GS-4 Preliminary results from a stratigraphic and structural investigation of the Trout Lake volcanogenic massive sulphide deposit, Flin Flon, Manitoba (part of NTS 63K13)

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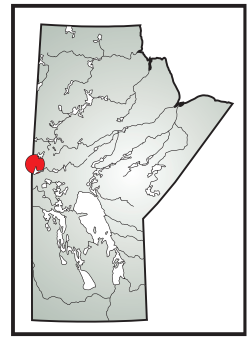

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Summary

The Trout Lake deposit is a large (>20.6 million tonnes) rhyolite-hosted Cu-Zn volcanogenic massive sulphide (VMS) deposit, which is strongly deformed and experienced regional greenschist-facies metamorphism. The stratigraphic and structural characteristics of this deposit have not been previously studied in detail. Whether the deposit is complexly fold and fault repeated at the mine (hundreds of metres) or regional scale (thousands of metres) has important implications for exploration.

Preliminary results from detailed underground and surface geological mapping as well as core logging establish that the footwall to hangingwall hostrocks of the Trout Lake VMS deposit can be subdivided into five different lithological units on the basis of lithofacies and petrographic characteristics. These lithological units show no evidence of stratigraphic repetition, which suggests that the overall mine stratigraphy has not been repeated by folds and faults at the mine scale.

This project aims to resolve the following critical questions regarding the geology of the Trout Lake deposit: 1) the precise age of the ore-hosting rhyolite units, 2) the space-time relation between it and other VMS deposits in the Flin Flon area, 3) the geodynamic setting, and 4) the sequence of deformation events that have modified the original geometry of the deposit. Resolution of these questions is fundamental to the development of successful exploration models that may lead to the discovery of new VMS deposits in the area.

Introduction

The Trout Lake deposit (Hudson Bay Mining and Smelting Co. Limited.) is a rhyolite-hosted volcanogenic massive sulphide (VMS) deposit (cf. Barrie and Hannington, 1999; Gibson et al., 1999; Franklin et al., 2005) located approximately 5 km northeast of Flin Flon, Manitoba, and is part of the Paleoproterozoic Flin Flon Belt of the Trans-Hudson Orogen (THO; Figure GS-4-1). The deposit is one of the largest VMS deposits in the Flin Flon area with >20.6 million tonnes grading 1.54% Cu, 5.12% Zn, 1.54 g/t Au, and 15.76 g/t Ag (T. Schwartz, pers. comm., 2009).

Several unpublished internal reports have addressed questions regarding the structure, stratigraphy and geochemistry of the Trout Lake VMS deposit (e.g., Price, 1990, 1992; Price et al., 1992; Rusk, 1992; Tessier, 1997, 2002; Brown and Rusk, 2000). However, the deposit has not been studied in detail for its geological and geochemical attributes, leaving its structural and stratigraphic setting unknown with respect to the Flin Flon, 777, and Callinan VMS deposits located 5 km to the southwest in the Flin Flon mining district (Figure GS-4-1). The precise age of formation of the Trout Lake deposit is unresolved. Regression of discordant U-Pb zircon-age results from a rhyolitic volcaniclastic rock containing massive sulphide lenses has been interpreted to record a ca. 1869 Ma crystallization age (Syme et al., 2001). However, Pb-Pb ages of individual zircon fractions could equally be taken to calculate a minimum crystallization age of ca. 1880 Ma (L. Heaman, N. Rayner, pers. comm., 2009). Additional analytical work is underway to resolve this uncertainty. Whether the Trout Lake deposit occupies the same stratigraphic horizon or is significantly older or younger than the Flin Flon mining district deposits has significant implications for models that are being developed for VMS exploration in the Flin Flon mining district, and for the interpretation of the overall tectonomagmatic evolution of the area (e.g., Devine et al., 2002; Gibson et al., 2003; Lewis et al., 2006, 2007; MacLachlan and Devine, 2007; DeWolfe et al., 2009a, b).

The purpose of this project is to reconstruct the stratigraphy and structure of the Trout Lake deposit. This investigation involves underground stratigraphic and structural mapping, characterization of all lithological units in terms of their volcanology and geochemistry, and the correlation of these units between underground and surface exposures. Uranium-lead zircon geochronology of the rhyolite hosting the VMS lenses and the intercalated argillite in the mine is being undertaken to establish the precise time frame for the Trout Lake mine stratigraphy.

