Petroleum Open File POF 14-93

Petroleum Potential of the Pre-Mississippian, Southwestern Manitoba: An Introduction and Review

By C.D. Martiniuk and D. Barchyn

Manitoba
Energy and Mines
Petroleum Branch

1993

Recycled Paper

Manitoba
Energy and Mines
Petroleum Branch

Petroleum Open File POF 14-93

Petroleum Potential of the Pre-Mississippian, Southwestern Manitoba: An Introduction and Review

By C.D. Martiniuk
Manitoba Energy and Mines
Petroleum Branch
Winnipeg, 1993

and D. Barchyn
Independent Geologist

Energy and Mines

Hon. James E. Downey
Minister

David Tomasson
Deputy Minister

Petroleum Branch

B. Dubreuil
Director

This publication is available in large print, audiotape or braille on request

TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

Exploration for oil and gas in the pre-Mississippian strata of southwestern Manitoba offers a unique opportunity in western Canada. Although this area is generally regarded as an intensely explored, mature producing petroleum province, the potential for large reserves of high quality oils at shallow depths exists over large areas of southwestern Manitoba (Fig. 1). These areas are virtually unexplored as evidenced by the low drilling density (Figs. 2, 3). Low drilling costs and a competitive fiscal regime, which includes special incentives for pre-Mississippian exploration, make the economics of exploring for this untested potential particularly attractive.

The existence of porosity and permeability systems of reservoir quality in the pre-Mississippian strata of southwestern Manitoba has been previously documented (Martiniuk, 1992; Sproule and Associates, 1964). The intent of this report is to assess two other essential ingredients required for identification of significant pre-Mississippian oil pools in southwestern Manitoba;

1) the occurrence of potential trapping mechanisms, and
2) the potential for hydrocarbon charge from thermally mature source rocks into the pre-Mississippian strata of southwestern Manitoba.

The approach is to examine the habitat of pre-Mississippian oil pools elsewhere in the Williston Basin and to assess the implications of these known pools on exploration concepts that may be applied in Manitoba.

Pre-Mississippian exploration in southwestern Manitoba can be regarded as essentially frontier exploration and thus lends itself to basin analysis techniques. The oil-source systems of the Williston Basin have been previously studied. This knowledge can be readily applied to southwestern Manitoba. The nature of these oil systems, generally characterized by long distance migration paths, bodes well for exploration opportunities in areas on the updip flanks of the basin, such as southwestern Manitoba. The large reserves of high quality oils in the Mississippian reservoirs of southwestern Manitoba and southeastern Saskatchewan are far removed from areas of thermally mature source rocks. This attests to the excellent hydraulic characteristics of the northeastern flank of the basin in terms of its ability to accommodate long distance lateral oil migration.

This report summarizes the pre-Mississippian stratigraphy of the Williston Basin and southwestern Manitoba, and highlights potential reservoir zones. Williston Basin oil-source systems are described with special attention to maximum observed lateral and cross-stratal migration. Examples of pre-Mississippian oil pools elsewhere in the Williston Basin are presented to illustrate some of the known play types specifically in terms of trapping mechanisms. Examples of stratigraphic and structural characteristics from southwestern Manitoba accompany each play type example. This provides evidence that the geological conditions responsible for trapping oil elsewhere in the Williston Basin are also present in southwestern Manitoba. The location of

Figure 1: Map of the Williston Basin.

potentially favourable trap settings in southwestern Manitoba are assessed in the context of maximum observed oil migration distances as inferred from known Williston Basin oil-source systems. This integration of evidence lends support to the assertion that the sparsely-explored pre-Mississippian strata of southwestern Manitoba presents an exciting exploration opportunity.

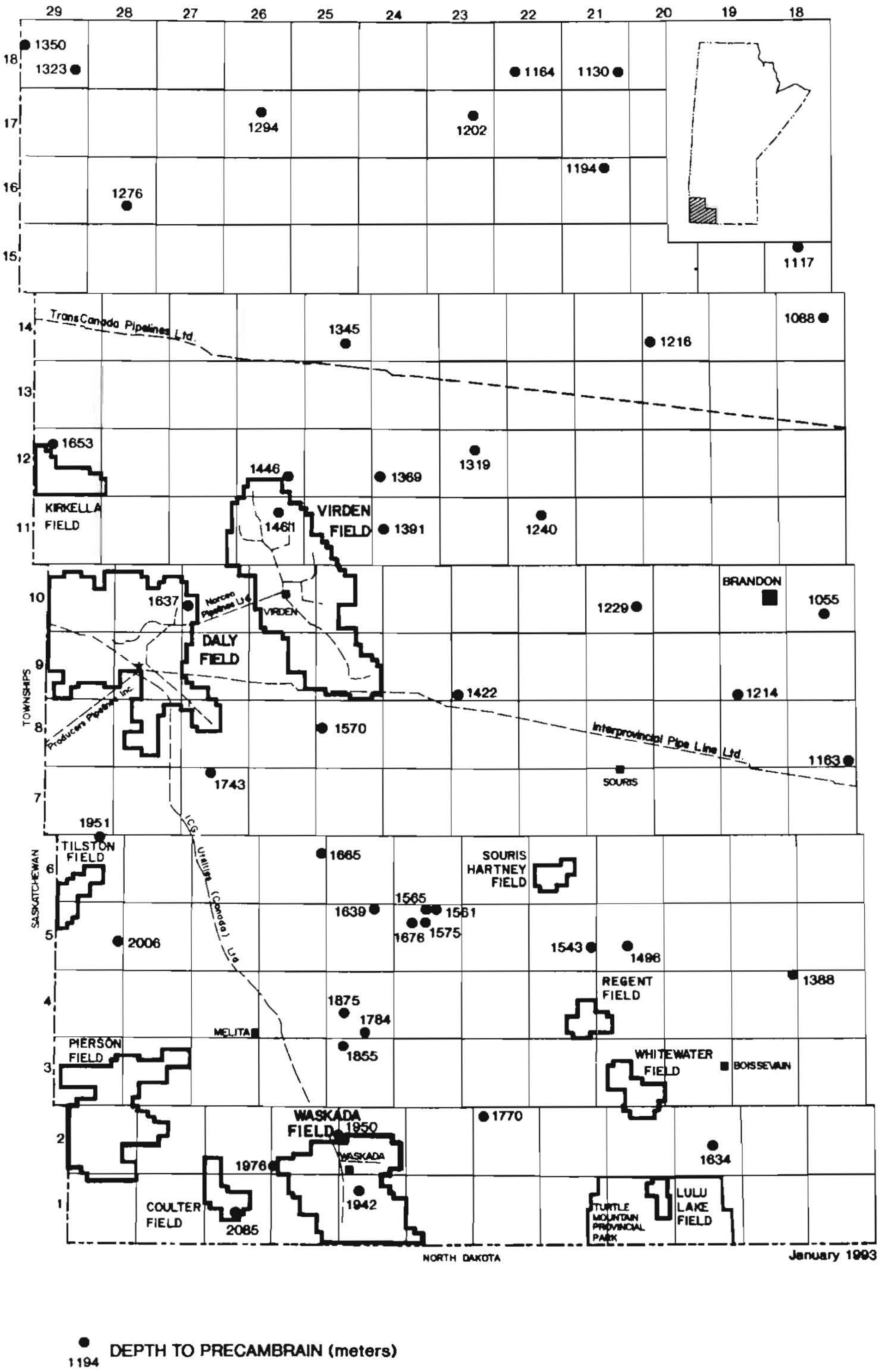


Figure 2: Map showing deep tests drilled to Precambrian, oil fields and producing areas in southwestern Manitoba. Depths shown in metres.

DRILLING DENSITY (S.W.MANITOBA)

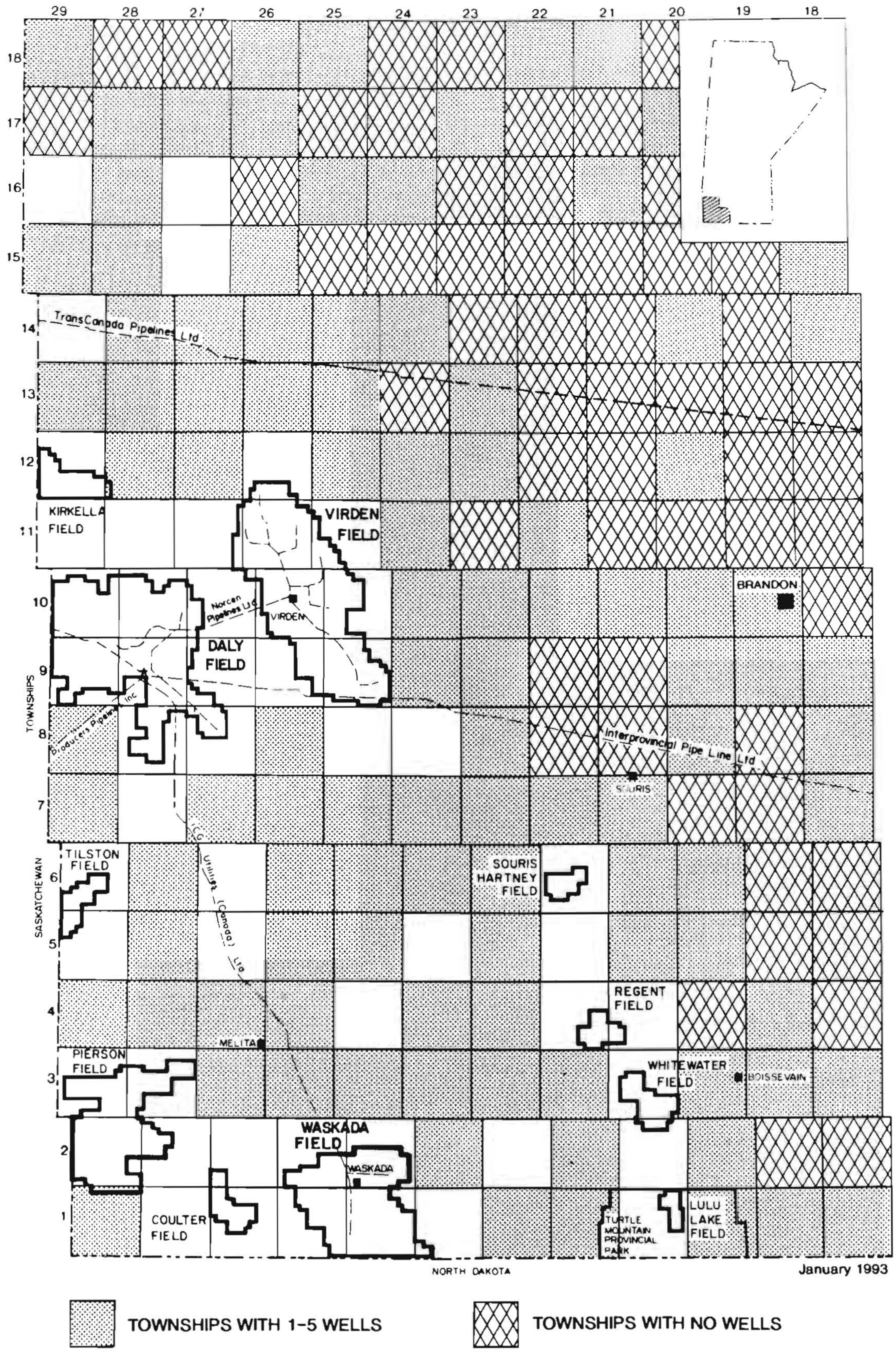


Figure 3: Map showing drilling density, oil fields and producing areas of southwestern Manitoba.

GEOLOGIC SETTING

The Williston Basin is an elliptical, intracratonic, structural and sedimentary basin located at the western edge of the Canadian Shield. It is located in southern Saskatchewan and southwestern Manitoba in Canada, and central and western North Dakota, eastern Montana and northwestern South Dakota in the United States (Fig. 4).

Total depression of the basin is approximately 4 900 m (16,000 ft), with the maximum thickness occurring in North Dakota. Phanerozoic Rocks, deposited during Cambrian through Tertiary time, are present in the basin. Basin sedimentation is characterized by cyclical transgressions and regressions and repeated carbonate/clastic sequences. Paleozoic strata are dominated by carbonates, whereas Mesozoic and Cenozoic strata consist mainly of clastics.

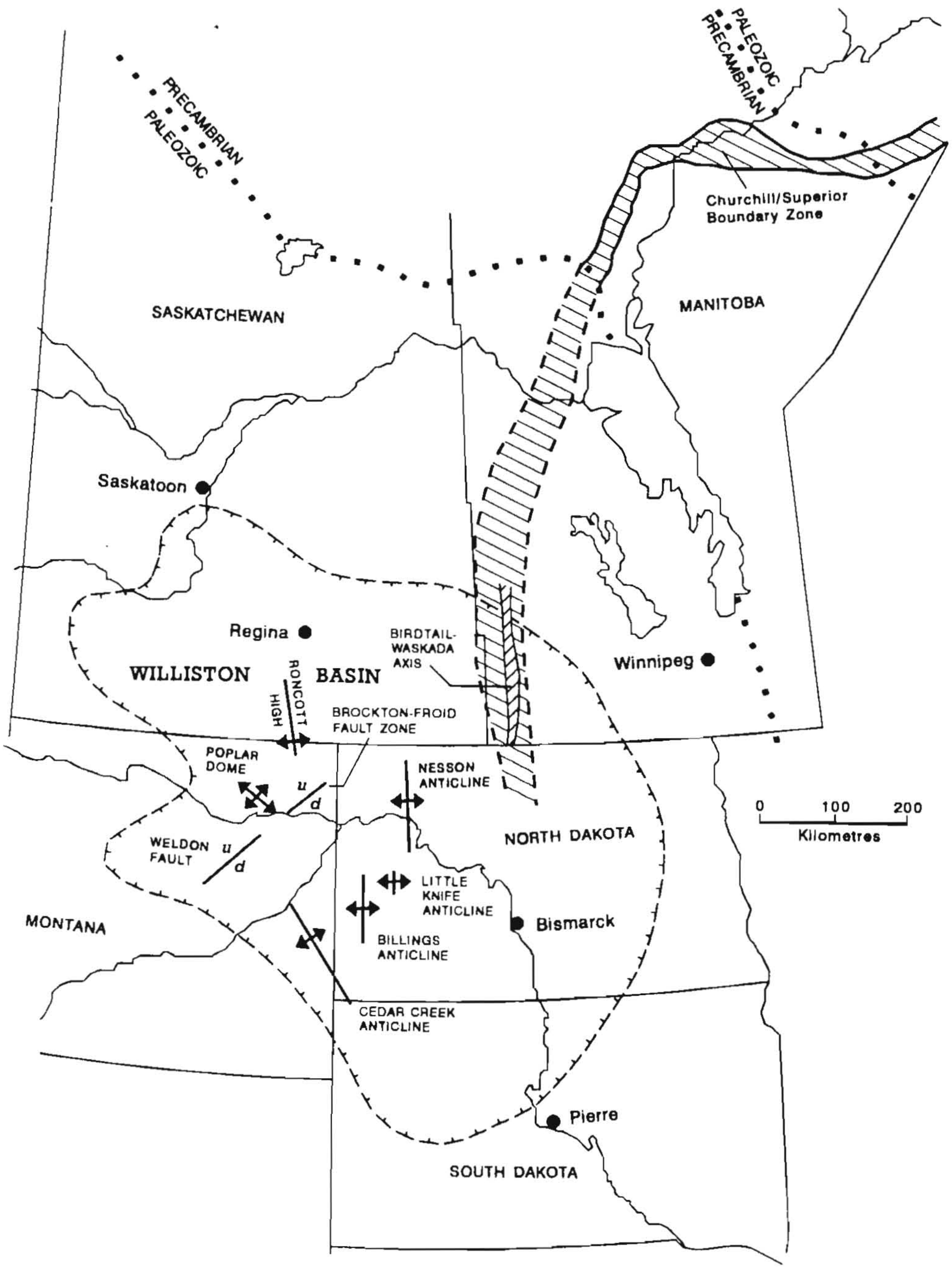


Figure 4: Major structural features of the Williston Basin (after Gerhard et al., 1990).

GENERAL STRATIGRAPHY

WILLISTON BASIN SEDIMENTARY SEQUENCES

The rocks in the Williston Basin have been divided into cratonic, stratigraphic assemblages, or packages, based on major unconformities within the preserved sedimentary section. Sloss (1963) and others (Carlson and Anderson, 1965; Gerhard *et al.*, 1982; Gerhard *et al.*, 1990), subdivided the sedimentary record into the following sequences;

1) Sauk (Cambrian-Lower Ordovician),
2) Tippecanoe (Ordovician-Silurian),
3) Kaskaskia (Devonian-Mississippian),
4) Absaroka (Pennsylvanian-Triassic),
5) Zuni (Jurassic-Tertiary), and
6) Tejas (Tertiary-Quaternary).

Each sequence represents a relative sea level rise and subsequent sedimentation, followed by a relative sea level fall and accompanying disconformity.

The most significant petroleum production in the Williston Basin is from reservoirs in the Paleozoic sequence (Sauk to Absaroka sequences). In southwestern Manitoba, current oil production is from Mississippian formations (Upper Kaskaskia Sequence) and the Jurassic (Zuni Sequence). Limited deep drilling in southwestern Manitoba has revealed the presence of potential reservoirs below traditional Mississippian targets within Cambrian, Ordovician, Silurian and Devonian strata.

The following discussion uses the sequences of Sloss and others (Carlson and Anderson, 1965; McCabe, 1971; Gerhard *et al.*, 1982; Gerhard *et al.*, 1990; LeFever, *et al.*, 1991; Martiniuk, 1992) to summarize the general stratigraphy of the pre-Mississippian (Sauk to Lower Kaskaskia sequence) of the Williston Basin and the petroleum potential of reservoirs within each sequence (Fig. 5). The reader is referred to Martiniuk (1992) for a reference to previous work and a more detailed discussion of the Lower Paleozoic stratigraphy of southwestern Manitoba.

Sauk Sequence

Williston Basin sedimentation was initiated in latest Cambrian time during an eastward transgression into an embayment on the western Cordilleran shelf. The Sauk Sequence, represented by the strata of the Deadwood Formation (Late Cambrian to Early Ordovician), was deposited on the highly irregular Precambrian erosion surface.

The Deadwood Formation is an onlapping sequence of sandstone overlain by shale and carbonate. Deposition of the Deadwood Formation was followed by a period of erosion that occurred between deposition of the Sauk and Tippecanoe sequences. Widespread truncation of the Deadwood Formation by erosion prior to deposition of the basal beds of the overlying Winnipeg Group, occurs in eastern North Dakota, southward toward the Black Hills of South Dakota and in the extreme southwest corner of southwestern Manitoba.

Oil production from the Deadwood Formation is restricted to the Nesson Anticline and the Newporte Field in North Dakota.

Tippecanoe Sequence

The Tippecanoe Sequence comprises rocks of Middle Ordovician through Silurian age (Fig. 5). It was deposited during a second cycle of marine transgression that invaded the area of the Williston Basin. At this time, the Williston Basin was nearly circular, with a marine connection to the southwest. The Tippecanoe transgression entered the Williston Basin from the southwest through a trough between the Colorado-Wyoming and Brockton-Froid Shear Systems.

