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An Overview of the Regional Geology and Petroleum Potential, Lodgepole Formation, Southwestern Manitoba

by H.J. Klassen

Manitoba
Energy and Mines
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An Overview of the Regional Geology and Petroleum Potential, Lodgepole Formation, Southwestern Manitoba

by H.J. Klassen
Winnipeg, 1996

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TABLE OF CONTENTS

FIGURES

TABLES

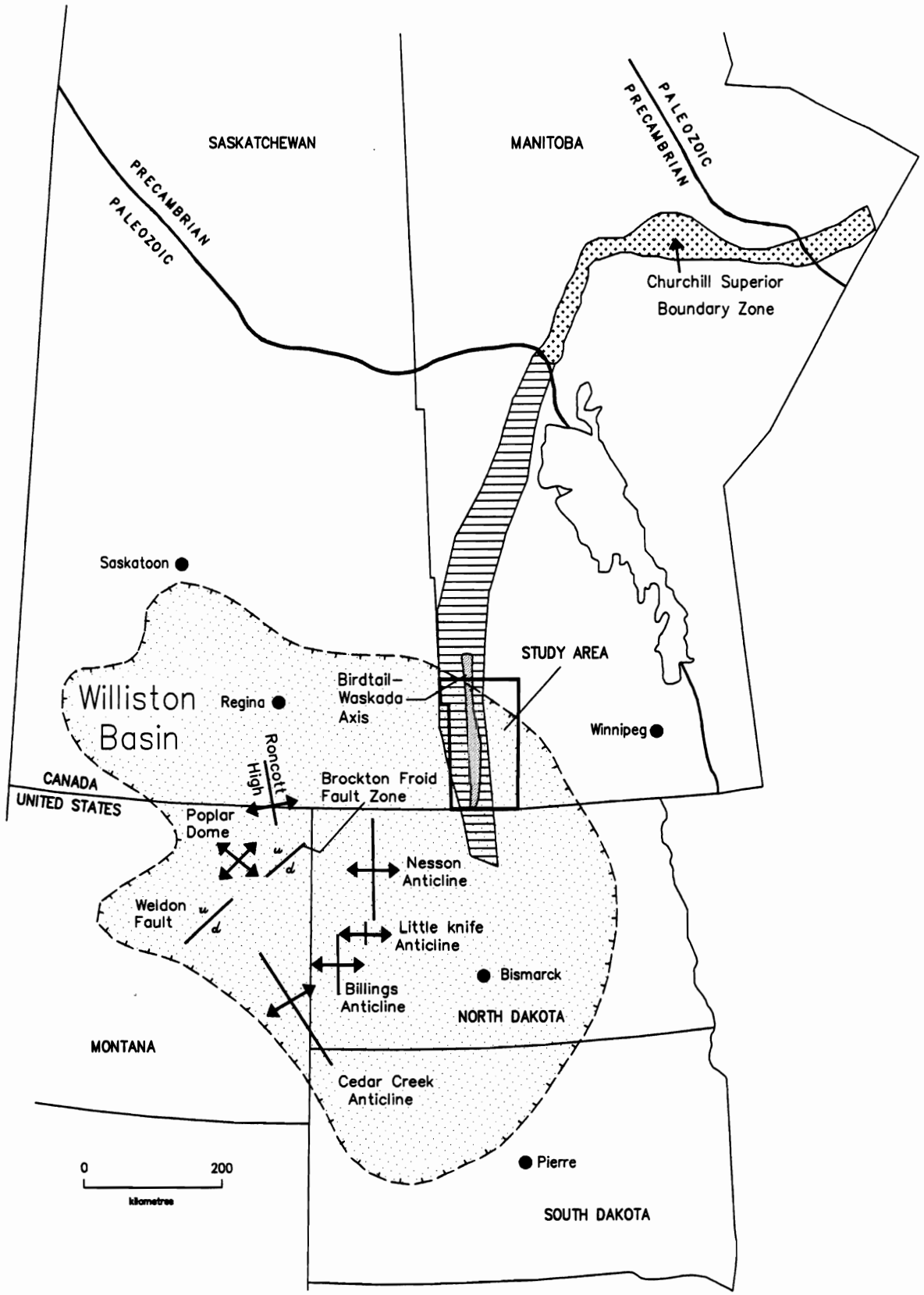


Figure 1: Map of the Williston Basin showing major structural features(after Martiniuk and Barchyn, 1993). Location of study area is shown.

INTRODUCTION

The first commercial oil production from the Lodgepole Formation in the Williston Basin was at 15-18-10-27 WPM in the Daly Field. Since the initial discovery, the Lodgepole has become one of the major producing zones in Manitoba, representing 87% of total production. Seven fields currently produce from the Lodgepole Formation including; Daly, Kirkella, Virden, Souris Hartney, Whitewater, Regent and Lulu Lake fields. A total of 949 active oil wells produce from these fields.

The Mississippian Lodgepole Formation is essentially a multi-member carbonate unit that lies between limestones and dolostones of the Mission Canyon Formation, and where the Mission Canyon is eroded, the red, anhydritic shale of the Lower Amaranth Formation and the black shale of the Upper Bakken Formation. The formation and its members have been defined in the subsurface by Organ and Russin (1956) in the Daly area and by Stanton (1956) in the Virden area of Manitoba.

This report presents a preliminary evaluation of the lithofacies and regional geology, and the petroleum potential of the Lodgepole Formation in southwestern Manitoba. An attempt has been made to present a model for the deposition of the Lodgepole Formation and to reconcile stratigraphic terminology between the Daly (slope) and the Virden-Lulu Lake trend (shelf). For the purposes of this report emphasis has been placed on slope (Daly and Kirkella areas) rather than the Lodgepole subcrop trend along the shelf areas (Virden, Souris Hartney, Whitewater, Regent and Lulu Lake fields). An expansion of the work by Young and Rosenthal (1991) and Sereda (1990) will lead to an exploration model for future Lodgepole Formation exploration and development in Manitoba.

STUDY AREA

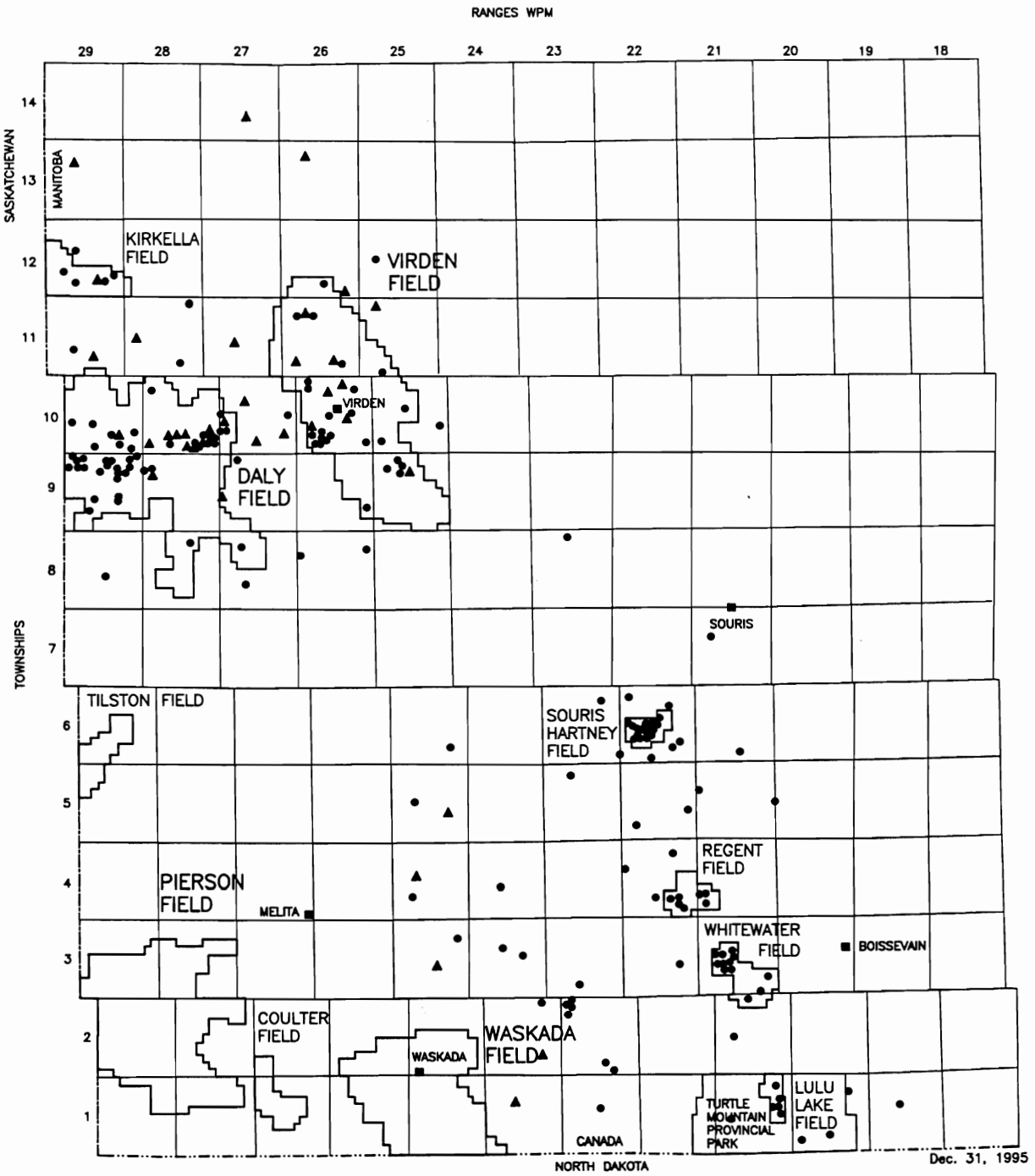
The study area encompasses 15 800 km^2 [from Townships 1 to 17 and Ranges 20 to 29 WPM of southwestern Manitoba (Fig. 1)].

ACKNOWLEDGMENTS

The author gratefully acknowledges the contributions and assistance of the staff of the Manitoba Energy and Mines, particularly Carol Martiniuk and the staff of the Petroleum and Energy Branch and the Rock Preparation Laboratory. The author also thanks Dr. Dave Baldwin for his editorial review of this report and Nancy Barton and Bonnie Lenton, Geological Services Branch, for drafting of maps and figures. In addition, Julie LeFever of the North Dakota Geological Survey, Steve Halabura of North Rim Oils Limited and Rick Sereda of Northrock Resources Ltd. deserve credit for their discussions and suggestions.

Data available to December 31, 1995 from approximately 3 500 wells were incorporated in the study. Cores from 32 wells were examined and described (Fig. 2).

MAP OF AVAILABLE LODGEPOLE FORMATION CORE, SOUTHWESTERN MANITOBA



- Wells with Lodgepole core
- ▲ Lodgepole Formation core examined (this report)

Figure 2: Map showing available Lodgepole Formation core, southwestern Manitoba. Shows Lodgepole Formation cores examined in this report.

REGIONAL GEOLOGICAL SETTING

Southwestern Manitoba is underlain by the northeastern flank of the Williston Basin (Fig. 1). A basinward thickening sedimentary wedge is formed by rocks of Paleozoic, Mesozoic and Cenozoic age that reach a total thickness of 2300 m in the extreme southwestern corner of the province. Several unconformities truncate strata within the Mesozoic and Paleozoic section.

A major angular unconformity separates the Paleozoic from the Mesozoic strata, and may represent one or more periods of erosion that occurred from late Mississippian to early Jurassic time. During this interval, Paleozoic strata in the northeastern portion of the basin were uplifted and differentially eroded where as strata in the southern part underwent relatively slight uplift (McCabe, 1959). Successively older Paleozoic strata were progressively truncated toward the basin margin. Deposition resumed during Mesozoic time when a thick sequence of Jurassic and Cretaceous strata was deposited on the eroded Paleozoic surface.

Within the Paleozoic, an unconformity separates Devonian and Mississippian strata and represents a period of uplift and erosion that occurred from late Devonian to early Mississippian time. During that interval, Devonian strata were uplifted and exposed along the basin margins while deposition continued in the deeper central portions of the basin. Mississippian sediments were deposited on the eroded Devonian surface following this period of erosion (Martiniuk, 1992). In Manitoba, the Lodgepole Formation subcrops along the northeastern portions of the study area where it is unconformably overlain by the Jurassic Lower Amaranth (Red Beds) Formation.

STRATIGRAPHIC CORRELATION CHART OF THE LODGEPOLE FORMATION, SOUTHWESTERN MANITOBA

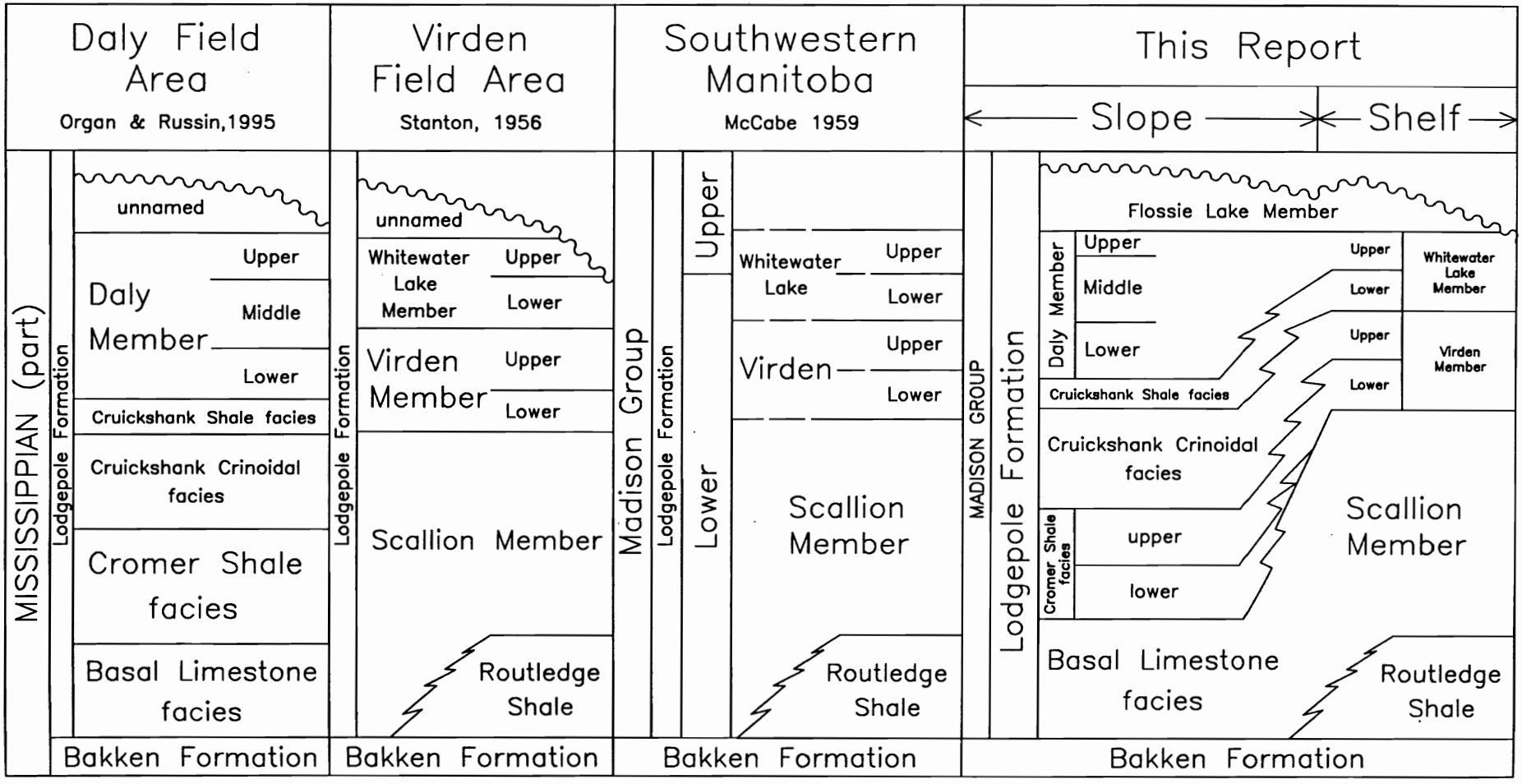


Figure 3: Stratigraphic correlation chart for the Lodgepole Formation in southwestern Manitoba (after Organ and Russin, 1995, Stanton, 1956 and McCabe, 1959).

