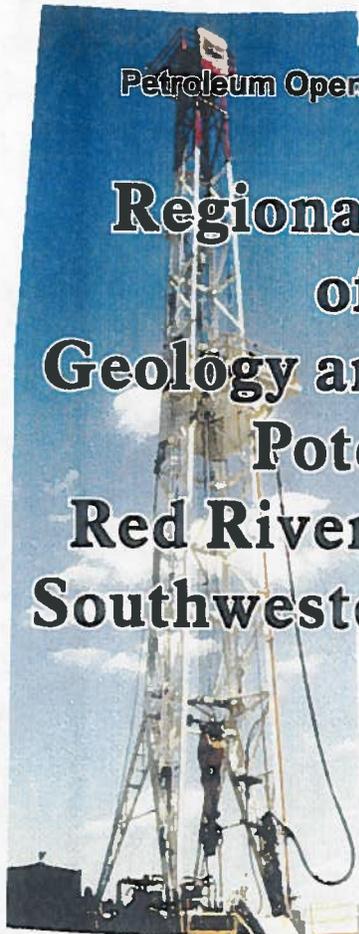


Petroleum Open File Report POF 17-98

**Regional Overview
of the
Geology and Petroleum
Potential,
Red River Formation,
Southwestern Manitoba**



By

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Winnipeg, 1998

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INTRODUCTION

The discovery of prolific oil reserves in the Red River Formation in the Midale area of Saskatchewan (Townships 6 and 7; Range 11 W2M) by Berkley Petroleum in December 1995, has generated renewed interest in the Red River Formation as a possible target in the Canadian portion of the Williston Basin.

Southwestern Manitoba lies up dip from areas of known Red River production in North Dakota and southeastern Saskatchewan and from radially oriented migration pathways and areas of thermally mature, organic-rich source rocks deeper in the basin. As evidenced by the low density and scarcity of deep tests in this part of the Williston Basin, the pre-Mississippian strata of southwestern Manitoba are virtually unexplored.

The vast majority of southwestern Manitoba's oil reserves discovered to date are within Mississippian and Jurassic age strata. The limited deep exploration for oil in the pre-Mississippian strata of southwestern Manitoba, however, has revealed the presence of potential reservoir horizons below the traditional Mississippian and Jurassic targets. The existence of porosity and permeability systems of reservoir quality, potential trapping mechanisms and potential for hydrocarbon charge from thermally mature source rocks into the pre-Mississippian strata of southwestern Manitoba have been documented (Sproule and Associates, 1964; Martiniuk, 1992; Martiniuk and Barchyn, 1993).

Numerous examples of geological conditions analogous to those that provide trapping mechanisms in typical pre-Mississippian Williston Basin hydrocarbon play types elsewhere in the basin are present within the pre-Mississippian of southwestern Manitoba. Large reserves of oil in the Williston Basin are pooled in basement controlled structural traps and stratigraphic-diagenetic traps. Potential for tectonically-generated structures and the localized development of stratigraphic-diagenetic features in the pre-Mississippian also exist in Manitoba.

The intent of this report is to provide a regional evaluation of the geology and petroleum potential of one specific horizon in the pre-Mississippian strata of southwestern Manitoba, the Ordovician Red River Formation. Although oil shows (derived primarily from core) have been reported within the Red River in Manitoba, the hydrocarbon potential of the formation has not been adequately studied. This report summarizes the regional stratigraphy of the Red River Formation and describes the lithofacies identified in the study area (Fig. 1). Depositional environments are discussed. Potential reservoir facies are highlighted in terms of their hydrocarbon potential. Evidence of favourable structural and stratigraphic traps are assessed in the context of maximum observed oil distances inferred from known Williston Basin oil-source systems. Comparisons are drawn to Red River oil pools elsewhere in the Williston Basin in an effort to present evidence of the potential for similar trapping mechanisms and geologic conditions in Manitoba.

STUDY AREA

The study area is restricted to an area west and south of the outcrop belt of the Red River Formation in southwestern

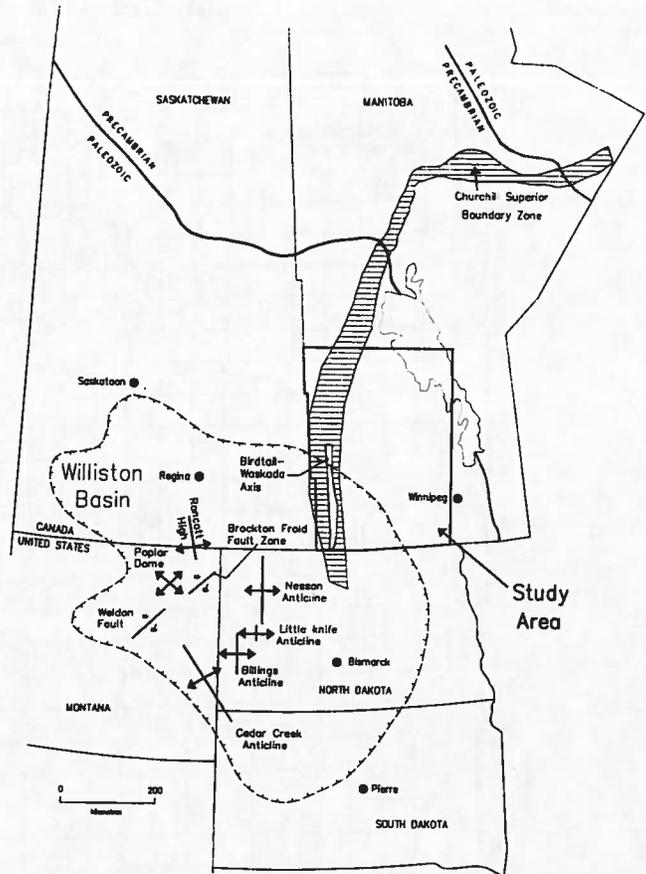


Figure 1: Map of the Williston Basin showing major structural features. Location of study area is shown.

Manitoba. The area of study is bounded to the south by the United States border, to the north by Township 39, to the east by the Principal Meridian and to the west by the Saskatchewan border at Range 29 WPM. It encompasses over 105 000 km².

Non confidential data available to December 31, 1997, from approximately 150 wells that penetrate the Red River Formation, including 35 drill stem tests, were incorporated in the study. Available cores from 11 selected wells were examined and described (Fig. 2; Appendices I and II).

Approximately 130 thin sections, stained with alizarin red for the determination of calcite and dolomite, were also studied.

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Map Showing Location of Wells Cored in the Red River Formation

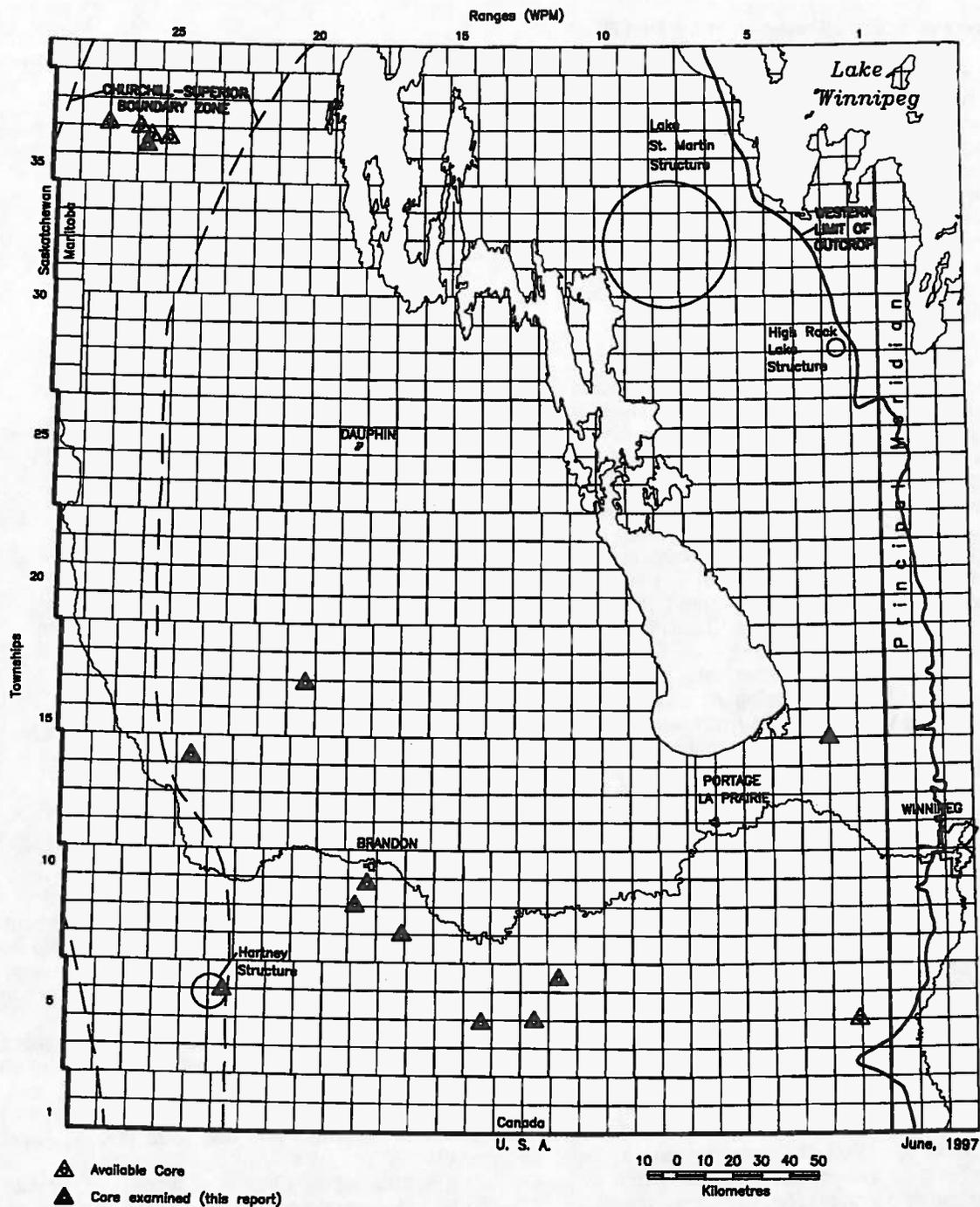


Figure 2: Map showing location of wells cored in the Red River Formation. Location of cores examined in this study are highlighted. Features shown at Lake St. Martin, Highrock Lake and Hartney are possible astroblemes (McCabe and Bannatyne, 1970; Swatzky, 1975; Clements and Mayhew, 1979; Anderson, 1980; Parson et al., 1980; McCabe et al., 1981; Gerlach et al., 1995).

REGIONAL GEOLOGICAL SETTING

Southwestern Manitoba lies along the northeastern flank of the Williston Basin (Fig. 1). A basinward thickening sedimentary wedge formed by rocks of Paleozoic, Mesozoic and Cenozoic age reaches 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 Paleozoic from 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 whereas 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).

GENERAL STRATIGRAPHY

In southwestern Manitoba, the Lower Paleozoic comprises the Cambrian Deadwood Formation, Ordovician Winnipeg, Red River, Stony Mountain and lower Stonewall formations, the Silurian upper Stonewall and Interlake Group and the Devonian Ashern, Winnipegosis, Dawson Bay, Souris River, Duperow, Birdbear and Three Forks formations.

The Williston Basin was the principal feature controlling sedimentation in southwestern Manitoba during Ordovician to Cretaceous time. The depocentre of the Williston Basin at that time was centred in northwestern North Dakota. Basin sedimentation was characterized by cyclical transgressions and regressions with repeated deposition of carbonate and clastic sedimentary rocks.

Williston Basin sedimentation was initiated in late Cambrian time during a eastward transgression of the sea into an embayment on the western Cordilleran shelf. An overlapping clastic sequence of the Deadwood Formation (Late Cambrian to Early Ordovician) was deposited on the Precambrian erosion surface. This was followed by a period of erosion and widespread truncation of the Deadwood and sedimentation of the clastics of the Winnipeg Formation (Middle Ordovician).

The organic-rich, partially dolomitized, mottled, lime wackestone to mudstone in the lower interval of the Red River Formation represent the initiation of a major carbonate cycle of deposition that followed Winnipeg sedimentation. These beds are overlain by interbedded sequences of laminated limestones or dolostones which are capped by beds of anhydrite in the upper interval of the Red River

Formation. This brining upward cycle is believed to record deposition in increasingly restricted, subtidal settings (Longman *et al.*, 1983; Elias *et al.*, 1988; Potter and St. Onge, 1991; Longman and Haidl, 1996; Montgomery, 1997).

Deposition of carbonates continued throughout Stony Mountain and Stonewall (Upper Ordovician) time. The shaly beds of the Gunn Member of the Stony Mountain Formation mark the maximum extent of marine transgression and represent relatively deep water, low energy deposition (McCabe, 1971).

During deposition of the Devonian strata, the depocentre shifted from northwestern North Dakota, northward into the Elk Point Basin of northwestern Saskatchewan and eastern Alberta. A marine transgression was initiated during the deposition of the Middle Devonian Ashern Formation (McCabe, 1971).

Winnipegosis sedimentation followed with the widespread deposition of normal marine carbonates. Winnipegosis deposition ended when the basin became restricted and the Prairie Evaporite was deposited. The Dawson Bay and Souris River formations were deposited following the re-establishment of normal marine conditions. These conditions continued throughout most of Duperow and Birdbear Formation sedimentation.

Deposition of the siltstones and shales of the Three Forks Formation followed Birdbear Formation sedimentation.

RED RIVER FORMATION

The Ordovician Red River Formation is essentially a carbonate unit that lies between the calcareous shales of the Gunn Member (Stony Mountain Formation) and the shales and sandstones of the Winnipeg Formation. The formation has been defined in the outcrop area by Foerste (1929) and McCabe and Bannatyne (1970).

The Red River Formation is of Late Ordovician age. In southwestern Manitoba, it ranges in thickness from approximately 80 to 170 m and is generally conformable with the underlying clastics of the Winnipeg Formation. North of the depositional limit of the Winnipeg Formation, Red River strata overstep the shales of the Winnipeg to rest unconformably on the Precambrian basement. The Red River is overlain, with possible slight disconformity, by the shaly beds of the Stony Mountain Formation.

Within the Manitoba outcrop belt, the Red River Formation is divided (in ascending order) into four members; the Dog Head, Cat Head, Selkirk and Fort Garry. Due to the lack of cores and, for many wells, modern well logs, it is difficult to recognize this subdivision in the subsurface. The Dog Head, Cat Head and Selkirk members of the outcrop belt are correlated approximately in the subsurface to the Yeoman Formation of the Red River in Saskatchewan. The Fort Garry Member is correlated with the Herald Formation (Canadian Society of Petroleum Geologists, 1990)(Fig. 3).

