent Routledge shale facies.

It is the intention of the author to, in this and the following sections, develop a theory that will be applicable to both the Carrington and Routledge shale facies.

**Environmental analysis**

Factors which should be considered when interpreting the environment of deposition of the shale facies are:

1. Location of the shale on the basin margin or shelf.
2. Separation of the shale from typical basinal shale deposits, i.e., the older Bakken Formation, which was deposited in the central basin.
3. Thickness and areal extent of the shale.
4. Extremely abrupt lateral facies change into the limestone unit of the Scallion subinterval basinward of the shale. This has been documented as occurring within three miles (McCabe, 1959).
5. Color variations within the shale units.
6. The presence of abundant illite associated with quartz, mica, K-feldspar and rock fragments.

From these statements the below conclusions can be made:

1. The source of the shale was likely a weathered igneous-metamorphic terrane, based on the composition of the shale and associated clasts, as discussed earlier.
2. The shale was deposited in an area of restricted circulation, based on the need for reducing conditions to account for the darker shales.

3. The shale was separated from the central basin by some type of barrier.

Conclusion

It is the author's interpretation that the Carrington-Routledge shale facies were deposited in restricted lagoonal environments. The areas were protected from the open sea by barriers located along the basin hinge line. The sediment being derived from the weathered land surface to the east.

Lime Mudstone Facies

Location

This facies is located westward and directly basinward of the previously discussed shale facies. Its precise location is difficult to map due to the lack of adequate control in the area. Plate 4 is an isopachous map which approximates the location of the facies. Thickness may be exaggerated in places as this map was constructed from mechanical log data only. On the stratigraphic cross sections this facies is represented by the crinoidal wackestone and micrite lithologic pattern. It is located directly west of the Carrington shale facies and below a thin silty shale bed. This facies onlaps the Carrington shale facies, as shown in figure 8.
Lithology and fauna

This facies is typically composed of crinoidal wackestones and micrites along with occasional packstones. Bryozoans and brachiopods are also present. This description is based on sample studies of the author. McCabe (1959) mentions "12 feet of very coarsely fossiliferous, porous limestone with a reefoid appearance," that was located five feet from the base of the Scallion subinterval, which directly overlies 10-20 feet of Routledge shale (well no. M-7). The fossils noted in this rock were bryozoans, brachiopods, and spines from brachiopods and/or echinoids. He described these fossils as appearing to be in growth position, including branching bryozoans. The limestone above and below this bed were described as fine grained, tight and with few to abundant scattered crinoid fragments. It is probable that this section is a part of the mudstone facies, as it is located above the Routledge along its northwestern margin.

Environmental analysis

Factors to consider in the environmental interpretation of this facies are:

1. This facies is the basinward lateral equivalent of the shale facies.
2. It is located on the basin shelf margin or hinge line.
3. It has an abundance of micrite.
4. It has a sparse fauna, dominated by crinoids, with the exception of the "reef-like" bed described by McCabe (1959).

From these knowns the conclusions below can be made.

1. This unit occupies the position of the barrier which
allowed the formation of the Carrington-Routledge shale facies.

2. The fabric and fauna of the facies is similar to that of the bioherm facies described by Smith (1972).

Smith's work in the Lodgepole Formation of central Montana revealed the presence of Waulsortian mounds. These mounds are composed of an inner core of micrite and flanking beds of crinoid and bryozoan wackestones (the lime mudstone facies is also composed of micrite and crinoid wackestones, with some evidence of bryozoan). These mounds are relatively common in the lower Mississippian (Wilson, 1975). Figure 10 shows a typical Waulsortian mound as described by Wilson. Examples of Waulsortian mounds are located in the Lodgepole Formation of Montana (Smith, 1972; Stone, 1972), Alamogordo Formation of New Mexico (Laudon and Bowsher, 1941). They are also found in England, France, Belgium (the name Waulsortian being taken from a village in the Dinant basin, south of Namur, Belgium), and Ireland (Wilson, 1975).

These mounds are believed by some (Wilson, 1975) to have formed below wave base by the entrapment of lime mud by the baffling action of the crinoids and bryozoans. Figure 10 shows the stages involved in the formation of a Waulsortian mound.

Characteristics which are common to most Waulsortian bioherm facies of Europe were listed by Wilson (1975). Some of the most important are:

1. They formed in clear open water near the shelf margin.

2. Basinal facies consisted of shale, sandstone and calcareous mudstone.
Fig. 10. Possible mode of formation of Waulsortian bioherms, after Wilson (1975).
3. Shelf facies are highly varied, including lagoonal carbonates, cross-beded grainstones, and deltaic clastics.

Stone (1972) described the distribution of these mounds in the Bridger Range of Montana. The mounds were located in an elongate trend with a surrounding facies composed of crinoid wacke-packstones. The individual mounds were dome shaped and up to 60 feet in height and up to 500 feet in length. The surrounding facies are continuous with original dips of up to 25° where it overlaps the bioherm cores. Stone states that up to 60 feet of depositional relief was present in places during the formation of these bioherms. Smith (1972) stated that these flank facies were deposited after the bioherm growth. He interpreted the bioherms to be located on the open shelf or slope in deeper water than later units within the Lodgepole Formation. Figure 11 illustrates the location of these bioherms in relation to early Mississippian basin tectonics of the area.

Conclusion

The lime mudstone facies was probably deposited as a Waulsortian bioherm complex, as described by Wilson (1975). Evidence for this conclusion is:

1. Similarity of fabric and fauna to that reported in other Waulsortian bioherms.

2. Location on a shelf margin away from the shoreline, as other bioherms have been reported to have formed.

3. Presence of mounds in the Lower Mississippian of central Montana on the western margin of the Williston basin, places these deposits in the proper time-stratigraphic framework.
Fig. 11. Relationship between known and probable Waulsortian bioherms and the basin-shelf configuration at the time of the bioherms formation (early Mississippian). After, Craig (1972), Macauley et al (1964), Stone (1972) and Carlson and Anderson (1970).
Fig. 12. Possible mode of formation of the lime mudstone facies and its lateral facies. (A) and (B) show accumulation of the mudstone facies as sea level rises. (C) illustrates the resulting facies relationships.
Figure 12 illustrates the possible mode of formation of the lime mudstone facies as a Waulsortian bioherm complex.

**Interbedded Shale-Limestone Facies**

**Location**

This facies is west (basinward) of the lime mudstone facies. It has an elongate north-south trend. The precise limits of this facies are not known. It can be seen on stratigraphic cross sections B-B' and C-C' plate 6, in wells numbered 693 and 61 respectively. It is a rock stratigraphic equivalent to the lime mudstone and Carrington shale facies. Figure 8 shows its areal distribution and its location on an east-west diagrammatic cross section. The facies ranges in thickness from 0-80 feet. Along its eastern margin it onlaps the lime mudstone facies.

**Lithology and fauna**

Well no. 693 (cross section B-B') has 75 feet of interbedded shale and crinoidal lime wackestones and packstones. Since this interval has not been cored it is difficult to describe the lithology in detail from the well cuttings alone. The above interpretation was based on the irregular nature of the spontaneous potential log, which suggests a varied lithology, and the presence of shale and carbonate in the samples, which leads to the conclusion of an interbedded nature.

**Environmental analysis**

The interbedded nature of this facies necessitates an environment in which some factor was cyclic. Building upon the conclusions
from the previous sections, this facies was probably deposited on the basin slope during and/or after the lime mudstone facies was deposited on the shelf margin. Periodic influxes of fine clastics washing off the shelf were interspersed with periods of reduced influx which allowed carbonate deposition to occur.

**Sand-silt-shale Facies**

**Location**

This facies is located directly above the mudstone and interbedded shale limestone facies, in approximately the middle of the Scallion subinterval. It is represented on the mechanical logs by an increase in spontaneous potential and gamma ray intensity. It ranges in thickness from 0-50 feet. Figure 13 shows the approximate areal distribution of this facies.

**Lithology and fauna**

This facies is composed of fine to medium well sorted sand, silt and gray shale, the grain size increasing basinward. Well no. 693 (cross section B-B') has an abundance of sand in this interval, while well no. 207 is dominantly shale (see appendix C for sample descriptions). No fauna was noted from this interval in the sample descriptions. No core was available from this interval.