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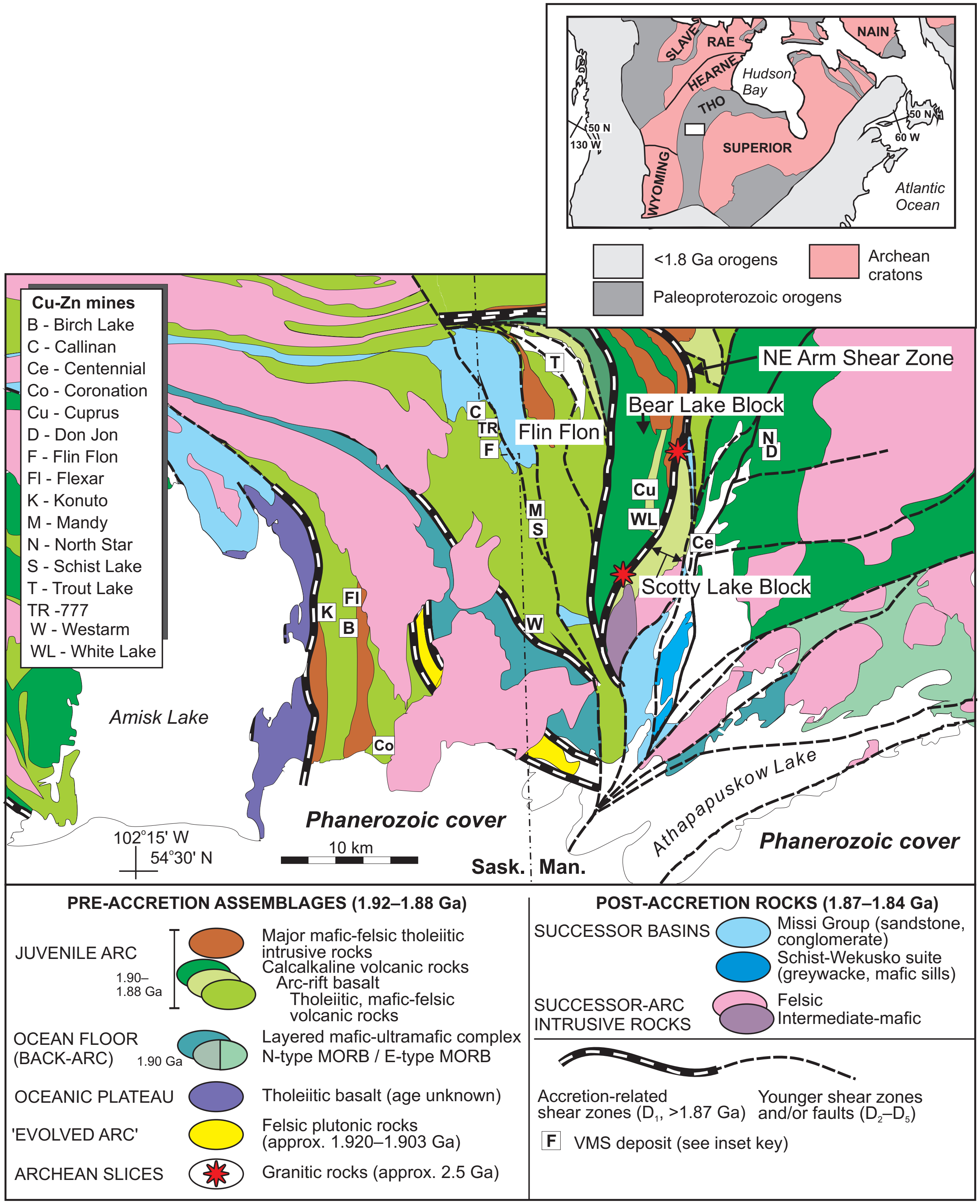

***Figure GS-4-1:** Geology of the Flin Flon Belt, showing the location of known volcanogenic massive sulphide (VMS) deposits (after Syme et al., 1999). Inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO). Abbreviations: N-MORB= normal mid-ocean-ridge basalt; E-MORB= enriched mid-ocean-ridge basalt.*

This report presents a brief summary of the main findings that have resulted from the underground and surface geological mapping done between January and August 2009.

Regional geology

The Paleoproterozoic Flin Flon Belt, part of the southeast Reindeer Zone of the THO (Figure GS-4-1), is a collage of accreted intra-oceanic–arc, back-arc, mid-ocean–ridge, oceanic-plateau and oceanic-island volcanic assemblages ranging in age from 1.92 Ga to 1.84 Ga (Bailes and Syme, 1989; Stern et al., 1995a, b; Syme et al., 1999). The volcanic stratigraphy of the Flin Flon Belt is dominated by basaltic flows and minor, but economically significant, rhyolitic flows and volcaniclastic rocks (Bailey and Gibson, 2004; DeWolfe et al., 2009a).