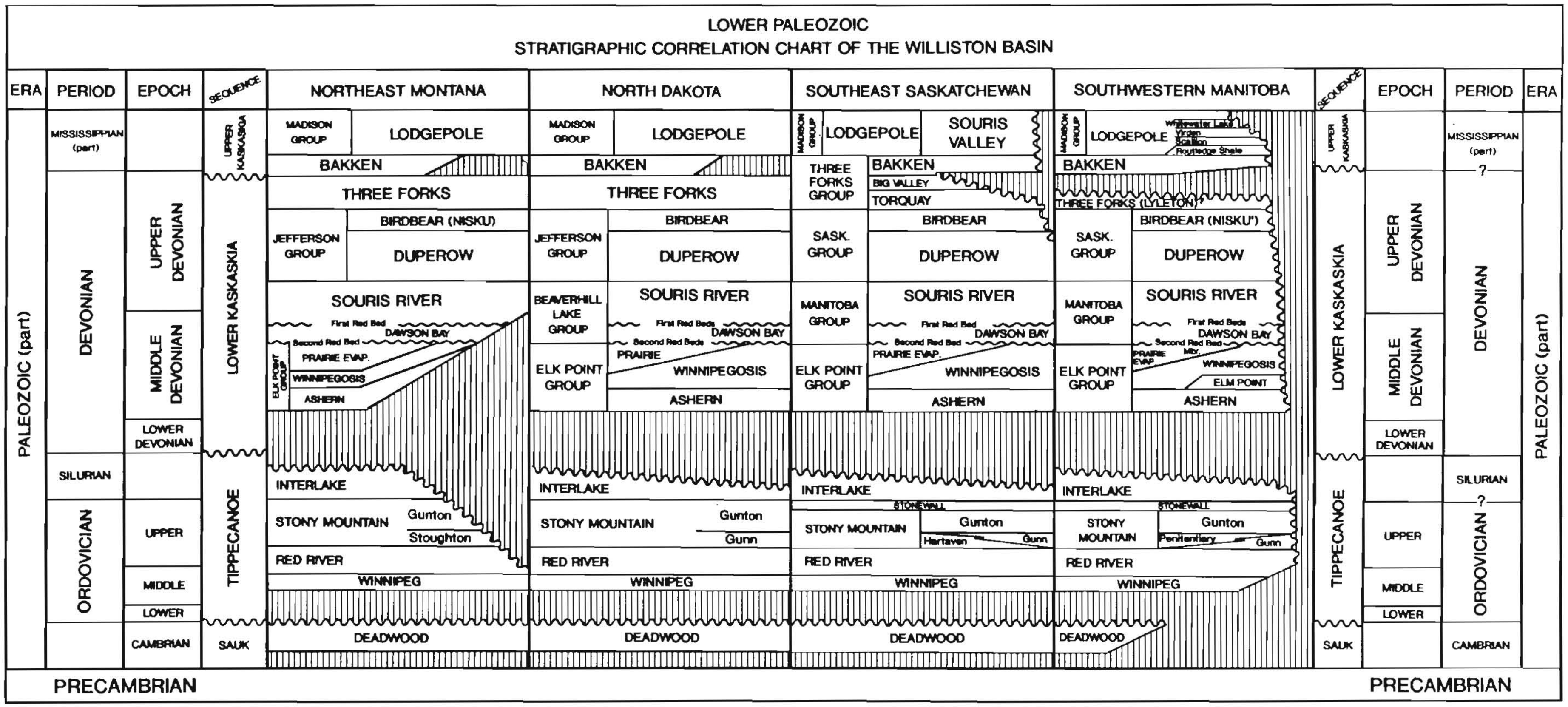
The Tippecanoe Sequence began with deposition of the clastics of the Winnipeg Group. The sedimentation of these strata was followed by a major carbonate cycle of deposition.

The carbonate cycle began with the sedimentation of the Red River Formation. The predominantly limestone or dolomitic limestone and evaporitic beds of the Red River Formation represent shelf and lagoonal deposits and cycles of supratidal carbonates and sabkha evaporites. The lower Red River Formation comprises repetitive cycles of organic-rich, partially dolomitized fossiliferous limestones and burrowed mudstones. The upper Red River Formation consists of cycles of shallow marine to sabka deposits.

Sedimentation was continuous throughout the remainder of the carbonate cycle of deposition when the shales and carbonates of the Stonewall and Stony Mountain formations and the predominantly dolostones and dolomitic limestones of the Silurian Interlake Formation were deposited. A major period of erosion followed Interlake deposition.

The tectonic features that resulted in the formation of major structures in the Williston Basin were active during the deposition of the Tippecanoe Sequence. By the end of the deposition of the Tippecanoe Sequence, ancestral forms of the major structures of the Williston Basin such as the Billings, Little Knife, Nesson and Cedar Creek anticlines, were present.

Oil production is obtained from several formations within the Tippecanoe Sequence in the Williston Basin. Reservoir beds within the basal quartzose sandstones of the Winnipeg Group are productive along the Nesson Anticline. Major production from the Red River Formation is obtained throughout the Williston Basin from dolomitized porosity zones within the upper part of the formation. The Interlake Formation is productive along the Nesson Anticline in North Dakota and on the Cedar Creek Anticline in Montana.



' Former Manitoba stratigraphic terminology.

Figure 5: *Stratigraphic correlation chart of the Williston Basin, Lower Paleozoic Sequence (after Department of Mineral Resources Petroleum and Natural Gas Branch, Regina, Saskatchewan, Drawing Number G-193, 1963).*

Lower Kaskaskia Sequence

Rocks of the Kaskaskia Sequence range from Lower Devonian to Mississippian in age (Fig. 5). The Kaskaskia Sequence represents two regional rises in sea-level, separated by an unconformity that was partially developed in late Devonian time. Gerhard *et al.* (1982) subdivided the Kaskaskia Sequence into upper and lower divisions based on that unconformity.

During deposition of the Lower Kaskaskia strata, the depocenter shifted from western North Dakota, northward into the Elk Point Basin of northwestern Saskatchewan and eastern Alberta. The shift in depositional setting occurred in response to an uplift of the Transcontinental Arch on the south margin of the basin that terminated the southwest marine connection and opened a new marine connection to the north and west. The Williston Basin became part of a larger Devonian seaway whose thickest deposits are in Western Canada. Initial deposits of the Kaskaskia Sequence represent a marine transgression of the Devonian Sea from the north and west onto the Interlake erosional surface.

The Lower Kaskaskia Sequence comprises the Ashern, Winnipegosis, Prairie, Dawson Bay, Souris River, Duperow, Birdbear and Three Forks formations. Shale and carbonate breccias of the Ashern Formation represent the initial deposits of marine transgression. Winnipegosis sedimentation followed with the widespread deposition of normal marine carbonates. Sediments that represent a shallow shelf and a deeper basin environment were, in turn, deposited. The shelf environment is represented by a fringing bank buildup around the perimeter of the basin. Pinnacle reefs and deeper water inter-reef facies developed basinward from the fringing bank. Winnipegosis sedimentation ended when the basin became restricted due to a drop in sea level. Deposition of the Prairie Evaporite followed.

Prairie Evaporite deposition was followed by a re-establishment of normal marine conditions, under which the Dawson Bay and Souris River formations were deposited. The basal red shales of the Dawson Bay Formation represent, in part, the insoluble residue from dissolution of salt from the underlying Prairie Evaporite. Deposition of the Dawson Bay and Souris River formations is characterized by repeated cycles of argillaceous limestones and dolostones that grade to fossiliferous and stromatolitic strata and reflect the prevailing normal marine conditions. The repeated occurrence of anhydrite reflects short periods of restricted circulation during deposition of the sediments in these carbonates. The recurrence of thin argillaceous zones throughout the strata of the Dawson Bay and Souris River formations may reflect influxes of clastic material into the basin during Devonian time.

Normal marine conditions continued throughout most of deposition of the Duperow and Birdbear formations. Sedimentation during the deposition of the Duperow Formation is characterized by shallowing upward cycles of argillaceous limestones, fragmental fossiliferous dolostones and limestones, massive anhydrites and thin argillaceous zones. The Duperow Formation represents the maximum advance of the late Devonian sea, which reached its peak during mid-Duperow time. The Birdbear Formation represents the initial phases of a regression that followed the major Devonian marine transgressive phase. The Birdbear Formation comprises fragmental, highly fossiliferous limestones and dolostones. Corals, bryozoa, stromatoporoids and algal material are commonly abundant. Devonian seas became more restricted towards the end of Birdbear time, which resulted in the deposition of interbedded dolostones and evaporites.

Deposition of siltstone and shale of the Three Forks Formation followed Birdbear Formation sedimentation. Erosion of the Three Forks Formation occurred along the flanks of the basin.

The Bakken Formation shale that overlies the Three Forks Formation represent the initial transgression of the Upper Kaskaskia Sequence and the reconnection to the Cordilleran sea through the Central Montana trough.

The Lower Kaskaskia Sequence contains many stratigraphic features that are favourable for the accumulation of oil. Environmental features, lithofacies relationships and structure are important to the accumulation of oil in this sequence. Dolomitization has enhanced permeability in many reservoirs within these rocks. The Ashern Formation and the Prairie Evaporite are the only formations that do not have oil production.

The Winnipegosis Formation is productive in areas of pinnacle reef development. Production has been obtained in the southern portion of the Elk Point Basin (southeastern Saskatchewan) where these reefs are encased by evaporite deposits of the Prairie Evaporite. In North Dakota, the platform margin basin slope facies of the Winnipegosis Formation is productive.

Production from the Dawson Bay Formation occurs along, or adjacent to the Nesson and Cedar Creek anticlines and is controlled by primary porosity trends. Production from the Souris River Formation is limited to the Nesson Anticline.

In the Duperow Formation, production is associated with the Nesson, Billings and Cedar Creek anticlines and is controlled by stratigraphy and structure.

The Birdbear Formation is most productive in the central portion of the basin within upper bank and back bank deposits.

The Three Forks Formation produces from isolated deposits of the "Sanish Sand" in the central portion of the basin in areas where tension fracture systems are existent.

SOUTHWESTERN MANITOBA

In southwestern Manitoba, Paleozoic (Sauk-Tippecanoe-Kaskaskia Sequences), Mesozoic (Zuni Sequence) and Cenozoic (Zuni-Tejas Sequences) sedimentary strata form a basinward-thickening wedge that reaches a total thickness of 2 300 m (7,546 ft) in the extreme southwest corner of the province. The Mesozoic and Cenozoic sequences mainly comprise of shale and sandstone. The Paleozoic sequence predominantly comprises limestones and dolostones with minor sandstone and shale.

A major angular unconformity separates Paleozoic from Mesozoic strata and probably represents one or more periods of erosion that occurred during late Mississippian to early Jurassic time. Paleozoic strata in the northeastern part of the Williston Basin were uplifted and differentially eroded during this interval, whereas strata in the southern portion of the basin were relatively unaffected. Successively older Paleozoic strata were progressively truncated toward the basin margin (Fig. 6). Deposition resumed during Mesozoic time, when a thick sequence of Jurassic and Cretaceous strata was deposited on the eroded Paleozoic surface.

Within the Paleozoic sequence, Devonian and Mississippian strata are separated by an unconformity that 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 margin, while deposition continued in the deeper portions of the basin. Mississippian sediments were later deposited on the eroded Devonian surface (Martiniuk, 1992).

In southwestern Manitoba, the Lower Paleozoic is represented by the Sauk, Tippecanoe and Lower Kaskaskia sequences. The Lower Paleozoic strata comprises fourteen (14) formations and five (5) groups in the Cambrian, Silurian, Ordovician and Devonian (Fig. 7). The wireline expression of these strata is shown in Figure 8 (in pocket).

The Lower Paleozoic is present throughout the subsurface of southwestern Manitoba. Most formations outcrop along a northwest-trending belt that extends from the Interlake region, northwest of Winnipeg, to the Precambrian Shield (Fig. 6). The Deadwood, Duperow and Birdbear formations do not crop out. A detailed discussion of these strata is given in Martiniuk (1992) and McCabe (1971).

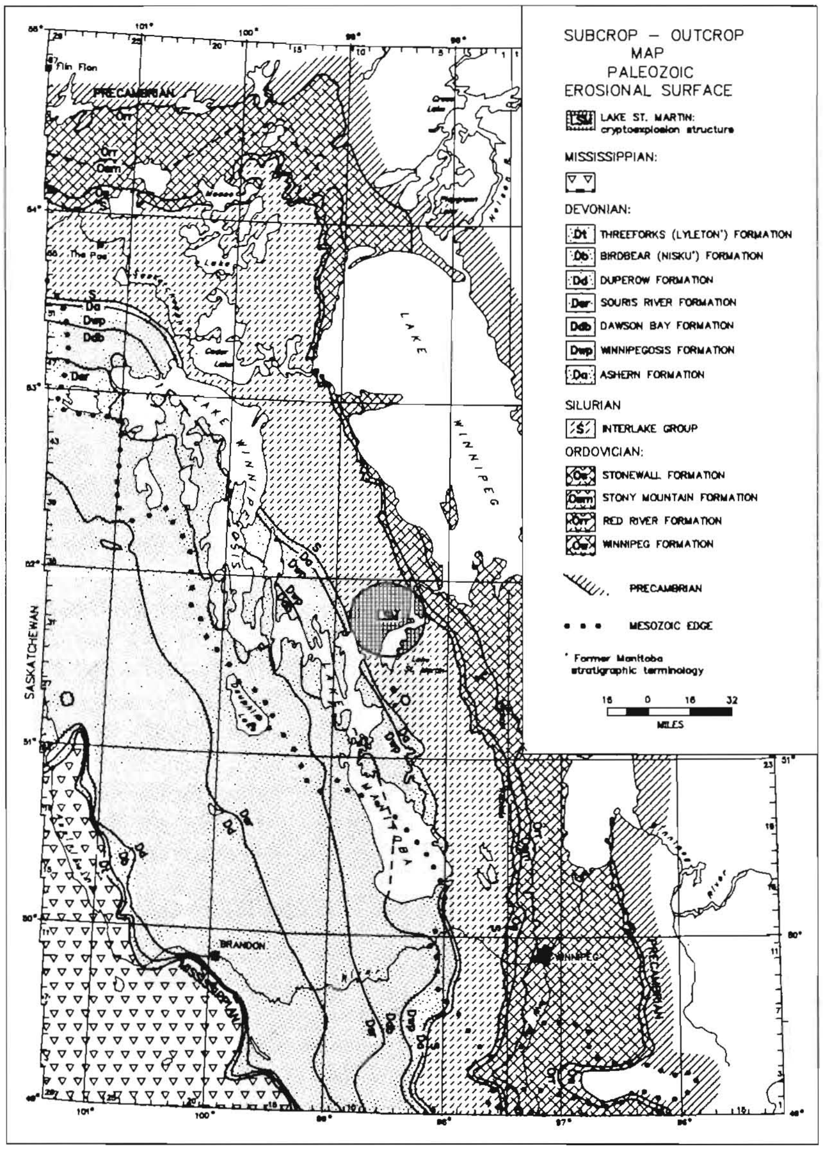


Figure 6: Subcrop-outcrop map of the Paleozoic erosion surface, southwestern Manitoba (after Martiniuk, 1992).

MANITOBA STRATIGRAPHIC COLUMN

ERA	PERIOD	GROUP	FORMATION	MEMBER	BASIC LITHOLOGY	MAXIMUM THICKNESS (m)
PALEOZOIC	Mississippian (part)	MADISON GROUP ●			Limestone and argillaceous limestone; light brown and red mottled, shaly, oolitic, crinoidal and cherty zones. OIL PRODUCING	
			BAKKEN FORMATION ●		Two black shale zones separated by siltstone. OIL PRODUCING	20
	?·DEVONIAN	Qu'appelle Group	THREE FORKS (LYLETON) FORMATION		Red siltstone and shale; dolomitic.	55
		SASKATCHEWAN GROUP	BIRDBEAR (NISKU) FORMATION *		Limestone and dolomite; yellow-grey, fossiliferous, porous, minor anhydrite.	43
			DUPEROW FORMATION *		Limestone and dolomite; argillaceous and anhydritic in places.	195
		MANITOBA GROUP	SOURIS RIVER FORMATION *	First Red Beds	Interbedded cycles of shale, limestone and dolomite; anhydritic.	96
			DAWSON BAY FORMATION *	Second Red Bed Member	Limestone and dolomite; porous anhydritic, local red and green shales.	73
		ELK POINT GROUP	WINNIPEGOSIS FORMATION *	Upper Member (Reef); PRAIRIE EVAPORITE	Halite, sylvite and carnallite (potash); with seams of dolomitic mudstone, dolomite and anhydrite.	130
				Lower Member (Platform) (Inter-reef)	Fossiliferous; yellow-grey dolomite banks (reefs) resting upon platform carbonates (mottled dolomite, bituminous and laminated in places).	107
			ELM POINT FORMATION		Limestone; fossiliferous, high calcium content.	
			ASHERN FORMATION		Dolomite and shale; brick red.	18
	SILURIAN	INTERLAKE GROUP *			Dolomite; yellow-orange to grey, fossiliferous, oolitic, stromatolitic, interrupted by argillaceous marker beds.	120
	?·ORDOVICIAN		STONEWALL FORMATION *	t-marker	Dolomite; yellow-grey, sparsely fossiliferous, interrupted by argillaceous zones and marker beds.	24
			STONY MOUNTAIN FORMATION *	Gunton Member *; Gunn Member; Penitentiary Member	Dolomite; yellow-brown, slightly nodular (Gunton). Dolomite; yellow to red-grey, fossiliferous, argillaceous (Penitentiary). Shale; red-green, burrow-mottled, fossiliferous, calcareous, minor limestone (Gunn).	49
			RED RIVER FORMATION *	Fort Garry Member; Selkirk Member; ? Cat Head Member; Dog Head Member	Dolomite and limestone; mottled, fossiliferous, cherty, overlain by argillaceous dolomite with breccia beds (Fort Garry).	175
			WINNIPEG FORMATION *	upper; lower	Quartzose sandstone overlain by green, waxy shale with sand and silt interbeds.	69
	CAMBRIAN		DEADWOOD FORMATION *		Sandstone; black to green-grey, waxy. Sandstone; glauconitic. Shale; grey to black.	60
PRECAMBRIAN						

● productive interval in Manitoba

* intervals productive in other areas of the Williston Basin

Figure 7: Manitoba stratigraphic column, Lower Paleozoic Sequence (after Martiniuk, 1992).

An oil-source system comprises a petroleum source rock, which has reached a sufficient level of thermal maturity to generate and expel oil, end point oil pools, and inferred migration pathways between the two. The ability to define and describe discreet oil-source systems in a sedimentary basin provides a valuable framework from which to assess the hydrocarbon potential of sparsely explored areas of the basin.

