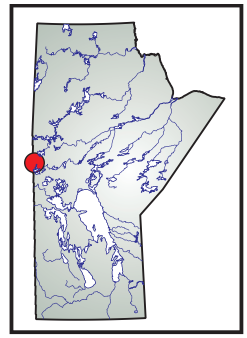
GS-9 Description of megabreccias and other evidence for subsidence and vent proximity in the Schist Lake–Mandy mines area, Flin Flon, west-central Manitoba (part of NTS 63K12)

by Y.M. DeWolfe[1]



DeWolfe, Y.M. 2010: Description of megabreccias and other evidence for subsidence and vent proximity in the Schist Lake–Mandy mines area, Flin Flon, west-central Manitoba (part of NTS 63K12); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 105–117.

Summary

The Schist Lake and Mandy deposits are located on the western edge of the Northwest Arm of Schist Lake in west-central Manitoba, approximately 4 km southeast of the town of Flin Flon. The deposits, which are currently inactive, are two of 27 known volcanogenic massive sulphide (VMS) deposits within the Paleoproterozoic Flin Flon Belt in the southeastern Reindeer Zone of the Trans-Hudson Orogen.

Detailed mapping (1:1000 and 1:2000 scales) of the strata that structurally overlie the hostrocks of the Schist Lake and Mandy deposits was the focus of fieldwork during the summer of 2010. The study area is located in the Hidden formation of the Flin Flon arc assemblage. It is bound to the west by a north-trending fault separating the Hidden formation from the Louis formation, and to the east by the north-trending Cliff Lake Fault.

Detailed mapping of the various volcanic facies and their lateral and vertical distributions suggests the presence of a synvolcanic structure in the rocks structurally overlying the Schist Lake and Mandy deposits. This structure is defined by 1) an abrupt lateral change in lithofacies from dominantly volcaniclastic in the south to dominantly flow facies in the north; 2) a synvolcanic dike that transitions upwards into a thin pillowed flow; and 3) the presence of a megabreccia (south side) and megapillows (north side) proximal to this structure lower in stratigraphy, and a spatter rampart deposit higher in stratigraphy. The megabreccias, megapillows and spatter rampart are all indicative of a vent-proximal environment. The synvolcanic structure most likely acted as a pathway for both magma and fluid while accommodating movement associated with primary subsidence related to volcanism, and subsequent deformation. Thus, this structure represents a potential analogue for reconstructing the environment in which the Schist Lake and Mandy deposits formed, and may be key for understanding the physical controls on mineralization. When traced downwards into the footwall, the synvolcanic fault could define a structural corridor in which the Schist Lake and Mandy deposits are located, depending on offset along the East Mandy Road Fault.

Introduction

The volcanic rocks near the town of Flin Flon host current (Callinan, Triple 7 and Trout Lake) and past-producing (Flin Flon, Schist Lake and Mandy) VMS deposits (Figures GS-9-1, -2). Collectively, these deposits total more than 90 million tonnes and constitute one of the largest massive-sulphide districts in the Proterozoic (Bailes and Syme, 1989; Syme et al., 1999).

Rocks that host the Schist Lake and Mandy deposits are part of an undivided package of volcanic rocks immediately east of the Flin Flon block across the Mandy Road faults. Mapping in 2010 marked the second summer of a project that is building upon the work by Simard (2006) and Cole et al. (2007, 2008) in the Schist Lake–Mandy mines area. The current project is concentrated on mapping the volcanic rocks of the Hidden formation west of the Mandy Road faults, and the rocks that host the Schist Lake and Mandy deposits east of the Mandy Road faults, with the primary objective of reconstructing the volcanic environment of the deposits to aid exploration in the area. This report summarizes the results of a five-week bedrock mapping and sampling program in the Schist Lake–Mandy mines area during the summer of 2010. New mapping focused on the Hidden formation strata west of the Mandy Road faults, which had been left unmapped in 2009 (Figure GS-9-3). Plans for 2011 are to extend mapping into the strata east of the Mandy Road faults, which host the Schist Lake and Mandy deposits, as well as areas west of the Mandy Road faults that were not mapped during the 2009 and 2010 field seasons (Figure GS-9-3).

Objectives and methodology

This study, which is ongoing, focuses on the strata structurally overlying the rocks that host the Schist Lake and Mandy deposits. Mapping at 1:1000 and 1:2000 scales forms the basis of this research and is augmented through drillcore logging, petrography, geochemical analysis and geochronology.

Specific objectives of this project include

- establishing a detailed litho- and chemostratigraphy for the rocks that host the Schist Lake and Mandy deposits, and for the structurally overlying sequence of Hidden formation west of the Mandy Road faults;

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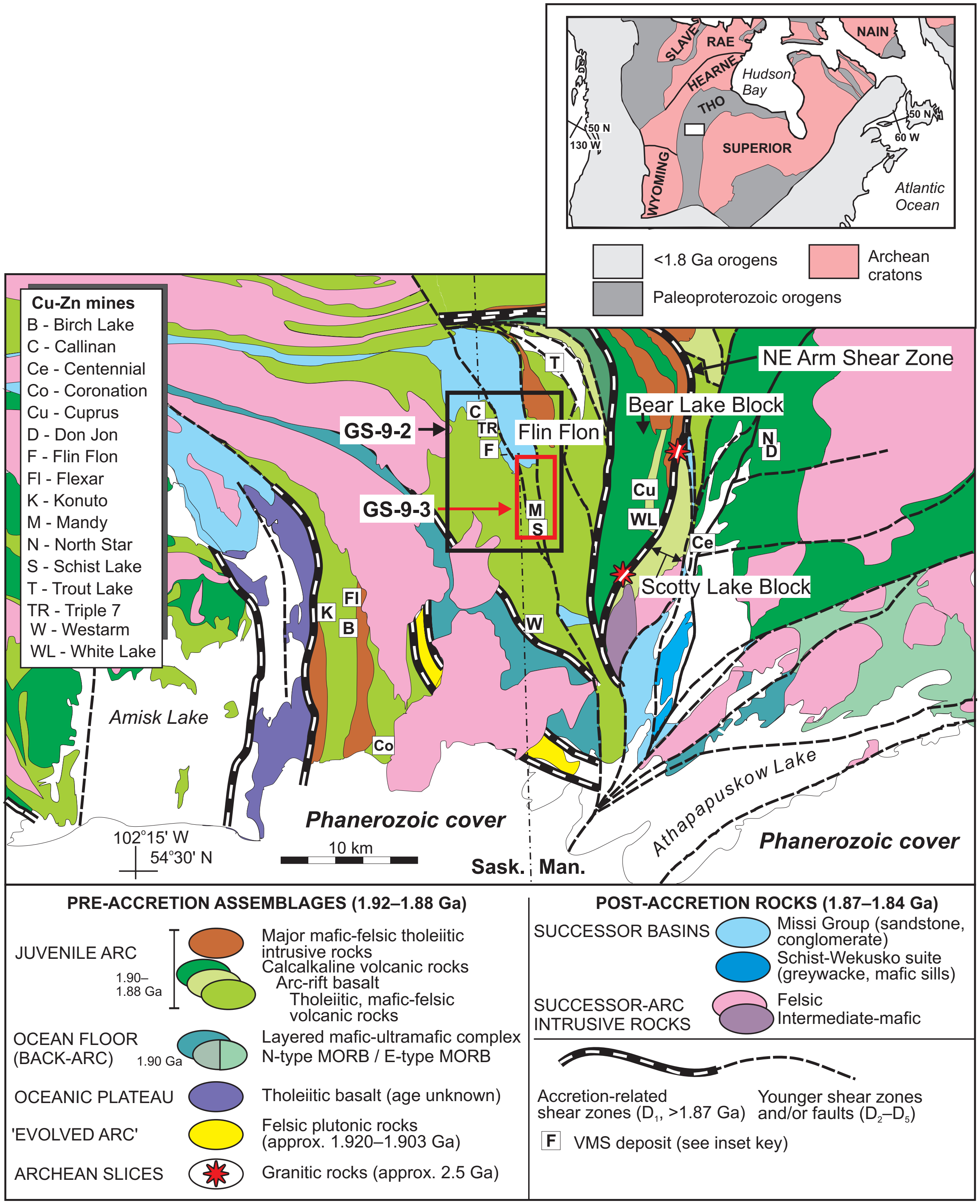