There are 27 known VMS deposits in the Flin Flon Belt and the potential for new discoveries is high. All of the VMS deposits in the Flin Flon area appear to be preferentially associated with juvenile-arc assemblages (Syme and Bailes, 1993; Syme et al., 1999). The Flin Flon, Callinan and 777 VMS deposits, all located in the Flin Flon mining district, formed during a period of localized rhyolitic volcanism (ca. 1890 Ma; N. Rayner, in press) within synvolcanic subsidence structures, which occurred in a much larger mafic volcanic complex formed during the buildup of the Flin Flon arc assemblage (Syme et al., 1999; DeWolfe et al., 2009a).

The stratigraphy of the Trout Lake VMS deposit shows some similarities with its Flin Flon, Callinan and 777 counterparts. The VMS mineralization in the Trout Lake deposit is also associated with rhyolitic volcanism; rhyolite flows and rhyolitic volcaniclastic rocks are spatially associated with more voluminous mafic volcanic flows and volcaniclastic rocks (Figure GS-4-2). However, the Trout Lake volcanic rocks are typically intercalated or tectonically interleaved with graphitic argillite, which is not commonly found in the other VMS deposits in the Flin Flon area.

Stratigraphy of the Trout Lake VMS deposit

Detailed underground and surface geological mapping and core logging observations indicate that the footwall and hangingwall hostrocks of the Trout Lake VMS deposit can be subdivided into five different lithological units on the basis of their lithofacies and petrographic characteristics (Figure GS-4-2). From bottom to top, these units include undivided mafic flows and mafic volcaniclastic rocks (unit 1), aphyric to sparsely quartz-phyric rhyolite (unit 2), graphitic argillite and rhyolitic tuff (unit 3), rhyolitic volcaniclastic rocks and quartz-phyric coherent rhyolite (unit 4), and graphitic argillite and greywacke (unit 5). Most of the volcanic stratigraphy lies underneath Trout Lake and only rarely is exposed at the surface. Units 3 to 5 are exclusively accessible through underground mapping and core logging; unit 2 is partly exposed along the shoreline of Trout Lake; unit 1, although exposed, is largely covered by dense vegetation. The lateral continuity of these stratigraphic units has been disrupted by syn- and post-volcanic felsic and mafic dikes and sills.

Undivided mafic flows and mafic volcaniclastic rocks (unit 1)

The stratigraphic thickness of unit 1, although not well constrained, is >300 m (Price, 1990; this study). It is dominated by mafic flows and lesser mafic volcaniclastic rocks (Figures GS-4-3a, -3b, -3c). Mafic flows are brown (weathered) to dark grey (fresh), massive to pillowed, fine- to medium-grained, and strongly plagioclase– (10–20%) and plagioclase-pyroxene– (15–30%) phyric. Individual pillows range in size from 0.3 to 1.5 m (Figure GS-4-3a). Vesicles in pillowed and massive flows vary from 3 to 5 mm in size and are commonly filled with quartz and calcite. The flows are commonly overprinted by quartz-epidote hydrothermal-alteration patches that range in size from 0.5 to 1.0 m. Reliable way-up indicators in pillowed flows are rare due to strong tectonic flattening.

Mafic volcaniclastic deposits include 75% heterolithic tuff-breccia and 25% lapilli tuff (Figures GS-4-3b, -3c). Heterolithic tuff-breccia consists of scoriaceous and plagioclase-phyric mafic clasts (30–40%, 7.0–15 cm in size), in lapilli- to ash-size plagioclase-crystal–rich matrix. The mafic scoriaceous clasts are light yellow (weathered) to dark grey (fresh) and well-rounded. The lapilli tuff beds are characterized by 60–70% plagioclase crystals, 2–4 mm in size, in fine-grained altered chloritic matrix.

Aphyric to sparsely quartz-phyric rhyolite (unit 2)

The stratigraphic thickness of unit 2 is approximately 100 m. It consists of aphyric to sparsely quartz-phyric (quartz <10%, <2 mm in size) coherent rhyolite and minor felsic volcaniclastic horizons (<10%). The coherent rhyolite is massive to flow-banded, locally autobrecciated, and commonly altered to sericite, chlorite and carbonate. Flow-banding is defined by alternating vesicle-rich (20–30%) and vesicle-poor (2–5%) zones (Figure GS-4-3d). Vesicles are 1–3 mm in size and are commonly filled with calcite. The volcaniclastic horizons consist of monomictic clast-supported (50–70% clasts) rhyolitic breccia. Rhyolite clasts are aphyric and range in size from 7 to 20 cm.