In an oil-source system, all end point pools must contain oils that can be grouped into a family by some distinct geochemical signature. Furthermore, this geochemical signature must correlate with that of the bitumens in the associated source rock. The chemical composition of a pooled oil is dependent on the composition of the source kerogen and the level of thermal maturity of that source. The cumulative effect of all interactions of that oil with formation rock and formation waters along the migration path and in the reservoir also affect oil chemistry. Certain biomarkers are generally unaffected by these post-generation changes and they provide a valuable tool for identification of compositionally distinct oil families (Osadetz *et al.*, 1992a).

Numerous organic geochemical studies have addressed the issue of identification of distinct oil families in the Williston Basin (Dow, 1974; Williams, 1974; Zumberge, 1983; Brooks *et al.*, 1987, 1988; Leenheer and Zumberge, 1987; Osadetz *et al.*, 1991; 1992a). Most of these studies conclude that oil pools that contain compositionally distinct families of oils have restricted stratigraphic and geographical distribution, and commonly have a close stratigraphic association with the source rock. This observation suggests that the Williston Basin has undergone discrete episodes of oil generation, migration, and pooling. This makes assessment of exploration opportunities in the basin amenable to the oil-source system approach.

A detailed review of the geochemical literature is beyond the scope of this report and the reader is referred to Osadetz *et al.* (1991; 1992a) for a discussion of previous research and different geochemical approaches used by previous workers. The following summarizes the salient points of some of the previous work as they relate to the evolution of the understanding of oil-source systems that are present in the Williston Basin.

PREVIOUS WORK

Geochemical work by Williams (1974) identified three oil families each having restricted stratigraphic occurrence in the Williston Basin. Type 1 oils occur predominantly in Ordovician and Silurian reservoirs. Ordovician Winnipeg Formation shale was identified as a probable source rock. Type 2 oils occur predominantly in Mississippian, Upper Devonian, and Mesozoic reservoirs and represent most of the discovered reserves in the Williston Basin. The transitional Devonian/Mississippian Lower Bakken Shale was identified as the probable source of these oils. Type 3 oils are restricted to Pennsylvanian reservoirs. Pennsylvanian Tyler Formation shale was identified as a probable source rock. Dow (1974) used an oil-source systems approach to apply this tripartite classification of Williston Basin oils to exploration problems. Stratigraphic and geographic distribution of each oil type was examined and possible migration pathways from areas of thermally mature source rock were considered and applied to exploration strategy.

Leenheer and Zumberge (1987) examined the geochemistry of several oils that occur in the central Williston Basin. The analysis resulted in the identification of five groups of oils, two of which could be directly correlated to the classification system of Williams (1974).

Brooks *et al.* (1987) studied pools from the Canadian portion of the Williston Basin and designated a family of oils from Ordovician reservoirs (Family A), correlative with the Type 1 oils of Williams (1974) and the Group 1 oils of Leenheer and Zumberge (1987). Based on geochemical factors, they also proposed a subdivision of the Type 2 oils of Williams (1974). Family B oils are sourced from clay-rich clastics such as shales of the Bakken Formation and Family C oils are derived from an euxunic carbonate source such as the argillaceous limestones of the Mississippian Lower Lodgepole Formation. Following the discovery of Devonian Winnipegosis pinnacle reef pools in southeastern Saskatchewan, Brooks *et al.* (1988) identified a distinct group of oils (Family D) that occur in the Upper Devonian. Family D oils correlate with the Group 3 and Group 4 oils of Leenheer and Zumberge (1987).

Osadetz and Snowdon *(in prep.)* further assessed Williston Basin oil-source systems and identified four regionally significant Paleozoic source rocks in the Canadian portion of the basin;

a) kukersite beds in the Upper Ordovician Bighorn Group (Red River Formation),
b) bituminous laminates in the Devonian Winnipegosis Formation,
c) bituminous shales in the transitional Devonian/Mississippian Bakken Formation, and
d) bituminous lime mudstones in the Mississippian Lower Lodgepole Formation.

Osadetz *et al.* (1991; 1992a) conducted additional analysis and elaborated on the oil characterization system of Brooks *et al.* (1987). They also applied the conclusions of Osadetz and Snowdon *(in prep.)* regarding significant source rocks to provide a characterization of oil-source systems in the Canadian portion of the Williston Basin. This work provides the most recent and complete analysis of oil-source systems as they pertain to southwestern Manitoba. Table 1 illustrates the correlation of this work with that of previous workers.

The North American Central Plains Conductivity Anomaly (NACPCA) and its associated area of elevated crustal heat flow coincident with the deepest part of the basin, provides the locus of oil generation for all Williston Basin oil-source systems (Majorowicz *et al.*, 1988).

Table 1: Williston Basin oil family classification schemes (after Osadetz *et al.*, 1992a, reprinted by permission)

Table 1. Williston Basin oil family classification schemes

Classification 1[1]	Classification 2[2]	Classification 3[3]
Type I	Group 1	Family A
	Group 3[4] Group 4[4]	Family D[4]
Type II	Group 2	Family B Family C
Type III	Not examined	Not examined
Not examined	Group 5	Not examined

[1]After Williams (1974) and Dow (1974) based on gasoline fraction (GFGC) and C_{15+} saturate fraction (SFGC) gas chromatography, and isotopic compositions. Followed by Thode (1981) and Thompson (1983).
[2]After Leenheer and Zumberge (1987), Zumberge (1983) and Leenheer (1984) based on carbon isotopic compositions and C_{15+} saturate fraction compositions with special emphasis on distributions of tricyclic diterpanes and SFGC's.
[3]This study, an augmentation and revision of Osadetz *et al.* (1991), Osadetz *et al.* (1990); Brooks *et al.* (1988), Brooks *et al.* (1987), based on terpane biomarkers and SFGC's.
[4]Critical compositional criteria to allow the correlation of Group 3 and Group 4 oils with Family D are not reported by Leenheer and Zumberge (1987). The equivalence suggested here only reflects the observation that both classifications indicate these are oils with non-kukersitic SFGC's occurring in the stratigraphic interval Winnipegosis to Birdbear and higher. No suggestion of a single source rock is implied, nor is there any implication that the Winnipegosis Formation is the source for either Group 3 or 4 oils, although both remain possibilities.

OIL-SOURCE SYSTEM CLASSIFICATION

The oil-source system classification of Osadetz *et al.* (1991; 1992a) provides the framework in which the hydrocarbon potential of the pre-Mississippian strata of southwestern Manitoba is assessed in this report. The stratigraphic range of each oil family in this classification scheme is illustrated in Figure 9. The migration characteristics of each oil-source system as inferred from the stratigraphic and geographical relationships between oil pools and known areas of thermally mature associated source rock are of particular interest. The following summarizes the key features of each oil-source system indentified in the Canadian portion of the Williston Basin as developed by Osadetz *et al.* (1991; 1992a).

Family A Oil-Source System

Family A oils are considered to be sourced from kukersite beds in the Upper Ordovician Red River Formation in an area of sufficient thermal maturity in the central Williston Basin (Fig. 10). Pools that contain Family A oils are predominantly in the same stratigraphic unit as the source (Red River Formation); however, these oils occur as stratigraphically high as the Devonian Winnipegosis Formation. Significant Family A Pools that occur outside the area of oil generation are indicated in Figure 10.

Although the oil discoveries to date suggest that this oil-source system is characterized by relatively short migration pathways, the large reserves located on the Cedar Creek anticline clearly indicate the potential for up-dip migration. The pool at Minton in southern Saskatchewan demonstrates that up-dip migration also characterizes the northern part of the basin. The observed absence of Family A oils on the up-dip northeastern margin of the basin may be more a reflection of the lack of deep exploration in these areas than an indication of any physical impediment to the migration process. Peak generation of Family A oils predates the development of the Nesson Anticline as a barrier to up-dip migration. The excellent hydraulic characteristics of the northeast flank of the basin, as demonstrated by its ability to accommodate long distance lateral migration associated with other oil systems, also supports the possibility of long migration pathways in that direction. The stratigraphic range of Family A oil pools is Upper Ordovician through to Middle Devonian (Fig. 9). As is true for all of the Williston Basin oil-source systems, a large proportion of the Family A oil reserves are found in the same stratigraphic unit as the source rock, which, in this case, is the Upper Ordovician Red River Formation.

STRATIGRAPHIC RANGE OF OIL FAMILIES

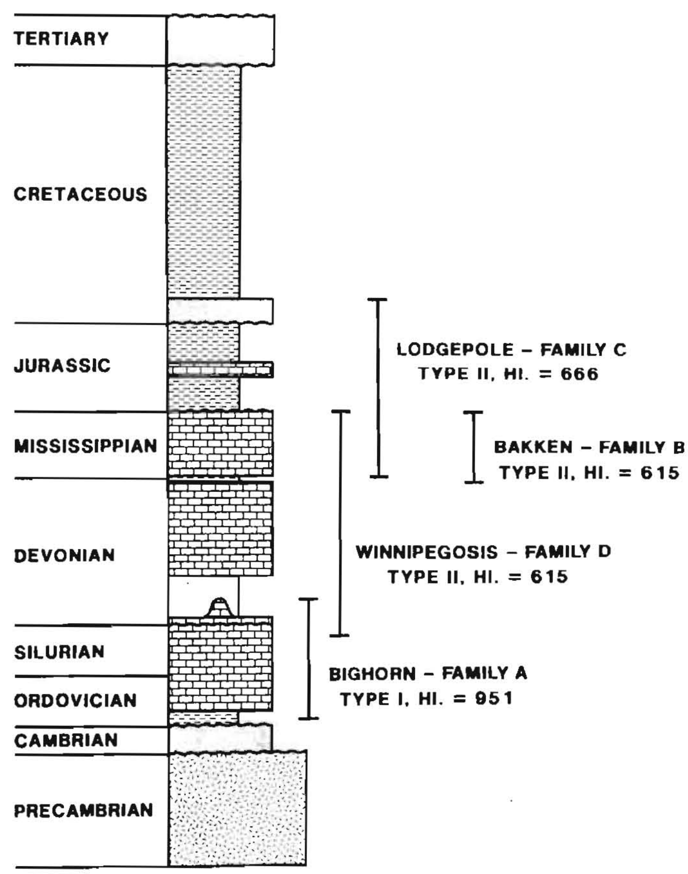


Figure 9: Stratigraphic range of oil families, Williston Basin (after Osadetz et al., 1992, reprinted by

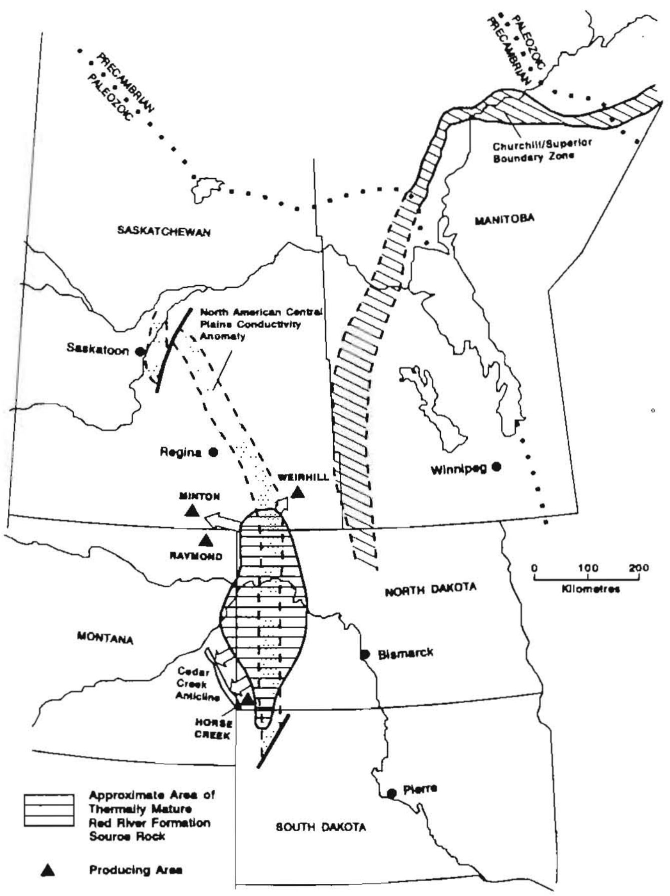


Figure 10: Family A Oil-Source System (after Osadetz, pers. comm.).

Family B Oil-Source System

Family B oils are considered to be sourced from bituminous shales in the transitional Devonian/Mississippian Bakken Formation. Figure 11 shows the area of thermally mature Bakken Formation shale. A significant lag between attaining the sufficient thermal maturity needed to generate oil and expulsion of the generated oil is characteristic of the Bakken Formation source. As a result, the area of oil expulsion is significantly smaller than the thermally mature area.

Significant reserves of Family B oil are pooled in fractured Bakken Formation shale reservoirs in the area of thermal maturity. These pools represent oil that has not migrated out of the source rock and are best exploited through horizontal drilling techniques (Fisher and Rygh, 1989; Hansen, 1991).

Significant Family B pools outside the area of oil generation and expulsion are also indicated on Figure 11. Although few in number, these Middle Bakken Formation pools demonstrate that, for the most part, this oil-source system is characterized by long distance up-dip migration within the stratigraphic unit. The Bakken Formation pools at Daly in southwestern Manitoba, situated approximately 200 km (124 mi) from the area of oil generation and expulsion, provide excellent illustrations of this characteristic. Stratigraphically, these pools commonly occur as little as 50 m (164 ft) below overlying Lodgepole Formation pools that contain oils that are compositionally distinct and compose a completely separate oil-source system (Family C). The stratigraphic range of Family B oil pools may extend into the overlying Mississippian Madison Group (Fig. 9).

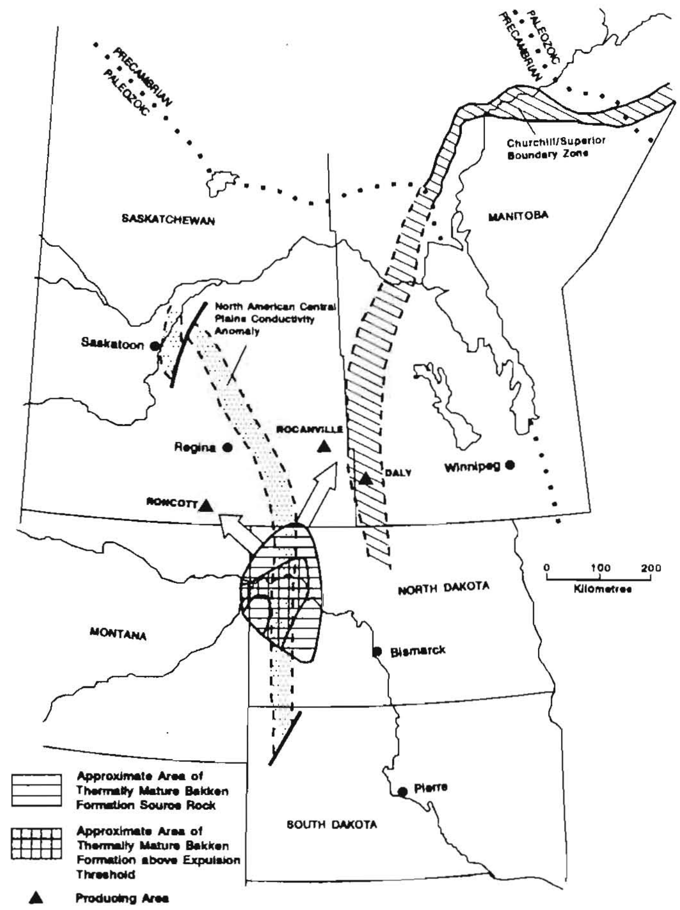


Figure 11: Family B Oil-Source System (after Osadetz, pers. comm.).

Family C Oil-Source System

Family C oils are considered to be sourced from bituminous lime mudstones in the lower part of the Lodgepole Formation. These oils account for the great majority of reserves in the Mississippian Madison Group that are pooled along the subcrop trends of southeastern Saskatchewan and southwestern Manitoba. Figure 12 shows the area of Lower Lodgepole Formation source rock that is above both the oil generation and expulsion thresholds. This oil window has charged the northeastern up-dip flank of the basin, which accounts for the large reserves found in this area. Comparisons of thermal maturity of pooled oils suggest that both short and long migration paths are present. In general, high gravity more mature oils, have undergone long distance lateral migration and tend to be found in the more easterly regions of the basin, including southwestern Manitoba. The presence of high gravity oils remote from the oil window attests to the excellent hydraulic characteristics of this flank of the basin.

Significant Family C oil reserves are also found in Mesozoic and Cretaceous strata on the northeast flank of the basin. These pools indicate a vertical component of migration accommodated by either fracturing of Mesozoic strata (Kreis, 1991) or leaky Mesozoic seals overlying Mississippian subcrop traps (Barchyn, 1982). The stratigraphic range of Family C oil pools is indicated in Figure 9.

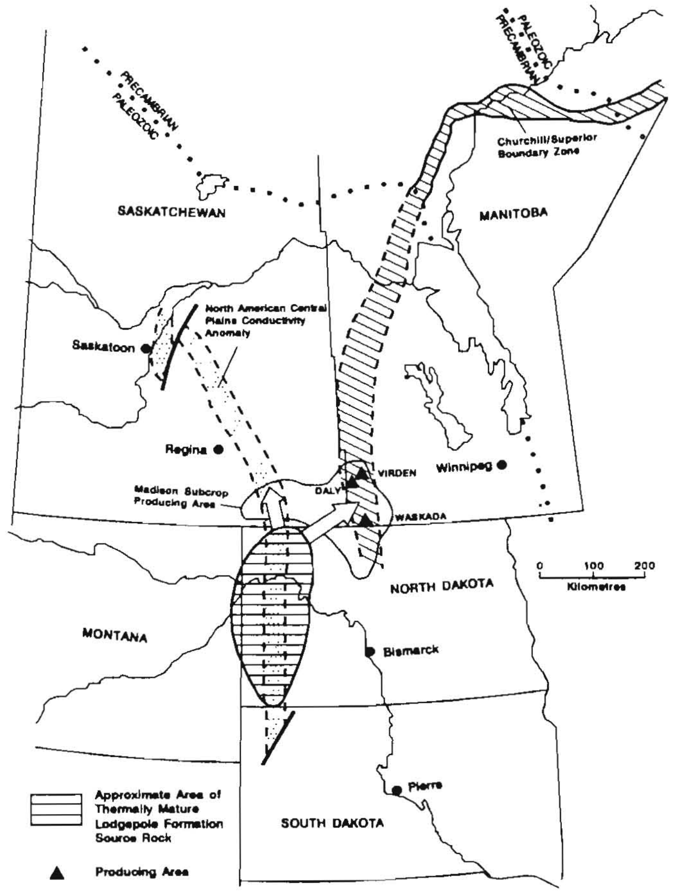


Figure 12: Family C Oil-Source System (after Osadetz, pers. comm.).