Figure GS-9-1: *Geology of the Flin Flon Belt, showing the locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1999); box indicates the area covered by Figure GS-9-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

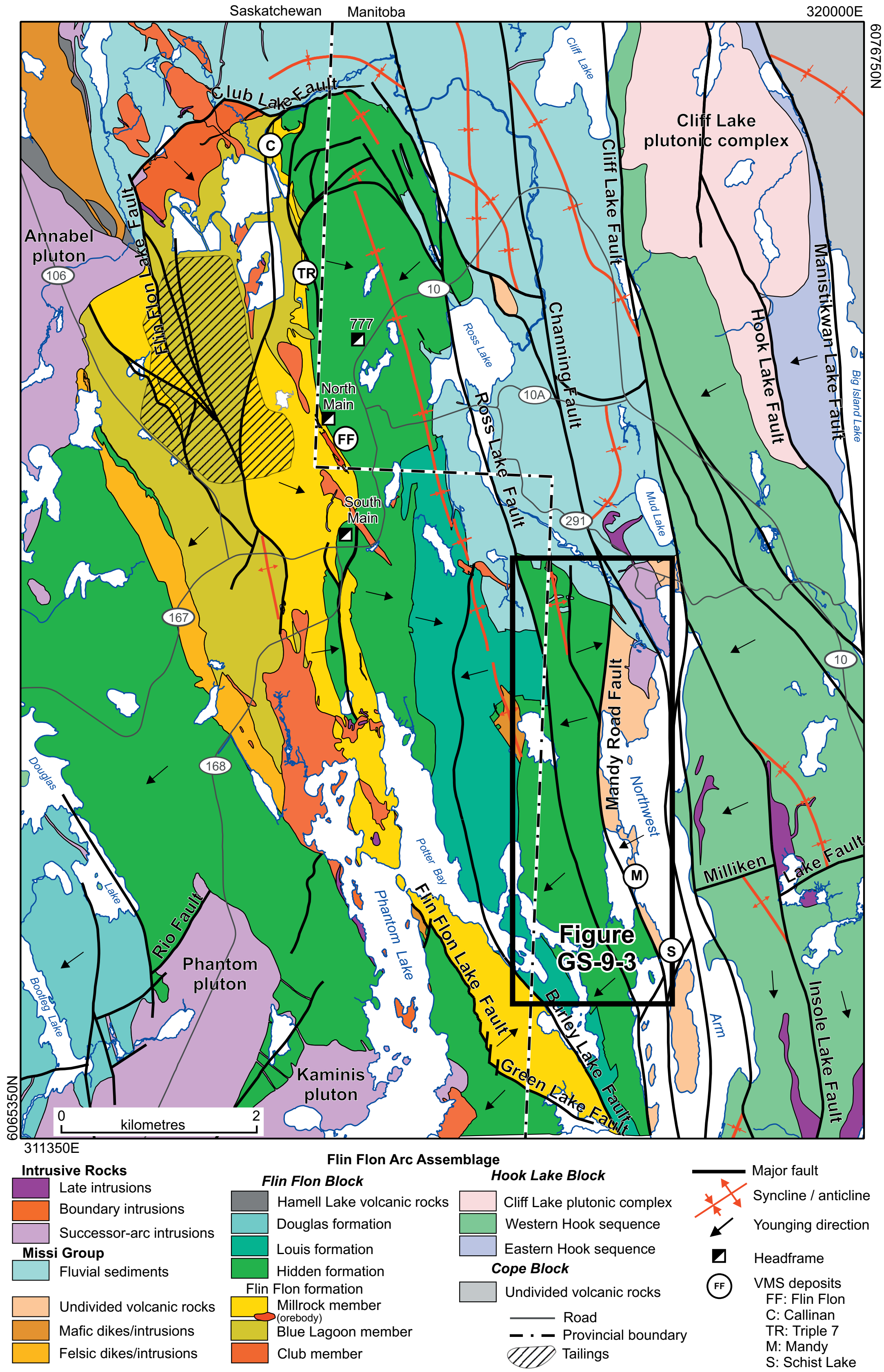


Figure GS-9-2: *Simplified geology of the Flin Flon area, showing the major stratigraphic units and structures (modified from Simard and MacLachlan, 2009); box indicates the area covered by Figure GS-9-3.*