**Environmental analysis**

The coarse clastic nature of parts of this facies are an aid in the interpretation of this facies. The medium sand that is moderately well rounded and sorted, such as the sand in well no. 693, can have but a few origins when the surrounding deposits are considered. The
Fig. 13. Lithofacies map and cross section illustrating the sand-silt-shale facies.
surrounding limestone units are definitely marine in origin with a typical marine fauna (crinoids, brachiopods, bryozoans). Within the marine environment the possible processes that could result in the formation of this deposit are:

1. Deposition in a shallow near shore environment. This would necessitate a fall in sea level following the deposition of the Carrington shale facies and a subsequent rise following the deposition of the sand beds as near shore sediments. A continued rise in sea level would then be necessary for the deposition of the shale beds to the east. This regression of the shoreline could explain the oxidation of the Carrington shale facies. Assuming that the sands were deposited as beach sands it is possible that the lower sand in well no. 693 was the regressive sand while the upper sand represents the transgressive phase. Following the period of sand deposition the sea level continued to rise allowing the deposition of the shales and siltstones.

2. Deposition of the shale and the silt on the shelf margin, possibly during the final phases of the deposition of the Carrington shale facies. At this same time and possibly during much of the time of the shale facies deposition, the sand was being deposited basinward of the shelf margin. Offshore submarine currents may have transported the sand from its point of entry into the basin and deposited it into elongate bodies which parallel the shoreline.
Support for the above hypotheses are scant. The partial oxidation of the Carrington shale facies seems to indicate that it was exposed to the surface at some time in the past. This conclusion supports the first hypothesis. Indirect evidence for the second hypothesis is related to the problem of source of the sand. Possible sources are:

1. The open area between the Routledge shale facies and the Carrington shale facies in Rolette County (see plate 1). The absence of the shale in this area may have been related to increased currents through this area.

2. The possible occurrence of channels on the surface of the Carrington shale facies in Benson and Emmons Counties (discussed in the section on Variations in thickness, Carrington shale facies).

These source areas, though not supported by a great deal of evidence, are possible feeder channels for the transport of the sand from the land surface, to the east, across the shelf platform and into the basin. This second hypothesis has one very favorable aspect in that, it does not necessitate a major regression and transgression of the shoreline, and simplifies the overall depositional model. The author prefers the latter hypothesis.

**Crinoid Packstone-Grainstone Facies**

**Location**

This facies directly overlies the Carrington shale facies and is the lateral equivalent of the wacke-packstone facies. It is bounded to the east by the erosional limit of the Mississippian
strata. Figure 14 shows the location of this facies in map view and cross section. It ranges in thickness from 0-160 feet.

Lithology and fauna

A large amount of loose rounded crinoid grains were noted in the samples from this interval. Based on this observation it is the author's interpretation that crinoidal grainstones compose a large portion of this rock. Actual rock chips in the samples were mostly packstones with abundant white chalky micrite and sand and shale. No core was available from this interval.

Environmental analysis

The presence of abundant crinoidal grainstones from this facies indicates that the facies was deposited under relatively high energy conditions. This along with the landward location of this facies on the shelf itself, indicates that the limestones were deposited as shallow subtidal shoal-like crinoid sands. Formed above wave base these sediments would have been continually reworked and redeposited by wave action. In outcrop (if one existed) it is likely that these sediments would be seen to be cross bedded.

Wacke-packstone Facies

Location

This facies is shown on figure 14. It is located above the sand-silt-shale facies and extends to the upper surface of the Scallion subinterval. It is approximately 0-90 feet in thickness. It is the lateral equivalent of the crinoid packstone grainstone facies which was discussed in the last section. The exact relationship between
Fig. 14. Lithofacies map and cross section illustrating the wacke-packstone and crinoid packstone-grainstone facies.
these two facies is difficult to determine due to lack of adequate well control. However, it is likely that the wacke-packstone facies overlaps the crinoid packstone-grainstone facies. This assumption is based on the relationships of the underlying facies.

**Lithology and fauna**

Crinoidal lime wackestones, packstones and micrites along with scattered brachiopods make up this facies. Samples from this interval also showed moderate to abundant amounts of shale and siltstone. However, the mechanical log character does not indicate the presence of these materials. The log normally has a low spontaneous potential and low gamma ray intensity. The presence of shale and siltstone should normally cause an increase in the intensity of these two log patterns. It is likely that most of the clastic material in the samples is the result of caving from above units. As with the facies discussed previously, no core was available from this interval. The above description was based solely on sample studies and mechanical log character.

**Environmental analysis**

Based on location of this facies with relation to the probable shoreline and the interpretation of the environment of the landward facies it is reasonable to assume that this carbonate was deposited on the shelf margin and basin slope. The assumption that the shoreline was as much as 100 kilometers eastward is based on the presence of the crinoidal packstone-grainstone facies which was deposited on a shallow shelf type environment landward of the wacke-packstone facies. The apparent lack of clastic sediments also indicates that the shoreline
was somewhat distant. This relatively fine grained carbonate was probably deposited below normal wave base, possibly being affected by storms. Evidence for this, is the dominance of mudsupported limestones, with the exception of the occasional packstones.
PALEOGEOGRAPHY

From the conclusions made about the environments of deposition of the facies in the previous section, the following statements of the paleogeography at the time of the deposition of the Scallion sub-interval can be made.

Prior to the start of Scallion deposition the Bakken Formation was being deposited in the central basin area. During this time the Devonian Birdbear and Duperow Formations, as well as the Stony Mountain, Red River and Winnipeg Formations, were exposed to the east. To the east of these sedimentary rocks, Precambrian igneous-metamorphic rocks were exposed. Figure 15 is a paleogeologic map of the eastern half of North Dakota before the deposition of the Scallion subinterval. The weathering of this exposed surface, provided the sediment necessary for the formation of the Bakken shales. Figure 16 is a paleogeographic map depicting the possible geography at this time. The location of streams on this map is arbitrary. The Basal Mississippian structure contour map (figure 2) shows that some contour lines are deflected eastward. This may be the result of channels on the pre-Mississippian erosional surface. The lack of sufficient well control in the area prevents further analysis.

Following deposition of the Bakken Formation sea level rose throughout the Williston basin (Carlson and Anderson, 1970). The shoreline extended farther eastward than the present erosional limit.
Fig. 15. Paleogeologic map of eastern North Dakota during the deposition of the Bakken Formation and prior to the start of Madison deposition.
Fig. 16. Diagrammatic paleogeographic map of the eastern margin of the Williston basin during deposition of the Bakken Formation.
of the Scallion subinterval. During this time the mudstone facies was deposited as a Waulsortian bioherm complex.

Figure 17 illustrates the possible geography at the time of the deposition of the Carrington shale facies. The location of streams is purely hypothetical. The topography of the land surface was most likely subdued as the result of the numerous periods of erosion that had taken place in earlier geologic time. The map also shows the location of the Waulsortian bioherms. These bioherms may have formed previous to the deposition of the majority of the shale facies. The breaks in the continuity of the bioherms correspond to areas of thinning of the Carrington shale facies. Increased currents in these areas, possibly associated with landward fluvial systems, may have prevented the formation of the bioherms and resulted in thinning of the shale facies (most notably in Benson and Emmons Counties).

These possible channels may have been related to the deposition of the sand beds in the sand-silt-shale facies as discussed in the section on this facies. Sand carried into the basin may have been deposited along the basin slope parallel to the shoreline. The remaining portions of this facies may have been deposited as a late stage of the Carrington shale facies deposition, if the shale extended over the top of the mudstone facies.

A regression of the shoreline at this time would be an aid in explaining the partial oxidation of the Carrington shale facies. The channels on the Carrington shale could also have occurred at this time and the deposition of the sand-silt-shale facies occurred as outlined in the earlier section on this facies. However, the author of this
Fig. 17. Diagrammatic paleogeographic map of the eastern margin of the Williston basin during the deposition of the Carrington shale facies.
report does not feel that a regression of the sea is essential to the explanation of these deposits.

Following the period of clastic deposition of the Carrington shale facies and the sand-silt-shale facies, a return to carbonate deposition occurred. This most likely happened as the result of decreased erosion and transport of clastics into the shelf area or the more efficient removal of these clastic by currents.