Family D Oil-Source System

Family D oils are considered to be sourced from bituminous laminates in the Middle Devonian Winnipegosis Formation. Both basinal and platform sources with distinct geochemical characteristics have been identified. To date, most Family D oil production has occurred within, or very close to, the area of thermally mature source rock (Fig. 13). Significant Family D pools occur in pinnacle reefs of the Winnipegosis Formation in southern Saskatchewan. Thermal maturity data suggests that some of these pools are locally sourced while others reflect significant lateral migration within the Winnipegosis Formation. Family D oil pools in the Mississippian Ratcliffe beds of the Flat Lake area indicate limited lateral migration and extensive cross-stratal migration. Family D pools in the Upper Devonian Birdbear Formation at Kisbey and Walpole suggest that extensive cross-stratal migration can also be accompanied with significant up-dip migration to the northeastern margin of the basin. It is not clear whether the lateral component of this migration path occurred in the Winnipegosis Formation or in the reservoir strata. Figure 13 shows some Family D pools that involve significant migration up-dip from the oil window. The stratigraphic range of Family D pools is indicated in Figure 9.

In general, all of the known oil-source systems have restricted and distinct patterns in stratigraphic occurrence. In assessing the hydrocarbon potential of the pre-Mississippian strata of southwestern Manitoba, it is clear that Family A and Family D oil-source systems deserve the most attention in terms of their ability to charge the pre-Mississippian section. Characteristics of the Family B and Family C oil-source systems, particularly the phenomenon of long distance up-dip migration, are worth consideration as they relate to an understanding of the hydraulic properties of the northeastern flank of the basin.

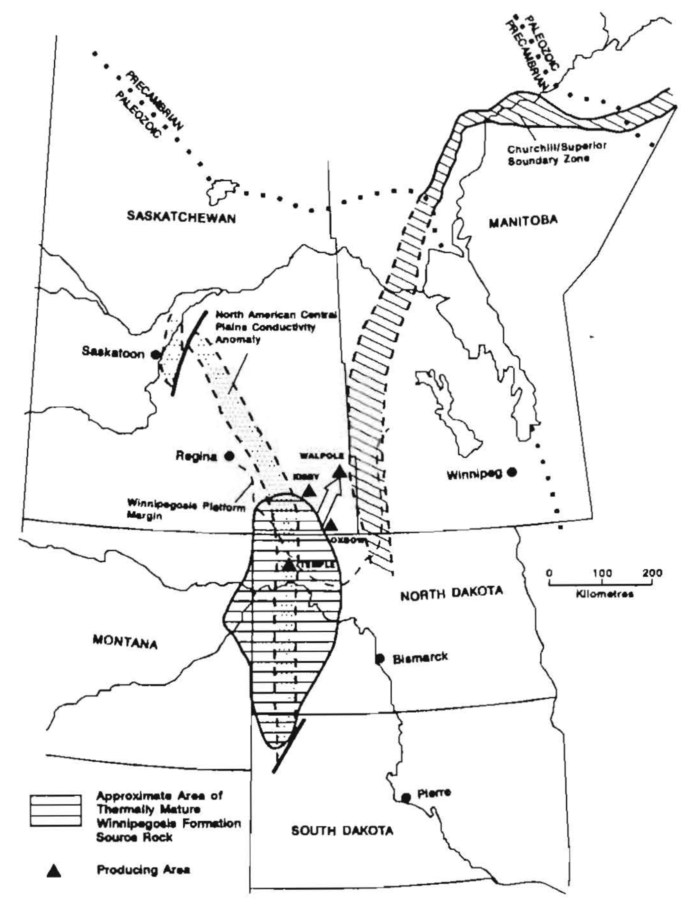


Figure 13: Family D Oil-Source System (after Osadetz, pers. comm.).

Several pools from different parts of the Williston Basin that comprise parts of the Family A and Family D oil systems have been examined and presented as possible analogs for similar pools in the pre-Mississippian strata of southwestern Manitoba. These pools, along with some of the other major pre-Mississippian pools of the Williston Basin, are shown in Figure 14.

In the following discussions, geological conditions responsible for trapping mechanisms are emphasized. The case for the presence of analogous reservoirs in southwestern Manitoba is supported with examples of geological conditions in Manitoba similar to those that provide the trapping mechanisms in the Williston Basin examples.

The presentation of the following play types is not intended to imply that these represent an exhaustive list of potential prospects. Clearly, given the rather limited knowledge of the pre-Mississippian strata of the basin, other significant play types can be conceptualized. Also, one-of-a-kind pools such as the Cambrian Pool at Newporte North Dakota may represent significant undiscovered potential. The approach in presenting the following play types is to demonstrate that southwestern Manitoba has potential for pre-Mississippian plays well established elsewhere in the basin.

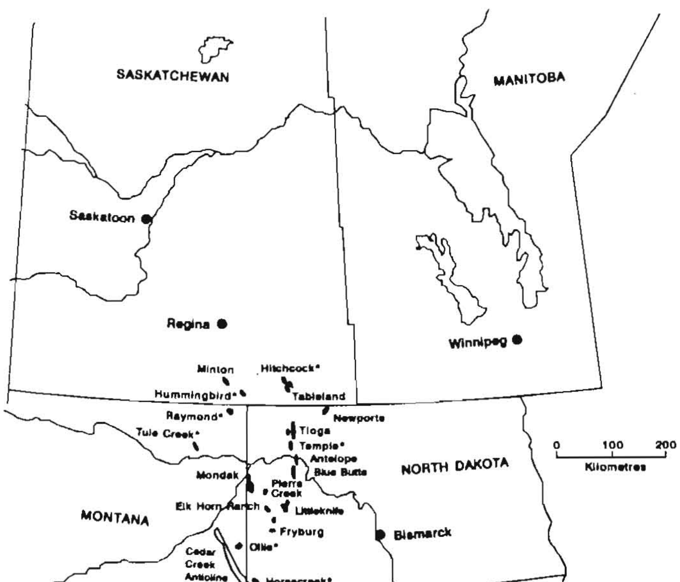


Figure 14: Map showing major fields and areas of pre-Mississippian production in the Williston Basin (after Martiniuk, 1992).

PLAY TYPE: DEEP STRUCTURAL STACKED PAY

Williston Basin Example: Raymond Field, Montana

Large reserves of Family A oil are pooled in basement-controlled structural traps in the Williston Basin. Although structural closure is the dominant trapping mechanism, most of these pools are combination traps. Reservoir development is strongly influenced by stratigraphic and diagenetic factors. Most of these pools are located on large structures such as the Nesson and Cedar Creek anticlines. Anticlinal structures which are small in areal extent, generally less than 256ha (640 acres) of closure, commonly have multiple pay horizons and are, therefore, economically attractive exploration targets. Pay zones are found in stratigraphic intervals that range from Ordovician to Mississippian. Cross-stratal migration of oil through fractures associated with anticlinal development is common. Pools in the Upper Devonian and Mississippian may contain Family D and B oils in addition to the Family A oils, which occur in the Ordovician and Silurian pay zones.

A north-south productive trend of these structural features occurs in eastern Montana and southern Saskatchewan. To date, the Minton Pool is the northernmost discovery (Potter and St. Onge, 1991). The Raymond Field in Sheridan County, Montana provides a good example of a small, but prolific deep structural multiple pay field (Parker and Powe, 1982) (Figure 14). The reservoir parameters of the four productive zones that range from the Ordovician Red River Formation to the Devonian Nisku Formation are summarized in Table 2.

At Raymond Field, the cumulative effect of structural development is approximately 30 m (100 ft) of closure on most of the productive horizons (Parker and Powe, 1982). A structural cross section that illustrates this closure in the Red River Formation is shown in Figure 15.

The evolution of structures such as these can best be deciphered through isopach analysis (Potter and St. Onge, 1991). Repeated basement-controlled vertical movements are evident and can be timed from Precambrian through to Cretaceous time. These reactivations suggest these anticlinal structures overlay crustal zones of weakness that respond to changing stress fields that affect the basin.

Southwestern Manitoba Play

The northeastern flank of the basin in southwestern Manitoba also has potential for tectonically-generated structures. This favorable tectonic setting is due, in large part, to the Precambrian Churchill-Superior crustal boundary zone (Fig. 4). This feature, termed the Birdtail-Waskada Axis by McCabe (1971), is the locus of numerous stratigraphic anomalies throughout the Phanerozoic section. The existence of this major basement tectonic feature along this axis is also supported by its pronounced geophysical expression (Luther, 1991). The superposition of isopach, depositional and

Table 2: Reservoir parameters of the Raymond Field, Montana (after 1991 Montana Oil and Gas Annual Review, Montana Board of Oil and Gas Conservation, v.35, 1992)

Location: T 36N; R. 54E, Sheridan County, Montana

	Red River Pool	Winnipegosis Pool	Duperow Pool	Nisku Pool
Discovery Date (year):	1972	1972	1979	1972
Estimated Ultimate Primary Recovery:				
(m^3)	178 000	260 611	N/A	150 000
(Bbls)	1 120 000	1 640 000		940 000
Average Producing Depth:				
(m)	3048	2 835	2 548	2 408
(ft)	10 000	9 300	8 360	7 900
A.P.I. Gravity:				
(degrees)	39	42	46	50
(kg/m^3)	830	816	797	780
Average Porosity (%):	12	5	N/A	9
Cumulative Oil Production to Jan. 1, 1992:				
(m^3)	149 533	230 895	16 530	129 510
(Bbls)	941 000	1 453 000	104 000	815 000

diagenetic anomalies reflect changes in depositional basin bathymetry and enhanced diagenesis along this trend. This suggests periodic reactivation of vertical movements along a zone of crustal weakness in response to changing stress fields. This process would occur in a manner similar to that which has given rise to the productive structures elsewhere in the basin. It is noteworthy that the great majority of southwestern Manitoba's Family C oil reserves in Mississippian and Jurassic strata are pooled in traps that occur along the Birdtail-Waskada Axis.

Although deep structural traps would require seismic delineation, the structural and stratigraphic features observed in some of the deep wells along the Birdtail-Waskada Axis suggest a structural history similar to that which has generated closed structural traps elsewhere in the basin. Figure 16 (in pocket) is a stratigraphic cross section through two deep wells in the Waskada area. The Waskada 11-29-1-25 WPM well exhibits a normal stratigraphic section for the area. The Deloraine 8-31-2-23 WPM well is located on an anomalous structural feature that, on the basis of Mississippian tops, indicates vertical displacements of a minimum of 30 m (98 ft) over a distance of less than a one kilometre (0.62 mi). Much of the stratigraphic succession in the 8-31 well is anomalous and correlation with the normal succession observed at the 11-29 well is difficult, particularly over the interval from Upper Silurian to Lower Mississippian. Several key isopachs are indicated on the section where picks can be made with some degree of confidence. These isopach variations exceed those expected from basin differentiation or any effect of salt dissolution in post-Elk Point Group strata. They also suggest recurring structural development that involved positive and negative vertical displacements. The timing of this structural development appears to range from post-Silurian, pre-Devonian through to post-Mississippian. The nature of this structural feature, as deciphered from isopach analysis, bears a resemblance to many of the productive structures elsewhere in the Williston Basin.

Figure 17 (in pocket) is a structural cross section across a large anticlinal feature in the Upper Devonian in the Daly Field. Although differential solution of the underlying Prairie Evaporite may have been involved in the formation of this structural closure, the structural position of the crest of the anticline is significantly above regional values and implies some degree of basement-controlled vertical displacement. The occurrence of approximately 30 m (98 ft) of closure with an estimated 920 $m^3 \times 10^6$ (32.4 BCF) of nitrogen-rich gas in the Devonian Souris River Formation (Intercomp Resource Development and Engineering Ltd., 1977), and additional reserves in the Duperow and Birdbear formations illustrate the trapping capacity of this anticlinal structure.

PLAY TYPE: RED RIVER STRATIGRAPHIC

Williston Basin Example: Horse Creek and South Horse Creek fields, North Dakota

As discussed in the previous section, stratigraphy plays an important role in defining the productive limits of pools associated with structural features. The trapping mechanism is therefore a combination of structure and varying degrees of stratigraphic factors. Some Family A Red River Formation pools have virtually no structural expression and are true stratigraphic traps. Longman (1981) discusses several examples of such traps and points out that

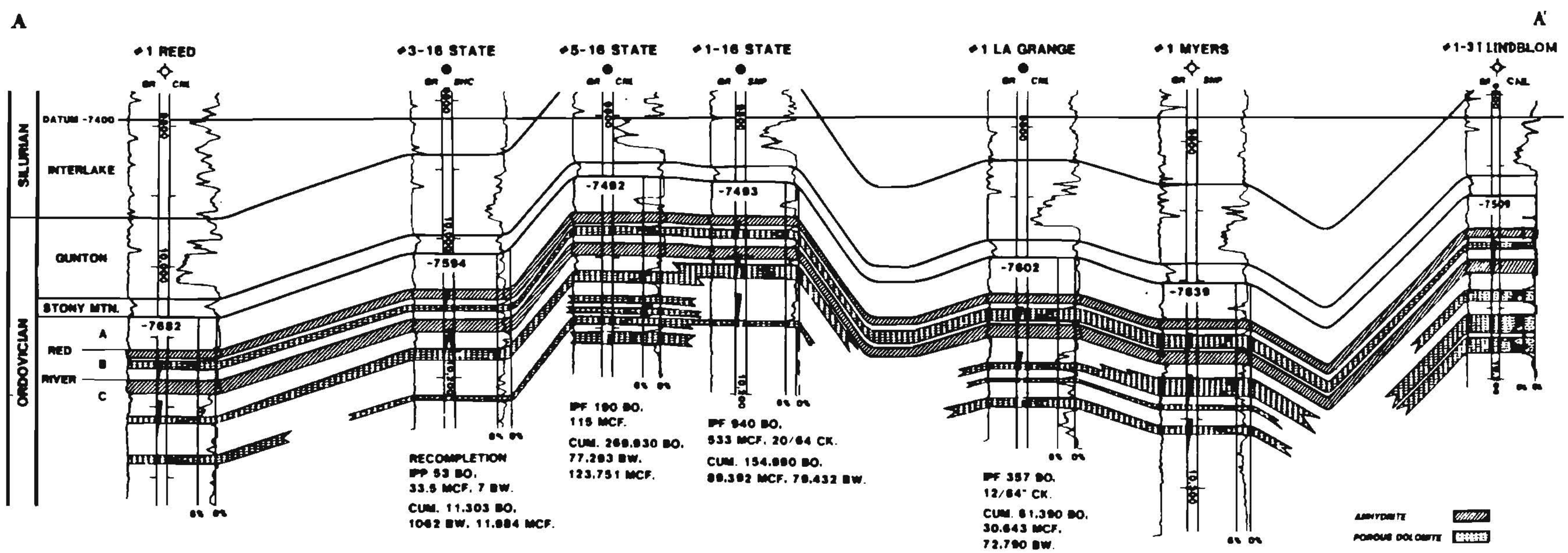


Figure 15: *Structural cross section, Raymond Field, Sheridan County, Montana (after Parker and Powe, 1982).*

the trapping mechanism is an up-dip pinchout of reservoir quality dolomite, essentially a diagenetic phenomenon. Kohm and Louden (1982) concluded that, although most of the Red River Formation oil reserves in western North Dakota and eastern Montana are in structural traps, stratigraphic accumulations such as those described by Longman (1981) also exist, but are largely underdrilled.

A good example of a stratigraphic Red River Formation pool is in the Horse Creek and South Horse Creek fields, Bowman County, North Dakota (Longman *et al.*, 1992). These fields contain a stratigraphically trapped pool and two smaller structurally trapped pools. These pools are located in southwestern North Dakota down-dip from the large structural traps associated with the Cedar Creek Anticline (Fig. 14). The reservoir parameters of the stratigraphic pool are summarized in Table 3.

Table 3: Reservoir parameters of the Horse Creek and South Horse Creek fields, Bowman County, North Dakota (after Longman *et al.*, 1992)

Location: T. 129N; R. 104, 105W, Bowman County, North Dakota

	Red River Pool
Discovery Date (year):	1969
Estimated Ultimate Primary Recovery:	
(m^3)	565 000
(Bbls)	3 555 000
Average Producing Depth:	
(m)	2 793
(ft)	9 165
A.P.I. Gravity:	
(degrees)	30
(kg/m^3)	876
Average Porosity (%):	17.8
Average Permeability (md):	5 to 11

A structural cross section showing the up-dip porosity pinchout in the Red River Formation "D" porosity zone is shown in Figure 18. The trapping mechanism is essentially diagenetic in nature; reservoir quality dolomite grades up-dip to undolomitized impermeable limestone. It is essential to establish the control on this localized dolomitization in the exploration strategy for such reservoirs. Longman (1981) suggests that localized faults or fractures may have been instrumental in allowing access of dolomitizing brines to the limestones, thereby explaining the localized lense-like geometry of these reservoirs. Kohm and Louden (1982) were able to map areal patterns of dolomitization to reflect the control of regional joint systems on the movement of dolomitizing brines.

Southwestern Manitoba Play

The phenomenon of local reservoir development due to dolomization is also seen in the Red River Formation of southwestern Manitoba. Figure 19 (in pocket) is a stratigraphic cross section between two relatively closely-spaced deep tests in the Napinka area along the Birdtail-Waskada Axis: note the localized development of porosity due to dolomitization in the Red River Formation "C" zone in the 2-17-4-25 WPM well. This lense of porosity does not occur in the offsetting well. The up-dip pinchout of such local porosity development could provide for stratigraphic trapping similar to that described by Longman *et al.* (1992) in the Horse Creek and South Horse Creek fields. It is interesting to note that a zone of open fractures accompanied by extensive lost circulation was encountered in the lower part of the Red River Formation section in the 2-17 well. This evidence of structural disturbance lends support to Longman's (1981) suggestion that local dolomitization may be initiated by fracturing that provides a local conduit for the dolomitizing brines.

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. An inferred shoal-trend that borders a restricted platform facies belt (Kendall, 1976) may provide an up-dip porosity pinchout that would entrap Family A oils migrating from the area of thermal maturity in the central part of the basin.

The development of such stratigraphic plays in the Red River Formation on the northeastern flank of the basin is hindered by the lack of deep drilling and core control. Structural traps, which are amenable to seismic exploration, are likely to attract more interest; however, as is the case in western North Dakota and eastern Montana, stratigraphy is thought to play an important role in trapping oil in the Red River Formation. Reserves in stratigraphic traps provide an interesting target, particularly at the shallower depths encountered on the northeast flank of the basin.

PLAY TYPE: WINNIPEGOSIS PINNACLE REEFS

Williston Basin Example: Hitchcock Area, Saskatchewan

During Devonian time, the Elk Point Basin extended from the Northwest Territories to the southern part of North Dakota and from the West Alberta Ridge in the west, to beyond the erosional outcrop in the east (Martindale *et al.*, 1991) (Fig. 20).

Middle Devonian sedimentation began during the initial stages of Devonian transgression when the Ashern Formation was deposited in the restricted embayment of the Elk Point Basin. Deposition of the Winnipegosis Formation followed a brief regression, and erosion of the Ashern Formation.