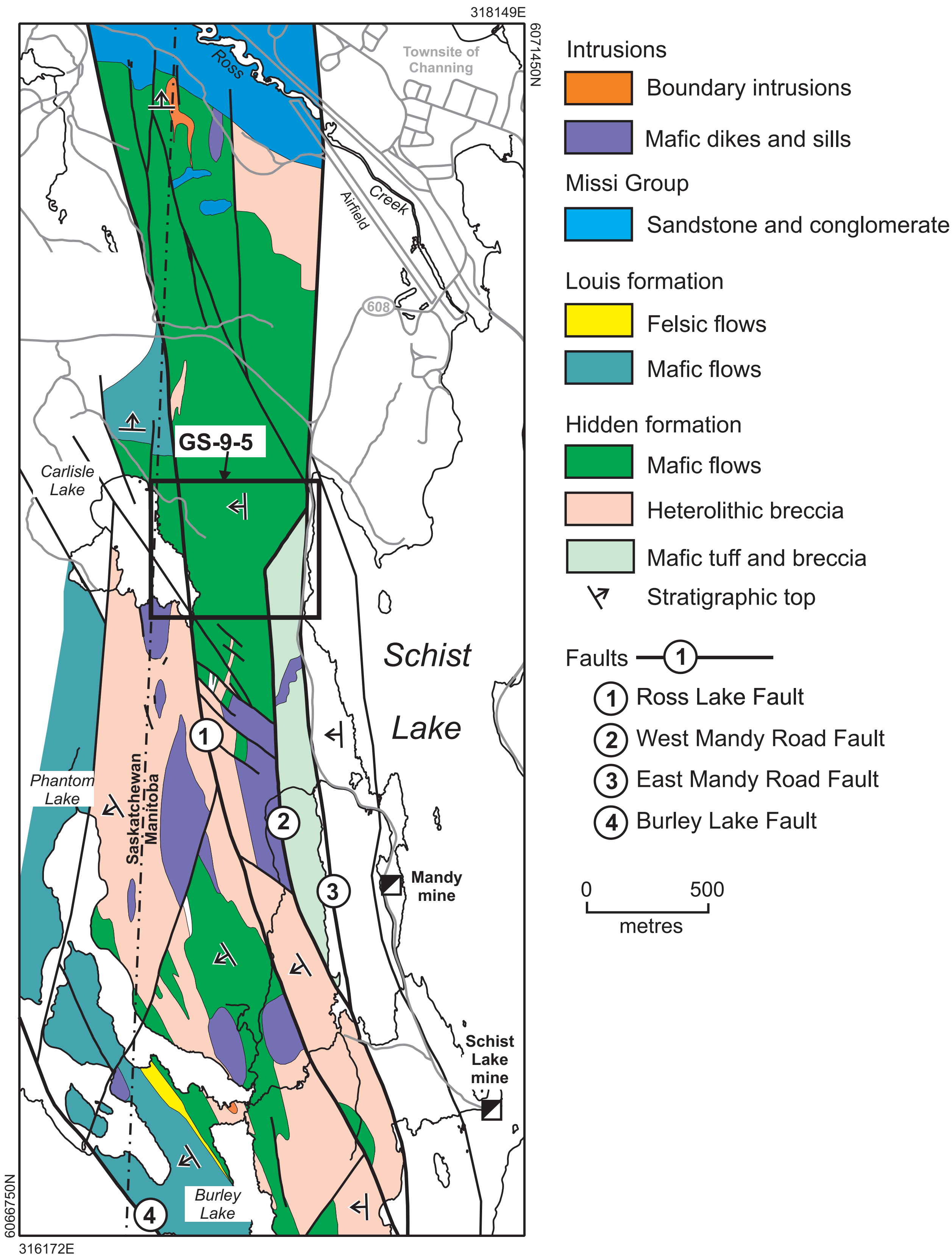


***Figure GS-9-3:** Simplified bedrock geology of the Schist Lake–Mandy mines area (modified from Simard, 2006).*

- determining if the Mandy Road faults have significantly affected the strata in the Schist Lake–Mandy mines area (i.e., have the faults structurally juxtaposed two different volcanic sequences?);
- determining if previous interpretations of the Mandy Road anticline and its morphology are correct, and ascertaining the exact location of its fold axis (discussed in DeWolfe, 2009);
- reconstructing the volcanic environment and emplacement/depositional history of these strata, including the location of synvolcanic faults (building on the observations of Simard, 2006);
- determining if synvolcanic structures recognized in these rocks, which form the host strata of the Schist Lake and Mandy deposits, can be traced into the footwall of the Mandy Road faults and, if so, whether these structures correspond with the location of VMS mineralization;
- documenting, delimiting and describing the hydrothermal alteration assemblages within the strata (building on the work of Cole et al., 2008); and
- assessing the potential for undiscovered base-metal mineralization, compared to the Schist Lake and Mandy deposits.

The last three objectives will be the focus of future work, including the 2011 field season.

Regional geology

The Paleoproterozoic Flin Flon Belt is part of the southeastern Reindeer Zone of the Trans-Hudson Orogen and contains 27 known VMS deposits (Figure GS-9-1). The Flin Flon Belt consists of a series of 1.91–1.84 Ga juvenile-arc, back-arc, ocean-floor and evolved-plutonic-arc tectonostratigraphic assemblages (Bailes and Syme, 1989; Stern et al., 1995; Lucas et al., 1996; Lucas et al., 1997; Bailes and Galley, 1999; Stern et al., 1999). The Flin Flon and Snow Lake juvenile-arc assemblages contain the majority of the VMS deposits (Syme et al., 1999).

The study area is located within the rocks of the Flin Flon arc assemblage, southeast of the town of Flin Flon (Figure GS-9-2). The Flin Flon arc assemblage is composed of juvenile metavolcanic rocks (1.91–1.88 Ga) that are unconformably overlain by younger fluvial sedimentary rocks of the Missi Group (ca. 1.84 Ga; Bailes and Syme, 1989; Stern et al., 1995; Lucas et al., 1996). Rocks of the Flin Flon arc assemblage are interpreted to have been erupted and emplaced in an island-arc–back-arc setting and consist of basalt, basaltic andesite flows and breccia and lesser rhyolitic flows (Syme and Bailes, 1989). The Flin Flon, Callinan and Triple 7 VMS deposits, which total more than 92.5 million tonnes grading 2.21% Cu, 4.25% Zn, 2.11 g/t Au and 27.22 g/t Ag (numbers include NI 43-101–compliant data for proven, probable and inferred resources; HudBay Minerals Inc., 2008), are interpreted to have formed during a period of localized rhyolitic volcanism in a synvolcanic subsidence structure, or cauldron, within a much larger, dominantly basaltic, central volcanic complex (Figure GS-9-2; Bailes and Syme, 1989; Syme et al., 1999). The Schist Lake (1.8 million tonnes grading 4.3% Cu, 7.27% Zn, 1.3 g/t Au and 37 g/t Ag; Mineral Inventory File 660, Manitoba Innovation, Energy and Mines, Winnipeg) and Mandy (0.13 million tonnes grading 7.3% Cu, 12.9% Zn, 2.8 g/t Au and 57 g/t Ag; Mineral Inventory File 662, Manitoba Innovation, Energy and Mines, Winnipeg) These two deposits are hosted by a quartz-porphyritic rhyolite unit compositionally similar to that which hosts the Flin Flon, Callinan and Triple 7 VMS deposits. They are structurally overlain, across the Mandy Road faults, by mafic flows, sills and volcaniclastic rocks that are similar to the rocks overlying the main Flin Flon VMS deposits (Figure GS-9-3; Simard, 2006; DeWolfe, 2009).

Geology of the Hidden formation in the Schist Lake–Mandy mines area

In the Schist Lake–Mandy mines area, strata of the Hidden formation occur west of the Mandy Road faults, trending north, dipping steeply to the east or west and younging to the west (Figure GS-9-3). To the north, they are in unconformable contact with the younger sedimentary rocks of the Missi Group.

These rocks could constitute the hangingwall strata to the Schist Lake and Mandy deposits, depending on the offset along the Mandy Road faults (DeWolfe, 2009). The Hidden and Louis formations form the lower and upper units, respectively, within the hangingwall to the Flin Flon, Callinan and Triple 7 VMS deposits (DeWolfe et al., 2009). In the study area, rocks of the Hidden formation consist of aphyric to plagioclase-phyric basalt flows, intercalated with mafic and heterolithic volcaniclastic rocks. Basaltic flows are the dominant lithofacies in the northern part of the area, whereas volcaniclastic rocks are dominant in the south (Simard, 2006; DeWolfe, 2009). This report focuses on the rocks in the transition zone between the volcaniclastic-dominated area to the south and the flow-dominated area to the north.

Because distinguishing primary and resedimented volcaniclastic rocks in the field can be ambiguous and difficult, the following descriptions use a nongenetic classification for volcaniclastic rocks, in which the granulometric names tuff, lapilli tuff, lapillistone, and tuff breccia reflect only the percentage and size of the components (Fisher, 1961; Gibson et al., 1999; White and Houghton, 2006). In this terminology, tuff particles are <2 mm, lapilli particles are 2–64 mm, and blocks and bombs are >64 mm. Peperite is "a genetic term applied to a rock formed essentially in situ by disintegration of magma intruding and mingling with poorly consolidated, typically wet sediments" (White et al., 2000). The term megabreccia is applied to coarse breccias, generally those with many clasts >1 m and some on the order of tens or hundreds of metres in diameter, and implies genesis through the slumping and caving of caldera walls during the initial stages of caldera collapse (Lipman, 1976).

Stratigraphy of the Hidden formation in the Schist Lake–Mandy mines area

This paper focuses on a stratigraphic section located west of the Mandy Road in the area north of Carlisle Lake (Figure GS-9-3). The volcanic lithofacies are highly variable along strike in this area (Simard, 2006; Simard and Creaser, 2007; DeWolfe, 2009). Figure GS-9-4 is a simplified stratigraphic column for the area, and Figure GS-9-5 is a geological map illustrating the lateral change from volcaniclastic lithofacies in the south to basaltic flows in the north. Detailed descriptions of units surrounding this area are contained in DeWolfe (2009).

Plagioclase crystal–rich mafic volcaniclastic unit

This unit has a maximum thickness of 60 m and a strike length of approximately 600 m. It ranges from lapillistone to lapilli tuff, is matrix supported and massive, and locally displays crude normally graded beds. The lapilli are angular to subrounded and exclusively mafic. They consist of 20% aphyric, quartz-amygdaloidal (≤1.5 mm, 10–40%), rounded basalt clasts; 10% aphyric, weakly quartz-amygdaloidal (<1 mm, ≤3%), rounded basalt clasts; and 1% angular, aphyric basalt clasts with 7% hematite-filled amygdules and 8% quartz-filled amygdules. The matrix consists of a pinkish brown, fine-grained mafic tuff with ~15% subhedral, rarely broken plagioclase crystals (1–3 mm; Figure GS-9-6a). The top of this unit is marked by 5–45 cm of finely laminated, strongly silicified and epidotized mafic tuff. The contact between the tuff and the overlying aphyric tuff breccia is locally intruded by a fine-grained mafic sill.