The two uppermost facies of the Scallion subinterval were then deposited on the shelf margin and basin slope. The packstone-grainstone facies being deposited on shallow water near the shoreline and the wacke-packstone facies being deposited basinward on the deeper shelf and basin slope. Figure 18 illustrates the possible paleogeography at the time of deposition of these two facies. The shoreline is highly speculative and possibly farther to the east. Pre-Mesozoic erosion has removed the eastern most sediments of the Scallion subinterval. The presence of 40 feet of Scallion sediments in well no. 36 in Cavalier County (see plate 5, for precise location) supports the extending of the shoreline eastward.
Fig. 18. Diagrammatic paleogeographic map of the eastern margin of the Williston basin during the time of the deposition of the wacke-packstone and crinoid packstone-grainstone facies.
ECONOMIC POTENTIAL

Oil

The number of oil tests drilled in the North Dakota portion of the study area which penetrate the Scallion subinterval are 194 to date. This portion of the study area covers approximately 31,500 square miles. This works out to a density of 1 well for every 162 square miles. This portion of the Williston basin can therefore be considered to be relatively untested.

Scallion production in Manitoba

The Scallion subinterval produces oil in the North Virden Scallion field and from other fields in the area. Oil production in Manitoba is associated with the truncation of porous reservoir rocks by the Mississippian erosional surface. The regional dip of the formations in this portion of the Williston basin is to the southwest. Therefore older strata are more productive to the northeast. According to McCabe (1963) this is not entirely due to the truncation of progressively older strata, but also is a function of the drop in the stratigraphic depth of dolomitization along the surface of the Mississippian strata. This dolomitized zone provides the seal necessary for the entrapment of the updip migrating oil. Variations in the permeability of reservoir rocks and dolomitization cause local variations in oil production. Berg (1956) reported that extensive leaching (pre-Jurassic) of the Scallion has resulted in porosities
of up to 40% and permeabilities of up to 500 millidarcies in the North Virden Scallion Field.

Relationship of the Routledge Shale to Manitoba oil production

According to McCabe (1963) the Routledge shale is not associated with any oil production in the province. He does mention the possibility of the shale being a source rock. This will be discussed in a later section along with the Carrington shale. Since at the present time no production of oil from the pre-Mississippian strata in this area has been reported it is difficult to discuss the possibility of the Routledge shale being a seal for oil traps below it. Also complicating this discussion is the fact that at present the Routledge appears to be underlain by the Bakken Formation throughout its area of occurrence. The possibility does exist that the middle siltstone bed of the Bakken Formation could serve as a reservoir rock as it does produce oil in both North Dakota and Saskatchewan. However, the siltstone bed would have to extend beyond the upper shale of the Bakken in order for the Routledge to seal it.

Facies changes along the western margin of the Routledge shale have been recognized by McCabe (1963) as possible areas in which accumulation of oil could possibly take place. He notes that, in one case, by moving down dip a distance of 2 miles, 70 feet of shale section is lost to carbonate. Normally this carbonate is rather tight but in one locality McCabe noted that rocks of a porous "reefy" nature were found near the base of the Scallion subinterval. This is unusual since the lower portion of the Scallion is normally finer grained and tight. The possibility exists that this material of a reedy nature is only the
edge of a much larger carbonate buildup. Should this be the case it could make an excellent stratigraphic trap for the accumulation of oil.

The Scallion Subinterval in North Dakota and possible oil accumulations

As stated earlier the Scallion subinterval has not been adequately tested for oil and gas in North Dakota. The lack of obvious structural features has probably been the greatest hindrance to exploration along the eastern margin of the Williston basin. Ballard (1963) mapped several structural features in the area (figure 2). However, due to the very low relief of these features it is likely that little or no closure is possible because of the basinward dip of the stratigraphic units. Any traps that are present in this area are probably of the same nature as those in southwestern Manitoba. All of the elements necessary for these traps exist in North Dakota. They are:

1. Truncation of porous units by the Mississippian erosional surface. The Scallion in the eastern portion of the study area is erosionally truncated (see plate 2 for area of Scallion subcrop).

2. The presence of what should be an effective cap rock above the subcropping Scallion. The Mesozoic age rocks in this area are typically shaly and impermeable.

3. The presence of known oil production in downdip from this area in the center of the basin.

4. Lateral closure, though not documented, is likely to be present just as it is present in Manitoba.

Traps other than those of the type found in Manitoba are possible in North Dakota. Facies changes within the Scallion subinterval have been
documented in this study. The presence of these rapid changes in lithology could result in the formation of a suitable stratigraphic trap.

The lime mudstone facies and possible stratigraphic traps

This facies appears to be overlain by a thin shale bed (see well no. 207, plate 6). It is also bounded up dip by the Carrington shale facies. This combination of relationships could result in the formation of a stratigraphic trap. If the lime mudstone facies has the porosity and permeability necessary it could be a reservoir rock. At present there is no evidence of this with the exception of "reefy" limestone mentioned by McCabe (1963). If the lime mudstone was exposed to the surface or near surface soon after its formation, as discussed earlier, the possibility exists that the upper portions of the facies were altered by groundwater solution. This could have resulted in the formation of porosity and permeability needed for this to become a reservoir rock.

Choquette and Pray (1970) term this stage in porosity development as the Eogenetic stage, this term applying to the time interval after final deposition and before burial of the sediments. Processes noted by Choquette and Pray are burrowing, root penetration, sediment shrinkage, boring, solution of selected minerals such as aragonite, and decomposition of organic matter. They also note that porosity reduction in this environment is also very prevalent. Solution in later times at deeper depths is not considered to be as extensive by these authors.
The Carrington shale facies as a reservoir seal

Anderson (1963) discusses the oil potential of the Devonian Birdbear and Duperow Formations. These formations were both truncated by erosion during the Early Mississippian, prior to the deposition of the Carrington shale which forms a cap over the two formations. Concerning the migration of the oil, Anderson notes that this locality is updip from the Nesson anticline and it is not unreasonable to assume that oil could migrate into this area.

The Devonian rocks would be adequate reservoir rocks. Core from well no. 403 of the Duperow Formation, immediately below the Carrington shale, exhibited excellent porosity. Vugs up to 2 inches in diameter were present. It is likely that this type of porosity is present in other areas also, assuming that the rocks underwent similar diagenetic and erosional processes during the period of time when these rocks were exposed to the surface. Figure 16 illustrates the paleogeography at that time. It is also very likely that some type of erosional relief developed during this time. Topographic highs on this surface would make excellent reservoirs.

To date the Devonian age rocks in eastern North Dakota have been tested even less than the Mississippian age strata. Most of the wells drilled in the area bottom in the Mississippian.

Source rocks

The most obvious source for petroleum in the area of study would be the Bakken Formation. Dow (1974) illustrated that the Bakken Formation probably provided the oil that migrated up dip to the northeast and resulted in the pinchout accumulations in north central North
Fig. 19. Possible petroleum reservoirs in the area of study.
Dakota and southwestern Manitoba. This was done by a comparison of chemical analysis of the Bakken shale with chemical analysis of oil produced from these areas. Dow was of the opinion that this oil would not have accumulated in eastern North Dakota due to the reduced thickness and the shallow depth of the Bakken which in his opinion would have prevented the formation of oil from the Bakken Formation. A greater depth being required for the oil forming reactions to proceed.

However, other shale in the Paleozoic section could have contributed to oil formation in this area. The Carrington and Routledge shales are unlikely source rocks due to their having been oxidized. Possible sources are in the Winnipeg and Deadwood Formations. Shales in these formations are stratigraphically lower than the potential reservoir rocks and are also at a greater depth, thus allowing the oil forming processes to proceed.

Figure 19 illustrates the possible petroleum reservoirs that could be present in the interval of this study.

**Uranium**

The Carrington and Routledge shale facies are both highly radioactive. This can be seen on plate 6. The gamma ray curves often go off scale for the shale sections. It was hoped that the source of this radioactivity was uranium within the shale. If this had been the case, there existed the possibility of concentration of uranium in other portions of the shale body. However, analyses of the shale (see figure 9) gave no indication that uranium was the cause of the radioactivity. Thorium and potassium are the probable sources of the radioactivity.
However, the possibility does exist that concentrations of uranium are present within portions of the shale itself or possibly immediately beneath it. Conditions necessary for these accumulations are:

1. Source area; The Precambrian shield to the east would be a likely source for uranium bearing sediments. Uranium is presently being produced from portions of the shield in the Blind River area, of Ontario, Canada (Lamey, 1966).

2. Method of transport; The shield is topographically higher than the Carrington shale facies. Normal erosional and fluvial processes which resulted in the transportation of the clay, silt and sand off the shield would also transport any uranium bearing minerals that were exposed at the surface.

3. Concentration of the uranium; This is probably the most difficult problem to resolve and will be discussed in greater detail.