During the initial marine transgression, normal marine carbonates were deposited. These carbonates were, in turn, overlain by sediments deposited during basin differentiation or "decoupling" into a shallow shelf environment, and a

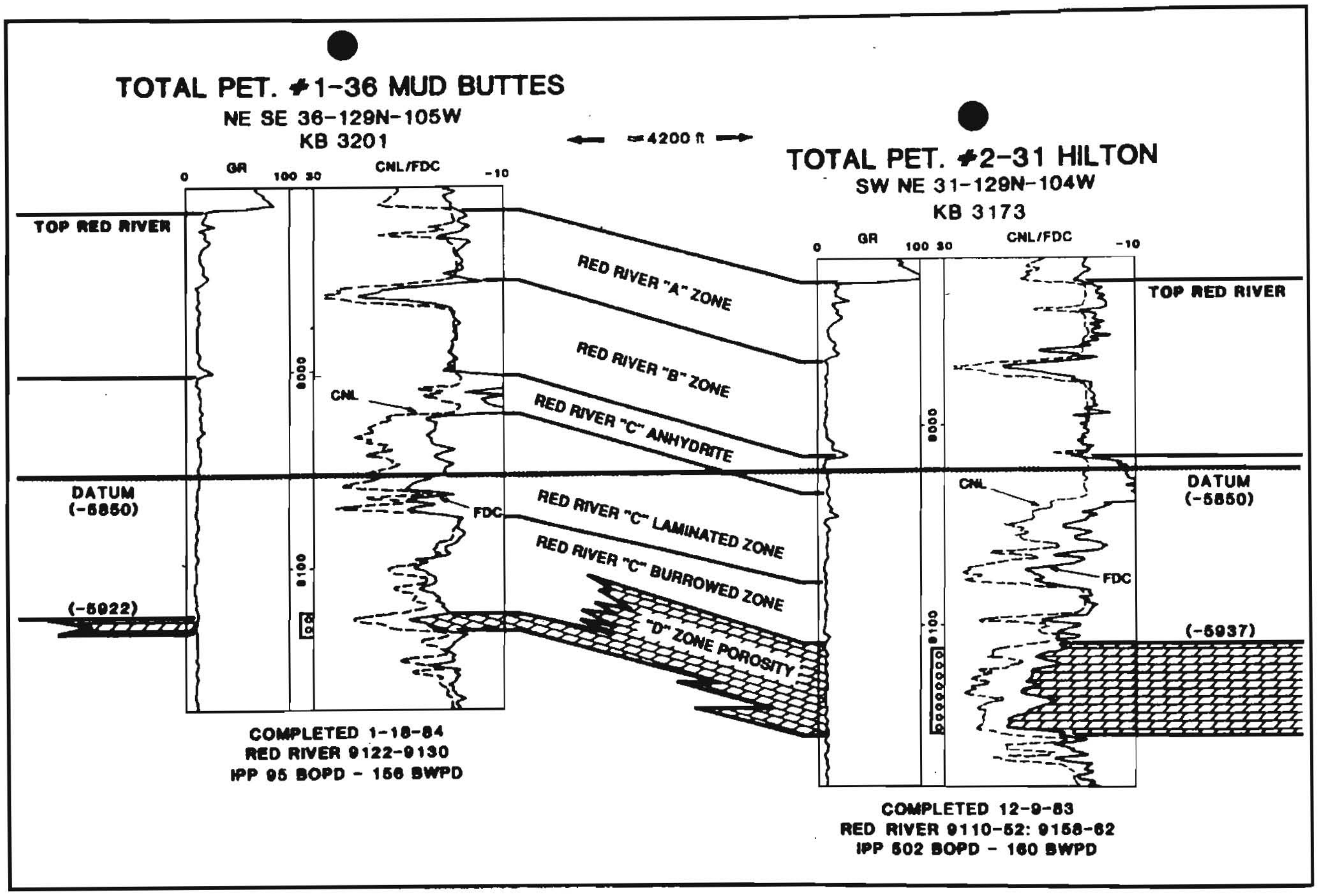


Figure 18: *Structural cross section, Horse Creek and South Horse Creek fields, Bowman County, North Dakota (after Longman et al., 1992, reprinted by permission).*

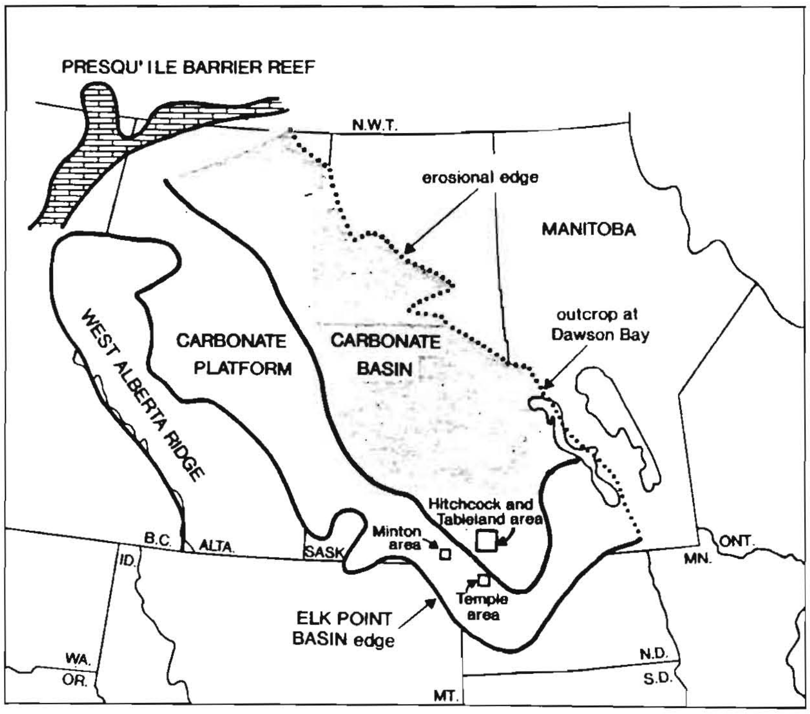


Figure 20: *Simplified map of the Elk Point Basin and Presqu'ile Barrier (after Martindale et al., 1991).*

deeper basin environment with scattered pinnacle reefs. The shelf environment is represented by a fringing bank buildup around the perimeter of the basin. The deeper basinal facies is represented by the pinnacle reef growth and the deeper water inter-reef facies that developed basinward of the fringing bank during Upper Winnipegosis time.

The Hitchcock area of southeastern Saskatchewan demonstrates the Winnipegosis Formation pinnacle reef play model. The Hitchcock area occupies a position in the southwestern corner of the Elk Point Basin (Fig. 20). Winnipegosis reefs in the Hitchcock area occur as isolated buildups of peloidal/codiacean algal shoals overlain by vertical accretions of corals, bryozoa, red algae and cyanobacteria that are encased by anhydrite and halite (Martindale *et al.*, 1991).

Discovery of pinnacle reefs in southeastern Saskatchewan has revealed the significant petroleum potential of these features. This is evidenced by the oil plays at Tableland and Hitchcock (Table 4).

Table 4: Reservoir parameters of the Hitchcock area, southeastern Saskatchewan (after Martindale *et al.*, 1991)

Location: Township 3, Range 8 & 9 W2M

	Winnipegosis Pool
Discovery Date (year):	1989
Estimated Ultimate Primary Recovery:	
(m^3)	N/A
(Bbls)	
Average Producing Depth:	
(m)	2 494
(ft)	8 182
A.P.I. Gravity:	
(degrees)	43.8
(kg/m^3)	807
Average Porosity (%):	N/A
Cumulative Oil Production to Jan. 1, 1992:	
(m^3)	80 120
(Bbls)	252 346

Southwestern Manitoba Play

The pinnacle reefs of the Winnipegosis Formation in Manitoba are developed along the basinward edge of the Winnipegosis fringing bank (Fig. 21). These reefs show excellent porosity and permeability and, where encased by salts of the Prairie Evaporite, have reservoir potential (Fig. 22).

The stratigraphic cross section (Fig. 23, in pocket) shows an example of a Winnipegosis reef buildup in the Binscarth area of southwestern Manitoba. The reef buildup is located in an area where the salt of the Prairie Evaporite is intact. The well at 16-18-18-29 WPM was drilled on a stromatoporoid reef, which is encased by the salt section of the Prairie Evaporite.

PLAY TYPE: WINNIPEGOSIS PLATFORM MARGIN

Williston Basin Example: Temple Field, North Dakota

As discussed in the previous section and shown in Figure 20, the Middle Devonian Elk Point Group reflects the differentiation of the Elk Point shelf into distinct basin and platform environments. The pinnacle reefs in the basinal regime are the main exploration target in southern Saskatchewan; however, the complex stratigraphy of prograding platform marginal facies provides potential for excellent reservoir development and stratigraphic trapping.

The Temple Field in Williams County, North Dakota is a Family D pool that is a combination structural-stratigraphic trap located on the southwestern platform margin of the Elk Point Basin. (Figure 14). The pool is situated on a subordinate structural limb on the northwestern flank of the Nesson Anticline (Ehrets and Kissling, 1987). Trapping is controlled to a large extent by an up-dip porosity pinchout along the platform margin (Fig. 24). In the Temple Field, salt plugging, to a large extent, occludes porosity development in the reefal facies. The main reservoir facies is the dolomitized basin slope deposits. The up-dip termination of this platform margin facies package is instrumental in providing the trap at Temple. Reservoir parameters of the Temple Winnipegosis pool are shown in Table 5.

Table 5: Reservoir parameters of the Temple Field, Williams County, North Dakota (after Ehrets and Kissling, 1987)

Location: T.158, 159N; R.95, 96W, Williams County, North Dakota

	Winnipegosis Pool
Discovery Date (year):	1982
Estimated Ultimate Primary Recovery:	
(m^3)	1 033 000
(Bbls)	6 500 000
Average Producing Depth:	
(m)	3 398
(ft)	11 150
A.P.I. Gravity:	
(degrees)	43.4
(kg/m^3)	809
Average Porosity (%):	15

Southwestern Manitoba Play

The northeastern platform margin of the Elk Point Basin is located in southwestern Manitoba (Fig. 20). The isopach of the Winnipegosis Formation in southwestern Manitoba (Fig. 21) clearly shows the north-trending platform margin. This platform margin is roughly coincident with the Birdtail-Waskada Axis; this suggests that this structural fea-

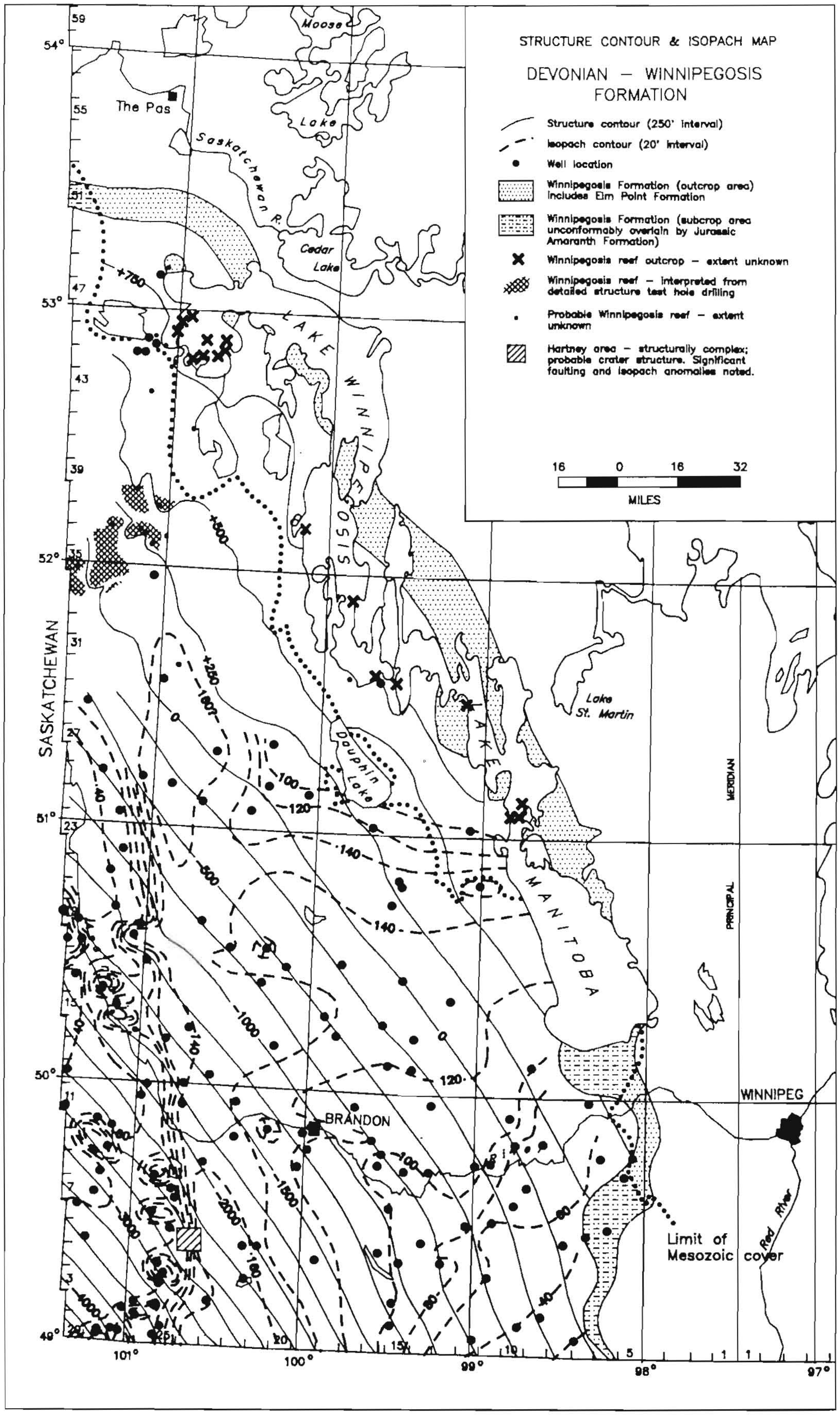


Figure 21: Winnipegosis Formation structure-isopach map (after McCabe, 1980; Martiniuk, 1992). Structure and isopach values are shown in feet.

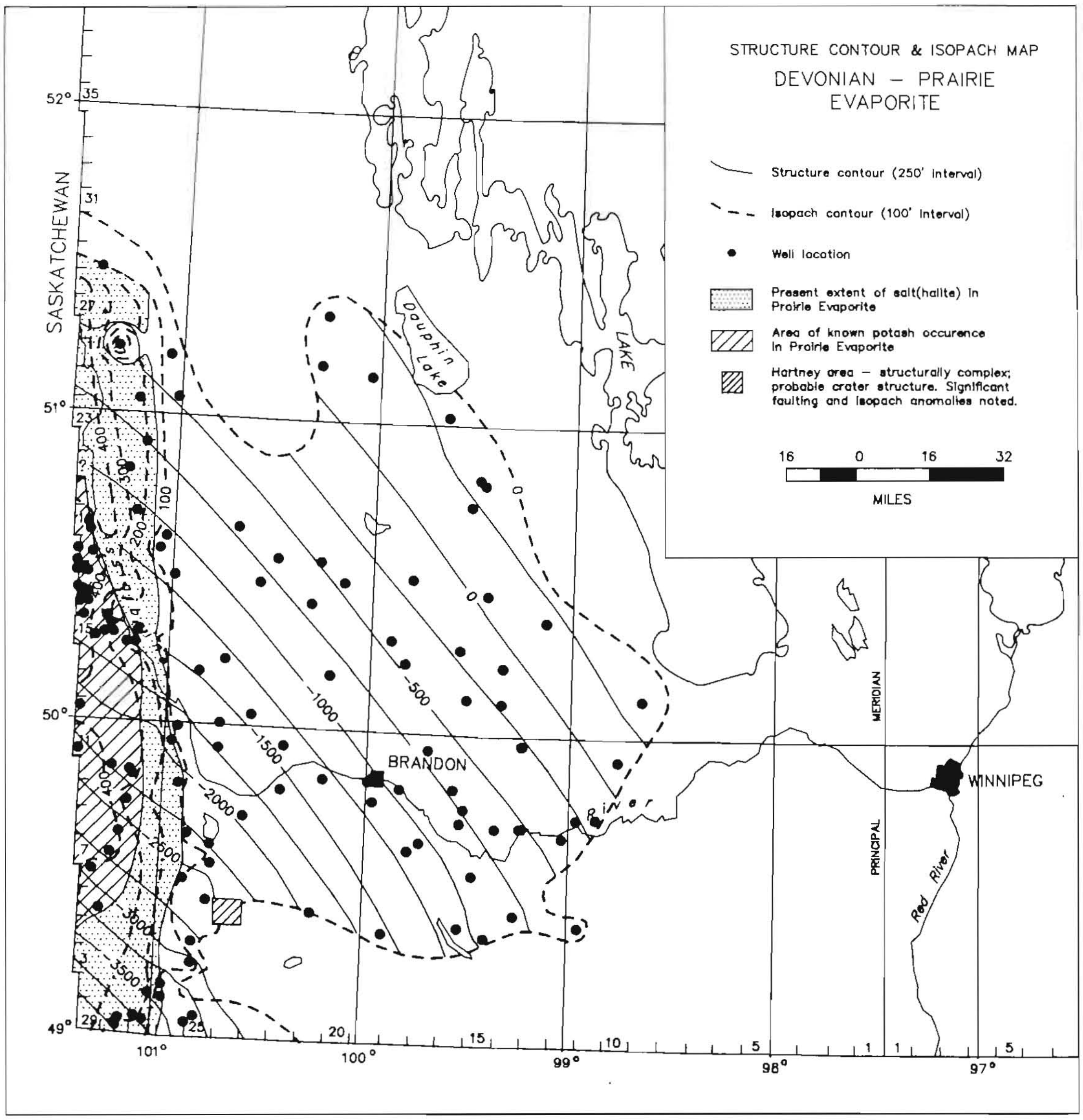


Figure 22: Prairie Evaporite structure-isopach map (after McCabe, 1980; Martiniuk, 1992). Structure and isopach values are shown in feet.

ture influenced the bathymetry of the Elk Point Basin and, hence, the location of the platform margin.

Figure 25 (in pocket) is an east-west stratigraphic cross section from the basin, across the platform margin, and on to the inner platform. The lithologies suggest a depositional facies assemblage similar to that described in the Temple Field area on the southwestern basin margin (Ehrets and Kissling, 1987). Unlike Temple, excellent reservoir development occurs in the platform margin reefal facies due to the absence of the overlying salts of the Prairie Evaporite and the associated salt plugging of porosity. The up-dip facies transition in southwestern Manitoba is from platform margin to platform interior, rather than the up-dip platform margin to basin transition at Temple. This up-dip transition provides potential for the stratigraphic pinchout of an organic reefal reservoir facies associated with the prograding platform margin (Fig. 25, in pocket).

The association of the platform margin depositional trend with the Birdtail-Waskada Axis enhances its appeal as an exploration target. As demonstrated at the Temple Field, trapping is achieved by a combination of structure and stratigraphy. The Birdtail-Waskada Axis provides the best potential for providing a structure along this depositional trend that would result in a combination of structural and stratigraphic trapping similar to that at Temple.

