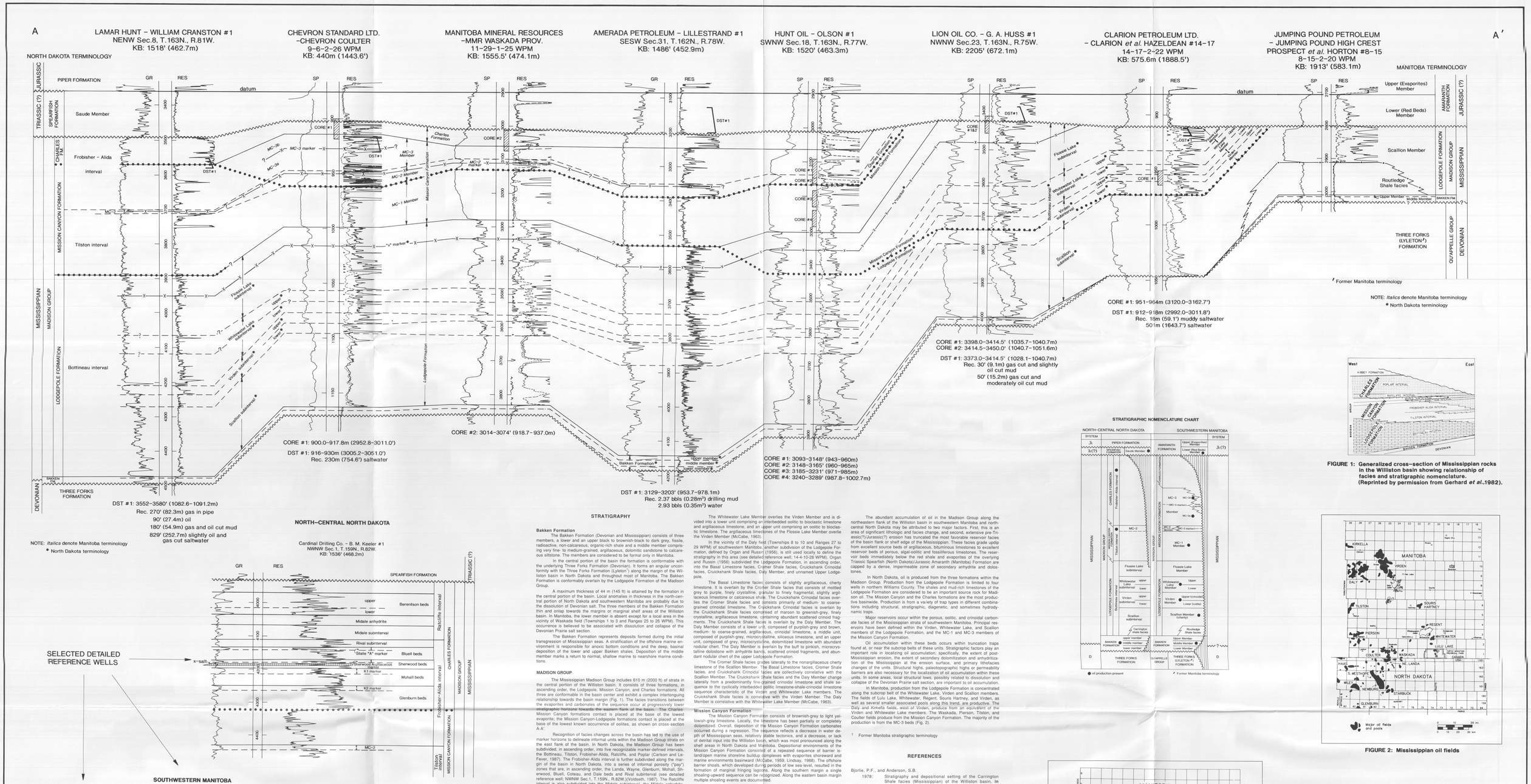
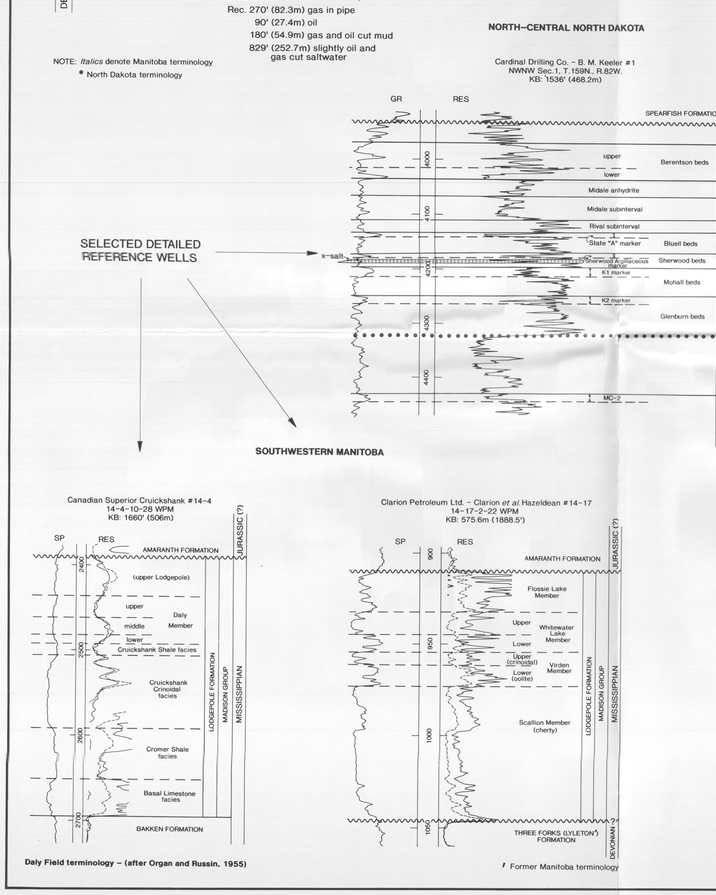


FIGURE 1: Generalized cross–section of Mississippian rocks in the Williston basin showing relationship of facies and stratigraphic nomenclature. (Reprinted by permission from Gerhard *et al.*,1982).



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

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 anomalies 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 (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 evaporites and carbonates of the sequence occur at progressively lower stratigraphic intervals 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 among 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 minor 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, purple, 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 lateral 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 25 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 lentils, 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 fringing 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 factors 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).

† 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.

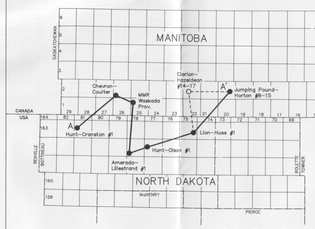
Organ, D.W.E., and Russin, G.M.
1956: Mississippian stratigraphy of the Daly oil field: Oil in Canada, v. 8, no. 22, p. 40-47.

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.



LINE OF CROSS–SECTION

FIGURE 2: Mississippian oil fields

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 #3: **MISSISSIPPIAN**

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

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