PREVIOUS WORK

Papers that describe the lithology, stratigraphy, environments of deposition and porosity development of the Red River Formation, either in outcrop in Manitoba, or in the subsurface of the Williston Basin in Saskatchewan, North Dakota and Montana include: Dowling (1900); Foerste (1929); Porter and Fuller (1959); McCabe and Bannatyne (1970);

STRATIGRAPHIC CORRELATION CHART

		NORTH DAKOTA	SASKATCHEWAN	THIS STUDY	MANITOBA OUTCROP	
ORDOVICIAN	SILURIAN	Stonewall Formation	Stonewall Formation	Stonewall Formation	Stonewall Formation	
	Stony Mountain Formation	Gunton Member	Gunton Member	Gunton Member	Gunton Member	
		Gunn Member	Gunn Member	Gunn Member	Penitentiary Member Gunn Member	
	Red River Formation	'A' anhydrite	Hartaven Member	Herald Formation	Herald (equivalent)	Fort Garry Member
		'B' anhydrite	Red River	Redvers Unit	Lake Alma Anhydrite (equivalent)	
		'B' laminated		Coronach Member	Yeoman (equivalent)	
		'B' burrowed		Lake Alma Anhydrite		
		'C' anhydrite		Lake Alma Member		
	'C' laminated	Yeoman Formation	Red River Formation	Red River Formation	Selkirk Member	
	'c' burrowed				Cat Head Member	
				Dog Head Member		
	Winnipeg Formation	Winnipeg Formation	Winnipeg Formation	Winnipeg Formation		

Figure 3: Stratigraphic Correlation Chart (modified after Norford et al., 1994).

Bannatyne (1975); Kendall, (1976); Kohm and Loudon (1978); Longman *et al.* (1983, 1992); Porter and St. Onge (1991); Haidl, (1990, 1995); Haidl, *et al.* (1996); Kreis and Haidl (1996); Longman and Haidl (1996); Haidl *et al.* (1997) and, Montgomery (1997).

Regional correlation of the Ordovician, from the outcrop belt to more central and deeper portions of the Williston Basin, have been compiled by Norford *et al.*, (1994) and Bezys and Conley (1997).

Studies emphasizing the nature and thermal maturation of Ordovician source rocks in the Williston Basin and the migration of Ordovician sourced oils include those of Osadetz and Snowden (1989, 1995), Stasiuk and Osadetz (1990), Osadetz *et al.* (1992) and Burrus *et al.* (1995).

CURRENT STUDY

The Red River Formation is easily distinguished on well logs. The base is marked by the high gamma ray response of the underlying shale of the Winnipeg Formation. The top is marked by the high gamma ray response of the

basal shale of the Gunn Member of the overlying Stony Mountain Formation (Fig. 4). The subdivisions of the Red River Formation used in this study are shown in the stratigraphic cross sections in Figures 5 and 6 (in pocket).

For the purposes of this study, the authors have used the terminology originally proposed by Kendall (1976) to describe the Red River Formation in the subsurface of southwestern Manitoba. In Manitoba, equivalents of the Yeoman and Herald are recognized (Fig. 3). However, in the absence of cycle-capping anhydrite over most of the study area, no attempt has been made to further subdivide the Herald, nor to resolve inherent problems in the nomenclature.

Reference Well - Red River Formation



09-32-09-25 WPM
KB : 439.4m

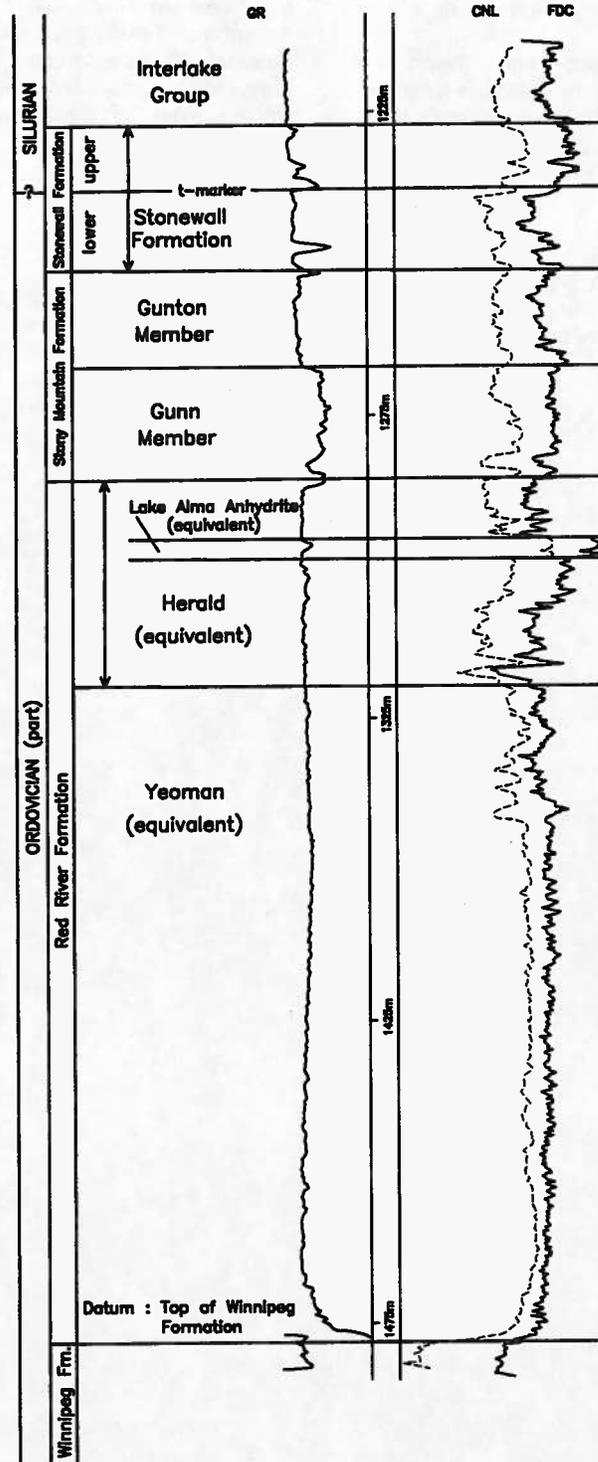


Figure 4: Reference Well - Red River Formation.

LITHOLOGY

Detailed descriptions of the lithology of the Red River Formation in southeastern Saskatchewan and in the United States portion of the Williston Basin have been provided by Kendall (1976), Kohm and Loudon (1978), Longman *et al.* (1983) and Longman and Haidl (1996). In the more central part of the Williston Basin, the Red River Formation is characterized by a series of sedimentary cycles that can be correlated over broad areas, with little change in facies or thickness (Longman and Haidl, 1996).

Each cycle consists of a lower, burrow mottled, wackestone to mudstone unit; an intermediate, nonfossiliferous, laminated or thinly bedded, mudstone or dolomitized mudstone unit; and, an upper unit of laminated and/or nodular anhydrite. The individual cycles represent a brining upward depositional sequence (Longman *et al.*, 1983; Haidl, 1995; Longman and Haidl, 1996).

In outcrop and in the subsurface in southwestern Manitoba, Red River strata are comprised primarily of dolostones and dolomitic limestones with minor limestones. In the subsurface, beds of anhydrite, believed to represent the eastward extension of the Lake Alma Anhydrite of Saskatchewan, are also present.

Based on the examination of available Red River cores and thin sections, the following six major lithofacies have been identified in the subsurface of southwestern Manitoba: dolostone; dolomitic, burrow mottled, fossiliferous lime wackestone; lime mudstone / skeletal lime wackestone; skeletal grainstone and packstone; intraclast-rich wackestone / packstone / grainstone; and, anhydrite.

LITHOFACIES 1 - DOLOSTONE

Lithofacies 1 is the predominant lithofacies of the Herald equivalent of the Red River Formation in southwestern Manitoba. It consists of a light to medium brown, pinkish brown or light grey, nonfossiliferous, very fine to finely crystalline dolostone. The dolostone is composed of subhedral to anhedral crystals, generally 2 to 10 microns in size, but ranging up to 20 microns in size. It is laminated or non-laminated. Laminae are a few millimetres in thickness, where present. In thin section, the laminae appear to be related to subtle changes in argillaceous content. The non-laminated dolostones of lithofacies 1 may represent the replacement of a limestone precursor (possibly a lime mudstone or wackestone), as suggested by the existence of dolomitized fossils or bands of moldic porosity in adjacent beds (Plate 1). Where porosity is developed in the laminated dolostones of this lithofacies ("C" Laminated in North Dakota and Montana; Lake Alma Member of the Herald Formation in Saskatchewan) in other areas of the Williston Basin, it is productive.

LITHOFACIES 2 - DOLOMITIC, BURROW MOTTLED, FOSSILIFEROUS LIME WACKESTONE

Lithofacies 2 is found within the Yeoman equivalent of the Red River Formation in the subsurface of Manitoba. Termed "Tyndall Stone" lithology in this study (Appendix II), lithofacies 2 consists of lime mudstones and skeletal wackestones with distinctive irregular, dolomite burrow mottles (Plate 2). Thin interbeds or patches of lime packstones to grainstones may also be present. Styolitic

partings and nodules of white, tripolitic chert are common. Macrofossils observed in core include echinoderms, solitary rugose corals, brachiopods, tabulate corals, bryozoans, gastropods and nautiloid cephalopods. Fragments of ostracods, trilobites and algae are noted in thin section.

The *Thalassinoides*-like burrows, which make up 30 to 40% of the unit, and typically have a second generation of smaller burrows within them, are composed of subhedral to euhedral dolomite crystals 10 to 50 microns in size. The burrow mottles may exhibit poor to fair intercrystalline porosity (Plate 3) and are often marked by small, central vugs. The boundary between the burrow mottles and the adjacent matrix varies from gradational to sharp. The mud matrix consists of a mosaic of finely crystalline calcite, 2 to 5 microns in diameter.

Lithofacies 2 is correlative with the Selkirk Member (Tyndall Stone) of the Red River Formation exposed at quarries in Garson, Manitoba (NW 03-13-06 EPM). In the subsurface, it is correlative with the Yeoman in Saskatchewan and the "C" Burrowed of western North Dakota and eastern Montana. Where extensively dolomitized, it is the primary Red River producing horizon in the Williston Basin.

LITHOFACIES 3 - LIME MUDSTONE / SKELETAL LIME WACKESTONE

The two rock types representing lithofacies 3 are common to both the Yeoman and Herald equivalents of the Red River Formation in the subsurface of Manitoba. Both the lime mudstone and skeletal lime wackestone units are gradational, one to another, by variation in fossil content. The skeletal lime wackestone unit is fossiliferous, while the lime mudstone unit is sparsely fossiliferous. The lime mudstone unit is dense, fine grained and composed of a mosaic of anhedral crystals of calcite 2 to 5 microns in size. Fossils, although rare, include articulated and disarticulated ostracods, gastropods and crinoids. The unit is occasionally finely laminated with thin intraclastic-rich horizons.

The skeletal lime wackestone unit is bioturbated, marked by the disruption of bedding and by the local presence of skeletal debris or pellets (Plate 4). Closely spaced, cylindrical, horizontal burrows are abundant in some beds. Fossils mainly include crinoids and brachiopods. Gastropods, pelecypods, solitary rugose corals, tabulate corals, algae (including *Dimorphosiphon*), bryozoans, trilobite, ostracods and sponge spicules may also be present.

The original texture of the lime mudstones and skeletal lime wackestones found in the Yeoman equivalent are generally better preserved than those observed in the Herald equivalent. The Herald is extensively dolomitized in southwestern Manitoba. Dolomitization of the lime mudstones and skeletal lime wackestones of lithofacies 3 varies in extent from scattered replacement dolomite rhombs and mottled or nodular-like mosaics of interlocking crystals, to near complete obliteration of original rock fabric.

LITHOFACIES 4 - SKELETAL GRAINSTONE AND PACKSTONE

The skeletal grainstones and packstones of lithofacies 4, as observed in core, generally constitute only a minor portion of the Yeoman equivalent in Manitoba. The lithofacies

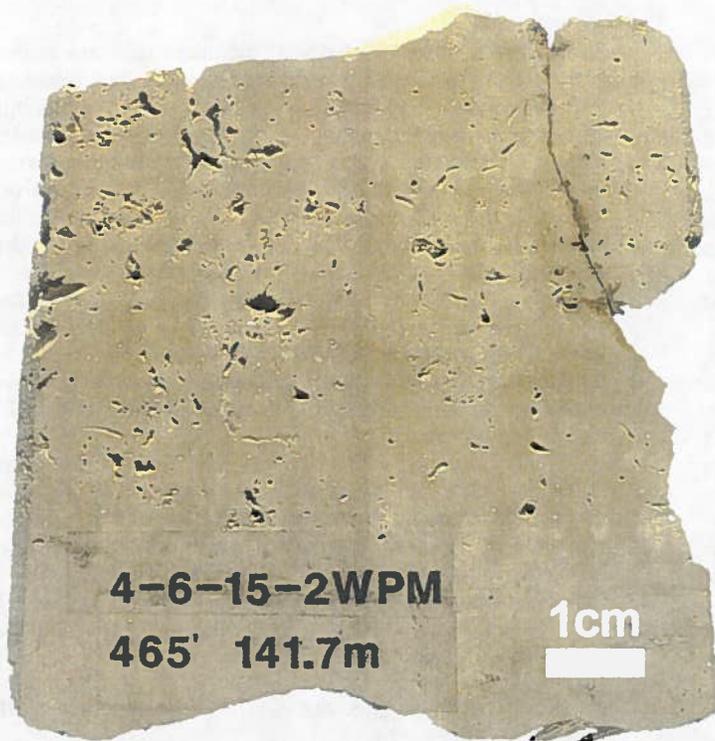


Plate 1: Core photo of Lithofacies 1 showing very finely crystalline dolostone with good moldic porosity within the Herald equivalent. Taken from the well at 04-06-15-02 WPM at a depth of 141.7 m (465 ft.) below K.B.



Plate 2: Core photo of dolomitized, burrow mottled, skeletal wackestone (Lithofacies 2) with thin interbeds of skeletal packstone (Lithofacies 4) within the Yeoman equivalent. Taken from the well at 12-10-14-25 WPM at a depth of 1227.4 m (4027 ft.) below K.B.

