# GS2017-14 Detailed examination of drillcore RP95-17, west-central Manitoba (NTS 63C7): evidence of potential for Mississippi Valley–type lead-zinc deposits

by K. Lapenskie and M.P.B. Nicolas

**In Brief:**

- In situ Pb-Zn mineralization have been identified in Paleozoic carbonates
- Two new occurrences of galena and sphalerite in the Winnipegosis area have been identified in core
- Structural and geological controls indicate that the Mississippi Valley-type deposits may occur in Manitoba

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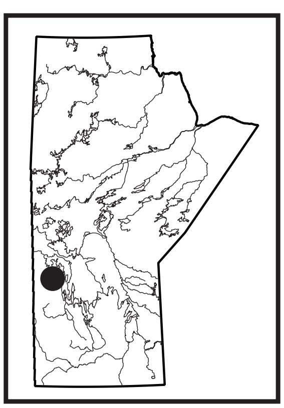

## Summary

Several examples of in situ lead-zinc mineralization have been found in Paleozoic carbonate rocks in the Williston Basin, which extends into southwestern Manitoba. The Manitoba Geological Survey (MGS) and several companies have undertaken exploratory investigations into occurrences of carbonate-hosted sphalerite-galena mineralization in the province but have yet to find any deposits. In the 1990s, Cominco Ltd. conducted several exploration programs in the Lake Winnipegosis area, looking for base-metal potential in the Superior boundary zone, which lies beneath a Phanerozoic cover. A re-examination of Paleozoic strata in drillcore from one of these programs has identified two new occurrences of in situ mineralization with a style comparable to that in Mississippi Valley–type deposits. Galena was identified in dolostone of the Ordovician Red River Formation and sphalerite was observed in a subvertical, calcite-lined fracture in dolostone of the lower member of the Devonian Winnipegosis Formation. Numerous structural and geological conditions in the province indicate that the Mississippi Valley–type model may be applicable within Manitoba. Platformal carbonates, shales, evaporites, karsting and reefal structures, often associated with Mississippi Valley–type deposits, are all present in southwestern Manitoba. Also, the Superior boundary zone may have acted as a source of base-metal–bearing fluids and provided conduits for fluid flow.

## Introduction

There is evidence to suggest potential for Mississippi Valley–type (MVT) deposits in Manitoba, specifically in the Williston Basin (Gale and Conley, 2000; Bamburak and Klyne, 2004), which is part of the larger Western Canada Sedimentary Basin (WCSB). There are 16 known MVT deposits in Canada, with the significant Pine Point deposit in the Northwest Territories located within the WCSB. Southwestern Manitoba is blanketed by a thick package of southwesterly dipping Phanerozoic sedimentary rocks, which was deposited within this basin. Underlying these strata are the Precambrian igneous and metamorphic rocks belonging to the Superior craton and Trans-Hudson orogen (THO), which are sutured together along the Superior boundary zone (SBZ).

Mississippi Valley–type deposits consist of stratabound, carbonate-hosted assemblages of sphalerite, galena and iron sulphides, typically occurring within marine platform 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. Mississippi Valley–type 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 facies changes.

Cominco Ltd. conducted an exploration program in the Lake Winnipegosis area in 1995, targeting Precambrian base-metal mineralization. Drillcore RP95-17 (Assessment File 94638, Manitoba Growth, Enterprise and Trade, Winnipeg) was recently examined by the authors, and resulted in the discovery of galena in the Ordovician Red River Formation and sphalerite in the Devonian Winnipegosis Formation. The former represents the first known occurrence of in situ carbonate-hosted galena in the Williston Basin.

## Previous work

Exploration for MVT deposits in Manitoba was prompted by the discovery of a galena pebble in surficial, glacially derived sediments near Balmoral (Figure GS2017-14-1, Table GS2017-14-1; McCabe, 1969). Cubic grains of galena may have been identified from the Winnipeg Formation near Grindstone Point, however, it was noted that the grains could have been tarnished pyrite (Genik, 1952). No samples were collected and no analyses were done of these cubic minerals, therefore, it

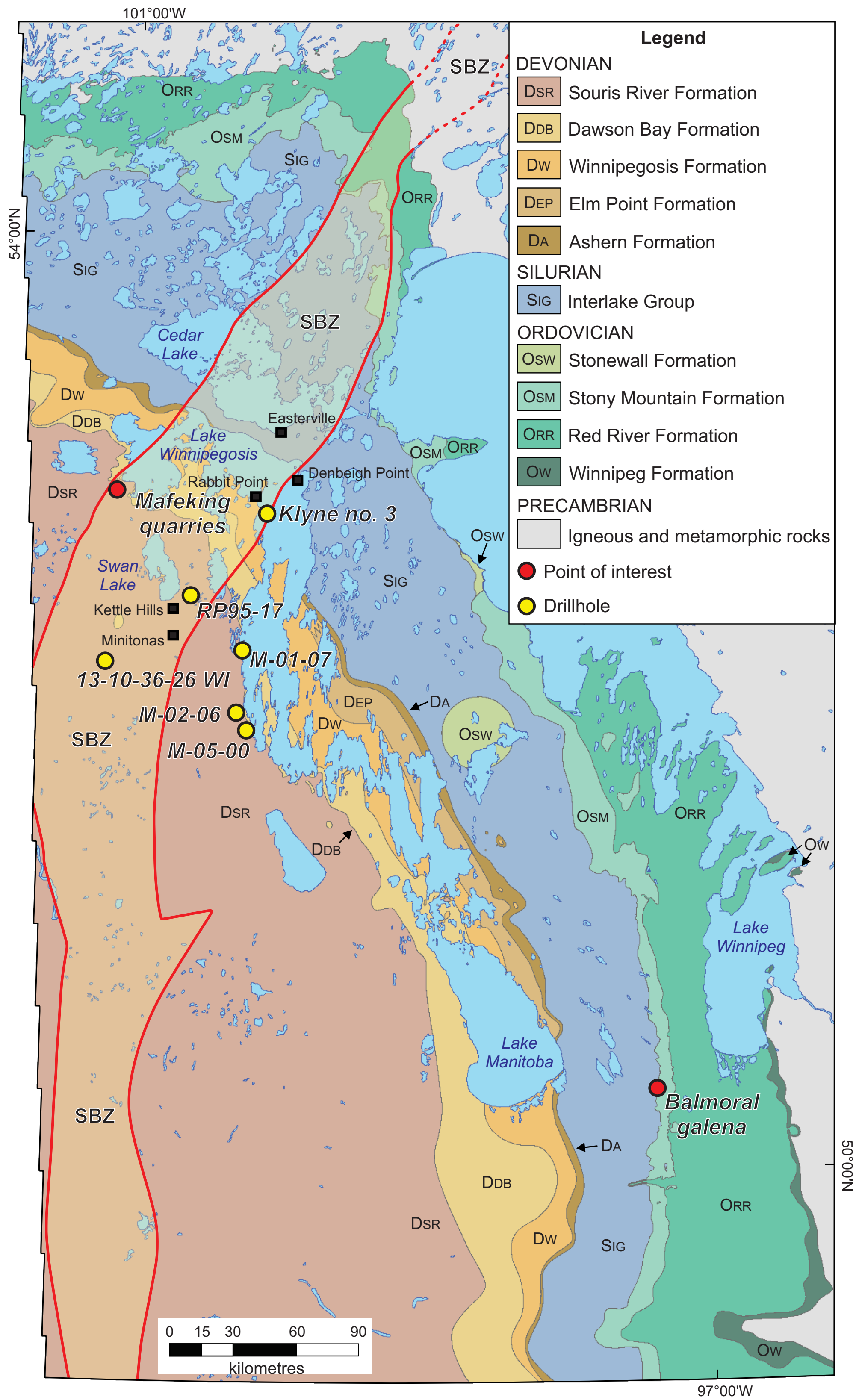


***Figure GS2017-14-1:*** *Regional bedrock geology of southwestern Manitoba (after Nicolas et al., 2010); formations younger than the Souris River Formation are not shown. The region consists of sedimentary rocks of the Williston Basin draped over Precambrian igneous and metamorphic rocks (exposed in the northern and eastern parts of the map area). The limits of the Superior boundary zone (SBZ) are projected to surface. Also indicated are occurrences of Pb-Zn mineralization and the locations of other features of relevance to the search for Mississippi Valley–type (MVT) deposits in Manitoba.*