The coherent rhyolitic facies locally grades laterally into monomictic rhyolite breccia and likely represents rhyolite flows. However, underground mapping and core logging results indicate that aphyric to sparsely quartz-phyric rhyolite also occurs as intrusive facies into the graphitic argillite and rhyolitic tuff of unit 3, where they are commonly characterized by the presence of peperitic

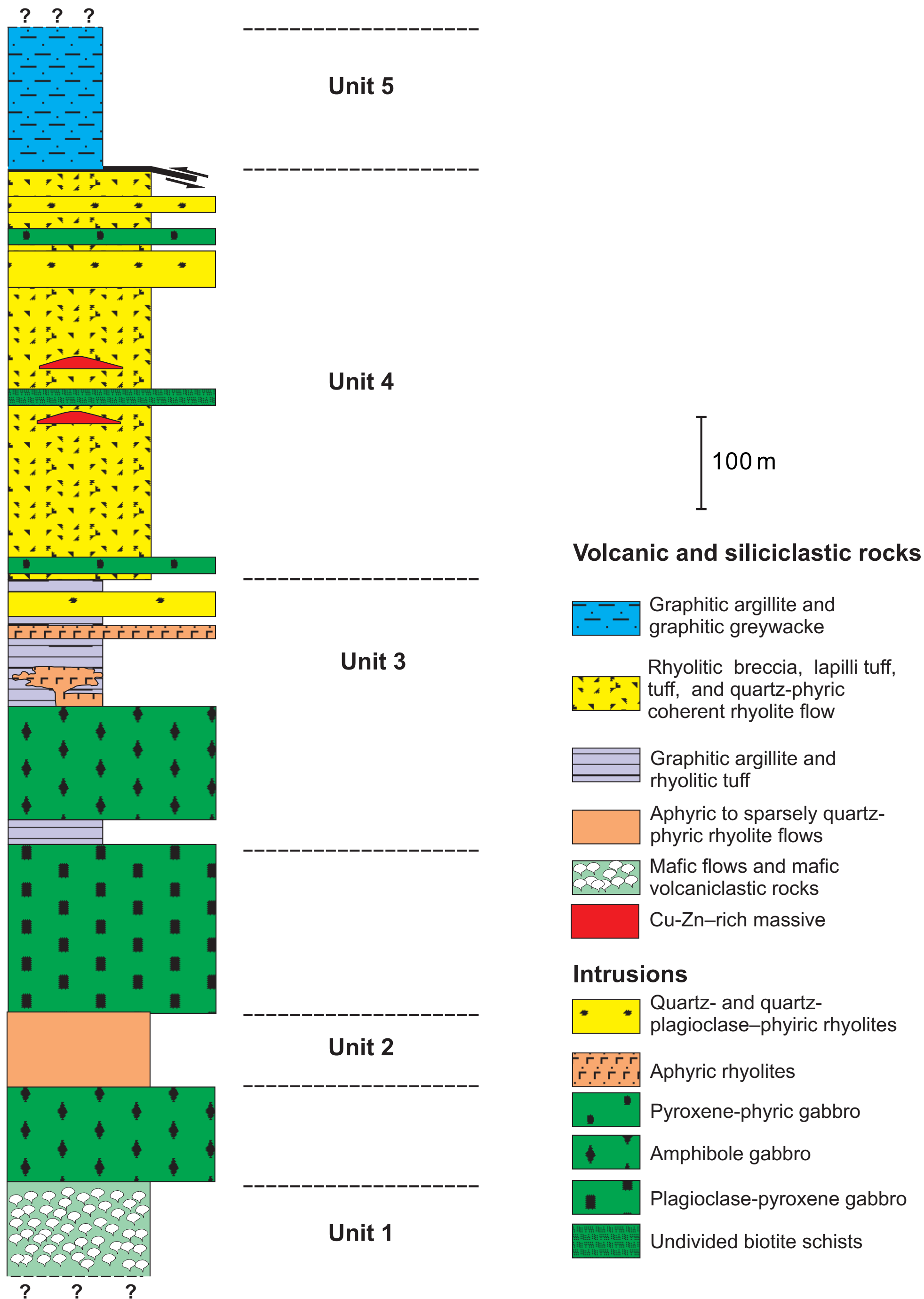

Figure GS-4-2: *Generalized stratigraphic section of the footwall and hangingwall of the Trout Lake volcanogenic massive sulphide (VMS) deposit.*

contacts and autobrecciated rhyolite lobes that truncate the bedding.

