Update on industrial mineral and stratigraphic investigations in Manitoba

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Evidence of the potential for Mississippi Valley-type lead-zinc deposits in Manitoba

Introduction

Mississippi Valley-type (MVT) deposits consist of stratabound, carbonate-hosted assemblages of sphalerite, galena and iron sulphides, typically occurring within marine platformal dolostone and limestone near basinal edges (Paradis et al., 2007; Leach et al., 2010). It is generally understood that metalliferous, saline basinal waters driven by large-scale tectonic events are the source of ore fluids. MVT deposits often occur in clusters of tens to hundreds of individual ore bodies that make up a broad district. The ore bodies are typically controlled by local lithological and structural features, such as solution collapse breccias, faults/fractures and shale-carbonate shale facies.

Several examples of in situ lead-zinc mineralization have been found in Paleozoic carbonates in the Williston Basin, southwestern Manitoba. The Manitoba Geological Survey (MGS) and several companies have undertaken exploratory investigations into occurrences of of carbonate-hosted sphalerite-galena mineralization in the province; as of yet no deposits have been discovered.

Numerous structural and geological conditions in the province indicate that the MVT model may be applicable within Manitoba. Platformal carbonates, shales, evaporites, karsting and reefal structures, often associated with MVT deposits, are all present in southwestern Manitoba. The Superior Boundary Zone (SBZ) may have acted as a source of base-metal bearing fluids and provided conduits for fluid flow.

Figure 2: Fracture-filled sulphide stringer within dolomite drillcore from Klyne no. 3 (Bamburak and Klyne, 2004).

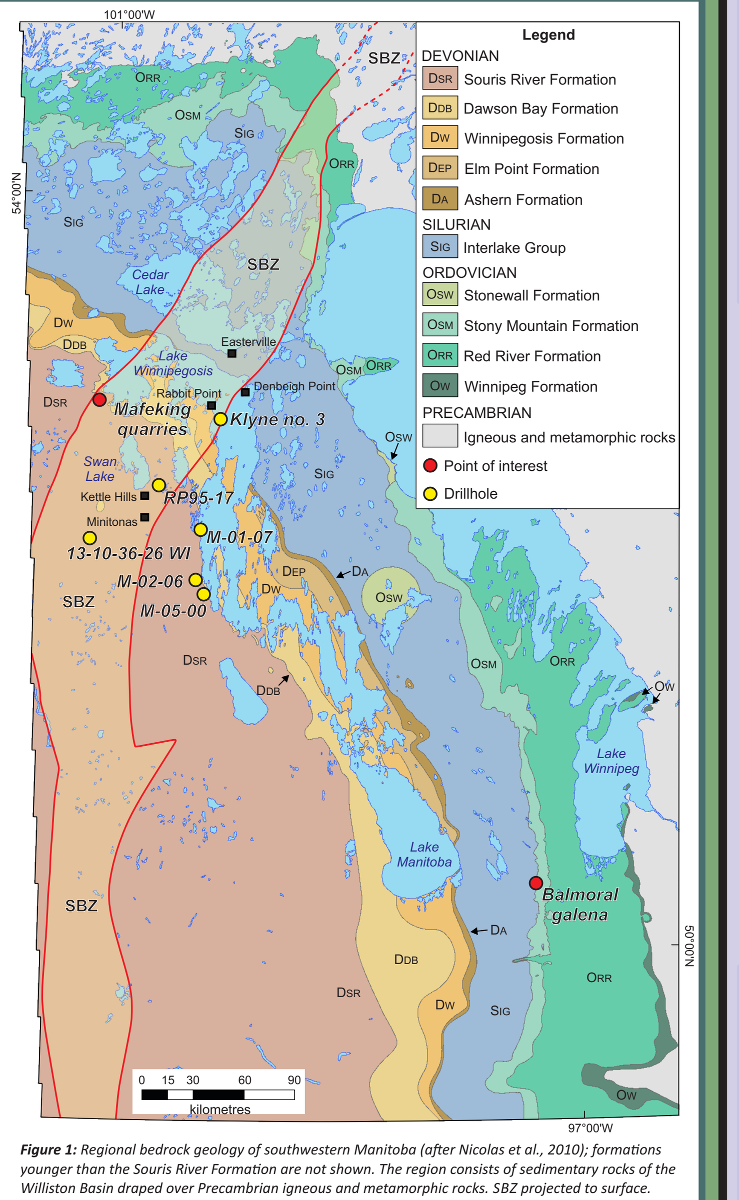

Figure 1: Regional bedrock geology of southwestern Manitoba (after Nicolas et al., 2010); formations younger than the Souris River Formation are not shown. The region consists of sedimentary rocks of the Williston Basin draped over Precambrian igneous and metamorphic rocks. SBZ projected to surface.

