A

LAMAR HUNT – WILLIAM CRANSTON #1
NENW Sec.8, T.163N., R.81W.
KB: 1518' (462.7m)

CHEVRON STANDARD LTD.
– CHEVRON COULTER
9–6–2–26 WPM
KB: 440m (1443.6')

MANITOBA MINERAL RESOURCES
– MMR WASKADA PROV.
11–29–1–25 WPM
KB: 1555.5' (474.1m)

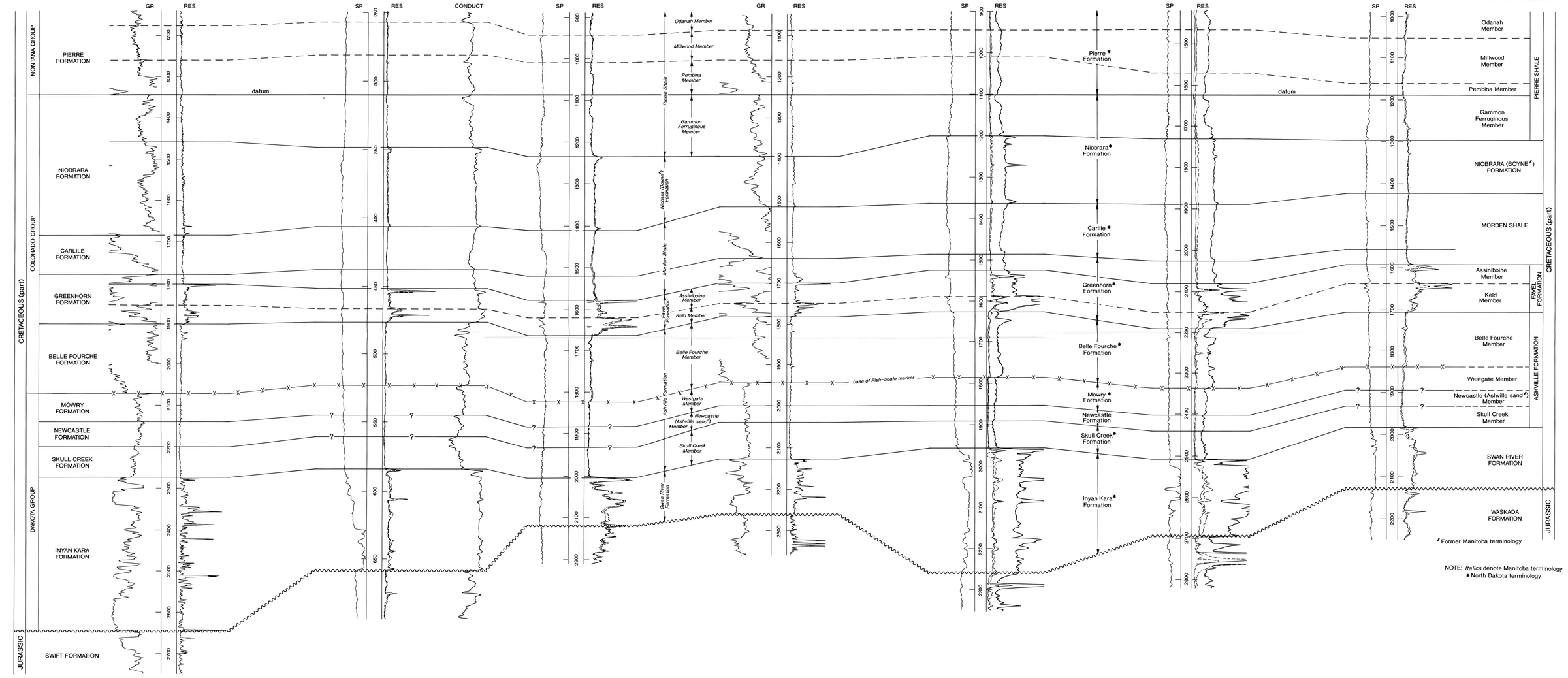
AMERADA PETROLEUM – LILLESTRAND #1
SESW Sec.31, T.162N., R.78W.
KB: 1486' (452.9m)

HUNT OIL – OLSON #1
SWNW Sec.18, T.163N., R.77W.
KB: 1520' (463.3m)

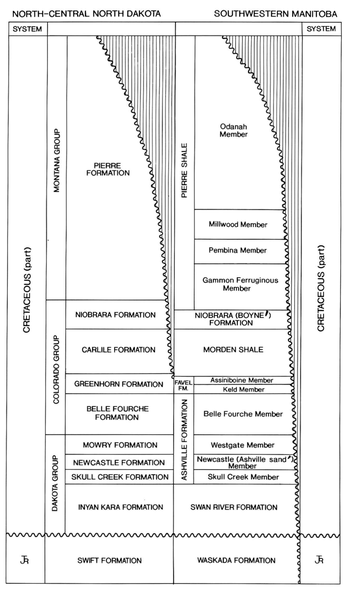
LION OIL CO. – G.A. HUSS #1
NWNW Sec.23, T.163N., R.75W.
KB: 2205' (672.1m)

JUMPING POUND PETROLEUM
– JUMPING POUND HIGH CREST
PROSPECT *et al.* HORTON #8–15
8–15–2–20 WPM
KB: 1913' (583.1m)

A′



STRATIGRAPHIC NOMENCLATURE CHART



STRATIGRAPHY

The Cretaceous sequence in North Dakota is divided, in ascending order, into the Dakota, Colorado and Montana groups and the Hell Creek Formation. The Dakota Group consists, in ascending order, of four formations, Inyan Kara, Skull Creek, Newcastle, and Mowry. The Colorado Group is divided into, in ascending order, the Belle Fourche, Greenhorn, Carlile, and Niobrara formations. The Montana Group is divided into two formations; these are, in ascending order, the Pierre and Fox Hills.

The subdivision of the Cretaceous System in Manitoba has recently been re-established to adopt the nomenclature proposed by McNeil and Caldwell (1981). The nomenclature adopted herein for the Cretaceous formations of Manitoba are, in ascending order, the Swan River, Ashville, Favel, Morden Shale, Niobrara, Pierre Shale, and Boissevain.

In the following discussion, only the formation names are retained to describe and compare Cretaceous strata in North Dakota and Manitoba (see Stratigraphic Nomenclature Chart). These formations are discussed in stratigraphic order. Descriptions for the Fox Hills and Hell Creek formations of North Dakota and the Boissevain Formation of Manitoba are not presented.

Swan River Formation (Manitoba)

The Swan River Formation in Manitoba unconformably overlies rocks of Jurassic and Devonian age. It occurs in two areas north and south of a broad belt (Townships 7 to 10) extending eastward from the Saskatchewan boundary through the Virden area, to beyond the Brandon area (Bannatyne, 1970).

The Swan River Formation consists mainly of fine-grained sand or sandstone, with silts and light to dark grey clays. In its type locality, the lower beds of the Swan River Formation consist of kaolinitic clays and silts with minor amounts of fine-grained sand, pyrite nodules and lignite fragments. The upper beds consist of fine, clean sands with interbedded dark clay and are distinguished by flaser bedding and a variety of biogenic sedimentary structures. Glauconite composes up to 25% of the sands in the upper beds

The depositional thickness of the Swan River Formation in Manitoba reaches a maximum of 122 m (400 ft) (McCabe, 1971).

Inyan Kara Formation (North Dakota)

The North Dakota equivalent to the Swan River Formation is the Inyan Kara Formation, commonly called Dakota or Lakota-Fuson-Fall River. The lower part comprises medium- to coarse-grained sandstone with lenses of grey bentonitic shale. Siderite spherulites are common in this section. The upper part comprises generally light grey, fine- to coarse-grained, quartzose sandstone and grey, silty, lumpy shale (Hansen, 1955). The lower portion of the Inyan Kara Formation is nonmarine in origin. Marine conditions appear to have begun near the end of deposition of this formation.

Maximum thickness of the Inyan Kara Formation is 137 m (450 ft). The main source of the sediments appears to have been from the southeast, in the Sioux arch area and from the southwest. Some of the sediment was probably derived from the Precambrian shield. The Inyan Kara Formation is absent in several areas of northeastern North Dakota. In these areas, the Skull Creek Formation unconformably overlies the Jurassic Swift Formation (Moore *et al.*, 1989).

Ashville Formation

The Ashville Formation is divided in ascending order, into the Skull Creek, Newcastle Sandstone (Ashville sand[1]), Westgate and Belle Fourche members. The thickness of the Ashville Formation in Manitoba ranges from 28 to 127 m (92 and 417 ft) (McCabe, 1971; Manitoba Energy and Mines, 1980).

The Skull Creek Member consists of dark grey to black shale, with minor amounts of sand, siltstone, rare phosphatic nodules, and disseminated pyrite. The contact of the Skull Creek Member with the overlying Newcastle Member can be gradational or sharp.

The Newcastle Member (previously the informal Ashville sand) comprises fine-grained sands, silts, and clays. It is absent, or extremely thin, in areas of southwestern Manitoba and north-central North Dakota. Where the Newcastle Member is absent, the Skull Creek Member cannot be differentiated from the lithologically similar Westgate Member. In this case, the equivalents of the Skull Creek, Newcastle and Westgate members are collectively referred to as ah informal unit, the lower Ashville Formation (McNeil and Caldwell, 1981).

The overlying Westgate Member consists of a dark grey, uniform shale with rare beds of silty shale with sandy lenses. Its contact with the underlying Newcastle Member is sharp. The upper contact of the Westgate Member is sharp and is placed at the base of the Fish-scale marker beds (see cross-section A-A′).

The Belle Fourche Shale, the uppermost member of the Ashville Formation, comprises predominantly black, carbonaceous shale. The lowermost part of the Belle Fourche Member consists of lenses and laminae of siltstone and fish fragments, which constitute the regional Fish-scale marker beds. The uppermost part of the Belle Fourche Member contains minor units of calcarenites, one of which is the *Ostrea beloiti* beds, a widespread, regional oyster-bearing calcarenite marker unit. The upper contact of the Belle Fourche Member with the overlying calcareous, chalk-speckled shale of the Favel Formation in southeastern Saskatchewan and southern Manitoba is conformable.

Four formations in North Dakota are equivalent to the Ashville Formation of Manitoba. In ascending order, they are, the Skull Creek, Newcastle, Mowry, and Belle Fourche formations.

Skull Creek Formation (North Dakota)

The Skull Creek Formation consists of medium to dark grey, micaceous, soft, flaky to lumpy shale over most of North Dakota (Hansen, 1955). However, in the eastern part of the state the formation grades from shale into interbedded siltstones and sandstones. The development of the siltstone and sandstone facies appears to mark the eastern shoreline limits of the Skull Creek sea (Moore *et al.*, 1987). The Skull Creek Formation was deposited under marine conditions. Maximum thickness of the Skull Creek Formation is 43 m (140 ft).

Newcastle Formation (North Dakota)

The Newcastle Formation, also known as the "Muddy," is generally described as a fine- to medium-grained, angular, quartz sandstone with some calcareous cement. Also present are medium to dark grey, soft, lumpy, fissile, micaceous shales. The formation reaches a maximum thickness of 46 m (150 ft).

The Newcastle Formation is present in the western third, southern quarter, and the eastern part of North Dakota. The sandstone is not present in the central and north-central parts of the state. In these areas, a stratigraphically equivalent shale section is recognized on wireline logs. The sandstone appears to mark the shorelines of a marine sequence (Anderson, 1967; Reishus, 1968).

Mowry Formation (North Dakota)

The Mowry Formation consists of medium to dark grey, soft, flaky, spongy shale with traces of light blue-grey bentonitic clay. The formation attains a maximum thickness of 55 m (180 ft) and is marked at the top of the section by a very distinctive gamma-ray marker on wireline logs (see cross-section A-A′) (Hansen, 1955). The Mowry Formation was deposited under marine conditions.

Belle Fourche Formation (North Dakota)

The Belle Fourche Formation consists of medium to dark grey, soft, micaceous, lumpy to massive, spongy shale, and includes beds of light blue-grey bentonitic clay over most of North Dakota (Hansen, 1955). In the eastern part of the state, an interbedded siltstone and very fine-grained sandstone facies is developed. This appears to mark the eastern boundary of deposition of the Belle Fourche Formation. The formation attains a maximum thickness of 107 m (350 ft).

Favel Formation (Manitoba)

The Favel Formation is divided in ascending order, into two members, the Keld and Assiniboine. The Keld Member consists of olive-black, calcareous, chalk-speckled shale, numerous bentonite seams, and thin argillaceous limestones. The Keld Member is richly fossiliferous in *Mytiloides labiatus* (McNeil and Caldwell, 1981).

The Assiniboine Member consists of olive-black, calcareous, chalk-speckled shale with thin interbeds of bentonite and calcarenites. It is less calcareous than the underlying Keld Member. The contact of the Assiniboine Member with the overlying Morden Shale is unconformable.

The thickness of the Favel Formation in Manitoba ranges approximately between 15 and 40 m (49 and 131 ft)(McCabe, 1971; Manitoba Energy and Mines, 1980). The Favel Formation is correlative with the Second White-speckled shale of the Colorado Group of Saskatchewan (Canadian Society of Petroleum Geologists, 1990).

Greenhorn Formation (North Dakota)

The Greenhorn Formation is the most distinctive wireline log marker in the entire Cretaceous section. The formation is composed of dark grey, calcareous, soft, thin-bedded shales and thin-bedded shaly limestones. It attains a maximum thickness of 46 m (150 ft). In addition to being an excellent marker on wireline logs, it is also distinguished in drill cuttings by calcareous "White Specks". It is sometimes referred to as the "Second White Specks" (Hansen, 1955). The Greenhorn Formation is believed to have been deposited under marine conditions.

Carlile Formation (North Dakota)

The Carlile Formation is composed of medium dark grey to black, noncalcareous, soft shale with occasional large ellipsoidal concretions containing abundant gypsum (selenite). The formation was deposited under marine conditions and attains a maximum thickness of 122 m (400 ft). It is the oldest outcropping formation in the state. Outcrops occur in the Pembina escarpment area of northeastern North Dakota.

Morden Shale (Manitoba)

The Morden Shale (formerly the lower member of the Vermillion River Formation) consists of uniform, black, noncalcareous shale, with rare, thin bentonite beds.

In the subsurface of Manitoba, the Morden Shale forms a northwestward thinning wedge. It ranges in thickness from 5 to 65 m (16 to 213 ft) (McCabe, 1971; Manitoba Energy and Mines, 1980).

Niobrara Formation

In North Dakota, the Niobrara Formation is known primarily in the subsurface. However, it crops out in eastern North Dakota. The formation is composed of medium light grey to medium grey shale. The shale is calcareous and has white, limey inclusions (commonly referred to by drillers as the "First White Specks"). A marly zone occurs near the middle of the section. The Niobrara Formation was deposited under marine conditions and attains a maximum thickness of 76 m (250 ft) (Carlson, 1964).

In Manitoba, the Niobrara Formation is unconformable with the underlying Morden Shale and the overlying Pierre Shale (see Stratigraphic Nomenclature Chart). The Niobrara Formation attains a maximum thickness of 73 m (240 ft) in Manitoba (Canadian Society of Petroleum Geologists, 1990). It correlates with the First White-speckled shale of the Colorado Group of Saskatchewan (McNeil and Caldwell, 1981).

The Niobrara Formation (previously the Boyne Member of the Vermillion River Formation) is informally divided into two members, a lower unit, referred to as the calcareous shale member, that consists of chalk-speckled, olive-black shale, with minor beds of greyish-black, noncalcareous shales and thin bentonite beds, and an upper unit, referred to as the chalky member, that consists of chalky shale with interbeds of olive-black, calcareous or noncalcareous shales and bentonite beds.

Pierre Formation (North Dakota)

The Pierre Formation is composed of light to medium or dark grey, fissile, flaky to blocky shale and is generally noncalcareous. The formation crops out on the Cedar Creek anticline in southern North Dakota, and along the Pembina escarpment in northeastern North Dakota. Four members are recognized in outcrop in northeastern North Dakota; these are, in ascending order, the Gammon Ferruginous, Pembina, Gregory, DeGrey, and the Odanah members. The Ardmore Bentonite bed marks the contact between the Gammon Ferruginous and Pembina members (Gill and Cobban, 1965; Rice, 1977).

The Pierre Formation is the thickest Cretaceous formation in North Dakota. It attains a maximum thickness of 701 m (2300 ft). The formation was deposited under marine conditions.

Pierre Shale (Manitoba)

In southwestern Manitoba, the Pierre Shale reaches a maximum thickness of 500 m (1640 ft). McNeil and Caldwell (1981) recognized five members within the Pierre Shale. These include, in ascending order, the Gammon Ferruginous, Pembina, Millwood and Odanah members, as well as an overlying, unnamed member. The Gammon Ferruginous Member consists of greyish-black shale containing numerous ferruginous concretions. The Pembina Member comprises greyish-black shales with numerous bentonite beds. The Millwood Member consists of olive-grey, bentonitic, slightly silty clay, composed largely of montmorillinite. The Odanah Member consists of siliceous, olive-grey clay or shale with thin interbeds of soft, olive-grey shale commonly containing reddish-brown, manganese-coated, weathered concretions. The unnamed member (Coulter Member of Bamburak, 1978) consists of olive-grey, soft shale (Canadian Society of Petroleum Geologists, 1990).

