New Occurrences of Carbonate-Hosted Pb-Zn Mineralization in Manitoba: Implications for Mississippi Valley-type Deposit Potential

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Several examples of in situ Pb-Zn 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 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 sub-Phanerozoic Superior boundary zone (SBZ). 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 (MVT) deposits.

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 SBZ may have acted as source of base-metal bearing fluids and provided conduits for fluid flow.

Introduction

There is evidence to suggest potential for MVT deposits in Manitoba, specifically in the Williston Basin (Gale and Conley, 2000; Bamburak and Klyne, 2004). Southwestern Manitoba is blanketed by a thick passage of southwesterly dipping Phanerozoic sedimentary rocks, which were 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 SBZ.

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.

Cominco Ltd. conducted an exploration program in the Lake Winnipegosis area in 1995, targeting Precambrian base-metal mineralization. Drillcore RP95-17 (A.F. 94638) 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 near Balmoral (Fig. 1, Table 1; McCabe, 1969). Geological, geochemical and geophysical exploration programs to investigate MVT potential in Manitoba began in 1970 and lasted until the present day.

1969
Galena pebble discovered in glacially-derived, surficial sediments (McCabe, 1969); exploration for MVT in Manitoba begins

1970-1971
Cominco Ltd. conducted exploration in Easterville-Denbeigh Point area (A.F. 91785); Husky Oil Ltd. conducted electro-magnetic survey, Dawson Bay area (A.F. 91776, 92239)

1976
Gulf Minerals Canada Ltd. completed drill program near Minitonas; single occurrence of sphalerite noted in core 13-10-36-26W1 (A.F. 92116)

1979-1983
Canadian Nickel Company Ltd. completed soil, rock, and water sampling, geophysical surveys, and a drill program in the Dawson Bay area (A.F. 93877, 93878, 92830)

2000
Sampling program conducted by the MGS; >6300 samples from Paleozoic stratigraphic drillcore revealed widespread Cu, Zn, Pb, and Ni anomalies (Gale and Conley, 2000)

2004
Precious and base metal 'Prairie-type micro-disseminated mineralization' investigated in late Devonian limestone (Fedikow et al., 2004)

2002 - Present
Base-metal bearing sulphides observed in Paleozoic rocks in the Pemmican Island area (Bamburak and Klyne, 2004; A.F. 74128)

1970 — 1980 — 1990 — 2000 — 2010 — 2017

Regional Geology

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

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).

- Pebble of galena found in surficial, glacially-derived sediments near Balmoral (McCabe, 1969)
- Gulf Minerals Canada Ltd. reported a single crystal of sphalerite in dolostone of the Stony Mountain Formation (drillcore 13-10-36-26W1, A.F. 92116)
- Drillcore M-05-00 intersected black-jack sphalerite, minercordeite (zinc-carbonate), stilleite (zinc-selenide), and pyrite in a vertical fracture and along a lamination surface in the inter-reefal facies of the upper member of the Winnipegosis Formation (Fig. 3) (Bamburak, 2007)
- Klyne no. 3 intersected 15 cm of sphalerite and pyrite off Pemmican Island (Bamburak and Klyne, 2004) (Fig. 4)
- Drillcore M-02-06 intersected sphalerite on the surface of a slickeside in the Second Red Bed Member of the Dawson Bay Formation (Bamburak, 2006, 2007)
- Drillcore M-01-07 intersected probably hydrothermal dolomite and confirmed saddle dolomite within the Cedar Lake Formation (Bamburak, 2007; Rawluk, 2010)
- Prairie-type microdisseminated mineralization was noted by Fedikow et al. (2004) in high-calcium limestone quarries, in the Point Wilkins Member of the Souris River Formation

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

[1]*UTM coordinates available, collected in NE½, 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*

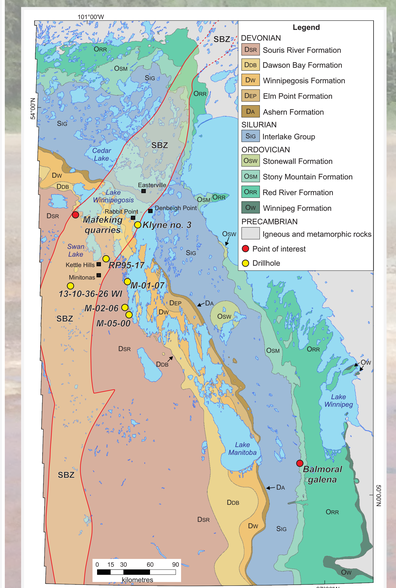

Figure 1: *Regional bedrock geology of southwestern Manitoba (after Nicolas et al., 2010); formations younger than the Souris River Formation are not shown. The region consists of sedimentary rocks of the Williston Basin draped over Precambrian igneous and metamorphic rocks. SBZ projected to surface.*