Carbonate-Hosted Pb-Zn Mineralization in Manitoba

Several occurrences of sphalerite and galena mineralization have been reported in Paleozoic strata in Manitoba (Table 1, Fig. 1).

Table 1: Reported occurrences of in situ carbonate-hosted sphalerite-galena and lithological features in Manitoba that a comparable to Mississippi Valley-type districts elsewhere. UTM co-ordinates are in NAD83, Zone 14.

	Easting	Northing	Mineralization	Stratigraphic unit	Reference
Balmoral pebble	NE¼-26-14-1-E[1]		Galena	Surficial sediments	Gale and Conley (2000)
Mafeking quarries	361740	5855814	Prairie-type	Point Wilkins Mb., Souris River Fm.	Fedikow et al. (2004)
13-10-36-26W1 drillhole	356371	5772556	Sphalerite	Stony Mountain Fm.	A.F. 92116
Klyne no. 3 drillhole	433525	5842645	Sphalerite (Figure 2)	Upper Interlake Group	Bamburak and Klyne (2004); A.F. 74128
M-05-00 drillhole	423445	5739324	Sphalerite, minrecordite, stilleite	Upper member, Winnipegosis Fm.	Bamburak (2007)
M-02-06 drillhole	415171	5739363	Sphalerite	Second Red Bed Mb., Dawson Bay Fm.	Bamburak (2006, 2007)
M-01-07 drillhole	421088	5774977	Saddle dolomite; hydrothermal dolomite	Cedar Lake Fm., Interlake Group	Bamburak (2007); Rawluk (2010)
RP95-17 drillhole	396816	5803656	Sphalerite; galena (Figure 3,a,b)	Lower member, Winnipegosis Fm.; lower Red River Fm.	Lapenskie and Nicolas (2017)

[1]UTM coordinates available, collected in NE¼, Sec. 26, Twp. 14, Rge. 1, E 1st Mer. Abbreviations: n/a, not applicable; A.F., Assessment File; Mb., Member; Fm., Formation; TVD, true vertical depth

Evidence of MVT Deposits in Manitoba

Many geological features common to MVT deposits (e.g., Paradis et al., 2007; Leach et al., 2010) are documented in the Williston Basin of Manitoba (Lapenskie and Nicolas, 2017). Modern understanding of MVT deposits suggests that the ores are sourced from high volumes of metal-rich, intrabasinal brines and require a tectonically driven, fluid-flow event and fluid conduits to allow for deposition within host carbonates (Paradis et al., 2007; Leach et al., 2010). In most known MVT districts, orogenic events are thought to be the main driver of saline fluid flow leading to precipitation of Pb-Zn sulphides, however, the Manitobe portion of the Williston Basin was far removed from orogenic regions. McRitchie (1991) and Dietrich et al. (1997) presented evidence to suggest that the sub-Phanerozoic extensions of the SBZ in Manitoba underwent movement through crustal flexure during the Paleozoic, which could have provided conduits for fluid flow via reactivation of basement faults. The SBZ coupled with evaporitic sequences (i.e., Prairie Evaporite), could have been the source of metalliferous brines.

Other geological features in the Williston Basin further imply potential for carbonate-hosted Pb-Zn occurrences in Manitoba, including karsting, reefal structures and facies changes. These are known to be preferential locations for sulphide precipitation and development of MVT deposits (Paradis et al., 2007; Leach et al., 2010). Some of these structures can be correlated to faults within the SBZ.

There are some features associated with the development of MVT deposits that have yet to be clearly identified in Manitoba. MVT deposits are located within 600 km of an orogenic belt and many were emplaced during the Late Devonian to Early Carboniferous and the Late Cretaceous to Early Paleocene (Paradis et al., 2007; Leach et al., 2010). The Manitoba portion of the Williston Basin was far removed from the nearest orogenic belts, exceeding the 600 km distance. Some other type of event must be proposed to be the driving force of basinal fluid movement. Saddle dolomite has been identified in drillcore M-01-07 (Rawluk, 2010), from an interval that may consist of hydrothermal dolomite. Hydrothermal alteration, and specifically saddle dolomite, is often associatd with Pb-Zn mineralization in host carbonate rocks (Paradis et al., 2007). Further isotope and fluid inclusion work is required to confirm that hydrothermal processes have taken place in this and other cores.