GENERAL STRATIGRAPHY

The Lodgepole Formation was first described by Collier and Cathcart (1922) from its type section in the Little Rocky Mountains, Montana (Knechtel, 1959).The Lodgepole Formation is of Early Mississippian (Kinderhookian) age and comprises a complex succession of shallow marine carbonates and shales.

PREVIOUS WORK

The Mississippian strata in the subsurface of Manitoba was originally defined by Kerr (1949). From 1949 to 1954 the term Lodgepole came into common usage as a stratigraphic subdivision of the Mississippian (Ower, 1952; Thomas, 1954).

Subsequent studies on the Lodgepole Formation were presented following the development of the Daly and Virden fields in Manitoba. Organ and Russin (1956) presented a detailed local stratigraphic subdivision and nomenclature for the Daly Field area of Manitoba. The units defined were applicable to the immediate field area and did not attempt to correlate the Daly section with the regional Lodgepole section. Organ and Russin (1956) defined the following terminology for the Daly Field (Township 9 to 10; Range 27 to 28 WPM) for the type well at 10-12-10-28 WPM between 685.8 and 774.2 metres: Basal Limestone facies, Cromer Shale facies, Cruickshank Crinoidal facies, Cruickshank Shale facies and Daly Member. The Daly Member was further subdivided into Lower ("main crinoidal" in field usage), Middle ("first crinoidal" in field usage) and Upper units.

Stanton (1956) described the Lodgepole Formation in the Virden Roselea area (Township 10 to 12; Range 25 to 26 WPM). He proposed the following nomenclature as defined by the type well, 9-25-10-26 WPM, between 563.8 and 624.8 metres: Routledge Shale facies, Scallion Member ("cherty zone" in field usage), Lower and Upper ("crinoidal" in field usage) Virden Member, Lower and Upper Whitewater Lake Member and the Unnamed Lodgepole. The Lower Virden Member is further subdivided into (in ascending order): the Fourth, Third, Second, First and Sandhill Oolite lentils. The "Roselea shale" is defined as the lower portion of the Lower Whitewater Lake Member. Although restricted to the general Virden area, the terms have been used throughout most of southwestern Manitoba, parallel to the eastern erosional edge of the Mississippian subcrop.

A major synthesis of the stratigraphy, petrography and petroleum geology was published by McCabe (1959, 1963). He informally subdivided the Lodgepole Formation into upper and lower units. The Lower Lodgepole was defined as that section between the top of the Upper Bakken Formation and the top of the Roselea shale. An eastern and western facies was recognized for the Lower Lodgepole. The Upper Lodgepole was defined as the section from the top of the Roselea shale to the top of the Lodgepole Formation.

Sereda (1990), working in southeastern Saskatchewan, indicated that the Lodgepole Formation portrays deposition during transgressive and regressive phases. Shelf/slope facies are found in Manitoba where as basin and bioherm facies are mainly present in Saskatchewan. Waulsortian-type mounds occur in a basin to lower slope setting in Saskatchewan.

Young and Rosenthal (1991) used the concept of carbonate sequence stratigraphy (Sarg, 1988) to construct a depositional model and a regional correlation of the Lodgepole Formation in southwestern Manitoba. Six stratigraphic units were correlated from Virden to Daly. The Virden area represents shelf sedimentation and contains bioclastic and oolitic grainstones and shales, where as the Daly area, bioclastic limy shales interbedded with packstones-wackestones represent sedimentation within a slope setting. These two areas demonstrate the progradation of a westward-dipping carbonate ramp. Using this concept, Young and Rosenthal (1991) were able to combine the previously defined format or marker defined terminology used by McCabe (1959, 1963) and others with time-stratigraphic or lithology based terminology (Fig. 3).

Recent work by LeFever *et al.* (1995) presented a correlation between 1-16-9-29 WPM in the slope area and 10-7-9-25 WPM in the shelf area of Manitoba (Fig. 3). They suggested that beds in the Lower Lodgepole were deposited in basin filling clinothems where as the Upper Lodgepole lack such bedding style and represent normal basin filling.

CURRENT WORK

Previous authors restricted Lodgepole nomenclature to specific field areas (Fig. 3). This report attempts to build on the models of Sereda (1990) and Young and Rosenthal (1991). In part, it adheres to the Lodgepole as a format based subdivision as defined by McCabe (1959, 1963) and others and incorporates the more clinothemic boundary definitions proposed by Sereda (1990) and Young and Rosenthal (1991). The model proposed by Young and Rosenthal (1991), which describes the units of the Lodgepole Formation as exhibiting classic sigmoidal clinoform morphology, was used as the basis for correlation in this report.

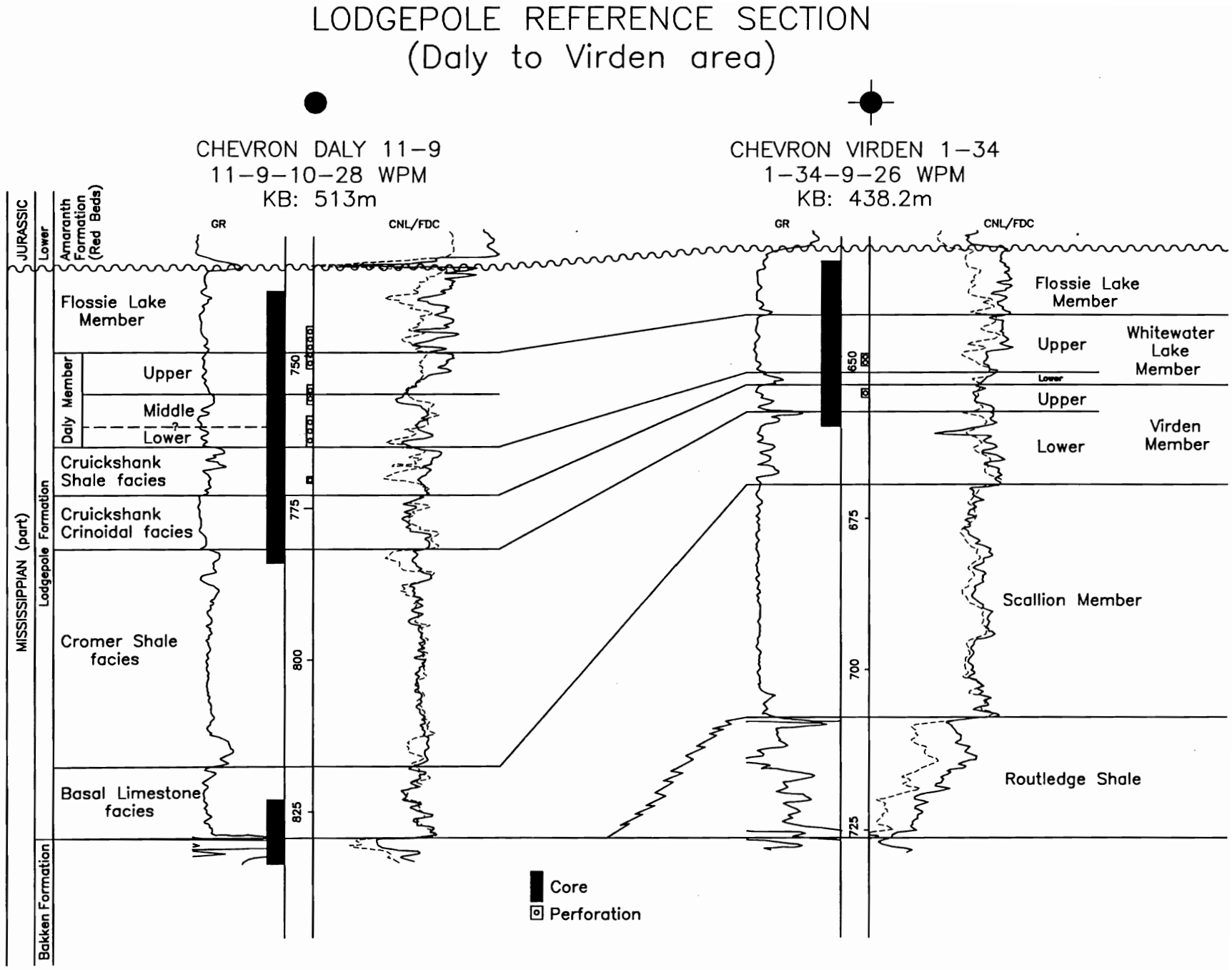


Figure 4: Lodgepole reference section showing correlation of slope to shelf terminology from Daly to Virden Field areas.

In this report, the following subdivisions and terminology of the Lodgepole Formation is used to describe the shelf facies; Routledge Shale facies, Scallion Member, Lower and Upper Virden Member; Lower and Upper Whitewater Lake Member and the Flossie Lake Member (Unnamed Lodgepole). In contrast, the slope area terminology was used to subdivide the Lodgepole into the Basal Limestone facies, lower and upper Cromer Shale facies, Cruickshank Crinoidal facies, Cruickshank Shale facies, Lower Middle and Upper Daly Member and Flossie Lake Member (Unnamed Lodgepole).

Correlation methodology is shown by the reference wells in Figures 4 and 5. Distinctive geophysical log characteristics coupled with lithological features observed in the core were used to make the correlations from shelf to slope areas. The Basal Limestone facies has been correlated to its shelf equivalent, the Scallion Member, based on the presence of chert. The interbedded oolitic grainstones and limy mudstones of the Lower Virden Member pass into the limy mudstones of the Cromer Shale facies. Beds along the shelf area such as the Cruickshank Crinoidal facies have been correlated to the equivalent Upper Virden Member along the shelf, both of which contain crinoids. Limy shales and mudstones of the Cruickshank Shale facies and the shelf equivalent Lower Whitewater Lake Member are correlative.

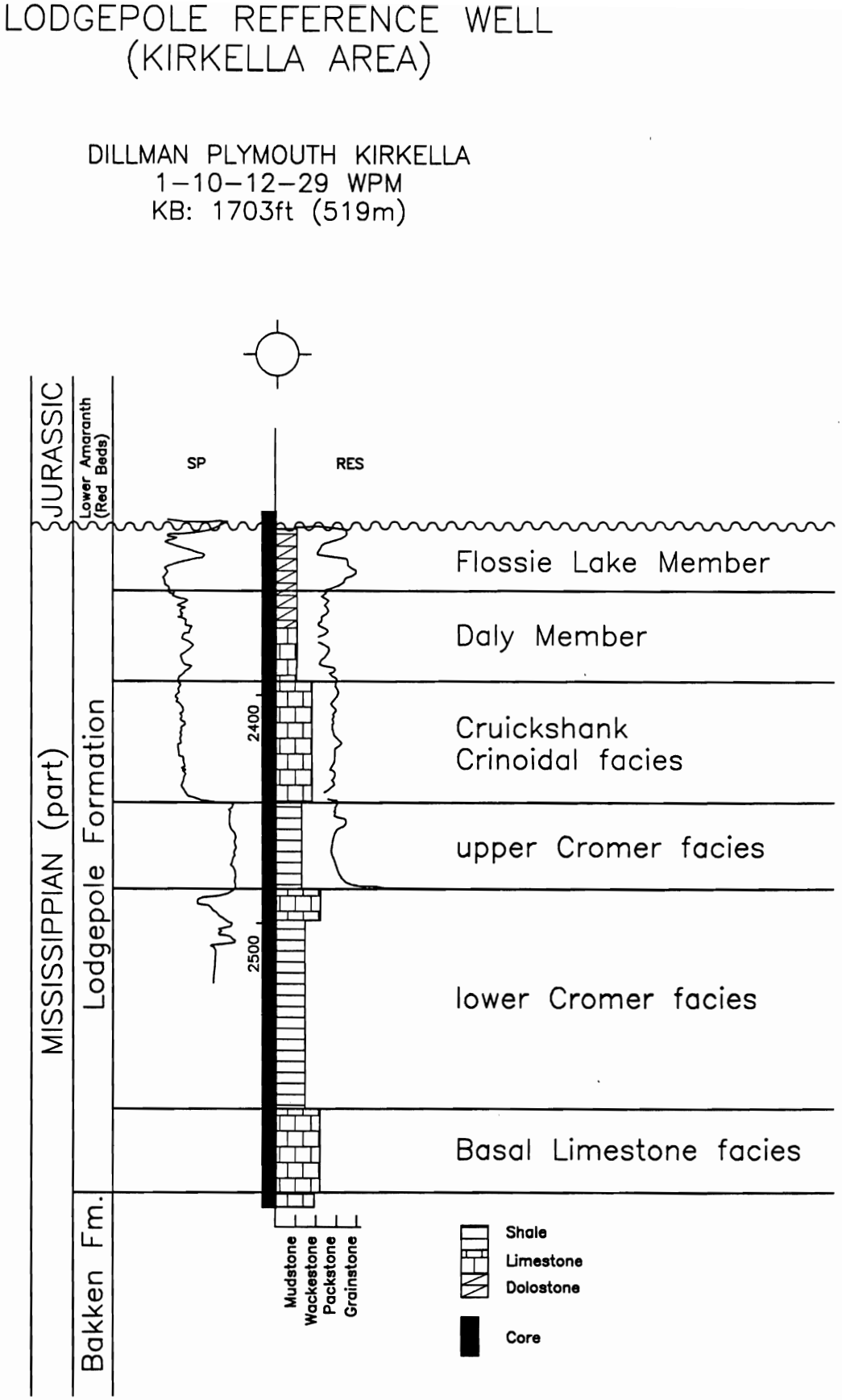


Figure 5: Lodgepole reference well from the Kirkella Field area showing 1-10-12-29 WPM.

DEPOSITIONAL ENVIRONMENT

SHELF, SLOPE AND BASIN FACIES

The general distribution of the shelf, slope and basin depositional settings within the Lodgepole Formation is shown in Figure 6 and the proposed model for regional deposition of the Lodgepole Formation is portrayed in Figure 7. Representative cross sections are shown in Figures 8 to 12 (in pocket).

Deposition of the Lodgepole marked the beginning of a major phase of marine transgression in Manitoba. In Lower Lodgepole time, an area of local subsidence, termed the Mandak Embayment by McCabe (1959) developed along the western portion of Manitoba. This embayment is characterized as an area of deepest water and fine argillaceous deposition. Eastward, where the water was shallower, higher energy grain supported rocks were deposited (Scallion Member) and local shoals developed.

Mississippian transgression appears to have ceased during late Lower Lodgepole time coupled with a decrease in water depth. Cyclical interbedded oolitic and crinoidal limestones and shales (Virden/Whitewater Lake) were deposited representing the first regressive phase of Mississippian seas. A subsequent decrease in the rate of subsidence followed with a slight increase in water depth. Basin infilling ensued, at which time the Upper Lodgepole sediments were deposited. This was followed by a regression and deposition of the Mission Canyon Formation (McCabe, 1959).

The proposed model for regional deposition of the Lodgepole Formation in Manitoba, shown in the schematic cross section (Fig. 7), is based on the previous work of Sereda (1990) and Young and Rosenthal (1991). In general, the grain supported rocks within the Lodgepole sequence represent higher energy, shoaling environments, where as the mud-supported rocks represent lower energy environments (LeFever *et al.*, 1995; Young and Rosenthal, 1991).

The Lodgepole sequence represents at least three depositional events (Sereda, 1990). The first is represented by the Scallion Member that forms a carbonate bank complex (Fig. 8, 9, 10) and is represented in the basin by a condensed section (Fig. 10). An unconformity at the top of the Scallion Member indicates that there may have been periods of subaerial exposure on the shelf (Young and Rosenthal, 1991).

The second event is marked by the deposition of oolitic and bioclastic carbonates on the shelf and mudstone and wackestone deposition on the slope and infilling of the basin (Fig. 9, 10). Along the shelf, deposits of oolitic and bioclastic carbonates such as the Lower Virden, Upper Virden and Upper Whitewater Lake Members predominate, where as wackestones and mudstones (Cromer Shale, Cruickshank Crinoidal and Middle Daly) prevail along the slope. Small localized depocentres may have occurred within the slope depositional setting. Examples of these local depocentres may occur at the Daly and Kirkella field areas. In the Tilston area, the entire Lower Lodgepole becomes more argillaceous (McCabe, 1959).The final event is represented by infilling of the Upper Lodgepole or Flossie Lake Member (Fig. 10).