Aphyric mafic tuff breccia to megabreccia

This unit overlies the plagioclase crystal–rich volcaniclastic unit, has a maximum thickness of 40 m and has a lateral facies change along strike to the north into an aphyric basaltic megabreccia (see description below). The transition/contact is covered by an approximately 10 m wide area of overburden. The tuff breccia comprises 65% subrounded blocks of quartz-amygdaloidal (4–15 mm, ≤10%) aphyric basalt and 25% aphyric, weakly quartz-amygdaloidal (≤5 mm, ≤1%) amoeboid blocks of basalt. The matrix contains 15% plagioclase crystals (≤2 mm, subhedral, rarely broken), 80% grey ash-sized particles and 5% red-brown, altered hyaloclastite (Figure GS-9-6b).

Clast sizes averaging >1 m and ranging up to 20 m (Figure GS-9-5) characterize the megabreccia, which is approximately 140 m in strike length. It terminates to the north abruptly against a pillowed basalt flow (see description below), the contact marked by a synvolcanic mafic dike and moderate shearing (Figure GS-9-5). The unit comprises 15% aphyric, weakly quartz-amygdaloidal (1–3 mm, <5%), angular to fluidal basalt clasts; 55% aphyric, quartz-amygdaloidal (1–8 mm, 5–55%) basalt clasts; and 10% plagioclase-porphyritic (≤7 mm, ≤5%), quartz-amygdaloidal (1–5 mm, ~15%) basalt clasts. The

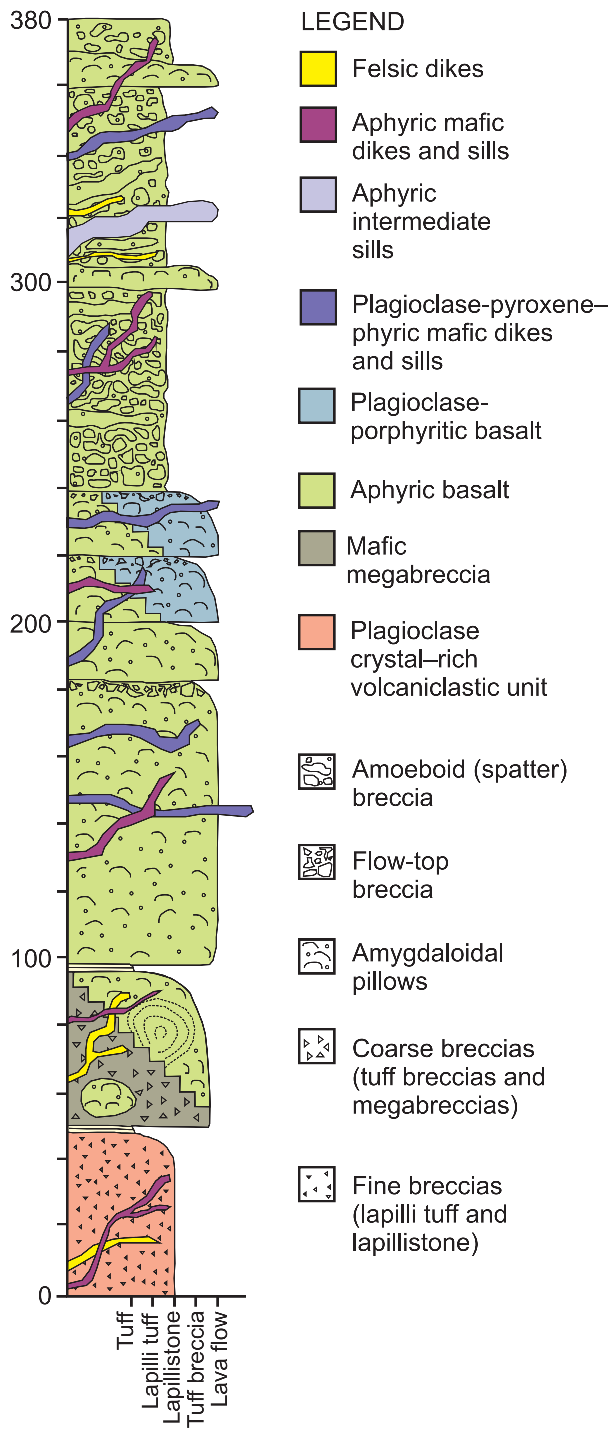


Figure GS-9-4: *Simplified stratigraphy of the Hidden formation between Schist Lake and Carlisle Lake.*

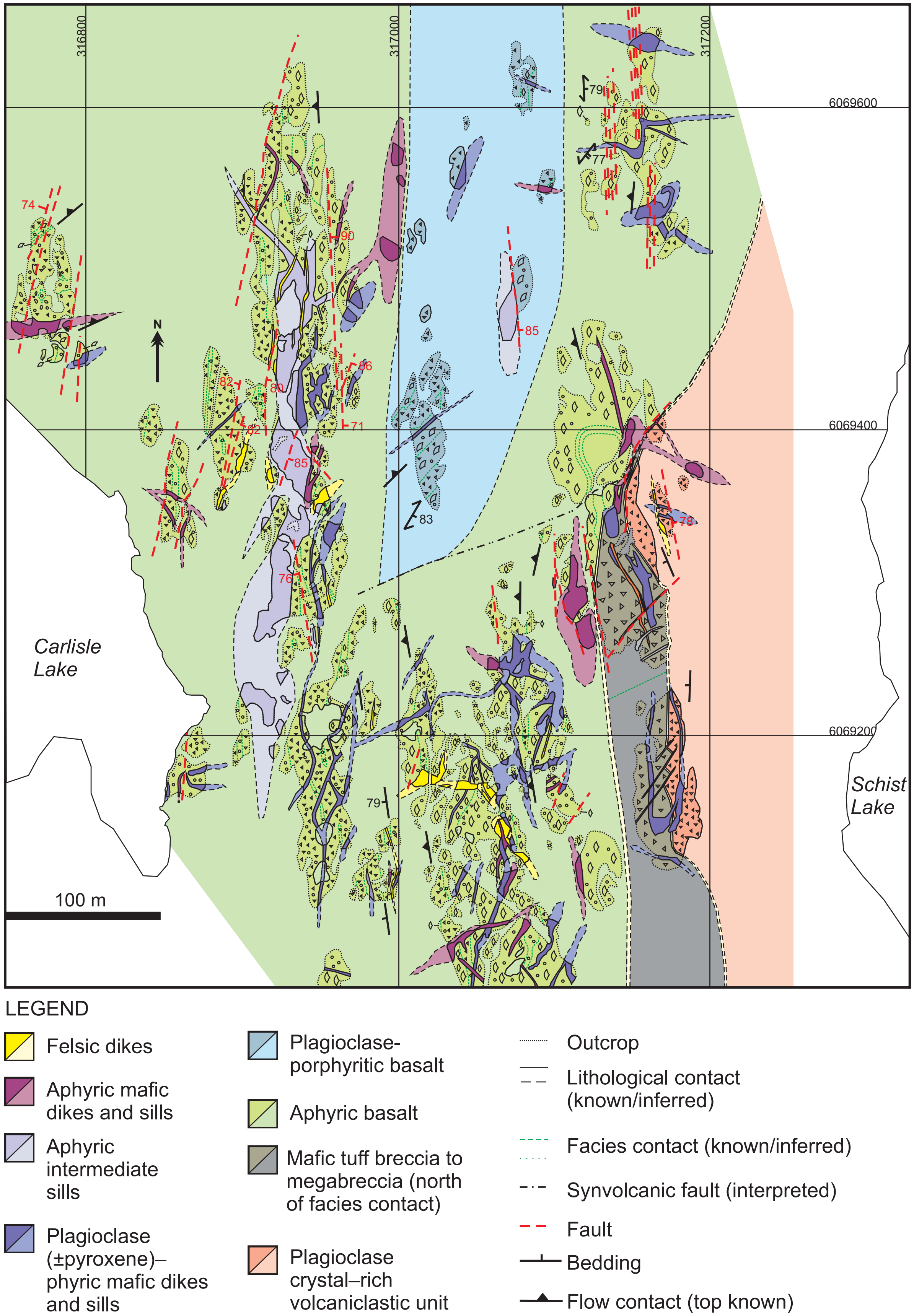


Figure GS-9-5: *Detailed geology of the Hidden formation between Schist Lake and Carlisle Lake.*