Graphitic argillite and rhyolitic tuff (unit 3)

The stratigraphic thickness of unit 3 is approximately 70–100 m. This unit is intruded by syn- to post-volcanic felsic and mafic dikes and sills. It consists of graphitic argillite and greywacke (70%) beds, ranging in thickness from 0.2 to 50 cm, intercalated with rhyolitic tuff and lapilli tuff (30%). The graphitic argillite exhibits planar-parallel lamination. Rhyolitic tuff commonly displays a light yellow or dark green colour due to strong sericite or chlorite alteration, respectively, and contains 0–30% blue quartz crystals 1–4 mm in size embedded in a very fine-grained matrix, which is commonly strongly sericite or chlorite altered. Graphite is a common component of these rhyolitic tuffs; graphite-rich tuff is black, massive to thinly laminated, and is similar in appearance to the argillite beds and laminae, except that the rhyolitic tuff

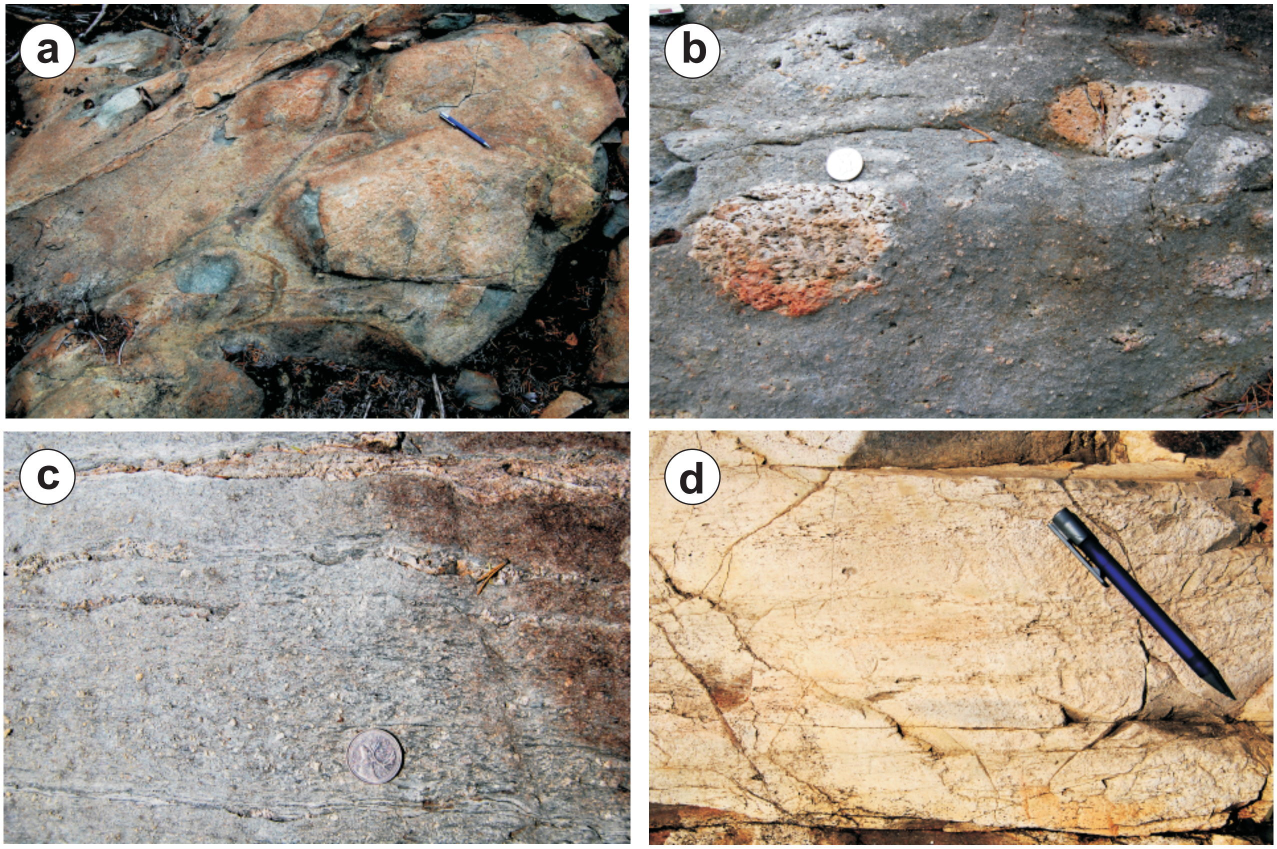

***Figure GS-4-3:** Field photographs of unit 1 (a–c) and unit 2 (d): **a)** plagioclase-phyric mafic pillowed flow; **b)** mafic tuff-breccia with well-rounded mafic scoriaceous clasts; **c)** plagioclase-rich lapilli tuff, and **d)** flow-banded aphyric rhyolite; the flow-banding is defined by alternation of vesicle-rich and vesicle-poor bands.*

contains blue quartz crystals (Figures GS-4-4a, -4b and Figure GS-4-5a).