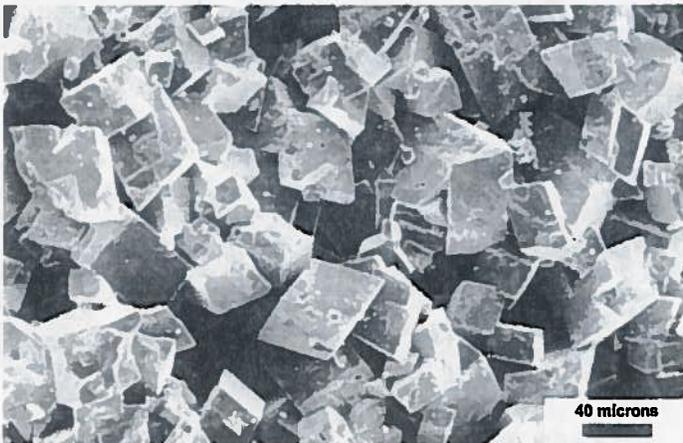


Plate 3: SEM photomicrograph of euhedral dolomite exhibiting intercrystalline porosity, replacing skeletal wackestone (Lithofacies 2) within the Yeoman equivalent. Taken from the well at 04-06-15-02 WPM at a depth of 191.7 m (629 ft.) below K.B.

consists of laminae or thin beds, 2 to 10 cm in thickness (Plate 2). Fossil fragments are predominantly crinoids, typically 0.25 to 1.5 mm in diameter. Other constituents include brachiopods, bryozoans, gastropods, pelecypods, trilobites and algal fragments. Good vuggy and intercrystalline porosity is locally present. Similar lithofacies are productive within the "C" Burrowed in the Montana portion of the Williston Basin (Longman and Haidl, 1996). Where porosity is sufficiently developed within Lithofacies 4 in Manitoba, it may also be a prospective reservoir.

LITHOFACIES 5 - INTRACLAST-RICH WACKESTONE / PACKSTONE / GRAINSTONE

Lithofacies 5 is present primarily in the Herald equivalent of the Red River Formation in the subsurface of Manitoba. The unit ranges from wackestone to packstone and grainstone and is typically 5 to 10 cm thick. Intraclasts generally consist of elongate and tabular, subangular to subrounded, lime mudstone or finely crystalline dolostone (Plate 5). The intraclasts are commonly aligned parallel or subparallel to bedding.

LITHOFACIES 6 - ANHYDRITE

Lithofacies 6 is a minor component throughout the Red River Formation in the subsurface of Manitoba. It consists of a blue grey, brown or white nodular mosaic anhydrite that generally occurs as nodules, fracture filling, skeletal replacement, or replacement laminae and irregular stringers. Nodules are generally less than 5 cm in diameter (Plate 6).

The local occurrence of a 1.14 m thick bed of laminated to nodular anhydrite was noted in core in the well at 12-10-14-25 WPM. This mappable bed is also recognizable on well logs from other wells within the subsurface in Manitoba and is believed to represent the eastward extension of the Lake Alma Anhydrite Member of the Herald Formation of the Red River in Saskatchewan.

DOLOMITIZATION

Dolomitization has played a significant role in the generation of reservoir quality porosity and permeability in Red River strata in the Williston Basin. It has been effected by a number of different processes, over prolonged periods of time. Dolomitization of beds underlying the Lake Alma Anhydrite in Saskatchewan ("C" Anhydrite in North Dakota and Montana) has created reservoirs in the upper part of the Yeoman and the lower part of the Herald in Saskatchewan ("C" Burrowed and "C" Laminated in North Dakota and Montana).

The stratigraphic distribution of porous Red River dolostones indicates that dolomitizing fluids were introduced by downward percolating brines. Gravity driven reflux of Mg-rich brines generated by the precipitation of the Lake Alma Anhydrite ("C" Anhydrite) resulted in the early diagenetic dolomitization of the underlying limestones (Longman *et al.*, 1983; Longman and Haidl, 1996). Solution-cannibalization of originally Mg/Ca-rich micrite underlying anhydrite horizons may have also provided the magnesium necessary for the formation of dolomite crystals (Longman and Haidl, 1996).

An alternative source for the brines may be those generated by the transformation of gypsum to anhydrite after burial (Kissling, 1997).

Kendall (1976), Kohm and Loudon (1978) and Kissling (1997) suggest that post depositional, gravity driven brines associated with the Silurian Interlake and Devonian Prairie Evaporite salt may also have been important in the dolomitization of Red River sediments. Kissling (1997) attributes most dolomitization of the Yeoman Formation in the central part of the Williston Basin to downward migration and invasion of brines produced during and following Interlake deposition and to those generated by the episodic dissolution of Prairie salt. Fracture systems related to basement tectonic movement, provided the conduit for the brines. Dolomitized burrow mottled mudstones and wackestones from the Yeoman equivalent examined in core in this study display a considerable range of alteration, from scattered euhedral dolomite rhombs, up to 100 microns in size with variable intercrystalline porosity, to a mosaic of predominantly subhedral crystals with little or no porosity. Many consider the original burrow systems in the Yeoman to have been key conduits for the reflux of dolomitization fluids, possibly because synsedimentary lithification reduced the permeability of the intervening sediments (Kendall, 1976, 1977; Longman *et al.*, 1983; Ruzyla and Friedman, 1985; Longman and Haidl, 1996). However, in areas beyond the limits of basin-centred Herald evaporites, solution-cannibalization of magnesium calcite may have been the only mechanism providing the magnesium necessary for dolomitization of burrow infilling (Kendall, 1977; Longman and Haidl, 1996).

The dolomite present within the Herald equivalent, as examined in core in this study, appears to represent dolomitization of mudstones and wackestones which accumulated in waters of normal to slightly elevated salinity. In the absence of documented evaporite horizons, other than the Lake Alma Anhydrite equivalent, pervasive dolomitization of the Herald by brine reflux seems unlikely. It is more plausible that, in the Manitoba portion of the Williston Basin, dolomitization was achieved by the downward percolation of brines associated with the Interlake or Prairie Evaporite salt (Kissling, 1997).

DEPOSITIONAL ENVIRONMENT

The Red River succession in the Williston Basin is characterized by well defined sedimentary cycles that can be traced over broad areas with little lateral variation. The continuity of these cycles attests to the general tectonic stability of the area during Late Ordovician time.

Two models have been proposed to explain Red River Formation sedimentation in the Williston Basin. The "shallowing-upward" model suggests that the cycles observed in the Red River record a transition from subtidal open marine through intertidal to supratidal, sabkha-type environments of deposition (Carroll, 1979; Reeckmann and Friedman, 1982; Clement, 1985; Derby and Kilpatrick, 1985; Ruzyla and Friedman, 1985). The current model, ascribed to in this study, suggests that all Red River deposition occurred under subtidal, "brining-upward" conditions. Sedimentation during each cycle was controlled by an increase in restriction and salinity in the basin which coincided with a decrease in water depth (Kendall, 1976; Kohm and Loudon, 1978; Longman *et al.*, 1983; Elias *et al.*, 1988; Longman and Haidl, 1996).

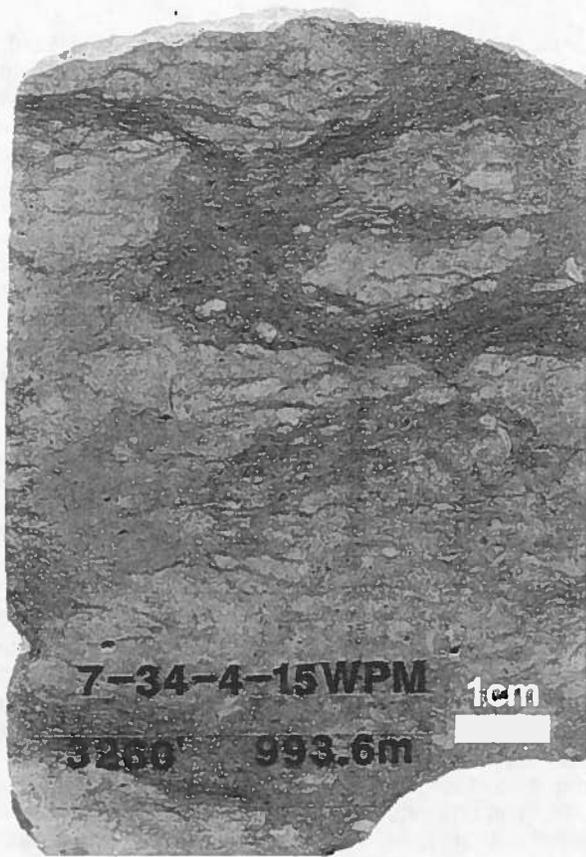


Plate 4: Core photo of Lithofacies 3 showing partially dolomitized, bioturbated, skeletal, lime wackestone within the Yeoman equivalent. Taken from the well at 07-34-04-15 WPM at a depth of 993.6 m (3260 ft.) below K.B.



Plate 5: Core photo of dolomitized, intraclast-rich grainstone (Lithofacies 5), showing good intergranular porosity in contact with laminated, finely crystalline dolostone (Lithofacies 1) within the Herald equivalent. Taken from the well at 13-16-06-12 WPM at a depth of 747 m (2451 ft.) below K.B.

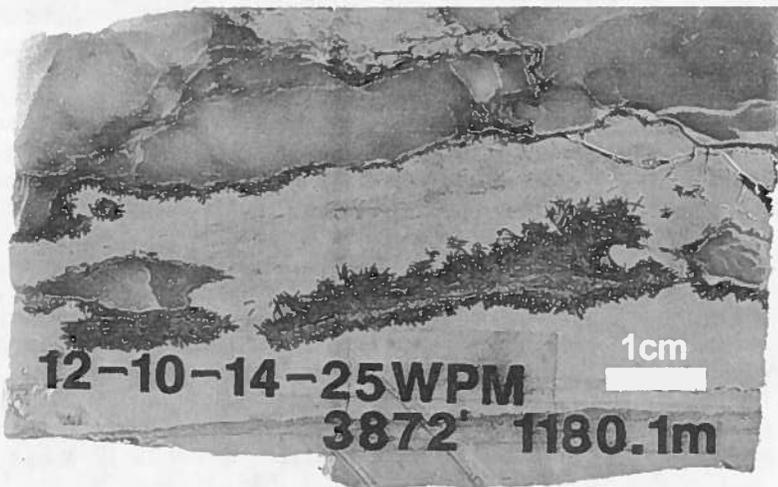


Plate 6: Core photo of irregular stringers and nodules of anhydrite (Lithofacies 6) embedded in very finely crystalline dolostone within the Herald equivalent. Margin of nodules marked by fringe of tabular anhydrite crystals that project into the surrounding matrix. Taken from the well at 12-10-14-25 WPM at a depth of 1180.1 m (3872 ft.) below K.B.

The mud-rich lithologies and their dolomitized counterparts which dominate the Red River succession in Manitoba, record subtidal deposition in relatively quiet water conditions, below wave base. The lime mudstones, burrowed and/or bioturbated skeletal wackestones and skeletal packstones present in the Red River display a diverse normal marine faunal assemblage of echinoderms (mainly crinoids), brachiopods, corals, bryozoans, gastropods, pelecypods, ostracods and calcareous algae. The *Thalassinoides*-type burrow network which characterize parts of the Yeoman were possibly constructed by arthropods and polychaete worms (Kendall, 1977).

The presence of calcareous algae in both the Yeoman and Herald equivalents in the subsurface in southwestern Manitoba suggests that deposition, in part, occurred within the photic zone. Longman and Haidl (1996) noted an absence of algae in the lower part of the "C" Burrowed Member of the Red River in the central part of the Williston Basin, indicating deposition may have taken place below the photic zone. However, the presence of *Dimorphosiphon* in the Herald in Manitoba and the "B" Burrowed in the central portion of the Williston Basin, indicates that similar conditions may have existed within the photic zone over broad areas during deposition.

Thin beds of skeletal grainstones observed within the mud-dominated sediments of the Yeoman in Manitoba, are believed to represent local, storm events. In contrast, the thicker sections of grainstone such as those encountered in the well at 07-34-04-15 WPM, are believed to represent localities where bottom sediments were subject to winnowing and reworking of skeletal debris over a longer period of time, possibly on paleostructural highs.

Lime mudstones, containing minor ostracods and gastropods, which for the most part, are devoid of fossils, may represent subtidal sedimentation that occurred under conditions of elevated water salinity. The laminated dolostones, common within the Herald, are believed to have had a lime mudstone precursor which was deposited under similar conditions. The absence of normal marine skeletal and burrowing organisms may be indicative of high salinity conditions during deposition (Haidl *et al.*, 1997).

The thin, intraclast-rich horizons identified at several stratigraphic levels within the Herald equivalent in Manitoba, are believed to represent shallow water deposition, above storm wave base, during episodes of high energy, storm activity. In most instances, the intraclasts have undergone minor transportation and are derived from the underlying sediments.

The laminated anhydrite of the Lake Alma Member equivalent recognized in Manitoba is believed to be subtidal in origin (Kendall, 1976; Longman *et al.*, 1983; Longman and Haidl, 1996).

Anhydrite also occurs as late diagenetically derived nodules, stringers and fracture fillings above and below the Lake Alma Anhydrite equivalent in Manitoba. Nodular anhydrite occurs in both limestone and dolostone and is believed to be associated with the downward percolation of sulphate-rich brines. The source of the brine and timing of anhydritization is uncertain. However, the brine may be related to that which produced anhydrite in the overlying Gunton Member of the Stony Mountain Formation, the lower part of the Stonewall Formation, or in younger formations.

The existence of anhydrite-filled fractures indicates that some anhydritization is post-lithification in age.

ISOPACH AND STRUCTURE

The regional east-trending isopach pattern of the Red River Formation (Fig. 7) reflects the differential movement of the underlying Precambrian Superior crustal province during deposition of the Red River Formation strata (Porter and Fuller, 1959). The isopach map of the Red River shows that the formation thins from over 171 m near the United States border, to less than 80 m north of Township 35 in Manitoba.

A broad, east-west trending isopach thin centred around Township 7, Range 7 WPM, appears to reflect an isopach thick on the underlying Carman Sand body of the Winnipeg Formation (McCabe, 1978). Andrichuk (1959) also recognized this feature and noted that it corresponded to a belt of extensive dolomitization and chert replacement in the strata of the lower Red River.

An isopach map of the Lake Alma Anhydrite equivalent (Fig. 8) constructed on the basis of neutron-density well log responses, shows the extent of this unit in Manitoba. The unit represents the eastward continuation of the Lake Alma Anhydrite as observed and mapped by Kendall (1976) and Kreis and Haidl (1996) in Saskatchewan. The unit caps the productive laminated dolostones at Lake Alma and Minton in Saskatchewan (Haidl, 1995). In Manitoba, the Lake Alma Anhydrite equivalent reaches a thickness of at least 8 m and is the only anhydrite unit observed within the Herald equivalent of the Red River in this portion of the Williston Basin. Other anhydrite units, such as the Coronach in Saskatchewan ("B" Anhydrite in North Dakota and Montana), are restricted to the basin centre in Saskatchewan (Kreis and Haidl, 1996).

Structure contour maps on the top of the Precambrian and the Red River Formation in Manitoba (Figs. 9 and 10) exhibit a regional dip to the southwest. The location of the Precambrian Churchill-Superior crustal boundary zone, delineated on the basis of magnetic and gravity data (McCabe, 1971; Dietrich *et al.*, 1997) is not apparent on the large scale maps shown in Figures 9 and 10. However, it is possible that localized basement features along the Precambrian Churchill-Superior crustal boundary zone, may have created small scale structures within the overlying Paleozoic section, including the Red River Formation.