**Table GS2017-14-1:** Reported occurrences of in situ carbonate-hosted sphalerite-galena and lithological features in Manitoba that are comparable to Mississippi Valley–type districts elsewhere. The UTM co-ordinates are in NAD83, Zone 14.

| | Easting | Northing | Mineralization | Depth (m) | Stratigraphic unit | Reference |
|---|---|---|---|---|---|---|
| Balmoral pebble | NE¼-26-14-1-E1[1] | | Galena | n/a | Surficial sediments | Gale and Conley (2000) |
| Mafeking quarries | 361740 | 5855814 | Prairie-type | n/a | Point Wilkins Member, Souris River Formation | Fedikow et al. (2004) |
| 13-10-36-26W1 drillhole | 356371 | 5772556 | Sphalerite | 429.2 | Stony Mountain Formation | Assessment File 92116 (Manitoba Growth, Enterprise and Trade, Winnipeg) |
| Klyne no. 3 drillhole | 433525 | 5842645 | Sphalerite (black-jack and ruby-jack) | 8.5; 15.2; 16.8; 17.7; 18.6 | Upper Interlake Group | Bamburak and Klyne (2004); Assessment File 74128 |
| M-05-00 drillhole | 423445 | 5739324 | Sphalerite, minrecordite, stilleite | 114.2 | Upper member, Winnipegosis Formation | Bamburak (2007) |
| M-02-06 drillhole | 415171 | 5739363 | Sphalerite | 72.8 | Second Red Bed Member, Dawson Bay Formation | Bamburak (2006, 2007) |
| M-01-07 drillhole | 421088 | 5774977 | Saddle dolomite; hydrothermal dolomite | 80.81–122.52 | Cedar Lake Formation, Interlake Group | Bamburak (2007), Rawluk (2010) |
| RP95-17 drillhole | 396816 | 5803656 | Sphalerite; galena | 109.95–110.28; 344.87 (TVD) | Lower member, Winnipegosis Formation; lower Red River Formation | Assessment File 94638 |

[1] No UTM coordinates available; galena pebble was collected in NE ¼, Sec. 26, Twp. 14, Rge. 1, E 1st Mer.
Abbreviations: n/a, not applicable; TVD, total vertical depth

should not be considered as a confirmed occurrence of in situ Pb-Zn mineralization.

Geological, geochemical and geophysical exploration programs to investigate MVT potential in Manitoba began in 1970 and lasted until the present day. Cominco Ltd. worked in the Easterville and Denbeigh Point area from 1970 to 1971, attempting to locate Pb-Zn mineralization (Assessment File 91785). During that same time period, Husky Oil Ltd. conducted an electromagnetic survey and drill program in the vicinity of Dawson Bay (Assessment files 91776, 92239).

Gulf Minerals Canada Ltd. drilled four holes in the Minitonas area in 1976 to examine the base-metal content of Paleozoic carbonates (Assessment File 92116). The Pb, Zn and Cu values from core were insufficient to warrant further work in this area. However, a single occurrence of sphalerite was noted from one of the cores (13-10-36-26W1) and is described below (see 'Carbonate-hosted Pb-Zn mineralization in Manitoba' section).

From 1979 to 1983, Canadian Nickel Company Limited (Canico) applied several techniques to explore for MVT deposits in the Dawson Bay area. A soil, rock and water sampling program was initially conducted, with numerous geochemical anomalies detected; geophysical surveys were also conducted (Assessment files 93877, 93878). Exploration activities culminated in a drill program, however, none of the holes intersected Pb-Zn mineralization (Assessment File 92830). Canico terminated exploration for MVT deposits in Manitoba in 1983.

To date, the best known example of carbonate-hosted Pb-Zn mineralization in Manitoba is located near Pemmican Island, in the north basin of Lake Winnipegosis. In 2004, Klyne Exploration drilled three holes near the island, with Klyne no. 3 encountering a 15 cm interval of pyrite and sphalerite within uppermost Interlake Group dolostone (Figure GS2017-14-1, Table GS2017-14-1; Bamburak and Klyne, 2004; Assessment File 74128). Analyses demonstrated the sulphide interval was 4.59% Zn, 0.41% Pb and 0.014% Cu. Previous work in the area also demonstrated that sulphide-bearing dolostone clasts along the shorelines of the north basin of Lake Winnipegosis contained elevated values of Ni, Zn and Pb, among other base metals (Bamburak et al., 2002). The mineralogy of the sulphides was not determined.

The MGS previously conducted investigations into the potential for MVT deposits in Manitoba. A large-scale sampling program by Gale and Conley (2000) involved analyzing approximately 6300 samples from various stratigraphic drillcores. This program demonstrated widespread anomalous values of Cu, Zn, Pb and Ni in Paleozoic strata across the Williston Basin. Gale and Conley (2000) concluded that the anomalous values obtained through this study, along with other geological features, indicated potential for MVT deposits west of Lake

Winnipegosis. Fedikow et al. (2004) investigated 'Prairie-type microdisseminated mineralization' in the Late Devonian Point Wilkins Member of the Souris River Formation in the Mafeking area. Altered and silicified cone structures in the high-calcium limestone were found to contain precious and base metals (Au, Zn, Ni, Co, Fe), and indicated that processes favourable for MVT deposits had occurred in this area. During a MGS stratigraphic drillcore program, several drillcores were chosen for further exploration for sphalerite-galena mineralization based on previous findings (Bezys, 2000; Bamburak, 2006, 2007). However, only a few of these cores intersected Pb-Zn mineralization (see 'Carbonate-hosted Pb-Zn mineralization in Manitoba' section).

## Regional geology

Southwestern Manitoba is blanketed by a thick succession of sedimentary rocks that were deposited in the Williston Basin during the Phanerozoic (Figure GS2017-14-1). Deposition during the Paleozoic spanned the Cambrian to the Mississippian periods, with significant episodes of nondeposition and/or erosion occurring between the Cambrian and Ordovician, and the Silurian and Devonian periods. These Paleozoic rocks are composed predominantly of marine platform carbonate rocks, with lesser amounts of siliciclastic and evaporitic rocks (Figure GS2017-14-2).

Underlying these sedimentary strata are Precambrian igneous and metamorphic rocks. The SBZ is a 40–50 km wide suture zone between the Archean Superior craton to the southeast and the Paleoproterozoic THO to the northwest (Bleeker, 1990). The SBZ extends from the southwestern corner of Manitoba beneath the Williston Basin, and continues northeastward through the Hudson Bay Lowland, beneath the Hudson Bay Basin (Figure GS2017-14-1). The Manitoba portion of the Hudson Bay Basin comprises a series of Paleozoic carbonates and could also theoretically host MVT deposits.