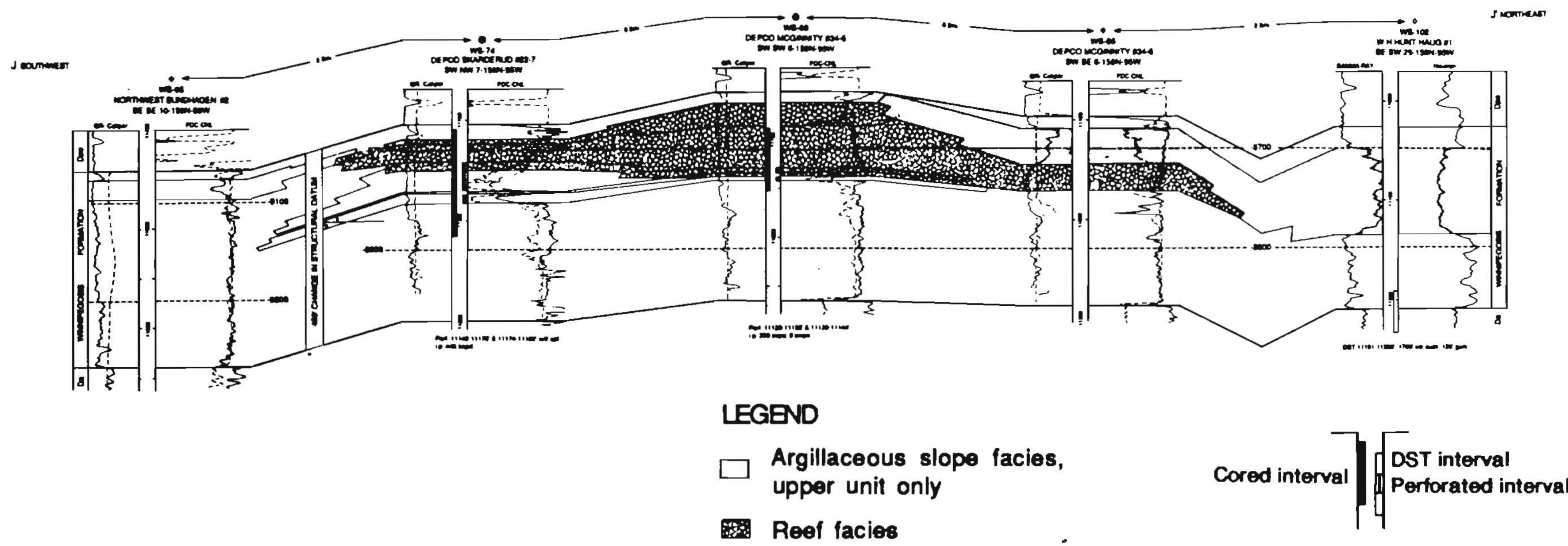


Figure 24: Structural cross section, Temple Field, Williams County, North Dakota. Illustrates stratigraphic relationships of reef and underlying reef slope reservoir facies (after Ehrets and Kissling, 1987).

PLAY TYPE: SALT DISSOLUTION STRUCTURES

Williston Basin Examples: Tule Creek Field, Montana, Hummingbird Field, Saskatchewan

Several oil accumulations in the Saskatchewan, North Dakota and Montana portions of the Williston Basin are associated with structures generated by salt dissolution and collapse of overlying strata. The removal of salt from the Middle Devonian Prairie Evaporite resulted in localized subsidence features and trap settings favourable for oil accumulation.

There are several fields in northeastern Montana, located along the western flank of the Williston Basin, that produce from areas of known multiple-stage salt dissolution. The Tule Creek Field and surrounding fields are prime examples (Fig. 14). Tule Creek is located west of, and up-dip from, the present salt dissolution edge of the Devonian Prairie Evaporite. Production is obtained from the Nisku (Birdbear) Formation (Table 6). The Nisku reservoir in the Tule Creek Field consists of a porous dolomite, capped by a bedded anhydrite. Oil is accumulated in structural traps created by locally developed, isolated Nisku closure. The origin of these structures is believed to result from two-stage salt dissolution of the Devonian Prairie salt (Fig. 26).

Table 6: Reservoir parameters of the Tule Creek Field, Montana (after Montana Geological Society, 1985; Montana Board of Oil and Gas Conservation, 1992)

Location: T.30N., R. 47E., Roosevelt County, Montana

	Birdbear (Nisku) Pool
Discovery Date (year):	1960
Estimated Ultimate Primary Recovery:	
(m^3)	1 333 249
(Bbls)	8 390 000
Average Producing Depth:	
(m)	2 286
(ft)	7 500
A.P.I. Gravity:	
(degrees)	46
(kg/m^3)	797
Average Porosity (%):	15
Average Permeability (md):	100
Cumulative Oil Production to Jan. 1, 1992:	
(m^3)	1 296 382
(Bbls)	8 158 000

The domal structure at the Hummingbird Field in southeastern Saskatchewan is another example of a salt-collapse feature. It is located on the northwestern flank of

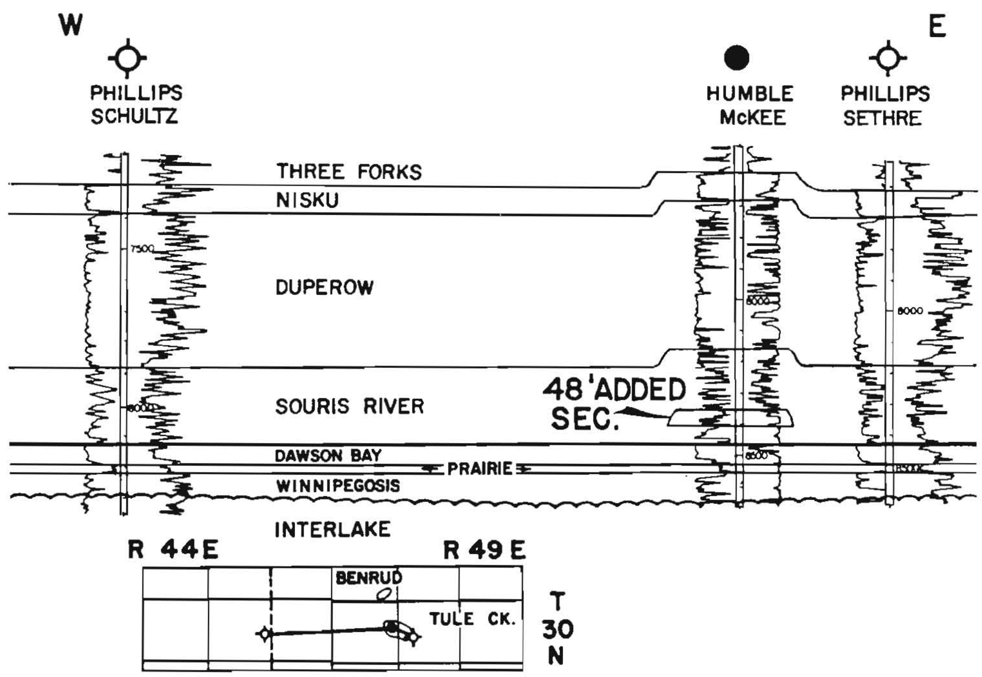


Figure 26: Stratigraphic cross section, Tule Creek Field, Montana (after Swenson, 1967, reprinted by permission).

the Williston Basin (Fig. 14). The Hummingbird structure is the result of the multi-stage dissolution of the Middle Devonian Prairie Evaporite salt. The structure represents approximately 90 m (300 ft) in compensated thickness of Souris River, Duperow and Bakken formations strata. The thickening was created by local dissolution of Prairie salt and collapse of overlying strata during late Devonian and early Mississippian time. Dissolutioning of the Prairie salt in the surrounding area during Mississippian and Cretaceous time, resulted in the collapse of post-Prairie strata and creation of a closed structural high draped over local pre-Mississippian thicks (Fig. 27).

Localized dissolutioning of the Prairie salt may have been initiated by upward movement of formation water from the Winnipegosis Formation into the Prairie Evaporite. The formation water is believed to have migrated vertically along high-angle basement controlled faults or through intersections of basement-controlled fault systems.

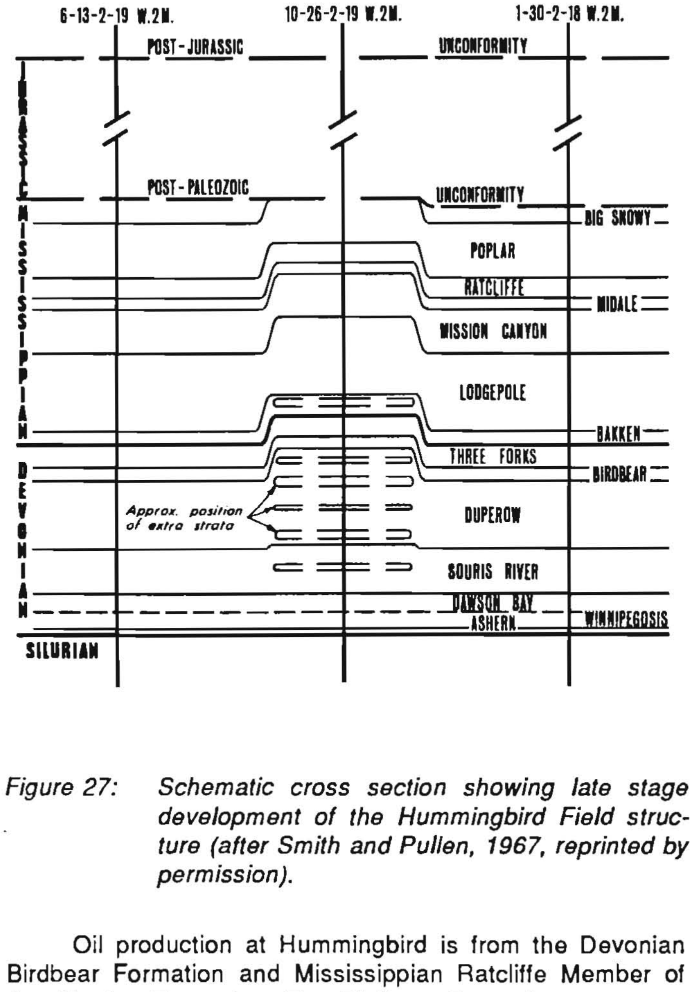


Figure 27: Schematic cross section showing late stage development of the Hummingbird Field structure (after Smith and Pullen, 1967, reprinted by permission).

Oil production at Hummingbird is from the Devonian Birdbear Formation and Mississippian Ratcliffe Member of the Charles Formation. The Birdbear Formation occurs as two units; a lower, fine crystalline, vuggy dolomite reservoir unit and an upper, interbedded, dense microcrystalline dolomite and anhydrite unit that provides a top seal (Table 7) (Smith and Pullen, 1967).

Table 7: Reservoir parameters of the Hummingbird Field, Saskatchewan (after Saskatchewan Energy and Mines, 1990)

Location: Township 2, Range 19 W2M

	Birdbear Pool
Discovery Date (year):	1966
Estimated Ultimate Primary Recovery:	
(m^3)	499 000
(Bbls)	3 140 157
Average Producing Depth:	
(m)	2 326
(ft)	
A.P.I. Gravity:	
(degrees)	39
(kg/m^3)	830
Average Porosity (%):	10.3
Cumulative Oil Production to Jan. 1, 1992:	
(m^3)	469 000
(Bbls)	2 951 370

Southwestern Manitoba Play

In southwestern Manitoba, salt removal and collapse is most evident in the areas along, or near the Birdtail-Waskada Axis. The eastern limit of the Prairie Evaporite salt is roughly coincident with this axis and represents a salt dissolution edge similar to that observed in other areas of the Williston Basin. Salt re-entrant features and subsidence structures occur along the salt dissolution edge of the Prairie Evaporite (Fig. 22).

Local structural and isopach anomalies that affect shallow Mississippian strata in southwestern Manitoba have been attributed to Devonian salt dissolution and collapse. At Waskada, the thickened section of the Mississippian Bakken Formation and thinning of the Devonian Prairie Evaporite section is attributed to salt dissolution and collapse of the Prairie salt during early Bakken time. Local occurrence of the lower shale member of the Bakken Formation at Waskada has also been related to salt collapse during early Bakken time (Martiniuk, 1988).

Indications of salt dissolution also occurs in pre-Mississippian strata. In the Napinka area (Township 3 to 6; Range 25 WPM) and St. Lazare area (Township 15 to 17; Range 27 to 29 WPM) the Devonian Duperow Formation has been locally thickened due to the dissolution of the Prairie Evaporite salt during Duperow and Souris River-Duperow time (Fig. 28).

Areas of localized multiple-stage salt solutioning and compensated thickened sections in the pre-Mississippian are commonly coincident with the Birdtail-Waskada Axis (eg. Township 1 to 5; Ranges 24 to 26 WPM). Local thickening of the Second Red Bed Member of the Dawson Bay Formation in this area is possibly related to salt dissolution

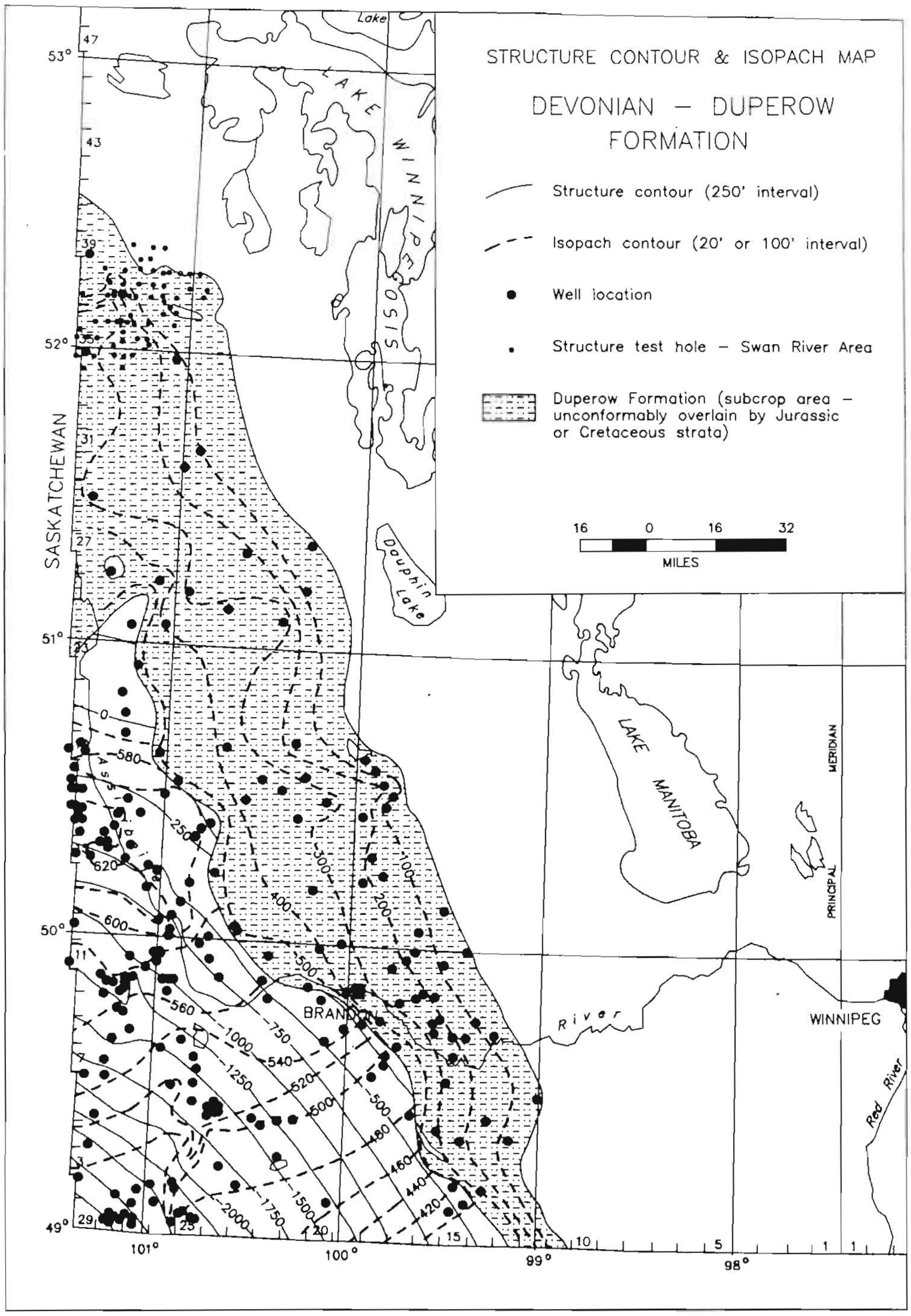


Figure 28: Duperow Formation structure-isopach map (after McCabe, 1980; Martiniuk, 1992). Structure and isopach values are shown in feet.

along the edge of the fringing bank of the Winnipegosis Formation during pre-Dawson Bay time. The stratigraphic cross section (Fig. 29, in pocket) shows the thickened section of the Second Red Bed Member of the Dawson Bay Formation in the well at 5-24-2-26 WPM. Such local thickening has given rise to localized multiple-stage dissolution structures similar to those at Hummingbird and Tule Creek.

Structural closure associated with the drape of younger strata over the present salt dissolution edge may also provide a trapping mechanism for oil accumulation.

The potential for salt edge "roll-over" and multiple-stage salt dissolution structural features is evident in southwestern Manitoba. The presence of these features and their proven relationship to hydrocarbon accumulation in other areas of the Williston Basin demonstrate the possibility for analogous traps in Manitoba.

Dissolution of the Devonian Prairie Evaporite salt section along or near the Birdtail-Waskada Axis resulted in numerous structural and isopach anomalies important in controlling Upper Mississippian (Lodgepole and Mission Canyon formations) oil accumulation within the Daly, Virden and Waskada producing areas of southwestern Manitoba (McCabe, 1963; Rodgers, 1986). The timing and relationship of oil migration to salt dissolution features at these fields has not been determined; however, it is evident that trapping of Family C and B oils in these fields, is related to salt dissolution and collapse.

These same scenarios may be applied to pre-Mississippian strata in southwestern Manitoba. Identification and timing of multiple-stage salt dissolution events within strata of Devonian age and older is crucial to pre-Mississippian salt dissolution plays. Recognition of these events help to define the direct, or indirect effects of salt dissolution on potential reservoir beds. This includes the identification of isopach and structural features necessary for the localized structural trapping, and the presence of local areas of vertical fracturing critical to the cross-stratal migration of oil.

PLAY TYPE: STRATIGRAPHIC SUBCROP TRUNCATION

Williston Basin Example: Ollie Field, Montana

During deposition of the Paleozoic sequence in the Williston Basin, periods of regional erosion occurred in the Middle Cambrian, Upper Cambrian, Ordovician, Middle Devonian, Lower Mississippian, Kibbey-Upper Mississippian, Middle Pennsylvanian and Middle Permian time (McCabe, 1954). These unconformities resulted in the truncation of strata along the shelf flank areas of the basin, thus creating stratigraphic trap settings suitable for oil accumulation.