EXPLORATION MODEL

OIL PRODUCTION AND RESERVOIR PARAMETERS

The Red River Formation has produced in excess of 87,791,050 m³ (552,205,700 bbls.) of oil in the Saskatchewan, North Dakota and Montana portions of the Williston Basin. In North Dakota and Montana, production is derived mainly from the "C" Burrowed, "C" Laminated and "B" Laminated units. In Saskatchewan, the upper part of the Yeoman and the lower part of the Herald (Lake Alma Member) are productive. Most of the oil trapped in these reservoirs is associated with small structural closures that are related to the episodic movement of blocks of the Precambrian basement (Kohm and Loudon, 1988; Potter and St. Onge, 1991).

Isopach Map of the Red River Formation

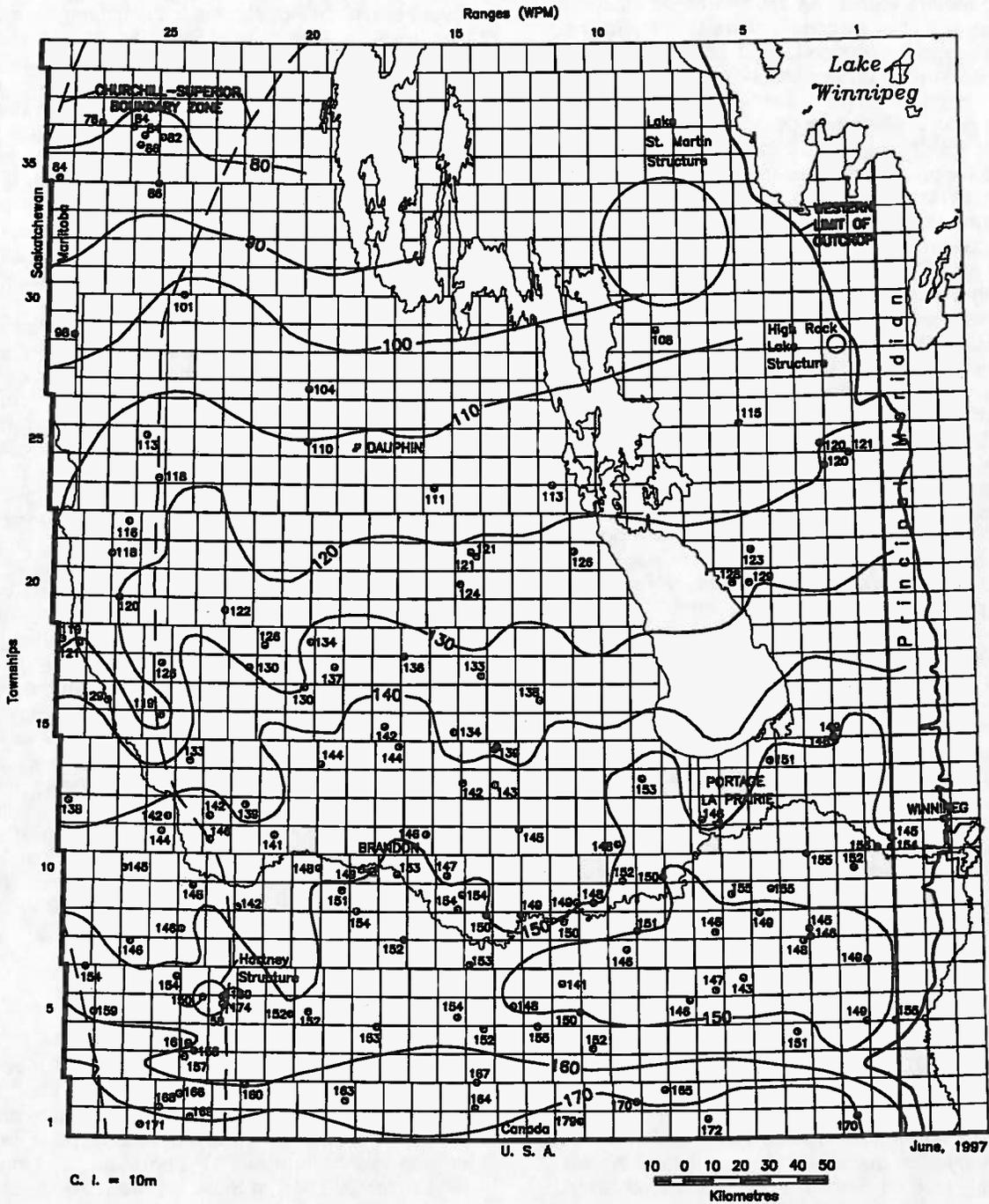


Figure 7: Isopach Map of the Red River Formation, southwestern Manitoba. Depths shown in metres. Contour interval is 10 metres.

Isopach Map of the Lake Alma Anhydrite (equivalent)

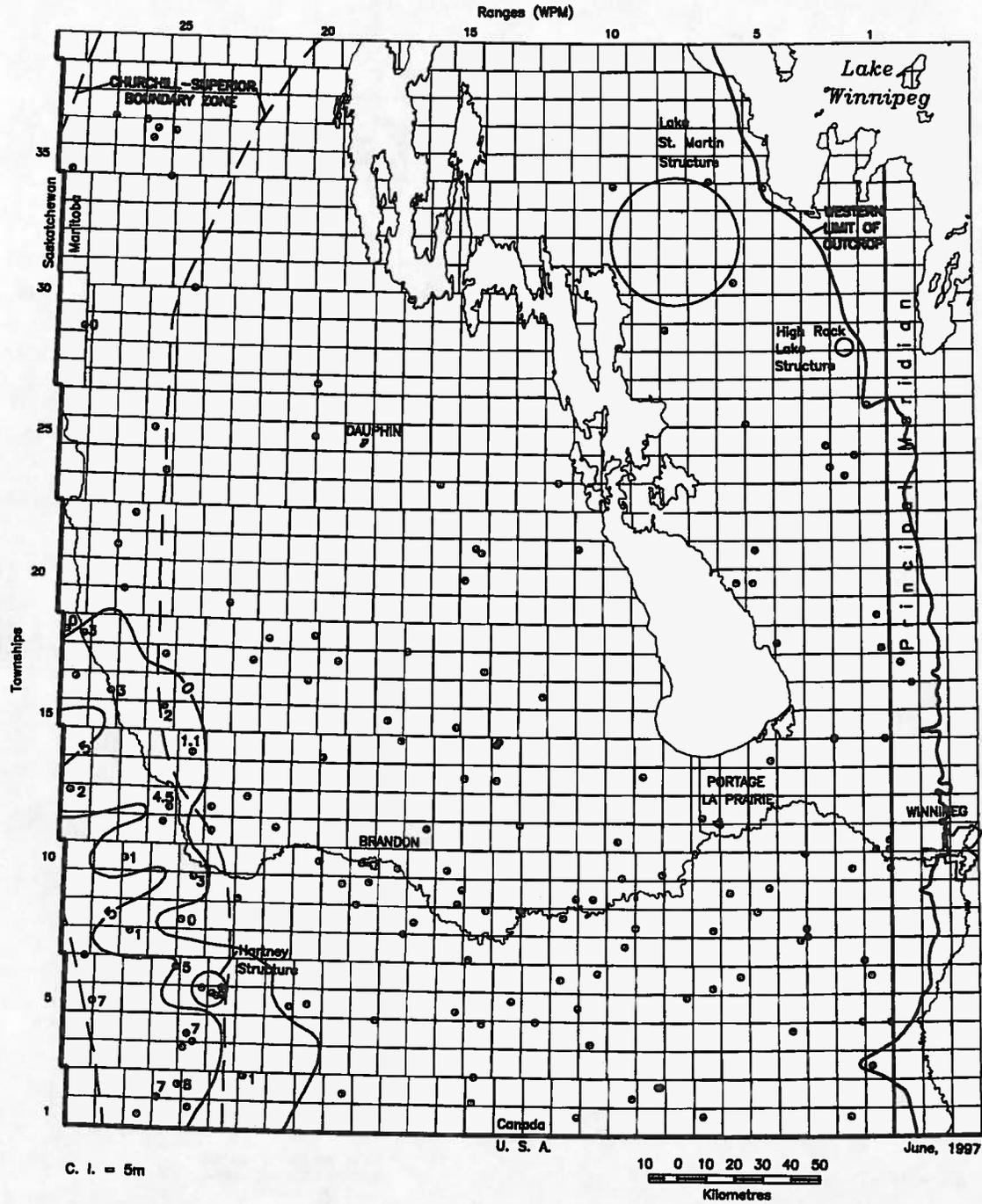


Figure 8: Isopach Map of the Lake Alma Anhydrite (equivalent), southwestern Manitoba. Depths shown in metres. Contour interval is 5 metres.

Structure Map on the Precambrian

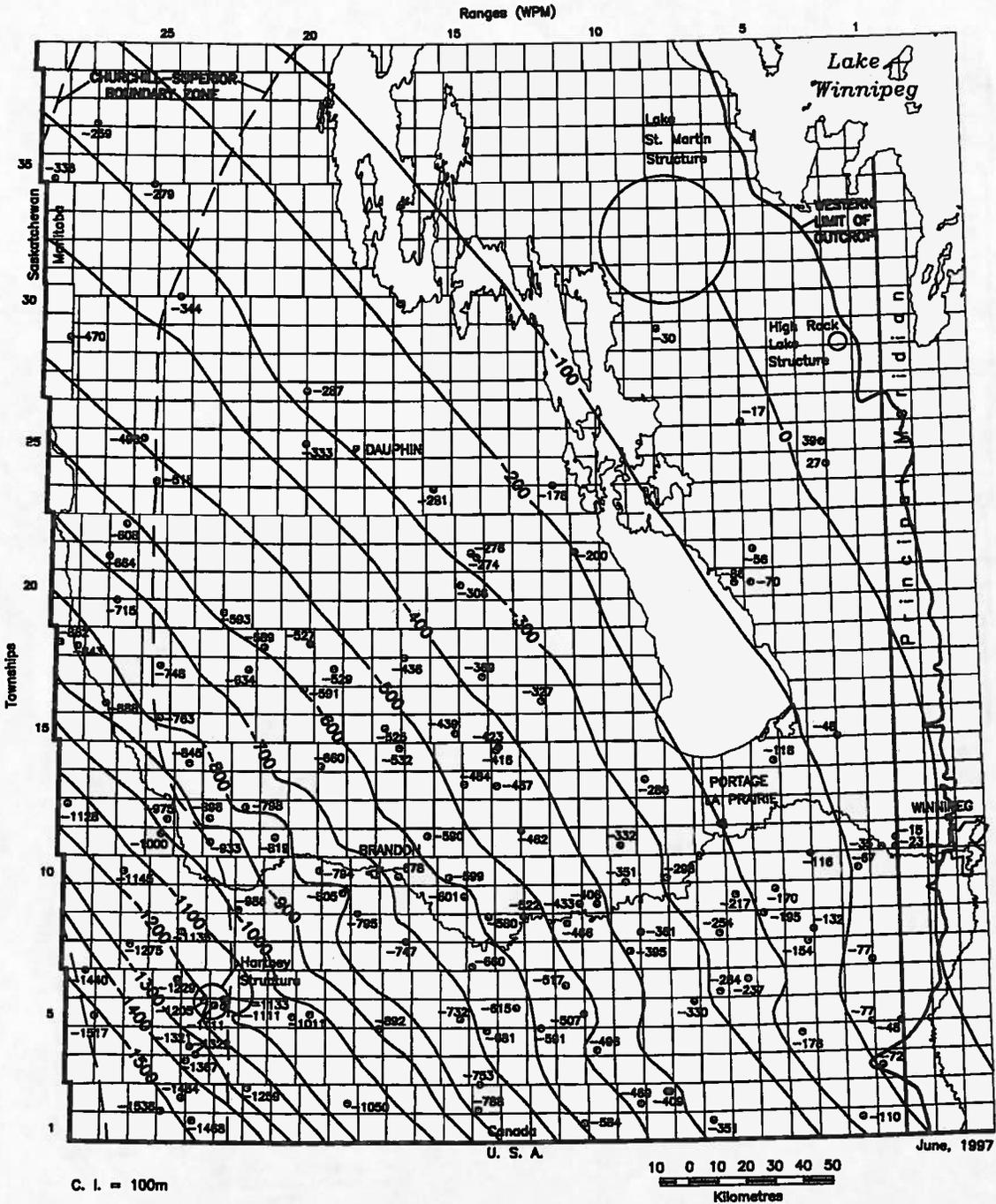


Figure 9: Structure Map on the Precambrian, southwestern Manitoba. Depths shown in metres. Contour interval is 100 metres subsea.

Structure Map on the Red River Formation

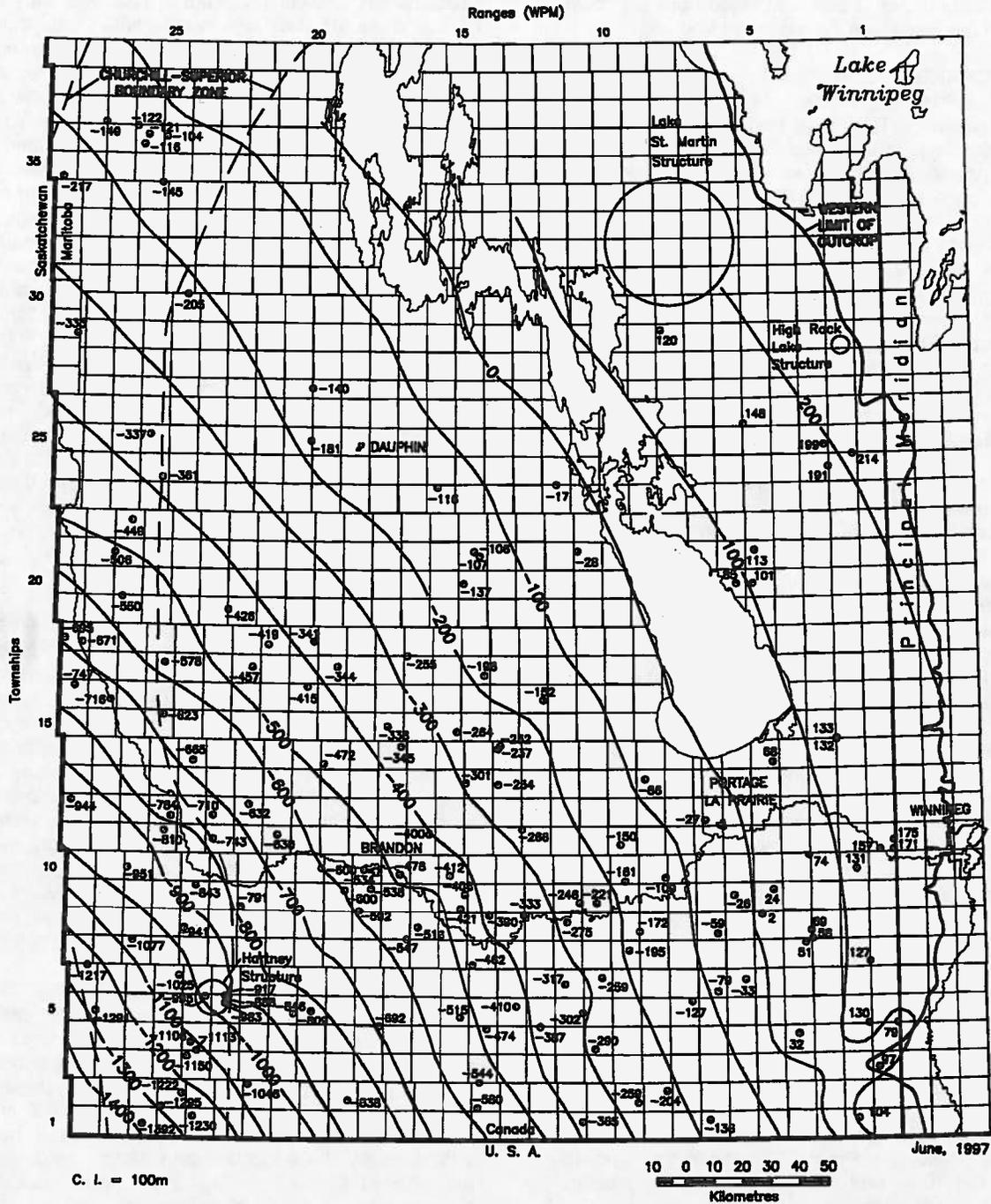


Figure 10: Structure Map on the Red River Formation, southwestern Manitoba. Depths shown in metres. Contour interval is 100 metres subsea.