Possible modes of uranium concentration

Assuming that more than trace amounts of uranium existed in the Carrington shale facies at one time, concentration of this uranium could have resulted in significant deposits. In order to concentrate the uranium it must become mobile. The best way for this to happen would be for the uranium to be in solution and carried by groundwater. The condition which would allow this to happen is the oxidation of the sediments. According to Park and MacDiarmid (1975) uranium is relatively soluble under oxidizing conditions. The presence of oxidizing conditions during and/or after the deposition of the Carrington shale facies has already been established in this report.
Following the oxidation of the uranium and subsequent transport by groundwater, the uranium may have been concentrated in underlying units. This could occur if the solutions encountered reducing conditions (Fischer, 1974). This is the accepted mode of formation of many sedimentary uranium deposits in the western United States (Finch, 1967). Gruner (1956) proposed that uranium leached directly from Precambrian plutonic rocks could be transported into drainage basins and deposited under locally reducing conditions. This is a possibility in the case of the Carrington shale due to its proximity to the Precambrian shield. Reducing conditions probably existed during the deposition of the shale followed by oxidizing conditions that may have further concentrated the uranium as previously stated.

The host rock should preferably be a sandstone. The possibility of sandstone deposits directly below the Carrington shale has already been alluded to. If stream channels did cross over the early Mississippian-Devonian erosional surface stream channel deposits are likely to have formed. Evidence for the presence of sand does exist in the samples studied. In a few instances minor to moderate amounts of sand were noted in the samples directly below the Carrington shale facies. Wells in which sand grains were noted are, 24, 23, 89, 660 and 672.

Uranium could also be concentrated within the Carrington shale facies. Sand and coarser clastics were also noted in several wells in the Carrington shale facies. These are 287, 590, 644, 645, 654, 683, 689 and 1346. Figure 20 illustrates the possible method of accumulation of uranium in the study area. Figure 21 shows the
Stage 1. Initial transport of Uranium

Oxidized uranium encounters reducing conditions fixing uranium in a dispersed state

Fluvial transport of uranium in oxidized state

Paleozoic sedimentary rocks

Stage 2. Concentration of Uranium

Mobilization of uranium caused by oxidizing meteoric or groundwaters

Carrington shale facies

Unoxidized portion of shale facies

Concentration of uranium under reducing conditions in underlying rocks

Precambrian igneous-metamorphic shield rocks

Fig. 20. Possible method of transportation and accumulation of uranium in the study area.
Fig. 21. Locations of wells from which sand and coarser clastics were noted from the samples from the Carrington shale facies or below it.
relationship between the wells noted above and the Carrington shale facies and the Pre-Mississippian structure contour surface.
CONCLUSIONS

As a result of this study the following conclusions can be made concerning the stratigraphy and depositional setting of the units studied.

1. The Scallion subinterval can be subdivided into six lithologic facies, each of which is described in the text.

2. The Carrington and Routledge shale facies, based on stratigraphic and mineralogic evidence, can be considered equivalent units.

3. The source of these shale units was the weathered Precambrian igneous-metamorphic surface to the east.

4. These shale units were deposited in protected lagoonal environments under reducing conditions.

5. The lagoonal environments were protected from the open sea by a barrier.

6. This barrier was composed of lime mudstone and can be considered a Waulsortian bioherm facies.

7. The bioherms formed on the Williston basin's shelf margin in early Mississippian time during a period of rising sea level. Much in the same manner as Waulsortian bioherms formed on the Alberta and Wyoming shelf margins during this same time period.

8. During and after deposition of the Carrington shale facies a clastic facies (sand-silt-shale facies) was deposited
above the bioherm facies (lime mudstone facies) and its associated facies (interbedded shale and limestone facies).

9. These clastics may have been transported into the area of deposition by submarine currents which formed channels across the Carrington shale facies and between the Carrington and Routledge shale facies.

10. It is also possible, though not as probable, that following the deposition of the Carrington shale facies sea level dropped resulting in the deposition of the sand-silt-shale facies. Partial oxidation of the Carrington shale facies may have occurred at this time.

11. A return to normal carbonate deposition occurred following the deposition of the sand-silt-shale facies. This was possible due to a reduced influx of clastics into the area of deposition, resulting from either a reduction in erosion of the neighboring landmass or changing current patterns which removed the clastics from the shelf area. At this time the wacke-packstone and crinoid packstone-grainstone facies were deposited on the basin slope and shelf respectively.

Some miscellaneous conclusions are:

1. The Carrington and Routledge shale facies are composed dominantly of the clay mineral illite. No other clay minerals were noted.

2. The cause of the slaking of the Carrington shale facies is related to water upsetting the interparticle attractive forces of the clay particles.
3. Abrupt facies changes, basinward dipping beds and unconformities all suggest potential petroleum traps.

4. The conditions necessary for the accumulation of uranium may have been present in the past.
APPENDICES
APPENDIX A - List of Wells Used in This Study

Explanation

Well numbers preceded by a capital M are numbers assigned by the author to wells from Manitoba. Well numbers without a prefix letter are numbers assigned by the North Dakota Geological Survey. Locations of North Dakota wells are based on the standard Land Office Grid System. Manitoba well numbers are based on a similar system. Township and range designation is the same, but sections are numbered 1-36 starting in the southeast corner of the township. Sections are subdivided into 16 legal subdivisions beginning in the southeast corner of the section.

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<tr>
<th>Well No.</th>
<th>Legal Description and Location</th>
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<td>Cities Service East Max Lake No. 1, Legal subdivision 14, S29, T1N, R20W, Manitoba.</td>
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<td>Western Orthez, Legal subdivision 13, S36, T4N, R19W, Manitoba.</td>
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APPENDIX B - Formation Tops

Explanation

Numbers are those of the North Dakota Geological Survey. Tops are given as feet below Kelly Bushing (K.B., approximately 10 feet above ground level). Letters in parentheses refer to specific shale facies (C) Carrington, (R) Routledge or underlying Formations (Bk) Bakken, (Tf) Three Forks, (Bd) Birdbear, and (Dp) Duperow. Dashes indicate that the particular unit was absent. In the case of the absence of the Scallion subinterval the K.B. and underlying formation was not recorded by the author.

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APPENDIX C - Sample Descriptions

Explanation

Numbers are those of the North Dakota Geological Survey. Measurement is in feet below K.B. Samples have not been adjusted to mechanical log picks, as have the Formation, subinterval and facies tops. These tops are shown in parentheses following the units name.

Well No. 16

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<td>3730-3760</td>
<td>SCALLION SUBINTERVAL (3723) Fossiliferous grainstones, lt. green gray shales, lt. green and red-brown siltstones.</td>
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<td>3760-3770</td>
<td>Lt. gray-green gray shale with crinoidal grainstones.</td>
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<td>Grainstones as above, some wackestones, abundant red siltstone, pyrite.</td>
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<td>Lt. green gray shale with imbedded fine clear sand and silt,</td>
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<td>Lt. gray brown micro-sparite.</td>
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<td>Crinoidal grainstones with shale as above.</td>
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<td>Green gray shale, slakes, with carbonate and quartz sand inclusions.</td>
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<td>3840-3900</td>
<td>Grainstones as above, plus wackestones and packstones, crinoids dominant, some brachiopods, shale as above.</td>
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<td>Limestone as above, shale increasing.</td>
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<td>Limestone as above plus coarse crystalline dolomite, anhydrite, yellow and purple siltstone.</td>
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<td>BIRDBEAR FORMATION (3935) Sparry dolomite, dk. gray shale, red siltstones.</td>
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<td>SCALLION SUBINTERVAL (3858) Crinoidal lime packstone, grainstones, dk. shale and red siltstone, few quartz grains, some clear calcite filled vugs, crinoid grains partially to completely micritized.</td>
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Well No. 23 cont.

3945-3950 Limestone as above, increasing shale.
3950-3955 Missing.
3955-4010 Dark gray pelletal crinoidal packstones, grainstones, some chalky limestone, micaceous shale, some brachiopod fragments.

CARRINGTON SHALE FACIES (4010)

4010-4060 Dark gray slaking shale, red siltstone near base, carbonate as above (cavings?).

BIRDBEAR FORMATION (4060)

4060-4070 Gray argillaceous limestone, coarse crystalline dolomite in calcite matrix.

4070-4085 Coarse sand, moderately to poorly rounded, angular, quartz some feldspar, dolomite as above.