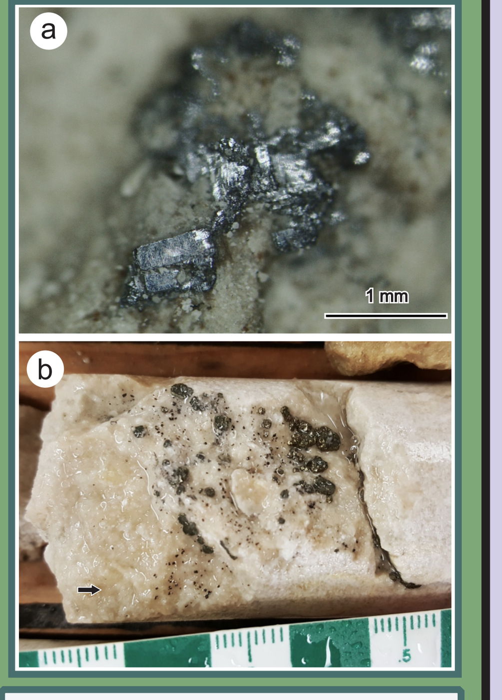

*Figure 3: Lead and zinc mineralization in drillcore RP95-17 (A.F. 94638): **a)** photomicrograph of galena associated with a rugose coral from the Red River Formation, at a depth of 344.87 m (TVD); and **b)** photograph of a subvertical fracture lined with calcite and sphalerite, in the lower member of the Winnipegosis Formation, at a depth of 109.95 to 110.28 m (TVD).Arrow indicates up direction in core.*

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Gypsum resources in the Amaranth area, west shore Lake Manitoba

Introduction

In 2015, the MGS initiated an investigation into the gypsum resources of Manitoba (Lapenskie and Bamburak, 2015). The aim of this project is to provide a comprehensive update on this commodity, which has been utilized for industrial purposes in Manitoba for over 100 years (Bannatyne, 1959, 1977; Gunter, 1987). Economic deposits of gypsum occur in the evaporitic Upper Amaranth Member of the Amaranth Formation. The member is composed predominantly of gypsum and/or anhydrite.

Objectives of this investigation are aimed at improving our knowledge of gypsum resources in Manitoba to encourage exploration and aid in future land-use planning:

- compile the history of gypsum quarrying, exploration, and production;
- provide a comprehensive update on the geological description and correlation of the evaporites of the Upper Amaranth Member; and
- general detailed structure contour and isopach maps of the overlying Quaternary sediments and Upper Amaranth Member.

Structure contour and isopach maps

Drillcore data, as well as water well data, for the Harcus-Amaranth area have been compiled, and detailed structure contour and isopach maps of the Quaternary sediments and Upper Amaranth Member have been generated (Figures 1 and 2). Drillcore and water well data were computer generated to create the structure contour and isopach maps. The underlying grids for the map were created using Spatial Analyst for ArcGIS, with the Spline with Barriers interpolation method. The grids were then contoured using the Contour with Barriers method in Spatial Analyst. In much of the map area, known member thickness is sparse; therefore, the accuracy of the contours can be low. Due to the highly variable thickness of the Quaternary sediments and gypsum in this area, these maps should only be used to guide exploration as a current best estimate. Karsting and/or erosional features are common in the Upper Amaranth Member, which provides additional caveats when modelling sediment and rock thicknesses.

Quaternary isopach map (Figure 1)

Quaternary sediments are generally thinnest in the central to eastern regions of the map area, and range from <2m to >78m in thickness. Gypsum quarrying is currently taking place in the northeastern region of the map area, where thin Quaternary cover allows easy access.

Elliptical areas of anomalously thicker Quaternary sediments may indicate the presence of large areas of karsting or sinkhole development. This would have occurred within the underling member before the deposition

Upper Amaranth Member isopach map (Figure 2)

The Upper Amaranth Member is generally thickest along a NNW-SSE trend on the right side of the map area. Thickness of the member ranges from 0 m to >20 m. Roughly elliptical areas of decreased gypsum thickness may represent sinkholes or karsted areas.

The edge of the Upper Amaranth Member trends irregularly east to west in the northern part of the map area.