Potential reservoir facies noted within the Red River in Manitoba are similar to productive Red River units described in other areas of the basin. The dolomitic, burrow mottled, fossiliferous lime wackestones of lithofacies 2, lime mudstones / skeletal lime wackestones of lithofacies 3 and the skeletal grainstones and packstones of lithofacies 4, where dolomitized, have been identified as potential reservoirs within the Red River Formation in Manitoba.

TRAPPING MECHANISMS

Potential exists for further exploration and the discovery of oil within the Red River Formation in Manitoba. Martiniuk and Barchyn (1993) evaluated the hydrocarbon prospects of pre-Mississippian strata in southwestern Manitoba in the context of known Williston Basin oil source systems, known migration pathways and trapping mechanisms. Pre-Mississippian strata, including the Red River Formation, possess many trap settings similar to that of the Mississippian Madison Group, where long distance, lateral migration is well documented. Basement controlled and deep structural, stratigraphic-diagenetic and primary lithostratigraphic related traps provide the most favourable conditions for oil entrapment within the Red River Formation in southwestern Manitoba. Hydrodynamic factors may also contribute to potential hydrocarbon trapping mechanisms.

Basement Controlled and Deep Structural Traps

Data on Red River oil pools that exist elsewhere in the Williston Basin indicate that structure plays an important role in oil entrapment. Large reserves of Red River oil are pooled in basement-controlled, deep structural traps. Although structural closure is the dominant trapping mechanism, most of these pools are combination traps. Reservoir development is greatly influenced by stratigraphic and diagenetic factors. Most of these pools are located on large structures, such as the Nesson and Cedar Creek anticlines. Many local anticlinal structures, which are small in areal extent, generally of 256 ha (640 acres) of closure, commonly have multiple pay horizons found in Ordovician to Mississippian age strata (Kohm and Loudon, 1978). Structural closure and the patterns of sedimentation and diagenesis of reservoir strata within these pools was controlled by the episodic movement of Precambrian aged basement blocks at various times during basin history (Haidl, 1990).

The oil pools at Minton, Lake Alma and Hummingbird in Saskatchewan are trapped within local, basement related structural closures, where porous and permeable reservoirs are preserved. These local structural highs are coincident with isopach thinning of overlying Silurian Interlake and Devonian Ashern strata and with a major area of Devonian Prairie Evaporite salt dissolution (Derby and Kilpatrick, 1985; Potter and St. Onge, 1991; McClellan, 1994; Haidl, 1995; Kissling, 1997; Montgomery, 1997). The distribution of the salt of the Devonian Prairie Evaporite salt and its relationship to fluid flow and fracture patterns may be an indicator of basement tectonic movement and thus, assist in the location of deep structures necessary for oil entrapment (Kent, 1960; Haidl, 1990).

In southwestern Manitoba, the potential for tectonically-generated structures may exist along the Precambrian Churchill-Superior crustal boundary zone. The

existence of this major feature is supported by its pronounced gravity, magnetic, seismic and well log data (Luther, 1991, Dietrich *et al.*, 1997). Basement faults, fault blocks and monadnocks have been identified along this zone. In the overlying Phanerozoic cover, the Birdtail-Waskada Axis (McCabe, 1971) is coincident with the Precambrian Churchill-Superior crustal boundary zone. The Birdtail-Waskada Axis is a north-trending anomalous zone approximately 32 km east of the Saskatchewan border, that extends from Township 23, south to the United States border and is the locus of numerous stratigraphic anomalies throughout the Phanerozoic section (Fig. 1). The superposition of isopach, depositional and diagenetic anomalies reflect changes in depositional basin bathymetry and enhanced diagenesis along this zone. The vast majority of Manitoba's oil reserves within Mississippian and Jurassic age strata are pooled within traps that occur along the Birdtail-Waskada Axis. These traps can be attributed to the dissolution and collapse of underlying Prairie Evaporite salt and to basement faulting, where the complete Prairie Evaporite salt section is preserved (Rodgers, 1986; Potter, 1991).

In southwestern Manitoba, the Birdtail-Waskada Axis provides the greatest potential for the occurrence of Red River structural traps. Although detailed seismic is necessary to locate and define these structures, the structural and stratigraphic features observed in some of the deep wells drilled to date along the Birdtail-Waskada Axis suggest a structural history similar to that which has generated closed structural traps elsewhere in the basin (Martiniuk and Barchyn, 1993).

Stratigraphic-Diagenetic Traps

Stratigraphy plays an important role in defining the productive limits of pools associated with structural features. Although most of the Red River Formation oil reserves in western North Dakota and eastern Montana are in structural traps, accumulations in stratigraphic traps also exist, but are largely under drilled (Longman, 1981). Dolomitization and porosity development within reservoirs in many Red River pools in the Williston Basin is related to the downward percolation of brines along localized fracture systems which provided the conduits for fluid flow (Longman, 1981; Kohm and Loudon, 1982). Evidence of the up dip pinch out of reservoir quality dolomite within the Red River Formation is present at Horse Creek, South Horse Creek and Killdeer fields in North Dakota (Derby and Kilpatrick, 1985; Longman *et al.*, 1992).

In Manitoba, basement faults along the Birdtail-Waskada Axis may affect regional hydrodynamic patterns and thus play a role in dolomitization and porosity development in the Red River Formation (Dietrich *et al.*, 1997; Dietrich, pers. comm., 1997). Stratigraphic-diagenetic traps within potential reservoir facies (lithofacies 2 and 3) may exist where porosity and permeability has been locally enhanced by dolomitization and where these facies pinch out against tighter, non reservoir strata. Local reservoir development due to dolomitization in the Red River Formation was observed in the well at 02-07-04-25 WPM in the Napinka area of southwestern Manitoba, along the Birdtail-Waskada Axis (Martiniuk and Barchyn, 1993). Evidence of a zone of open fractures in the Red River within this well, suggests that fracturing may have provided a local

conduit for fluid induced dolomitization. The up dip pinch out of the local porosity development observed in this well may indicate the potential for stratigraphic trapping similar to that at Horse and South Horse Creek fields.

Potential stratigraphic trapping within the Red River Formation may also be found within the Yeoman and portions of the Herald equivalents below the Lake Alma Anhydrite equivalent in Manitoba. Beds of anhydrite form effective top seals for many Red River reservoirs in the Williston Basin (Kohm and Loudon, 1978; Potter and St. Onge, 1991; Longman and Haidl, 1996). Potential stratigraphic traps exist in southwestern Manitoba where the Lake Alma Anhydrite equivalent is present, provided dolomitization has created favourable reservoir conditions in the underlying beds.

Primary Lithostratigraphic Traps

Osadetz *et al.* (1991) suggest that a stratigraphic play based on primary depositional facies distribution in the Red River Formation may be present on the northeastern side of the Williston Basin. A shoal-trend that borders a restricted platform facies within the upper part of the Red River Formation, associated with a Precambrian gravity high, may provide an up dip porosity pinch out that would entrap Red River oils migrated from central parts of the basin (Kendall, 1976, Stasiuk and Osadetz, 1990, Haidl, 1995).

In southwestern Manitoba, grainstone horizons (lithofacies 4) within the Red River Formation may provide conditions for primary lithostratigraphic trapping of hydrocarbons. In the well at 07-34-04-15 WPM, a 4 m thick bed of skeletal grainstone in the Yeoman equivalent of the Red River Formation in Manitoba was observed. Potential stratigraphic trapping may exist where this facies and the development of similar facies, are pinched out against impermeable carbonate facies. As in other areas along the northeastern flank of the Williston Basin, deposition of this facies may be associated with localized structures controlled by deep basement movement. Uplifted basement blocks along the Birdtail-Waskada Axis may have created such localized structures and thus sufficient shallow water conditions necessary for the deposition of this higher energy ("shoal-like") facies in the Red River in Manitoba.

Other Traps

Hydrodynamic factors may play an important role in the trapping of hydrocarbons in the Red River Formation in Manitoba. The outcropping of pre-Mississippian formations in Manitoba may have provided a possible entry point for meteoric waters creating hydrodynamic traps in the subsurface, down dip of the Manitoba Paleozoic outcrop belt (Sproule and Associates, 1964). Pre-Mississippian water analyses may be useful in the determination of possible hydrodynamic boundaries.

SOURCE BEDS AND MIGRATION PATHWAYS

Oil production from the Red River Formation is derived from the Family A oil-source system. Family A oils are considered to be sourced from the thin beds and laminae of kukersite found in the Upper Ordovician Red River Formation in an area of sufficient maturity in the central Williston Basin (Osadetz and Snowden, 1995). Kukersite, a bituminous lime mudstone containing abundant

Gloeocapsomorpha prisca alginite, occurs in the upper 15 to 20 m of the Yeoman Formation (Osadetz *et al.*, 1989).

Pools that contain Family A oils occur mainly in the same stratigraphic unit as their source beds, the Red River Formation. Most Family A oil production to date, has occurred close to the area of thermally mature source rock (Fig. 11). However, large reserves located on the Cedar Creek Anticline and in numerous smaller fields in eastern Montana and western North Dakota clearly indicate the potential for up dip migration. The existence of Red River production outside the areas of thermally mature source rocks at Minton, Midale and Weir Hill in southeastern Saskatchewan suggest that extensive cross-stratal migration can accompany significant up dip migration to the northern margins of the basin (Martiniuk and Barchyn, 1993; Burrus *et al.*, 1995). Oil migration is believed to have taken place prior to emplacement of significant barriers such as the Nesson Anticline and other traps.

The Red River pool at Minton in Saskatchewan is thought to be generated from Red River Formation sources in the central portion of the basin (Osadetz *et al.*, 1992). This suggests lateral migration with the Red River of a minimum of 70 km. Oil pools within the Mississippian in

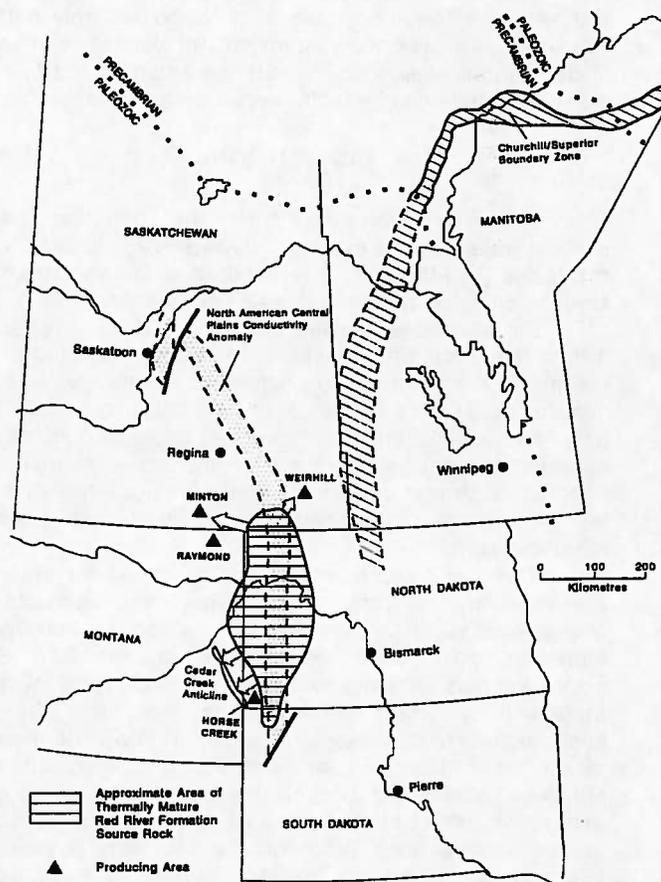


Figure 11: Family A Oil-Source System (after Martiniuk and Barchyn, 1993).

Manitoba occur at distances of at least 170 km from central basin, Upper Paleozoic source beds. Assuming that the Lower Paleozoic possesses similar hydraulic characteristics to that of the Upper Paleozoic oil-source system, the study area lies well within an area of maximum up dip migration. Significant reserves of oil may have accumulated along the northeastern flank of the Williston Basin (Martiniuk and Barchyn, 1993; Burrus *et al.*, 1995). The absence of Family A reserves on the northeastern flank of the Williston Basin, may simply reflect a lack of exploration directed toward the discovery of hydrocarbons within pre-Mississippian strata, rather than a lack of petroleum potential within these strata.

The presence of oil staining in pre-Mississippian cuttings and cores in southwestern Manitoba provides supportive evidence of long distance migration from areas of thermal maturation. Oil staining has been reported from cuttings of the Red River Formation in several wells in southwestern Manitoba as far east as Township 1, Range 2 WPM (Manitoba Energy and Mines, 1991; Martiniuk, 1992; Martiniuk and Barchyn, 1993). Two of these wells, located at 16-33-05-24 WPM and 01-27-17-26 WPM, lie along the Birdtail-Waskada Axis. It is noteworthy that to date, less than 20 wells penetrating the Red River Formation have been drilled along this zone.

Drill stem tests in the Red River Formation in southwestern Manitoba have to date yielded only mud or salt water. However, the vast majority of wells tested lie east of the Birdtail-Waskada Axis; the area considered to have the highest potential for hydrocarbon entrapment.

CONCLUSIONS

The Red River Formation was deposited under shallow water, normal marine to hypersaline, brining upward conditions. In Manitoba, it is subdivided in the subsurface study into the Yeoman and Herald equivalents.