[1] Former Manitoba stratigraphic terminology

REFERENCES

Anderson, S.B.
1967: Where North Dakota's best Newcastle sand trends are located: World Oil, v. 165, p. 91-93.

Bamburak, J.D.
1978: Stratigraphy of the Riding Mountain, Boissevain and Turtle Mountain formations in the Turtle Mountain area, Manitoba: Winnipeg, Manitoba, Manitoba Mines, Resources, and Environmental Management, Mineral Resources Division, Geological Report 78-2, 47 p.

Bannatyne, B.B.
1970: The clays and shales of Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 67-1, 107 p.

Canadian Society of Petroleum Geologists
1990: Lexicon of Canadian stratigraphy, volume 4, western Canada including eastern British Columbia, Alberta, Saskatchewan and southern Manitoba: Calgary, Alberta, Canadian Society of Petroleum Geologists, 772 p.

Carlson, C.G.
1964: The Niobrara Formation of eastern North Dakota - its possibilities for use as a cement rock: Grand Forks, North Dakota, North Dakota Geological Survey, Report of Investigation No. 41, 56 p.

Gill, J.R., and Cobban, W.A.
1965: Stratigraphy of the Pierre Shale, Valley City and Pembina Mountain areas, North Dakota: United States Geological Survey, Professional Paper No. 392-A, 20 p.

Hansen, D.E.
1955: Subsurface correlations of the Cretaceous Greenhorn-Lakota interval in North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Bulletin No. 29, 46 p.

Manitoba Energy and Mines
1980: Manitoba stratigraphic map series.

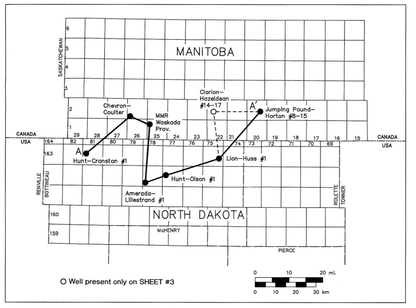
McCabe, H.R.
1971: Stratigraphy of Manitoba, an introduction and review, **in** Turnock, A.C. (ed.), Geoscience studies in Manitoba: Geological Association of Canada, Special Paper No. 9, p. 167-187.

McNeil, D.H., and Caldwell, W.G.E.
1981: Cretaceous rocks and their foraminifera in the Manitoba escarpment: Geological Association of Canada, Special Paper No. 21, 439 p.

Moore, W.L., Fischer, D.W., and Anderson, S.B.
1987: Isopach map of the Inyan Kara Formation (Cretaceous), North Dakota including four cross sections: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Map No. 27.

Reishus, M.
1968: The Newcastle Formation in the Williston basin of North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Report of Investigation No. 47, 26 p.

Rice, D.D.
1977: Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, North Dakota and South Dakota: United States Geological Survey, Oil and Gas Investigation Chart OC-72.



LINE OF CROSS–SECTION

METRIC CONVERSION TABLE	
1 metre (m)	= 3.28 feet (ft)
1 cubic metre (m^3)	= 6.29 barrels (bbls) (oil) = 220 imperial gallons = 35.49 cubic feet (gas)
1 hectare (ha)	= 2.47 acres
1 kilometre (km)	= 0.62 miles (mi)

SHEET #1: **CRETACEOUS**

CORRELATION CROSS–SECTIONS ALONG THE UNITED STATES–CANADA INTERNATIONAL BORDER (NORTH DAKOTA–MANITOBA)

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December, 1991

NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 92

MANITOBA ENERGY AND MINES
PETROLEUM OPEN–FILE REPORT POF 12–91

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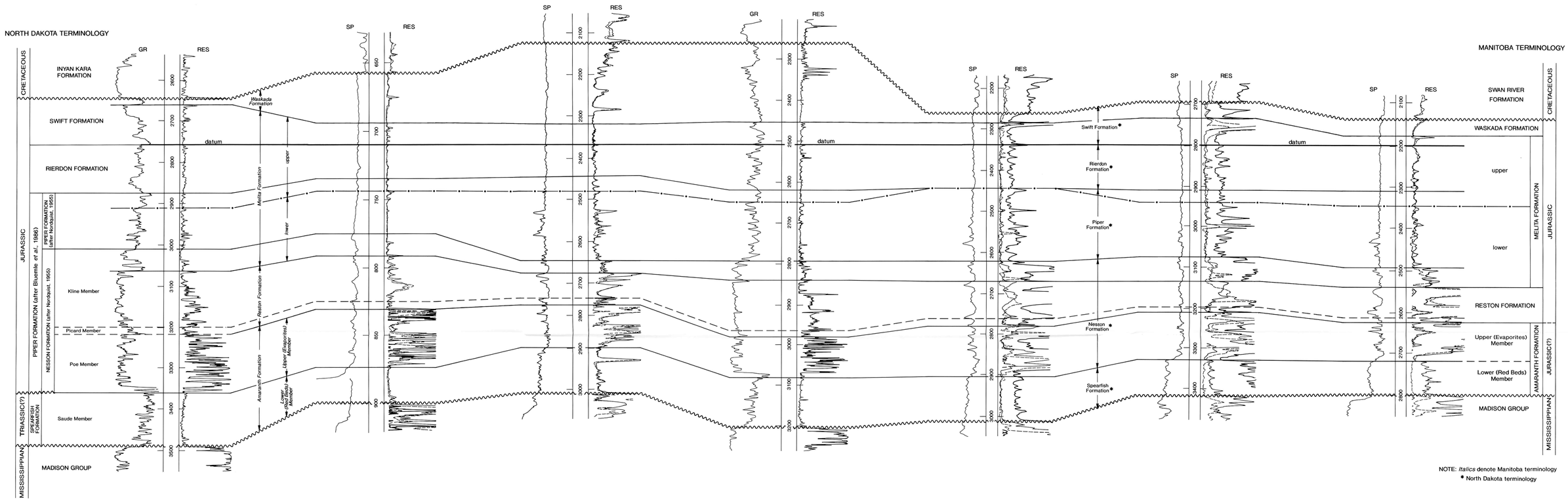

NOTE: *Italics* denote Manitoba terminology
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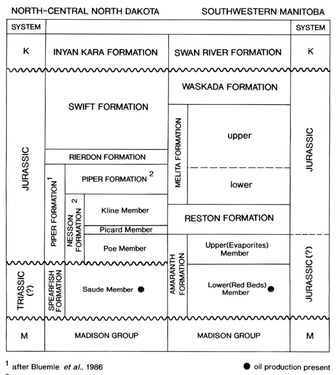
STRATIGRAPHIC NOMENCLATURE CHART



[1] after Bluemle *et al.*, 1986
[2] after Nordquist, 1955

● oil production present

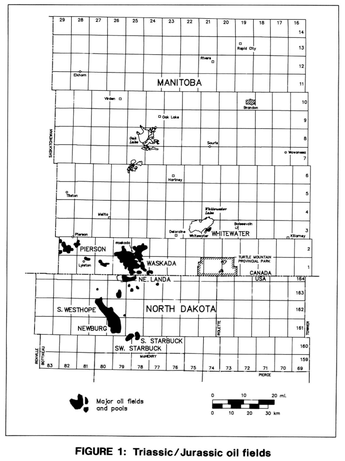


FIGURE 1: Triassic/Jurassic oil fields

STRATIGRAPHY

Spearfish Formation (North Dakota)

The Spearfish Formation (Triassic (?)) occurs in the subsurface in over half of North Dakota and attains its maximum thickness of 218 m (715 ft) in the southwestern corner of the state. The formation consists of three members that in ascending order are, the Belfield, Pine Salt and Saude members.

The Belfield Member conformably overlies the Minnekahta Formation and does not extend beyond the Minnekahta depositional limit (Dow, 1967). The Belfield Member varies in thickness from an erosional edge to a maximum of 71 m (232 ft). It consists of fissile, grey shale interbedded with reddish-orange siltstone and mudstone. Thin beds of white and pink anhydrite are locally present. Traces of pyrite and pink dolomite have also been noted. The Belfield Member is conformably overlain by either the Pine Salt or Saude members.

A maximum thickness of 66 m (215 ft) is attained by the Pine Salt Member (Dow, 1967). It consists of clear halite with thin interbeds of reddish-orange siltstone and white anhydrite, and represents a period of restricted marine conditions. The Pine Member extends beyond the underlying Belfield Member and rests in angular discordance on the pre-Spearfish unconformity.

The Saude Member conformably overlies the Pine Salt Member. Referred to as the upper red mudstone unit, it reaches a maximum thickness of 107 m (350 ft). The Saude Member consists predominantly of reddish-orange siltstones and fine-grained sandstones commonly interbedded with anhydrite (Dow, 1967). Reddish-brown and grey siltstone and shale lenses are locally present. Frosted sand grains are scattered throughout the siltstone. The Saude Member extends beyond the Pine Salt Member to rest unconformably on progressively older Paleozoic rocks.

Individual beds of the Saude Member exhibit an onlapping relationship along the unconformity surface in the north-central portion of North Dakota. This is reflected in the thickness of the member. In this area, a local, 3 to 12 m (10 to 40 ft) thick, very fine-grained sandstone with interbeds of greenish-grey siltstone and reddish-brown shale known as the "Spearfish pay" is developed (Marafi, 1972). A 6 to 8 m (20 to 25 ft) thick impermeable red shale, reddish-brown to grey siltstone, and lightly cemented sandstone onlaps the pay section and forms the vertical seal.

Amaranth Formation (Manitoba)

The Amaranth Formation (Jurassic (?)) rests with marked angular unconformity on Mississippian carbonates in southwestern Manitoba and oversteps progressively older Paleozoic strata to the north and east. It is overlain with slight disconformity by limestone of the Reston Formation.

The Amaranth Formation is divided into two members. The Lower (Red Beds) Member consists of interbedded, reddish-brown, dolomitic siltstones, shales and fine-grained sandstones (Stott, 1955). The Upper (Evaporites) Member conformably overlies the Lower Member and consists of massive, finely crystalline, bluish-white anhydrite with interbeds of greenish-grey to brown shale and buff dolostone. In southwestern Manitoba, the Lower and Upper members of the Amaranth Formation reach a maximum thickness of 46 and 51.8 m (151 and 170 ft), respectively (Stott, 1955).

The age assignment generally accepted for the Upper Member of the Amaranth Formation is Middle Jurassic. However, the age assignment of the Lower Member of the Amaranth Formation is in question due to the lack of fossil evidence. A Jurassic age has been assigned to the Lower Member in southwestern Manitoba. The contact between the Upper and Lower members of the Amaranth Formation is considered to be conformable in this area (Stott, 1955; McCabe, 1956).

The Lower Member is correlative with the Spearfish Formation of North Dakota and the Lower Watrous Formation of Saskatchewan. In North Dakota and Saskatchewan, a Triassic age has been assigned to these equivalent units (see Stratigraphic Nomenclature Chart).

Nesson and Piper Formations (North Dakota)
(after Nordquist, 1955)

Nordquist (1955) examined the Jurassic strata that lie between the Spearfish and Rierdon formations and divided this strata into two formations, the Nesson and Piper. The Nesson formation is defined as the strata that overlies the Spearfish Formation and underlies the Piper Formation. These strata are present only in the subsurface of the Williston basin. Three members comprise the Nesson Formation; in ascending order, they are, the Poe, Picard, and Kline (see Stratigraphic Nomenclature Chart). The Piper Formation is the name given to describe the strata above the Nesson Formation and below the Rierdon Formation. It is divided, in ascending order, into three members, the Tampico Shale, Firemoon Limestone and Bowes.

Nesson Formation
(after Norquist, 1955)

The Nesson Formation is a sequence of carbonates and evaporites that overlie the Spearfish Formation (Triassic (?)) and underlie the Piper Formation (Jurassic). The formation is recognizable only in the subsurface and comprises the Poe, Picard, and Kline members.

Faunal evidence for the formation is limited. Therefore, the Nesson Formation is considered to be Jurassic in age based on its stratigraphic position. A pronounced unconformity separates the Nesson Formation from the underlying Spearfish Formation. The Nesson Formation is lithologically similar and probably genetically related to the overlying Middle Jurassic Piper Formation.

The basal member of the Nesson Formation is the Poe Member. It unconformably overlies the Spearfish Formation. This contact is locally marked by a conglomeratic bed. The Poe Member consists of a sequence of evaporites thought to represent earliest Jurassic deposition. It is stratigraphically equivalent to the Upper Member of the Amaranth Formation of Manitoba.

At its type section in McKenzie County, the Poe Member consists of a 20 m (65 ft) thick bed of massive salt. The salt, referred to as the Dunham salt, is restricted to the central portion of the Williston basin (Anderson, 1964). It is overlain by 16 m (53 ft) of white to pink gypsum, anhydrite, and dark red shale with thin interbeds of grey, dense dolostone. The top of the sequence is marked by a thin bed of buff to brown, very finely crystalline to earthy limestone. The Poe Member varies lithologically across the Williston basin. To the east it consists of a massive anhydrite, and to the west, it is characterized by interbedded red shales and claystones.

The Picard is the middle member of the Nesson Formation and conformably overlies the Poe Member. At its type section in Roosevelt County, Montana, the Picard Member is 12 m (40 ft) thick and consists of dark red shale that is slightly silty in part. The lower part commonly contains masses, or thin interbeds of white earthy gypsum. The colour of the member varies locally from red to dark grey to green.

The uppermost member of the Nesson Formation is the Kline Member. This member is predominantly carbonate, consisting of a lower limestone and an upper dolostone sequence. Four units are present at its type section in Ward County, North Dakota. These include, in ascending order: a 19 m (63 ft) thick bed of light grey to buff coloured, fine to medium crystalline limestone that is gypsiferous and fossiliferous in part; a 11 m (37 ft) thick bed of light to dark brown, finely crystalline limestone that is oolitic in part and shaly toward the base; a 4 m (13 ft) thick bed of grey-green calcareous shale containing white gypsum crystals; and, a 10 m (34 ft) thick bed of light grey to white, earthy dolostone and fine-grained sandstone. The Kline Member is present only in the subsurface.

Piper Formation
(after Nordquist, 1955)

A sequence of Middle Jurassic red beds, gypsum, and normal marine beds underlying the Rierdon Formation compose the Piper Formation. The formation consists of three members, the Tampico Shale, Firemoon Limestone, and Bowes.

The lowermost member of the Piper Formation is the Tampico Shale. At its type section in Valley County, Montana, the Tampico Shale Member consists of 26 m (86 ft) of grey-green calcareous shale that is slightly silty in the middle of the section. Large amounts of interbedded red shale are present locally. Also present are a few thin beds of dense, buff to brown limestone, gypsum, and white calcareous sandstone. The member conformably overlies the Nesson Formation.

The Firemoon Limestone Member, also referred to as the "Piper Limestone," is the middle member of the Piper Formation. It consists of buff to brown, dense to earthy limestone at its type section in Valley County, Montana and is 21 m (69 ft) thick. Locally the limestone is sandy and oolitic or dolomitic and cherty. East of the Nesson anticline, the limestone becomes silty and interbedded with shale. It is conformable with the underlying Tampico Shale Member.

The Bowes Member, the uppermost member of the Piper Formation, comprises red to varicoloured shales in the Williston basin. It grades westward into a sandstone and sandy oolitic limestone. At its type section in Blaine County, Montana, the Bowes Member is 17 m (57 ft) thick. In ascending order, it consists of four units: a light grey, sandy and oolitic limestone that grades upward into a light brown, fine-grained calcareous sandstone; a light grey, oolitic to sandy limestone with thin beds of light grey calcareous sandstone; a light grey, fine- to coarse-grained, very calcareous sandstone with rounded limestone and quartz grains; and, a light brown, finely crystalline to fragmental limestone that is very sandy to argillaceous in part. The member is conformable with the underlying Firemoon Limestone.

Piper Formation (North Dakota)
(after Bluemle, et al., 1986)

Following the work of Nordquist (1955), Bluemle *et al.* (1986) redefined the sequence of strata above the Spearfish formation and below the Rierdon Formation in North Dakota as the Piper Formation (see Stratigraphic Nomenclature Chart).

The Piper Formation (Jurassic) as defined by Bluemle *et al.* (1986) in North Dakota represents a sequence of white to buff, brown or grey, dense, finely crystalline limestones, red, grey-green, and purple, slightly silty shales, gypsum, and anhydrites. The limestones can be oolitic, dolomitic, and fossiliferous. Bluemle *et al.* (1986) includes seven members within the Piper Formation; these are, in ascending order, the Dunham Salt, Poe, Picard, Kline, Tampico Shale, Firemoon Limestone, and Bowes members. The sequence reaches a maximum thickness of 191 m (625 ft) and is equivalent to the Upper Member of the Amaranth Formation, the Reston Formation, and the lower unit of the Melita Formation of Manitoba.