4085-4100 Decreasing sand, sparry dolomite.

Well No. 24

3750-3775 Brachiopod, crinoid wacke-packstones and grainstones, loose crinoid fragments.

SCALLION SUBINTERVAL (3779)

3775-3780 As above plus dark gray shale.

3780-3790 Microcrystalline wacke-packstones.

3790-3880 Crinoidal lime packstones and grainstones, pelletal (?) grainstones. Abundant loose rounded crinoid grains, brachiopods, trilobites?

3880-3930 Crinoidal grainstone, sand sized rounded crinoid fragments.

CARRINGTON SHALE FACIES (3933)

3930-4000 Lt. green gray to dark gray slaking shale.

BIRDBEAR FORMATION (3998)

4500- Pink coarse crystalline porous dolomite, few loose coarse sand grains, pyrite.

Well No. 49

SCALLION SUBINTERVAL (6174)

6170-6235 Lt. gray argillaceous fossiliferous wackestones, some packstones & micrites, lt. gray shale & carbonaceous siltstone, bryozoans, syringopora coral (?). (6200-6205)
Well No. 49 cont.

6235-6250 Carbonate as above, lt. gray shale, red siltstone.

6250-6270 Sand, moderately well sorted, quartz, K-feldspar, light & dark rock fragments, shale as above (cavings?).

6270-6290 Lt. gray limestone, micritic & wackestone, lt. gray shale, sand as above (caving?).

6290-6325 Limestone and shale as above.

BAKKEN FORMATION (6332)

THREE FORKS FORMATION (6353)

6325-6380 Lt. gray shale interbedded with lt. gray lime micrite & wackestone.

Well No. 61

SCALLION SUBINTERVAL (4653)

4600-4670 Gray fossiliferous, argillaceous wackestone, crinoids, brachiopods, some sand & siltstone.

4670-4710 As above, lt. gray & dk. gray shales, some crinoidal packstones increasing towards base.

4710-4790 Interbedded lt. gray shales and lt. gray argillaceous limestones, wackestones, micrites.

4790-4820 White lime micrite, crinoidal wacke-packstones, loose crinoid debris.

BAKKEN FORMATION (4820)

4820-4840 Dk. gray, black shale.

THREE FORKS FORMATION (4838)

4840-4850 Sand, siltstone, quartz, feldspars, rock fragments, shale as above.

4850-4870 Dark gray micaceous shale.

4870-4910 Sand, quartz, feldspar, rock fragments, some flattened pebbles, lt. gray and red brown shales, calcareous siltstones.

BIRDBEAR FORMATION (4905)

4970- Fine grained sparry dolomitic limestone & wacke-packstones, recrystallized.

Well No. 89

3400-3420 White pelletal and crinoidal grainstones, few sand grains.
Well No. 89 cont.

SCALLION SUBINTERVAL (3421)
3420-3430 Crinoidal grainstones, shale and quartz sand, moderately to well rounded clear, well sorted, abundant rounded carbonate grains, oolites (?).
3430-3450 Carbonate as above, packstones, decreasing sand, increasing shale.
3450-3520 Pelletal crinoidal grainstones, some chalky limestone, micrite, aragonite, shale.
3520-3565 Limestone as above, packstones, loose carbonate grains and qtz. grains.
3565-3590 Dolomitic crinoidal packstones and grainstones sparites, brachiopod fragment.

CARRINGTON SHALE FACIES (3590)
3590-3610 As above, lt. green and red brown slaking shale.

BIRDBEAR FORMATION (3612)
3610- Red brown dolomitic sparites and white micrites, well rounded sand.

Well No. 145

SCALLION SUBINTERVAL (4244)
4330-4340 Lt. green gray shale, red siltstone, white sparry limestone.
4340-4360 White to lt. gray silty fossiliferous wacke-packstones, brachiopod, crinoidal packstone, little sand, shale as above.
4360-4365 Missing.
4365-4370 Shale as above, carbonate as above.
4370-4430 Lt. gray crinoidal wackestones, micrites, sparites, some packstones, some sparry dolomite, pyrite, shale as above.
4430-4445 Missing.

BIRDBEAR FORMATION (4437)
4445-4455 Sandy argillaceous dolomitic limestone, brachiopods.
4455-4460 Missing.
4460-4480 As above, coarse crystalline dolomite, loose sand grains.
Well No. 155

SCALLION SUBINTERVAL (4210)
4260-4275 Light gray shale (60%), argillaceous wacke-packstones of poorly consolidated limestone (40%), some red siltstone fragments (caving?).
4275-4285 Crinoidal wackestone partially dolomitized, some crinoidal grainstone, fragments of columnal aragonite crystals.
4285-4310 White to gray micritic limestone and fragments as above.
4310-4330 Increasing light gray shale, carbonate as above, poorly consolidated.
4330-4350 Shale as above, micrite and wackestone limestones, argillaceous wackestones, improved consolidation.
4350-4370 Argillaceous wackestones and packstones.
4370-4390 Micritic and wackestone limestones, some dolomitic sparites.

BIRDBEAR FORMATION (4400)
4390-4420 As above, increasing sparites.
4420-4450 Lt. brown dolomite spar, dk. shale, red siltstone, limestone decreasing rapidly.
4450-4460 Vuggy coarse crystalline dolomite.

Well No. 207

SCALLION SUBINTERVAL (4004)
4000-4005 Silty dark gray and green gray shale, red brown siltstone with green mottles.
4005-4075 Light gray to white crinoidal packstones and grainstones, very porous, poorly consolidated, shale and siltstone as above (caving?), some packstones consisting of small needles (spines?).
4075-4085 Lt. gray green shale and siltstones.
4085-4135 Packstones with few grainstones, brachiopod fragment.
4135-4185 Micritic limestone, white carbonate silt, some packstones and grainstones, poorly consolidated (caving?).

CORED INTERVAL
4185-4195 Lt. gray to white to pink micritic to crinoidal wackestone with red horizontal mottles, shale partings at base, faint bedding visible.
Well No. 207 cont.

4195-4196 Lt. gray argillaceous limestone, layer of rounded elongate intraclasts at base.

CARRINGTON SHALE FACIES (4196)

4196-4206 Dk. gray shale, thin shaley carbonate layer at 4198.7.

BIRDDBEAR FORMATION (4206)

4206- Light gray pinkish dolomite with darker pink mottles. 1-5 mm. vugs throughout and some large cavities up to 10 cm. diameter, some cavities filled with a geopetal carbonate silt (?).

Well No. 232

SCALLION SUBINTERVAL (5365)

5400-5410 Lt. gray micritic limestone, some crinoidal grainstones, dk. gray shale, micaceous.

5410-5420 Shale as above, carbonate as above.

5420-5495 Lt. gray micritic limestone & brachiopod wackestone, trace of grainstones, shale.

5495-5510 Wacke-packstone, increasing shale.

5510-5550 Carbonate as above, some grainstones, shale.

5550-5570 Lt. gray to dk. gray shale, red siltstone, fine grained grainstones and micrites, anhydrite.

THREE FORKS FORMATION (5580)

5570-5620 Shale as above, micrite, trace of grainstone, some fine sandstone, anhydrite.

BIRDDBEAR FORMATION (5617)

5620- Lt. tan sparry, porous dolomite.

Well No. 287

1700-1750 Lt. gray green gray shale, mod. well sorted granules and pebbles of limestone, quartz, K-feldspar, chert, rock fragments.

SCALLION SUBINTERVAL (1750)

1750-1760 Increasing shale, mica rich, sandstone and siltstone fragments, pyrite.

1760-1800 White chalky carbonate, poorly consolidated, shale.

1800-1840 Lt. gray shale, few pebbles & sandstone fragments (cavings?).
Well No. 287 cont.

1840-1900  Sparry calcite, sugary, very porous, some crinoid debris, some grainstones.

CARRINGTON SHALE FACIES (1877)

1900-1930  Red brown slaking shale, silty with sand inclusions, pyrite red carbonate fragments.

DUPEROW FORMATION (1933)

Well No. 316

SCALLION SUBINTERVAL (2587)

2600-2645  Lt. green gray shale, red siltstone some white micrite and gray wackestones.

2645-2700  White to pink micrite, scattered crinoid fragments, shale as above (caving?), some gray wackestone.

2700-2750  Interbedded lt. gray shale and argillaceous limestone and white chalky micrite.