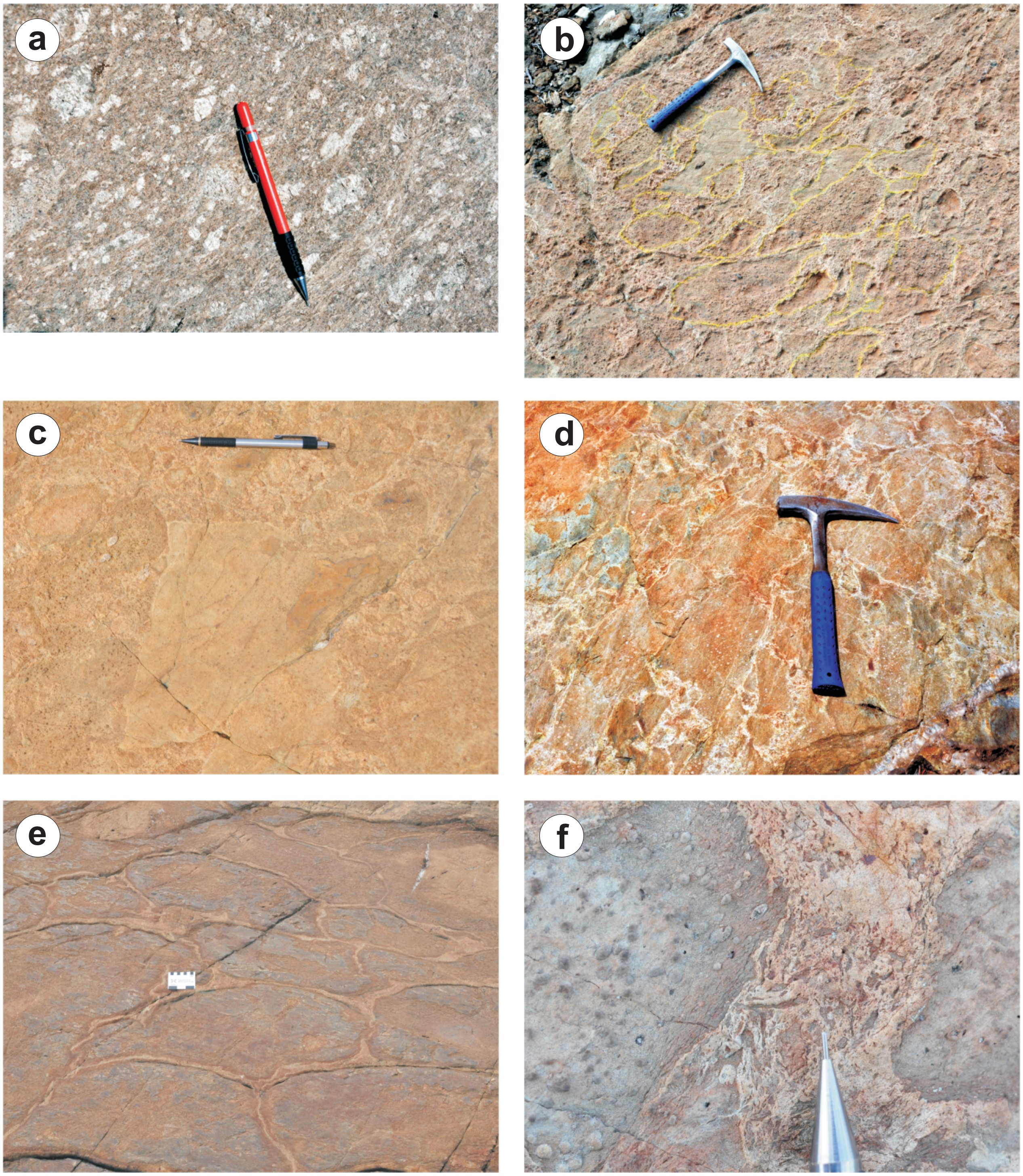


***Figure GS-9-6:** Rocks of the Hidden formation, Schist Lake–Mandy mines area: **a)** plagioclase crystal–rich mafic lapillistone; **b)** aphyric mafic tuff breccia showing variably amygdaloidal blocks of basalt; **c)** mafic megabreccia (note plagioclase crystal–rich matrix and variably amygdaloidal blocks of basalt); **d)** large block of in situ–brecciated aphyric basalt within the megabreccia; **e)** aphyric pillowed basalt; **f)** hyaloclastite between two aphyric, amygdaloidal basalt clasts in a flow-top breccia.*

matrix consists of plagioclase crystals (subangular, 2–15 mm, 50%), hyaloclastite (1–3 mm angular to cuspate fragments, 5–10%) and grey ash-sized particles (Figure GS-9-6c). Locally, the unit contains large blocks (6.4 cm to 5 m) of in situ–brecciated aphyric basalt that is variably quartz amygdaloidal (<5 mm, ≤15%; Figure GS-9-6d). These blocks are described as in situ brecciated because they consist of jigsaw-puzzle-fit basalt fragments separated only by hairline fractures. Commonly these blocks display thin (<2 mm) chilled margins.

Aphyric pillowed basalt

This unit occurs along strike to the north of, and in contact with, the aphyric mafic megabreccia. The contact is moderately sheared and locally intruded by a dike; however, where the pillows are in contact with the adjacent breccia, they are not truncated and thus the contact is interpreted as a primary volcanic fault that has had subsequent minor movement during later deformational events. A small (<3 m) offset of a bedded, plagioclase crystal–rich mafic volcaniclastic is evidence for only minor, postvolcanic movement along this structure. The unit is pillowed and approximately 60 m in thickness. It is aphyric and quartz amygdaloidal (1–7 mm, ≤25%), and contains moderate, patchy quartz-epidote alteration, commonly in the cores of pillows. The pillows are 30–120 cm in diameter, have well-defined quartz-epidote–altered selvages (1–2 cm thick) and commonly have finely laminated tuff at the triple junctions of pillows (Figure GS-9-6e). The laminations, where present, are convolute. The top of the unit is marked by a flow-top breccia (Figure GS-9-6f).

Within this unit, just north of the interpreted synvolcanic fault that separates it from the megabreccia unit to the south, are large (2–20 m in diameter) lava tubes or megapillows. These megapillows are defined by areas of massive facies with flow-banded margins that are completely surrounded by, but do not truncate, the pillows.

Plagioclase-porphyritic basalt and associated volcaniclastic rocks

This unit occurs along strike to the north from the aphyric pillowed basalt, but the lateral, transitional contact is not exposed. It has a maximum thickness of 60 m and a strike length of approximately 600 m. The unit is in conformable contact with the flow-top breccia of an underlying aphyric pillowed flow, and is conformably overlain by aphyric fluidal breccias. Pillow shape and the orientation of flow tops indicate younging to the northwest.