The orientation of the shelf/slope break within the Lodgepole Formation is believed to be a lineament termed the Birdtail-Waskada axis, which was the locus for dissolution of Devonian Prairie Formation salts and influenced subsidence rates during Lodgepole time (Young and Rosenthal, 1991).The Birdtail-Waskada axis (McCabe, 1971) is a north-trending anomalous zone that extends from Township 23 south to the international boundary (Fig. 6). Tectonic movements have occurred along the Birdtail-Waskada axis since Precambrian time and it is the site of various structural anomalies (McCabe, 1971).

MOUND FACIES

Mounds, or similar "build-ups", may be present in various zones within the slope or basin depositional settings. These "build-ups" differ from the Waulsortian-type features noted by Sereda and Kent (1987) and Sereda (1990) in eastern Saskatchewan with respect to their areal extent and stratigraphic position along the Lodgepole depositional slope. In Manitoba, the mound "build-ups" are 0.4 to 0.8 km or less in size. They occur approximately mid-slope within the Cruickshank Crinoidal facies, as seen in the well at 14-4-10-28 WPM (Appendix II) and within the Middle Daly Member, where the crinoidal facies are locally thickened. Mounds or "build-ups" may also have developed near the toe of slope or basinal depositional setting of the Lodgepole Formation (Fig. 6, 7), in western Manitoba.

MAP SHOWING THE GENERAL DISTRIBUTION OF LODGEPOLE FORMATION DEPOSITIONAL ENVIRONMENTS

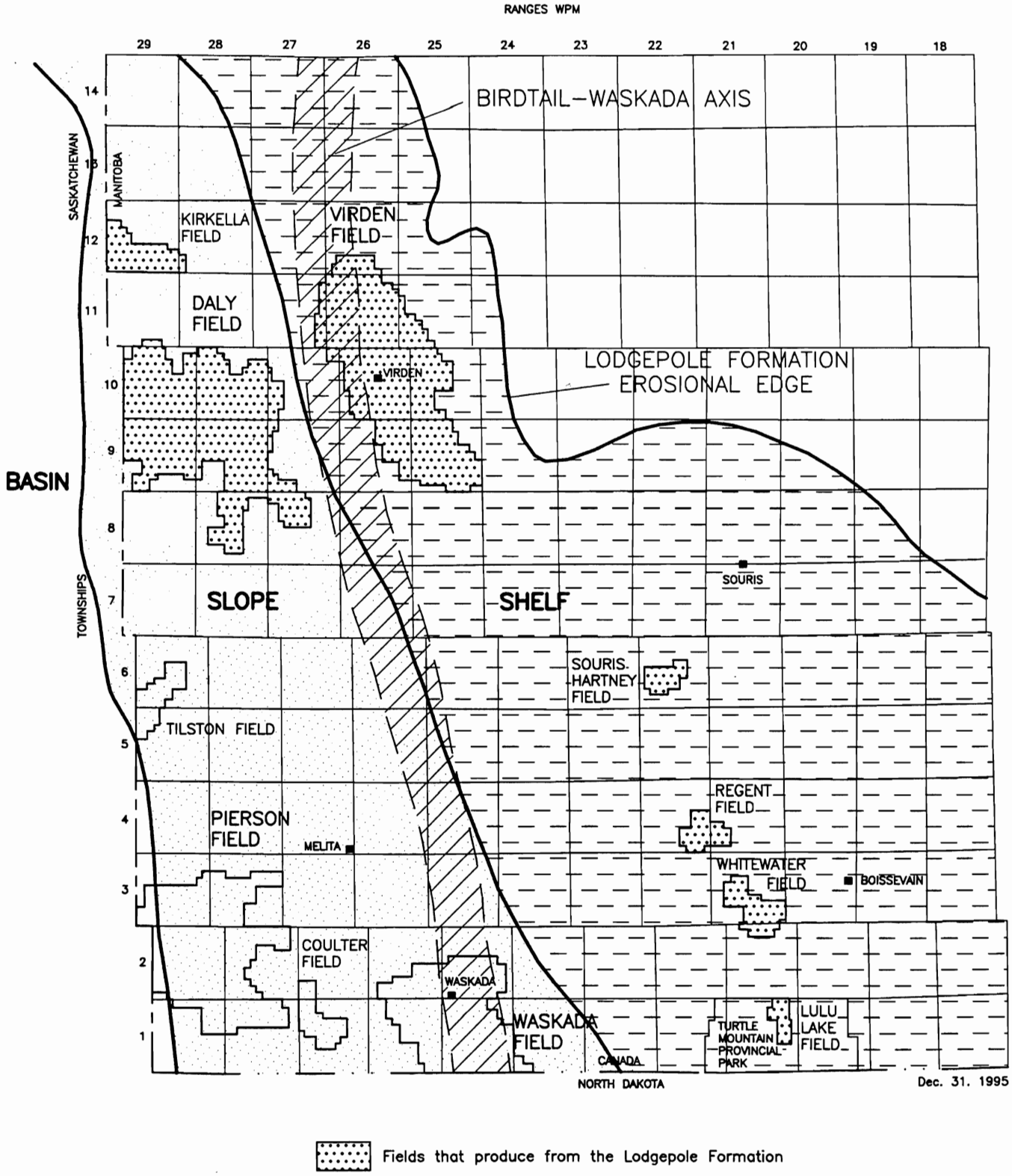


Figure 6: Map showing the general distribution of the Lodgepole Formation, depositional environments and major features.

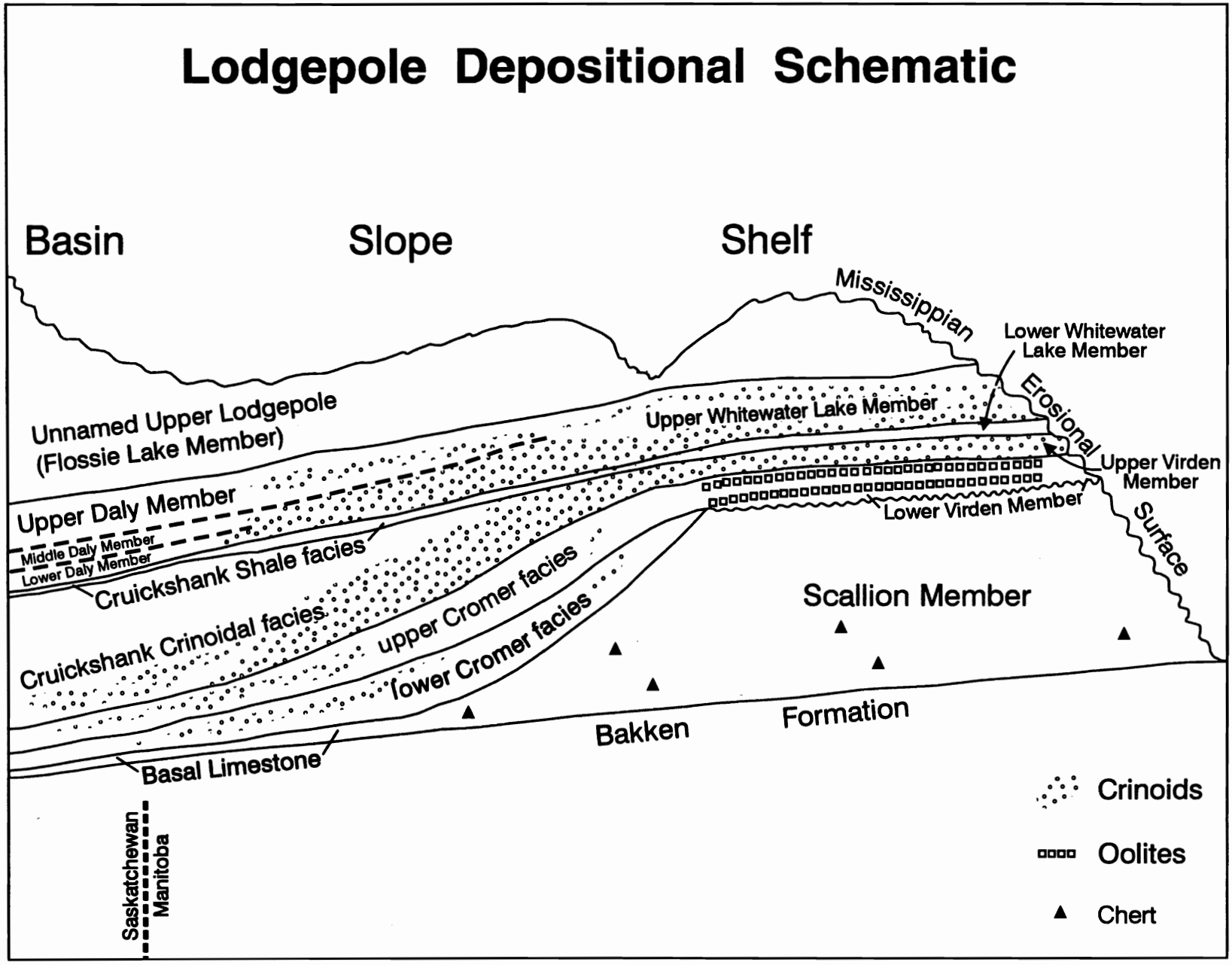


Figure 7: Depositional schematic of the Lodgepole Formation, southwestern Manitoba. Shows shelf, slope and basin stratigraphy.

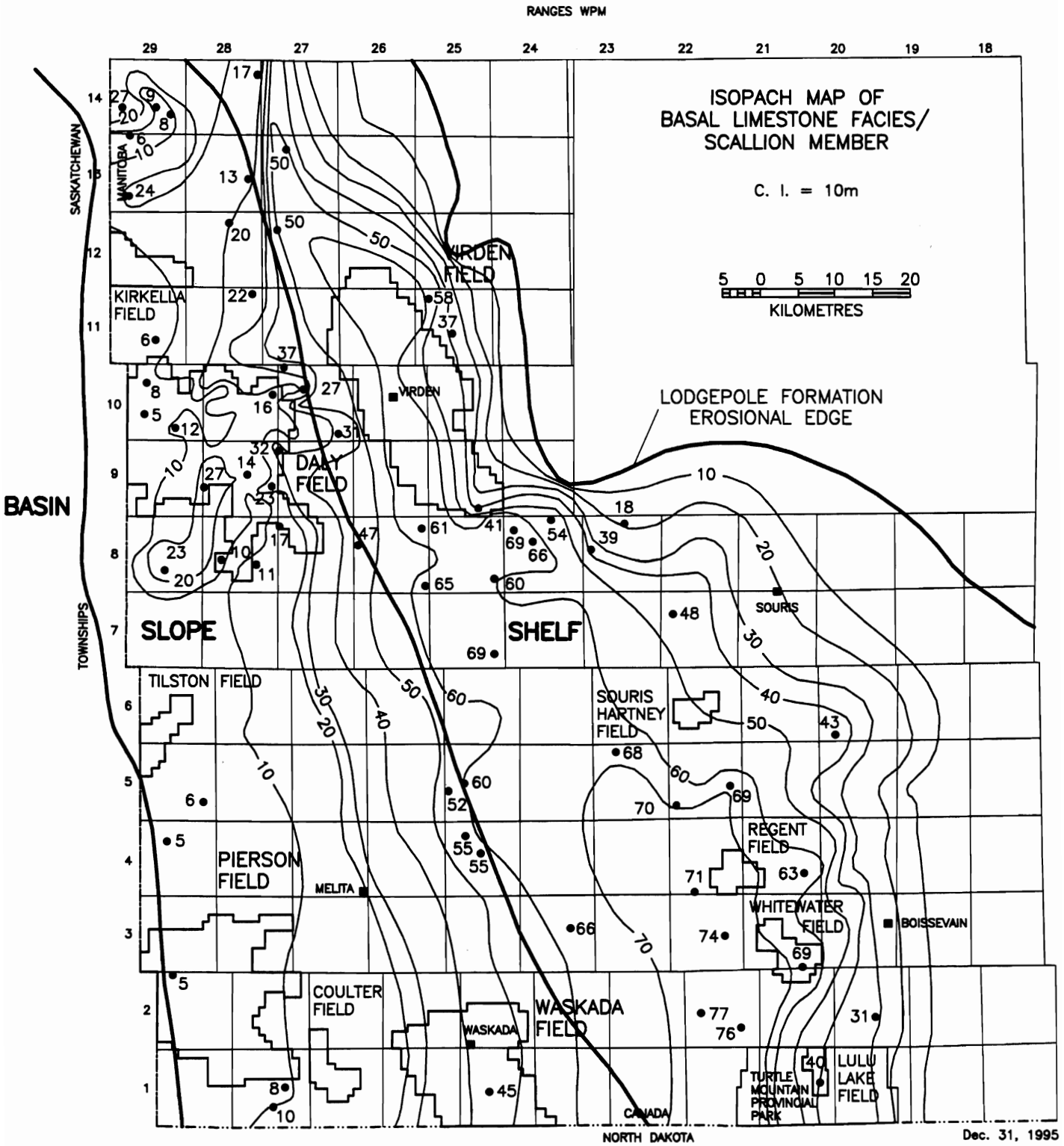


Figure 13: Isopach map of the Basal Limestone facies/Scallion Member.

LITHOLOGY

The following is a detailed description of lithofacies of the Lodgepole Formation based on observations derived from the examination of cores from thirty-two (32) wells in the study area (Fig. 2, Appendix I). Description of the core is based on the classification of Dunham (1962).

BASAL LIMESTONE FACIES (EQUIVALENT TO THE SCALLION MEMBER)

The dominant lithology of this unit is a maroon, mottled limy mudstone to a lesser abundant wackestone. Chert nodules are present. Fossils include crinoids, and corals are rare. Some vertical fracturing and stylolites were noted. Poor vuggy porosity was noted, but no staining was found. On the gamma log this facies is marked by a low response (Fig. 4).

The shelf equivalent of the Basal Limestone facies is the Scallion Member. It is composed of a mottled red and purple, fine to microcrystalline limestone with chert (McCabe, 1959; Martiniuk and Arbez, 1986). It is a reservoir facies and has produced at Virden, Souris Hartney and Whitewater Fields. The top of the Scallion is marked by an exposure event shown as a dolomitized mudstone with reddish colourization and interpreted as a "terra rosa" paleosol (Young and Rosenthal, 1991). The Routledge Shale, which is described as black shale similar to the underlying Upper Bakken, is present locally in the lowermost portion of the Scallion Member at Virden and Lulu Lake Fields. The Routledge is considered a time equivalent of the lower portion of the Scallion Member (Stanton, 1956). The facies ranges from 5 to 55 metres thick along the slope (Basal Limestone facies) and is up to 77 metres thick along the shelf (Scallion Member) (Fig. 13).

CROMER SHALE FACIES (EQUIVALENT TO THE LOWER VIRDEN MEMBER)

The Cromer Shale facies is a maroon to reddish brown, mottled shale to limy mudstone with interbeds of bioclastic grainstone (0.25 to 0.5 m). Scattered crinoids are present throughout. Grainstone beds are crinoid rich. The Cromer can be subdivided into a lower and upper unit. The top of the lower unit is marked by a prominent (2.6 m) bed of oil stained, wackestone to packstone noted locally in the well, 1-10-12-29 WPM, in the Kirkella Field (Fig. 5). This bed is recognized on the spontaneous potential log by a blocky, clean response. The lower unit pinches out before the shelf edge. The upper unit changes laterally to what is believed to be its shelf equivalent, the Lower Virden Member. The Lower Virden Member is described as cyclically interbedded oolitic grainstones and limy mudstones (McCabe, 1959; Martiniuk and Arbez, 1987). The facies ranges in thickness from 10 to 20 m on the shelf (Lower Virden Member) and ranges from 10 to 78 m along the slope (lower and upper units of the Cromer Shale facies) (Fig. 14).