The lateral continuity of unit 3 has been significantly disrupted by dikes and sills. It is intruded by quartz-phyric rhyolite and aphyric rhyolite; these felsic intrusive rocks locally exhibit peperitic contacts and autobrecciated lobes, which suggest that they were emplaced when unit 3 was still unconsolidated. Pyroxene-phyric gabbro sills commonly have planar sharp contact with unit 3 and develop chilled margins up to 2 m thick.

Rhyolitic volcaniclastic rocks and quartz-phyric coherent rhyolite (unit 4)

Unit 4 has a stratigraphic thickness of approximately 300 m. It conformably overlies unit 3, although the contact between these units is commonly intruded by felsic and mafic sills. Unit 4 consists of rhyolitic volcaniclastic rocks (70%) and quartz-phyric coherent rhyolite (30%). This unit hosts the Cu-Zn–rich massive sulphide mineralization. Available geochronological data, although controversial, suggest that this unit is younger than other economically important rhyolite units in the main Flin Flon area (Syme et al., 2001; L. Heaman, N. Rayner, pers. comm., 2009); the precise age of unit 4 is currently under investigation.

Volcaniclastic rocks occur as intercalations of tuff-breccia, lapilli tuff and tuff beds 0.5 to 3 m thick (Figure GS-4-4c). These volcaniclastic rocks exhibit a light yellow or dark green colour due to strong sericite or chlorite alteration, respectively (Figure GS-4-5b). Tuff-breccia and lapilli tuff are monomictic and matrix supported (Figure GS-4-4c); they contain quartz-phyric rhyolite clasts, 1.0–20 cm in size, embedded in a quartz-rich, lapilli- to ash-size felsic matrix. Quartz crystals are characteristically blue and range in size from 1 to 4 mm. Individual volcaniclastic beds are difficult to identify given the strong tectonic flattening and hydrothermal alteration in the area. However, variations in the percentage and grain size of quartz crystals and rhyolite clasts facilitate recognition of individual beds. Tuff occurs as massive to thinly laminated beds 0.2–1 m thick, with 0–15% blue quartz crystals measuring 1–3 mm. Tuff commonly contains disseminated fine-grained graphite, which results in a black muddy appearance (Figures GS-4-4a, -4b and Figure GS-4-5a). In the absence of visible quartz crystals, the graphitic tuff is difficult to distinguish from graphitic argillite.

Coherent felsic rocks are primarily rhyolite flow, and lesser intrusive rhyolite and dacite. Rhyolite flows range up to 40 m in thickness and are intercalated with felsic