Reston Formation (Manitoba)

The Reston Formation consists of an interbedded sequence of dark grey to greenish-grey, locally reddish- to yellowish-brown shales and light buff to white, slightly dolomitic, argillaceous, partly sandy limestones. The limestone beds are more common towards the top of the unit, which is marked by an oolitic, sandy zone. Anhydrite and gypsum are present locally.

The Reston Formation conformably overlies the evaporites of the Amaranth Formation throughout most of southwestern Manitoba, except north of the Virden area (approximately Township 12), where it rests unconformably on the carbonates of the Lodgepole Formation (Mississippian). The Reston is overlain with slight disconformity by sandstones and shales of the Melita Formation. The thickness of the Reston Formation ranges approximately from zero to 46 m (151 ft) in southwestern Manitoba (Stott, 1955).

Melita Formation (Manitoba)

The Melita Formation is underlain with slight disconformity by the oolitic and argillaceous limestones of the Reston Formation. North of Township 20, the Melita Formation oversteps the Reston Formation to rest unconformably on Mississippian and Upper Devonian strata. The Melita Formation is conformably overlain by the Waskada Formation, south of Township 12. North of Township 12, the Melita is overlain unconformably by either the Swan River Formation or the Ashville Formation, both Cretaceous in age (Canadian Society of Petroleum Geologists, 1990).

The Melita Formation is subdivided into two units. The lower unit comprises a basal fine-grained sandstone, overlain by beds of varicoloured shales and thin interbeds of sandstone. The upper unit consists of greenish-grey to brownish-grey, slightly calcareous, silty shales. Interbeds of light grey, dense, variably fossiliferous limestones occur in the upper part of the unit (Bannatyne, 1970; Stott, 1955). The maximum thickness of the Melita Formation in southwestern Manitoba is approximately 143 m (469 ft) (Canadian Society of Petroleum Geologists, 1990).

Rierdon Formation (North Dakota)

The Rierdon Formation is a 30 m (100 ft) sequence of varicoloured shales that conformably overlie the Piper Formation. It is conformably overlain by the Swift Formation in the central portion of the Williston basin, but this contact is unconformable along the flanks of the basin (Francis, 1957). The Rierdon Formation has a notable wireline log characteristic in comparison to the Swift Formation. This log characteristic is referred to as the "Rierdon shoulder."

Lithologically, the Rierdon Formation consists of grey to green to red, calcareous shales with thin beds of limestone (Francis, 1957; Peterson, 1957; Bluemle *et al.*, 1986). The formation grades eastward in North Dakota into sandstone and becomes difficult to distinguish from the overlying Swift Formation. The shales also become less calcareous to the east.

Swift Formation (North Dakota)

The Swift Formation in the Williston basin consists of three informal members, a lower shale, a middle sandstone, and an upper shale (Francis, 1957). The formation attains a maximum thickness in North Dakota of 152 m (500 ft) (Bluemle *et al.*, 1986). The Inyan Kara Formation (Cretaceous) of the Dakota Group unconformably overlies the Swift Formation.

The lower shale member consists of a greenish-grey, splintery, slightly silty, slightly calcareous to noncalcareous shales (Francis, 1957). The shales become interbedded with siltstones to the east. Brown to yellowish shales also occur at the base of the member. The middle member is a fine-grained, calcareous sandstone. It consists primarily of clear quartz grains that are fairly well sorted and angular to subrounded. Glauconite is common, but is not present everywhere. Minor beds of greenish-grey calcareous to noncalcareous shale are common. The upper member consists of greenish-grey and light grey, generally calcareous shale.

Waskada Formation (Manitoba)

The Waskada Formation is conformably underlain by the Melita Formation. It is unconformably overlain by the Swan River Formation (Cretaceous), except along the northern edge where strata of the Swan River pinch out and the Waskada beds are overlain by the Cretaceous Ashville Formation (Canadian Society of Petroleum Geologists, 1990).

The Waskada Formation consists predominantly of varicoloured shale. Green, bentonitic shales and thin beds of white, very fine- to fine-grained, calcareous, pyritic and glauconitic sandstones are common throughout the formation. Minor beds of grey to black, slightly carbonaceous shales and trace red shales and ironstones are also present within the unit (Bannatyne, 1970; Stott, 1955).

The Waskada Formation occurs as an erosional wedge, extending as far north as the Virden area (Township 12). It attains a maximum thickness in southwestern Manitoba of approximately 53 m (174 ft) (Canadian Society of Petroleum Geologists, 1990).

PETROLEUM POTENTIAL

The Spearfish Formation is productive in several fields in north-central North Dakota (Fig. 1). Newburg and South Westhope fields are the most prominent. Production from these fields is from a combined structural/stratigraphic trap. In the Newburg/South Westhope area, a basal sandstone bed of the Spearfish Formation onlaps productive Mississippian Madison Group strata. The sandstone bed is, in turn, onlapped by impermeable red shales, green siltstones and cemented sandstones that form vertical and lateral seals. This sequence is located on the updip flank of a syncline formed by the dissolution of the Devonian Prairie Formation salt section.

The Spearfish Formation also produces east of the Newburg/South Westhope area. Production is from beds that are stratigraphically higher than those productive in Newburg/South Westhope. These beds are part of an interbedded sequence of sandstones and shales that progressively overstep the underlying Paleozoic erosional surface to rest unconformably on productive Mississippian strata. Production from the sanstone beds is believed to be Mississippian sourced.

The Amaranth Formation is the only productive zone within the Jurassic sequence of southwestern Manitoba. Production is obtained from a lower sandy interval of the Lower Member of the Amaranth Formation. The most prospective areas occur where this sandy interval overlies productive portions of Mississippian strata that have been truncated at the Paleozoic erosion surface. It is believed that the oil produced from the Lower Member of the Amaranth Formation is sourced by the Mississippian (Barchyn, 1982).

The majority of production from the Amaranth Formation in southwestern Manitoba is obtained from the Waskada Field, a field which also produces oil from Mississippian strata. Production in the Pierson and Coulter fields (Fig. 1) is also obtained from the Amaranth Formation.

REFERENCES

Anderson, S.B.
1964: Salt deposits in North Dakota, in Tufte, O. (ed.), Mineral Resources of North Dakota: Grand Forks, North Dakota, University of North Dakota, p. 60-79.

Bannatyne, B.B.
1970: The clays and shales of Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 67-1, 107 p.

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 82-6, 30 p.

Bluemle, J.P., Anderson, S.B., Andrew, J.A., Fischer, D.W., and LeFever, J.A.
1986: North Dakota stratigraphic column: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 66, 3 sheets.

Canadian Society of Petroleum Geologists
1990: Lexicon of Canadian stratigraphy, volume 4, western Canada including eastern British Columbia, Alberta, Saskatchewan and southern Manitoba: Calgary, Alberta, Canadian Society of Petroleum Geologists, 772 p.

Dow, W.G.
1967: The Spearfish Formation in the Williston basin of western North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Bulletin No. 52, 28 p..

Francis, D.R.
1957: Jurassic stratigraphy of the Williston basin area: American Association of Petroleum Geologists Bulletin, v. 41, p. 367-398.

Hansen, B.J.
1987: Sedimentology and reservoir portential of the Lower Amaranth Member, southwestern Manitoba: Master's thesis, University of Manitoba, Winnipeg, Manitoba, 179 p.

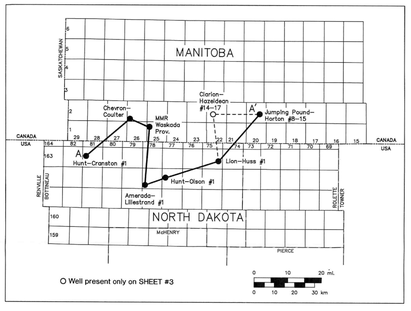
Marafi, H.
1972: Newburg-South Westhope oil fields, North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 47, p. 633-640.

McCabe, H.R.
1956: Lyleton and Amaranth red beds in southwestern Manitoba: Master's thesis, University of Manitoba, Winnipeg, Manitoba, 133 p.

Nordquist, J.W.
1955: Pre-Rierdon Jurassic stratigraphy in northern Montana and Williston basin, in Lewis, P.J. (ed.), Sweetgrass area-disturbed belt Wyoming, Billings Geological Society Guidebook, 6th Annual Field Conference: Billings, Montana, Billings Geological Society, p. 96-106.

Peterson, J.A.
1957: Marine Jurassic of northern Rocky Mountains and Williston basin: American Association of Petroleum Geologists, v. 41, p. 399-440.

Stott, D.F.
1955: Jurassic stratigraphy of Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 54-2, 78 p.



LINE OF CROSS–SECTION

METRIC CONVERSION TABLE	
1 metre (m)	= 3.28 feet (ft)
1 cubic metre (m^3)	= 6.29 barrels (bbls) (oil) = 220 imperial gallons = 35.49 cubic feet (gas)
1 hectare (ha)	= 2.47 acres
1 kilometre (km)	= 0.62 miles (mi)

SHEET # 2 : TRIASSIC/JURASSIC

CORRELATION CROSS–SECTIONS ALONG THE UNITED STATES–CANADA INTERNATIONAL BORDER (NORTH DAKOTA–MANITOBA)

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December, 1991

NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 92

MANITOBA ENERGY AND MINES
PETROLEUM OPEN-FILE REPORT POF 12-91

A

LAMAR HUNT – WILLIAM CRANSTON #1
NENW Sec.8, T.163N., R.81W.
KB: 1518' (462.7m)

CHEVRON STANDARD LTD.
–CHEVRON COULTER
9–6–2–26 WPM
KB: 440m (1443.6')

MANITOBA MINERAL RESOURCES
–MMR WASKADA PROV.
11–29–1–25 WPM
KB: 1555.5' (474.1m)

AMERADA PETROLEUM – LILLESTRAND #1
SESW Sec.31, T.162N., R.78W.
KB: 1486' (452.9m)

HUNT OIL – OLSON #1
SWNW Sec.18, T.163N., R.77W.
KB: 1520' (463.3m)

LION OIL CO. – G. A. HUSS #1
NWNW Sec.23, T.163N., R.75W.
KB: 2205' (672.1m)

CLARION PETROLEUM LTD.
– CLARION *et al.* HAZELDEAN #14–17
14–17–2–22 WPM
KB: 575.6m (1888.5')

JUMPING POUND PETROLEUM
– JUMPING POUND HIGH CREST
PROSPECT *et al.* HORTON #8–15
8–15–2–20 WPM
KB: 1913' (583.1m)

A′

NORTH DAKOTA TERMINOLOGY

MANITOBA TERMINOLOGY

PIPER FORMATION

Saude Member

Frobisher – Alida interval

Tilston interval

Bottineau interval

Flaxton Member

Upper (Evaporites) Member

Lower (Red Beds) Member

Scallion Member

Routledge Shale facies

THREE FORKS (LYLETON′) FORMATION

′ Former Manitoba terminology

NOTE: *Italics* denote Manitoba terminology
* North Dakota terminology

CORE #1: 900.0–917.8m (2952.8–3011.0')
DST #1: 916–930m (3005.2–3051.0')
Rec. 230m (754.6') saltwater

CORE #2: 3014–3074' (918.7–937.0m)

DST #1: 3129–3203' (953.7–978.1m)
Rec. 2.37 bbls (0.28m³) drilling mud
2.93 bbls (0.35m³) water

CORE #1: 3093–3148' (943–960m)
CORE #2: 3148–3165' (960–965m)
CORE #3: 3185–3231' (971–985m)
CORE #4: 3240–3289' (987.8–1002.7m)

DST #1: 3552–3580' (1082.6–1091.2m)
Rec. 270' (82.3m) gas in pipe
90' (27.4m) oil
180' (54.9m) gas and oil cut mud
829' (252.7m) slightly oil and gas cut saltwater

CORE #1: 3398.0–3414.5' (1035.7–1040.7m)
CORE #2: 3414.5–3450.0' (1040.7–1051.6m)

DST #1: 3373.0–3414.5' (1028.1–1040.7m)
Rec. 30' (9.1m) gas cut and slightly oil cut mud
50' (15.2m) gas cut and moderately oil cut mud

CORE #1: 951–964m (3120.0–3162.7')

DST #1: 912–918m (2992.0–3011.8')
Rec. 18m (59.1') muddy saltwater
501m (1643.7') saltwater

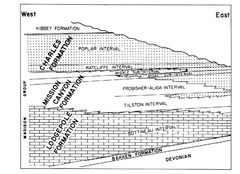


FIGURE 1: Generalized cross–section of Mississippian rocks in the Williston basin showing relationship of facies and stratigraphic nomenclature. (Reprinted by permission from Gerhard *et al.*,1982).

SELECTED DETAILED REFERENCE WELLS

SOUTHWESTERN MANITOBA

Canadian Superior Cruickshank #14–4
14–4–10–28 WPM
KB: 1660' (506m)

Clarion Petroleum Ltd. – Clarion *et al.* Hazeldean #14–17
14–17–2–22 WPM
KB: 575.6m (1888.5')

AMARANTH FORMATION

(upper Lodgepole)

Daly Member

Cruickshank Shale facies

Cruickshank Crinoidal facies

Cromer Shale facies

Basal Limestone facies

BAKKEN FORMATION

Flaxton Member

Flaxton Lake Member

Whitewater Lake Member

Virden Member

Scallion Member (cherty)

THREE FORKS (LYLETON′) FORMATION

′ Former Manitoba terminology

Daly Field terminology – (after Organ and Russin, 1955)

NORTH–CENTRAL NORTH DAKOTA

Cardinal Drilling Co. – B. M. Keeler #1
NWNW Sec.1, T.159N., R.82W.
KB: 1536' (468.2m)

SPEARFISH FORMATION

Berentson beds

Midale anhydrite

Midale subinterval

Rival subinterval

Bluell beds

Sherwood beds

Mohall beds

Glenburn beds

Ratcliffe interval

Frobisher–Alida interval

Slate "A" marker

K1 marker

K2 marker

MC-2

x–salt

CHARLES FORMATION

MADISON GROUP

MISSISSIPPIAN

TRIASSIC (?)

STRATIGRAPHY

Bakken Formation

The Bakken Formation (Devonian and Mississippian) consists of three members, a lower and an upper black to brownish-black to dark grey, fissile, radioactive, non-calcareous, organic-rich shale and a middle member comprising very fine- to medium-grained, argillaceous, dolomitic sandstone to calcareous siltstone. The members are considered to be formal only in Manitoba.

In the central portion of the basin the formation is conformable with the underlying Three Forks Formation (Devonian). It forms an angular unconformity with the Three Forks Formation (Lyleton′) along the margin of the Williston basin in North Dakota and throughout most of Manitoba. The Bakken Formation is conformably overlain by the Lodgepole Formation of the Madison Group.

A maximum thickness of 44 m (145 ft) is attained by the formation in the central portion of the basin. Local variations in thickness in the north-central portion of North Dakota and southwestern Manitoba are probably due to the dissolution of Devonian salt. The three members of the Bakken Formation thin and onlap towards the margins or marginal shelf areas of the Williston basin. In Manitoba, the lower member is absent except for a local area in the vicinity of Waskada field (Townships 1 to 3 and Ranges 25 to 26 WPM). This occurrence is believed to be associated with dissolution and collapse of the Devonian Prairie salt section.

The Bakken Formation represents deposits formed during the initial transgression of Mississippian seas. A stratification of the offshore marine environment is responsible for anoxic bottom conditions and the deep, basinal deposition of the lower and upper Bakken shales. Deposition of the middle member marks a return to normal, shallow marine to nearshore marine conditions.

MADISON GROUP

The Mississippian Madison Group includes 610 m (2000 ft) of strata in the central portion of the Williston basin. It consists of three formations, in ascending order, the Lodgepole, Mission Canyon, and Charles formations. All three are conformable in the basin center and exhibit a complex intertonguing relationship towards the basin margin (Fig. 1). The facies transitions between the evaporite and carbonates of the sequence occur at progressively lower stratigraphic horizons towards the eastern flank of the basin. The Charles-Mission Canyon formations contact is placed at the base of the lowest evaporite; the Mission Canyon-Lodgepole formations contact is placed at the base of the lowest known occurrence of oolites, as shown on cross-section A-A′.

Recognition of facies changes across the basin has led to the use of marker horizons to delineate informal units within the Madison Group strata on the east flank of the basin. In North Dakota, the Madison Group has been subdivided, in ascending order, into five recognizable marker-defined intervals, the Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar (Carlson and LeFever, 1987). The Frobisher-Alida interval is further subdivided along the margin of the basin in North Dakota, into a series of informal porosity ("pay") zones that are, in ascending order, the Landa, Wayne, Glenburn, Mohall, Sherwood, Bluell, Coteau, and Dale beds and Rival subinterval (see detailed reference well, NWNW Sec.1, T.159N., R.82W.)(Voldseth, 1987). The Ratcliffe interval is also subdivided into the Midale subinterval, the Midale anhydrite, and the Berentson beds.