CRUICKSHANK CRINOIDAL FACIES (EQUIVALENT TO THE UPPER VIRDEN MEMBER)

The Cruickshank Crinoidal facies is a light to medium brown, fine- to medium- crystalline wackestone to grainstone. It is dolomitic and contains abundant crinoids, brachiopods and some bryozoans. Anhydrite replacement of fossils is common. Commonly oil stained, the unit contains fair pinpoint and vuggy porosity. On gamma ray logs the facies exhibit a low response (Fig. 4). In the Daly Field, the Cruickshank Crinoidal facies is a productive facies.

This facies is correlative with the Upper Virden Member along the shelf and is composed of bioclastic grainstones (McCabe, 1959; Martiniuk and Arbez, 1987). Thickness of the unit ranges from 3 to over 18m along the shelf (Upper Virden Member) and from 2 to 49 m along the slope (Cruickshank Crinoidal facies) (Fig. 15).

CRUICKSHANK SHALE FACIES (EQUIVALENT TO THE LOWER WHITEWATER LAKE MEMBER)

The Cruickshank Shale facies is composed of mottled, maroon mudstone and maroon to pinkish grey, fine- to medium- crystalline dolomitic wackestone. The interval is fossiliferous with abundant crinoids and bryozoans. On the gamma ray log, the facies shows a higher response as compared to the Cruickshank Crinoidal facies.

This unit is believed to be equivalent to the Lower Whitewater Lake Member along the shelf and is described as a limy mudstone with bioclastic wackestone (McCabe, 1959; Martiniuk and Arbez, 1986). The facies ranges in thickness from 1 to 14m on the slope (Cruickshank Shale facies) to 1 to 10m along the shelf (Lower Whitewater Lake Member) (Fig. 16).

DALY MEMBER (EQUIVALENT TO THE UPPER WHITEWATER LAKE MEMBER)

The Daly Member has been divided into three units; the Lower, Middle and Upper (Organ and Russin, 1956). In the present study the Lower Daly could not be defined; only the Middle and Upper units will be described. In core, the top of Upper Daly sequence in core is noted by the first occurrence of limestone, where as the Middle Daly is marked by the presence of chert blebs and thin chert beds.

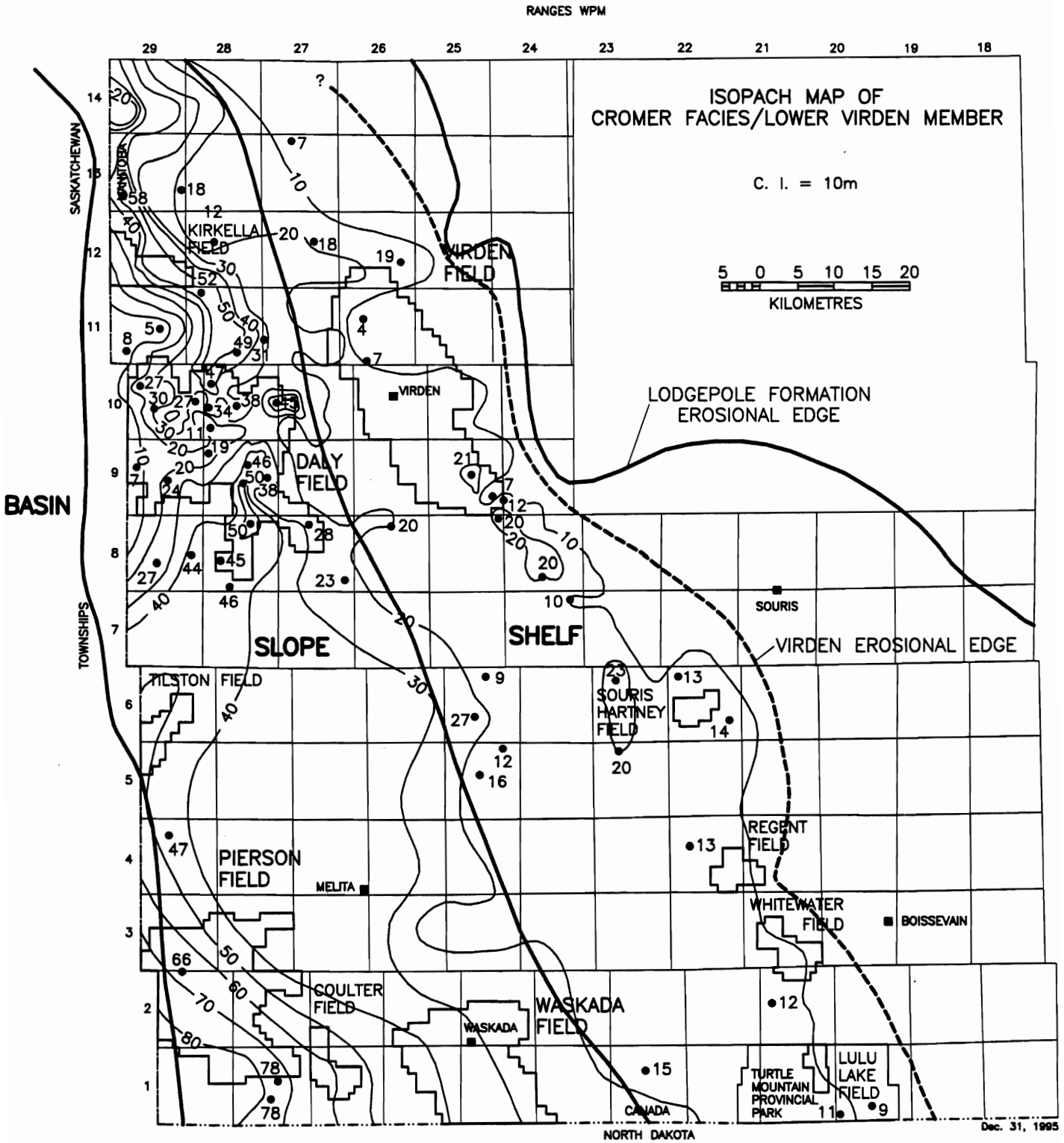


Figure 14: Isopach map of the Cromer Shale facies/Lower Virden Member.

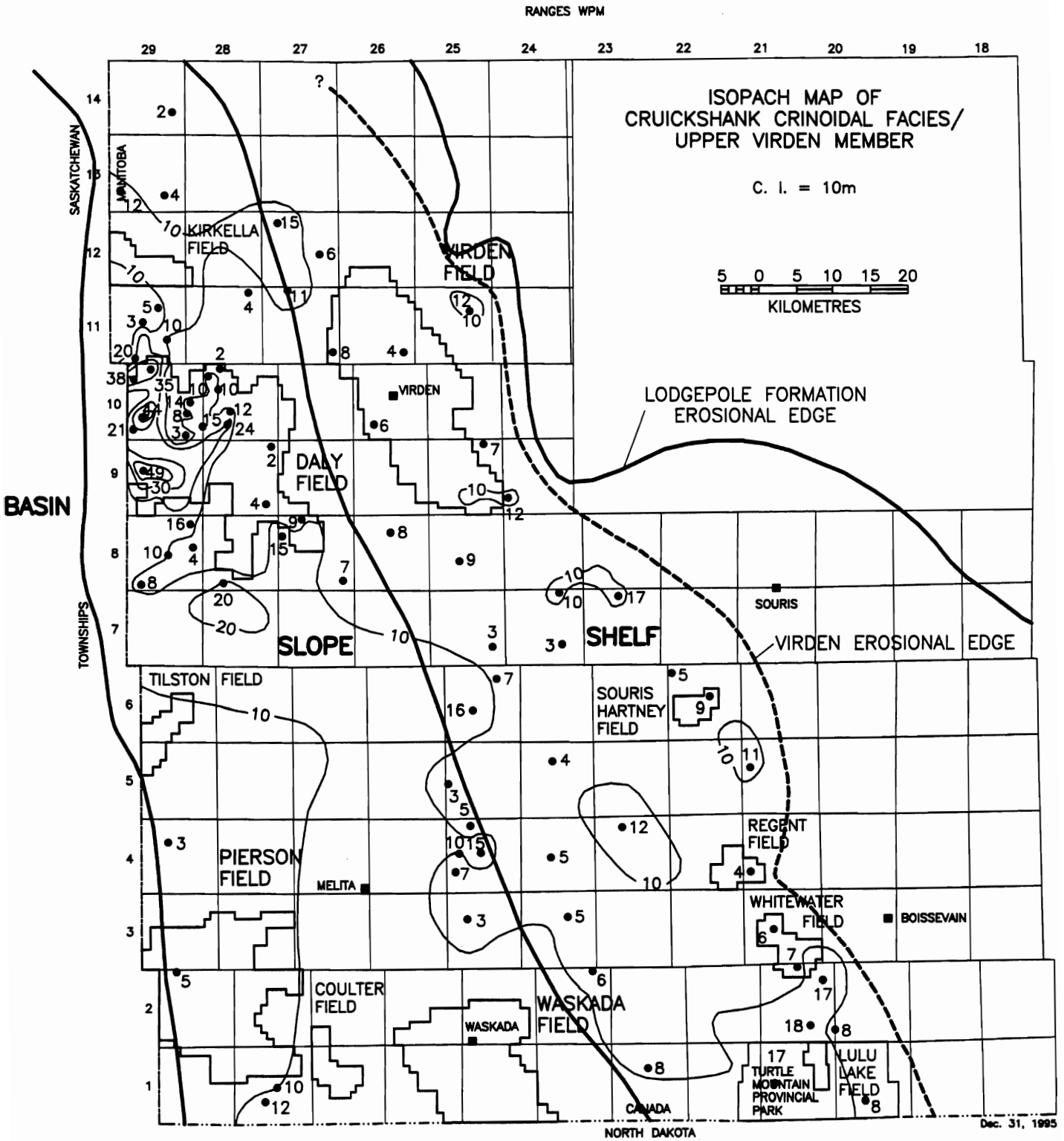


Figure 15: Isopach map of the Cruickshank Crinoidal facies/Upper Virden Member.

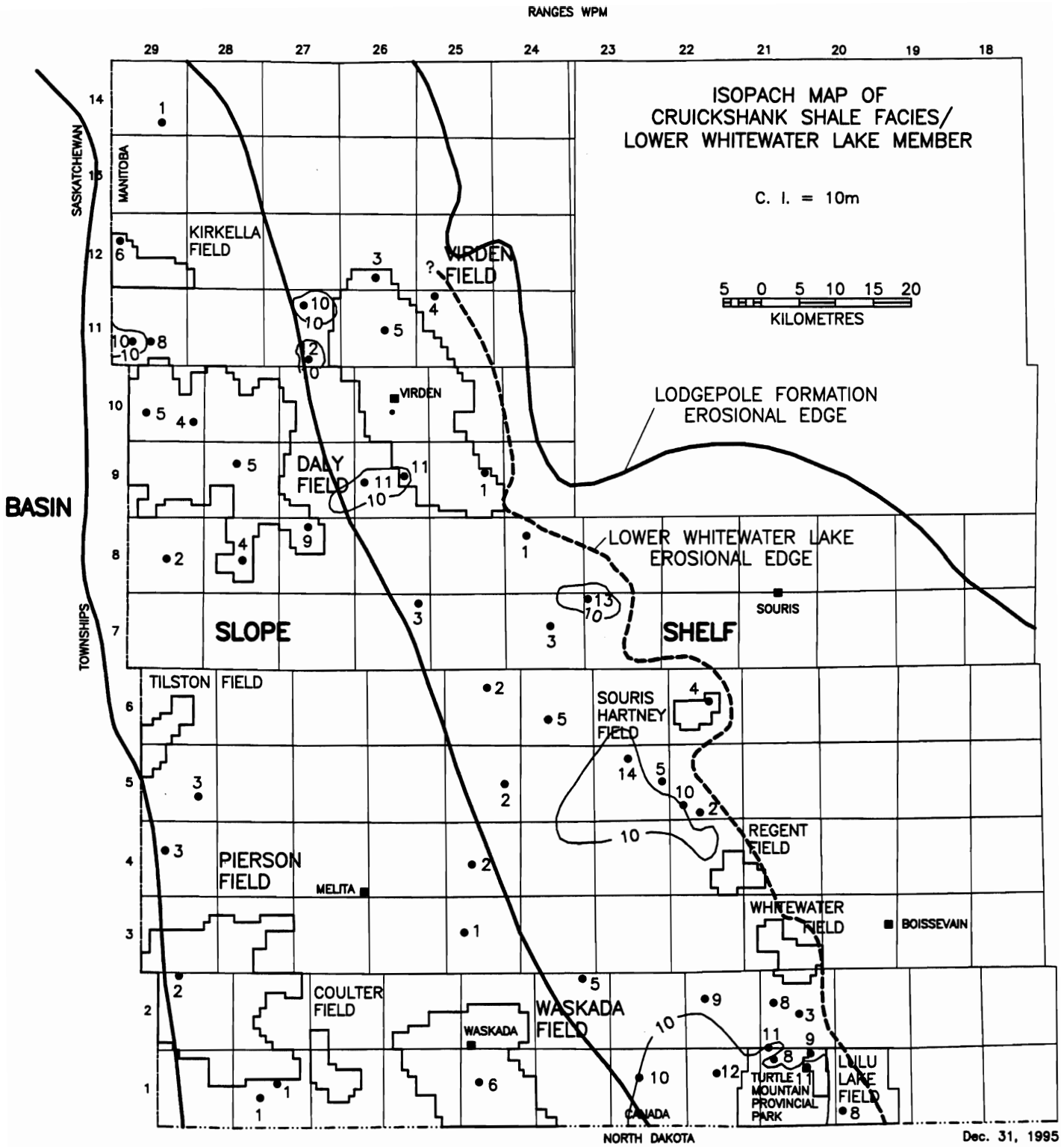


Figure 16: Isopach map of the Cruickshank Shale facies/Lower Whitewater Lake Member.

The Middle Daly Member is a light to medium brown, medium crystalline wackestone to packstone. Brachiopods, crinoids and bryozoans are the major fossil constituents. Oil staining is present with fair intercrystalline, microvuggy and vuggy porosity. Chert nodules and chert beds are distinctive. Blebs of anhydrite are also present.

The Upper Daly Member is composed of maroon, grey and light brown, limy mudstone, with blebs of anhydrite and minor chert. Fossils present are brachiopods, crinoids, and corals.

Even oil stain is present throughout the Daly units. Oil stained carbonates occur in juxtaposition within unstained silicifed units or anhydrite blebs which reflecting the complex diagenetic history of the unit. Both healed and open vertical fractures are present in the slope facies in the Daly area. In the Daly and Kirkella fields, the Middle Daly is the main reservoir bed.

On the shelf, the equivalent facies, the Upper Whitewater Lake Member, is composed of dolostone that has been altered from bioclastic limestone (McCabe, 1959; Martiniuk and Arbez, 1986). The unit varies in thickness from an average of 10 m on the shelf to an average of 34 m on the slope (Fig. 17).

UNNAMED UPPER LODGEPOLE (EQUIVALENT TO THE FLOSSIE LAKE MEMBER)

This unit is perhaps ironically called the "unnamed" and has been designated as the Upper Lodgepole undivided or Flossie Lake Member equivalent. McCabe (1963) applied the name Flossie Lake Member to the unnamed Upper Lodgepole beds in the well 10-21-1-23 WPM. The "unnamed" represents the section from the top of the Daly Member to the top of the Lodgepole Formation and is described as a light grey to mottled maroon, anhydritic, dolomitic wackestone to mudstone with occasional thin (less than 10 cm) beds of grainstone. Fractures are common and commonly infilled with anhydrite. The unit is fossiliferous and commonly includes crinoids, which are anhydrite replaced, and some brachiopods. Some oil staining is usually observed in this unit.

A breccia containing red, dolomitic shale of the overlying Lower Amaranth Formation and abundant anhydrite commonly marks the top of the Lodgepole Formation, representing the Mississippian erosional surface.