Figure 1

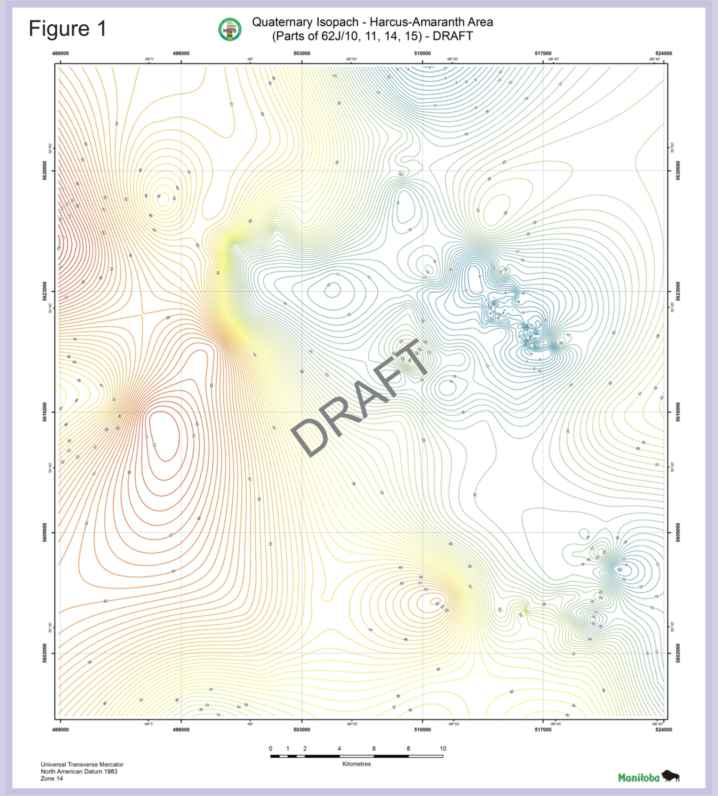
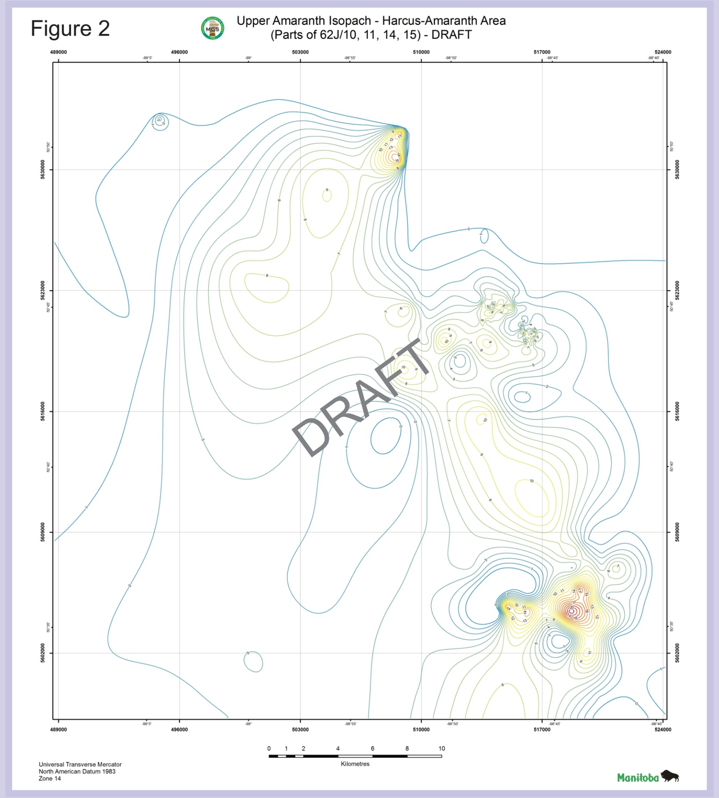


Figure 2



Economic Considerations

Current gypsum quarrying activities significantly contribute to the cement and wallboard industries in the province. The gypsum-based wallboard manufacturing company in Winnipeg is the only one of its kind in Manitoba, and has strong economic significance as it exclusively serves a large geographic region. Detailed isopach and structure contour maps of the Harcus-Amaranth area will help operators guide expansion plans and identify future exploration targets. Investigations into the stratigraphy and karst development in the Upper Amaranth Member will provide valuable information for future land-use planning. Resolving the stratigraphic correlation between the Williston Basin and the Lake St. Martin igneous and metamorphic complex will add to the understanding of the depositional history of Phanerozoic strata in Manitoba.