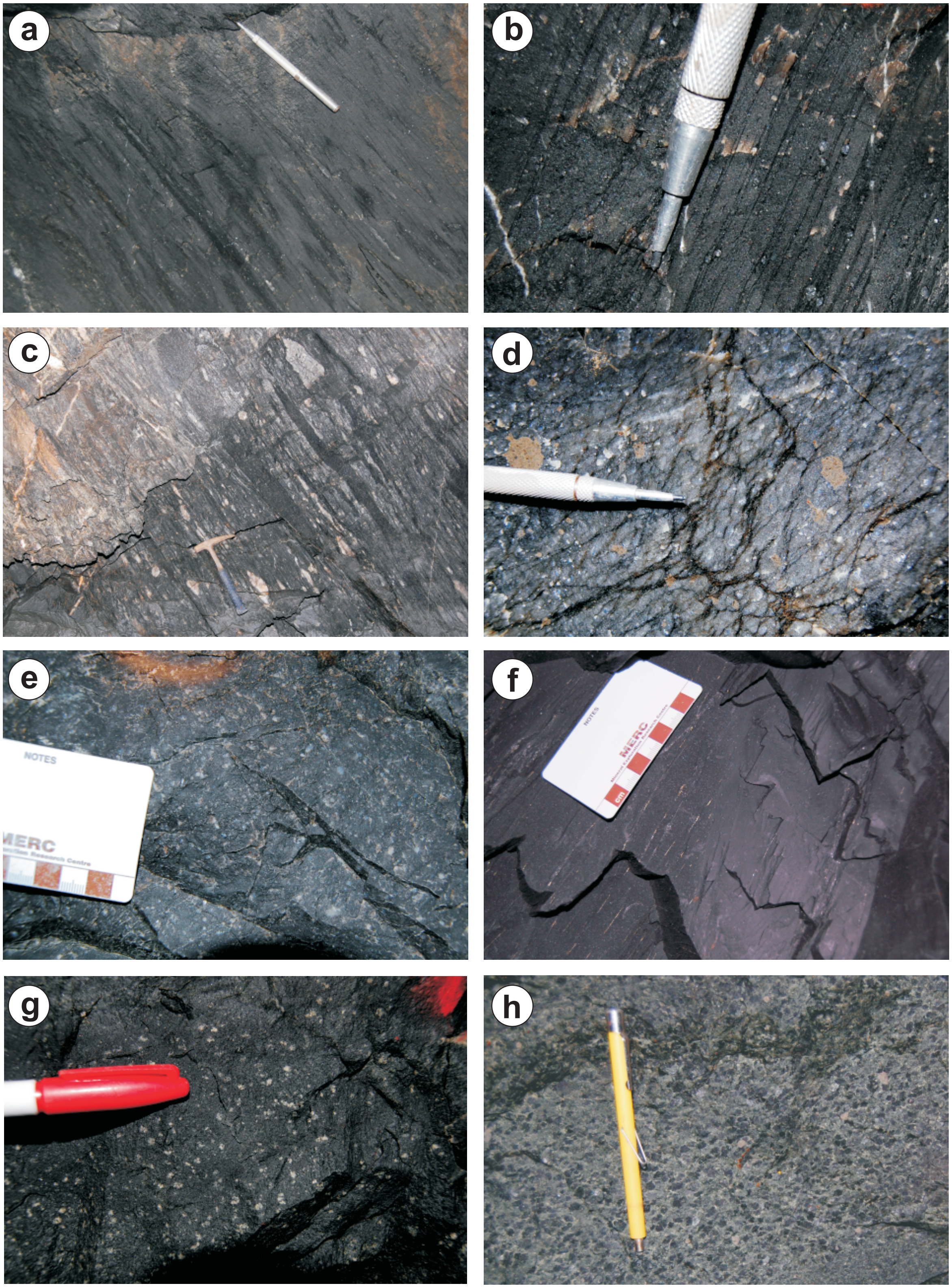

Figure GS-4-4: *Underground photographs of unit 4 (a–e), unit 5 (f), and mafic intrusive rocks (g, h):* ***a)*** *graphite-rich rhyolitic tuff;* ***b)*** *close-up of graphite-rich rhyolitic tuff in (a), showing blue quartz crystals and thin planar-parallel lamination defined by alternation of graphite-rich and graphite-poor laminae (cf. Figure GS-4-5a);* ***c)*** *thickly bedded, matrix-supported rhyolitic tuff-breccia, showing dominantly quartz-phyric rhyolite clasts;* ***d)*** *close-up of quartz-phyric rhyolite flow;* ***e)*** *quartz-phyric intrusive rhyolite (scale bar in centimetres);* ***f)*** *intercalation of graphitic argillite and greywacke (scale bar in centimetres);* ***g)*** *plagioclase-pyroxene gabbro; pyroxene is not evident due to chloritic alteration;* ***h)*** *characteristic strongly porphyritic texture of pyroxene-phyric gabbro.*