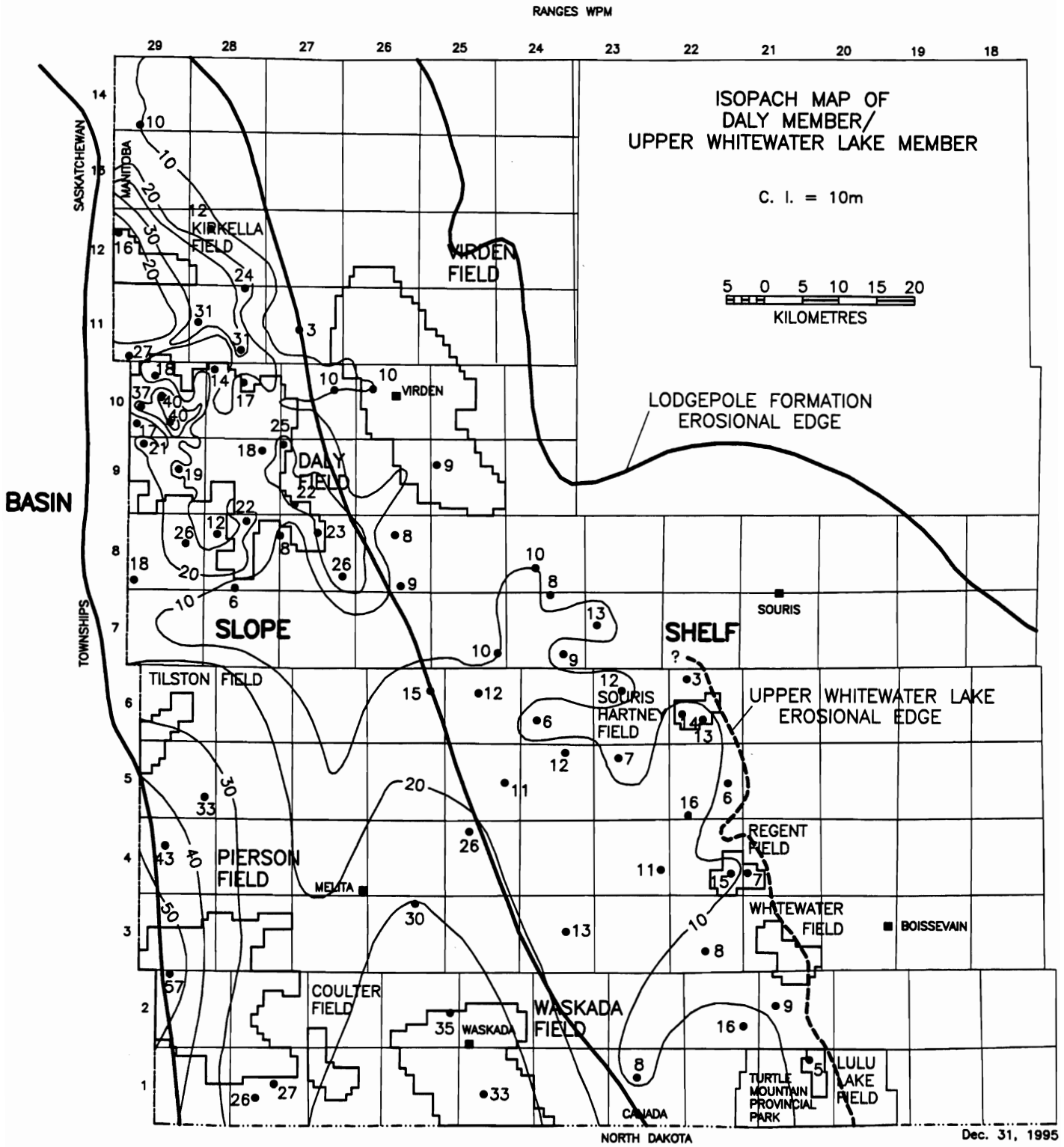


Figure 17: Isopach Map of Daly Member/Upper Whitewater Lake Member.

ISOPACH AND STRUCTURE

The five isopach maps (Fig. 13 to 17) included in this report reflect the overall clinoformal nature of Lodgepole Formation deposition in Manitoba.

The isopach map of the Basal Limestone facies/Scallion Member exhibits the clinoformal nature of the unit (Young and Rosenthal, 1991) (Fig. 13). The map shows a thick unit of up to 75m on the shelf thinning to less than 5m in the west towards the edge of the slope/basin The break in slope reflects deep structural features such as the Birdtail-Waskada axis (Fig. 6).

Figure 14 reflects the facies change in deposition from the thinner, high energy interbedded oolitic grainstones of the Lower Virden Member on the shelf, to the thicker shales of the lower Cromer Shale facies along the slope. The isopach of the Cruickshank Crinoidal facies (Fig. 15) exhibits thickening values in the Daly field area, reflecting the presence of localized "build-ups" within the slope depositional setting and within the various slope units.

The Cruickshank Shale facies/Lower Whitewater Lake Member isopach (Fig. 16) displays few changes within the Lower Whitewater on the shelf, but thins considerably along the slope and basin. It is interpreted that the nature of the Cruickshank Shale facies may be local in occurrence and that it may be recognized only as a marker in the basin depositional setting. The Lower Whitewater Lake Member appears to be a more widespread unit that can be correlated to other parts of the Williston Basin.

The Daly Member thickens into the basin in the Daly Field area (Fig. 17). Not mapped, but completing the sequence, is the Flossie Lake Member, which infills the entire basin (McCabe, 1959). Figure 11 displays a thickening of the Flossie Lake Member from 30 m in Township 12 to over 90 m in Township 1.

The structure map on top of the eroded Mississippian surface (Fig. 18) shows a regional dip to the southwest. A regional structural feature exhibited by the Lulu Lake to Virden Field trend indicates a structural rise to the northwest, which has been termed the "Birdtail Creek nose" by Potter (1991). A major synclinal trend exists between the Virden and Daly fields, which reflects the Birdtail-Waskada axis.

Deposition of the Lodgepole Formation has also been affected by Middle Devonian Prairie Formation salt dissolution in the Virden area (Potter, 1991) and in the Daly Field (McCabe, 1961). Dissolution of the Prairie salt may also have influenced the secondary dolomitization and diagenesis within the Lodgepole at these fields.

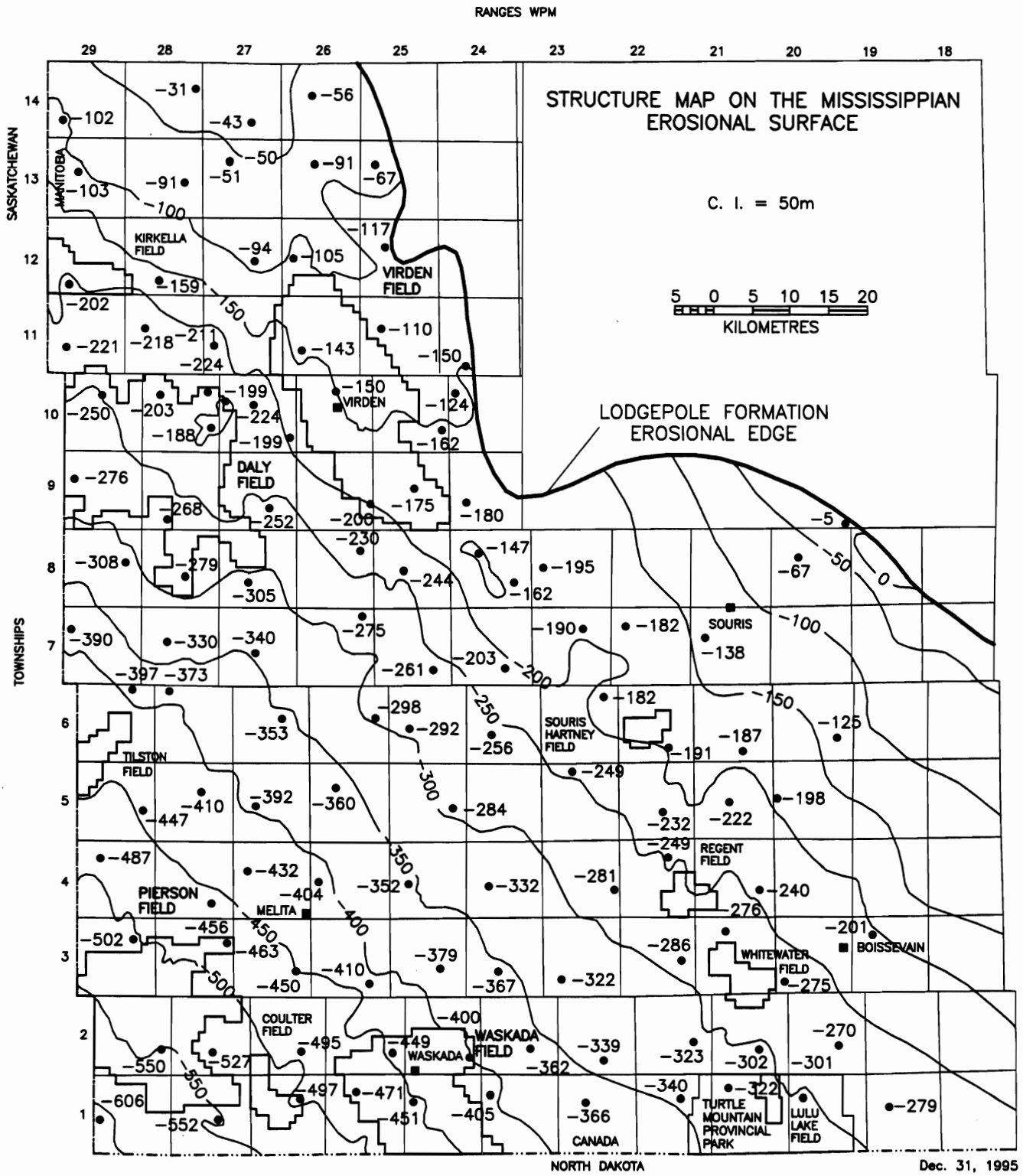


Figure 18: Structure on top of Mississippian Erosional Surface in southwestern Manitoba.

OIL PRODUCTION AND RESERVOIR PARAMETERS

SOUTHWESTERN MANITOBA

Reservoir characteristics and reserve parameters of the Lodgepole Formation in Southwestern Manitoba are presented in Tables 1 and 2. Cumulative oil production for the Lodgepole is shown in Figure 19.

Fields within the Lodgepole Formation produce from both the shelf and slope facies (Fig. 3, 19). Daly and Kirkella fields occur along the slope and produce from the Middle and Lower Daly Member and the Cruickshank Crinoidal facies. Virden, Souris Hartney, Whitewater, Regent and Lulu Lake fields occur along the Lodgepole shelf and produce from the Upper Whitewater Lake Member, the Upper Virden Member (Crinoidal), the Lower Virden Member (Sandhill, First, Second, Third, Fourth Oolite lentils) and the upper part of the Scallion Member.

Traps along the Lodgepole slope are mainly structural in nature with local stratigraphic influences. Porosity in Lodgepole Formation fields range from 9 to 19 % with water saturations ranging from 30 to 64 % and average pay thicknesses ranging from 1 to 13.6 m. Permeabilities range from 5 to 10 millidarcies in the Daly Field and 15 to 20 millidarcies in the Virden Field. Lodgepole reservoirs occur at shallow depths between 610 and 1007 m. Pool size varies from 16 ha to 3725 ha.

SASKATCHEWAN/NORTH DAKOTA

In southeastern Saskatchewan, the Lodgepole Formation has produced oil from mound facies equivalent to the Cruickshank Crinoidal facies in southwestern Manitoba (Sereda and Kent, 1987). In North Dakota, the Lodgepole Formation produces oil from Waulsortian-type mounds in the Dickinson County area that are believed to be equivalent to the Cruickshank Crinoidal facies (LeFever *et al.*, 1995; Burke and Diehl, 1994).

SOURCE ROCK AND MIGRATION PATHWAYS

Osadetz and Snowdon (1995) recognized four regionally significant Paleozoic source rock formations. Madison Group oils fall into Type II (Family C) oils. Lodgepole oils are believed to be sourced by bituminous carbonates within the Lodgepole Formation. These oils are characterized by long distance, lateral migration from the centre of the Williston Basin. Large reserves of Lodgepole Formation oil indicate the excellent hydraulic characteristics of the northeast flank of the basin (Martiniuk and Barchyn, 1993).

Table 1: Lodgepole Formation reservoir parameters by field, pool and unit, southwestern Manitoba (December 31, 1995)

FIELD/Pool/Unit	Developed Area (ha)	Average Pay Thickness (m)	Average Porosity	Average Water Saturation	Formation Volume Factor	Initial Solution GOR (m^3/m^3)	Density (kg/m^3)	Temp (°C)	Initial Pressure (kPa)	Producing Depth (m KB)
DALY FIELD										
Lodgepole A Pool										
Daly Unit 1	615.1	13.60	0.107	0.39	1.08	21.00	859	30.0	5861	762.0
Daly Unit 3	1263.0	7.32	0.107	0.39	1.08	21.00	859	30.0	5930	732.0
Daly Unit 4	840.0	8.30	0.134	0.39	1.05	21.00	845	26.1		750.0
Non Unit	2396.0	7.60	0.108	0.44	1.06	18.50	859	28.0	5516	775.0
Lodgepole B Pool	809.0	4.30	0.110	0.51	1.05		850			765.0
Lodgepole C Pool	260.0	8.01	0.086	0.40	1.06	15.50	856	29.0	7757	745.0
Lodgepole D Pool										
Daly Unit 5	97.0	7.10	0.130	0.35	1.04	18.00	850	40.0	6700	820.0
Ebor Unit 1	129.5	4.20	0.121	0.40	1.07	17.80	850	30.0	6688	795.5
Non Unit	1926.0	5.51	0.112	0.35	1.08	16.90	850	31.0	6688	795.0
Lodgepole F Pool										
W. Butler Unit 1	80.9	7.50	0.106	0.35	1.07	18.60	860	27.8	7239.8	853.0
Non Unit	97.1	7.50	0.106	0.35	1.07	18.50	854	27.8	7240	840.0
LULU LAKE FIELD										
Lodgepole WL A Pool	151.1	3.90	0.140	0.59	1.08		847	36.0	7544	1003.0
Lodgepole WL B Pool	67.0	3.00	0.130	0.56	1.06		850	38.0	7789	1007.0
VIRDEN FIELD										
Lodgepole A Pool										
N.V. Scallion Unit 1	3724.7	9.89	0.127	0.31	1.05	12.50	853	28.3	6247	612.0
N.V. Scallion Unit 2	226.6	3.35	0.190	0.35	1.05		860	27.8	6274	640.0
Non Unit	1510.0	5.03	0.131	0.30	1.05	12.50	853	28.3	6247	612.0
Lodgepole B Pool										
V. Roselea Unit 1	1488.0	9.20	0.122	0.50	1.05	15.70	852	28.9	5833	610.0
V. Roselea Unit 2	890.3	6.90	0.122	0.52	1.05	16.00	852	30.6	5171	610.0
V. Roselea Unit 3	1846.0	8.25	0.115	0.51	1.06	16.10	852	28.9	6378	610.0
Non Unit	2768.0	7.41	0.121	0.53	1.05	16.10	852	28.9	6032	610.0
Lodgepole C Pool										
Routledge Unit 1	1748.3	8.76	0.123	0.45	1.06	16.10	852	31.7	6716	635.0
Non Unit	712.3	7.80	0.120	0.45	1.05	16.10	852	33.0	6720	635.0
Lodgepole D Pool										
E. Routledge Unit 1	437.1	7.00	0.135	0.41	1.05	16.00	852	27.8	6743	635.0
Non Unit	81.0	4.20	0.128	0.50	1.08		852	28.0		635.0
Lodgepole E Pool	129.5	7.80	0.120	0.55	1.03					
WHITEWATER FIELD										
Lodgepole WL A Pool										
Whitewater Unit 1	97.0	6.10	0.113	0.35	1.05	17.80	861	29.0	7240	
Non Unit										
Lodgepole WL B Pool	724.0	3.50	0.140	0.43	1.06	10.60	861	33.0	7435	804.0
KIRKELLA FIELD										
Lodgepole Daly A Pool	210.5	8.10	0.116	0.44	1.02	1.50	888	29.1		730.0
Lodgepole Daly B Pool	194.3	5.42	0.116	0.52	1.03	3.19	896	37.8	6890	745.0
Lodgepole Daly C Pool	227.0	5.42	0.116	0.50	1.02	1.77	889	28.9		725.0
SOURIS HARTNEY FIELD										
Lodgepole Virden A Pool	536.9	2.85	0.121	0.53	1.06	12.48	866	32.2	6619	650.0
REGENT FIELD										
Lodgepole WL A Pool	192.0	4.71	0.135	0.49	1.06			37.0		
Lodgepole Virden B Pool	16.0	1.00	0.103	0.64	1.05			33.0	7102	
OTHER AREAS										
Lodgepole WL E Pool	96.0	4.31	0.152	0.54	1.06		860	31.0	6934	898.0
Average		6.32	0.122	0.45	1.05	14.85	858	30.8	6649	734.6