The Ollie Field in northeastern Montana is an example of a pre-Mississippian subcrop play. It is located along the southwestern flank of the Williston Basin (Fig. 14). Production at the Ollie Field is from the Devonian Duperow and Ordovician Red River formations (Table 8). Oil accumulation within the Red River and Duperow formations is stratigraphically and structurally controlled.

The stratigraphic control on oil accumulation within the Duperow Formation is unconformity-related. Production occurs at the subcrop of Duperow porosity. The Duperow Formation is overlain by a black shale believed to belong to either the Mississippian Bakken Formation, or a lower shale of the Mississippian Lodgepole Formation. The Devonian Three Forks, Nisku and upper Duperow formations have been truncated beneath the erosional unconformity in this area.

Table 8: Reservoir parameters of the Ollie Field, Montana (after Montana Geological Society, 1985; Montana Board of Oil and Gas Conservation, 1991)

Location: T. 10N., R. 60E., Fallon County, Montana

	Duperow Pool
Discovery Date (year):	1980
Estimated Ultimate Primary Recovery:	
(m^3)	31 710
(Bbls)	199 548
Average Producing Depth:	
(m)	2840
(ft)	9 316
A.P.I. Gravity:	
(degrees)	41
(kg/m^3)	820
Average Porosity (%):	14
Average Permeability (md):	324
Cumulative Oil Production to Jan. 1, 1992:	
(m^3)	20 022
(Bbls)	126 000

Southwestern Manitoba Play

Oil accumulations within Mississippian and Jurassic reservoirs in the Canadian portion of the Williston Basin are closely associated with stratigraphic traps created by post-Mississippian and post-Jurassic unconformities.

In southwestern Manitoba, production from the Mississippian Lodgepole Formation is concentrated along the subcrop belts of the Whitewater Lake, Virden and Scallion members. The fields of Lulu Lake, Whitewater, Regent, Souris Hartney, and Virden, as well as several smaller associated pools along this trend, are productive. The Daly and Kirkella fields, west of Virden, produce from a stratigraphic equivalent of the Virden and Whitewater Lake members.

The Waskada, Pierson, Tilston, and Coulter fields produce from the Mission Canyon Formation (Fig. 2). Oil accumulation within these beds occurs within truncation traps found at, or near, the subcrop belts of these units. Stratigraphic factors that play an important role in localizing oil accumulation are; the extent of post-Mississippian erosion, the extent of secondary dolomitization and anhydritization of the Mississippian at the erosion surface, and primary lithofacies changes of the units.

Oil may have migrated into Manitoba along the subcrop belts of the Mississippian reservoir beds. It is believed to have migrated northwestward along the structural rise that extends from the Lulu Lake Field to the Virden Field where it is trapped at paleotopographic highs, structural highs or by permeability barriers (McCabe, 1963; Potter, 1991).

Analogous truncation traps are also present within the pre-Mississippian strata where potential reservoir beds subcrop at the Paleozoic erosion surface (Fig. 6). The structural cross section in Figure 30 (in pocket) demonstrates the truncation of pre-Mississippian strata along the Paleozoic unconformity. The Birdbear and Duperow formations have been partially eroded in this area. Beds with good porosity and permeability within the Birdbear Formation have been correlated between the wells at 6-30-10-24 WPM and 14-34-10-24 WPM (Fig. 31, in pocket). These zones are sealed above and below by impermeable mudstone and anhydrite beds, and are laterally sealed at the Paleozoic unconformity, where they are capped by impermeable shales of the Lower Member of the Jurassic Amaranth Formation.

Prospects along the pre-Mississippian subcrop trend are controlled by the development of favourable or high-quality reservoir facies that have been eroded at, or near, the Paleozoic unconformity, and overlain by impermeable red beds of the Jurassic Amaranth Formation. In the example from the Birdbear Formation (Fig. 30, in pocket), the highly permeable reservoir facies, capped by an impermeable, possibly supratidal facies, is truncated at the Paleozoic unconformity, thus creating the potential for trapping similar to that in the overlying Mississippian rocks.

Similar trap settings are possible within older Paleozoic strata where potential reservoir beds in Ordovician, Silurian and Devonian age formations are progressively truncated at the Paleozoic unconformity. These subcrops extend over a large area of southwestern Manitoba, to exposures east of Winnipeg (Fig. 6).

The potential for accumulation and trapping at relatively shallow depths has been demonstrated in the Michigan Basin, where recent exploration resulted in the discovery of oil in shallow Ordovician reservoirs. Similar scenarios are present in southwestern Manitoba.

Hydrodynamic factors may also play a role in the trapping of oil in the pre-Mississippian of southwestern Manitoba. It has been suggested that the outcropping of pre-Mississippian formations in Manitoba is a possible entry point for meteoric waters that may have formed hydrodynamic traps in the subsurface, down-dip of the Manitoba Paleozoic outcrop belt (Sproule and Associates, 1964).

POTENTIAL FOR HYDROCARBON CHARGE

Having established the existence of favorable reservoirs and trap settings in the pre-Mississippian strata of southwestern Manitoba, the migration characteristics of the known Williston Basin oil-source systems can be integrated to assess the potential for hydrocarbon charge into these strata. Little is known about the specifics of oil migration because it is a process that is not easily observed. Migration pathways are generally inferred on the basis of the spatial relationship between pooled oils and their associated source rocks, which have been sufficiently thermally matured to generate and expel oil. In a sedimentary basin that consists of interbedded permeable and impermeable rocks, up-dip migration would occur in stratigraphically-defined, regionally extensive permeable beds, whereas cross-stratal migration is likely to involve open vertical fault or fracture systems. Together, the lateral and vertical permeability components define the three-dimensional hydraulic characteristics of a basin, such as the Williston, that govern the movement of any fluid along a hydraulic gradient.

The empirical evidence of oil migration, i.e. the distribution of pools associated with an oil-source system, is, perhaps, the only reliable information available on the migration process. Oil shows reported from exploratory dry holes may provide an indication of a migration pathway even though information on the geochemistry of the oil and, hence, its family affiliation, is not generally available. Both hypothesis are important in assessing the potential of unexplored areas and can be applied to the pre-Mississippian strata of southwestern Manitoba.

As discussed previously and shown in Figures 10, 11, 12, and 13, southwestern Manitoba is clearly outside of the area of thermal maturity for all known Williston Basin oil-source system source rocks. Long distance up-dip migration is required to charge these strata with hydrocarbons. Direct evidence in the form of hydrocarbon shows can be combined with indirect evidence in the form of the migration characteristics of Williston Basin oil-source systems to support the assertion that this long-distance migration has, in fact, occurred.

WILLISTON BASIN MIGRATION CHARACTERISTICS

Prior to examining the migration characteristics of the Family A and D oil-source systems, characteristics of the more intensely explored Family B and C oil-source systems are worth noting because they may provide a better indication of the hydraulic characteristics of the northeastern flank of the basin. Pools in southwestern Manitoba represent some of the longest migrated and the most thermally mature oils in these systems. In addition, they occur at some of the shallowest producing depths in the Williston Basin. The Virden Field provides an excellent example with ultimate recoverable reserves of 23,470,000 m^3 (148 million bbls.) of 35° API (850 kg/m^3) oil at an average producing depth of 635 m (2,083 ft). The minimum distance this oil has migrated is approximately 170 km (106 mi). This distance represents up-dip migration from the edge of the Lodgepole source rock area, which is above the generation and expulsion threshold (Figure 12). Family B pools in the Daly Field have undergone migration of a minimum distance of approximately 200 km (124 mi) (Fig. 11).

These pools have a close stratigraphic association to the source rock. Lateral migration, within strata that have regionally extensive permeability, dominated the migration history. This involved both up-dip migration from the center of the basin, and migration up structure along the subcrop trends. The configuration of oil pools along the Virden-Whitewater Lake paleo-erosional trend provides a good example of the result of this migration process (Potter, 1991).

Family A Oil-Source System

Examples of a similar long distance lateral migration process in the Family A oil-source system have not yet been identified (Fig. 10). The Family A pools in the Red River and Winnipegosis formations at Minton in southern Saskatchewan demonstrate that cross-stratal and limited up-dip migration out of the area of thermal maturity has occurred in the northern part of the basin. Large reserves of Family A oils have also migrated up-dip on the southwest flank of the basin and have been trapped along the Cedar Creek Anticline. Knowing that the estimated period of peak oil generation in the Red River Formation predates development of the Nesson Anticline as a significant structural barrier (Osadetz *et al.*, 1991, 1992b), there is reason to believe that a significant volume of hydrocarbons may have migrated up-dip into the northeast flank of the basin. This oil would likely charge a stratigraphic interval similar to that elsewhere (i.e. Ordovician Red River Formation through to Devonian Winnipegosis Formation). The lack of reported oil shows along the lower Paleozoic outcrop belts in Manitoba suggests that little, if any, of this oil made it to outcrop. Therefore, if long distance migration of Family A oils occurred in the northeastern portion of the basin, such oil is likely trapped somewhere down-dip.

Figure 32 shows southwestern Manitoba in relation to some of the attributes of the Family A oil-source system. The location of the geological examples previously discussed, along with significant structural features, are indicated. The area of thermally mature Family A source rock is shown along with two radii that define significant maximum known up-dip migration distances. The first radius is the maximum known up-dip migration distance in the Family A oil-source system at Minton (70 km (44 mi)). The second radius represents the up-dip migration distance associated with the Family C oil-source system at Virden in southwestern Manitoba (170 km (106 mi)). This radius assumes that the hydraulic characteristics of the lower Paleozoic accommodated a long distance migration process similar to that for the Family C oil-source system. It should be emphasized that both these radii relate to currently known oil pools and, therefore, represent minimum potential migration distances.

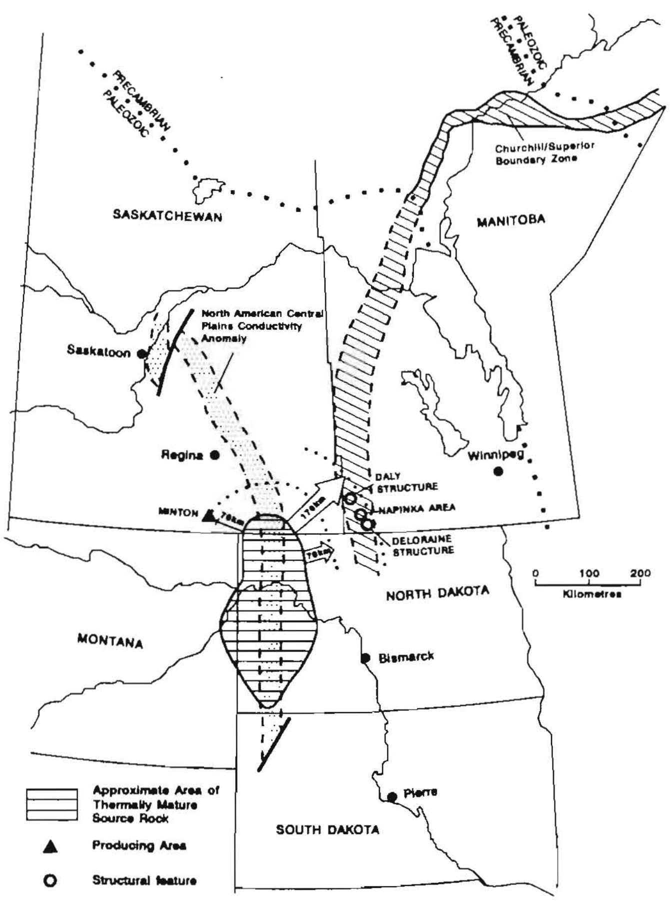


Figure 32: *Family A Oil-Source System migration potential. Maximum known migration distances are illustrated.*

The preponderance of oil shows outside of these radii suggests that migration has, in fact, exceeded these limits.

It is clear that the potential exists for a large area of southern Manitoba to have been charged with oils related to the Family A oil-source system. The absence of examples of long distance migration of Family A oils is considered to be a reflection of sparse exploration on the up-dip flanks of the basin, rather than an indication of any known constraints on this process.

Family D Oil-Source System

The Family D oil-source system has a few examples of long distance up-dip migration that rival that for Family C and B systems. The Birdbear Formation Pool at Walpole in southeastern Saskatchewan (Fig. 13) is thought to be sourced from rocks of the Winnipegosis Formation western platform (Osadetz *et al.*, 1992a). This implies a minimum lateral migration distance of 170 km (106 mi) in addition to the cross-stratal migration into the Birdbear. As stated previously, it is not clear whether this extensive lateral migration occurred in the Winnipegosis Formation or in the Birdbear Formation. The affiliation of the long distance migrated oils at Walpole and Kisbey with structures that may have facilitated the cross-stratal migration component implies that the Winnipegosis Formation may have accommodated a significant degree of lateral migration. Several Winnipegosis pinnacle reef pools in southeastern Saskatchewan, where the pooled oil has a higher level of thermal maturity than the local source rocks, also suggest that significant lateral migration from deeper basin, more mature, source rocks has occurred (Osadetz *et al.*, 1991).

Figure 33 shows southwestern Manitoba in relation to some of the attributes of the Family D oil-source system. The location of the geological examples previously discussed, along with significant structural features, are indicated. The area of thermally mature Family D source rock is shown along with a radius defining the maximum known up-dip migration distance in the Family D oil-source system at Walpole (170 km (106 mi)). This distance is similar to up-dip migration distances associated with the Family C oil-source system in southwestern Manitoba. These limits represent minimum distances derived from known occurrences. Oil shows outside of these areas imply that lateral migration has exceeded these limits.

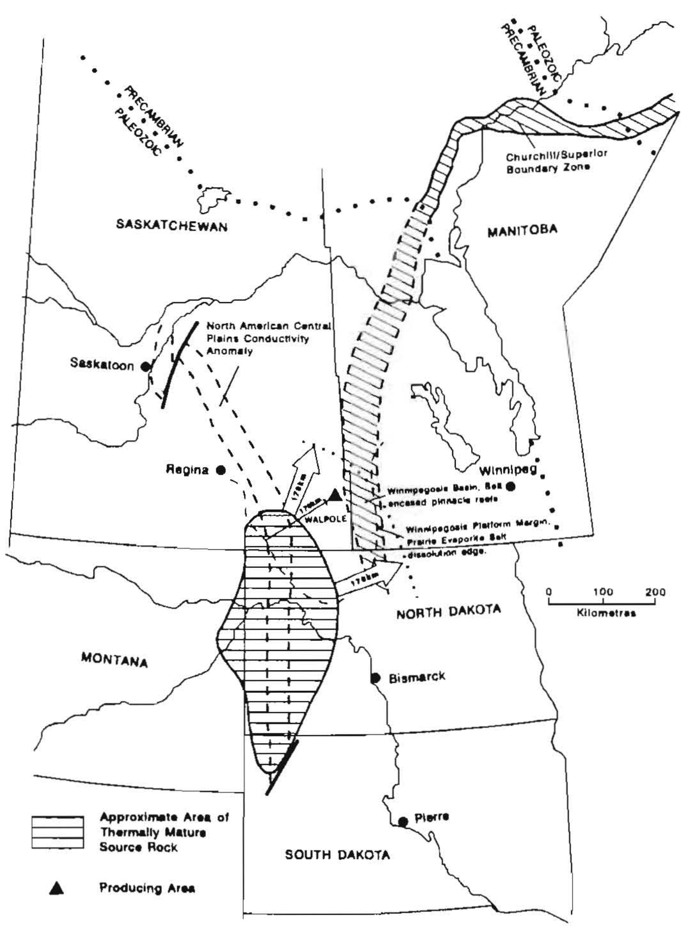


Figure 33: *Family D Oil-Source System migration potential. Maximum known migration distances are illustrated.*

Clearly, a large area of southwestern Manitoba is well within the area defined by the maximum up-dip migration in the Family D oil-source system. The process of long distance up-dip migration of Family D oils is well established. The lack of significant Family D reserves on the northeastern flank of the basin is apparently a reflection of the lack of exploration directed towards the pre-Mississippian strata.

OIL SHOWS

Despite sparse exploration on the northeastern flank of the Basin, as reflected by the very low deep drilling density in southwestern Manitoba, numerous oil shows in the form of stains on cuttings and cores have been reported from the lower Paleozoic in this area (Martiniuk, 1992; Manitoba Energy and Mines, 1991). The location of these shows is illustrated in Figure 34. Although the oil family affiliation of these shows cannot be determined, they are important in determining that hydrocarbons are present in these strata that are well removed from areas of source rock thermal maturity. These oils must have undergone long distance migration from the central basin in a manner similar to the Family C and B oils. The reader is referred to Manitoba Energy and Mines (1991) for a complete listing of these shows.

The stratigraphic distribution of these shows may provide an indication of the most likely family affiliation. Table 9 shows the number of oil shows reported for each of the pre-Mississippian Formations in southwestern Manitoba. The stratigraphic range of these shows is similar to that of the stratigraphic distribution of the Family A and D pools in other parts of the basin. The oil shows recorded in the Winnipeg Formation to Interlake Group interval may be interpreted as evidence of migration of Family A oils through these strata. It is interesting to note that shows in this interval

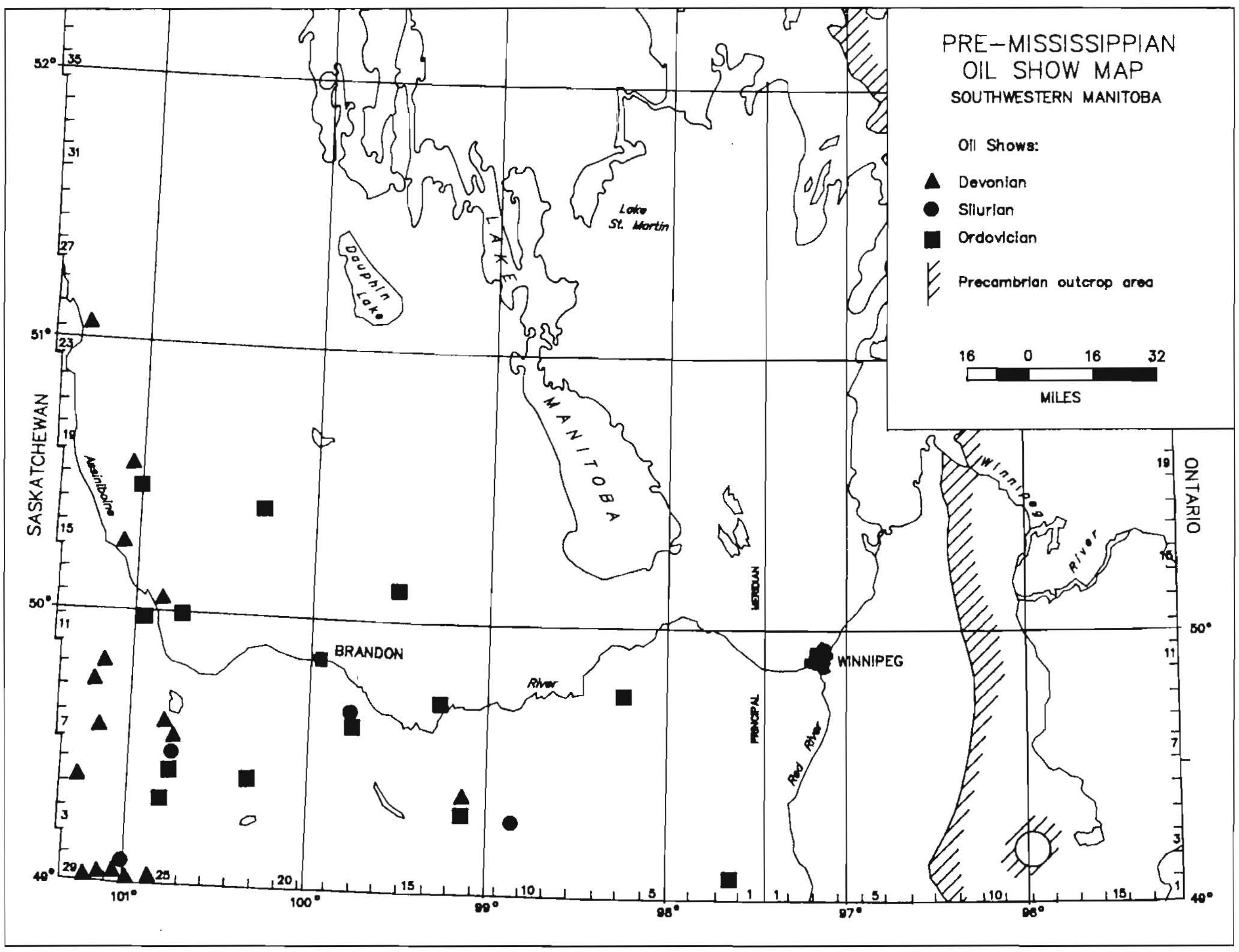


Figure 34: Pre-Mississippian oil show map, southwestern Manitoba (after Manitoba Energy and Mines, 1991). Also includes additional oil shows noted in the following wells: 2-17-4-25 WPM; 8-13-5-29 WPM; 10-9-1-28 WPM; 14-13-9-28 WPM; 7-18-10-27 WPM; 15-11-12-26 WPM.