The SBZ hosts magmatic Ni-Cu deposits of the Thompson nickel belt, with some of these deposits occurring below the Phanerozoic cover of the Williston Basin. The Minago (Ni-Cu-platinum group elements [PGE]) and Tower (Cu-Zn) deposits both occur along the SBZ beneath the northeastern portion of the Williston Basin, north of William Lake. There are also known Cu-Zn and Ni-Cu-PGE deposits that occur beneath the northern margin of the Williston Basin, hosted within the Flin Flon and Snow Lake greenstone belts of the THO (Gagné, 2016; Reid and Gagné, 2016; Reid, GS2017-7, this volume).

## Carbonate-hosted Pb-Zn mineralization in Manitoba

Several occurrences of sphalerite and galena mineralization have been reported in Paleozoic strata in Manitoba (Table GS2017-14-1, Figure GS2017-14-1). Gulf Minerals Canada Ltd. reported a single crystal of sphalerite in dolostone of the Stony Mountain Formation (drillcore 13-10-36-26W1; Assessment File 92116), representing the first documented occurrence of in situ carbonate-hosted base-metal mineralization in Manitoba.

McCabe (1980) noted "honey-coloured sphalerite" in drillcore M-06-80, which was identified by X-ray diffraction (XRD), however, the data was never published and is no longer available. To confirm the results, the drillcore was resampled. Microscope and X-ray fluorescence (XRF) analyses of the samples suggest that the "honey-coloured sphalerite" is in fact coarsely crystalline dolomite partially infilling vuggy porosity (Figure GS2017-14-3a). Small stringers of dark grey material, observed in cut sections of core under stereo microscope, may be very finely disseminated sphalerite mineralization, which could account for elevated Zn values obtained from this interval (Gale and Conley, 2000).

Drillcore M-05-00 was bored in the vicinity of drillcore M-06-80 to confirm the presence of the above-described "honey-coloured sphalerite" (Bezys, 2000). The core intersected black-jack sphalerite and pyrite in a vertical fracture and along a lamination surface in the inter-reefal facies of the upper member of the Winnipegosis Formation (Figure GS2017-14-3b). The XRD analysis also demonstrated the presence of minrecordite (zinc-carbonate) and stilleite (zinc-selenide; Table GS2017-14-1; Bamburak, 2007). Drillcore M-02-06, also completed to test for Pb-Zn mineralization in the vicinity of M-06-80 and M-05-00, intersected sphalerite on the surface of a slickenside in the Second Red Bed Member of the Dawson Bay Formation (Bamburak, 2006, 2007). Drillcore M-01-07, drilled north of this area on the western shore of Lake Winnipegosis (Figure GS2017-14-1), intersected probable hydrothermal dolomite within the Cedar Lake Formation (Bamburak, 2007); saddle dolomite was also identified in thin section from this zone (Rawluk, 2010; Table GS2017-14-1).

Prairie-type microdisseminated mineralization was noted by Fedikow et al. (2004) in the Mafeking area in high-calcium limestone quarries (Figure GS2017-14-1). Micrometre-sized precious- and base-metal sulphide aggregates were found to occur within altered and silicified inverted cone structures in the Upper Devonian Point Wilkins Member of the Souris River Formation.

## Drillcore RP95-17

In 1995, Cominco Ltd. (Cominco) drilled six holes in the vicinity of Rabbit Point (Assessment File 94638) targeting the sub-Phanerozoic extension of the SBZ for base-metal potential in the Winnipegosis komatiite belt, which is interpreted to represent a Paleoproterozoic rift basin (Waterton et al., 2017). Previous to this program, Cominco had completed several drill and geophysical programs targeting the sub-Phanerozoic extension of the SBZ (Assessment files 94639, 94640, 94642, 94643, 94780, 94782), and continued working in this area until 1999 (Assessment files 94641, 94765, 94771, 94772). The MGS acquired some of the Cominco drillcore from the Rabbit Point programs, however, some of the intervals of Paleozoic strata were abandoned at drill sites or later discarded, after being logged by MGS geologists.

Drillholes RP95-17 and RP95-18 were drilled by Cominco in 1995, in the Kettle Hills area near the south end of Swan Lake

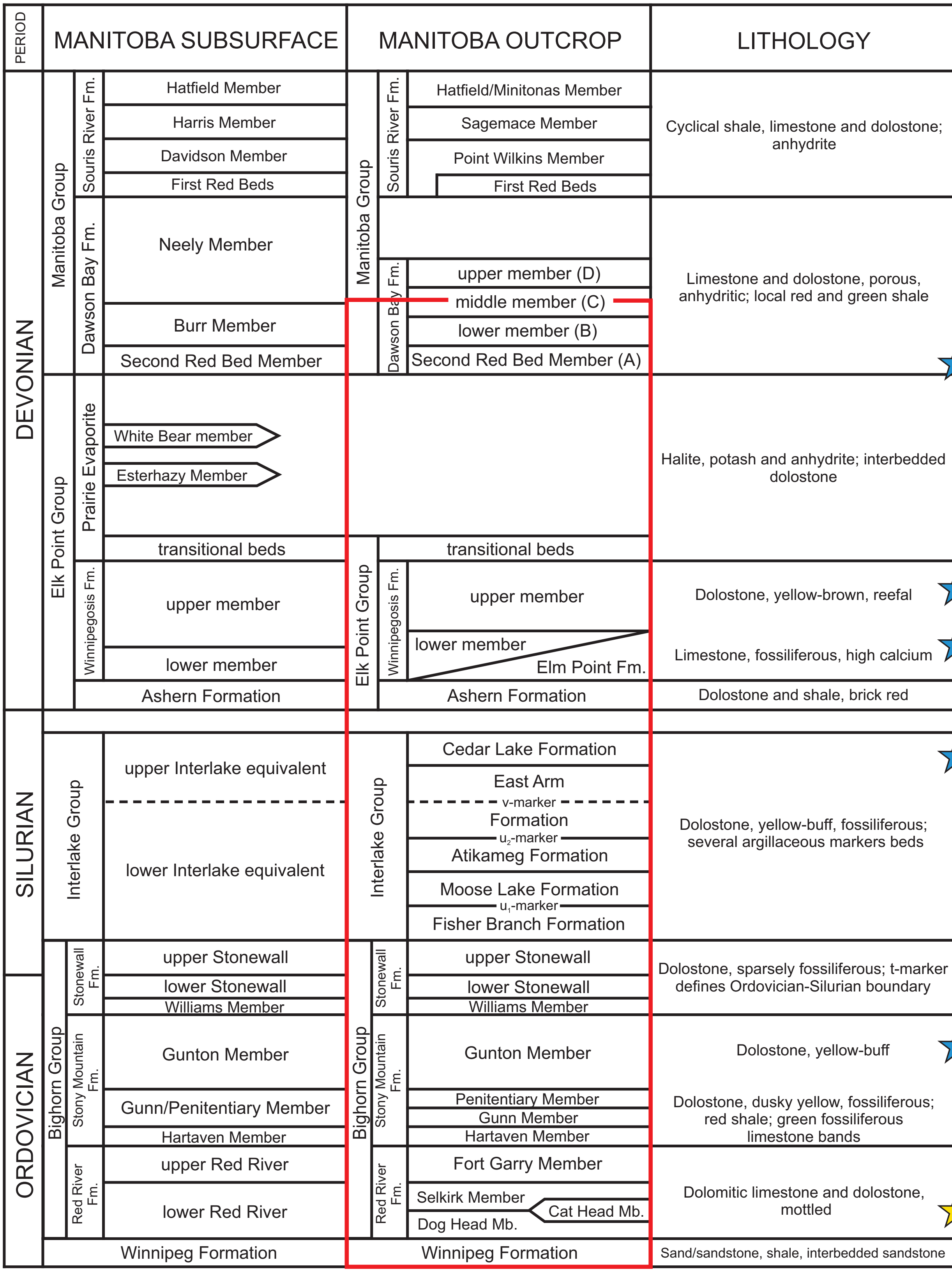


***Figure GS2017-14-2:*** *Stratigraphy and general lithology of Ordovician to mid-Devonian strata in the Williston Basin, Manitoba. The stratigraphic units encountered in drillhole RP95-17 (Assessment File 94638, Manitoba Growth, Enterprise and Trade, Winnipeg) are outlined in red. Known occurrences of sphalerite and galena are indicated with blue and yellow stars, respectively.*

