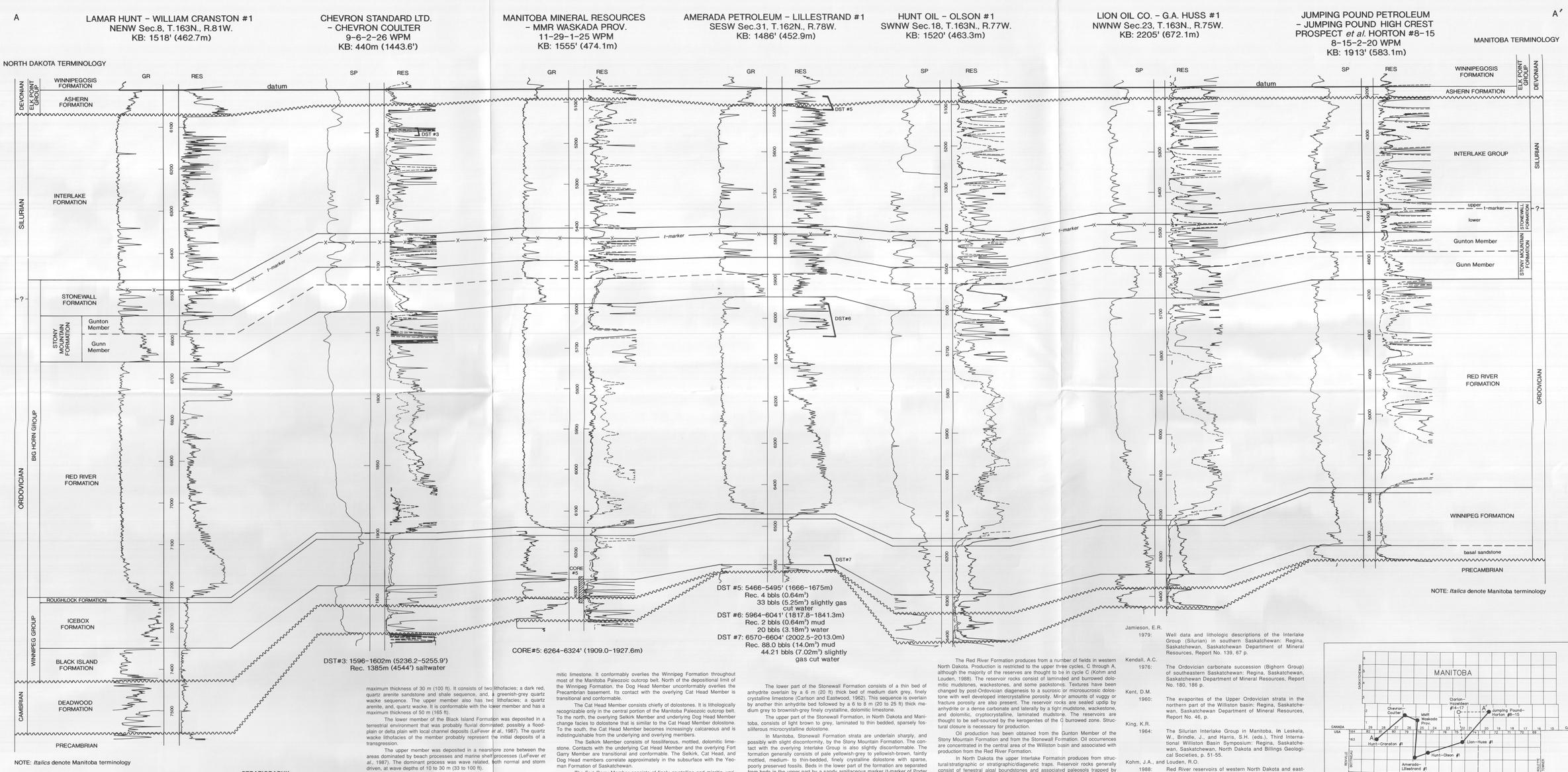

STRATIGRAPHY

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 formation unconformably underlies 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 conformably 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 Formation 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 sedimentary structures were 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 prevailed during the local sandstone lithosome deposition. 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 conformably underlies the Red River Formation.

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 beds 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 abruptly 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 fossiliferous limestone. 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 electric 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 a relatively deeper 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; Porter and Fuller, 1959; Stenzel, 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); use 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 thick, gray, bioclastic limestone. Based on lithologic similarities (and faunal 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 (1988) 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 correlative 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 intervals 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, pelecypods, ostracods, conodonts, 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 bass a shales, micritic limestones, 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 Grandale 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 are characterized by a cyclic fill-ing of a terrestrial inland basin by lakes, marsh, and stream sediments canibalized 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 microsuroic 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.

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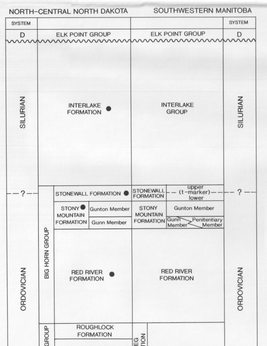
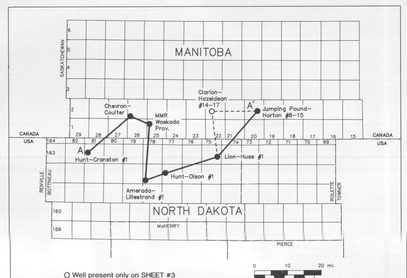
STRATIGRAPHIC NOMENCLATURE CHART





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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