In southwestern Manitoba, stratigraphic subdivisions of the Lodgepole, Mission Canyon and Charles formations sequences adhere to the "formation" system of nomenclature, rather than the marker-defined or "bed" system of nomenclature employed in North Dakota. In the following discussion, the formal unit names Lodgepole, Mission Canyon, and Charles formations, are retained to describe and compare Madison Group strata in Manitoba and North Dakota.

Lodgepole Formation

The Lodgepole Formation conformably overlies the Bakken Formation in the central portion of the basin and unconformably overlies Devonian strata along the margin. It reaches a maximum thickness of 274 m (900 ft) and represents the maximum transgression of the Mississippian seas. In North Dakota, the formation consists of dense, dark grey to brownish-grey limestones and calcareous shales with mino amounts of chert and anhydrite. Components include crinoids, ostracods, brachiopods, pelets, and oolites in varying abundance. Clastic content is highly variable in the middle and upper Lodgepole Formation rocks.

Lower Lodgepole Formation rocks are represented by five facies in North Dakota (Heck, 1979). Environments of deposition for these facies are central basin, basin slope, open shelf, at or near shelf break, and a lagoonal environment. A marine regression, which began during middle Lodgepole Formation sedimentation, resulted in the basinward progradation of the marginal facies. Middle and upper Lodgepole Formation rocks are represented by three different facies. Depositional environments of these three facies include shallow open shelf, shoals, and shoreward of the shoals. In Manitoba, the Lodgepole Formation is a repetitive sequence of shale and oolitic-crinoidal limestones.

The terminology proposed by Stanton (1958) is used to subdivide the Lodgepole Formation throughout most of Manitoba (see detailed reference well; 14-17-2-22 WPM). The thickness of the Lodgepole Formation in Manitoba ranges from 146 to 176 m (479 to 577 ft). It is subdivided, in ascending order, into the Scallion, Virden, Whitewater Lake, and Flossie Lake (formerly unnamed) members. The Scallion Member corresponds in field usage to the "cherty" and consists of white to medium grey, cherty, red to pink, microcrystalline to sucrosic, cherty to siliceous, dense to chalky limestone to argillaceous limestone. The Routledge Shale facies, a black, fissile, calcareous shale, is the basinal equivalent of the Scallion Member. It occurs locally at the base of the Scallion Member and is limited to two lobe-shaped bodies, one at the Virden field (Townships 9 to 12 and Ranges 29 to 26 WPM), and another at the Lulu Lake field (Townships 1 to 3 and Ranges 19 to 21 WPM). The shale is correlative with an equivalent unit in eastern North Dakota, known as the Carrington shale facies (Bjorlie and Anderson, 1978).

The Virden Member overlies the Scallion Member and is divided into a lower and upper unit. The lower unit corresponds to the "oolite" of field usage, and consists of interbedded oolitic and/or bioclastic (lentils) and argillaceous limestone. The lower unit is subdivided into a sequence of these lenticles, referred to, in ascending order, as the Fourth, Third, Second, and First Oolite, and the Sandhill. The upper unit corresponds to the "crinoidal" of field usage, and consists primarily of crinoidal limestone.

The Whitewater Lake Member overlies the Virden Member and is divided into a lower unit comprising an interbedded oolitic to bioclastic limestone and argillaceous limestone, and an upper unit comprising an oolitic to bioclastic limestone. The argillaceous limestones of the Flossie Lake Member overlie the Virden Member (McCabe, 1963).

In the vicinity of the Daly field (Townships 8 to 10 and Ranges 27 to 29 WPM) of southwestern Manitoba, another subdivision of the Lodgepole Formation, defined by Organ and Russin (1956), is still used locally to define the stratigraphy in this area (see detailed reference well; 14-4-10-28 WPM). Organ and Russin (1956) subdivided the Lodgepole Formation, in ascending order, into the Basal Limestone facies, Cromer Shale facies, Cruickshank Crinoidal facies, Cruickshank Shale facies, Daly Member, and unnamed Upper Lodgepole.

The Basal Limestone facies consists of slightly argillaceous, cherty limestone. It is overlain by the Cromer Shale facies that consists of mottled grey to purple, finely crystalline, granular to finely fragmental, slightly argillaceous limestone or calcareous shale. The Cruickshank Crinoidal facies overlies the Cromer Shale facies and consists primarily of medium- to coarse-grained crinoidal limestone. The Cruickshank Crinoidal facies is overlain by the Cruickshank Shale facies comprised of maroon to greenish-grey, finely crystalline, argillaceous limestone, containing abundant scattered crinoid fragments. The Cruickshank Shale facies is overlain by the Daly Member. The Daly Member consists of a lower unit, composed of purplish-grey and brown, medium- to coarse-grained, argillaceous, crinoidal limestone, a middle unit, composed of purplish-grey, microcrystalline, siliceous limestone, and an upper unit, composed of grey, microcrystalline, dolomitized limestone with abundant nodular chert. The Daly Member is overlain by the buff to pinkish, microcrystalline dolostone with anhydrite bands, scattered crinoid fragments, and abundant nodular chert of the upper Lodgepole Formation.

The Cromer Shale facies grades laterally to the nonargillaceous cherty limestone of the Scallion Member. The Basal Limestone facies, Cromer Shale facies, and Cruickshank Crinoidal facies are collectively correlative with the Scallion Member. The Cruickshank Shale facies and the Daly Member change laterally from a predominantly fine-grained crinoidal limestone and shale sequence to the cyclically interbedded oolitic limestone-shale-crinoidal limestone sequence characteristic of the Virden and Whitewater Lake members. The Cruickshank Shale facies is correlative with the Virden Member. The Daly Member is correlative with the Whitewater Lake Member (McCabe, 1963).

Mission Canyon Formation

The Mission Canyon Formation consists of brownish-grey to light yellowish-grey limestone. Locally, the limestone has been partially or completely dolomitized. Overall, deposition of the Mission Canyon Formation carbonates occurred during a regression. The sequence reflects a decrease in water depth of Mississippian seas, relatively stable tectonics, and a decrease, or lack of detrital input into the Williston basin, which was most pronounced along the shelf areas in North Dakota and Manitoba. Depositional environments of the Mission Canyon Formation consisted of a repeated sequence of barrier island/open marine shoreline buildup complexes with evaporites shoreward and marine environments basinward (McCabe, 1959; Lindsay, 1988). The offshore barrier shoals, which developed during periods of low sea-level, resulted in the formation of marginal ringing lagoons. Along the southern margin a single shoaling-upward sequence can be recognized. Along the eastern basin margin multiple shoaling events are documented.

The Mission Canyon and Charles formations, in Manitoba, represent the beginning of a complex cyclical sequence of interbedded carbonates and evaporites. Much of this sequence was removed during pre-Jurassic erosion and, as a result, only the lowest part of this sequence is preserved. The Mission Canyon Formation, as defined by McCabe (1959), consists predominantly of fragmental carbonates that overlie the argillaceous carbonates of the Lodgepole Formation and underlie the evaporitic beds of the Charles Formation.

The formation is subdivided, in ascending order, into three members, the MC-1, MC-2, and MC-3. The thickness of the Mission Canyon Formation in Manitoba ranges approximately from 82 to 98 m (269 to 322 ft). The MC-1 Member consists of crinoidal-fragmental and oolitic limestones and dolomitic limestones and dolostones.

The overlying MC-2 Member is defined as the first, or lowest evaporite-shale member of the Mission Canyon Formation (Thomas, 1954). The MC-2 Member includes the evaporites and shaly carbonates found above and below a thin interbed of dense to earthy, argillaceous dolostone, referred to as the MC-2 marker (McCabe, 1959). The MC-3 Member consists predominantly of fragmental limestone, with some dolomitic limestone, medium saccharoidal dolostone and earthy limestone. This member is further subdivided into two porous zones: a lower unit, referred to as the MC-3a; and, an upper unit, referred to as the MC-3b. These units are separated by an argillaceous bed designated as the MC-3 marker. This marker bed undergoes a facies change to become the primary evaporite unit known locally as the Dando Evaporite. The Dando Evaporite is a local remnant of a westward-extending, basin margin evaporite and is limited to the Waskada area of Manitoba (Townships 1 to 3 and Ranges 25 to 26 WPM)(McCabe, 1959).

Charles Formation

The Charles Formation is predominantly comprised of evaporites with minor amounts of interbedded limestones, shales and sandstone tongues. It was deposited in a restricted environment during the latest stage of a regressive event. In Manitoba, the maximum thickness of the Charles Formation is approximately 37 m (121 ft) (McCabe, 1971).

PETROLEUM POTENTIAL

Bakken Formation production in North Dakota occurs along the depositional limit in the southwestern portion of the state and the Nesson anticline where it is considered to be a thermally mature source rock (at depths 2743+ m (9000+ ft)) (Webster, 1984). Production is from a fracture porosity that is related to overpressuring due to hydrocarbon generation. This fracture porosity is enhanced by regional fracture systems.

Production from the Bakken Formation in Manitoba is located a considerable distance from the area where it is considered to be thermally mature and is restricted to Daly field, where it produces from the Middle Member. Presently, this is the stratigraphically lowest oil production in southwestern Manitoba. Oil accumulation from the Bakken Formation in the Daly field is primarily controlled by stratigraphic traps created by the lateral pinch-out of the porous basal sandstone of the Middle Member against the dolomitic shale of the Three Forks (Lyleton′) Formation. It is trapped vertically by a tight sandstone.

The abundant accumulation of oil in the Madison Group along the northeastern flank of the Williston basin in southwestern Manitoba and north-central North Dakota may be attributed to two major factors. First, this is an area of significant lithologic and facies change, and second, extensive pre-Triassic(?)/Jurassic(?) erosion has truncated the most favorable reservoir facies of the basin flank or shelf edge of the Mississippian. These facies grade updip from excellent source beds of argillaceous, bituminous limestones to excellent reservoir beds of porous, algal-oolitic and fossiliferous limestones. The reservoir beds immediately below the red shale and evaporites of the overlying Triassic Spearfish (North Dakota)/Jurassic Amaranth (Manitoba) Formation are capped by a dense, impermeable zone of secondary anhydrite and dolostones.

In North Dakota, oil is produced from the three formations within the Madison Group. Production from the Lodgepole Formation is limited to four wells in northern Williams County. The shales and mud-rich limestones of the Lodgepole Formation are considered to be an important source rock for Madison oil. The Mission Canyon and the Charles formations are the most productive basinwide. Production is from a variety of trap types in different combinations including structural, stratigraphic, diagenetic, and sometimes hydrodynamic traps.

Major reservoirs occur within the porous, oolitic, and crinoidal carbonate facies of the Mississippian strata of southwestern Manitoba. Principal reservoirs have been defined within the Virden, Whitewater Lake, and Scallion members of the Lodgepole Formation, and the MC-1 and MC-3 members of the Mission Canyon Formation.

Oil accumulation within these beds occurs within truncation traps found at, or near the subcrop belts of these units. Stratigraphic traps play an important role in localizing oil accumulation; specifically, 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. Structural highs, paleotopographic highs or permeability barriers are also necessary for the localization of oil accumulation within these units. In some areas, local structural lows, possibly related to dissolution and collapse of the Devonian Prairie salt section, are important to oil accumulation.

In Manitoba, production from the Lodgepole Formation is concentrated along the subcrop belt 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 an equivalent of the Virden and Whitewater Lake members. The Waskada, Pierson, Tilston, and Coulter fields produce from the Mission Canyon Formation. The majority of the production is from the MC-3 beds (Fig. 2).

[1] Former Manitoba stratigraphic terminology

REFERENCES

Bjorlie, P.F., and Anderson, S.B.
1978: Stratigraphy and depositional setting of the Carrington Shale facies (Mississippian) of the Williston basin, In Estelle, D., and Miller, R. (eds.), The economic geology of the Williston Basin, 1978 Williston Basin Symposium: Billings, Montana, Montana Geological Society, p. 165-176.

Carlson, C.G., and LeFever, J.A.
1987: The Madison, a nomenclatural review with a look to the future, In Carlson, C.G., and Christopher, J.E. (eds.), Fifth International Williston Basin Symposium: Regina, Saskatchewan., Saskatchewan Geological Society, Special Publication No. 9, p. 77-82.

Gerhard, L.C., Anderson, S.B., LeFever, J.A., and Carlson, C.G.
1982: Geological development, origin, and energy mineral resources of the Williston basin: American Association of Petroleum Geologists Bulletin, v. 66, p. 989-1020.

Heck, T.J.
1979: Depositional environments and diagenesis of the Mississippian Bottineau interval (Lodgepole) in North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 227 p.

Lindsay, R.F.
1988: Mission Canyon Formation reservoir characteristics in North Dakota, In Goolsby, S.M., and Longman, M.W. (eds.), Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 317-346.

McCabe, H.R.
1959: Mississippian stratigraphy of Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 58-1, 99 p.
1963: Mississippian oil fields of southwestern Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 60-5, 50 p.
1971: Stratigraphy of Manitoba, an introduction and review, in Turnock, A.C. (ed.), Geoscience studies in Manitoba: Geological Association of Canada, Special Paper No. 9, p. 167-187.

Organ, D.W.E., and Russin, G.M.
1956: Mississippian stratigraphy of the Daly oil field: Oil in Canada, v. 8, no. 22, p. 40-47.

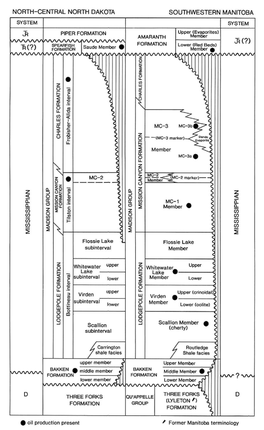
Stanton, M.S.
1958: Stratigraphy of the Lodgepole Formation, Virden-Whitewater area, Manitoba, In Goodman, A.G. (ed.), Jurassic and Carboniferous of Western Canada: Tulsa, Oklahoma, American Association of Petroleum Geologists, John Andrew Allan Memorial Volume, p. 372-390.

Thomas, G.E.
1954: The Mississippian of the northeastern Williston: Canadian Institute of Mining and Metallurgy Transactions, v. 57, p. 68-74.

Voldseth, N.E.
1987: Coteau and Dale intervals of the Mississippian Mission Canyon Formation; Flaxton field, Burke County, North Dakota, In Fischer, D.W. (ed.), Core Workshop Volume, Fifth International Williston Basin Symposium: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 69, p. 89-109.

Webster, R.W.
1984: Petroleum source rocks and stratigraphy of the Bakken Formation in North Dakota, In Woodward, J., Meissner, F.F., and Clayton, J.L. (eds.), Hydrocarbon source rocks of the greater Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 57-82.