THREE FORKS FORMATION (2756)

2750-2865  Lt. green gray, red brown, dk. gray shale, red siltstone, argillaceous limestone, well rounded quartz sand.

Well No. 403

SCALLION SUBINTERVAL (2233)

2250-2300  White chalky micrite, crinoidal grainstones, loose crinoid debris, lt. gray green shale, red siltstone.

2300-2310  Chalky micrite with faint irregular dark laminations, large amount of sand sized crinoidal debris.

2310-2320  As above, increasing shale.

2320-2360  Carbonate as above, some crinoidal packstones, shale decreasing.

CARRINGTON SHALE FACIES (2363)

2360-2390  Red brown slaking shale.

CORED INTERVAL

2390-2418  Pale red 1OR 6/3 finely laminated slaking shale, color uniform except for lime green mottles which appear to surround metallic-like grains, several thin (4 cm.) layers of limestone, occasional red iron concretions (1 cm. dia.).

2418-2422  Massive pale red dolomite, abundant vugs filled with calcite, appears extensively bioturbated.
Well No. 403 cont.

2422-2423  Shale as above.

DUPEROW FORMATION

2423-2423  Limestone, pale red, mottles surrounding vugs, compression fractions.

Well No. 435

MESOZOIC AGE ROCKS

2350-2380  Red brown siltstone, lt. green gray shale, gypsum.

SCALLION SUBINTERVAL (2385)

2380-2420  White to lt. gray crinoidal packstones and grainstones, quartz sand, lt. gray shale, loose crinoid fragments, white chalky micrite.

2420-2440  Lt. gray sparry dolomitic packstones, shale as above.

2440-2450  Lt. gray shale.

2450-2510  White crinoidal lime wackestone and packstones, with interbedded lt. gray shale.

CARRINGTON SHALE FACIES (2547)

2510-2580  Lt. gray to dark gray shale, lt. green gray shale, some slakes.

BIRDBEAR FORMATION (2575)

2580-  White to lt. tan sparry dolomite, very porous.

Well No. 437

SCALLION SUBINTERVAL (2398)

2400-2420  Lt. to dk. gray shale (cavings?), crinoidal grainstones, abundant loose crinoid fragments.

2430-2550  White crinoidal packstones and grainstones interbedded with lt. gray shale, some wackestones and chalky micrites.

CARRINGTON SHALE FACIES (2555)

2550-2560  As above, carbonaceous silty mudstone, purple micritic to sparry dolomite.

BIRDBEAR FORMATION (2564)

2560-  Lt. tan to purple sparry dolomite.
Well No. 590

SCALLION SUBINTERVAL (3700)
3750-3760 Argillaceous limestone, loose carbonate grains (grainstone?), lt. green and dk. gray shale, red siltstone.
3760-3780 Missing.
3780-3800 Shale more abundant, carbonate as above plus chalky micrite, loose crinoid fragments, few well rounded sand grains, pyrite, red siltstone.
3800-3810 Missing.
3810-3820 As above decreasing shale.
3820-3830 White crinoidal packstone and grainstone poorly consolidated, shale as above.
3830-3840 Missing.
3840-3860 Carbonate as above, shale as above.

CARRINGTON SHALE FACIES (3857)
3860-3880 Dk. gray, green gray shale, red siltstone, qtz. sand, pyrite, argillaceous carbonate, anhydrite pebbles.
3880- Missing.

Well No. 631

4200-4230 Brachiopod, crinoidal packstones and grainstones, red and yellow siltstone, lt. to dk. gray shale, brachiopod fragments common.
4230-4290 As above plus crinoidal grainstone.
4290-4310 As above, increasing shale (micaceous), some anhydrite.

SCALLION SUBINTERVAL (4307)
4310-4330 Carbonate as above except finer grained, more micrites and wackestones, few chalk fragments.
4330-4420 Crinoidal grainstone, grain size decreasing towards base, few angular chert fragments.

CARRINGTON SHALE FACIES (4416)
4420-4480 Lt. to dk. green gray shale and chert fragments.
4480-4500 Shale as above and fine sparry dolomite.

BIRDBEAR FORMATION (4506)
4500- White to lt. brown sparry dolomite, very porous.
Well No. 642

SCALLION SUBINTERVAL (3098)
3050-3160 Crinoidal packstones and grainstones, some brachiopods, interbedded lt. gray shale, abundant loose rounded crinoid fragments.
3160-3220 Increasing shale, carbonate as above, plus white chalky micrite, and some sand.

CARRINGTON SHALE FACIES (3200)
3220-3310 Lt. to dk. gray shale, slakes in water.

BIRDBEAR FORMATION (3298)
3310- Lt. tan sparry dolomite.

Well No. 644

SCALLION SUBINTERVAL (2830)
2890-2910 White to orange to pink pelletal or crinoidal lime grainstone, brachiopod fragments.
2910-2950 Missing.
2950-2970 White chalky limestone with irregular dark laminations, loose sand size crinoid fragments medium quartz sand plus some coarser rock fragments (chert, lmst.), some dk. gray shale.
2970-2980 Shale as above, yellow brown sparry dolomite limestone.
2980-2990 Missing.
2990-3000 Dolomitic lime sparites and crinoidal or pelletal lime grainstones, shale as above.
3000-3010 Missing.
3010-3050 As above, plus white chalky limestone, quartz sand and rock fragments.
3050-3060 Carbonate as above, up to 50% sand and rock fragments (feldspar, dolomite, igneous rock) up to 7 mm. diameter.

CARRINGTON SHALE FACIES (3059)
3060-3100 Sand as above, gray to red brown slaking shale.

DUPEROW FORMATION (3100)
3100- White to pink crystalline dolomite, porous.
Well No. 645

SCALLION SUBINTERVAL (2273)

2300-2320
Pink to white sparry limestone, micrites, wacke-packstones and grainstones, lt. green gray shale, chert, aragonite, some shale has 1 mm. carbonate inclusions.

2320-2345
Shale as above, carbonate as above plus chalky micrite, calcite filled vugs.

2345-2375
Carbonate as above, increasing chalk, loose crinoid fragments, pyrite.

2375-2390
Carbonate and shale as above, increasing shale, shale slakes.

2390-2410
Crinoidal packstones, wackestones, sparites, some red pyrite, shale as above.

CARRINGTON SHALE FACIES (2414)

2410-2430
Lt. green gray shale, carbonates as above.

2430-2445


2445-

DEVONIAN BIRDBEAR (2437)

2450-
Red coarse crystalline dolomite, sand & shale as above.

Well No. 651

SCALLION SUBINTERVAL (2735)

2790-2835
Pinkish dolomite lime micrite, tan sparry limestone, some packstone, shale, dk. gray green, quartz pebble, oxidized layers, micaceous siltstone, columnar aragonite fragments.

2835-2840
Missing.

2840-2875
Carbonate as above, crinoid fragments not as dolomitic.

2875-2895
White lime packstone, crinoidal, high porosity, much coarser than above rock, loose crinoidal fragments, friable.

CARRINGTON SHALE FACIES (2895)

2895-2900
Med. gray green shale, carbonate as above.

BIRDBEAR FORMATION (2900)

2900-
Sparry dolomitic, fine grained, porous.

Well No. 654

SCALLION SUBINTERVAL (2747)

2800-2815
Pinkish white, brachiopod, crinoidal lime packstones and grainstones, dk. gray slaking shale.
Well No. 654 cont.

2815-2825 Carbonate as above, increasing shale, chert, pyrite, quartz grains, mica flakes.

CARRINGTON SHALE FACIES (2827)

2825-2835 Lt. gray silty shale, decreasing carbonate. Abundant quartz grains & mica flakes.

2835-2845 White crinoidal packstones, grainstones, loose crinoidal debris, calcite filled vugs, red siltstone, shale & sand.

2845-2865 Shale as above, increasingly red, carbonate a.a. (cavings?).

2865-2890 Crinoidal packstone and grainstone, red & white, mica flakes, shale as above.

2890-2920 Lt. gray shale, red brown siltstone, pyrite, gypsum.

BIRDBEAR FORMATION (2922)

2920- Reddish white dolomite, vuggy, some calcite.

Well No. 659

SCALLION SUBINTERVAL (3330)

3440-3460 White to lt. gray crinoidal lime grainstone, packstones, some white chalky micrite, abundant loose crinoid fragments, some lt. gray shale.

ROUTLEDGE SHALE FACIES (2462)

3460-3480 Lt. brownish gray shale, slakes.

3480-3510 Lt. gray shale, slakes.