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High-purity silica sand of the Winnipeg Formation

Summary

The Winnipeg Formation contains some of the purest silica sand deposits in North America. Historically, this silica sand has been quarried and processed in the province to produce glass. The MGS is re-examining this formation to determine the economic potential of the silica sand for a variety of applications, including as a very high quality proppant for fracking. The SiO_2 content and the morphology of the sand grains will need to be defined for the various sandstone lithofacies of the Winnipeg Formation. Several objectives must be achieved:

- compile detailed geological descriptions of outcrops and drillcore to correlate lithofacies variations across the subcrop-outcrop belt of the basin;
- determine quality of the silica sand as it pertains to the various lithofacies through geochemical analyses and quantitative descriptions of sand; and
- create isopach and structure contour maps where necessary using drillhole and water well data.

Regional Geology

The Winnipeg Formation occurs in southwest Manitoba at the base of the Williston Basin strata (Figure 1). It comprises the oldest Ordovician rocks in Manitoba and is the oldest outcropping Phanerozoic rock in the province. The formation noncomformably overlies Precambrian bedrock, except in the southwestern corner of Manitoba where it unconformably overlies the Cambrian Deadwood Formation (McCabe, 1978). The Winnipeg Formation is overlain by the Red River Formation.

The Winnipeg Formation is subdivided into Upper and Lower units, with a vestigial off-shore sand bar, termed the Carman sand, occurring between these units in southern Manitoba (Vigrass, 1971; Nicolas, 2008). The formation is comprised of quartz-rich sandstones and variably arenaceous mudstones. The maximum thickness of the Winnipeg Formation is 60 m.

Figure 1: Section of the Winnipeg Formation in the Black Island quarry. Cross-stratified bed is approximately 1.75 m thick.

Black Island, south basin Lake Winnipeg

The Winnipeg Formation is exposed in a quarry on the south shore of Black Island. The maximum thickness of the section is ~7.8 m. The outcrops on Black Island and in Hecla-Grindstone Provincial Park are from the Lower unit (McCabe, 1978; Watson, 1985).

There are two lithologic units on Black Island, a lower sandstone unit and an upper pyritic shale unit (Figure 1). The sandstone is composed of bedded to cross-bedded, burrowed, grain-supported quartz arenite. The sand is comprised entirely of well-rounded to rounded, equant, very coarse to fine-grained quartz grains. The overlying unit is composed of pyritic, bedded to laminated shale.

Hecla-Grindstone Provincial Park, south basin Lake Winnipeg

Exposures of the Winnipeg Formation were observed on Grindstone and Little Grindstone points. The formation attains a maximum thickness of 1.4 m, although the base of the sections observed were covered with slumped material.

Here the Winnipeg Formation is only composed of a single sandstone unit. The sandstone is composed of massively bedded, pyritic, variably calcareous quartz arenite (Figure 2). Pyrite nodules occur concentrated in irregular laminations. The sane is comprised of well sorted, well rounded, equant, predominantly fine-grained quartz grains. The upper contact with the Red River Formation is sharp; the lower contact was not observed.

Figure 2: Section of the Winnipeg and Red River formations on Little Grindstone Point.

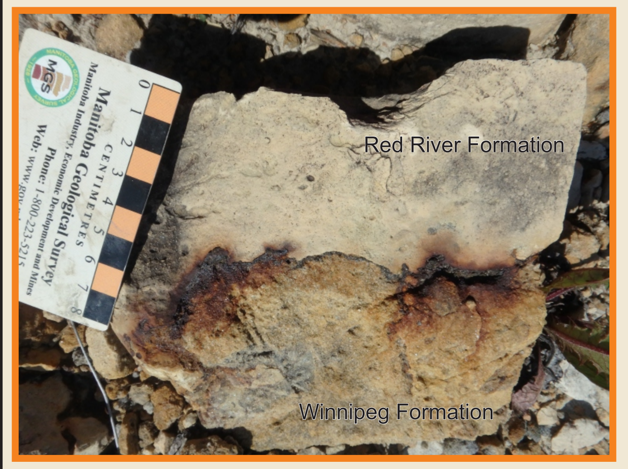

Figure 3: Contact between the Winnipeg and Red River formations; note disseminated sulphides along the contact.

Northern edge, Williston Basin

There are few outcrops of the Winnipeg Formation in the Wekusko Lake to Athapapuskow Lake area; more field work is needed in the area to identify and substantial sections.