Six lithofacies identified in core and in thin section within the Red River include: dolostone (lithofacies 1); dolomitic, burrow mottled, fossiliferous lime wackestone (lithofacies 2); lime mudstone / skeletal lime wackestone (lithofacies 3); skeletal grainstone and packstone (lithofacies 4); intraclast-rich wackestone / packstone / grainstone (lithofacies 5); and, anhydrite (lithofacies 6). Lithofacies 2, 3 and 4, where dolomitized, are identified as potential reservoir facies.

There is evidence that the potential for reservoir development, trapping mechanisms and hydrocarbon charge exist within the Red River Formation in southwestern Manitoba. Oil shows documented in the Red River Formation may be direct evidence of long distance migration of oils from central basin source rocks into the pre-Mississippian of southwestern Manitoba. The large reserves of oil within Mississippian and Jurassic aged strata in Manitoba, located up dip from the central basin area of oil generation, attest to the excellent hydraulic characteristics of the northeastern flank of the Williston Basin. Pre-Mississippian oil-source systems appear to have similar migration characteristics. Family A oils (Red River) may have been charged into up dip, basin flank areas, such as southwestern Manitoba.

Limited deep drilling in southwestern Manitoba has revealed numerous examples of geological conditions

analogous to those that provide trapping mechanisms in typical Red River oil pools in other areas of the Williston Basin.

Southwestern Manitoba is favourably situated for the occurrence of stratigraphic and structural features necessary to provide trapping mechanisms within Red River strata. Potential for tectonically-generated structures in Manitoba exists particularly along the southern extension of the Precambrian Churchill-Superior crustal boundary zone (Birdtail-Waskada Axis). The majority of southwestern Manitoba's oil reserves in Mississippian and Jurassic aged strata are pooled in traps along the Birdtail-Waskada Axis. The combination structural-stratigraphic traps and multiple-pay zones within the Red River Formation may be developed along this axis.

Stratigraphic-diagenetic traps may also be associated with the Birdtail-Waskada Axis. Localized development of porosity due to dolomitization has been noted in the Red River Formation in the Napinka area (Township 4; Range 25 WPM).

Potential stratigraphic traps may exist below the Lake Alma Anhydrite equivalent within the Yeoman and Herald equivalents, provided that sufficient dolomitization has created favourable reservoir conditions in the underlying beds. Primary lithostratigraphic trapping may exist where the grainstones of lithofacies 4 are trapped against impermeable carbonate facies.

Hydrodynamic factors may also play a role in trapping hydrocarbons in the Red River Formation in Manitoba.

A combination of structural and diagenetic factors are important to potential Red River hydrocarbon trapping mechanisms in Manitoba. Seismic methods are key in defining complex basement-controlled structural traps along the Birdtail-Waskada Axis. The areal extent of Prairie Evaporite salt may serve as an indicator of basement derived fracture systems and thus, help to define structural features and areas of fluid movement necessary for the entrapment, dolomitization and enhancement of porosity and permeability of potential reservoir facies.

The information and interpretation presented in this report is based on the limited amount of deep drilling data available and is therefore intended to provide a basic framework for future study of the Red River Formation in southwestern Manitoba. Future seismic exploration is recommended to delineate deep structural features and the tectonics of the Precambrian basement and its control on the development of the structures necessary for oil entrapment. Detailed analysis of the reservoir characteristics of the Red River with respect to porosity/permeability and diagenesis is also proposed for future study as an aid to understanding the process of dolomitization and defining potential reservoir facies.

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APPENDIX I

List of Wells with Red River Formation Core, Southwestern Manitoba.

Well Location	Core Interval
16-33-04-13 WPM ⁽¹⁾	2964 to 2979 ft. (903.4 to 908.0 m)
07-34-04-15 WPM ⁽¹⁾	3260 to 3310 ft. (993.6 to 1108.9 m)
03-01-05-02 WPM	425 to 520 ft. (129.5 to 158.5 m)
16-33-05-24 WPM ⁽¹⁾	4425 to 4452 ft.; 4787 to 4813 ft. (1348.7 to 1357.0 m; 1459.1 to 1467.0 m)
13-16-06-12 WPM ⁽¹⁾	2424 to 2474 ft. (738.8 to 754.1 m)
03-01-08-18 WPM ⁽¹⁾	3335 to 3345 ft. (1016.5 to 1019.6 m)
03-05-09-19 WPM ⁽¹⁾	3325 to 3361 ft.; 3490 to 3520 ft. (1013.4 to 1024.4 m, 1063.8 to 1072.9 m)
16-27-09-19 WPM ⁽¹⁾	3100 to 3150 ft. (944.9 to 960.1 m)
12-10-14-25 WPM ⁽¹⁾	3830 to 3880 ft. ; 3975 to 4025 ft. (1167.4 to 1182.6 m, 1211.6 to 1226.8 m)
04-06-15-02 WPM ⁽¹⁾	458 to 639 ft. ; 750 to 800 ft. (139.6 to 194.8 m; 228.6 to 243.8 m)
08-34-16-21 WPM ⁽¹⁾	3538 to 3590 ft (1078.4 to 1094.2 m)
03-29-36-25 WPM	267 to 1668 ft. (81.4 to 508.4 m)
13-10-36-26 WPM ⁽¹⁾	1348.5 to 1760 ft. (411.0 to 536.4 m)
01-28-36-26 WPM	304 to 1757 ft. (92.7 to 535.5 m)
15-32-36-26 WPM	284 to 1697 ft. (86.6 to 517.2 m)
09-01-37-28 WPM	1698 to 1703 ft.; 1754 to 1759 ft.; 1802 to 1807 ft.; 1857 to 1862 ft.; 1913 to 1917 ft.; (517.6 to 519.1 m; 534.6 to 536.1 m; 549.2 to 550.8 m; 566.0 to 567.5 m; 583.1 to 584.3 m)

⁽¹⁾ Core described in Appendix II

APPENDIX II

Select Red River Formation Core Descriptions, Southwestern Manitoba.

Dome Greenway 16-33

16-33-04-13 WPM

KB: 1427 ft. (434.9 m)

Cored Interval:

2964-2979 ft. (903.4-908.0 m)

Interval	Thickness	Description
2964-2972 ft. (903.4-905.9 m)	8 ft. (2.5 m)	<u>Lime Mudstone to Wackestone</u> : light to medium tan; variably dolomitized; vaguely to well mottled; white tripolitic chert nodules common; irregular bituminous stylolites common; thin zone of horizontal cylindrical burrows at 2966 ft. (904 m); 2 in. (5.1 cm) intraclast(?) bearing crinoidal grainstone band at 2970.3 ft. (905.3 m); crinoids common.
2972-2973.8 ft. (905.9-906.4m)	1.8 ft (0.5m)	<u>Grainstone</u> : grey; limy; white, irregular nodules of tripolitic chert; wispy shaly partings grading into stylolites occur throughout, some are at slight angles to horizontal (up to 15°); fair to good vuggy porosity at 2973 ft. (906.2 m).
2973.8-2979 ft. (906.4-908.0 m)	5.2 ft (1.6 m)	<u>Skeletal Lime Wackestone</u> : light brown mottled with medium brown dolostone; distinct mottling in top half of interval; entire core at 2965 ft. (903.7 m) marked by abundant horizontal cylindrical burrows, with rare examples occurring oblique to bedding; 3-4 ft. (0.9-1.2 m) burrowed patches occur throughout interval; low amplitude bituminous-coated stylolites and dense, white tripolitic chert nodules occur throughout.

Dome Pelican Lake 07-34
 07-34-04-15 WPM
 KB: 1499 ft. (456.9 m)

Cored Interval:
 3260-3310 ft. (993.6 - 1108.9m)

Interval	Thickness	Description
3260-3264.1 ft. (993.6-994.9 m)	4.1 ft. (1.3 m)	<u>Lime Mudstone</u> : light grey; dolomitic; irregularly banded; poor to fair vuggy porosity.
3264.1-3266.3 ft. (994.9-995.6m)	2.2 ft (0.7m)	<u>Lime Mudstone</u> : light grey to brown grey; slightly dolomitic; poor vuggy porosity.
3266.4-3270.7 ft. (995.6-996.9 m)	4.3 ft (1.3 m)	<u>Lime Mudstone</u> : light grey brown; mottled; good vuggy porosity in top 2.3 ft. (0.7 m).
3270.7-3273.5 ft. (996.9-997.8 m)	2.8 ft. (0.9 m)	<u>Dolostone</u> : light to medium brown; finely crystalline; generally dense; rare vuggy and intercrystalline porosity.
3273.5-3277.4 ft. (997.8-999.0 m)	3.9 ft. (1.2 m)	<u>Lime Mudstone</u> : light grey; mottled with darker grey; rare stylolites; vertical fracture in top 1.5 ft. (0.5 m); rare vugs.
3277.4-3282.3 ft. (999.0-1000.5 m)	4.9 ft. (1.5 m)	<u>Lime Mudstone</u> : light brown; dolomitic; laminated with brown bituminous partings; tight.
3282.3-3297.6 ft. (1000.5-1005.1 m)	15.3 ft. (4.6 m)	<u>"Tyndall Stone" lithology</u> : mottled; light grey nodules in brown dolostone matrix; 1-2 in. (2.5-5.1 cm) white tripolitic chert throughout; solitary and colonial corals; horizontal burrows common; scattered small solution vugs.
3297.6-3298.3 ft. (1005.1-1005.3 m)	0.7 ft. (0.2 m)	<u>Skeletal Grainstone</u> : light brown; tight.
3298.3-3299.1 ft. (1005.3-1005.6 m)	0.8 ft. (0.3 m)	<u>"Tyndall Stone" lithology</u> : as in interval above from 3282.3-3297.6 ft. (1000.5-1005.1 m).
3299.1-3312.8 ft. (1005.6-1009.7 m)	13.7 ft. (4.2 m)	<u>Skeletal Grainstone</u> : light brown; makes up approximately 80% of interval; remainder of interval is "Tyndall Stone" lithology in bands up to 0.7 ft. (0.2 m); tabulate coral at 3300 ft. (1005.8 m); solitary corals; scattered white bryozoan fragments up to 1.5 in. (3.8 cm) aligned parallel to bedding; poor to fair intergranular and vuggy porosity.

Cal Stan Hartney 16-33
16-33-05-24 WPM
KB: 1420 feet (432.8 m)

Cored Interval:
4425-4452 feet (1348.7-1357.0 m)

Interval	Thickness	Description
4425-4427.3 ft. (1348.7-1349.4 m)	2.3 ft. (0.7 m)	<u>Dolostone</u> : medium grey; finely crystalline; burrow mottled; scattered brachiopod and crinoid fragments.
4427.3-4429.9 ft. (1349.4-1350.2 m)	2.6 ft. (0.9 m)	<u>Mudstone to Wackestone</u> : light grey to grey; burrow mottled; sharp basal contact; crinoid fragments.
4429.9-4438.4 ft. (1350.2-1352.8 m)	8.5 ft. (2.6 m)	<u>Mudstone</u> : light brown to grey; limy; anhydrite common as stringers and blebs in basal 3 feet (0.9 m); stylolitic.
4438.4-4452.4 ft. (1352.8-1357.1 m)	14 ft. (4.3 m)	<u>Dolostone</u> : light brown; thin argillaceous partings common throughout; rare chert nodules; scattered crinoid fragments in basal 2.5 feet (0.8 m) along with <i>Dimorphosiphon</i> algae.

Cored Interval:
4787-4813 feet (1459.1-1467.0 m)

Interval	Thickness	Description
4787-4813 ft. (1459.1-1467.0 m)	26 ft. (7.9 m)	<u>Wackestone</u> : light brown matrix with dark brown mottles. "Tyndall Stone" lithology.

Dome St. Alphonse 13-16
 13-16-06-12 WPM
 KB: 1331 feet (405.7 m)

Cored interval:
 2424-2474 feet (738.8-754.1 m)

Interval	Thickness	Description
2424-2434.7 ft (738.8-742.1 m)	10.7 ft (3.3 m)	<u>Dolostone</u> : pinkish grey on surface but greyish green on fresh surface; very finely crystalline; occasional thin, red brown to grey-green laminae; weakly laminated throughout; lighter in colour and siliceous in appearance from 2428.5-2429.8 ft. (740.2-740.6 m); discontinuous fracture in top of core; rare surface vugs.
2434.7-2451 ft. (742.1-747.1 m)	16.3 ft. (5.0 m)	<u>Dolostone</u> : cream to light brown, may have slight pinkish cast; finely crystalline; dense; 4.9 ft (1.5 m) laminated zone from 2439-2441.5 ft. (743.3-744.2 m) with laminae 0.2-0.4 in. (0.5-1.0 cm) thick, breakage surfaces are reddish brown and argillaceous; occasional reddish purple, argillaceous bands from 2443-2443.7 ft. (744.6-744.8 m) and from 2448.5-2449.5 ft. (746.3-746.6 m); 1.6 in. (4 cm) band beginning at 2443.9 ft. (744.9 m) appears to be a dolomitized grainy bed marked by abundant moldic to fine vuggy porosity.
2451-2451.3 ft. (747.1-747.2 m)	0.3 ft. (0.1 m)	<u>Dolostone</u> : pinkish brown; finely crystalline; replaced intraclastic grainstone; trace colonial(?) corals; good to excellent intergranular porosity; sharp basal contact.
2451.3-2457.1 ft. (747.2-748.9 m)	5.8 ft. (1.7 m)	<u>Dolostone</u> : pinkish brown; finely crystalline; dense; oblique limonite stained fracture in bottom 1.3 ft. (0.4 m) of interval; scattered solution vugs in bottom 3 ft. (0.9 m) of interval.
2457.1-2475.3 ft. (748.9-754.5 m)	18.2 ft. (5.6 m)	<u>Dolostone</u> : cream to light brown to slightly purple; finely crystalline; sharp contact at 2459.9 ft. (749.8 m) with 2 in. (5.1 cm) thick, light brown intraclastic zone with <0.25 in. (0.6 cm) diameter intraclasts; white chert nodules at 2405.5 ft.(733.2 m), 2466.5 ft. (751.8 m) and 2470 ft. (752.9 m); siliceous dolostone at 2467.5 ft. (752.1 m); good to fine vuggy porosity from 2457.5-2458 ft. (749.0-749.1 m).

Cai Stan Wawanesa 3-1
03-01-08-18 WPM
KB: 1364 ft. (415.7 m)

Cored Interval: 3335-3345 ft. (1061.5-1019.6 m)

Interval	Thickness	Description
3335-3338.3 ft. (1016.5-1017.5 m)	3.3 ft. (1.0 m)	<u>Wackestone to Packstone</u> : light to medium grey; dolomitic(?); light grey, mottled in basal 5.2 ft. (1.6 m); oblique fracture splits central part of interval; occasional tabulate and horn corals; surface vugs except in top 10 in. (25.4 cm) of interval; base of interval grades into mottled zone below.
3338.3-3343.3 ft. (1017.5-1019 m)	5.0 ft. (1.5 m)	<u>Mudstone to Wackestone</u> : light brown; strongly nodular in part; occasional stylolitic partings; major stylolite at 3339.8 ft. (1018 m); occasional horn corals and scattered, fragmented tabulate corals; scattered surface vugs.
3343.3 - 3345 ft. (1019-1019.6 m)	1.7 ft 0.6 m)	Core missing.