3510-3515 Dk. gray shale, does not slake.

BAKKEN FORMATION (3540)

3515-3560 Lt. gray shale, does slake.

3560-3580 Lt. gray calcareous siltstone.

Well No. 660

2570-2580 White to red brachiopod, crinoidal lime packstone, lt. greenish gray shale.

SCALLION SUBINTERVAL (2580)

2580-2590 Red carbonate sparite, packstones as above and white chalky micrite.

2590-2680 Crinoidal packstones and grainstones, calcite filled voids, chalky micrite, few quartz grains and aragonite.
Well No. 660 cont.

CARRINGTON SHALE FACIES (2682)

2680-2755
Red brown and green shale, slakes, pyrite aragonite, little sand.
Shale becomes darker towards base & does not slake as readily.

BIRDBEAR FORMATION (2756)

2755-2785
Coarse crystalline dolomitic limestone, shale and few well rounded quartz grains, increasing dolomite downward.

Well No. 663

SCALLION SUBINTERVAL (2959)

3000-3005
Red tinted micritic dolomite.

3005-3015
Coarse fossil hash packstone, brachiopods and bryozoans.

3015-3025
Lt. gray dolomitic lime micrite, pyrite.

3025-3035
As above with greenish gray shale.

3035-3070
Lime and dolomitic lime micrite, few fossiliferous wacke-packstones, few clear calcite crystals, columnar aragonite crystals, lacy bryozoan fragment, brachiopod fragment.

3070-3085
Carbonate as above, sand and sandy shale.

3085-3115
Microspar and micritic limestone, shale.

3115-3120
Lt. green gray shale, carbonate as above.

BIRDBEAR FORMATION (3120)

3120-
Red sparry vuggy dolomite.

Well No. 672

SCALLION SUBINTERVAL (2655)

2600-2670
White crinoidal wacke-packstone, abundant sand sized crinoidal debris, some med. quartz sand, K-feldspar fragments, pyrite.

2670-2700
Lt. brown sparry dolomitic lime wackestone, shale, sand.

2700-2710
As above, increasing shale, does not slake.

2710-2730
Brown sparry lime dolomite and white micritic dolomite.

2730-2740
As above plus dk. gray & lt. green gray shale, slakes.
Well No. 672 cont.

CARRINGTON SHALE FACIES (2775)
DUPEROW FORMATION (2798)
2740-2860 Carbonate as above, 25% sand and rock fragments, well sorted & rounded, black glass spheres, sand sized, some raindrop shape.
2860-2870 Sand as above and carbonate.

Well No. 683

SCALLION SUBINTERVAL (2796)
2810-2935 Lt. pinkish gray to white, fossiliferous wackestones, packstones, crinoids, brachiopods, some micrites, grainstones, white chalky micrite towards base, interbedded with lt. to dk. gray shales and red siltstones.
CARRINGTON SHALE FACIES (2933)
2935-2945 Limestone as above plus med. quartz sand, well rounded, crinoidal grainstones.
2945-2990 Sand to gravel, med. well rounded quartz sand to coarse (15-20 mm.) pebbles of dolomite, chert granite, sandstone, med. well to poorly rounded K-feldspar, dk. mafic. Pinkish white lime crinoidal wacke-pack and grainstones, some lt. gray shale.
BIRDBEAR FORMATION (2989)
2990- Lt. brown dolomitic sparite, vuggy.

Well No. 689

3410-3420 Crinoidal, brachiopod packstone and grainstone.
SCALLION SUBINTERVAL (3427)
3420-3480 White chalk-like friable limestone, dk. green shale, few crinoid stem fragments, chert and gypsum, carbonate as above.
3480-3540 Increasing chalk, shale as above, few moderately well rounded chert granules, few rounded quartz sand grains, dolomitized grainstone at base.
CARRINGTON SHALE FACIES (3537)
3540-3580 Red brown slaking shale, some lt. green gray shale also, few sand sized quartz grains, some shale shows fine lamination appears disrupted.
3580-3620 Lt. gray to dk. gray shale, does not slake, no sand grains.
Well No. 689 cont.

BIRDBEAR FORMATION (3623)

3620-  
Lt. pink porous sparry dolomite.

Well No. 693

SCALLION SUBINTERVAL (4954)

4960-5000  
Lt. gray silty argillaceous limestone micritic to wackestone fabric, brachiopods, some shale and quartz sand grains.

5000-5025  
Carbonate as above with increasing amounts of sand sized quartz, red to tan siltstone, few flat rounded chert fragments, loose crinoid segments, few jet black carbon fragments.

5025-5085  
Sandstone, loose sand sized, well rounded well sorted quartz with abundant feldspar grains, also rock fragments and rounded chert pebbles, some rounded limestone fragments, siltstones.

5085-5165  
Shale and limestone (interbedded?) crinoidal wackestone, intraclastic (angular) packstone, pyrite, sand as above (cavings?).

5165-5180  
As above plus sparites.

THREE FORKS FORMATION (5177)

5180-5190  
Increasing dk. gray to lt. green gray shale, silty & very hard, limestone as above.

5190-5200  
As above increasing limestone.

5200-5210  
Recrystallized grainstone with pyrite filling voids & packstones, shale as above.

BIRDBEAR FORMATION (5210)

5210-  
Porous lt. pink dolomite, dk. gray shale.

Well No. 723

4100-4150  
Crinoidal, brachiopod packstone, argillaceous, dk. gray shale.

4150-4180  
Carbonate as above, brachiopod fragment, increasing wackestone and micrite, red siltstone, lt. gray shale, anhydrite.

4180-4210  
Packstones and grainstones, decreasing shale.

SCALLION SUBINTERVAL (4210)

4210-4220  
White sparites and micrites, poorly consolidated, shale as above.
Well No. 723 cont.

4220-4280  Lt. gray green shale, micaceous, red siltstones wackestones and micrites.

4280-4330  As above, increasing lt. gray micrites, wackestones.

4330-4360  Shale as above, lt. gray argillaceous wackestones.

4360-4400  Wackestones and micrites, some dolomitic.

4400-     BIRDBEAR FORMATION (4400)

Well No. 735

SCALLION SUBINTERVAL (4372)

4400-4430  Light gray sparry to micritic limestone, clear calcite filled cavities. Crinoid stem fragments (grainstones?).

4430-4440  Medium dark gray fossiliferous packstones.

4440-4480  Increasing amounts of dark gray micaceous shale, K-feldspar and quartz sand grains, med. to coarse sand, red siltstones, limestone shaley.

4480-4540  Cleaner carbonate, micrites, fossiliferous wackestones and packstones, some grainstones, lacy bryozoan fragment.

4540-4565  Increasing shale, carbonate as above.

THREE FORKS FORMATION (4565)

4565-4570  Dark gray shale.

4570-4610  BIRDBEAR FORMATION (4570)

4610-4620  Coarse crystalline vuggy dolomite.

4620-     Missing.

Well No. 742

SCALLION SUBINTERVAL (3918)

3950-3980  Medium dark gray shale, few fragments of red siltstone and gypsum (caving?).

3980-4030  Crinoidal, brachiopod packstone, very porous carbonate, slakes, poor consolidation.

4030-4040  Crinoidal packstone increasing lithification, some fresh shale.
Well No. 742 cont.

4040-4050 As above with some micrite, shale gray green to dark gray, fragments of oolitic grainstone.

4050-4120 Limestone as above increasingly porous, few iron concretions, shale as above decreasing with depth.

4120-4150 Micritic limestone with fossiliferous packstone fragment of dk. carbonate with angular intraclast, some siltstone and shale, quartz and feldspar grains, some well rounded carbonate fragments.

BIRDBEAR FORMATION (4156)

4150-4180 Increasing amounts of dk. gray to med. green gray shale, carbonate as above (cavings?).

4180-4200 Vuggy coarse crystalline dolomite.

Well No. 756

SCALLION SUBINTERVAL (4472)

4500-4560 Lt. gray to white sparry limestones, micrites, wackestones & few packstones, brachiopods and crinoids, med. dk. gray shale, red siltstone, pyrite, calcite filled voids.

4560-4570 As above, few sand sized quartz grains, chert fragments, aragonite.

4570-4580 Carbonate and shale as above.

4580-4610 Carbonate as above, few grainstones, aragonite, shale as above.

4610-4630 Fossiliferous wacke-packstones, intraclastic? packstone.

4630-4660 Shaley micrites and wackestones, shale increasing, some sand, some packstones at base.