Along provincial highway 39, a relatively recent excavation of the ditch adjacent to the road results in large blocks of the Winnipeg Formation being exposed. These boulders provide excellent examples of the contact between the Winnipeg and Red River formations in this region. Disseminated sulphides are abundant in the uppermost Winnipeg Formation and along the upper contact (Figure 3). These Winnipeg Formation is comprised of massive, fossiliferous, pyritic quartz arenite.

Ongoing drillcore exploration projects in the sub-Phanerozoic extension of the Flin Flon-Snow Lake belt provide further insight into the lithofacies of the Winnipeg Formation (Lapenskie, 2019). In the northern portion of the Williston Basin, the Winnipeg Formation is very heterogenous. Lithologies vary from unconsolidated sand, kaolin-rich mudstone, quartz wacke to arenite, feldspathic wacke to arenite, and quartzose conglomerate to diamictite. Immature sandstones containing gravel-sized quartz clasts, as well as garnet and biotite grains were observed in some drillcore. These sandstones are variably pyritic, with elevated concentrations of sulphides most commonly occurring near the upper contact of the Winnipeg Formaiton with the overlying Red Red Formation dolomudstones.

Figure 4: Red River and Winnipeg formations and regolith (drillcore HAR164), showing multiple lithofacies of the Winnipeg Formation (R.R., Red River Formation; W.F., Winnipeg Formation; q.a., quartz arenite; q.d., quartz diamictite; R., regolith)

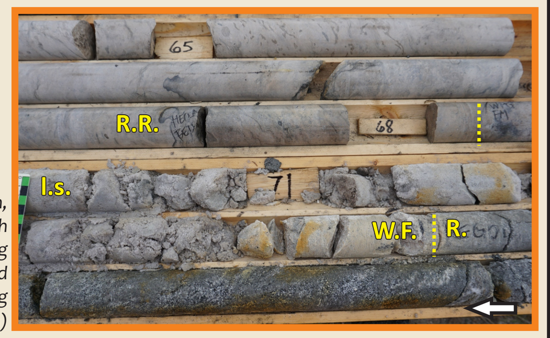

Figure 5: Red River Formation, Winnipeg Formation and regolith (drillcore HAR197), showing unconsolidated sand (R.R., Red River Formation; W.F., Winnipeg Formation; l.s., loose sand; R., regolith)

Economic Considerations

The high-purity silica sands of the Winnipeg Formation are a possible source of foundry sand, and has a great deal of potential for being a very high quality frac sand. Other potential uses of the silica sand include creating silicon carbide, silicon metal, and enamels. Geological investigations into the quality and purity of these silica sands as they pertain to the various lithofacies changes across the Williston Basin will help guide industry in selecting areas of high economic potential.

Further work is required to quantitatively assess the quality of the silica sands of the different facies of the Winnipeg Formation in northern portions of the Williston Basin. Microscope and thin section observations will be conducted to quantitatively describe and classify the lithofacies of the Winnipeg Formation. Geochemical analysis will be performed to quantitatively assess the quality of the silica sands.

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Phanerozoic corelogging activities in southwestern Manitoba

Summary

The lower Paleozoic stratigraphic framework of southwestern Manitoba contains many inconsistencies (Lammers, 1988; Bezys and Conley, 1998; Nicolas and Barchyn, 2008; Lapenskie and Nicolas, 2017) (Figure 1). Lateral variations in lithology, facies changes and stratigraphic boundaries, coupled with few core available in the transitional areas between the deeper subsurface and outcrop belt, have made correlating units across the Williston Basin challenging. In particular, parts of the Ordovician Red River Formation, the Silurian Interlake Group, and parts of the Devonian Dawson Bay and Souris River formations are not consistently correlated between outcrop and the subsurface.

The MGS is engaged in ongoing efforts to refine the stratigraphic framework of the Manitoba portion of the Williston Basin, by re-examining drillcore and by examining new drillcore generated from mineral exploration projects across the southwestern area of the province. These activities also feed into various industrial mineral-related projects being investigated by the MGS. Refining the stratigraphic framework of the Williston Basin has positive implications for the petroleum and industrial mineral industries and for Mississippi Valley-type deposit exploration.

Several important drillcore that have recently been examined have yielded important insights into the subsurface stratigraphy of Manitoba, most notably in transitional areas between outcrops and the basinal edge, to the deeper subsurface of the Williston Basin (Lapenskie and Nicolas, 2017; Lapenskie and Nicolas, 2018; Lapenskie, 2019). Drillcores Rp95-17 (Lapenskie and Nicolas, 2017), Neepawa DDH No. 1 Prov. 15-29-14-14W1 (Lapenskie and Nicolas, 2018), and GMCL Minitonas 3-29-36-25W1 (Lapenskie, 2019) provide near complete sections of Lower Paleozoic strata in areas where the subsurface stratigraphy is relatively understudied (Figure 2).