Table 2: Lodgepole Formation cumulative production by field and pool, southwestern Manitoba (December 31, 1995)

FIELD	POOL	Discovery Year	Avg. Depth Producing Zone (m)	Oil Density kg/m³	Sulphur Content g/kg	1995 Active Wells Oil Producers	Other	1995 Production (10^3 m³)	Cum. Oil Production to 95-12-31 (10^3 m³)	Remain. Proved Oil Reserves 12/31/95 (10^3 m³)	Remarks
Daly	Lodgepole A	1951	775	859	14.80	180	28	59.7	3981.1	783.4	P&W
	Lodgepole B	1954	765	850	12.90	17	3	2.5	295.6	6.2	P
	Lodgepole C	1954	745	856	13.00	5	0	0.5	156.4	0.5	P
	Lodgepole D	1954	795	850	12.00	83	6	12.9	407.1	57.1	P&Term.W
	Lodgepole E	1951	765	861	16.20	21	2	8.1	105.4	40.6	P
	Lodgepole F	1955	840	854	14.80	6	1	1.1	41.1	1.0	P&Term.W
	Lodgepole I	1985	825	850	12.00	1	0	0.1	5.2	0.0	P
	Lodgepole O	1993	750			1	0	0.0	1.2	0.0	Inactive
	Lodgepole P	1986	785			1	0	0.1	0.2	0.0	p
	Lodgepole Q	1986	770			3	0	0.3	4.8	0.9	P
	Lodgepole S	1986	860			1	0	0.1	3.6	0.0	P
	Abandoned Pools								2.5	0.0	Abandoned
Lulu Lake	Lodgepole WL A	1953	1000	847	9.48	5	0	0.7	50.5	0.9	P
	Lodgepole WL B	1984	1010	850	8.50	2	0	0.7	21.3	2.5	P
Virden	Lodgepole A	1953	610	860	14.00	225	62	101.1	11070.2	1261.5	P&W
	Lodgepole B	1953	610	852	13.10	210	72	73.8	7107.7	924.3	P&W
	Lodgepole C	1955	635	852	12.80	87	7	27.9	2271.0	126.6	P&W
	Lodgepole D	1964	630	857	13.30	18	7	5.4	539.3	40.9	P&W
	Lodgepole E	1956	645	851	13.70	1	1	0.4	24.2	3.2	P
	Abandoned Pools								0.1	0.0	Abandoned
Whitewater	Lodgepole WL A	1953	858	858	9.30	1	0	0.2	77.3	0.9	Term. W
	Lodgepole WL B	1982	859	859	10.20	24	0	8.4	159.9	52.0	P
	Abandoned Pools								1.2	0.0	Abandoned
Kirkella	Lodgepole Dolomite A	1978	730	897	21.60	3	0	0.5	11.6	0.0	P
	Lodgepole Dolomite B	1981	735			1	0	0.0	1.1	0.0	Inactive
	Lodgepole Daly A	1957	730	888	20.50	8	1	1.5	156.9	10.5	P
	Lodgepole Daly B	1978	745	696	21.10	10	2	1.4	49.4	10.0	P
	Lodgepole Daly C	1980	725	903	22.40	12	3	3.0	75.6	3.6	P
	Abandoned Pools								1.5	0.0	Abandoned
Souris Hartney	Lodgepole Virden A	1962	655	866	10.40	10	0	8.2	162.5	44.4	P
Regent	Lodgepole WL A	1986	770	853	9.80	8	0	1.5	27.9	3.2	P
	Abandoned Pools								11.2	0.0	Abandoned
Other	Lodgepole WL E	1982	895	860	10.30	3	1	3.5	40.1	21.3	P
	Lodgepole B	1954	755			1	0	0.0	0.1	0.0	Inactive
	Lodgepole H	1985	820			1	0	0.0	0.8	0.1	P
Total						949	196	323.6	26865.6	3395.6	

Key to Remarks
P - Primary
W - Waterflood
Term. W. - Terminated Waterflood

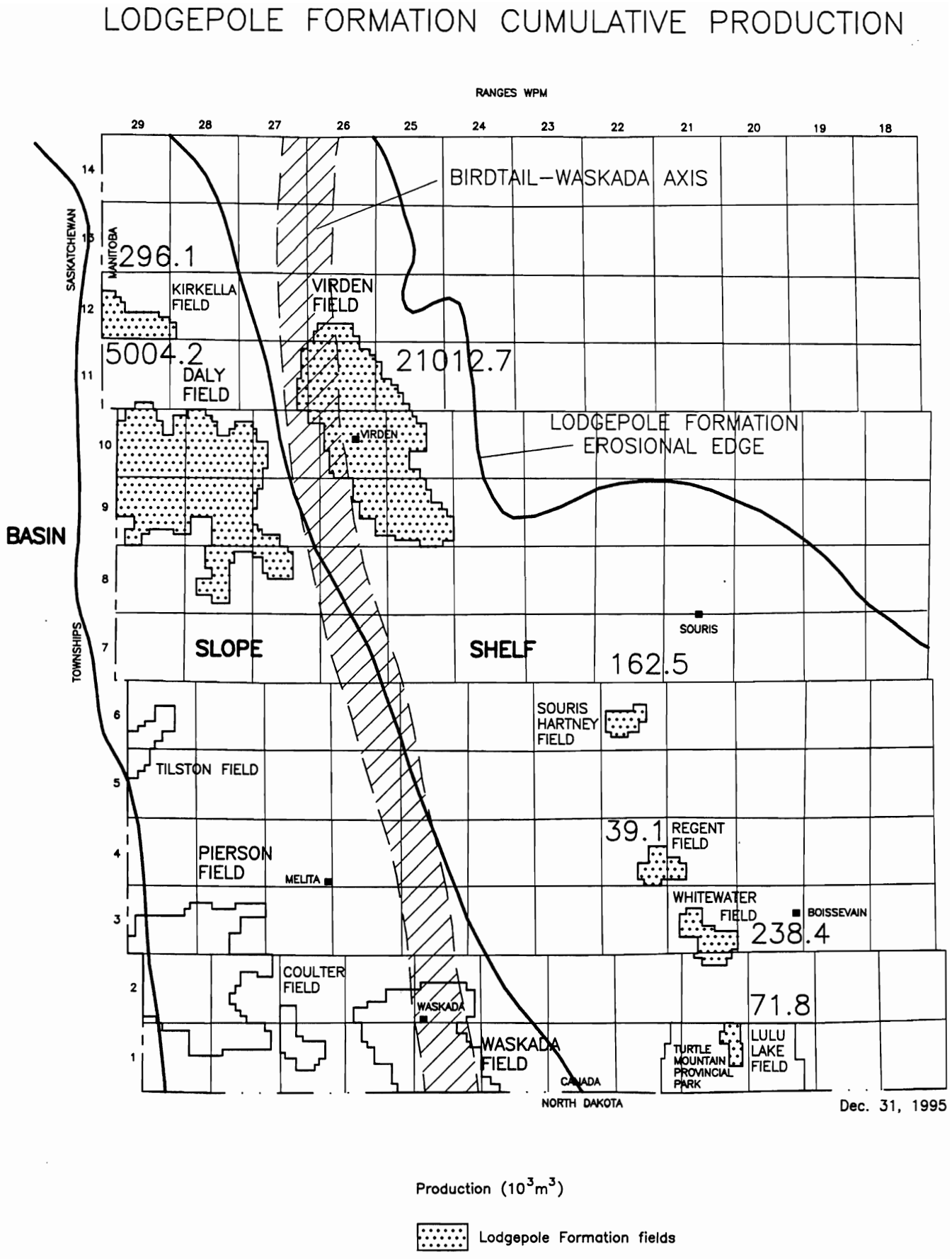


Figure 19: Map showing Lodgepole Formation producing fields. Cumulative oil production to December 31, 1995 (x 1000 m^3)

EXPLORATION MODEL

Potential for new plays within the Lodgepole Formation can be found within the three depositional environments recognized in this report; the shelf, slope and basin.

In the shelf area, bioclastic and oolitic grainstones of the Upper Whitewater Lake and Upper and Lower Virden Members are the main target south of the Virden Field. New plays should focus along this trend where Lodgepole erosional highs may be present (Potter, 1991; Fox and Martiniuk, 1992). Due to the heterogeneous nature and low permeabilites of reservoirs within this area, potential for horizontal drilling to improve oil recovery, particularly unswept of oil in mature waterfloods, should be investigated.

Regions north (Township 11, Range 28 and 29 WPM) and south (Townships 7 and 8, Ranges 27 to 29 WPM) of the Daly field have little well control and may be the focus of new plays centred on the recognition of a new stratigraphic model for the slope area. The slope depositional setting may have additional potential reservoirs based on finding anomalous thicks such as the Cruickshank Crinoidal facies at 14-4-10-27 WPM (Fig. 10). Within the slope, increases in carbonate grain size within multiple zones may reflect the potential for new reservoirs. In the Kirkella area, potential may exist within oil stained wackestones at the top of lower Cromer Shale facies (Fig. 5). Based on the recognition of fractures observed in slope cores, horizontal drilling would appear to be beneficial and should be investigated further.

Mounds or "build-ups" may be present in basinal or lower slope areas along or near the Saskatchewan border which may be located by seismic. In addition, the extreme southwest corner of Manitoba, which may be in a basinal depositional setting, has been unexplored for Lodgepole reservoirs potential. Possibilities may exist for mounds south of Township 8 (Fig. 6). Other areas in the extreme western portion of the Daly and Kirkella fields may also be good sites for investigation. The presence of inclined bedding (Cromer Shale facies) in the core at 1-10-12-29 WPM are similar to those beds described by Sereda and Kent (1987) in eastern Saskatchewan and may indicate proximity to local mounds or "build-ups".

The importance of regional structural trends such as the Birdtail-Waskada Axis and the presence of major salt solution features should not be overlooked. The Birdtail-Waskada Axis is coincident with the break between slope and shelf (Fig. 6). Numerous structural lows in the Virden area are the result of salt dissolution (McCabe, 1963). These lows are important in preventing further updip oil migration and because these lows affect structure, trapping and diagenesis are also affected. Potential traps related to the dissolution of Prairie Formation salt remain an important target in southwestern Manitoba.

Examination of the cores indicates that diagenesis plays an important role in the development and/or maintenance of porosity and permeability within the Lodgepole Formation. This opens the prospect of additional stratigraphic traps which will require further study.

CONCLUSIONS

In Manitoba, the Lodgepole Formation is the main producing horizon. As of December 31, 1995, it has cumulatively produced 26 865 600 m^3 of oil.

The Lodgepole Formation can be described as three depositional settings; shelf, slope and basin. Multiple carbonate zones within these settings have oil potential.

Virden, Souris Hartney, Whitewater Lake, Regent and Lulu Lake produce from shelf facies; while the Daly and Kirkella fields produce from slope facies. Additional reservoirs may be exist within the slope facies within the lower unit of the Cromer Shale facies and within the Cruickshank Crinoidal facies between the Daly and Kirkella fields, where an increase in carbonate grain size is observed. Areas south of Daly Field also have potential in the slope depositional setting. Although the basin facies may be of limited extent in Manitoba, potential may also exist for the presence of mounds or "build-ups".

Utilizing the new stratigraphic interpretation is key to developing new plays in a relatively mature portion of the Williston Basin. Seismic interpreted in the area should be related to the three depositional settings noted within the Lodgepole Formation in this report.

Because of diagenetic effects observed within the Lodgepole Formation, it is recommended that new studies are required to assess the effects of diagenesis as a control on porosity and permeability distribution within the Daly, Virden and Kirkella field areas.

On the shelf area, the main play is Lodgepole erosional highs similar to the trend of fields from Virden to Lulu Lake. In addition, the broad area of the shelf and slope depositional settings south of Township 8 (Fig. 6) requires additional study within the Lodgepole Formation to develop new plays.

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APPENDIX I

List of Lodgepole Formation cores from select wells in southwestern Manitoba examined for this report

Well Location	Interval Feet (ft.) or Metres (m)
1-28-1-24 WPM	2915-2975 ft. (888.5-906.8 m)
15-11-2-24 WPM	873-891 m
1-15-3-25 WPM	2801-2864, 2936-2986 ft. (853.7-872.9, 894.9-910.1 m)
8-20-4-25 WPM	2640-2820 ft. (804.7-859.5 m)
9-14-5-25 WPM	2447-2625 ft. (745.8-800.1 m)
14-28-9-25 WPM	1974-2125 ft. (601.7-647.7 m)
5-18-9-27 WPM	2332-2477 ft. (710.8-755 m)
1-30-9-28 WPM	2569-2920 ft. (783-890 m)
13-29-9-29 WPM	2665-2825 ft. (812.3-861.1 m)
1-31-9-29 WPM	2667-2839 ft. (812.9-865.3 m)
13-8-10-26 WPM	2050-2268 ft. (624.6-691.3 m)
11-14-10-26 WPM	1950-2084 ft. (594.4-635.2 m)
6-28-10-26 WPM	2055-2162 ft. (626.4-659 m)
A7-34-10-26 WPM	581-609 m
5-3-10-27 WPM	2296-2503 ft. (699.8-762.9 m)
4-12-10-27 WPM	2215-2325, 2332-2432 ft. (675.1-708.7, 710.8-741.3 m)
10-18-10-27 WPM	2200-2334 ft. (670.6-711.4 m)
16-20-10-27 WPM	2339-2592 ft. (712.9-790 m)
12-2-10-28 WPM	2340-2460 ft. (713.2-749.8 m)
15-2-10-28 WPM	2304-2318 ft. (702.3-706.5 m)
14-4-10-28 WPM	2388-2727 ft. (727.9-831.2 m)
9-6-10-28 WPM	2492-2617 ft. (759.6-797.7 m)
1-9-10-28 WPM	2411-2536 ft. (734.9-773 m)
6-10-10-28 WPM	2361-2501 ft. (719.6-762.3 m)
10-12-10-28 WPM	2246-2595 ft. (684.6-791 m)
15-2-10-29 WPM	767-785 m
2-32-11-25 WPM	1842-1929 ft. (561.4-588 m)
7-8-11-26 WPM	609-645 m
5-11-11-26 WPM	1965-2041 ft. (598.9-622.1 m)
7-16-11-27 WPM	2209-2229, 2244-2264 ft. (673.3-679.4, 684-690 m)
16-18-11-28 WPM	2350-2500 ft. (716.3-762 m)
16-3-11-29 WPM	2476-2615 ft. (754.7-797.1 m)
5-1-12-26 WPM	1824-1974 ft. (556-601.7 m)
1-10-12-29 WPM	2215-2760 ft. (675.1-841.2 m)
12-28-13-26 WPM	1760-1810 ft. (536.4-551.7 m)
3-28-13-29 WPM	2001-2080 ft. (609.9-634m)
15-10-14-27 WPM	1420-1445 ft. (432.8-440.4 m)

APPENDIX II
Select Lodgepole Formation core descriptions

Interval (ft./m)	Thickness (ft/m)	Description
Cdn Sup Cruickshank 14-4 14-4-10-28 WPM KB: 1660 ft. (506 m) Cored Interval: 2388-2727 ft. (727.9-831.2 m)		
Upper Lodgepole		
2388-2398 ft. (727.9-730.9 m)	10.0 ft. 3m)	Dolostone: light brown, fine crystalline, brecciated in part, reddish-brown shale as rip-up clasts and interbeds. Anhydrite: light grey, as interbeds (0.7-14"; 1.7-35.6 cm) and blebs throughout.
2398-2437 ft. (730.9-742.8 m)	39.0 (11.9m)	Dolostone: light brown fine crystalline, pinpoint vugs, massive, patchy to continuous oil staining (in part) with bands and stringers of light grey anhydrite (1-6 in.; 2.5-15.2 cm) and interbeds (2-4 in.; 5-10.2 cm) of bio clastic dolomite ("fossil hash": crinoids and brachio pods), fractures infilled with anhydrite, moldic and pin point porosity associated with brachiopods, interbeds throughout.
Upper Daly Member	2437 ft. (742.8 m)	
2437-2437.5 ft. (742.8-743m)	0.5 ft. (0.2 m)	Dolostone: purplish grey, fossiliferous (crinoids, brachiopods), silicified.
2437.5-2441 ft. (743-744 m)	3.5 ft. (1.0 m)	Dolostone: light brown, fine crystalline, light (brown oil stain with interbeds of white to light grey anhydrite(1-3 in.; 2.5-7.6 cm), thinly laminated reddish-brown bioclastic dolomite and purplish-red shale partings.
2441-2450 ft. (744-746.8m)	9.0 ft. (2.8 m)	Lime Mudstone: purplish grey, fine crystalline, with purplish-red argillaceous shale parting throughout, soft sediment deformation in part, occasional blebs of blue-grey anhydrite, interbeds of 0.5 in. (1.3 cm) thick of massive lime mudstone.
2450-2456 ft. (746.8-748.6m)	6.0 ft. (1.8 m)	Lime Mudstone: light grey to purplish-grey with interbeds of fine laminated mudstone, some brachiopods near base, some replacement anhydrite.
2456-2460 ft. (748.6-749.8 m)	4.0 ft. (1.2 m)	Lime Mudstone: light brown to grey, very fine crystalline, blebs of chert (2 in.; 5 cm), blebs of anhy drite (0.25 in.; 0.64 cm).
2460-2467 ft. (749.8-751.9 m)	7.0 ft. (2.1m)	Mudstone with Packstone interbeds: light brown to purple with purple shale partings and (2-8 in.; 5-8 cm) interbeds of Packstone: pink to purple, fossiliferous brachiopods/corals/crinoids).