4660-4680 Sparry and wackestone limestone, more friable, sand increasing slightly, shale decreasing, calcite filled void.

BIRDBEAR FORMATION (4674)

4680- Porous sparry dolomite, dk. gray shale. (Trace of THREE FORKS FORMATION'S shale)

Well No. 1211

SCALLION SUBINTERVAL (2727)

2700-2740 Dk. gray shale (caving?), brachiopod, crinoidal packstones and grainstones, poorly consolidated, iron concretions, red siltstone.
Well No. 1211 cont.

2740-2750  Increasing shale, siltstone, few quartz grains, carbonate as above.

2750-2840  White chalky carbonate, red stained crinoidal packstone & grainstone fragments, some grainstone in silt matrix, some micrite and wackestones, decreasing shale.

CARRINGTON SHALE FACIES (2840)

2840-2880  Red brown slaking shale, lt. green mottles.

2880-2920  Lt. gray shale, does not slake.

BIRDBEAR FORMATION (2916)

2920-  Buff tan to white sparry dolomite.

Well No. 1346

SCALLION SUBINTERVAL (3327)

3300-3370  Crinoidal packstones and grainstones, silty matrix, abundant loose sand sized carbonate grains, lt. green gray shale & red siltstone.

3370-3400  Crinoidal grainstone and chalky micrite.

3400-3460  Crinoidal grainstone, loose crinoid fragments.

3460-3500  Lt. gray sparry dolomitic limestone.

CARRINGTON SHALE FACIES (3480)

3500-3530  Lt. green gray slaking shale, red fragments, pyrite, sand (quartz and feldspar), mica flakes, dark rock fragments.

DUPEROW FORMATION (3525)

3530-  Lt. gray sparry dolomite.

Well No. 1409

SCALLION SUBINTERVAL (4715)

4700-4750  Brachiopod, crinoid wacke-packstones, some micrite, lt. gray shale, red siltstone.

4750-4760  As above, some grainstones.

4760-4790  As above, increasing argillaceous micrites.

4790-4800  As above, fine grained grainstones.

4800-4820  As above, increasing shale.

4820-4840  As above, some quartz grains, anhydrite, sand quartz carbonate packstone.
Well No. 1409 cont.

4840-4850  Shale as above, decreasing carbonate.

4850-4920  Micritic and wackestone lime, poorly consolidated few fragments of grainstone fabric, shale towards base.

BIRDBEAR FORMATION (4935)

4920-        Vuggy dolomite, trace of sand, shale.

Well No. 1517

SCALLION SUBINTERVAL (3138)

3130-3150  Lt. gray to white crinoidal & fossiliferous packstones, some grainstones & wackestones, dk. gray micaceous shale, red siltstone, loose quartz and crinoid grains.

3150-3200  White slightly dolomitic lime sparite, lt. pink micrite, dk. gray and green gray shale.

3200-3350  White lime micrite, sparite & shale as above, calcite lined vugs, few crinoidal wackestones and packstones, aragonite, gypsum.

THREE FORKS FORMATION (3320)

3350-3360  Lt. to dk. gray micaceous shale, red siltstone.

3360-3380  Shale as above, stained red brown, some red brown slaking shale, abundant sand sized quartz.

BIRDBEAR FORMATION (3378)

3380-       Lt. pink sparry dolomite.

Well No. 3920

SCALLION SUBINTERVAL (3738)

3710-3810  Lt. gray brachiopod crinoidal wackestones, micrites & some packstones, interbedded dk. gray shales, chert, bryozoan.

3810-3870  Dk. gray shale with interbedded argillaceous crinoidal wackestones.

3870-3880  White to lt. gray dolomitic micrite, heavily pitted, spongy looking, some crinoidal grainstones.

3880-3890  Lt. gray lime micrite, very abundant, some crinoidal grainstones.

3890-3900  Micrite as above, plus dk. gray shale, sandstone and rock fragments.

3900-3910  As above decreasing shale.
Well No. 3920 cont.

3910-3950  Lt. gray micrite, crinoidal wacke-packstones.

THREE FORKS FORMATION (3935)

3950-
Lt. tan sparry dolomite, dk. gray shale, red brown siltstone.

Well No. 4719

MESOZOIC AGE ROCKS

1600-1620  Lt. gray and brown shale, quartz & feldspar sand, poorly to well rounded, pyrite.

1620-1630  Med. quartz sand, shale as above.

1630-1660  Sand and pebble conglomerate, good bimodal sorting, quartz, feldspar, sedimentary and igneous rock fragments.

1660-1690  Shale and sand as above.

DUPEROW FORMATION (1695)

1690-1760  Sparry dolomite, shale and sand as above. Some fine grained limestone.
APPENDIX D - X-ray Diffraction Procedures

Instrument Used:

Norelco Diffractometer

Instrument settings:

Radiation Cu Kα, Filter Ni, Kv. 37, Ma. 18,
Scan speed 20° per minute, Time constant 1 sec.,
Div. slit 1°, Rec. slit .006", Scatter slit 1°,
Ratemeter $5 \times 10^3$ for clay samples and $2 \times 10^3$ for silt samples.

Sample preparation:

Separation of size fractions was made using the methods of Brekke (1978). The clay size fraction was prepared for X-ray analysis by placing the clay on a porous ceramic tile and using suction to create a durable oriented layer on the tile. These tiles were X-rayed three times, (1) untreated, (2) after being placed in an ethylene glycol saturated atmosphere for at least 48 hours, (3) after heating at 600°C for 1 hour. Sideloaded clay samples were X-rayed for 060 reflections. Silt size fractions were prepared by backfilling a cylindrical aluminium sample holder and X-rayed using a rotating sample holder.

Results:

Results of oriented clay samples can be seen on figure 6, backloaded silt samples on figure 7. Results of sideloaded clay samples revealed the clay to have a 060 dioctahedral muscovite peak at 1.502 Å.
APPENDIX E - Results of Chemical Analyses of Shale Samples

Explanation

Samples from wells no. 207 and 403 were sent to Merle Crew, Casper Field Office of the Energy Research and Development Administration (presently the Department of Energy), for assaying. Results obtained are shown below. Emission spectrograph and gamma-ray spectroscopy were used. Lower detection limits are given in parentheses at the base of the elements column. N- indicates the element was not detected. L- indicates the element was detected but its amount was below the limit of determination. Values are in parts per million unless indicated to be in percentages. Elements Au, Zn, Mo, W, Cd, As, Sb, Bi, Sn, were not detected in the samples.

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<th>Depth</th>
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<th>K%</th>
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<td>2391</td>
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(20) (10) (5) (100) (10) (0.05%) (0.02%) (0.001%) (0.2%)
REFERENCES


Fischer, R. P., 1974, Exploration guides to new uranium districts and belts, Econ. Geol., v. 69, no. 3, pp. 362-376.


Macauley, G., et al., 1964, Chapter 7; Carboniferous, in Geologic History of Western Canada: Alberta Soc. of Petroleum Geol., Calgary, Alberta, pp. 89-102.


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ISOPACHOUS MAP
OF
SCALLION SUBINTERVAL'S
BASAL CARBONATE

LEGEND
• control well
— contour line
— inferred contour

contour interval 10 feet

MAP AREA

SASKATCHEWAN
MANITOBA

NORTH DAKOTA

MONTANA

SOUTH DAKOTA

0 100 miles
0 100 kilometers

P. BJORLIE
PLATE 4
SUBINTERP: _i;: - - C

BAKKEN Fm.

STANOLIND-MOLEAN

McLEAN, CO.

McLEAN, CO.

HUNT-FULLER

BAKKEN

HUNT-PFIEFFER

SHERIDAN CO.

Hunt-Pfieffer

CONN. CONTINENTAL - LUETH No. 1

207 CO.

Well 31 -147 -71

Mesozoic, Ge,

grainslone facies

Shale facies

Carrington

SCALLION

Wells 2400 -

DEVONIAN

No. 1

5430 --z.____

Wacke

14 mi

12’ Bl

36 -164 -61

Whitewater Lake

1a00

25

PENDLETON - WEBER

ORDOVICIAN - SILLURIAN

AGE ROCKS

Laffey

3900

Potentially Gamma

Ray

Carrington

Facies

26 -146 -73

4400

32-150 -70

16 mi

36 -164 -61

Whitewater Lake

1a00

25

PENDLETON - WEBER

ORDOVICIAN - SILLURIAN

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