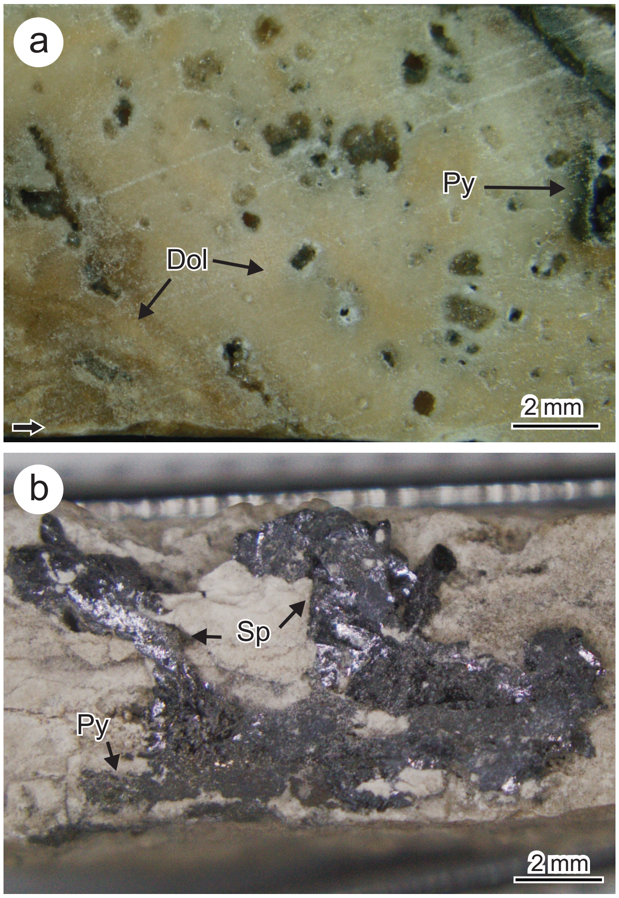


***Figure GS2017-14-3:*** *Photographs of sphalerite occurrences in drillcore:* ***a)*** *'honey-coloured' dolomite with vuggy porosity; dark grey material associated with vugs is pyrite (core M-06-80, 112.90 m depth);* ***b)*** *sphalerite and pyrite occurring within a vertical fracture in laminated dolomudstone from the upper member, Winnipegosis Formation (core M-05-00, 114.20 m depth). Arrow indicates up direction in core. Abbreviations: Dol, dolomite; Py, pyrite; Sp, sphalerite.*

(Figure GS2017-14-1). Both drillholes targeted magnetic features along the sub-Phanerozoic section of the SBZ, and intersected sulphidic, graphitic, argillaceous metasedimentary rocks and peridotite-dunite intrusions (Assessment File 94638). The Phanerozoic section of drillcore RP95-17 was retained by MGS for future study, and is described below.

### *Stratigraphy*

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. The section is mostly composed of dolostones and limestones, with subordinate sandstones and argillaceous/shaly units. A detailed description of the lithostratigraphy of RP95-17 is provided in Table GS2017-14-2. Drillhole RP95-17 was drilled to a true vertical depth (TVD) of 633.05 m (total measured depth 731.00 m), including 58.59 m (TVD) of Quaternary sediments and 321.57 m (TVD) of Paleozoic sedimentary rock. Refer to Assessment File 94638 for a detailed description of the Precambrian section of this core.

The Ordovician section of core RP95-17 comprises the siliciclastic Winnipeg Formation and a thick succession of dolomudstones and dolowackestones of the Red River, Stony Mountain and Stonewall formations (Table GS2017-14-2). The Winnipeg Formation is only represented by its upper unit in this part of the Williston Basin (Vigrass, 1971), and is reflected in the core as quartz arenites to wackes interbedded with arenaceous shale. The Lake Alma Member in the Red River Formation is represented by a restricted dolomudstone capped by an evaporitic dolomudstone equivalent to the Lake Alma anhydrite. The lack of anhydrite is most likely due to lateral facies variations across the Williston Basin and the proximity of the drillhole to the basinal edge, or may be related to postdepositional dissolution of primary evaporites and subsequent solution collapse. The Stony Mountain Formation is only represented by the upper Gunton Member; in northern portions of the Williston Basin the lower Hartaven, Gunn and Penitentiary members are not present.

The upper Stonewall Formation and Interlake Group contain a succession of dolomudstones separated by several argillaceous and arenaceous marker beds. The core box containing the v-marker bed in the East Arm Formation had been disturbed, so the exact depths of the bed are unknown. Breccia becomes more common upward through the Interlake Group, with the Cedar Lake Formation possessing multiple beds of chaotic and crackle breccia (Figure GS2017-14-4a, b). The basal portion of the Cedar Lake Formation is subdivided into two lower reefal units: the lowermost crinoidal reefal facies Cross Lake Member and the overlying stromatolitic reefal facies Chemahawin Member (Table GS2017-14-2). The upper contact of the Interlake Group is defined by a prominent hardground, representing a significant period of nondeposition and erosion.

The Devonian section of core RP95-17 consists of interbedded shales and dolostones/limestones that are interpreted to record one complete carbonate-evaporite cycle (Ashern-Winnipegosis-Prairie Evaporite) and the beginning of a second cycle (Dawson Bay Formation). Extensive brecciation occurred in the Ashern Formation, Winnipegosis Formation (Figure GS2017-14-4c), Prairie Evaporite and Dawson Bay Formation (GS2017-14-4d), which may be related to the dissolution of the Prairie Evaporite, karsting in the Interlake Group and other processes. The Prairie Evaporite is represented only by the conglomeratic to argillaceous transitional beds (Table GS2017-14-2), as dissolution in the subcrop belt has removed the evaporitic material from this formation. The Devonian section of core RP95-17 terminates in the middle member of the Dawson Bay Formation, and is overlain by Quaternary sediments.