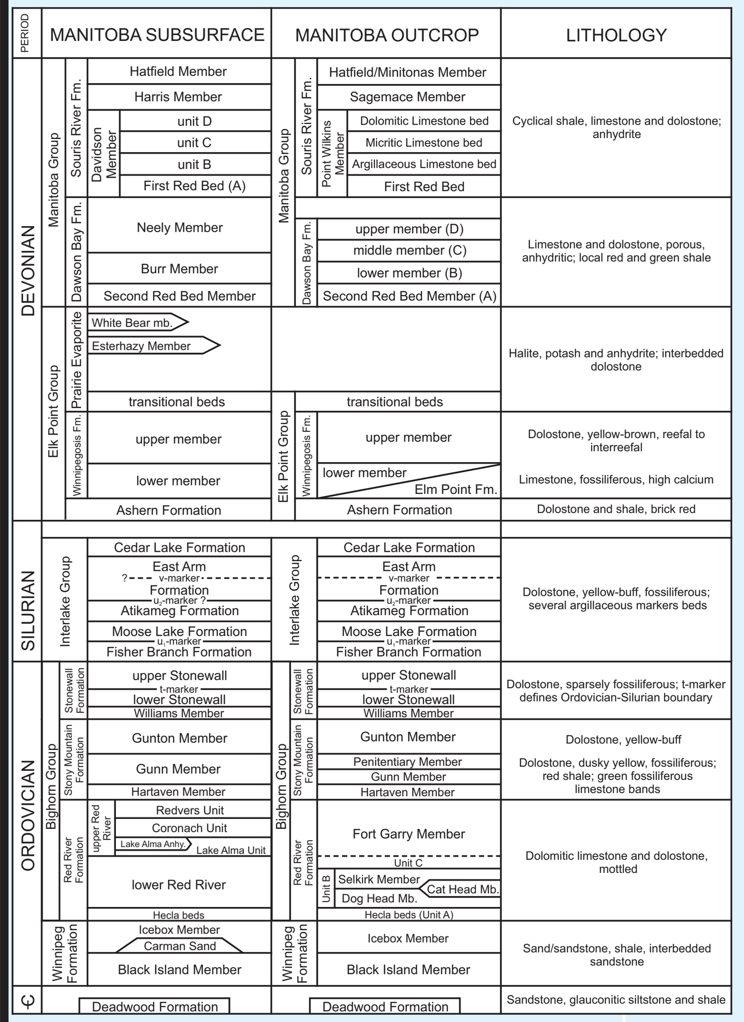

Figure 1: Lower Paleozoic stratigraphic framework for the subsurface and outcrop belt of the Williston Basin in Manitoba

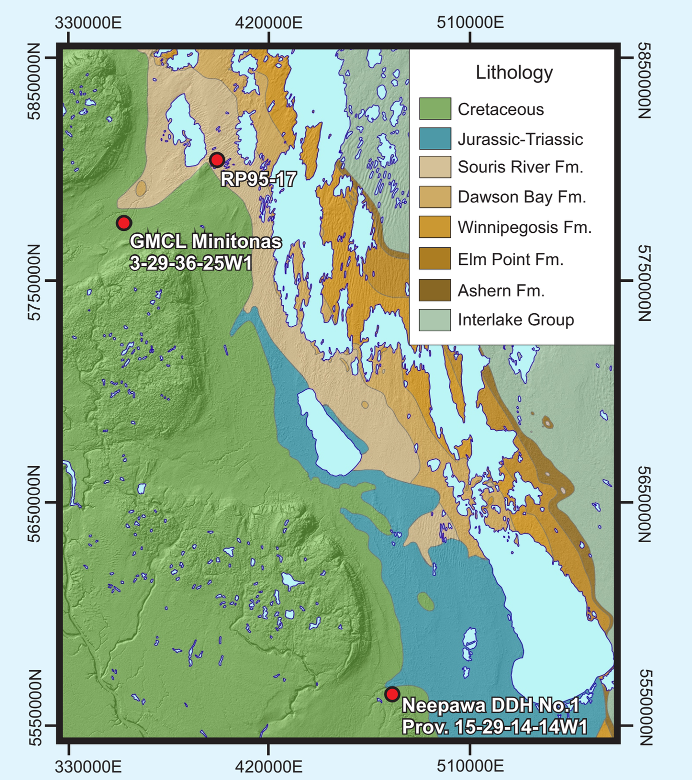

Figure 2: Regional bedrock geology of southwestern Manitoba (after Nicolas et a. 2010); locations of drillcore are shown.