STRATIGRAPHIC NOMENCLATURE CHART



O Well present only on SHEET #3

LINE OF CROSS–SECTION

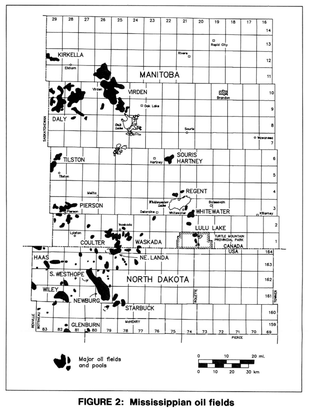


FIGURE 2: Mississippian oil fields

METRIC CONVERSION TABLE

1 metre (m)	= 3.28 feet (ft)
1 cubic metre (m³)	= 6.29 barrels (bbls) (oil) = 220 imperial gallons = 35.49 cubic feet (gas)
1 hectare (ha)	= 2.47 acres
1 kilometre (km)	= 0.62 miles (mi)

SHEET #3: **MISSISSIPPIAN**

CORRELATION CROSS–SECTIONS ALONG THE UNITED STATES–CANADA INTERNATIONAL BORDER (NORTH DAKOTA–MANITOBA)

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December, 1991

NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 92

MANITOBA ENERGY AND MINES
PETROLEUM OPEN–FILE REPORT POF 12–91

A

NORTH DAKOTA TERMINOLOGY

LAMAR HUNT – WILLIAM CRANSTON #1
NENW Sec.8, T.163N., R.81W.
KB: 1518' (462.7m)

CHEVRON STANDARD LTD.
– CHEVRON COULTER
9–6–2–26 WPM
KB: 440m (1443.6')

MANITOBA MINERAL RESOURCES
– MMR WASKADA PROV.
11–29–1–25 WPM
KB: 1555.5' (474.1m)

AMERADA PETROLEUM – LILLESTRAND #1
SESW Sec.31, T.162N., R.78W.
KB: 1486' (452.9m)

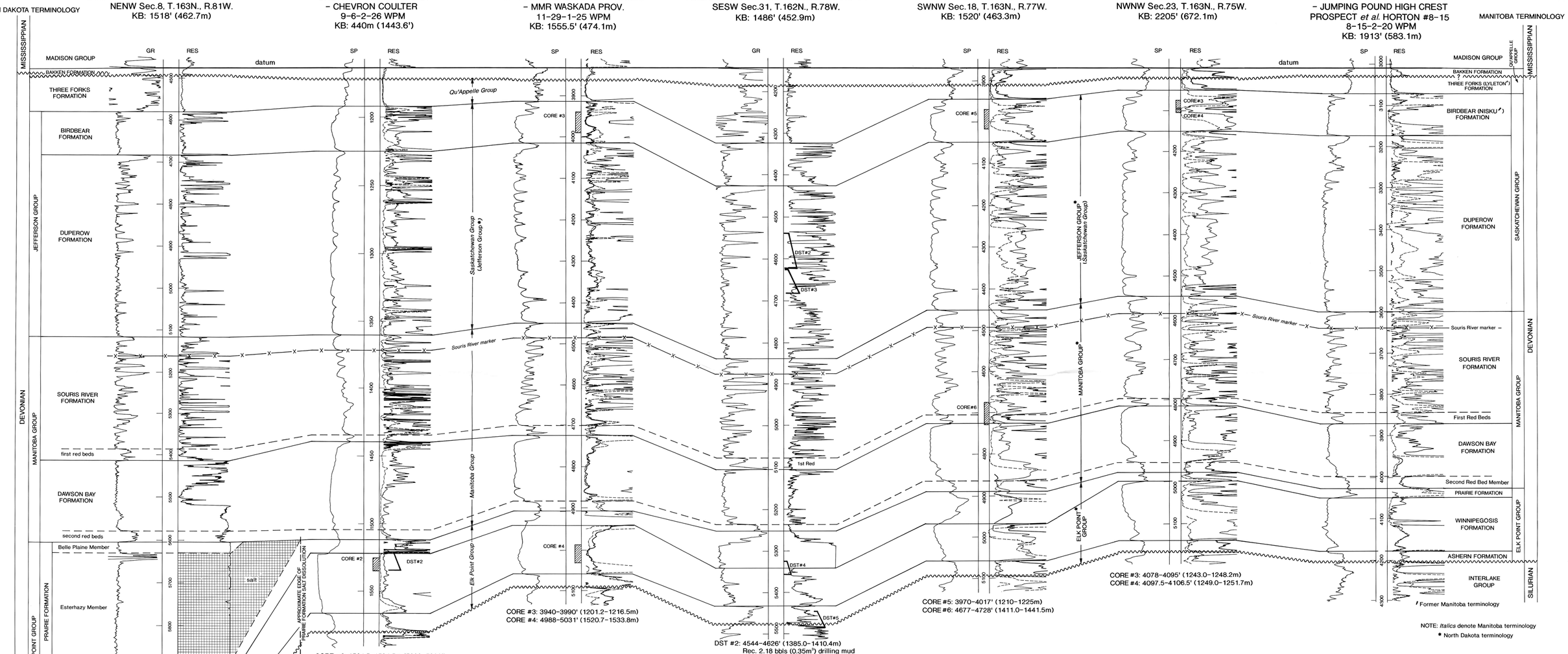
HUNT OIL – OLSON #1
SWNW Sec.18, T.163N., R.77W.
KB: 1520' (463.3m)

LION OIL CO. – G. A. HUSS #1
NWNW Sec.23, T.163N., R.75W.
KB: 2205' (672.1m)

JUMPING POUND PETROLEUM
– JUMPING POUND HIGH CREST
PROSPECT *et al.* HORTON #8–15
8–15–2–20 WPM
KB: 1913' (583.1m)

A'

MANITOBA TERMINOLOGY



CORE #2: 1524.5–1534.5m (5000–5033')

DST #2: 1520–1535m (4986.0–5034.8')
Rec. 1234m (376') saltwater

DST #2: 5922–5942' (1805.5–1811.6m)
Rec. 184' (56m) saltwater cut mud
545' (166m) saltwater

CORE #3: 3940–3990' (1201.2–1216.5m)
CORE #4: 4988–5031' (1520.7–1533.8m)

DST #2: 4544–4626' (1385.0–1410.4m)
Rec. 2.18 bbls (0.35m³) drilling mud
4.23 bbls (0.67m³) slightly gas cut mud

DST #3: 4630–4687' (1411.6–1429.0m)
Rec. 1.51 bbls (0.24m³) drilling mud
24.20 bbls (3.85m³) very slightly gas cut water

DST #4: 5333–5365' (1625.9–1635.7m)
Rec. 6.74 bbls (1.07m³) drilling mud
17.71 bbls (5.4m³) saltwater

DST #5: 5466–5495' (1666–1675m)
Rec. 4.36 bbls (0.69m³) drilling mud
33.02 bbls (5.25m³) slightly gas cut formation water

CORE #5: 3970–4017' (1210–1225m)
CORE #6: 4677–4728' (1411.0–1441.5m)

CORE #3: 4078–4095' (1243.0–1248.2m)
CORE #4: 4097.5–4106.5' (1249.0–1251.7m)

NOTE: *Italics* denote Manitoba terminology
* North Dakota terminology
' Former Manitoba terminology

NOTE: *Italics* denote Manitoba terminology
* North Dakota terminology

STRATIGRAPHY

The Devonian System in North Dakota and Manitoba is divided into four major lithologic units (Baillie, 1953; Bluemle *et al.*, 1986). These are, in ascending stratigraphic order, the Elk Point, Manitoba, Saskatchewan and Qu'Appelle groups.

ELK POINT GROUP

The Elk Point Group is divided, in ascending order, into the Ashern, Elm Point (Manitoba only), Winnipegosis, and Prairie formations.

Ashern Formation

The Ashern Formation attains a maximum thickness of 55 m (180 ft) in the central portion of the basin. It unconformably overlies the Silurian Interlake Formation in North Dakota. In North Dakota, Lobdell (1984) informally subdivides the Ashern into a lower red member and upper grey member, both comprising argillaceous, microcrystaline dolostones containing minor amounts of quartz silt. Anhydrite is present in both members, however, it is more abundant as nodules in the lower red member. Bedded halite may also be present and is noted in two areas of North Dakota, eastern Williams and western Mountrail Counties.

The lower red member is present in North Dakota as a north-trending, weakly positive feature. It is believed to have been deposited as a peninsula or large island (Lobdell, 1984). Coastal sabkas developed on this feature, and are represented by red microcrystalline dolostones and local anhydrites. This feature was later inundated by the Middle Devonian restrictive sea. Subtidal sediments formed at this time became the microcrystalline dolostones of the upper grey member.

In Manitoba, the depositional thickness of the Ashern Formation ranges from approximately 3 to 12 m (10 to 39 ft). The Ashern Formation unconformably overlies the Middle Silurian Interlake Group and is overlain with slight unconformity by the Winnipegosis Formation, or the Elm Point Formation where it is developed. Its lithology consists mainly of interbedded red and green dolomitic shales and red argillaceous dolostones (Baillie, 1953).

The Ashern Formation constitutes the basal part of the Devonian succession throughout a large part of the Elk Point basin of Manitoba and Saskatchewan. The sediments of the Ashern Formation represent, in part, the reworking of residual soil formed during the later Silurian to early Devonian erosional interval (Norris *et al.*, 1982).

Elm Point Formation (Manitoba)

The Elm Point Formation is identified only in Manitoba. It overlies the Ashern Formation with possible unconformity and ranges in thickness from approximately 5 to 20 m (16 to 66 ft). The Elm Point Formation in outcrop typically consists of medium yellowish-brown, very fine-grained, variably dolomitized, mottled high-calcium limestone. It grades laterally in the subsurface to a dolostone that is generally indistinguishable from the overlying Winnipegosis Formation. It is essentially equivalent to the Lower Member, platform carbonate facies of the Winnipegosis Formation (Norris *et al.*, 1982).

Winnipegosis Formation

The Winnipegosis Formation disconformably overlies the Ashern Formation in North Dakota and Manitoba. It attains a maximum thickness of 105 m (344 ft). The Winnipegosis Formation is subdivided into a lower member, platform facies, consisting generally of a mottled dolostone, and an upper member, carbonate mound, reef, or inter-reef facies (Norris *et al.*, 1982). Argillaceous-bituminous or laminated beds separate the two units. The subdivisions of the Winnipegosis Formation are recognized in North Dakota and Manitoba, but are formally defined only in Manitoba. In Manitoba, a transition zone occurs locally at the top of the Upper Member that consists generally of limestone-shale breccias and coarsely crystalline limestone (Norris *et al.*, 1982).

A transgression and regression of the Devonian sea into the Elk Point basin is represented by sediments of the Winnipegosis Formation. Widespread, normal marine carbonates represent the initial deposits of the formation (Norris *et al.*, 1982; Perrin, 1982; Ehrets and Kissling, 1987). These are, in turn, overlain by sediments representing two distinctly different environments, a shallow shelf environment, and a deeper basin environment with scattered pinnacle reefs. The shelf environment is represented by a fringing bank built up around the perimeter of the basin. Shoreward of this bank exists a sequence of either thin bituminous, laminated, inter-reef carbonates, or thick mound or reef carbonate complexes. Basinward from the bank, the pinnacle reefs and deeper basinal facies developed. The two environments represent a "decoupling" of the deeper basin environment from the shelf environment in response to varying rates of carbonate production.

Regression of the Devonian sea began during the initial deposition of the upper portion of the Winnipegosis Formation. At this time, supratidal deposition occurred on both the shelf and pinnacle reefs. The pinnacle reefs were probably periodically exposed. Shallow water sediments, dolostones, stromatolites, and anhydrites were deposited around the emergent reefs. The basin was eventually filled by salt of the overlying Prairie Formation (McCabe, 1987).

Prairie Formation

The Prairie Formation conformably overlies the Winnipegosis Formation completing the sequence of the Elk Point Group. The evaporites of the Prairie Formation attain a maximum thickness of 198 m (650 ft) with variations occurring locally and regionally due to dissolution and the differential accumulation of salt during deposition (Oglesby, 1988). Four members are recognized in the Prairie Formation of North Dakota; these include, in ascending order, the Ratner, Esterhazy, Belle Plaine, and Mountrail.

The Ratner Member consists principally of anhydrite and is transitional with the underlying Winnipegosis Formation. The Ratner Member is overlain by a transition zone. Interbeds of the anhydrite occur within the overlying halite (Oglesby, 1988; Bannatyne, 1960). These interbeds reflect a periodic recharge of the Elk Point basin. Overlying this transition zone are the remaining three members of the Prairie Formation, the Esterhazy, Belle Plaine, and Mountrail. These are regionally correlative upward brining sequences of halite capped with halite dominated potash beds. The potash represents the shallowest brine depth and the highest level of salinity. The final, unnamed halite cycle is capped by a red to green, nonfossiliferous dolostone to calcareous shale, known informally as the "second red beds". These beds probably protected the Prairie salt from dissolution during the Dawson Bay transgression. Generally included in the Dawson Bay Formation, Oglesby (1988) includes the "second red beds" as the uppermost member of the Prairie Formation.

In Manitoba, the Prairie Formation comprises a sequence of halite beds with minor anhydrite, and a potash-rich interval near the top. The present extent of the Prairie Formation in Manitoba represents a salt dissolution edge (see cross-section A-A'). The Formation originally extended north and east of the present salt edge. The Prairie Formation thickens from a zero edge, due to dissolution, to approximately 125 m (410 ft) (Norris *et al.*, 1982; Manitoba Energy and Mines, 1980). The main body of evaporite is restricted primarily to an area west of the Winnipegosis fringing bank along, or near, the Manitoba/Saskatchewan border. A tongue of anhydrite beds extends eastward from this main body, over part of the Winnipegosis fringing bank (McCabe, 1971).

MANITOBA GROUP

The Manitoba Group in North Dakota and Manitoba comprises the Dawson Bay and Souris River formations.

Dawson Bay Formation

The Dawson Bay Formation attains a maximum thickness of 48 m (157 ft). In Manitoba, four rock units are recognized in the Dawson Bay Formation; these include, a basal unit termed the Second Red Bed Member, and three upper units. The Second Red Bed Member (Mafeking Member; Norris *et al.*, 1982) consists of red to green, noncalcareous, fissile shale that grades upward to argillaceous and dolomitic limestone and argillaceous dolostone. These beds are recognizable in the subsurface and in outcrop. Where underlain by Prairie Formation evaporites, the lower contact of the Second Red Bed Member is disconformable (McCabe, 1971).

The upper part of the Dawson Bay Formation consists of three rock units that are recognizable in outcrop. The unit overlying the Second Red Bed Member comprises argillaceous dolostones and fossiliferous biomicritic limestones (Member B; Norris *et al.*, 1982). The second unit consists of calcareous shales and argillaceous limestones (Member C; Norris *et al.*, 1982). The uppermost unit of the Dawson Bay Formation comprises saccharoidal dolostones and fragmental limestones that commonly contain stromatoporoids (Member D; Norris *et al.*, 1982; Baillie, 1953; Pound, 1985).

The Second Red Bed Member of the Dawson Bay Formation represents sediments that accumulated under continental or very shallow water, intertidal conditions. The Second Red Bed Member was once underlain by the Prairie Formation, much of which has since been removed by dissolution in southwestern Manitoba. Deposition of the argillaceous dolostones, fossiliferous limestones, and argillaceous limestones of the upper units of the Dawson Bay Formation represent an increase in water depth and transgression of the Dawson Bay sea (Norris *et al.*, 1982).

Deposition of the Dawson Bay Formation in North Dakota occurred on a low relief platform with slightly restricted marine waters (Dean, 1982). Environments range from subtidal to supratidal. Diagenesis, primarily dolomitization, destroyed much of the original texture.

Souris River Formation

The Souris River Formation conformably overlies the Dawson Bay Formation and generally consists of a sequence of dark grey and brownish-grey, argillaceous, anhydritic, or silty limestones or dolostones (Bluemle *et al.*, 1986). Interbeds of siltstones, shales and evaporites are also present. These sediments represent an influx of clastics and supratidal carbonates into the basin in Devonian time. The formation attains a maximum thickness of 107 m (350 ft) in the central portion of the basin.

In Manitoba, the lower contact of the Souris River Formation is transitional. The Souris River Formation, as defined by Norris *et al.* (1982) is comprised of a lower unit, the Point Wilkins Member, and an upper unit, the Sagamace Member, both of which are recognized in Manitoba outcrop. The Point Wilkins Member consists of four rock units, in ascending sequence: the First Red Beds (only unit recognized in the subsurface); a red and green calcareous shale; a fossiliferous, argillaceous limestone; a dense, micritic and fragmented limestone (original Point Wilkins Member of Baillie, 1951); and a yellowish-brown, finely crystalline dolostone and dolomitic limestone. The Sagamace Member consists of variably fossiliferous, micritic limestone grading in part to laminated and pelletal limestone and saccharoidal dolostone. The Souris River Formation ranges in thickness, in Manitoba, from 66 to 95 m (216 to 312 ft) (McCabe, 1971; Manitoba Energy and Mines, 1980).

Recent standardized correlations established by McCabe and Bezys (pers. comm.) for the latest edition of the Western Canadian Atlas (in prep.) and the Lexicon of Canadian Society of Petroleum Geologists, 1990) have redefined the top of the Souris River Formaton to correspond with its type section. The previous top of the Souris River Formation in Manitoba was defined as the base of a white break roughly 15 m (49 ft) below the established top of the Souris River Formation. This pick has been retained in Manitoba as the "Souris River marker" (see cross-section A-A').

Deposition of the Souris River Formation represents an alternating cycle of marine transgression and regression. The First Red Beds and argillaceous and micritic limestones of the Point Wilkins Member represent a transgressive phase. The dolomitic limestone represents the initial part of a regressive phase. The Sagemace Member represents the transgressive phase of a second cycle (Norris *et al.*, 1982).

JEFFERSON GROUP (North Dakota) / SASKATCHEWAN GROUP (Manitoba)

The Duperow and Birdbear formations represent two different groups. The Jefferson Group was proposed by Sandberg and Hammond (1958) for use in North Dakota. The Saskatchewan Group was proposed by Baillie (1953) for equivalent strata in Manitoba.

Duperow Formation

The Duperow Formation conformably overlies the Souris River Formation. The formation consists of up to 152 m (500 ft) of microcrystalline limestone, fine-grained argillaceous dolostone and anhydritic limestone, and microcrystalline dolostone with lesser amounts of bedded anhydrite and calcareous shale (Hoganson, 1978). Terrigenous clastics are scattered throughout the section. Numerous complete and incomplete shoaling upward sedimentary cycles are represented by the Duperow Formation (Wilson and Pilatzke, 1987; Burke and Heck, 1988). The Duperow Formation represents the maximum advance of the late Devonian sea. Environments of deposition range from subtidal to supratitoral. A stromatoporoid bank environment is also represented.

In Manitoba, the formation is characterized by a cyclical sequence of strata similar to that of the underlying Souris River Formation. The lowermost cycle consists of dark brown limestone interbedded with black, argillaceous limestone and dark grey shale. The second phase consists mainly of fragmented, saccharoidal dolostone and lesser amounts of limestone. Corals, stromatoporoids, bryozoa and algal material are commonly present. The third and final phase is composed of massive anhydrite. An argillaceous zone marks the top of the Duperow Formation. The depositional thickness of the Duperow Formation in Manitoba ranges from approximately 122 to 195 m (400 to 640 ft).