### *Mineralization in RP95-17*

The Paleozoic section of RP95-17 contains two occurrences of Pb-Zn mineralization. In the lower dolomudstone of the Red River Formation, aggregates (<0.65 mm) of galena were identified at 344.87 m (TVD) within the skeleton of a poorly

**Table GS2017-14-2:** Lithostratigraphy and general lithological descriptions of drillcore RP95-17; refer to Assessment File 94638 (Manitoba Growth, Enterprise and Trade, Winnipeg) for a detailed description of the Precambrian section. Abbreviations: MD, measured depth; TVD, true vertical depth.

| MD (m) | TVD (m) | Thickness (m) | | | Description |
|---|---|---|---|---|---|
| 0–64.65 | 0–58.59 | 58.59 | Quaternary sediments | | |
| 64.65–89.82 | 58.59–81.4 | 22.81 | Manitoba Group | | |
| 64.65–89.82 | 58.59–81.4 | 22.81 | Dawson Bay Formation | | |
| 64.65–72.85 | 58.59–66.02 | 7.43 | | middle member (C) | |
| | | | | | Medium grey, argillaceous, lime mudstone–wackestone to argillaceous dolomudstone; bedded to laminated; fossiliferous, abundant echinoderms; somewhat brecciated; intercrystalline porosity, <2%; vugs and fractures partially or fully infilled by coarsely crystalline calcite; upper contact sharp, irregular |
| 72.85–78.2 | 66.02–70.87 | 4.85 | | lower member (B) | |
| | | | | | Grey to yellowish-grey, argillaceous, lime mudstone–wackestone; some brecciation; massively bedded; fossiliferous, abundant brachiopods; intercrystalline and fracture porosity, <5%; upper contact sharp, irregular |
| 78.2–89.82 | 70.87–81.4 | 10.53 | | Second Red Bed Member (A) | |
| | | | | | Red, grey and buff, variably calcareous dolostone and interbedded argillaceous dolomudstone; extensively brecciated, intraformational clasts contain multiple lithologies; bedded to laminated; finely disseminated pyrite-marcasite trace; upper contact sharp, directly overlain by shaly-clayey grey sediment |
| 89.82–134.65 | 81.4–123.95 | 42.55 | Elk Point Group | | |
| 89.82–90.62 | 81.4–83.42 | 2.02 | Prairie Evaporite | | |
| | | | | transitional beds | |
| | | | | | Red, buff and grey, variably calcareous conglomerate to mudstone; intraclasts have multiple lithologies; brecciated; upper contact sharp and irregular |
| 90.62–120.53 | 83.42–110.95 | 27.53 | Winnipegosis Formation | | |
| 90.62–97.95 | 83.42–90.16 | 6.74 | | upper member | |
| | | | | | Grey and buff, lime mudstone to calcareous dolostone; argillaceous; well laminated, some bituminous laminations (varve-like); stylolitic; extensively brecciated; porosity 10–15%; inter-reefal facies; upper contact sharp |
| 97.95–120.53 | 90.16–110.95 | 20.79 | | lower member | |
| | | | | | Buff to brownish-buff, calcareous dolomudstone to lime mudstone, grading upward into lime wackestone; argillaceous, wispy laminations common; massive to massively bedded also burrowed and mottled; vuggy and fracture porosity, 5–20%; some vugs and fractures partially or fully infilled by coarse calcite crystals; rare fossil fragments; rarely brecciated; subhedral to euhedral sphalerite crystals and chalcopyrite occurring on calcite-lined fracture from 109.95–110.28 m; upper contact sharp, marked by bituminous marker beds |

**Table GS2017-14-2 *(continued)*:** Lithostratigraphy and general lithological descriptions of drillcore RP95-17; refer to Assessment File 94638 (Manitoba Growth, Enterprise and Trade, Winnipeg) for a detailed description of the Precambrian section. Abbreviations: MD, measured depth; TVD, true vertical depth.

| MD (m) | TVD (m) | Thickness (m) | | Description |
|---|---|---|---|---|
| 120.53–134.66 | 110.95–123.95 | 13.00 | Ashern Formation | |
| | | | | Brown, red, green and grey, argillaceous, calcareous dolomudstone; massive to massively bedded; very permeable; finely disseminated pyrite-marcasite throughout, 1%; multiple brecciated intervals; coarsely crystalline calcite infilling vugs and fractures associated with brecciation; upper contact sharp |
| 134.66–242.75 | 123.95–226.63 | 102.68 | Interlake Group | |
| 134.66–177.89 | 123.95–164.94 | 40.99 | Cedar Lake Formation | |
| | | | | Pinkish-, greyish- or brownish-buff, variably calcareous dolomudstone–boundstone; massive to bedded, uncommonly weakly laminated; variably argillaceous; interbeds of stromatoporoidal or stromatolitic intervals; uncommonly intraclastic to brecciated; rare vuggy and fracture porosity, <5%, permeable; 'raindrop' texture common throughout; upper contact sharp, hardground |
| 176.6–177.55 | 163.74–164.62 | 0.88 | Chemahawin Member | |
| | | | | Buff, slightly calcareous doloboundstone; stromatolitic; vuggy porosity, 30%; upper contact gradational |
| 177.55–177.89 | 164.62–164.94 | 0.32 | Cross Lake Member | |
| | | | | Pinkish-buff, slightly calcareous dolowackestone; bedded to massive; fossiliferous, abundant crinoidal material; finely disseminated pyrite-marcasite throughout, 1%; upper contact sharp, faint |
| 177.89–204.10 | 164.94–189.24 | 24.30 | East Arm Formation | |
| | | | | Buff dolomudstone–boundstone; laminated to bedded to massive, uncommon brown, wispy, argillaceous laminations, few green clay laminations; possibly burrowed in places; few fossiliferous beds, stromatolitic and stromatoporoidal; vuggy and intercrystalline porosity in places, <5%; porcelaneous in places; finely disseminated pyrite-marcasite, 1%; upper contact sharp |
| 195.4–199.75 | 181.17–185.21 | 4.04 | v-marker bed | |
| | | | | Buff, arenaceous (abundant fine- to medium-grained quartz sand), some intraformational clasts; 20 cm thick; sharp upper and lower contacts; core in this box was mixed, therefore exact depths are unknown |
| 202.95–204.10 | 188.18–189.24 | 1.06 | $u_2$-marker bed | |
| | | | | Green-grey buff, somewhat calcareous dolomudstone; argillaceous and arenaceous, abundant green clay laminations and thin beds; abundant fine- to medium-grained rounded quartz grains; some beds of intraformational breccias; rarely vuggy, porosity <2%; finely disseminated pyrite-marcasite, in basal section of $u_2$-marker bed, 1%; upper contact sharp |

**Table GS2017-14-2 *(continued)*:** Lithostratigraphy and general lithological descriptions of drillcore RP95-17; refer to Assessment File 94638 (Manitoba Growth, Enterprise and Trade, Winnipeg) for a detailed description of the Precambrian section. Abbreviations: MD, measured depth; TVD, true vertical depth.