The pillowed portion of this unit (Figure GS-9-7a) comprises multiple pillowed flows, ranging in thickness from 2.5 to 10 m and separated by very well defined flow-top breccias (0.5–3 m thick; Figure GS-9-7b). The pillows are ≤1 m in diameter, plagioclase porphyritic (1–4 mm, 20%), quartz amygdaloidal (1–8 mm, 15%, concentrated in the cores of pillows) and quartz-epidote altered (concentrated in cores of pillows), and have 1–2 cm wide, fine-grained selvages. The selvages and interpillow areas contain up to 30% angular plagioclase crystals that are seldom broken. The rest of the interpillow areas comprise fine-grained tuff (±hyaloclastite). One of the thinner flows (3 m) contains in situ–brecciated pillows, where the margin of the pillow is intact but the interior is composed of fragments with a jigsaw-puzzle fit separated by hairline fractures. This feature was also recognized in the plagioclase-porphyritic pillowed basalt in the Stockwell member of the Hidden formation, in the main camp (DeWolfe and Gibson, 2005). The flow-top breccias consist of closely packed amoeboid clasts of plagioclase-porphyritic, quartz-amygdaloidal basalt, 1–30 cm in diameter and with fine-grained chilled margins (1–3 mm), in a matrix of fine-grained tuff, plagioclase crystals (1–3 mm, angular) and hyaloclastite.

The pillowed flows are capped by a plagioclase-crystal–rich, mafic volcaniclastic unit (Figure GS-9-7c). This unit is dominated by lapilli-tuff and tuff beds, but also contains coarser lapillistone and tuff-breccia beds. Its thickness is highly variable, ranging from <20 to 80 m. The beds are commonly massive and only seldom do they display normal grading. The unit comprises quartz-amygdaloidal (1–4 mm, <5 to 45%), aphyric basalt clasts and plagioclase-porphyritic basalt clasts (<1–30 cm) in a plagioclase crystal–rich (1–2 mm, 15–20%), fine-grained tuff matrix. The ratio of aphyric to plagioclase-porphyritic basalt clasts is highly variable, as is the ratio of clasts to matrix.

Aphyric fluidal breccias with minor flows

This unit is in conformable contact with an underlying aphyric pillowed basalt unit, or plagioclase-porphyritic flows and associated volcaniclastic rocks. It is approximately 90 m thick, extends approximately 450 m along strike, and is dominated by coarse fluidal breccias with minor (<10%) thin pillowed and massive flows. The breccia portion of the unit comprises fluidal, aphyric, amygdaloidal basalt clasts ranging in size from 1 to 100 cm and having 1–3 mm wide, red, fine-grained chilled margins (Figure GS-9-7d, e). Commonly, the clasts also have light brown quartz-epidote–altered rims. The breccia is clast supported with a reddish brown, fine-grained tuff matrix, and is commonly intruded by thin, massive to pillowed, aphyric mafic sills (Figure GS-9-7f).

Discussion

The volcanic lithofacies are highly variable along strike in the area west of the Schist Lake and Mandy deposits (Simard, 2006; Simard and Creaser, 2007; DeWolfe, 2009). Figure GS-9-8 summarizes the sequence of events that are interpreted to have led to the distribution of rock types and facies observed in the area between Schist Lake and Carlisle Lake.

Detailed mapping has revealed a principal change from a flow-dominated regime in the north to a volcaniclastic-dominated regime in the south. This lateral change is abrupt and locally marked by an aphyric mafic body, approximately 1–2 m wide, that locally crosscuts bedding lower in the stratigraphy and changes orientation, becoming parallel to bedding higher in the stratigraphy. This change in orientation corresponds to a change from massive to pillowed facies; therefore, the mafic body is interpreted to represent an aphyric mafic dike,

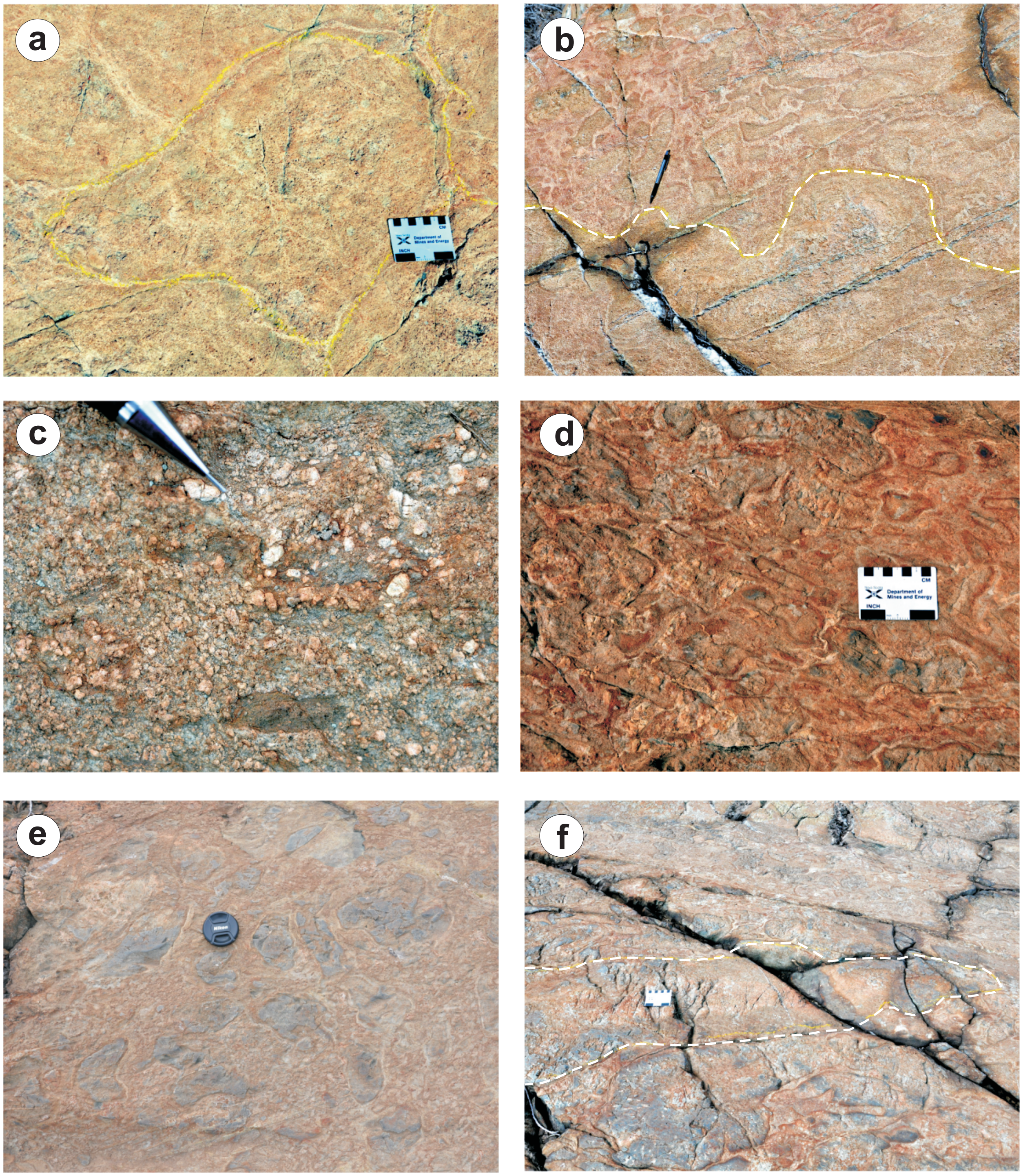
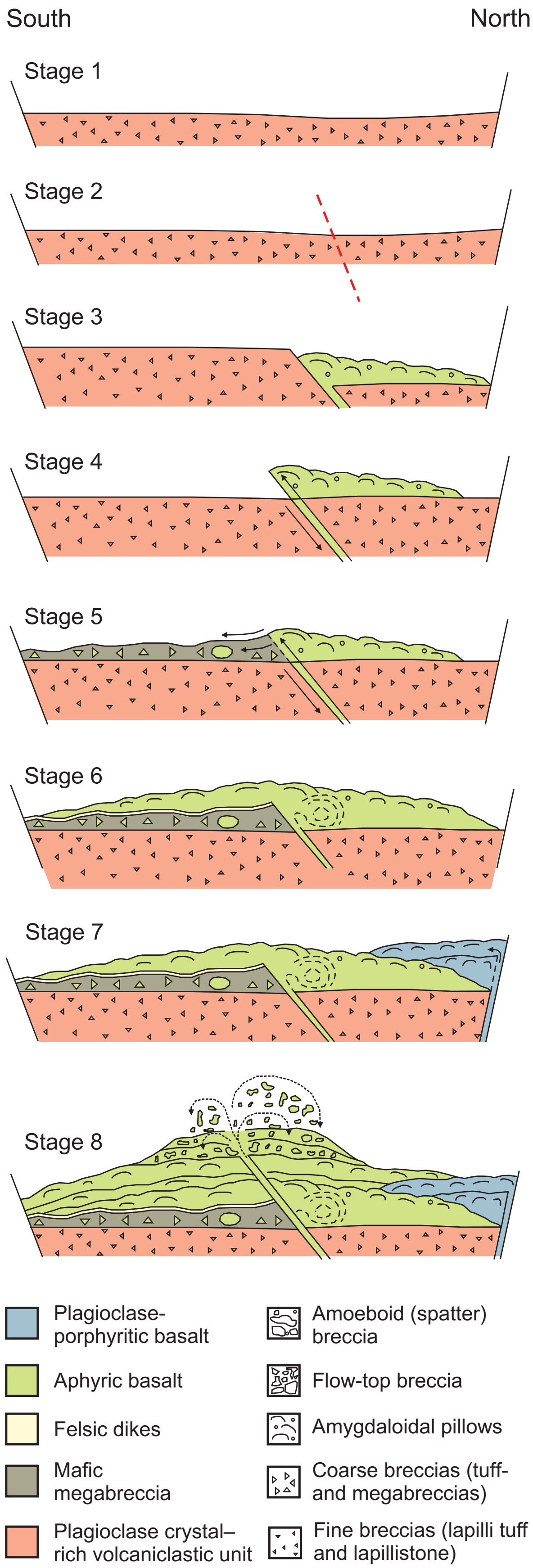