Neepawa DDH No. 1 Prov. 15-29-14-14W1

Drillcore Neepawa DDH consists of almost 500 m of continuous core from Precambrian basement to the Devonian Souris River Formation (Lapenskie and Nicolas, 2018). Correlations of established outcrop-based lithostratigraphic units were extrapolated to the subsurface in Manitoba and, where established, mostly Manitoba-derived lithostratigraphic units and nomenclature were used. Several correlation issues were resolved within this core and inconsistencies were identified.

Below is a summary of the correlation issues that were resolved:

- the Lake Alma Member, Coronach Member and Redvers Unit, were defined in the upper Red River Formation; these units are formally recognized in eastern Saskatchewan
- the Fisher Branch, Moose Lake, Atikameg, East Arm and Cedar lake formations where defined in the Interlake Group; these units are formally recognized in the Manitoba outcrop belt

Some correlation issues still remain to be resolved:

- investigating the occurrence and reliability of the u2- and v-marker beds in the Interlake Group
- formalizing and correlating the informal units of the subsurface Davidson Member to the information beds of the outcrop-based Point Wilkins Member
- resolving the number of discrete shale-carbonate-evaporite cycles present in the Harris Member, Souris River Formation (Figure 4)

Figure 4: Interbedded shale-carbonate-evaporite cycles from the Harris Member, drillcore Neepawa DDH, from 281.9m to 285.0m. Up direction to the left.

Figure 5: Limestone and diamictites of the transitional beds, Prairie Evaporite in drillcore GMCL Minitonas, from 235.0m to 237.4m. Up direction to the left.

RP95-17

Drillcore RP95-17 provides a nearly complete section of the lower Paleozoic from the basal Ordovician Winnipeg Formation to the Devonian middle member of the Dawson Bay Formation (Lapenskie and Nicolas, 2017). Below is a summary of important observations of the stratigraphy of RP95-17:

- the Lake Alma Member, Coronach Member and Redvers Unit were identified in the upper Red River Formation
- the Fisher Branch, Moose Lake, Atikameg, East Arm and Cedar lake formations where defined in the Interlake Group
- the Cross Lake and Chemahawin members were defined in the Cedar Lake Formation
- extensive brecciation was observed in the Devonian strata, most likely related to Prairie Evaporite dissolution and karsting in the Interlake Group (Figure 3)

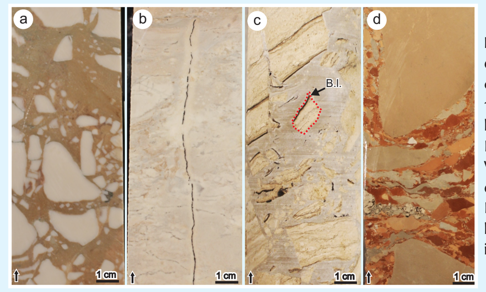

Figure 3: Photographs of drillcore RP97-15 showing chaotic breccias from a) 134.3m, Cedar Lake Formation, b) 1307.m, Cedar Lake Formation; c) 89.37m, Winnipegosis Formation; and d) 76.45m, Dawson Bay Formation. Abbreviations: B.I., bituminous laminations. Arrow indicates up direction in core.

GMCL Minitonas 3-29-36-25W1

Drillcore GMCL Minitonas transected over 500 m of Phanerozoic strata, including 430.1 m of Paleozoic rock (Lapenskie, 2019). This drillcore offers a complete section, with excellent core recovery, of the lower Paleozoic strata of the Manitoba outcrop belt, from the lowermost Ordovician Winnipeg Formation to uppermost Devonian Hatfield Member, Souris River Formation. Below are some of the important observations made during logging of this drillcore:

- The Winnipeg Fm was subdivded into the lower sandstone and upper shaly Black Island and Icebox members
- The upper Red River Fm was subdivided into the Lake Alma Mbr, Coronach Mbr, and Redvers Unit
- The Interlake Group was subdivided into all constituent fms
- The u1-, u2- and v-marker beds were all present
- The Prairie Evaporite consisted only of limestone and diamictite transitional beds (Figure 5)
- The Sagemace and Hatfield mbrs are composed of a complex series of interbeds, defined by basal shaly units

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