| MD (m) | TVD (m) | Thickness (m) | | Description |
|---|---|---|---|---|
| 204.1–215.4 | 189.24–199.72 | 10.48 | Atikameg Formation | |
| | | | | Buff, variably calcareous dolomudstone; occasionally stromatolitic; laminated to bedded to massive, wispy argillaceous laminations, sometimes with green clay; arenaceous; intercrystalline porosity, 1%; finely disseminated pyrite-marcasite, trace to 1%; upper contact sharp, marked with green clay |
| 215.4–225.25 | 199.72–210.29 | 10.57 | Moose Lake Formation | |
| | | | | Buff dolomudstone; laminated to bedded, stromatolitic; argillaceous, wispy laminations sometimes with green clay; intercrystalline and vuggy porosity, 1%; raindrop texture; rarely fossiliferous; finely disseminated pyrite-marcasite, associated with fractures, 1%; upper contact sharp |
| 223.85–225.25 | 208.99–210.29 | 1.30 | $u_1$-marker bed | |
| | | | | Bluish-greyish buff dolomudstone; laminated to bedded; arenaceous and argillaceous, fine- to medium-grained quartz sand; intercrystalline porosity, 1%; finely disseminated pyrite-marcasite, trace; upper contact gradational |
| 225.25–242.75 | 210.29–226.63 | 16.34 | Fisher Branch Formation | |
| | | | | Buff, variably calcareous dolomudstone–wackestone; bedded to massive; argillaceous, rare wispy laminations; fossiliferous; chert nodules common; intercrystalline, vuggy and mouldic porosity, <2%; finely disseminated pyrite-marcasite, <1%; upper contact sharp |
| 242.75–378.55 | 226.63–355.72 | 129.09 | Bighorn Group | |
| 242.75–265.7 | 226.63–248.06 | 21.43 | Stonewall Formation | |
| 242.75–255.5 | 226.63–238.53 | 11.90 | upper Stonewall | |
| | | | | Greyish-buff, slightly calcareous dolomudstone–wackestone; laminated to bedded, wispy argillaceous laminations; arenaceous, fine- to medium-grained quartz sand; fossiliferous, stromatolitic; mottled in places; vuggy to intercrystalline porosity, <2%; finely disseminated pyrite-marcasite, <1%; upper contact sharp |
| 255.5–256.6 | 238.53–239.56 | 1.03 | t-marker bed | |
| | | | | Medium grey-blue dolomudstone; laminated to bedded, possible crossbedding or ripple marks; argillaceous; intercrystalline porosity, <1%; upper contact sharp, marked with argillaceous laminations |
| 256.6–259.85 | 239.56–242.6 | 3.04 | lower Stonewall | |
| | | | | Blue-grey buff, dolomudstone; laminated to bedded to massive, occasional mottling; some brecciated beds (crackle breccia); rarely fossiliferous, echinoid fragments; wispy, argillaceous laminations common; intercrystalline and vuggy porosity, <2%; upper contact sharp |

**Table GS2017-14-2 *(continued)***: Lithostratigraphy and general lithological descriptions of drillcore RP95-17; refer to Assessment File 94638 (Manitoba Growth, Enterprise and Trade, Winnipeg) for a detailed description of the Precambrian section. Abbreviations: MD, measured depth; TVD, true vertical depth.

| MD (m) | TVD (m) | Thickness (m) | | | | Description |
|---|---|---|---|---|---|---|
| 259.85–265.7 | 242.6–248.06 | 5.46 | | Williams Member | | |
| | | | | | | Buff, variably calcareous dolomudstone–wackestone; argillaceous; vuggy and intercrystalline porosity, <2%; occasionally laminated; few intraformational conglomeratic beds; finely disseminated pyrite-marcasite, 1%; upper contact sharp |
| 265.7–297.7 | 248.06–277.93 | 29.87 | Stony Mountain Formation | | | |
| 265.7–297.7 | 248.06–277.93 | 29.87 | | Gunton Member | | |
| | | | | | | Buff dolomudstone–wackestone; laminated to bedded, wispy argillaceous laminations; blue-grey mottling in places; nodular in places; chert nodules common throughout; vuggy and intercrystalline porosity, 2–5%; fossiliferous, echinoderms and rugose corals common; upper contact gradational |
| 297.7–378.55 | 277.93–355.72 | 77.79 | Red River Formation | | | |
| 297.7–320.4 | 277.93–299.13 | 21.19 | | upper Red River Formation | | |
| 297.7–302 | 277.93–281.95 | 4.02 | | | Redvers unit | |
| | | | | | | Blue-grey buff dolomudstone; laminated to mottled, crossbedded in places; argillaceous; core very rubbly in places, may be cherty; uncommon intraclastic beds; intercrystalline to vuggy porosity, <2%; upper contact gradational? |
| 302–313.05 | 281.95–292.26 | 10.31 | | | Coronach unit | |
| | | | | | | Brownish- to bluish-grey buff, slightly calcareous dolomudstone–wackestone; laminated to bedded to massive, wispy argillaceous laminations throughout; mottled and burrowed intervals; nodular in places; fossiliferous, echinoderm fragments; intercrystalline and vuggy porosity, <5%; upper contact sharp |
| 313.05–320.4 | 292.26–299.13 | 6.87 | | | Lake Alma Member | |
| 313.05–314.3 | 292.26–293.43 | 1.17 | | | | Lake Alma anhydrite equivalent |
| | | | | | | Brownish-buff, slightly calcareous dolomudstone; laminated; argillaceous; some chert nodules; vuggy porosity, 30%; upper contact sharp and irregular |
| 314.3–320.4 | 293.43–299.13 | 5.70 | | | | lower unit |
| | | | | | | Buff dolomudstone–wackestone; laminated, sometimes massive; wispy argillaceous laminations common, often associated with burrows; rarely fossiliferous, echinoid fragments concentrated in beds; rare chert nodules; intercrystalline porosity, 1%; upper contact sharp |
| 320.4–377.7 | 299.13–354.92 | 55.79 | | lower Red River Formation | | |
| | | | | | | Buff dolomudstone; massively bedded, wispy argillaceous laminations; mottled and nodular; rarely fossiliferous, echinoid fragments and corals; chert nodules common; blue-grey mottling in places; galena occurs at 344.87 m, associated with a rugose coral; upper contact gradational |

**Table GS2017-14-2 *(continued)*:** Lithostratigraphy and general lithological descriptions of drillcore RP95-17; refer to Assessment File 94638 (Manitoba Growth, Enterprise and Trade, Winnipeg) for a detailed description of the Precambrian section. Abbreviations: MD, measured depth; TVD, true vertical depth.

| MD (m) | TVD (m) | Thickness (m) | | | Description |
|---|---|---|---|---|---|
| 377.7–378.55 | 354.92–355.72 | 0.80 | | Hecla beds | |
| | | | | | Blue-grey buff dolomudstone; laminated to bedded, few wispy argillaceous laminations; arenaceous, abundant frosted quartz grains; vuggy to intercrystalline porosity, <5%; finely disseminated pyrite-marcasite throughout, locally concentrated (~30%) in some beds; upper contact sharp, marked by abundant sulphides |
| 378.55–404.55 | 355.72–380.16 | 24.44 | Winnipeg Formation | | |
| 378.55–404.55 | 355.72–380.16 | 24.44 | | upper unit | |
| | | | | | Light to medium grey, interbedded quartz arenite-wacke and arenaceous shale; massive to massively bedded, lenticular and flaser bedding, in places fissile; burrow-mottled in places; coarse- to very fine grained quartz sand, frosted, well rounded, well sorted; kaolinitic; hematitic; pyritic; upper contact sharp |
| 404.55–731.00 | 380.16–633.05 | 252.89 | Precambrian | | |
| 404.55–442.55 | 380.16–415.86 | 35.70 | | | Regolith; weathered Precambrian rocks |
| 442.55–731.00 | 415.86–633.05 | 217.19 | | | Argillite, volcaniclastics, sulphides |

preserved solitary rugose coral (Figure GS2017-14-5a). Under microscope one well-formed crystal face was observed with cubic cleavage and high reflectance (Figure GS2017-14-5b). The XRF analysis confirmed elevated levels of Pb above 3%.