Birdbear Formation

The Birdbear Formation is conformable with the underlying Duperow and overlying Three Forks formations. In peripheral areas where the Three Forks Formation is absent, the Birdbear Formation is disconformable or forms an angular unconformity with overlying units. It is composed of fossiliferous and argillaceous, micritic limestone and attains a maximum thickness of 36 m (119 ft) in the central portion of the basin (Loeffler, 1982). Local structural anomalies are related to two stage salt dissolution of the Devonian Prairie Formation.

Loeffler (1982) recognized seven lithofacies within the Birdbear Formation. These facies represent environments ranging from restricted, shallow marine to supratidal, and indicate progressively shallowing conditions.

The Birdbear (Nisku') Formation of Manitoba is lithologically similar to strata in North Dakota. It also comprises fragmental, fossiliferous limestones and dolostones. Corals, bryozoa, stromatoporoids and algal material are usually abundant. The depositional thickness of the formation ranges from 12 to 43 m (39 to 141 ft) (Manitoba Energy and Mines, 1980).

Three Forks Formation

The Three Forks Formation is conformable with the underlying Birdbear Formation and the overlying Bakken Formation, except along the basin margin where it is unconformably overlain by the Lodgepole Formation. A series of interbeds of greenish-grey and reddish-brown micrite and dolomicrite with anhydrite nodules and subordinate amounts of biomicrite and argillaceous material comprise the formation. There are local accumulations of coarse-grained siltstone to fine-grained sandstone in the upper few feet of the Three Forks Formation, informally referred to as the "Sanish sand". In the central portion of the basin, the Three Forks Formation reaches a maximum thickness of 81 m (265 ft).

In North Dakota, Dumonceaux (1984) divided the Three Forks Formation into five lithofacies that showed considerable vertical and lateral variability due to the degree of onlap and offlap between adjacent depositional environments. Depositional environments ranging from sublittoral to supralittoral have been interpreted by Dumonceaux for these lithofacies.

QU'APPELLE GROUP (Manitoba)

Three Forks Formation

The Qu'Appelle Group, as proposed by Baillie (1953), consists of a single formation in Manitoba, the Three Forks (Lyleton') Formation. It is comprised predominantly of red, dolomitic siltstones and silty shales and argillaceous dolostones and ranges in thickness from 11 to 55 m (36 to 180 ft) (McCabe, 1971). It conformably overlies the Birdbear Formation and is unconformably overlain by the Middle Member of the Bakken Formation. Locally in areas of the late Devonian to early Mississippian salt dissolution, the Three Forks Formation is overlain by the Lower Member of the Bakken Formation.

' Former Manitoba stratigraphic terminology

PETROLEUM POTENTIAL

The predominantly marine strata of the Devonian sequence contain many stratigraphic features that are considered to be favourable for the accumulation of oil. The lithofacies relationships, together with the tectonic and environmental features of certain stratigraphic intervals, are more favourable than others for the generation and accumulation of oil. Two Devonian formations are nonproductive; these are, the Ashern and the Prairie formations.

The Winnipegosis Formation of the Elk Point Group has potential to be a suitable oil reservoir. The reefs and shoal Winnipegosis Formation show excellent porosity and permeability and, where developed along the basinward edge of the fringing bank, have reservoir potential. Production has been obtained from dolomitized reefs of the upper Winnipegosis Formation in the southwestern portion of the Elk Point basin in the Tablelands area of Saskatchewan (Martindale, 1987). Economic production from the pinnacle reefs has not been found in North Dakota and Manitoba. Temple and Hamlet fields in North Dakota produce from the platform margin argillaceous slope facies. The Round Prairie field produces from a small patch reef on the platform.

The Dawson Bay Formation in North Dakota produces along, or adjacent to, the Nesson anticline and along the Cedar Creek anticline. Production is from diagenetically enhanced vuggy or intercrystalline porosity. Porosity development (enhancement) is controlled by primary porosity trends. Evaporites commonly plug porosity.

The stromatoporoid zone occurring near the top of the Dawson Bay Formation of the Manitoba Group also has potential as a reservoir. These beds, where exhibiting good porosity, could be a potential reservoir zone as it is capped by impermeable beds of the basal Souris River Formation. Potential exists, as well, within the upper dolomitic unit of the Point Wilkins Member.

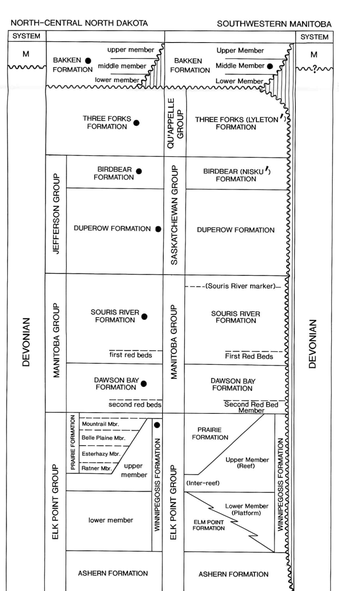
Production from the Souris River Formation is limited and restricted to the central portion of the basin. Production along the Nesson anticline is not differentiated from the Duperow Formation.

Fields scattered about the central portion of the basin produce from the Duperow Formation. This production is associated with major structural features within the Williston basin, including the Nesson, Billings and Cedar Creek anticlines. The Duperow Formation produces from both stratigraphic and structural traps. Developed porosities are either primary, or a result of diagenetic processes.

Production from the Birdbear Formation presently appears to be restricted to deposits of upper bank and back bank depositional environments within the central portion of the basin. Porosity is either primary or diagenetic, related to dolomitization. The Birdbear Formation also produces in Montana from structures associated with two stage salt dissolution.

The Three Forks Formation produces from isolated deposits of the "Sanish sand" in the central portion of the basin. Interpreted to be either beach sand deposits, or shallow water sand bars, the sands produce where tension fracture systems are present.

STRATIGRAPHIC NOMENCLATURE CHART



● oil production present
' Former Manitoba terminology

REFERENCES

Baillie, A.D.
1951: Devonian geology of Lake Manitoba - Lake Winnipegosis area, Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 49-2, 72 p.
1953: Devonian System of the Williston basin area: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 52-5, 105 p.

Bannatyne, B.B.
1960: Potash deposits, rock salt, and brines in Manitoba: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 59-1, 30 p.

Bluemle, J.P., Anderson, S.B., Andrew, J.A., Fischer, D.W., and LeFever, J.A.
1986: North Dakota stratigraphic column: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 66, 3 sheets.

Burke, R.B., and Heck, T.J.
1988: Reservoir characteristics of the Duperow Formation at Tree Top field, North Dakota, in Goolsby, S.M., and Longman, M.W. (eds.), Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 303-316.

Canadian Society of Petroleum Geologists
1990: Lexicon of Canadian stratigraphy, volume 4, western Canada including eastern British Columbia, Alberta, Saskatchewan and southern Manitoba: Calgary, Alberta, Canadian Society of Petroleum Geologists, 772 p.

Dean, K.
1982: Devonian Dawson Bay Formation in North Dakota, in Christopher, J.E., and Kaldi, J. (eds.), Fourth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 6, p. 89-93.

Dumonceaux, G.M.
1984: Stratigraphy and depositional environments of the Three Forks Formation (Upper Devonian), Williston basin, North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 189 p.

Ehrets, J.R., and Kissling, D.L.
1987: Winnipegosis platform margin and pinnacle reef reservoirs, northwestern North Dakota, in Fischer, D.W. (ed.), Core Workshop Volume, Fifth International Williston Basin Symposium: Grand Forks, North Dakota, North Dakota Geological Society, Miscellaneous Series No. 69, p. iv-31.

Hoganson, J.W.
1978: Microfacies analysis and depositional environments of the Duperow Formation (Fransnian) in the North Dakota part of the Williston basin, in Estelle, D., and Miller, R. (eds.), The economic geology of the Williston Basin, 1978 Williston Basin Symposium: Billings, Montana, Montana Geological Society, p. 131-144.

Lobdell, F.K.
1984: The Ashern Formation (Middle Devonian) in the Williston basin, North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 187 p.

Loeffler, P.T.
1982: Depositional environment and diagenesis, Birdbear Formation (Upper Devonian), Williston basin, North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 268 p.

Manitoba Energy and Mines
1980: Manitoba stratigraphic map series.

Martindale, W., and Orr, N.E.
1987: Middle Devonian Winnipegosis reefs of the Tablelands area of southeastern Saskatchewan (abs.), in Marchand, T. (ed.), Second International Symposium on the Devonian System, program and abstracts: Calgary Alberta, Canadian Society of Petroleum Geologists, p. 156.

McCabe, H.R.
1971: Stratigraphy of Manitoba, an introduction and review, in Turnock, A.C. (ed.), Geoscience studies in Manitoba: Geological Association of Canada, Special Paper No. 9, p. 167-187.
1987: Preliminary Manuscript - a tentative model for Winnipegosis (Middle Devonian) "Reefs", Manitoba outcrop belt: Winnipeg, Manitoba, Manitoba Energy and Mines, Geological Services Branch.

Norris, A.W., Uyeno, T.T., and McCabe, H.R.
1982: Devonian rocks of the Lake Winnipegosis - Lake Manitoba outcrop belt, Manitoba: Geological Survey of Canada, Memoir 392, 280 p.
1982: Devonian rocks of the Lake Winnipegosis - Lake Manitoba outcrop belt, Manitoba: Winnipeg, Manitoba, Manitoba Energy and Mines, Mines Branch, Publication 77-1, 280 p.

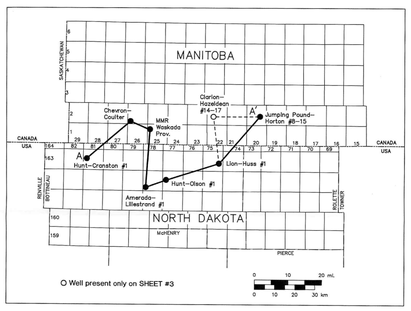
Oglesby, C.A.
1988: Deposition and dissolution of the Middle Devonian Prairie Formation, Williston basin, North Dakota and Montana: Master's thesis, Colorado School of Mines, Golden, Colorado, 79 p.

Perrin, N.A.
1982: Environments of deposition and diagenesis of the Winnipegosis Formation (Middle Devonian), Williston basin, North Dakota, in Christopher, J.E., and Kaldi, J. (eds.), Fourth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 6, p. 52-67.

Pound, W.R.
1985: The geology and hydrocarbon potential of the Dawson Bay Formation carbonate unit (Middle Devonian), Williston basin, North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 320 p.

Sandberg, C.A., and Hammond, C.R.
1958: Devonian System in Williston basin and central Montana: American Association of Petroleum Geologists Bulletin, v. 42, p. 2293-2334.

Wilson, J.L., and Pilatzke, R.H.
1987: Carbonate-evaporite cycles in Lower Duperow Formation of Williston basin, in Longman, M.W. (ed.), Williston basin - anatomy of a cratonic oil province: Denver, Colorado, Rocky Mountain Association of Geologists, p. 119-146.



○ Well present only on SHEET #3

LINE OF CROSS–SECTION

METRIC CONVERSION TABLE

1 metre (m)	= 3.28 feet (ft)
1 cubic metre (m^3)	= 6.29 barrels (bbls) (oil) = 220 imperial gallons = 35.49 cubic feet (gas)
1 hectare (ha)	= 2.47 acres
1 kilometre (km)	= 0.62 miles (mi)

SHEET #4: DEVONIAN

CORRELATION CROSS–SECTIONS ALONG THE UNITED STATES–CANADA INTERNATIONAL BORDER (NORTH DAKOTA–MANITOBA)

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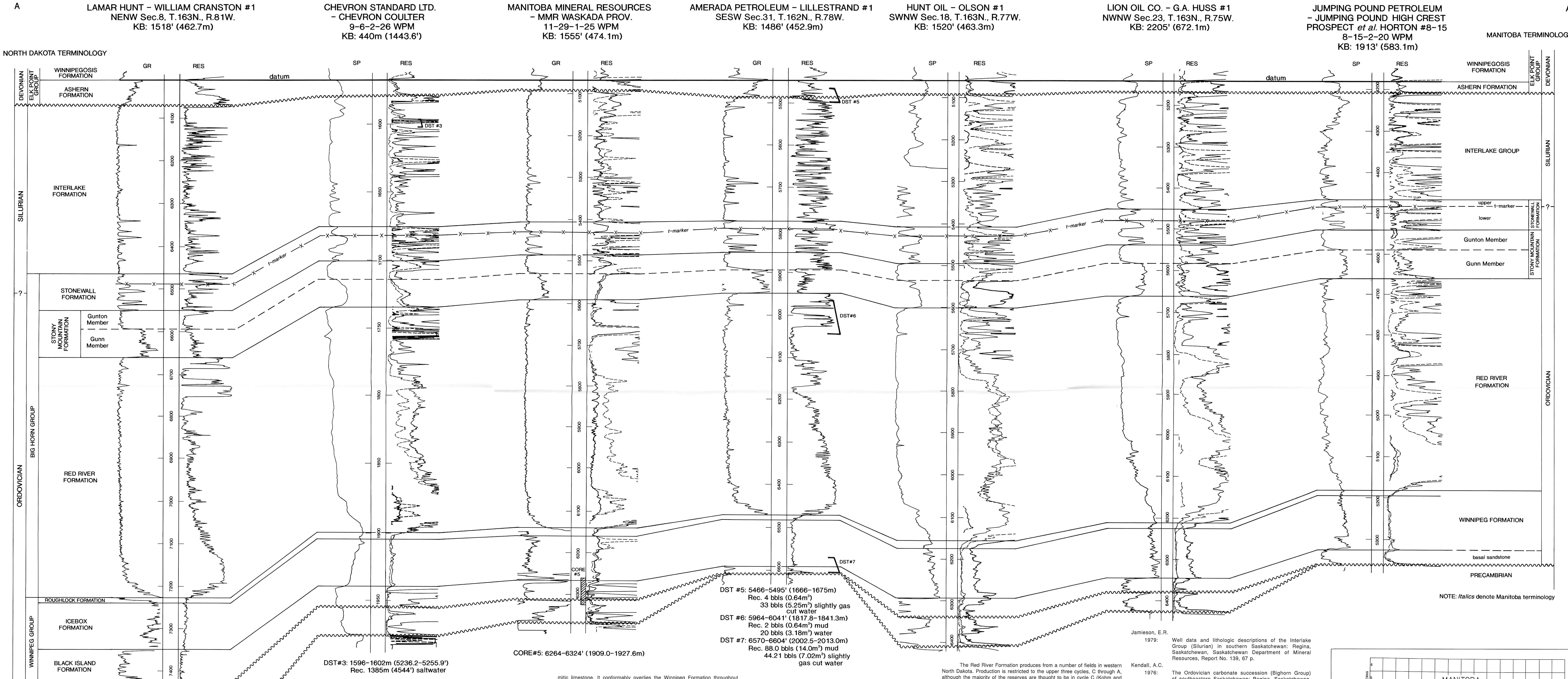
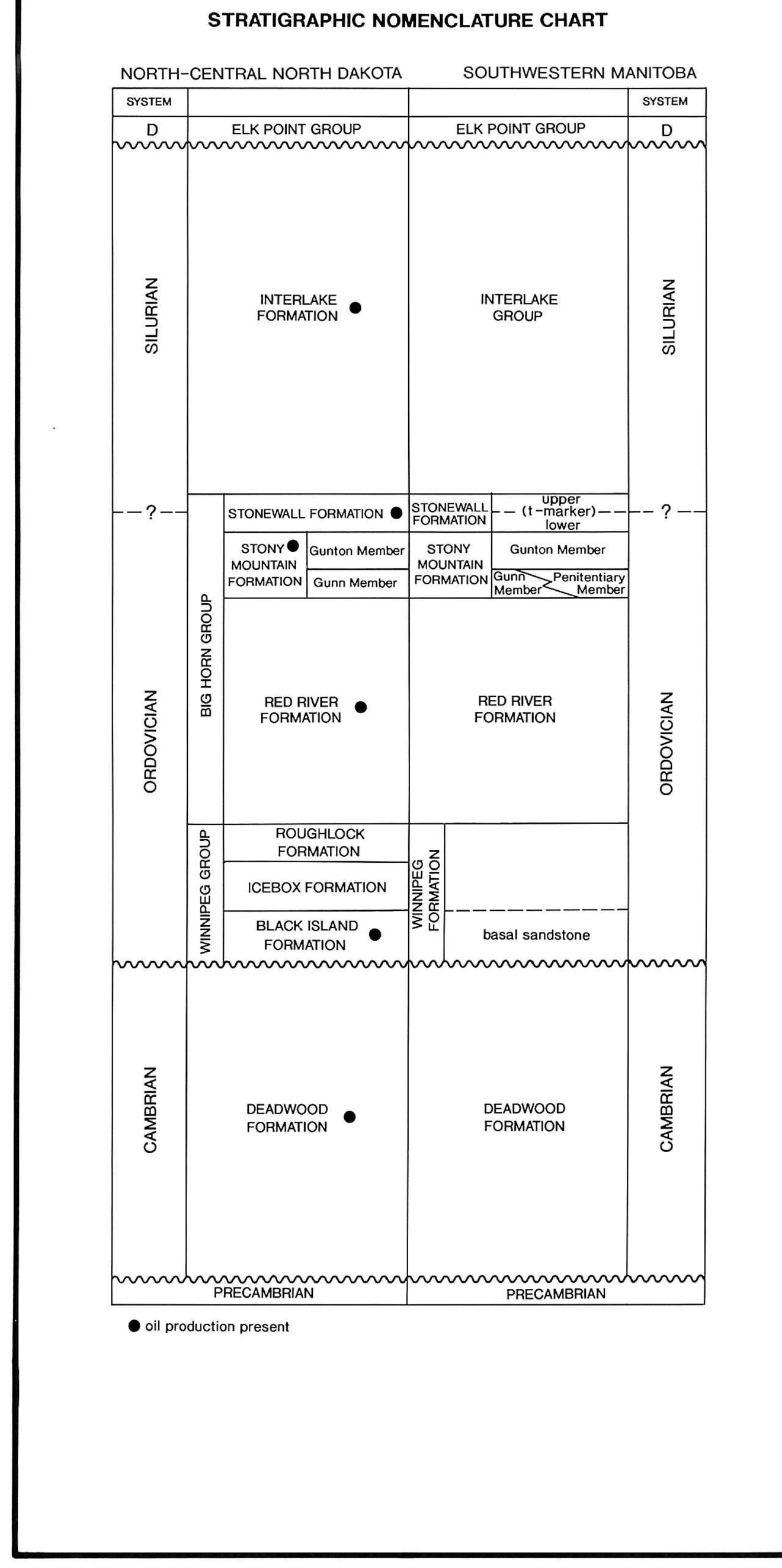
NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 92