2467-2468.5 ft. (751.9-752.4 m)	1.5 ft. (0.5 m)	Wackestone to Packstone: pink to light brown, medium to coarse crystalline, fossils (brachiopods/crinoids/bryozoans), saccharoidal.
Lower Daly Member	2468.5 ft. (752.4 m)	
2468.5-2480.5 ft. (752.9-756.1 m)	12.0 ft. (3.7 m)	Lime Mudstone: light to medium. brown, oil-stained, fine laminated in part with bands of (0.5-2 in.; 1.3-5 cm thick) replaced Wackestone: medium brown, fossiliferous (crinoids/brachiopods/corals), chert odules (2 in.; 5 cm) and bands common.
2485.5-2487.75 ft. (757.6-758.5 m)	2.25 ft. (0.7 m)	Mudstone to Wackestone: medium brown to pink, fair moldic porosity, scattered oil stain, crinoids, branching bryozoan, corals, anhydritic.
Cruickshank Shale facies	(2487.75 ft.; 758.3 m)	
2487.75-2489.5 ft. (758.3-758.8 m)	2.25 ft. (0.7m)	Dolomitic Packstone: pinkish-grey, crinoids replaced by anhydrite, coral fragments, red shale partings.
2489.5-2491.4 ft. (758.8-759.4 m)	1.75 ft. (0.5 m)	Dolomitic Packstone: pinkish-grey, abundant crinoids, medium crystalline, minor red shale partings.
2491.4-2495.8 ft. (759.4-760.7 m)	4.4 ft. (1.3 m)	Dolomitic Wackestone: purplish-grey, laminated with anhydrite replacement as blebs and lenses, abundant bryozoans, argillaceous laminations and lenses(purple), crinoids towards base with poor moldic porosity: anhydrite blebs common in basal 6 in. (15.2 cm)
2495.8-2504.3 ft. (760.7-763.3 m)	8.5 ft. (2.6 m)	Limy Dolostone: mottled purplish-grey, fine crystalline with shale partings throughout, anhydrite as replacement cement and blebs, abundant crinoids and bryozoans with some brachiopods in muddy matrix.
Cruickshank Crinoidal facies	2504.3 ft. (763.3 m)	
2504.3-2510.0 ft. (763.3-765 m)	5.7 ft. (1.7 m)	Packstone: light grey-brown, medium to coarsely crystalline, poor pin point vuggy porosity and fair intercrystalline porosity, light oil stain, anhydrite cement, dolomitic.
2510-2516.8 ft. (765-767.1 m)	6.8 ft. (2.1 m)	Dolostone: light to medium brown fine-to medium-crystalline, fair moldic porosity, trace light oil stain, blebs and stringers of anhydrite and replacing crinoids and brachiopods,(0.5-1 in.; 1.3-2.5 cm) bands of fine laminated dolostone.
2516.8-2524.8 ft. (767.1-769.6 m)	8.0 ft. (2.5 m)	Dolomitic Wackestone to Packstone: light to medium brown, saccharoidal (recrystallized crinoids), even oil staining, poor moldic porosity, occasional wispy anhydrite parting (shale replacement ?), anhydrite as cement and replacement.
2524.8-2532.8 ft. (769.6-772 m)	8.0 ft. (2.5 m)	Limy Dolostone: light brown, fine crystalline, medium even oil stain throughout, poor intercrystalline porosity, black and white chert nodules (up to 2 in.; 5 cm), anhydrite replacing scattered brachiopods and crinoids and as occasional wispy partings, saccharoidal in part.

2532.8-2541.0 ft. (772-774.5 m)	8.2 ft. (2.5 m)	Dolomitic Wackestone: light to medium brown, medium to coarse crystalline, wispy black shale partings, occasional medium even oil stainthroughout, poor to fair intercrystalline porosity, crinoids with trace of brachiopods, saccharoidal.
2541.0-2571.8 ft. (774.5-783.9 m)	30.8 ft. (9.4 m)	Mudstone to Wackestone: medium to light brown,wispy black shale parting and laminations throughout,silicified limestone beds (3-6 in.; 7.6-15.2 cm), even oil stained in non-silicified beds, very poor intercrystalline porosity. Crinoids with some-brachiopods (replaced by anhydrite).
2571.8-2578.5 ft. (783.9-785.9 m)	6.7 ft. (2 m)	Grainstone: light brown to light grey, abundant crinoids (replaced by anhydrite), occasional brachiopods, spotty staining, occasionally poor moldic porosity, mottled light grey to light brown in part (anhydrite replacement ?), occasionally faint wispy black shale partings.
2578.5-2582.5 ft. (785.9-787.1 m)	4.0 ft. (1.2 m)	Mudstone with Wackestone to Grainstone interbeds: Grainstone: light brown to pinkish brown, abundant crinoids replaced by anhydrite, very poor moldic porosity, 0.5-1 in. (1.3-2.5 cm) thick. Mudstone: light brown, wispy laminations, exhibits soft sediment deformation.
Cromer Shale facies	2582.5 ft.; (787.1 m)	
2582.5-2614.5 ft. (787.1-796.9 m)	32 ft. (9.8 m)	Lime mudstone: purplish-grey and mottled light brown, "fossil hash" is Packstone to Grainstone, brachiopods, rare Foraminifera, bryozoans, cephalopods and crinoids floating in mud matrix-infilled by mud and anhydrite, replaced at 2582.5 (787.1 m) and 2585.5 ft. (788 m) (4-6 in.; 10.1-15.2 cm thick), argillaceous. Upper contact is gradational.
2614.5-2615.5 ft. (796.9-797.2m)	1 ft. 0.3 m)	Missing.
2615.5-2620.0 ft. (797.2-797.2 m)	4.5 ft. (1.4 m)	Shale to Mudstone: reddish, very argillaceous, few scattered crinoids in concentrated (2-4 in.; 5-10.1 cm) bands, faintly laminated throughout.
2620.0-2654.0 ft. (797.2-808.9.m)	34.0 ft. (10.3 m)	Missing.
Basal Limestone facies	2654.0 ft.; (808.9 m)	
2654.0-2696.0 ft. (808.9-821.7 m)	42 ft. (12.8 m)	Lime Mudstone: pink and purple mottled throughout, scattered crinoids and rare corals, "birdseye" wispy laminations of purple shale-soft sediment deformation throughout, grey irregular chert nodules (2 in.; 5 cm), occasionally vertical fractures infilled with anhydrite (5 ft.; 1.5 m) from 2665 ft. (812.3 m), with reddish coloration in top 15 feet (4.6 m).
Bakken Formation	2696.0 ft. (821.7 m)	
2696.0-2702.0 ft. (821.7-823.6 m)	6 ft. (1.8 m)	Shale: black to reddish black, massive, non-calcareous, sharp upper contact.
2702-2727 ft. (823.6-831.2 m)	5 ft. (1.5 m)	Not examined.

Cdn Sup Skinner 6-28
6-28-10-26 WPM
KB: 1486 ft. (452.9m)

Cored Interval:
2055-2211 ft. (626.4-673.9 m)

2053-2067 ft. (625.8-630 m)	12 ft. (4.2 m)	Dolomitic Mudstone: light grey/brown to light maroon, occasional beds of maroon to purple Grainstone, (2-3 in.; 5-7.6 cm thick), "fossil hash" of mainly crinoids, some thin, wispy, dark maroon beds of mudstone, thin bands of light grey anhydrite and blebs of light grey chert, anhydrite filled fractures.
2067-2078 ft. (630-633.4 m)	11 ft. (3.4 m)	Mudstone: mottled light grey/brown and light maroon, dolomitic, very fine crystalline, rare crinoids, thin interbeds of brown-grey mudstone, mottled appearance predominates, vertical fractures with some blebs and thin bands of light grey anhydrite.
2078-2082 ft. (633.4-634.6 m)	4 ft. (1.2 m)	Mudstone: light grey to light maroon, dolomitic, slightly calcareous, some thinly laminated beds
2082-2083 ft. (634.9-638.6 m)	1 ft. (0.3 m)	Grainstone: limy, grey with maroon specks, abundant crinoids and brachiopods.
2083-2095 ft. (634.9-638.6 m)	12 ft. (3.7 m)	Mudstone to Wackestone: light grey, white to occasional light maroon, very fine crystalline, dolomitic, some crinoids and light grey chert blebs (2 in.; 5 cm), some wispy bedding in mudstone.
2095-2110 ft. (638.6-643.1 m)	15 ft. (4.5 m)	Mudstone to Wackestone: limy, very fine crystalline, some crinoids, blebs of tripolitic chert, poor vuggy porosity, even oil stain.
Lower Whitewater Lake Member	2110.0 ft. (643.1 m)	
2110-2117 ft. (643.1-645.3 m)	7 ft. (2.1 m)	Grainstone with Mudstone interbeds: Grainstone: light grey to light maroon, fine to medium crystalline, limy. Mudstone grey to light maroon, some maroon and grey mottling, blebs of light grey tripolitic chert, some dark maroon, wispy bedding.
2117-2126 ft. (645.3-648 m)	9 ft. (2.7 m)	as above: mudstone predominates, mottling prominent in mudstone interval, light grey chert blebs, crinoids in grainstone beds.
Upper Virden Member	2126.0 ft. (648 m)	
2126-2131 ft. (648-649.5 m)	6 ft (1.7 m)	Grainstone: light grey to light maroon, fine to medium crystalline, limy, crinoids, brachiopods and bryozoans.
2131-2135 ft. (649.5-650.7 m)	4 ft. (1.2 m)	Packstone: light grey, fine crystalline, crinoids, chert blebs.
2135-2136 ft. (650.7-651.1 m)	1 ft. (0.3 m)	Missing.

2136-2143 ft. (651.1-653.2 m)	7 ft. (2.1 m)	Mudstone to Wackestone: light grey/brown to occasionally maroon, limy, very fine crystalline, fossiliferous (crinoids and some brachiopods).
Lower Virden Member	2143.0 ft. (653.2 m)	
2143-2154 ft. (653.2-656.5 m)	11 ft. (3.3 m)	Mudstone: grey brown, occasionally maroon, very fine crystalline, limy, thinly bedded, wispy laminations of maroon mudstone, some mottling, crinoids.
2154-2157 ft. (656.5-657.5 m)	3 ft. (1 m)	Oolitic Grainstone: light grey/brown, limy, oolites predominant.
2157-2159 ft. (657.5-658.1 m)	2 ft. (0.6 m)	Mudstone: as above.
2159-2162 ft. (658.1-659 m)	3 ft. (0.9 m)	Oolitic Grainstone: as above.
2162-2169.5 ft. (659-661.3 m)	7.5 ft. (2.3 m)	Mudstone: as above. Fossils include gastropods.
2169.5-2172.5 ft. (661.3-662.2 m)	3 ft. (0.9 m)	Oolitic Grainstone: as above.
2172.5-2178.5 ft. (662.2-664 m)	6 ft. (1.8 m)	Mudstone: as above.
2178.5-2180.5 ft. (664-664.6 m)	2 ft. (0.6 m)	Oolitic Grainstone: as above.
2180.5-2183 ft. (664.6-665.4 m)	2.5 ft. (0.8 m)	Mudstone: as above.
Scallion Member	2183 ft. (665.4 m)	
2183-2211 ft. (665.4-673.9 m)	28 ft. (8.5 m)	Mudstone: light grey/brown, cryptocrystalline, light grey chert blebs (up to 1-2 in.; 2.5-5 cm), chert predominant.
Imperial Routledge 14-28 14-28-9-25 WPM KB 1441 ft. (439.2 m) **Cored Interval: 1974-2125 ft. (601.7-647.7m)**		
Lower Amaranth Member		
1974-1978 ft. (601.7-602.9 m)	4.0 ft. (1.2 m)	Shale: red
Upper Lodgepole	(1978 ft. (602.9 m)	
1978-1988 ft. (602.9-605.9 m)	10.0 ft. (3 m)	Anhydrite: grey and breccia with Shale: as above.

1988-1993 ft. (605.9-607.5 m)	5 ft. (1.5 m)	Anhydrite: grey, with Mudstone: maroon with mottled appearance.
1993-1999 ft. (607.5-609.3 m)	6 ft. (1.8 m)	Packstone: light grey/pinkish, slightly limy, very fine crystalline, anhydritic.
1999-2009 ft. (609.3-612.3 m)	10 ft. (3 m)	Interbedded Mudstone and Packstone: red-brown and maroon, grey anhydrite. Packstone: light grey tolight maroon, mottled, very fine crystalline, some crinoids and corals.
Upper Virden Member	2009 ft. (612.3 m)	
2009-2023 ft. (612.3-616.6 m)	14 ft. (4.3 m)	Wackestone: light grey to buff, very fine crystalline, dolomitic, chalky appearance, light grey anhydrite.
Lower Virden Member	2023 ft. (616.6 m)	
2023-2028 ft. (616.6-618.1 m)	5 ft. (1.5 m)	Mudstone: red-brown to maroon mottled in part, trace bryozoans.
2028-2034 ft. (618.1-620 m)	6 ft. (1.9 m)	Mudstone: red brown with Wackestone: light grey to buff, very fine to fine crystalline.
2034-2039 ft. (620-621.5 m)	5 ft. (1.5 m)	Wackestone: light grey, dolomitic, very fine to fine crystalline, crinoids.
2039-2044 ft. (621.5-623 m)	5 ft. (1.5 m)	Wackestone: light grey to light maroon, mottled in part, very fine to fine crystalline, fossiliferous(crinoids, brachiopods, corals).
2044-2046 ft. (623-623.6 m)	2 ft. (0.6 m)	Packstone: light grey to buff fine crystalline, crinoids.
2046-2049.6 ft. 623.6-624.7 m)	3.6 ft. (1.1 m)	Grainstone: buff, oolitic, very fine to fine crystalline, interval completely oolitic, some replacement anhydrite.
2049.6-2050.6 ft. (624.7-625 m)	1 ft. (0.3 m)	Grainstone: light grey-pink, very fine to fine crystalline, limy, crinoids, spotted appearance.
2050.6-2052.6 ft. (625-625.6 m)	2 ft. (0.6 m)	Grainstone: oolitic, as above.
2052.6-2111 ft. (625.6-643.4 m)	58.4 ft. (17.8 m)	Missing.
Scallion Member	2111 ft. (643.4 m)	
2111-2121 ft. (643.4-646.5 m)	10 ft. (3.1 m)	Wackestone: light grey, limy, very fine crystalline, blebs and lenses of light grey and black chert.
2121-2125 ft. (646.5-647.7 m)	4 ft. (1.2 m)	Missing.