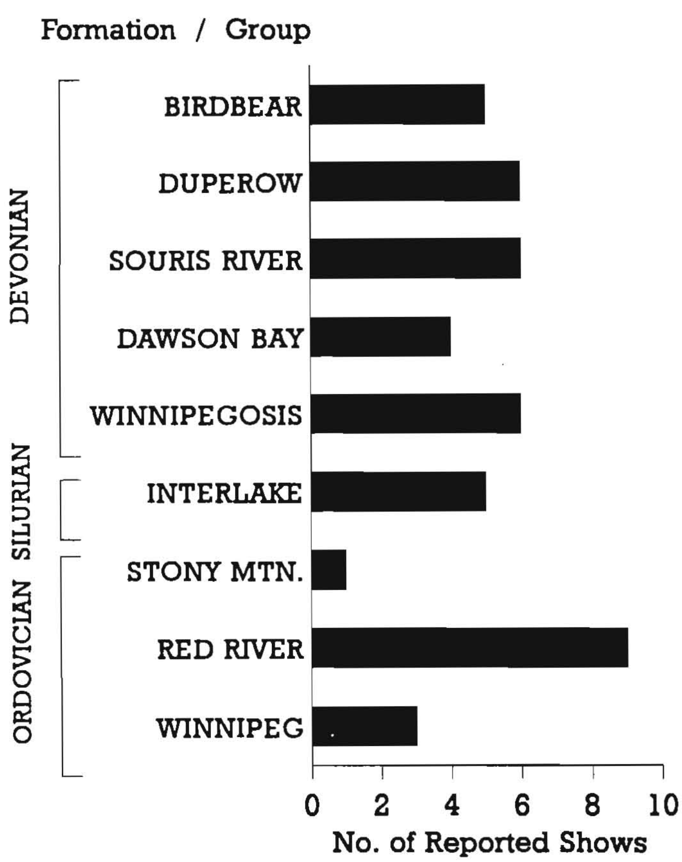
occur as far east as Range 2 WPM at shallow depths, near the lower Paleozoic outcrops. This raises the possibility that very shallow oil pools occur close to the basin margin outcrop belts - a phenomenon that occurs in other cratonic basins, such as the Michigan Basin.

The numerous oil shows reported in the Winnipegosis Formation - Birdbear Formation stratigraphic interval may be representative of migration of Family D oils through these strata. The long distance migration of these oils that occur elsewhere in the basin, particularly southeastern Saskatchewan, supports the affiliation of these shows with the Family D oil-source system.

The presence of these oil shows supports the assertion that long distance up-dip migration of Family A and D oils has occurred and has charged the pre-Mississippian strata of southwestern Manitoba with hydrocarbons.

Table 9: Stratigraphic distribution of reported oil shows (after Manitoba Energy and Mines, 1991), and the following reported shows:

2-17-4-25 WPM: Oil stain on cuttings - Red River Formation
8-13-5-29 WPM: Oil stain on core - Winnipegosis Formation
10-9-1-28 WPM: Oil stain on core - Winnipegosis Formation
14-13-9-28 WPM: Oil stain on core - Winnipegosis Formation
7-18-10-27 WPM: Oil stain on core - Duperow Formation
15-11-12-26 WPM: Oil stain on core - Winnipeg Formation



OTHER CONSIDERATIONS

The foregoing discussion has evaluated the hydrocarbon prospects in southwestern Manitoba within the context of known Williston Basin oil-source systems. Given the paucity of deep drilling in the basin, in general and on the northeastern flank in particular, the knowledge of these systems is certainly less than complete. Additional details of the known systems have yet to be resolved and the existence of other oil-source systems, which may have a significant impact on the prospects in this area, cannot be ruled out.

A somewhat enigmatic oil pool in the Cambrian Deadwood Formation in the Newporte Field in Renville County, North Dakota is worth mention in this regard (Clements and Meyhew, 1979) (Figure 14). This pool, discovered in 1977, was the first Cambrian producer in the basin and marked the first deep production east of the Nesson Anticline on the northeast flank of the basin. The discovery resulted in leasing activity over much of the northeastern flank of the basin, including southwestern Manitoba. A second pool with similar oil and analogous trapping conditions has yet to be found elsewhere in the basin. The geochemical signature of the oil at Newporte does not match any of the known Williston Basin oil families (Osadetz, *pers. comm.*). The distinctive composition of this oil, along with the pool's unique stratigraphic and structural setting, illustrates that assessment of the potential of an area within the context of known oil-source systems and known reservoir analogs has limitations. It is clear that whatever combination of source, migration, and trapping that resulted in the Newporte pool may have significant implications on the potential of southwestern Manitoba, 48 km (30 mi) further up-dip on the northeastern flank of the basin.

In summary, the migration characteristics of Williston Basin oil-source systems and the occurrence of numerous shows in the pre-Mississippian of southwestern Manitoba suggest evidence that these strata have been charged with hydrocarbons from deeper basinal sources. The stratigraphic distribution of these shows is consistent with that elsewhere in the basin and appears to reflect oil charge from known Williston Basin oil-source systems. The possibility that other, poorly understood, oil-source systems may also have contributed to the potential of this area must be considered.

CONCLUSIONS

1. The Pre-Mississippian strata of southwestern Manitoba comprises a wedge of sediments that attain a maximum thickness in the southwestern corner of the province, and are progressively truncated to the east and north. This erosional truncation forms a series of progressively older subcrop and outcrop belts towards the northeast. These strata contain numerous beds that have reservoir characteristics comparable to productive stratigraphic equivalents elsewhere in the Williston Basin.
2. Southwestern Manitoba is favorably situated for the occurrence of stratigraphic and structural features necessary to provide trapping mechanisms. Limited deep drilling has revealed numerous examples of geological conditions analogous to those instrumental in providing trapping mechanisms in typical pre-Mississippian Williston Basin play types.
3. Known Williston Basin oil-source systems are generally characterized by long-distance lateral migration of oils from the center of the basin to the up-dip flanks. The large reserves of the Madison Group subcrop producing province, located a long distance up-dip from the area of oil generation, attest to the excellent hydraulic characteristics of the northeast flank of the basin. Pre-Mississippian oil-source systems appear to exhibit similar migration characteristics. This bodes well for the prospect of oil charge into the up-dip, basin-flank areas, such as southwestern Manitoba.
4. The limited deep exploration to date in southern Manitoba has yielded numerous shows in the form of oil stains on cuttings and cores. The stratigraphic distribution of these shows is consistent with that of pre-Mississippian pools elsewhere in the Williston Basin. These shows may be direct evidence of long-distance migration of oils into the pre-Mississippian strata of Manitoba from central basin source rocks.
5. There is evidence that reservoir development, trapping mechanisms, and hydrocarbon charge are present in the pre-Mississippian strata of southwestern Manitoba. Potential exists for large reserves of high-quality oils at relatively shallow depths. This area has been very sparsely explored and offers a somewhat unique and exciting exploration opportunity.

REFERENCES

Barchyn, D.

1982: Geology and hydrocarbon potential of the Lower Amaranth Formation, Waskada - Pierson Area, Southwestern Manitoba: Winnipeg, Manitoba, Manitoba Energy and Mines, Geological Report GR 8-26, 30p.

Brooks, P. W., Snowdon, L.R., and Osadetz, K.G.

1987: Families of oils in Southeastern Saskatchewan, In C.G. Carlson and J.E. Christopher (eds.) , Fifth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 9, p. 253-264.

Brooks, P.W., Osadetz, K.G., and Snowdon, L.R.

1988: Geochemistry of Winnipegosis discoveries near Tablelands, Saskatchewan, In Current Research, Part D, Geological Survey of Canada, Paper 88-1D, p.11-20.

Carlson, C. G. and Anderson, S.B.

1965: Sedimentary and tectonic history of North Dakota part of Williston Basin: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1833-1846.

Clements, J.H. and T.E. Meyhew

1979: Newporte discovery opens new pay: Oil and Gas Journal, v. 77, no. 26, p. 165-172.

Dow, W. G.

1974: Application of oil-correlation and source-rock data to exploration in the Williston Basin: American Association of Petroleum Geologists Bulletin, v. 58, p. 1253-1262.

Ehrets, J.R. and Kissling, D. L.

1987: Winnipegosis platform margin and pinnacle reef reservoirs, northwestern North Dakota, In D.W. Fisher (ed.), Fifth International Williston Basin Symposium, Core Workshop Volume: Grand Forks, North Dakota, North Dakota Geological Survey, Misc. Series no. 69, p. 1-31.

Fisher, D. W. and Rygh, M. E.

1989: A synoptic overview of the Bakken Formation in portions of Billings, Golden Valley, and McKenzie Counties, North Dakota: Grand Forks, North Dakota, North Dakota Report of Investigations No. 89, 14p.

Gerhard, L.E., Anderson, S.B., LeFever, J.A., and Carlson, C.G.

1982: Geological development, origin, and energy mineral resources of Williston Basin, North Dakota: American Association of Petroleum Geologists Bulletin, v. 66, no. 8, p. 989-1020.

Gerhard, L.E., Anderson, S.B., and Fischer, D.W.

1990: Petroleum geology of the Williston Basin, In M.W. Leighton, D.R. Kolata, D.F. Oltz and J.J. Eidel (eds.), Interior Cratonic Basin: American Association of Petroleum Geologists, Memoir 51, p. 507-559.

Hansen, W. B.

1991: Geology and horizontal drilling of the Bakken Formation: Billings, Montana, Montana Geological Society, 1991 Guidebook, 197p.

Intercomp Resource Development and Engineering Ltd.

1977: Norcen gas storage feasibility study, Daly area, Manitoba, geological and petrophysical report prepared for Norcen Energy Resources Limited.

Kendall, A. C.

1976: The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan: Regina, Saskatchewan, Saskatchewan Department of Mineral Resources, Report No. 180, 185p.

Kohm, J. A. and Louden, R. O.

1982: Ordovician Red River of eastern Montana and western North Dakota - Relationships between lithofacies and production, In J.E. Christopher, and J. Kaldi (eds.), Fourth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 6, p. 27-28.

Kreis, L. K.

1991: Stratigraphy of the Jurassic System in the Wapella-Moosomin area, southeastern Saskatchewan: Regina, Saskatchewan, Saskatchewan Energy and Mines Report No. 217, 90p.

Leenheer, M. J. and Zumberge, J. E.

1987: Correlation and thermal maturity of Williston Basin crude oils and Bakken source rocks using terpane biomarkers, In M.W. Longman (ed.), Williston Basin - Anatomy of a Cratonic Oil Province: Denver, Colorado, Rocky Mountain Association of Geologists, p. 287-298.

LeFever, J.A., Martiniuk, C.D., and Anderson, S.B.

1991: Correlation cross sections along the United States-Canada International Border (North Dakota-Manitoba): Winnipeg, Manitoba, Manitoba Energy and Mines, Petroleum Branch, Petroleum Open File Report POF 12-91, 5 sheets.

Longman, M. W.

1981: Carbonate diagenesis as a control on stratigraphic traps: American Association of Petroleum Geologists, Education Course Note Series No. 21, 159p.

Longman, M. W., Fertal, T. G., and Stell, J. R.

1992: Reservoir performance in Ordovician Red River Formation, Horse Creek and South Horse Creek fields, Bowman County, North Dakota: American Association of Petroleum Geologists Bulletin, v. 76, no. 4, p. 449-467.

Luther, K. C.

1991: Gravity Modeling of Proterozoic structures in North-central North Dakota, **In** J.E. Christopher and F.M. Haidl (eds.), Sixth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Montana Geological Societies, Special Publication No. 11, p. 234-243.

Majorowicz, J.A., Jones, F.W., and Osadetz, K.A.

1988: Heat flow environment of the electrical conductivity anomalies in Williston Basin, and occurrence of hydrocarbons: Canadian Bulletin of Petroleum Geology, v. 36, no. 1, p. 86-90.

Manitoba Energy and Mines

1991: Lower Paleozoic drill stem tests and oil and gas shows, Three Forks to Precambrian (December 31, 1991), 29p.

Martindale, W., Erkmen, D., Metcalfe, D., and Potts, E.

1991: Winnipegosis buildups in the Hitchcock area, southeast Saskatchewan - a case study, **In** J.E. Christopher and F. Haidl (eds.), Sixth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Montana Geological Societies, Special Publication No. 11, p. 47-63.

Martiniuk, C.D.

1988: Regional geology and petroleum potential of the Bakken Formation: Winnipeg, Manitoba, Manitoba Energy and Mines, Petroleum Branch, Petroleum Open File Report POF 8-88, 34p.

1992: Lower Paleozoic sequence, southwestern Manitoba - an overview: Winnipeg, Manitoba, Manitoba Energy and Mines, Petroleum Branch, Petroleum Open File Report POF 13-92, 40p.

McCabe, H.R.

1963: Mississippian oil fields of southwestern Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 60-5, 50p.

1971: Stratigraphy of Manitoba, an introduction and review, **In** A.C. Turnock (ed.), Geoscience studies in Manitoba: Geological Association of Canada, Special Paper No. 9, p. 167-187.

1980: Manitoba Stratigraphic Map Series.

McCabe, W.M.

1954: Williston Basin Paleozoic unconformities: American Association of Petroleum Geologists Bulletin, v. 38, no. 9, p. 1997-2010.

Montana Geological Society

1985: Montana Oil and Gas Fields Symposium, v.2, p.iii-1217, 7 illustrations.

Montana Board of Oil and Gas Conservation

1991: 1990 Montana State Oil and Gas Review, v. 34.

1992: 1991 Montana State Oil and Gas Review, v. 35.

Osadetz, K. G., Snowdon, L. R., and Brooks, P. W.

1991: Relationships amongst oil quality, thermal maturity, and post-accumulation alteration in Canadian Williston Basin (southeastern Saskatchewan and southwestern Manitoba, **In** J.E.Christopher and F. Haidl (eds.), Sixth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Montana Geological Societies, Special Publication No. 11, p. 293-311.

Osadetz, K. G., Brooks, P. W., and Snowdon, L. R.

1992a: Oil families and their sources in Canadian Williston Basin: Bulletin of Canadian Petroleum Geology, v.40, no. 3, p. 254-273.

Osadetz, K. G., Snowdon, L. R., and Brooks, P. W.

1992b: Sub-Devonian petroleum systems and plays in the Williston Basin (abstract): American Association of Petroleum Geologists, 1992 Annual Convention Official Program, p.100.

Osadetz, K. G. and Snowdon, L. R.

in prep.: Significant Paleozoic petroleum source rocks, their distribution, richness, and thermal maturity in Canadian Williston Basin, Geological Survey of Canada Bulletin.

Parker, J.M.

1967: Salt solution and subsidence structures: American Association of Petroleum Geologists Bulletin, v. 51, no. 10, p. 1929-1947.

Parker, T. S. and Powe, W. H.

1982: Geology of the Raymond Field area, Sheridan County, Montana, **In** J.E. Christopher and J. Kaldi (eds.), Fourth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 6, p. 225-234.

Potter, D.

1991: Routledge pool: a model for development of the Virden-Whitewater Lake paleoerosional trend, southwest Manitoba, In J.E. Christopher and F. Haidl (eds.), Sixth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Montana Geological Societies, Special Publication No. 11, p. 103-112.

Potter, D. and St. Onge, A.

1991: Minton Pool, south-central Saskatchewan - a model for basement induced structural and stratigraphic relationships, In J.E.Christopher and F. Haidl (eds.), Sixth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Montana Geological Societies, Special Publication No. 11, p. 21-33.

Rodgers, M.

1986: Petroleum geology of the Mississippian Mission Canyon Formation, Waskada Field, southwestern Manitoba: Winnipeg, Manitoba, Manitoba Energy and Mines, Petroleum Report PR 1-85, 33p.

Saskatchewan Energy and Mines

1990: Petroleum and Natural Gas Report 91-1.

Sloss, L.L.

1963: Sequences in the cratonic interior of North America: Bulletin of the Geological Society of America, v. 74, n. 2, p. 93-114.

Smith, D.G. and Pullen, J.R.

1967: Hummingbird structure of southeast Saskatchewan: Bulletin of Canadian Petroleum Geology, v. 15, no. 4, p. 468-482.

Sproule, J.C. and Associates

1964: The oil and gas prospects of the pre-Mississippian sedimentary rocks of southern Manitoba, report prepared for Manitoba Mines and Natural Resources, 64p., 52 maps.

Swenson, R.E.

1967: Trap mechanics in Nisku Formation of northeast Montana: American Association of Petroleum Geologists Bulletin, v. 51, no. 10, p. 1948-1958.

Williams, J. A.

1974: Characterization of oil types in the Williston Basin: American Association of Petroleum Geologists Bulletin, v. 58, p. 1243-1252.

Zumberge, J. E.

1983: Tricyclic diterpane distributions in the correlation of Paleozoic crude oils from the Williston Basin, In Advances in Organic Geochemistry 1981, John Wiley and Sons Ltd., p. 738-745.