MANITOBA ENERGY AND MINES
PETROLEUM OPEN–FILE REPORT POF 12–91



STRATIGRAPHIC NOMENCLATURE CHART



STRATIGRAPHY

Deadwood Formation

The Deadwood Formation is defined as the glauconitic, predominantly siliciclastic beds of Cambro-Ordovician age that unconformably overlie the Precambrian basement and are unconformably overlain by the Middle Ordovician Winnipeg Formation (Manitoba)/Winnipeg Group (North Dakota). Regionally, Deadwood Formation strata comprise a thick wedge of clastic sediments throughout most of the Williston basin area. The Deadwood Formation attains a maximum thickness of 274 m (900 ft) in North Dakota (LeFever *et al.*, 1987). In Manitoba, the Deadwood Formation reaches a maximum thickness of approximately 60 m (197 ft) in the extreme southwest corner of the province (McCabe, 1978; Manitoba Energy and Mines, 1980). The Deadwood Formation thins northeastward into Manitoba, where it is regionally truncated at the pre-Winnipeg unconformity.

The formation consists of greenish-grey, highly glauconitic, siliciclastic rocks. The rocks principally consist of quartz arenites, quartz wackes, and siltstones with lesser amounts of carbonate rocks that range in texture from mudstone to grainstone (LeFever *et al.*, 1987). Multiple sedimentary structures that include ripple cross-laminations, horizontal parallel laminations, water escape structures, soft sediment deformation features and structures associated with bioturbation are present throughout the sequence.

In North Dakota, the Deadwood Formation is subdivided into six informal lithostratigraphic members based on wireline logs and the analysis of available cores. These informal members are designated, in ascending order, as A through F (LeFever *et al.*, 1987; Anderson, 1988). The distribution of the members A and B is strongly influenced by the topography of the underlying Precambrian surface, whereas members C through F are generally influenced by Precambrian topography, and have a more limited distribution.

The Deadwood Formation was deposited during a gradual major eustatic sea level rise with several smaller transgressive and regressive events (LeFever *et al.*, 1987). Nine separate lithologies compose the six lithostratigraphic units. Environments of deposition for these units range from marginal marine to offshore conditions. The Early Ordovician was marked by a major eustatic sea level drop at which time, the marine deposition of the Deadwood Formation ceased. This was followed by a period of erosion.

Winnipeg Formation (Manitoba)

The Winnipeg Formation in Manitoba comprises a complex sequence of interbedded shales and sandstones. It unconformably overlies weathered Precambrian basement, except in the extreme southwestern corner of Manitoba, where the it is unconformably underlain by a thin wedge of the Deadwood Formation. The Winnipeg Formation is conformably overlain by limestones of the Upper Ordovician Red River Formation.

The Winnipeg Formation attains a maximum thickness of 68 m (223 ft). It consists predominantly of argillaceous to nonargillaceous, siliceous to faintly calcareous shales and poorly consolidated to unconsolidated, very fine- to coarse-grained, quartzose sandstone (Genik, 1952; Baillie, 1952; McCabe, 1978; Manitoba Energy and Mines, 1980). A unique feature of the Winnipeg Formation in Manitoba is the Carman sand body located south of Winnipeg. It is a large, east-trending, bar-like sand body that attains a maximum thickness of 30 m (100 ft) and consists of very fine- to medium-grained sandstone (Andrichuk, 1959).

Baillie (1952), Genik (1954) and Vigrass (1971) attempted to subdivide the Winnipeg Formation into distinct stratigraphic units. These units generally consist of a lower, basal sandstone unit, and one, or two, overlying units of sandstone and shale. A formal stratigraphic subdivision of the Winnipeg Formation has not been accepted in Manitoba.

The Winnipeg Formation represents the initial deposits of a marine transgressional cycle that began during Middle to Late Ordovician time, and continued until Late Silurian time. The Winnipeg beds consist of terrigenous clastics. Strata deposited later in the transgressional cycle are almost entirely carbonates and evaporites (Vigrass, 1971; Porter and Fuller, 1959). The Carman sand probably represents an offshore bar deposit (McCabe, 1978).

WINNIPEG GROUP (North Dakota)

The Winnipeg Group in North Dakota attains a maximum thickness of 134 m (440 ft) and unconformably overlies the Deadwood Formation, except in the extreme southeastern and northeastern portion of the state, where it rests directly on the Precambrian surface. Three formations are correlative within the state, which in ascending order are, the Black Island, Icebox, and Roughlock formations.

Black Island Formation

The Black Island Formation consists predominantly of sandstone with minor amounts of shale and is subdivided into two informal members. The lower member is restricted to the western half of North Dakota and has a maximum thickness of 30 m (100 ft). It consists of two lithofacies; a dark red, quartz arenite sandstone and shale sequence, and, a greenish-grey quartz wacke sequence. The upper member also has two lithofacies; a quartz arenite, and, quartz wacke. It is conformable with the lower member and has a maximum thickness of 50 m (165 ft).

The lower member of the Black Island Formaton was deposited in a terrestrial environment that was probably fluvial dominated; possibly a flood-plain or delta plain with local channel deposits (LeFever *et al.*, 1987). The quartz wacke lithofacies of the member probably represent the initial deposits of a transgression.

The upper member was deposited in a nearshore zone between the areas dominated by beach processes and marine shelf processes (LeFever *et al.*, 1987). The dominant process was wave related, both normal and storm driven, at wave depths of 10 to 30 m (33 to 100 ft).

Icebox Formation

The Icebox Formation is primarily a shale sequence with local sandstone lithosomes (LeFever *et al.*, 1987). It is conformable with the underlying Black Island Formation and the overlying Roughlock Formation. The Icebox Formation is present throughout the state of North Dakota, except in the extreme southeastern corner. It is 46 m (150 ft) thick in the central basin area and 50 m (165 ft) thick in Grand Forks County.

The shale is bioturbated and in some localities is fossiliferous. Three sandstone lithosomes are locally present, in Divide County, Grand Forks County, and in southwestern North Dakota. These bodies consist of fine- to medium-grained quartz wackes that are highly bioturbated, argillaceous, and in places, cross-laminated (LeFever *et al.*, 1987).

The Icebox Formation was deposited in an offshore environment adjacent to, and seaward from, nearshore sand deposits. Three different environments of deposition are proposed for the local sandstone lithosomes. A nearshore environment is suggested for the sandstone body in Divide County. The lithosome in Grand Forks County was probably deposited as an offshore bar deposit. A deltaic environment is suggested for the sandstone in southwestern North Dakota.

Roughlock Formation

The Roughlock Formation is a transitional unit between the noncalcareous shales of the underlying Icebox Formation and the limestone of the overlying Red River Formation. It is predominantly an argillaceous and fossiliferous limestone that in south-central North Dakota contains a sandstone lithosome. The formation reaches a maximum thickness of 27 m (90 ft).

Deposition of the Roughlock and Icebox formations occurred in similar, offshore environments (LeFever *et al.*, 1987). Carbonate deposition of the Roughlock Formation reflects a decrease in detrital input into the basin. The faunal assemblage supports the interpretation of an open marine environment with normal marine salinities; a deltaic environment is suggested for the sandstone lithosome. This lithosome, and the one in the stratigraphically lower Icebox Formation, appear to be stacked and may be genetically related.

Red River Formation

Red River Formation strata conformably overlie the shales and sandstones of the Winnipeg Formation (Manitoba)/Winnipeg Group (North Dakota). The strata overstep Winnipeg Formation strata to rest unconformably on the Cambrian Deadwood Formation in western Saskatchewan, and on the Precambrian basement in northern Manitoba. The Red River Formation is overlain sharply and slightly disconformably, by the shale beds of the Stony Mountain Formation.

In North Dakota, the Red River Formation forms the basal formation of the Big Horn Group. The formation attains a maximum thickness of 213 m (700 ft) in the central portion of the Williston basin (Bluemle *et al.*, 1986).

It is informally subdivided into two members. The lower member is described as a burrowed wackestone. The upper member is further subdivided into four zones referred to, in ascending order, as D through A. The basal D zone consists of dolomitic, porous, burrowed, brown mudstone and wackestone. It is overlain by a 0.6 to 1.5 m (2 to 5 ft) thick, impermeable, regularly laminated, argillaceous, black, organic, skeletal wackestone and packstone (Carroll, 1978). Zones C through A consist of separate repetitions of four lithologic units. The basal lithologic unit of the sequence is a light to dark grey, slightly dolomitic, bioturbated, skeletal wackestone to packstone. This is overlain by a fine-grained, brown, dolomitic mudstone with good intercrystalline porosity. Included in this unit are desiccation features, individual and massed acicular anhydrite crystals, subaerially laminated crusts, pelletal fabrics and erosional surfaces. The mudstone is overlain by an impermeable layer of nodular anhydrite and interlaminated anhydrite and dolostone. The uppermost lithologic unit is a 2.5 cm (1 in) thick, noncalcareous, dark grey, fissile, argillaceous bed that acts as a definitive marker for each sequence on wireline logs. Vertically, zones C through A become successively thinner and the anhydrite unit becomes less widespread.

Carbonate deposition of the lower member and D zone of the Red River Formation represent a shallow subtidal to low intertidal regime. The presence of some organic detritus in the D zone reflects local restriction in circulation into the basin. Zones C through A initially were deposited in shallow water, probably an open shelf environment. This was followed by high intertidal or supratidal deposition. The overlying anhydrites are interpreted by Carroll (1978) to be a sabkha deposit, in a high supratidal evaporitic environment. This was followed by a short diastem and repetition of the sequence.

In Manitoba, the Red River Formation ranges in thickness from 150 to 175 m (492 to 574 ft) (Manitoba Energy and Mines, 1980). It is subdivided into four units that are recognizable in the Manitoba Paleozoic outcrop belt. These are, in ascending order, the Dog Head, Cat Head, Selkirk, and Fort Garry members. The Dog Head Member consists of a fossiliferous, mottled, dolomitic limestone. It conformably overlies the Winnipeg Formation throughout most of the Manitoba Paleozoic outcrop belt. North of the depositional limit of the Winnipeg Formation, the Dog Head Member unconformably overlies the Precambrian basement. Its contact with the overlying Cat Head Member is transitional and conformable.

The Cat Head Member consists chiefly of dolostones. It is lithologically recognizable only in the central portion of the Manitoba Paleozoic outcrop belt. To the north, the overlying Selkirk Member and underlying Dog Head Member change facies to dolostone that is similar to the Cat Head Member dolostone. To the south, the Cat Head Member becomes increasingly calcareous and is indistinguishable from the underlying and overlying members.

The Selkirk Member consists of fossiliferous, mottled, dolomitic limestone. Contacts with the underlying Cat Head Member and the overlying Fort Garry Member are transitional and conformable. The Selkirk, Cat Head, and Dog Head members correlate approximately in the subsurface with the Yeoman Formation of Saskatchewan.

The Fort Garry Member consists of finely crystalline and micritic, variably argillaceous dolostones, with a medial zone of shaly dolomite breccia that probably resulted from evaporite dissolution. It is overlain sharply, and possibly disconformably, by the Stony Mountain Formation (Andrichuk, 1959; Foerste, 1929a, 1929b; Kendall, 1976; McCabe and Bannatyne, 1970; Porter and Fuller, 1959; Sanford *et al.*, 1968). In the subsurface the Fort Garry Member correlates approximately with the Herald Formation of Saskatchewan.

The Red River Formation was deposited in subtidal upward brining sequences. Sedimentation during each cycle was mainly controlled by an increase of salinity (Elias *et al.*, 1988; Longman *et al.*, 1983).

Stony Mountain Formation

In North Dakota, the Stony Mountain Formation represents the medial formation of the Big Horn Group. It conformably overlies the Red River Formation. Thickness of the formation reaches up to 55 m (180 ft) (Carlson and Eastwood, 1962).

The Stony Mountain Formation is divided into, in ascending order, the Gunn and Gunton members. The Gunn Member is equivalent to the Stoughton Member of current usage (Bluemle *et al.*, 1986; Lobdell, 1988); usage of "Gunn" predates and supersedes the usage of "Stoughton". The original name, Gunn, will be used in the following discussion. The Gunn Member exceeds 30 m (100 ft) in thickness in eastern North Dakota and thins northwestward to a depositional edge in eastern Montana and southern Saskatchewan. It consists of thin, pale bluish-grey, bioclastic (articulate brachiopod-bryozoan assemblage) limestones interbedded with highly calcareous shale or argillaceous limestone. The shale is a medium olive grey or pinkish-grey in eastern North Dakota and grades to black in western North Dakota.

The Gunton Member conformably overlies the argillaceous strata of the Gunn Member. It consists of a pale orange to yellowish-brown, faintly mottled, finely crystalline, dense, medium- to thin-bedded, sparsely fossiliferous, slightly nodular dolostone. In the deeper basinal areas, Kendall (1976) noted the presence of a thin evaporite at the top of the member, defined as the Gunton anhydrite. Based on lithologic similarities, Lobdell (l988) suggested that the Gunton be included in the Stonewall Formation.

In Manitoba, the contact between strata of the Stony Mountain and Red River formations is sharp and possibly slightly disconformable. The Stony Mountain Formation is overlain with slight disconformity by sandy argillaceous (non-sequential) marker beds that compose the basal unit of the Stonewall Formation. The thickness of the formation ranges from 35 to 40 m (115 to 131 ft) (Manitoba Energy and Mines, 1980).

The Stony Mountain Formation has previously been subdivided into four members. In ascending order these are, the Gunn, Penitentiary, Gunton, and Williams members. Recent standardized correlations, established by McCabe and Bezys (pers. comm.) for the latest edition of the Atlas of Western Canada (in prep.) and the Lexicon of Canadian Stratigraphy (Canadian Society of Petroleum Geologists, 1990), place the top of the Stony Mountain Formation at the base of the Williams Member. It is therefore proposed that the Williams Member be included in the overlying Stonewall Formation rather than in the Stony Mountain Formation, as originally defined by Smith (1963; 1964).

The Gunn Member consists of greyish-red to purplish- and reddish-grey, burrow-mottled, fossiliferous, calcareous shale with thin interbeds of highly fossiliferous limestone. The Penitentiary Member consists of yellow to reddish-grey, medium- to thin-bedded, finely crystalline, fossiliferous, argillaceous dolostone. Where present, the Penitentiary Member is conformably overlain by the Gunton Member. Where the Gunn Member is absent, the Penitentiary Member is underlain sharply and with slight disconformity, by the Fort Garry Member of the Red River Formation.

The Gunn Member, together with the Penitentiary Member, form the lower Stony Mountain Formation (equivalent to the Stoughton Member of Saskatchewan) and are complete lateral facies equivalents. The Penitentiary Member represents a northern, more shelfward, dolomitized and less argillaceous facies. The Gunn represents a southern, deeper basinal limestone-shale facies. These members cannot be differentiated in the subsurface.

The Gunton Member conformably and transitionally overlies strata of the Penitentiary or Gunn members. It consists of very pale orange to yellowish-brown, faintly mottled, finely crystalline, dense, medium- to thin-bedded, sparsely fossiliferous, slightly nodular dolostone, that contain scattered chert nodules. Several interbeds of reddish mottled, nodular, argillaceous dolostone (Penitentiary type lithology) occur near the base of the unit (Baillie, 1951, 1952; Kent, 1960; Okulitch, 1943; Sinclair and Leith, 1958; Carlson and Eastwood, 1962).