Figure GS-9-7: *Rocks of the Hidden formation, Schist Lake–Mandy mines area:* ***a)*** *plagioclase-porphyritic pillowed basalt flow;* ***b)*** *plagioclase-porphyritic pillowed basalt flow (below dashed white line) and its fluidal, flow-top breccia;* ***c)*** *plagioclase crystal–rich, mafic lapilli tuff;* ***d)*** *aphyric fluidal breccia (note fine-grained, red-coloured chilled margins on clasts);* ***e)*** *larger fluidal clasts of aphyric basalt in 'matrix' of finer, similarly shaped clasts of basalt;* ***f)*** *synvolcanic sill (dashed white line) intruded into fluidal, aphyric breccia deposit.*

crosscutting the megabreccia and feeding a thin, pillowed flow that was extruded on top of the breccia. Because the dike separates the megabreccia and other volcaniclastic units to the south from the basaltic flows to the north, it is interpreted to have been emplaced along a synvolcanic fault, which marks the northern boundary of a subsidence structure into which the megabreccias and other volcanic debris flows were deposited.

Although there is evidence of minor shearing along this dike, no pillows are truncated in the unit to the north, and the vertical offset of the underlying plagioclase crystal–rich volcaniclastic unit along this structure is on the



order of only a few metres, suggesting this is a primary volcanic fault that has been reactivated by later deformation (Figure GS-9-8). This synvolcanic structure corresponds to the location of the northern portion of the West Mandy Road Fault where it has a northeast orientation (Figures GS-9-3, -5). In this area, there is no evidence of significant displacement (>3 m) of the plagioclase crystal–rich volcaniclastic unit (Figure GS-9-5). Also, where the West Mandy Road Fault changes to a north-trending structure (Figures GS-9-3, -5), aphyric basalt is mappable across the structure and, although there is evidence of shearing in this area, there is no evidence of significant offset of the basalt on either side of the structure. Thus, a preliminary interpretation of this structure is that, where it has a northeast trend, it represents a synvolcanic fault that has been reactivated by later deformation, leading to minor offset of a volcaniclastic unit. This later faulting continues to the south, where there is local evidence of shearing, and it trends north, separating basalt to the east from either basalt or mafic volcaniclastic rocks to the west (Figures GS-9-3, -5). More detailed mapping of the southern portion of the West Mandy Road Fault is needed, but there appears to be no evidence in the area illustrated in Figure GS-9-5 that the late movement along this fault has juxtaposed two unrelated volcanic packages. Rather, it appears that the volcanic units on either side of the fault are part of the same volcanic sequence and were erupted and emplaced in the order in which they are observed.

The interpreted synvolcanic fault marks the northern edge of a subsidence structure, or graben, that structurally overlies the Schist Lake and Mandy deposits, and into which a thick sequence of volcaniclastic rocks was deposited; see Simard (2006) and DeWolfe (2009) for further descriptions of these rocks. The volcaniclastic rocks decrease in clast size south of the graben wall, changing from megabreccia, to tuff breccia, to lapillistone, to volcaniclastic rocks dominated by lapilli-tuff and tuff beds.

The megabreccias are interpreted to have resulted from slumping and caving of the graben wall during initial stages of subsidence. The finer volcaniclastic deposits to the south are the result of mass-flow deposits travelling a greater distance into the centre of the graben as subsidence continued (Figure GS-9-8). As a result, the deposits

Figure GS-9-8: *Schematic diagram illustrating possible sequence of events resulting in the volcanic strata observed between Schist Lake and Carlisle Lake:* ***1)*** *early rifting/subsidence and deposition of plagioclase crystal–rich volcaniclastic debris downslope into the basin;* ***2)*** *fault development as rifting/subsidence continues;* ***3)*** *extrusion of basaltic flows along developing fault structure;* ***4)*** *change to compressional regime, moving northern fault block upwards;* ***5)*** *erosion and subsequent debris flows to the south;* ***6)*** *extrusion of basalt along reverse fault structure;* ***7)*** *extrusion of plagioclase-porphyritic basalt flows to the north;* ***8)*** *extrusion of aphyric basaltic flows and development a spatter rampart along the feeding fissure.*

farther south of the graben wall are commonly bedded, but the units closer to the fault are massive and poorly sorted.

Aphyric fluidal breccia that overlies the aphyric pillowed basalt or plagioclase-porphyritic pillowed basalt unit is not laterally continuous (not shown on Figure GS-9-5), having a strike length of ~450 m compared to its ~90 m thickness. It is interpreted as a spatter rampart deposit formed by a lava fountain along a fissure (Figure GS-9-8). This spatter deposit lies above the inferred extension of the synvolcanic fault mentioned above. A synvolcanic dike, utilizing a similar synvolcanic feature, occurs higher in the strata 100 m to the north. This synvolcanic dike is ~2 m wide and 'sills-out' horizontally into the surrounding spatter deposit. Where the dike propagates laterally into bedding, the amoeboid, aphyric, quartz-amygdaloidal basalt spatter blocks and bombs are larger and more abundant proximal to the dike (vent). The megabreccias, megapillows and spatter rampart are all indicative of a vent-proximal environment (Dimroth, 1978, 1985; Lipman, 1976; Gibson et al., 1999).

Future work

Plans for summer 2011 include the completion of 1:2000 scale mapping of the area west of the Mandy Road faults and east of the Carlisle Lake Fault. This will allow for the pre-deformation reconstruction of the volcanic environment of the rocks that structurally overlie the Schist Lake and Mandy deposits. This environment can then be compared to that of the Hidden formation overlying the Flin Flon Main, Callinan and Triple 7 deposits. Following completion of the mapping of the Hidden formation in the Schist Lake–Mandy mines area, the project will focus on mapping and drillcore logging of the strata that host the two deposits east of the East Mandy Road Fault. The resulting three-dimensional reconstruction of the volcanic environment in which the deposits formed will greatly aid new exploration for base metals in the area.