Sphalerite was identified within a calcite-encrusted fracture in calcareous dolomudstone of the lower member of the Winnipegosis Formation at a depth of 109.95 to 110.28 m (TVD; Figure GS2017-14-5c). Several subhedral to euhedral crystals occur atop the medium- to coarsely-crystalline calcite lining of the fracture (Figure GS2017-14-5d). Trace amounts of chalcopyrite also occur in this section of core, formed on top of the calcite crystals lining this fracture. The sphalerite was originally reported as spinel in Assessment File 94638.

## 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, as summarized in Table GS2017-14-3.

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 Manitoba 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 extension 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 in the Williston Basin, such as the Prairie Evaporite, could have been the source of metalliferous brines.

A number of 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 all found within the Paleozoic strata of the Williston Basin and 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, therefore favourable areas of emplacement could have been closely connected to fluid-flow conduits.

There are some features associated with the development of MVT deposits that have yet to be clearly identified in Manitoba. Typically, 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 during times of increased orogenic activity (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

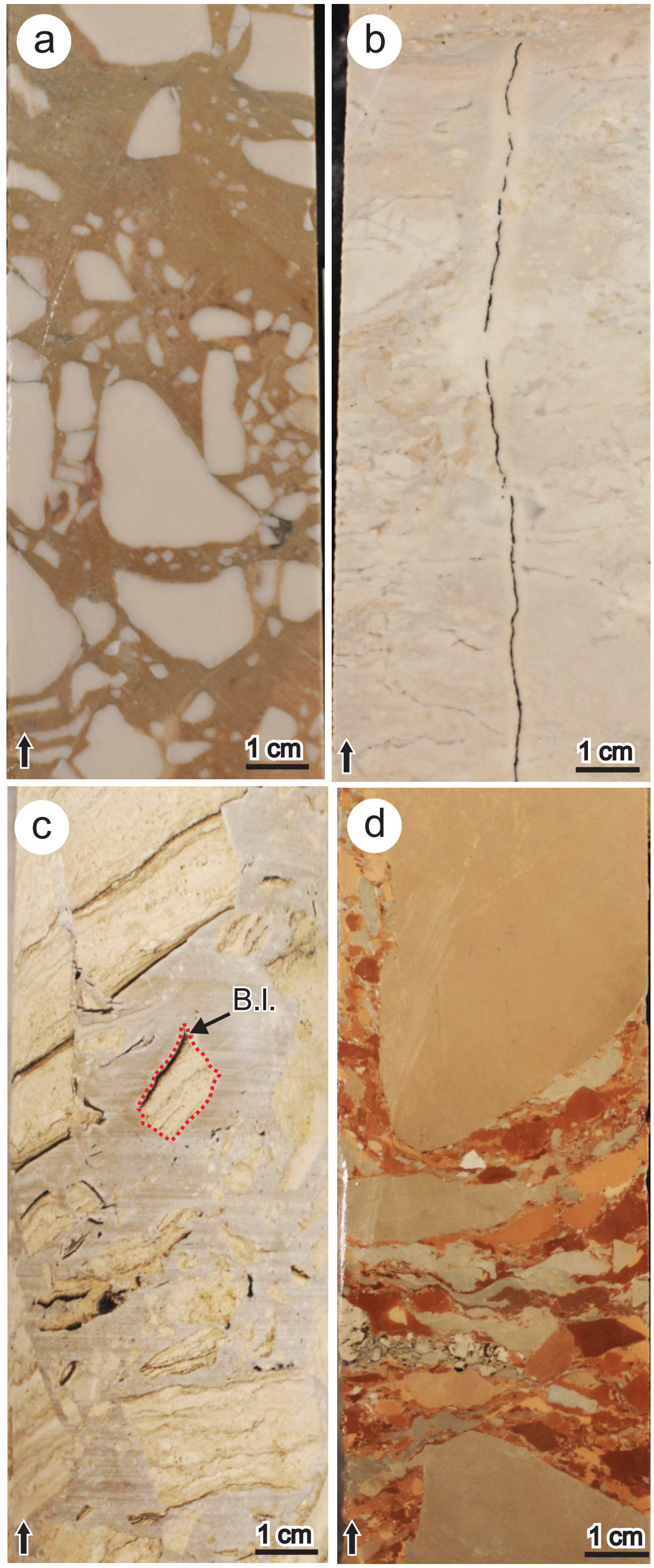


***Figure GS2017-14-4:*** *Photographs of drillcore RP95-17 (Assessment File 94638, Winnipeg Growth, Enterprise and Trade, Winnipeg), showing* ***a)*** *chaotic breccia in the Cedar Lake Formation, at a depth of 134.4 m (true vertical depth [TVD]); buff dolomudstone clasts are embedded in a red argillaceous matrix;* ***b)*** *weakly brecciated dolomudstone in the Cedar Lake Formation, at a depth of 130.7 m (TVD); note the vertical fracture infilled with pyrite-marcasite;* ***c)*** *crackle to mosaic breccia in the inter-reefal facies upper member of the Winnipegosis Formation, at a depth of 89.37 m (TVD); note the clasts of bituminous laminated dolomudstone, red dotted line outlines a single clast;* ***d)*** *chaotic breccia in the Second Red Bed Member of the Dawson Bay Formation, at a depth of 76.45 m (TVD); clasts include several different lithologies. Abbreviation: B.l., bituminous laminations. Arrow indicates up direction in core.*