Stonewall Formation

In North Dakota, the Stonewall Formation is conformable with the underlying Stony Mountain Formation and the overlying Interlake Formation. The Stonewall Formation is the uppermost formation in the Big Horn Group of North Dakota and reaches a maximum thickness of 37 m (120 ft).

The lower part of the Stonewall Formation consists of a thin bed of anhydrite overlain by a 6 m (20 ft) thick bed of medium dark grey, finely crystalline limestone (Carlson and Eastwood, 1962). This sequence is overlain by another thin anhydrite bed followed by a 6 to 8 m (20 to 25 ft) thick medium grey to brownish-grey finely crystalline, dolomitic limestone.

The upper part of the Stonewall Formation, in North Dakota and Manitoba, consists of light brown to grey, laminated to thin bedded, sparsely fossiliferous microcrystalline dolostone.

In Manitoba, Stonewall Formation strata are underlain sharply, and possibly with slight disconformity, by the Stony Mountain Formation. The contact with the overlying Interlake Group is also slightly disconformable. The formation generally consists of pale yellowish-grey to yellowish-brown, faintly mottled, medium- to thin-bedded, finely crystalline dolostone with sparse, poorly preserved fossils. Beds in the lower part of the formation are separated from beds in the upper part by a sandy argillaceous marker (t-marker of Porter and Fuller, 1959) (see cross-section A-A′). The Ordovician/Silurian boundary occurs within the upper part of the Stonewall Formation, possibly at the medial t-marker (Smith, 1963; Kendall, 1976; Porter and Fuller, 1959).

The Williams Member (previously assigned to the Stony Mountain Formation, Smith, 1963; 1964) forms the basal unit of the lower Stonewall beds. It consists of grey to reddish and brownish, argillaceous or sandy dolostone. The Williams Member represents the oldest of a series of "para-time-stratigraphic" markers that can be traced throughout most of the Williston and Elk Point basins.

INTERLAKE GROUP (Manitoba) / Interlake Formation (North Dakota)

In North Dakota, the Interlake Formation consists primarily of dolostones and limestones. It is conformable with the underlying Stonewall Formation and reaches a maximum thickness of 335 m (1100 ft). The formation is informally divided into lower, middle, and upper members. The lower member consists of supratidal and intertidal lithofacies characterized by felted anhydrite nodules, laminated and non-laminated dolostones, hypersaline oolites, and laminar or columnar stromatolites (LoBue, 1982). Fossiliferous wackestones representing subtidal deposits compose the middle member. Fauna included in this sequence consist of brachiopods, gastropods, pelmatozoan fragments, tabulate and rugose corals and stromatoporoids. The upper member is generally absent due to extended erosion during Late Silurian-Early Devonian time. Where present, it represents an intertidal and supratidal sequence of peloidal, intraclastic wackestones, packstones, and grainstones that locally contain gastropods. Scattered discontinuous beds of salt are also present in the lowermost portion of the upper member (Fischer and Anderson, 1984). Well developed karst, caliche, and lateritic soil zones are present on the upper surface as further evidence for a period of subaerial exposure.

Megathan (1987), raised the Interlake Formation, in North Dakota, to group status and divided it into eight formations. The lower part of the group consists of the Strathclair, Fife Lake, and Guernsey formations. Lithologies for these formations include turbidites, organic-rich basin laminites, anhydrite, and quartz-bearing marker beds. These lithologies represent a deep marine environment of deposition with normal salinities, that shallow upward and become hypersaline.

The middle part of the group is divided into the Cedar Lake and Grondale formations, which consist of a dolostone sequence that is alternately rich and barren in fossils. The presence or absence of fossils is interpreted to result from salinity variations.

The Mendenhall, Missouri Breaks, and Sherven formations form the upper part of the group. These formations were interpreted to result from the filling of a terrestrial inland basin by lakes, marsh, and stream sediments cannibalized from older carbonates along the basin margin. Inden *et al.* (1988) described the upper part of the Interlake Group as a series of thin, low-energy, shallowing-upward, restricted marine cycles represented primarily by mudstones and dolostones.

In Manitoba, the Interlake Group overlies the Stony Mountain Formation with possible slight disconformity and is overlain with gently angular unconformity by the Ashern Formation (Devonian). The thickness of the Interlake Group in Manitoba ranges from 50 to 70 m (164 to 230 ft) (Manitoba Energy and Mines, 1980). It consists primarily of pale, yellowish-grey to yellowish-brown, finely crystalline to sublithographic dolostones with coarse fossil fragmental, oolitic and stromatolitic interbeds (Porter and Fuller, 1959). Subdivision of the Interlake in the subsurface is difficult and alternative subdivisions, which are not discussed here, have been proposed by Porter and Fuller (1959); King (1964); Jamieson (1979) and others.

PETROLEUM POTENTIAL

Production has been obtained within the Deadwood Formation of North Dakota. The North Dakota producing zone comprises the basal sandstone unit of the Deadwood Formation and is restricted to the Nesson anticline and Newporte field in Renville County. Strata equivalent to the producing beds extend into Manitoba.

Strata in the Winnipeg Formation are sufficiently high in organic content to source Lower Paleozoic (Ordovician and Silurian) rocks in the Williston basin. The Winnipeg Formation provides excellent reservoir beds. These, in combination with complex facies changes, provide several possible areas for stratigraphic entrapment. In North Dakota, production from the Winnipeg Formation is located along the Nesson anticline, along the fault-bounded structure in eastern Stark County (Richardton and Taylor fields), and in Renville County (Newporte field).

Red River Formation oil occurrences are most probable in the central portion and along the flanks of the Williston basin where cyclic alternation of evaporites and porous dolomites are developed, creating stratigraphic trap settings (Andrichuk, 1959; Porter and Fuller, 1959).

The Red River Formation produces from a number of fields in western North Dakota. Production is restricted to the upper three cycles, C through A, although the majority of the reserves are thought to be in cycle C (Kohm and Louden, 1988). The reservoir rocks consist of laminated and burrowed dolomitic mudstones, wackestones, and some packstones. Textures have been changed by post-Ordovician diagenesis to a sucrosic or microsucrosic dolostone with well developed intercrystalline porosity. Minor amounts of vuggy or fracture porosity are also present. The reservoir rocks are sealed updip by anhydrite or a dense carbonate and laterally by a tight mudstone, wackestone, and dolomitic, cryptocrystalline, laminated mudstone. The reservoirs are thought to be self-sourced by the kerogenites of the C burrowed zone. Structural closure is necessary for production.

Oil production has been obtained from the Gunton Member of the Stony Mountain Formation and from the Stonewall Formation. Oil occurrences are concentrated in the central area of the Williston basin and associated with production from the Red River Formation.

In North Dakota the upper Interlake Formation produces from structural/stratigraphic or stratigraphic/diagenetic traps. Reservoir rocks generally consist of fenestral algal boundstones and associated paleosols trapped by dolomitic mudstones or brecciated dolomitic mudstones of supratidal origin. Fractures enhance production. The middle Interlake Formation produces in Stark County. The lower Interlake Formation produces from several porosity zones along major structural features.

REFERENCES

Anderson, D.B.
1988: Stratigraphy and depositional history of the Deadwood Formation (Upper Cambrian and Lower Ordovician), Williston basin, North Dakota: Master's thesis, University of North Dakota, Grand Forks, North Dakota, 330 p.

Andrichuk, J.M.
1959: Ordovician and Silurian stratigraphy and sedimentation in southern Manitoba, Canada: American Association of Petroleum Geologists Bulletin, v. 43, p. 2333-2398.

Baillie, A.D.
1951: Silurian geology of the Interlake area: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 50-1, 82 p.
1952: Ordovician geology of Lake Winnipeg and adjacent areas: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Publication 51-6, 64 p.

Bluemle, J.P., Anderson, S.B., Andrew, J.A., Fischer, D.W., and LeFever, J.A.
1986: North Dakota stratigraphic column: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 66, 3 sheets.

Canadian Society of Petroleum Geologists
1990: Lexicon of Canadian stratigraphy, volume 4, western Canada including eastern British Columbia, Alberta, Saskatchewan and southern Manitoba: Calgary, Alberta, Canadian Society of Petroleum Geologists, 772 p.

Carlson, C.G., and Eastwood, W.P.
1962: Upper Ordovician and Silurian rocks of North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Bulletin No. 38, 52 p.

Carroll, W.K.
1978: Depositional and paragenetic controls on porosity development, Upper Red River Formation, North Dakota, **in** Estelle, D., and Miller, R. (eds.), The economic geology of the Williston Basin, 1978 Williston Basin Symposium: Billings, Montana, Montana Geological Society, p. 79-97.

Elias, R.J., Nowlan, G.S., and Bolton, T.E.
1988: Paleontology of the type section, Fort Garry Member, Red River Formation (Upper Ordovician), southern Manitoba: Socorro, New Mexico, New Mexico Bureau of Mines and Mineral Resources, Memoir 44, p. 341-359.

Fischer, D.W., and Anderson, S.B.
1984: Little-known mid-Paleozoic salts of northwestern North Dakota: Grand Forks, North Dakota, North Dakota Geological Survey, Report of Investigations No. 83, 18 p.

Foerste, A.F.
1929a: The Ordovician and Silurian of the American arctic and sub-arctic regions: Denison University Science Lab Journal, v. 24, p. 27-79.
1929b: The cephalopods of the Red River Formation of southern Manitoba: Denison University Science Lab Journal, v. 24, p. 129-235.

Genik, G.J.
1952: A regional study of the Winnipeg Formation: Master's thesis, University of Manitoba, Winnipeg, Manitoba, 174 p.
1954: A regional study of the Winnipeg Formation: Journal of the Alberta Society of Petroleum Geologists, v. 2, p. 1-5.

Inden, R.F., Cluff, R.M., and Brynes, A.P.
1988: Reservoir geology and petrophysics of the Upper Interlake Group, Nesson anticline area, North Dakota, **in** Goolsby, S.M., and Longman, M.W. (eds.), Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 291-302.

Jamieson, E.R.
1979: Well data and lithologic descriptions of the Interlake Group (Silurian) in southern Saskatchewan: Regina, Saskatchewan, Saskatchewan Department of Mineral Resources, Report No. 139, 67 p.

Kendall, A.C.
1976: The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan: Regina, Saskatchewan, Saskatchewan Department of Mineral Resources, Report No. 180, 186 p.

Kent, D.M.
1960: The evaporites of the Upper Ordovician strata in the northern part of the Williston basin: Regina, Saskatchewan, Saskatchewan Department of Mineral Resources, Report No. 46, p.

King, K.R.
1964: The Silurian Interlake Group in Manitoba, **in** Leskela, W., Brindle, J., and Harris, S.H. (eds.), Third International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan, North Dakota and Billings Geological Societies, p. 51-55.

Kohm, J.A., and Louden, R.O.
1988: Red River reservoirs of western North Dakota and eastern Montana, **in** Goolsby, S.M., and Longman, M.W. (eds.), Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 291-302.

LeFever, R.D., Thompson, S.C., and Anderson, D.B.
1987: Earliest Paleozoic history of the Williston basin in North Dakota, **in** Carlson, C.G., and Christopher, J.E. (eds.), *Fifth International Williston Basin Symposium*: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 9, p. 22-36.

Lobdell, F.K.
1988: Macropaleontology of the Gunn Member, Stony Mountain Formation (Upper Ordovician), Manitoba and North Dakota: Ph.D. dissertation, University of North Dakota, Grand Forks, North Dakota, 371 p.

LoBue, C.L.
1982: Depositional environments and diagenesis of the Silurian Interlake Formation Williston basin, western North Dakota, **in** Christopher, J.E., and Kaldi, J. (eds.), Fourth International Williston Basin Symposium: Regina, Saskatchewan, Saskatchewan Geological Society, Special Publication No. 6, p. 29-42.

Longman, M.W., Fertal, T.G., and Glennie, J.S.
1983: Origin and geometry of Red River dolomite reservoirs, western Williston basin: American Association of Petroleum Geologists Bulletin, v. 67, p. 744-771.

Manitoba Energy and Mines
1980: Manitoba stratigraphic map series.

McCabe, H.R.
1978: Reservoir potential of the Deadwood and Winnipeg formations, southwestern Manitoba: Winnipeg, Manitoba, Manitoba Mines, Natural Resources and Environment, Mineral Resources Division, Geological Paper GP 78-3, 54 p.

McCabe, H.R., and Bannatyne, B.B.
1970: Lake St. Martin crypto-explosion crater and geology of the surrounding area: Winnipeg, Manitoba, Manitoba Mines and Natural Resources, Mines Branch, Geological Paper GP 70-3, 79 p.

Megathan, E.R.
1987: Silurian Interlake Group - a sequence of cyclic marine and freshwater carbonate deposits in the central Williston basin, **in** Fischer, D.W. (ed.), Core workshop Volume, Fifth International Williston Basin Symposium: Grand Forks, North Dakota, North Dakota Geological Survey, Miscellaneous Series No. 69, p. 59-88.

Okulitch, V.J.
1943: The Stony Mountain Formation of Manitoba: Transactions of the Royal Society of Canada, v. 37, p. 59-74.

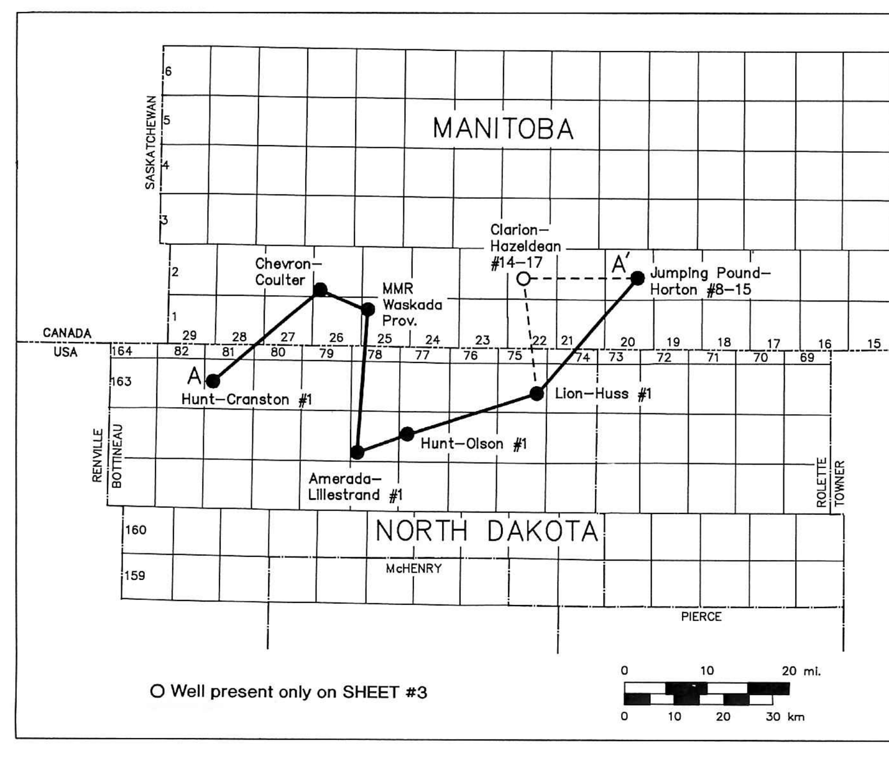
Porter, J.W., and Fuller, J.G.C.M.
1959: Lower Paleozoic rocks of northern Williston basin and adjacent area: American Association of Petroleum Geologists Bulletin, v. 43, p. 124-189.

Sanford, B.V., Norris, A.W., Bostock, H.H., and Bell, R.T.
1968: Geology of the Hudson Bay lowlands - Operation Winisk: Geological Survey of Canada, Paper 67-60, p. 1-46.

Sinclair, G.W., and Leith, E.I.
1958: New name for an Ordovician shale in Manitoba: Journal of Paleontology, v. 32, p. 243-244.

Smith, D.L.
1963: A lithologic study of the Stony Mountain Formation and Stonewall Formation in southern Manitoba: Master's thesis, University of Manitoba, Winnipeg, Manitoba, 219 p.
1964: A lithologic study of the Stony Mountain and Stonewall formations in southern Manitoba (abs.): Canadian Mining Journal, v. 85, p. 114, 117.

Vigrass, L.W.
1971: Depositional framework of the Winnipeg Formation in Manitoba and eastern Saskatchewan, **in** Turnock, A.C. (ed.), Geoscience Studies in Manitoba: Geological Association of Canada, Special Paper No. 9, p. 225-234.



LINE OF CROSS-SECTION

METRIC CONVERSION TABLE

1 metre (m)	= 3.28 feet (ft)
1 cubic metre (m^3)	= 6.29 barrels (bbls) (oil)
	= 220 imperial gallons
	= 35.49 cubic feet (gas)
1 hectare (ha)	= 2.47 acres
1 kilometre (km)	= 0.62 miles (mi)

SHEET # 5: **CAMBRIAN–ORDOVICIAN–SILURIAN**

CORRELATION CROSS–SECTIONS ALONG THE UNITED STATES–CANADA INTERNATIONAL BORDER (NORTH DAKOTA–MANITOBA)

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