Dome Brandon 3-5
 03-05-09-19 WPM
 KB: 1373 ft. (418.5 m)

Cored Interval:
 3325-3361 ft. (1013.5-1024.4 m)

Interval	Thickness	Description
3325-3328.7 ft. (1013.5-1014.6 m)	3.7 ft (1.1 m)	<u>Mudstone</u> : buff; dolomitic; dense; finely laminated with thin, bituminous partings in basal 6 in. (15.2 cm); possible algal structure at 3326 ft. (1013.8 m).
3328.7-3343 ft. (1014.6-1019 m)	14.3 ft. (4.4 m)	<u>Dolomitic Wackestone</u> : buff to tan; interval occasionally marked by faint, discontinuous, wavy black bituminous partings; occasional black stylolitic partings associated with concentrations of shell material; open vertical fracture occurs in the top 5 in. (13 cm) of interval; crinoids, brachiopods, bryozoans, small colonial, <i>Favositid</i> -type corals and <i>Dimorphosiphon</i> ; some fossils have bituminous coating with moldic porosity; light grey chert nodules, up to 4 in. (10 cm), occur throughout.
3343-3344.4 ft. (1019-1019.4 m)	1.4 ft (0.4m)	<u>Limy Dolostone</u> : as above. Dark tan with grainstone bed in basal 1 in. (3 cm) of interval.
3344.4-3354.9 ft. (1019.4-1022.6 m)	10.5 ft (3.2 m)	<u>"Tyndall Stone" lithology</u> : darker brown; consists of tightly packed, buff nodules in basal 3.5 ft. (1.7 m); bituminous laminae occur in basal 6 in. (15.2 cm) of interval; coarse calcite-filled vertical fracture cuts central part of interval; scattered irregular white chert throughout.
3354.9-3357.8 ft. (1022.6-1023.4 m)	2.9 ft. (0.8 m)	<u>Argillaceous Dolostone</u> : buff; 50% of interval is argillaceous; 2 in. (5 cm) thick algal(?) structure in upper 10 in. (25 cm) of interval; interlaminated with buff dolostone.
3357.8-3361.0 ft. (1023.4 - 1024.4 m)	3.2 ft. (1.0 m)	<u>Dolostone</u> : buff; finely crystalline.

Dome Brandon 3-5
 03-05-09-19 WPM
 KB: 1373 ft. (418.5 m)
 (cont'd.)

Cored Interval:
 3490-3520 ft. (1063.8-1072.9 m)

Interval	Thickness	Description
3490-3503.1 ft. (1063.7-1067.7 m)	13.1 ft. (4.0 m)	<u>Lime Mudstone to Wackestone</u> : buff; dense; irregular patches of blue-grey calcite; rare vug-filling euhedral calcite crystals up to 1.2 in. (3 cm); brachiopod and gastropod molds filled with blue-grey calcite; minor stylolitic basal contact.
3503.1-3509.5 ft. (1067.7-1069.7 m)	6.4 ft. (2.0 m)	<u>Lime Mudstone</u> : light grey to blue; dense; fine argillaceous or bitumen filled stylolites; abundant, thin, calcite-filled vertical closed fractures; non-fossiliferous; scattered irregular "eyes" of calcite common.
3509.5-3516.8 ft. (1069.7-1071.9 m)	7.3 ft. (2.2 m)	<u>Nodular Wackestone</u> : blue-grey nodules in yellow matrix grading to yellow nodules in grey matrix in the lower part of the interval; bituminous-filled stylolites with fairly pronounced amplitudes up to 0.8 in. (2 cm) fairly common; scattered crinoids, brachiopods and bryozoans; blue-grey calcite-filled molds and burrow-infill; sharp basal contact.
3516.8-3518.1 ft. (1071.9-1072.3 m)	1.3 ft (0.4 m)	<u>Lime mudstone</u> : light grey to light brown; <1.2 in. (<3 cm) thick beds; some laminae appear disrupted into tabular, intraclast-like grains up to 1.2 in. (3.0 cm); sharp basal contact.
3518.1-3519.3 ft. (1072.3-1072.7 m)	1.2 ft. (0.4 m)	<u>Lime Mudstone</u> : buff; finely crystalline.
3519.3-3520 ft. (1072.7-1072.9 m)	0.7 ft. (0.2 m)	Core missing.

Dome Brandon 16-27
 16-27-09-19 WPM
 KB: 1329 ft. (405 m)

Cored interval:
 3100-3150 ft. (944.9-960.1 m)

Interval	Thickness	Description
3100-3111.8 ft. (944.9-948.5 m)	11.8 ft. (3.6 m)	<u>Dolostone</u> : light grey; finely crystalline; blue-grey anhydrite replacement in top 1 in. (2.5 cm); bituminous partings in basal 4 ft. (1.2 m); white chert nodules; poor to very poor moldic porosity.
3111.8- 3114 ft. (948.5-949.1 m)	2.2 ft. (0.6 m)	<u>Dolostone</u> : mottled light and medium grey-brown; finely crystalline; matrix light grey; poor vuggy porosity.
3114-3123.2 ft. (949.1-952.1 m)	9.2 ft. (3.0 m)	<u>Dolostone</u> : brownish grey; finely crystalline; white chert nodules throughout; bituminous partings and stylolites throughout; tubular burrows in bed 2-3 in. (5-7 cm) thick at 3117 ft. (950 m); <i>Dimorphosiphon</i> algae(?) near base; basal 3 ft. (0.9 m) exhibits original grainstone(?) texture; poor moldic porosity.
3123.2-3132.9 ft (952.1-954.9 m)	9.7 ft. (2.8m)	<u>Dolostone</u> : medium grey and brown; very finely crystalline; fragmental; white chert nodules abundant throughout; few dark, bituminous partings in top portion of interval; very poor moldic porosity.
3132.9-3146.7 ft. (954.9-959.1 m)	13.8 ft. (4.2 m)	<u>Dolostone</u> : light brown; finely crystalline; occasional weakly laminated zones; intraclastic zone 2 ft. (0.6 m) from top; intraclasts of laminated dolostone; no visible porosity.
3146.7-3155.7 ft. (959.1-961.9 m)	9 ft (2.7 m)	<u>Dolostone</u> : brown with grey laminates throughout; anhydrite replacement as crystals in basal 2 ft. (0.6 m).

Dome Arrow River 12-10
12-10-14-25 WPM
KB: 1643 ft. (500.8 m)

Cored Interval:
3830-3880 ft. (1167.4-1182.6 m)

Interval	Thickness	Description
3830-3838 ft. (1167.4-1169.8m)	8.0 ft. (2.4) m	<u>Dolostone</u> : finely crystalline; bituminous laminae; brachiopods, bryozoans and crinoids; trace anhydrite and chert throughout; poor intercrystalline porosity.
3838-3839.8 ft. (1169.8-1170.4 m)	1.8 ft. (0.6 m)	<u>Wackestone to Packstone</u> : tan to buff, dolomitic; horizontal burrows; trace chert, poor to fair moldic and intercrystalline porosity.
3839.8-3842.3 ft (1170.4 -1171.1 m)	2.5 ft (0.7 m)	<u>Dolostone</u> : buff to light brown; nodular, bituminous laminae; anhydritic.
3842.3 -3846.5 ft. (1171.1-1172.4 m)	4.2 ft. (1.3 m)	<u>Dolostone</u> : light buff to tan; bituminous partings, darker patches are pelleted; trace bryozoans; rare anhydrite and chert; poor pinpoint and vuggy intercrystalline porosity.
3846.5-3849.4 ft. (1172.4-1173.3 m)	2.9 ft. (0.9 m)	<u>Dolostone</u> : tan; dolomitized wackestone to packstone; bioturbated; bituminous partings; vertical fractures; anhydrite nodules; trace vuggy intercrystalline moldic porosity.
3849.4-3861.5 ft (1173.3-1177 m)	12.1 ft. (3.7 m)	<u>Dolostone</u> : tan to brown grey; limy; very finely crystalline; dense; fracture in top 13 in. (33 cm); anhydrite in laminae and thin beds.
3861.5-3865.5 ft. (1177-1178.2 m)	4 ft. (1.2 m)	<u>Dolostone</u> : tan; dolomitized wackestone; poorly nodular; bituminous partings throughout; trace chert and anhydrite; stylolitic.
3865.5-3876.4 ft. (1178.2-1181.5 m)	10.9 ft. (3.3 m)	<u>Dolostone</u> : brown; finely crystalline; dense; weakly laminated; anhydrite nodules in central part of interval.
3876.4-3880.2 ft. (1181.5-1182.7 m)	3.8 ft. (1.2 m)	<u>Anhydrite</u> : blue-grey to light brown; nodular, exhibits weak chicken wire texture in top 6 in. (15.2 cm); laminated in basal portions of interval.
3880.2-3885.2 ft. (1182.7-1184.2 m)	5 ft. (1.5 m)	<u>Dolostone</u> : buff; finely crystalline; dense; faintly laminated; open vertical and horizontal fractures; silicified fossil fragments; scattered anhydrite nodules.

Dome Arrow River 12-10
 12-10-14-25 WPM
 KB: 1643 feet (500.8 m)
 (cont'd.)

Cored Interval:
 3975-4025 ft. (1211.6-1226.8 m)

Interval	Thickness	Description
3975-3977.8 ft. (1211.6-1212.4 m)	2.8 ft. (0.8 m)	<u>Dolostone</u> : tan, faint buff burrows and darker mottles; 0.8 in (2 cm) thick grainstone bed 2 in. (5 cm) from top of interval.
3977.8-3982 ft. (1212.4-1213.7 m)	4.2 ft. (1.3 m)	<u>Dolomitic Limestone</u> : buff limestone with dark tan dolomitic mottles; occasional 0.8 (2 cm) thick crinoidal grainstone interbeds with sharp wavy bases; bituminous partings; some brachiopods, crinoids, bryozoans and <i>Favositid</i> corals; trace anhydrite; gradational basal contact.
3982-4025 ft. (1213.7-1226.8 m)	43 ft (13.1 m)	<u>Wackestone</u> : buff, limy with dark tan mottles of sucrosic dolostone; "Tyndall Stone" lithology; fossiliferous interbeds 0.4-1.6 in. (1-4 cm) thick, with crinoids, brachiopods, rare corals, bryozoans and cephalopods.

Cal Stan Woodlands Core Hole #1
 04-06-15-02 WPM
 K. B.: 889 ft. (271 m)

Cored Interval:
 458-639 ft. (139.6-194.8 m)

Interval	Thickness	Description
458-465.6 ft. (139.6-141.9 m)	7.6 ft. (2.3 m)	<u>Dolostone</u> : buff alternating with pink bands, mainly buff with 6-12 in. (15-31 cm) pink beds with irregular, sharp contacts between buff and pink beds; finely crystalline; buff beds are massive with 0.2 in. (0.5 cm) wide vertical anhydrite filled fractures and horizontal fractures; thin (<0.04 in.; <0.1 cm) argillaceous (?) partings in top 10 in. (25 cm) of interval; intraclastic zone (0.4 in.; 1 cm thick) occurs within pink dolostone at 460 ft. (140.2 m); pinkish-brown argillaceous zone (8 in.; 20 cm thick) begins 1.0 ft. (0.3 m) from the base of the interval; few intraclastic zones, intraclasts are buff, ~0.2 in. (~0.5 cm) in red-pink matrix; some zones of closely spaced nodules; some bands of vuggy and moldic porosity in bottom 18 in. (46 cm) of interval; sharp basal contact.
465.6-479.6 ft. (141.9-146.2 m)	14 ft. (4.3m)	<u>Dolostone</u> : buff to very light brown; fine grained; dense; mainly massive; minor (<1 %) irregular chert nodules up to 1 in. (2.5); 0.1-0.5 in. (0.3-1.3 cm); zones of abundant moldic porosity with associated <i>Favositid</i> corals, <i>Dimorphosphon</i> and gastropod molds; sparry dolomite crystals line some vugs; good to excellent moldic porosity in 30% of interval as 1-5 in. (2.5-12.7 cm) thick bands.
479.6-483.3 ft. (146.2-147.3 m)	3.7 ft. (1.1 m)	<u>Dolostone</u> : light tan to medium brown with light tan matrix and medium tan mottles; irregular chert nodules (1-2%); good moldic porosity throughout that may be associated with leached fossils.
483.3-487 ft. (147.3-148.4)	3.7 ft. (1.1 m)	<u>Dolostone</u> : buff to very light brown, as in interval above from 465.6-479.6 ft. (141.9-146.2 m) with chert nodules up to 3 in. (7.6 cm); <i>Favositid</i> corals; poor to fair moldic porosity throughout.
487-495.7 ft. (148.4-151.1 m)	8.7 ft. (2.7 m)	<u>Dolostone</u> : as above.
495.7-499.8 ft. (151.1-152.3 m)	4.1 ft. (1.2 m)	<u>Dolostone</u> : light tan to dark brown; mottled with irregular white chert nodules and scattered solution vugs associated with fossils(?) or solutioned chert(?); near vertical fracture cuts basal 18 in. (46 cm) of interval.
499.8-500.5 ft. (152.3-152.6 m)	0.8 ft. (0.3 m)	<u>Dolostone</u> : pink to brown; finely crystalline; dense.
500.5-503.5 ft. (152.6-153.5 m)	3.0 ft. (0.9 m)	<u>Dolostone</u> : red, brown to buff; finely crystalline; dense; interbedded and laminated argillaceous dolostone with reddish material in the top half of interval; vertically fractured; stylolitic basal contact.
503.5-507.5 ft. (153.5-154.7 m)	4.0 ft. (1.2 m)	<u>Dolostone</u> : buff, very finely crystalline; dense; abundant oblique to near vertical fractures in the top 3 in. (8 cm) of the interval; occasional bands of moldic porosity; sharp planar basal contact.
507.5-514.5 ft. (154.7-156.8)	7.0 ft. (2.1 m)	<u>Dolostone</u> : buff; finely crystalline; dense; thin (~0.4 in.; ~1 cm) thick, irregular, pinkish laminae with scattered irregular chert nodules; vertical fracture traverses entire interval with bleached adjacent areas; occasional anhydrite as vug infills and minor thin (~0.08 in.; ~2 cm) irregular fractures; scattered moldic porosity associated with chert nodules.

Cal Stan Woodlands Core Hole #1
 04-06-15-02 WPM
 K. B.: 889 ft. (270.9 m)
 (cont'd.)