Cdn Sup Williams 11-14
11-14-10-26 WPM
KB: 1445 ft. (440.4m)

Cored Interval:
1950-2011, 2013-2084 ft.
(594.4-612.9, 613.5-635.2 m)

Lower Amaranth		
1950-1954 ft (594.4-595.6 m)	4 ft. (1.2 m)	Shale: red, brecciated and anhydritic, grey.
Upper Lodgepole	(1954 ft. (595.6 m)	
1954-1965 ft. (595.6-598.9 m)	11 ft. (3.3 m)	Wackestone: light pink to light grey, dolomitic, very fine crystalline, crinoids(?), interbeds of grey anhydrite, thin interbeds of maroon mudstone.
1965-1973.75 ft. (598.9-601.6 m)	8.75 ft. (2.7 m)	Mudstone: grey maroon to red/brown, mottled in part.
1973.75-1990.25 ft. (601.6-606.6 m)	16.5 ft. (5 m)	Mudstone to Wackestone: light grey to light maroon. mottled, non-calcareous, fractures, some crinoids, near base grainstone(1'; 0.3 cm), light maroon, fine crystalline, tight.
1990.25-2003.9 ft. (606.6-610.8 m)	13.6 ft. (4.2 m)	Wackestone: light grey to light brown, non-calcareous, very fine crystalline, some interbeds maroon mudstone, occasional oil stain.
Upper Whitewater Member	2003.9 ft. (610.8 m)	
2003.9-2011 ft. (610.8-612.9 m)	7.1 ft. (2.2 m)	Wackestone: light brown/grey, very fine crystalline, some beds of 3 in. (7.6 cm) fractured tripolitic chert, occasional anhydrite, patchy oil stain.
2011-2013 ft. (612.9-613.5 m)	2 ft. (0.6 m)	Not cored.
2013-2024 ft. (613.5-616.9 m)	11 ft. (3.4 m)	Mudstone to Wackestone: light grey to light maroon, mottled, very fine crystalline, some crinoids, trace oil stain.
2024-2034 ft. (616.9-620 m)	10 ft. (3.1 m)	Missing.
Upper Virden Member	2034 ft. (620 m)	
2034-2147.3 ft. (620-624 m)	13.3 ft. (4 m)	Packstone to Wackestone: light brown, fine crystalline, trace bryozoans and brachiopods, poor to good vuggy porosity, some intercrystalline porosity.
Lower Virden Member	2147.3 ft. (624 m)	
2147.3-2157.8 ft. (624-627.2 m)	10.5 ft. (3 m)	Mudstone: grey to maroon mottled. Wackestone: as above, spotty oil stain.

2157.8-2167.8 ft. (627.2-630.3 m)	10 ft. (3.m)	Packstone: light brown to grey, fine- to medium- crystalline, some interbeds of Mudstone: dark grey to maroon, patchy oil stain.
2167.8-2169.5 ft. (630.3-630.8 m)	1.7 ft. (0.5 m)	Oolitic Grainstone: buff to light brown, some oil staining.
2169.5-2172.1 ft. (630.8-631.6 m)	2.6 ft. (0.8 m)	Mudstone: light grey to light maroon, grading in part to Packstone: large brachiopod (productid ?).
2172.1-2176.1 ft. (631.6-632.8 m)	4 ft. (1.2 m)	Oolitic Grainstone, buff to light brown, some intercrystalline and vuggy porosity, some oil staining.
2176.1-2180.1 ft. (632.8-634 m)	4 ft. (1.2 m)	Mudstone: light grey to light maroon, limy, some brachiopods
2180.1-2182.3 ft. (634-634.7 m)	2.2 ft. (0.7 m)	Oolitic Grainstone: buff to light brown, some intercrystalline and vuggy porosity, 6 in.(15 cm) at top bioclastic grainstone, with gastropods and brachiopods, patchy oil stain.
2182.3-2184.0 ft. (634.7-635.2m)	1.7 ft. (0.5 m)	Mudstone: light grey to light maroon, limy.

Imperial Virden 13-8
13-8-10-26 WPM
KB: 1484 ft. (452.3 m)

Cored Interval:
2050-2268 ft. (624.8-691.3 m)

Lower Amaranth

2050-2059 ft. (624.8-627.6 m	9 ft. (2.7 m)	Anhydrite: grey.
2059-2060 ft. (627.6-627.9 m)	1 ft. (0.3 m)	Missing.
2060-2070.5 ft. (627.9-631.1 m)	10.5 ft. (3.2 m)	Shale: reddish brown, brecciated in part, with interbeds of grey anhydrite
Upper Lodgepole	2070.5 ft. (631.1 m)	
2070.5-2096 ft. (631.1-638.9 m)	25.5 ft. (7.8 m)	Wackestone: light brown to buff (pinkish), dolomitic, very fine crystalline, spotty oil stain at top of interval, with interbeds of grey anhydrite.
2096-2114 ft. (638.9-644.3 m)	18 ft. (5.4 m)	as above: interbeds of maroon mudstone, occasional crinoids, patchy oil stain in wackestone, some light grey chert nodules.
2114-2138 ft. (644.3-651.7 m)	24 ft. (7.4 m)	Wackestone: light grey to light maroon, mottled, limy, very fine crystalline, fractured, occasional maroon mudstone, some crinoids, spotty oil stain, some contorted bedding.

2138-2157 ft. (651.7-657.5 m)	19 ft. (5.8 m)	Wackestone to Packstone: light grey to light brown, limy, very fine crystalline, crinoids, chert or silica interbeds up to 2 in.(5 cm), some intercrystalline and moldic to vuggy porosity, oil stain restricted to wackestone beds, some intercrystalline porosity associated with oil staining.
Upper Whitewater Lake Member	2157 ft. (657.5 m)	
2157-2169 ft. (657.5-661.1 m)	12 ft. (3.6 m)	Wackestone: grey, limy, very fine crystalline, some crinoids, beds of light grey chert/silica, occasional vugs.
Lower Whitewater Lake Member	2169 ft. (661.1 m)	
2169-2177.3 ft. (661.1-663.6 m)	8.3 ft. (2.5 m)	Wackestone: as above. Mudstone: maroon, chert beds and silica, some oil staining.
Upper Virden Member	2177.3 ft. (663.6 m)	
2177.3-2201.3 ft. (663.6-671 m)	24 ft. (7.3 m)	Wackestone to Packstone: light grey, crinoids, some chert, patchy oil stain.
Lower Virden Member	2201.3 ft. (671 m)	
2201.3-2208 ft. (671-673 m)	6.7 ft. (2.0 m)	Missing.
2208-2211 ft.	3 ft.	Grainstone: buff, oolitic, fine crystalline, 6 in. (15.2 cm) grey mudstone at top.
2211-2214 ft. (673.9-674.8 m)	3 ft. (0.9 m)	Mudstone: light grey to occasional maroon, crinoids, oolitic grainstone as above.
2214-2215.6 ft. (674.8-675.3 m)	1.6 ft. (0.5 m)	Oolitic Grainstone: buff, fine crystalline.
2215.6-2220.6 ft. (675.3-676.8 m)	5 ft. (1.5 m)	Mudstone: light grey to light maroon, mottled, limy, some crinoids.
2220.6-2222.1 ft. (676.8-677.3m)	1.5 ft. (0.5 m)	Oolitic Grainstone: buff, fine crystalline
2222.1-2229.85 ft. (677.3-679.7 m)	7.8 ft. (2.4 m)	Mudstone: light grey to light maroon, mottled, crinoids and brachiopods.
2229.85-2230.4 ft. (679.7-679.8m)	0.6 ft. (0.1 m)	Oolitic Grainstone: buff, fine crystalline.
2230.4-2246.2 ft. (679.8-684.6 m)	15.8 ft. (4.8 m)	Wackestone to Packstone: light grey to light brown, very fine crystalline, some interbeds maroon mudstone, wispy bedding, some nodules of chert.
Scallion Member	2246.2 ft. (684.6 m)	
2246.2-2264 ft. (684.6-690.1 m)	17.8 ft. (5.5 m)	Wackestone: light grey, very fine crystalline, chertnodules, interbeds and lenses of chalk, brecciated in part. Mudstone: grey to maroon, mottled, crinoids.

2264-2268 ft. (690.1-691.3 m)	4 ft. (1.2 m)	Missing.

Calstan Daly 1-30
1-30-9-28 WPM
KB: 1690 ft. (515m)

Cored Interval:
2569-2776, 2780-2920 ft
(783-846, 847-890 m)

Upper Lodgepole		
2569-2602.6 ft. (783-793.3 m)	33.6 ft. (10.3 m)	Dolostone: light brown, occasional beds of mottled maroon, very fine crystalline, ? fossil ghosts/or replacements, some poor intercrystalline porosity even oil stain, interbeds Mudstone: 1-2 in. (2.5-5 cm) thick, soft sediment deformation, rip up clasts, interbeds of light grey anhydrite, beds up to 5 in. (12.7 cm) and blebs.
2602.6-2614.5 ft. (793.3-796.9 m)	11.9 ft. (3.6 m)	Dolostone: as above, limy with maroon mudstone more prominent than above, poor moldicporosity, patchy oil stain, interbeds of light grey anhydrite, beds up to 2 in. (5 cm) thick.
Upper Daly Member	2614.5 ft. (796.9 m)	
2614.5-2680 ft. (796.9-816.9 m)	65.5 ft. (20 m)	Mudstone and Grainstone interbeds: Mudstone, grey, limy, abundant crinoids, some vugs, spotty oil stain, fractures (healed), stylolitic. Colour is distinctive throughout interval. Beds of Grainstone, grey to maroon mottled, 2-3 in.(5-7.6 cm) thick with "fossil hash" (replaced with anhydrite), moldic and vuggy porosity, rare oil staining.
Cruickshank Shale facies	2680 ft. (816.9 m)	
2680-2683 ft. (816.9-817.8m)	3 ft. (0.9m)	Mudstone: mottled grey/green and maroon (interbeds), some wispy thin beds of maroon shale, some interbeds of maroon grainstone, 1-2 in.(2.5-5 cm) thick.
Cruickshank Crinoidal facies	2683 ft. (817.8m)	
2683-2689 ft. (817.8-819.6 m)	6 ft. (1.8m)	Grainstone: mottled maroon and grey, limy, fine to medium crystalline, abundant replaced crinoids, no porosity.
Cromer Shale facies	2689 ft. (819.6 m)	
2689-2707 ft. (819.6-825.1 m)	18 ft. (5.5 m)	Mudstone to Shale: maroon and grey to green, mottled, limy, crinoids rich, bryozoans on bedding planes, brachiopods, some thin beds and lenses (2 in.; 5 cm) of crinoid rich maroon grainstone, as above.
2707-2735 ft. (825.1-833.6 m)	28 ft. (8.5 m)	Mudstone: as above. Maroon, crinoids, some interbeds of maroon, fine crystalline grainstone, crinoid rich.

2735-2755 ft. (833.6-839.6 m)	20 ft. (6.1 m)	Mudstone: as above. Thin interbeds(2-4 in.; 2.5-10 cm) of Grainstone: light grey, fine crystalline, no porosity, no oil stain.
2755-2758 ft. (839.6-840.6 m)	3 ft. (0.9 m)	Shale, maroon to medium red, limy.
2758-2762 ft. (840.6-841.9 m)	4 ft. (1.3 m)	Missing.
Basal Limestone facies	2762 ft. (841.9 m)	
2762-2798 ft. (841.9-852.8 m) Note: not cored 2776-2780 ft. (846-847 m)	36 ft. (10.9 m)	Grainstone: light grey to maroon, fine- to medium- crystalline, stylolitic, crinoids predominate (replaced by anhydrite), bio-clastic material ("fossil hash"), some thin wispy laminae of maroon shale.
2798-2839 ft. (852.8-863.5 m)	41 ft. (10.9 m)	Grainstone: as above. Interbeds of mudstone: grey to maroon mottled, soft sediment deformation, beds 2-6 in. (5-10 cm), crinoids predominate with some brachiopods, some dark grey and light grey chert (distinctive mottling near 2837 ft.; 864.7 m).
2839-2858 ft. (863.5-871.1 m)	19 ft. (5.8 m)	Mudstone: limy light grey or maroon, lighter colour than above. Some darker maroon near base, mottled throughout, distinctive light grey chert blebs.
Upper Bakken	2858 ft. (863.5 m)	
2858-2920 ft. (863.5-890 m)	62 ft. (18.9 m)	Not examined.

Dillman Plymouth Kirkella 1-10
1-10-12-29 WPM
KB: 1703 ft. (519 m)

Cored Interval: 2215-2760 ft. (675-841.2 m)

2215-2300 ft. (675-701 m)	85 ft. (25.9 m)	Not examined.
Upper Amaranth		
2300-2315 ft. (701-705.6 m)	15 ft. (4.6 m)	Anhydrite: grey.
Lower Amaranth	2315 ft. (705.6 m)	
2315-2330 ft. (705.6-710.2 m)	15 ft. (4.6 m)	Shale: reddish brown, anhydrite as blebs and interbeds.
2330-2337 ft. (710.2-712.3 m)	7 ft. (2.1 m)	Shale: as above. Brecciated, grey anhydrite.

Upper Lodgepole	2337 ft. (712.3 m)	
2337-2350 ft. (712.3-716.3 m)	13 ft. (4 m)	Wackestone: light grey to brown, dolomitic, very fine crystalline, fractured, poor porosity, patchy oil stain throughout, brecciated in part at 2340 ft.(713 m), occasional interbed maroon mudstone with wispy bedding.
Daly Member	2350 ft.(716.3 m)	
2350-2360 ft. (716.3-719.3 m)	10 ft. (3 m)	Missing.
2360-2380 ft. (719.3-725.4 m)	20 ft. (6.1 m)	Wackestone: light grey, very fine- to fine-crystalline, calcareous, some maroon mottling and wispy maroon beds of mudstone, occasional thin beds (up to 4 in.; 10 cm) of Grainstone: maroon, fine crystalline, crinoids replaced.
2380-2390 ft. (725.4-725.4 m	10 ft. (3 m)	Missing.
2390-2391 ft. (725.4-728.4 m)	1 ft. (0.4 m)	Wackestone: as above.
Cruickshank Crinoidal facies	2391 ft. (728.4 m)	
2391-2400 ft. (728.4-731.5 m)	9 ft. (2.7 m)	Wackestone to Packstone: light grey to light brown, fine crystalline to occasional medium crystalline, some crinoids, patchy oil stain (usually associated with vuggy porosity), patches up to 2-4 in. (5-10 cm) thick, lenses and thin beds of light grey chert, trace pyrite.
2410-2449 ft. (731.5 m-746.5 m)	39 ft. (11.9 m)	Wackestone to Packstone: as above.
upper Cromer Shale facies	2449 ft. (746.5 m)	
2449-2488.5 ft. (746.5-758.5 m)	39.5 ft. (12 m)	Mudstone: grey to light maroon, thin bedded appearance prominent through entire interval, mottled, crinoids throughout some large, trace bryozoans.
lower Cromer Shale facies	2488.5 ft. (758.5 m)	
2488.5-2497 ft. (758.5-761.1 m)	8.5 ft. (2.6 m)	Packstone to Wackestone: light grey to light brown, fine crystalline, crinoids, at 2491'(759 m) good vuggy porosity (thin 6 in.; 14.4 cm bed), oil stained.
2497-2589.5 ft. (761.1-789.3 m)	92.5 ft. (28.2 m)	Mudstone: as above.

Basal Limestone facies	**2589.5 ft. (789.3 m)**	
2589.5-2617 ft. (789.3-797.7 m)	27.5 (8.5 m)	Wackestone to Packstone: light grey to light brown, occasionally light maroon, limy, very fine crystalline, some mottled wackestone near top of interval, occasional vuggy porosity, no oil stain, lenses and blebs of light grey to grey chert (beds up to 2 in.; 5 cm)
Upper Bakken	**2617 ft. (797.7 m)**	
2617-2629 ft. (797.7-801.3 m)	12 ft. (3.6m)	Shale: black, sharp upper contact.
Middle Bakken	**2629 ft. (801.3 m)**	
2629-2760 ft. (801.3-842.1 m)	131 ft. (39.9m)	Not examined.