Economic considerations

The discovery of a synvolcanic basin and associated fault(s) west of the Mandy Road faults suggests that the rocks structurally overlying the Schist Lake and Mandy VMS deposits may also be prospective for VMS-type mineralization.

The general association of VMS deposits with extensional tectonic settings in arc-volcanic environments, including Flin Flon, has been well documented (e.g., Franklin et al., 1981, 2005; Sillitoe, 1982; Cathles et al., 1983; Syme et al., 1996; Gibson et al., 1999; Syme et al., 1999). The documented evidence for extension during mineralization in Flin Flon is that the footwall is dominated by thick mass-flow deposits that infill nested basins within a larger cauldron subsidence structure that is crosscut by a synvolcanic dike swarm (Gibson et al., 2003).

Recognition of a similar basin and associated faulting in the strata that structurally overlie the Schist Lake and Mandy deposits provides evidence that some of the key variables required to form a VMS deposit are present in the rocks structurally overlying the Schist Lake and Mandy VMS deposits. Such variables include

- vent proximity (required for high heat flow and cross-strata permeability), as evidenced by megapillows, a spatter rampart and synvolcanic dikes and sills;
- synvolcanic faults (required for cross-strata permeability and to act as magma and hydrothermal fluid pathways), as evidenced by the megabreccia, fault-bounded lithofacies, spatter rampart and synvolcanic dikes;
- synvolcanic graben (provides evidence of the rifting, or the thinning of the crust, that is needed for high heat flow), as evidenced by a thick succession of volcaniclastic rocks that ends abruptly along strike against nontruncated pillows;
- hydrothermal alteration (evidence of an active, synvolcanic hydrothermal system), as defined by the occurrence of strong, patchy quartz-epidote alteration within the flows and volcaniclastic rocks in the Schist Lake–Mandy mines area; and
- a hiatus in effusive volcanism (allowing for the concentration of mineralization along a specific stratigraphic horizon), as evidenced by the large volume of volcaniclastic rocks in the Schist Lake–Mandy mines area.

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References

Bailes, A.H. and Galley, A.G. 1999: Evolution of the Paleoproterozoic Snow Lake arc assemblage and geodynamic setting for associated volcanic-hosted massive sulphide deposits, Flin Flon Belt, Manitoba, Canada; Canadian Journal of Earth Sciences, v. 36, p. 1789–1805.

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Geological Services, Geological Report GR87-1, 313 p.

Cathles, L.M., Guber, A.L., Lenagh, T.C. and Dudàs, F. Ö. 1983: Kuroko-type massive sulphide deposits of Japan: products of an aborted island-arc rift; Economic Geology Monograph 5, p. 96–114.

Cole, E.M., Gibson, H.L. and Lafrance, B. 2007: Preliminary description of the lithofacies and structure of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 33–42.

Cole, E.M., Piercey, S.J. and Gibson, H.L. 2008: Geology and geochemistry of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 18–28.

DeWolfe, Y.M. 2009: Stratigraphy and structural geology of the hangingwall to the Schist Lake and Mandy volcanogenic massive deposits, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 22–36.

DeWolfe, Y.M., Gibson, H.L., Lafrance, B. and Bailes, A.H. 2009: Volcanic reconstruction of Paleoproterozoic arc volcanoes: the Hidden and Louis formations, Flin Flon, Manitoba, Canada; Canadian Journal of Earth Sciences, v. 46, p. 481–508.

DeWolfe, Y.M. and Gibson, H.L. 2005: Physical description of the Bomber, 1920 and Newcor members of the Hidden formation, Flin Flon, Manitoba (NTS 63K16SW); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 7–19.

Dimroth, E., Cousineau, P., Leduc, M. and Sanschagrin, Y. 1978: Structure and organization of Archean subaqueous basalt flows, Rouyn-Noranda area, Quebec, Canada; Canadian Journal of Earth Sciences, v. 15, p. 902–918.

Dimroth, E., Imrah, L., Cousineau, P., Leduc, M. and Sanschagrin, Y. 1985: Paleogeographic analysis of mafic submarine flows and its use in the exploration for massive sulphide deposits; Geological Association of Canada, Special Paper 28, p. 203–222.

Fisher, R.V. 1961: Proposed classification of volcaniclastic sediments and rocks; Geological Society of America Bulletin, v. 72, p. 1395–1408.

Franklin, J.M., Gibson, H.L., Jonasson, I.R. and Galley, A.G. 2005: Volcanogenic massive sulfide deposits; Economic Geology, 100th Anniversary Volume, p. 523–560.

Franklin, J.M., Lydon, J.W. and Sangster, D.F. 1981: Volcanic-associated massive sulphide deposits; Economic Geology, 75th Anniversary Volume, p. 485–627.

Gibson, H., Devine, C., Galley, A., Bailes, A., Gilmore, K., MacLachlan, K. and Ames, D. 2003: Structural control on the location and formation of Paleoproterozoic massive sulfide deposits as indicated by synvolcanic dike swarms and peperite, Flin Flon, Manitoba and Saskatchewan; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Abstracts Volume 28.

Gibson, H.L., Morton, R.L. and Hudak, G.J., 1999: Submarine volcanic processes, deposits, and environments favourable for the location of volcanic associated massive sulfide deposits; *in* Volcanic Associated Massive Sulfide Deposits: Processes and Examples in Modern and Ancient Settings, C.T. Barrie and M.D. Hannington (ed.), Reviews in Economic Geology, v. 8, p. 13–49.

Lipman, P.W. 1976: Caldera collapse breccias in the western San Juan Mountains, Colorado; Geological Society of America Bulletin, v. 87, p. 1397–1410.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, p. 602–629.

Lucas, S.B., Stern, R.A., Syme, E.C., Zwanzig, H., Bailes, A.H., Ashton, K.E., Maxeiner, R.O., Andsell, K.M., Lewry, J.F., Ryan, J.J. and Kraus, J. 1997: Tectonics of the southeastern Reindeer Zone, Trans-Hudson Orogen (Manitoba and Saskatchewan); Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Abstracts Volume 22.

Sillitoe, R.H. 1982: Extensional habitats of rhyolite-hosted volcanogenic massive sulphide deposits; Geology, v. 10, p. 403–407.

Simard, R-L. 2006: Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2006, Manitoba Science Technology, Energy and Mines, Manitoba Geological Survey, p. 9–21.

Simard, R-L. and Creaser, R.A. 2007: Implications of new geological mapping, geochemistry and Sm-Nd isotope data, Flin Flon area, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 7–20.

Simard, R-L. and MacLachlan, K. 2009: Highlights of the new 1:10 000 scale geology map of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63K12, 13); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 6–14.

Stern, R.A., Syme, E.C., Bailes, A.H. and Lucas, S.B. 1995: Paleoproterozoic (1.90–1.86 Ga) arc volcanism in the Flin Flon belt, Trans-Hudson Orogen, Canada; Contributions to Mineralogy and Petrology, v. 119, p. 117–141.

Stern, R.A., Machado, N., Syme, E.C., Lucas, S.B. and David, J. 1999. Chronology of crustal growth and recycling in the Paleoproterozoic Amisk collage (Flin Flon Belt), Trans-Hudson Orogen, Canada; Canadian Journal of Earth Sciences, v. 36, p. 1807–1827.

Syme, E.C., Bailes, A.H., Lucas, S.B., and Stern, R.A. 1996: Tectonostratigraphic and depositional setting of Paleoproterozoic volcanogenic massive sulphide deposits, Flin Flon Belt, Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Abstract Volume 21, p. A93.

Syme, E.C., Lucas, S.B., Bailes, A.H. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, p. 1767–1788.

White, J.D.L., and Houghton, B.F. 2006: Primary volcaniclastic rocks; Geology, v. 34, p. 677–680.

White, J.D.L., McPhie, J. and Skilling, I. 2000: Peperite: a useful genetic term; Bulletin of Volcanology, v. 62, p. 65–66.