Interval	Thickness	Description
514.5-524.7 ft. (156.8-159.9 m)	10.2 ft. (3.1 m)	<u>Dolostone</u> : light buff; finely crystalline; dense; 0.25 -3.0 in.(0.6-8 cm) leached (originally grainstone?) beds and thin (<0.04-0.2 in.; <0.1-0.5 cm) discontinuous pyrite laminae; pyrite also occurs on fracture surfaces and as lensoid patches parallel to bedding; moldic porosity associated with grainstone(?) beds; gradational basal contact.
524.7-534.7 ft. (159.9-163 m)	10.0 ft. (3.1 m)	<u>Dolostone</u> : buff to light grey/pink; nodular; grey disseminated pyrite-rich interstices; becomes vaguely nodular toward base of interval; occasional 2-4 in. (5-10 cm) thick tripolitic chert nodules/beds that extend across width of core, constitute 10% of overall thickness; surface moldic porosity associated with tripolitic chert; poor overall moldic porosity.
534.7-537.0 ft. (163-163.7 m)	2.3 ft. (0.7 m)	Core missing.
537.0-555.8 ft. (163.7-169.4 m)	18.8 ft. (5.7 m)	<u>Dolostone</u> : as above. Buff, nodular dolostone with pink-purple dolomitic interstices; varying from nodular to vaguely nodular; occasional 1-2 in. (3-5 cm) thick stylolitic partings infilled with purple, argillaceous(?) material; vertical fractures; surface moldic porosity as above, predominant in upper portions of interval.
555.8-559 ft. (169.4-170.4 m)	3.2 ft. (1.0 m)	<u>Dolomitic Limestone to Limy Dolostone</u> : buff; finely crystalline; vaguely nodular with remnants of purple pink interstices, as above; pelleted(?) intraclastic bed in top 3 in. (8 cm) of interval; remainder of interval consists of irregular pinkish mottles; 0.5 in. (1.3 cm) zone of closely spaced stylolitic partings.
559-568.8 ft. (170.4-173.4)	9.8 ft. (3.0 m)	<u>Dolomitic Limestone to Limy Dolostone</u> : buff-purple/pink; finely crystalline; vaguely nodular limestone with 18 in. (46 cm) bed of massive buff limestone at 561 ft. (171 m); 2 in. (5 cm) leached grainstone(?) bed at 559.3 ft.(170.5 m); occasional 3-4 in. (8-10 cm) thick purple bands that contain intraclast-like inclusions, 0.2-0.4 in. (0.5-1 cm); some 1-2 in. (3-5 cm) limonite stained bands; 1 in. (3 cm) weakly laminated band begins at 566.8 ft. (172.8 m).
568.8-570.4 ft. (173.4-173.9 m)	1.6 ft. (0.5 m)	<u>Dolostone</u> : light tan; finely mottled dolostone with flecks of hematite and occasional surface vugs; gradational basal contact.
570.4-576.1 ft. (173.9-175.6 m)	5.7 ft. (1.7 m)	<u>Limy Dolostone to Dolomitic Limestone</u> : light tan and very slightly dark tan; irregular, vague mottles; basal 2 ft. (0.6 m) of interval is finely mottled with flecks of disseminated hematite; occasional 1 in. (3 cm) chert nodules throughout; sharp basal contact marked by argillaceous parting.
576.1-576.3 ft. (175.6-175.7 m)	0.2 ft. (0.1 m)	<u>Limestone</u> : buff and purple; laminated with thin (<0.04 in.; <0.1 cm) argillaceous partings; sharp basal contact.

Cal Stan Woodlands Core Hole #1
 04-06-15-02 WPM
 K. B.: 889 ft. (270.9 m)
 (cont'd.)

Interval	Thickness	Description
576.3-589.3 ft. (175.7-179.6 m)	13 ft. (3.9 m)	<u>Lime Mudstone</u> : light brown; thinly bedded to massive; lensoid chert nodules up to 4 in. (10 cm) thick, occasionally reaching or surpassing width of core; evidence of soft sediment deformation; occasional concentrated stylolitic partings (0.04 in.; 0.1 cm thick) and shaly partings; no visible porosity; sharp basal contact.
589.3-590.5 ft. (179.6-180 m)	1.2 ft. (0.4 m)	<u>Lime Wackestone to Packstone</u> : light brown; bioturbated; patches of grainstone containing brachiopods and crinoids; basal 3 ft. (0.9 m) is massive lime mudstone; sharp basal contact.
590.5-609 ft. (180-185.6 m)	18.5 ft. (5.6 m)	<u>"Tyndall Stone" lithology</u> : irregular white chert nodules in the top 15 ft. (4.6 m) of interval.
609-615 ft. (185.6-187.5 m)	6 ft. (1.9 m)	<u>Limy Dolostone</u> : light dark buff with slight pink-purple and/or greenish cast; irregularly mottled; 90-95% of interval composed of dolostone with limestone that occurs as buff-white wackestone patches; dolostone contains purple burrows (~0.2 in.; ~0.5 cm) that occur within closely spaced nodules with hematite stained margins; rare, small (<0.4 in.; <1 cm) tripolitic chert nodules and minor scattered surface vugs; matrix of lime wackestone contains crinoid plates; large (~1.6 in.; ~4 cm) well preserved <i>Streptelasma</i> ; decrease in dolostone towards base; gradational basal contact.
615-639.7 ft. (187.5-195 m)	24.7 ft (7.5 m)	<u>Wackestone</u> : cream coloured lime matrix with light tan (irregularly dolomitized) mottles; "Tyndall Stone" lithology; gradational upper contact; tan mottles in 50% of top of interval, grading to <25% at base; minor (<5 %) irregular, buff, tripolitic chert nodules (~2-3 in.; ~5-8 cm) throughout; rare, grey, spherical, dense chert nodules; concentrated band of stylolitic partings filled with brown, bituminous(?) material at 636 ft. (193.9 m); surface vugs throughout.

Cal Stan Woodlands Core Hole #1
 04-06-15-02 WPM
 K. B.: 889 ft. (270.9 m)
 (cont'd.)

Cored Interval:
 750-800 ft. (228.6-243.8 m)

Interval	Thickness	Description
750-757.5 ft. (228.6-230.9 m)	7.5 ft. (2.3 m)	<u>Dolomitic Lime Mudstone to Wackestone</u> : pinkish-brown to light brown; vaguely mottled, becoming more distinct in bottom 1 ft. (0.3 m) of interval; irregular purplish, wavy, discontinuous laminae (~0.08 in.; ~0.2 cm), especially in the middle of the interval; irregular tripolitic chert nodules (up to ~1.2 in.; 3 cm); scattered brachiopod and crinoid fragments; gradational basal contact.
757.4-767.4 ft. (230.9-233.9)	10 ft. (3.0 m)	<u>Dolomitic Lime Mudstone to Wackestone</u> : light tan to slightly pink; light tan-buff matrix of dolomitic limestone and orange-tan irregular mottles of dolomite with purplish rims; irregular dark brown patches of silicified limestone throughout; discontinuous, wavy, (~0.04-0.08 in.; ~0.1-0.2 cm) thick, purple laminae occur throughout; brachiopod and crinoid fragments; rare white tripolitic chert and dense chert nodules; scattered surface vugs.
767.4-778.3 ft. (233.9-237.2 m)	10.9 ft. (3.3 m)	<u>Dolomitic Lime Mudstone to Wackestone</u> : as above. Argillaceous; purple hematitic material; purple rims outline cylindrical and horizontal burrows; purple hematite also concentrated at lithologic boundaries; mottling varies from defined to indistinct; gradational contacts.
778.3-790.4 ft. (237.2-240.9 m)	12.1 ft. (3.7 m)	<u>Dolomitic Mudstone</u> : buff to light tan; very finely crystalline; very vaguely mottled; rare crinoid fragments scattered throughout, limestone is buff and dolomite is light tan; small (0.5 in.; 1 cm) tabulate corals at 787.3 ft. (240 m); 0.5 in. (1 cm) thick grainstone bed with crinoid/brachiopod debris 3 in. (8 cm) from top of interval; irregular, lensoid white, 1.2-2.0 in. (3-5 cm) tripolitic chert nodules throughout; sharp and irregular, wavy upper and lower contacts.
790.4-799.8 ft. (240.9-243.7 m)	9.4 ft. (2.9 m)	<u>"Tyndall Stone" lithology</u> : 25% of interval consists of a brown, dolostone; 75% of interval consists of a buff, lime wackestone to mudstone; boundary between lithologies is occasionally marked by purple hematite staining that is also associated with stylolites; hematite also occurs as small patches of colouration; rare tripolitic chert nodules throughout; occasional surface solution vugs.

Dome Strathclair 8-34
 08-34-16-21 WPM
 KB: 1993 feet (607.5 m)

Cored Interval:
 3538-3590 feet (1078.4-1094.2 m)

Interval	Thickness	Description
3538-3546.3 ft. (1078.4-1081 m)	8.3 ft. (2.5 m)	<u>Grainstone to Packstone</u> : light to medium grey-brown; wispy argillaceous partings; abundant crinoids and brachiopods; abundant chert nodules and rare anhydrite blebs; poor moldic porosity.
3546.3-3548.8 ft. (1081-1081.7 m)	2.5 ft. (0.7 m)	<u>Lime Mudstone</u> : light brown; wispy argillaceous partings give nodular appearance; rare blue anhydrite nodules; abundant chert nodules (0.5-2.0 in.; 1-5 cm).
3548.8-3568.8 ft. (1081.7-1087.8 m)	20 ft. (6.1 m)	<u>Dolostone</u> : light brown; finely crystalline; cylindrical, horizontal burrows common throughout; white chert nodules; rare anhydrite nodules.
3568.8-3571.5 ft. (1087.8-1088.6 m)	2.7 ft. (0.8 m)	<u>Dolostone</u> : light brown; finely crystalline; mottled throughout; burrowed; irregular blue-grey anhydrite nodules; white chert nodules.
3571.5-3581.8 ft. (1088.6-1091.7 m)	10.3 ft. (3.1 m)	<u>Dolostone</u> : light brown; finely crystalline; burrows common throughout; scattered chert (3.5 in.; 8.9 cm) and anhydrite (0.5 in.; 1.3 cm) nodules throughout.
3581.8-3584.2 ft. (1091.7-1092.5 m)	2.4 ft. (0.8 m)	<u>Dolostone</u> : medium brown matrix with grey mottles throughout; small anhydrite blebs throughout; horizontal tubular burrows; bands (0.5-1.5 in.; 1-4 cm) of skeletal material.
3584.2-3592.0 ft. (1092.5-1094.8 m)	7.8 ft. (2.3 m)	<u>Dolostone</u> : light to medium brown; abundant horizontal tubular burrows; rare white chert nodules up to 2 in. (5 cm); rare poor moldic porosity.

Gulf Minerals Minltonas Prov. 13-10
13-10-36-26 WPM
KB: 1079 ft. (328.9 m)

Cored Interval:
1348.5-1760 ft. (411.0-536.4 m)

Stony Mountain Formation 1348.5 ft. (411.0 m)
Gunn Member

Interval	Thickness	Description
1348.5-1358 ft. (411.0-413.9 m)	9.5 ft (2.9 m)	<u>Shale</u> : medium to dark grey and greenish grey; massive.
1358-1362.5 ft. (413.9-415.3 m)	4.5 ft. (1.4 m)	<u>Dolostone</u> : light brown; finely crystalline.
1362.5-1364 ft. (415.3-415.7 m)	1.5 ft. (0.4 m)	<u>Dolostone</u> : light and dark grey; shale laminae.

Red River Formation 1364 ft. (415.7 m)

Interval	Thickness	Description
1364-1376 ft. (415.7-419.4 m)	12 ft. (3.7 m)	<u>Dolostone</u> : light brown; upper 3 ft. (0.9 m) contains 5% thin argillaceous partings; mottled; slightly nodular bedding.
1376-1431.6 ft. (419.4-436.4 m)	55.6 ft. (17.0 m)	<u>Dolostone</u> : light brown nodules (dark brown stringers surrounding nodules); trace dolomitized corals(?); fair to poor moldic to vuggy porosity.
1431.6-1448.3 ft (436.4-441.4 m)	16.7 ft (5.0 m)	<u>Dolostone</u> : light grey to greenish grey; finely crystalline; appears "bioturbated"; occasional cylindrical burrows; occasional wispy argillaceous laminae.
1448.3-1470.6 ft. (441.4-448.2 m)	22.3 ft. (6.8 m)	<u>Dolostone</u> : as above. Scattered colonial corals and occasional brachiopods; basal 2 ft. (0.6 m) highly mottled and burrowed, pinpoint to vuggy porosity in centre of burrows; fair solution vuggy porosity and fair intercrystalline porosity.
1470.6-1473.9 ft (448.2-449.2 m)	3.3 ft (1.0 m)	<u>Dolostone</u> : medium grey; argillaceous; massive; laminated in top 9 in. (23 cm); top 3 in. (8 cm) has rip-up intraclastic grainy zones.
1473.9-1496.2 ft. (449.2-456.0 m)	22.3 ft. (6.8 m)	<u>Dolostone</u> : light brown; finely crystalline; dense; argillaceous from 1480-1482 ft. (451-451.7 m); frequent leached zones 3-6 in. (8-15 cm) thick; rare carbonaceous shale partings.

Gulf Minerals Minitonas Prov. 13-10
 13-10-36-26 WPM
 KB: 1079 ft. (328.9 m)
 (cont'd.)

Interval	Thickness	Description
1496.2-1535.6 ft. (456.0-468.0 m)	39.4 ft. (12.0 m)	<u>Dolostone</u> : light brown; nodular; wispy, argillaceous laminae surrounds nodules; cylindrical, horizontal burrows throughout; fair pinpoint solution porosity in centre of cylindrical burrows; occasional vuggy porosity up to 1 in. (3 cm) in diameter; fair intercrystalline porosity.
1535.6-1548.9 ft. (468.0-472.1 m)	13.3 ft. (4.1 m)	<u>Dolostone</u> : medium to greenish grey; dense; occasional horizontal, cylindrical burrows; some soft sediment deformation; argillaceous; occasionally bioturbated; more uniform with less burrowing near base; vertical fracture in basal 4 ft. (1.2 m).
1548.9-1688.9 ft. (472.1-514.8 m)	140 ft (42.7 m)	<u>Dolostone</u> : light to medium brown; massive to faintly mottled; some horizontal, cylindrical burrows; rare horn corals; poor vuggy and moldic porosity; poor intercrystalline porosity.
1688.9-1741.9 ft. (514.8-530.9 m)	53 ft. (16.1 m)	<u>Lime Mudstone</u> : light to medium brown; faintly mottled, as above; rare burrows; vertical fracture from 1730-1733 ft. (527.3-528.2 m); no visible fossil fragments; very poor intercrystalline porosity; sharp basal contact with underlying greenish grey shale of Winnipeg Formation.

Winnipeg Formation 1741.9 (530.9 m)

Interval	Thickness	Description
1741.9-1760 ft. (530.9-536.4 m)	18.1 ft. (5.5 m)	Not described.