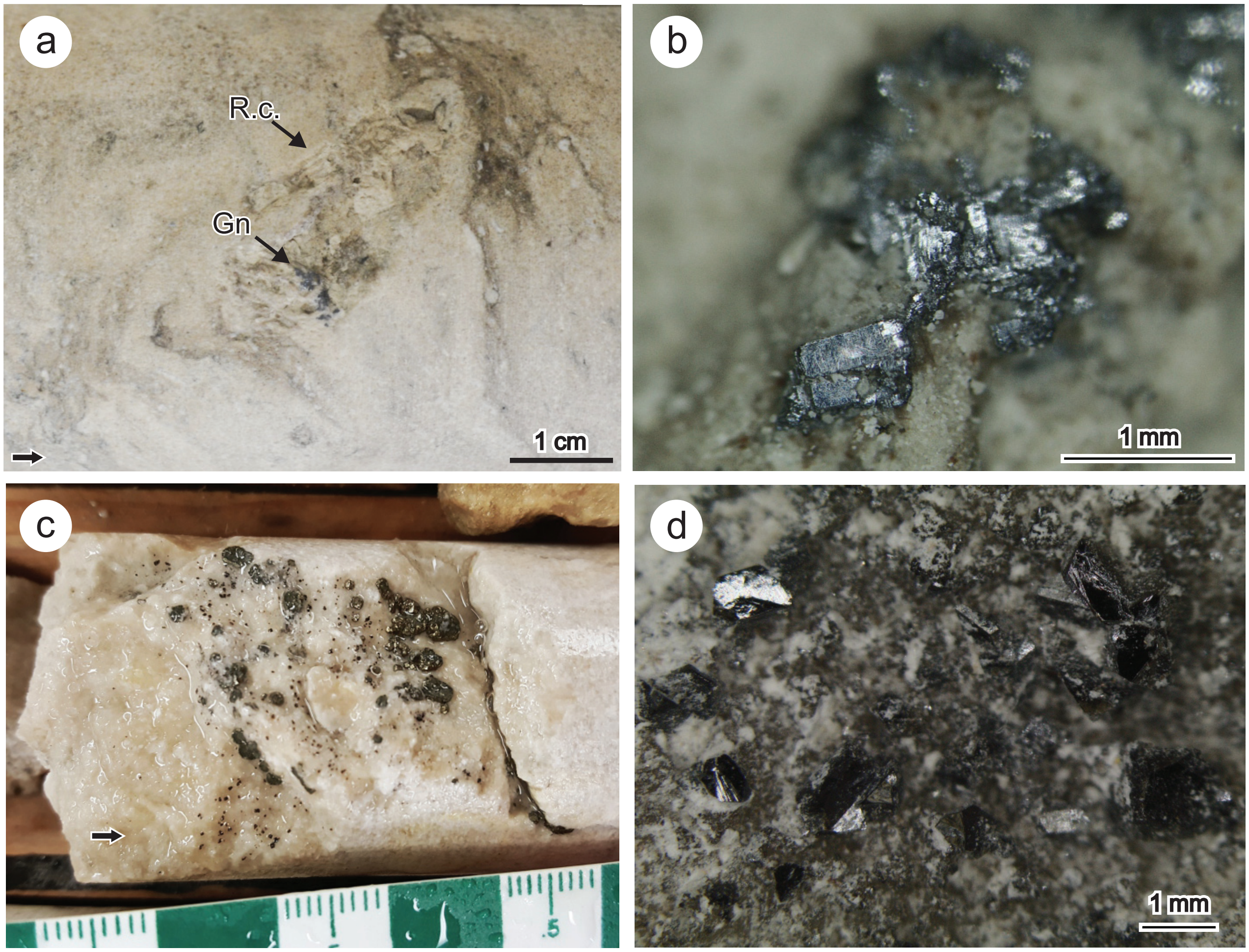


***Figure GS2017-14-5****: Lead and zinc mineralization in drillcore RP95-17 (Assessment File 94638, Winnipeg Growth, Enterprise and Trade, Winnipeg):* ***a)*** *photograph of galena (Gn) associated with a poorly preserved rugose coral (R.c.), from the Red River Formation at a depth of 344.85 to 344.90 m (true vertical depth [TVD]);* ***b)*** *photomicrograph of galena associated with a rugose coral from the Red River Formation, at a depth of 344.87 m (TVD);* ***c)*** *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);* ***d)*** *photomicrograph of sphalerite on calcite crystals that line a subvertical fracture in the lower member of the Winnipegosis Formation, at a depth of 110.23 m (TVD). Arrow indicates up direction in core.*

(Rawluk, 2010), from an interval that may consist of hydrothermal dolomite. Hydrothermal alteration, and specifically saddle dolomite, is often associated with Pb-Zn mineralization in host carbonate rocks; in the Pine Point district, saddle dolomite is a gangue mineral that often encloses bodies of sulphide mineralization (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.

Further work on known occurrences of carbonate-hosted Pb-Zn mineralization in Manitoba is required to demonstrate that these occurrences were formed from the same metalliferous brines. The X-ray diffraction (XRD) analysis of Pb-Zn mineralization in core RP95-17 will confirm the presence of sphalerite and galena. Isotopic analyses and fluid inclusion work may also be pursued to better understand the source fluid and compare it to other known occurrences of sphalerite and galena.

## Economic considerations

Major occurrences of carbonate-hosted Pb-Zn mineralization have yet to be discovered in Manitoba. At this stage, however, a combination of features, including minor occurrences of galena and sphalerite, indicate that the potential for MVT deposits may exist in the Williston Basin. Given the tendency for such deposits to occur in district-scale clusters, the discovery of additional Pb-Zn occurrences in the Williston Basin could spur renewed interest in Manitoba's Interlake region.

The discovery of sphalerite and galena in previously logged core indicates that relogging the Paleozoic sections of drillcore from along and adjacent to the SBZ may be a cost-effective means of exploration for MVT deposits. Compiling geochemical data from industry and previously published and unpublished MGS programs, as well as modelling subsurface stratigraphy, may indicate areas of greater potential. There are still some

**Table GS2017-14-3:** Geological characteristics of Mississippi Valley–type deposits and districts, and possible equivalents in Manitoba.

| General characteristics of Mississippi Valley–type deposits | Manitoba equivalent |
|---|---|
| Evidence of evaporite facies in regional carbonates[1] | Multiple evaporitic sequences in the Williston Basin: Prairie Evaporite, Hubbard Evaporite, Lake Alma anhydrite |
| Proximity to transtensional, wrench, strike-slip and fore bulge normal faults[1] | Evidence that the SBZ in southwestern Manitoba underwent movement through crustal flexure (McRitchie, 1991; Dietrich et al., 1997) |
| Presence of karstification[1,2] | Abundant karst development in Manitoba carbonates (Sweet et al., 1988); evidence of solution and collapse breccias (i.e., Dawson Bay Formation); major karst events occurred at the Cambrian-Ordovician and Silurian-Devonian boundaries, with minor karsting occurring in the Stonewall, Winnipegosis and Dawson Bay formations (McRitchie, 1991) |
| Widespread trace and minor occurrences of MVT mineralization and sulphides in carbonate rocks[1,2] | Wide distribution of minor lead-zinc mineralization; many documented occurrences of anomalous base-metal values in Paleozoic carbonates (i.e., Gale and Conley, 2000; Bamburak and Klyne, 2004; Fedikow et al., 2004; Assessment files 93877, 93878, Manitoba Growth, Enterprise and Trade, Winnipeg ) |
| Presence of regional basal sandstone[1] | Ordovician Winnipeg Formation (and to a lesser degree the siliciclastic Cambrian Deadwood Formation) blankets the base of the Williston Basin |
| Presence of reef and barrier reef facies[1,2] | Devonian upper member Winnipegosis Formation contains reefal and inter-reefal facies, as well as massive reef complexes (Norris et al., 1982; Dietrich and Magnusson, 1998) |
| Presence of regional aquitards[1] | Multiple shale and argillaceous carbonate facies in Lower Paleozoic strata (i.e., Ashern Formation; Second Red Bed Member, Dawson Bay Formation; First Red Beds, Souris River Formation) |
| Rapid transition of basin sediments with basement contacts, and rapid facies changes in sedimentary strata[1] | Multiple sequences of shale to carbonate facies in Devonian strata; lateral facies variations across the Williston Basin (reefal to inter-reefal facies, Winnipegosis Formation) |
| Presence of hydrothermal dolomite[1,2] | Suspected hydrothermal dolomite and confirmed saddle dolomite in drill-core M-01-07 (Rawluk, 2010) |
| Deposits hosted in platform carbonate successions developed on the flanks of sedimentary basins[2] | Paleozoic strata of the Williston Basin are mostly composed of platformal carbonates; these strata are located at the edge of the much larger WCSB |
| Carbonate sequences that commonly overlie deformed and meta-morphosed continental crustal rocks, and have some hydrological connection to basins affected by orogenic events[2] | Williston Basin overlies igneous and metamorphic Precambrian basement, specifically the SBZ shear zone; the Williston Basin is part of the larger WCSB, which is bordered to the west by the Cordilleran orogeny |
| Local geological features permitting upward migration of fluids[2] | Faults and fractures in the SBZ and overlying fractured Paleozoic strata may provide paths for fluid migration (McRitchie, 1991) |

[1] Leach et al. (2010)
[2] Paradis et al. (2007)
Abbreviations: MVT, Mississippi Valley–type; SBZ, Superior boundary zone; WCSB, Western Canada Sedimentary Basin

stratigraphic inconsistencies within the lower Paleozoic strata of the Williston Basin, chiefly in the Silurian section; resolution of these issues through continued stratigraphic investigations will allow for industry to better develop targeted exploration programs for stratabound MVT deposits.

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