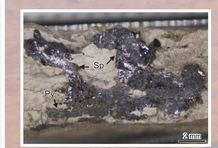

Figure 3: *Photomicrograph of sphalerite and pyrite occurring within a vertical fracture in laminated dolomudstone from the upper member, Winnipegosis Formation (core M-05-00, 114.20 m depth). Abbreviations: Py, pyrite; Sp, sphalerite.*

Figure 4: *Fracture-filled sulphide stringer within dolomite drillcore from Klyne no. 3 (Bamburak and Klyne, 2004).*

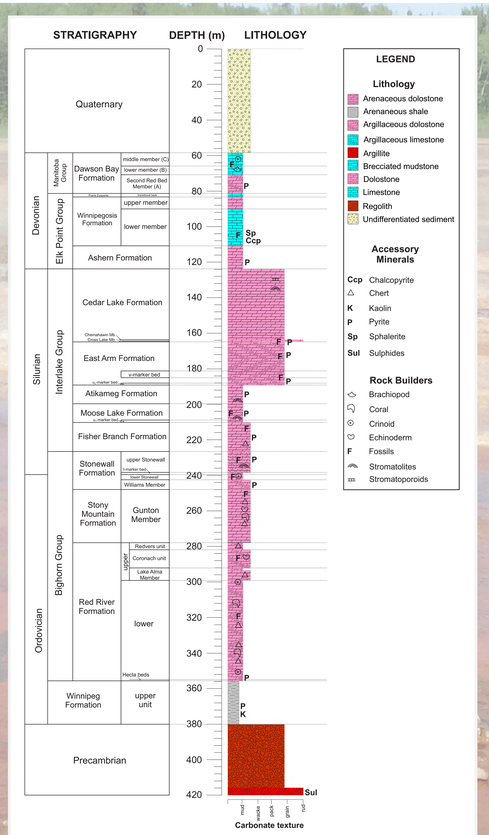

Figure 5: *Stratigraphic and lithological profile Paleozoic and uppermost Precambrian section of drillcore RP95-17. Depth track is true vertical depth.*

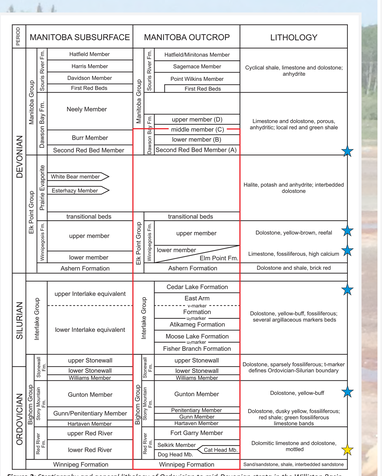

Figure 2: *Stratigraphy and general lithology of Ordovician to mid-Devonian strata in the Williston Basin, Manitoba. The stratigraphic units encountered in drillhole RP95-17 are outlined in red. Known occurrences of sphalerite and galena are indicated with blue and yellow stars, respectively.*

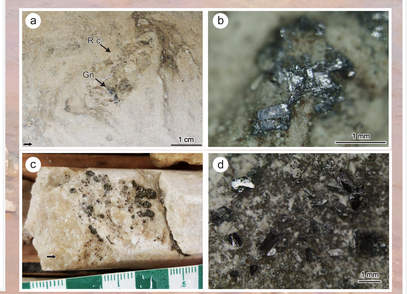

Figure 6: *Lead and zinc mineralization in drillcore RP95-17 (A.F. 94638): **a)** photograph of galena (Gn) associated with a poorly preserved rugose coral (R.c.), from the Red River Formation at a depth of 344.85 to 344.90 m (TVD); **b)** photomicrograph of galena associated with a rugose coral from 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 lower member of the Winnipegosis Formation, at a depth of a 110.23 m (TVD). Arrow indicates up direction in core.*

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Drillcore RP95-17

In 1995, Cominco Ltd. (Cominco) drilled six holes in the vicinity of Rabbit Point (A.F. 94638) targeting the sub-Phanerozoic extension of the SBZ for base-metal potential in the Winnipegosis komatiite belt (Waterton et al., 2017). The MGS acquired some of this drillcore from the Rabbit Point programs, including drillcore 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. The section is mostly composed of dolostones and limestones, with subordinate sandstones and argillaceous/shaly units (Fig. 5). A detailed description of the lithostratigraphy of RP95-17 is provided in Lapenskie and Nicolas (Report of Activities 2017). 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.

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 preserved solitary rugose coral (Fig. 6a,b). 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; Fig. 6c). Several subhedral to euhedral crystals occur atop the medium- to coarsely-crystalline calcite lining of the fracture (Fig. 6d). Trace amounts of chalcopyrite also occur in this section of core, formed on top of the calcite crystals lining this fracture.

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 (Table 2). 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 associated 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.

Table 2: *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 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; A.F. 93877, 93878)
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 carrier 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, 1988)
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 drillcore 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 metamorphosed 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.*

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 Willistn 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 stratigraphic inconsistences 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.