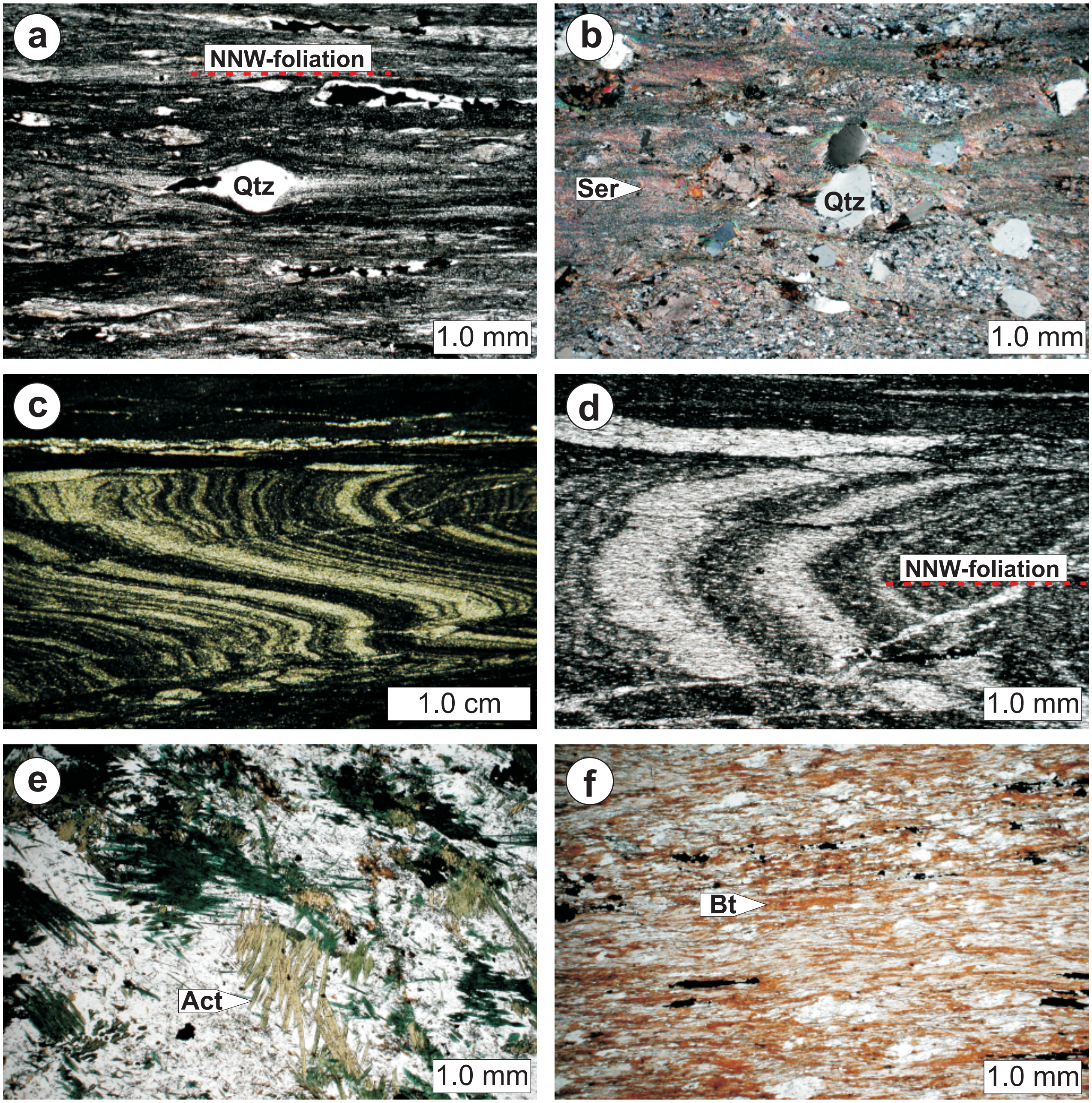

Figure GS-4-5: *Photomicrographs of various rock types, showing* ***a)*** *graphite-rich tuff with abundant quartz crystals (Qtz); wing-shaped quartz crystals, which commonly display strain shadows, embedded in fine-grained graphite-rich volcanic ash; north-northwest-trending foliation is strongly developed;* ***b)*** *quartz-rich rhyolitic tuff (the ash-rich matrix is strongly sericite (Ser) altered); unlike (a), this tuff does not contain graphite;* ***c, d)*** *isoclinal folds in graphitic argillite from unit 5; the regional north-northwest-trending foliation is axial planar to these early folds;* ***e)*** *amphibole gabbro with metamorphic-actinolite (Act) needles;* ***f)*** *strongly foliated biotite (Bt) schist interpreted to represent a mafic intrusion deformed and recrystallized when subjected to greenschist-facies metamorphism.*

volcaniclastic rocks. Coherent rhyolite flows are quartz-phyric, with 10–15% blue quartz 1–4 mm in size, and commonly autobrecciated, with chlorite alteration preferentially localized along curved cracks (Figure GS-4-4d). Intrusive coherent felsic rocks are dominated by quartz-phyric rhyolite, lesser quartz-plagioclase–phyric rhyolite and rare sparsely quartz-phyric dacite (Figure GS-4-4e). These felsic intrusive rocks, which normally display peperitic contacts, occur as 20–30 m thick sills emplaced in the felsic volcaniclastic rocks and, accordingly, are interpreted as high-level synvolcanic sills. Unit 4 includes rare, 1–2 m thick beds of graphitic argillite.

Graphitic argillite and greywacke (unit 5)

Although the exact stratigraphic thickness of unit 5 is not well constrained, detailed core logging results suggest that it is likely >300 m thick. The contact between unit 5 and the underlying volcanic rocks of unit 4 is delimited by a reverse-sinistral fault near-parallel to the stratigraphy. Unit 5 consists of intercalations of graphitic argillite and greywacke beds (Figure GS-4-4f and Figures GS-4-5c, -5d) ranging from 20 to 50 cm in thickness. This unit does not contain volcaniclastic rocks and is not intruded by mafic and felsic dikes.

Recent U-Pb zircon geochronology analysis of a graphitic argillite sample from unit 5 shows a dominant population of detrital zircons of 1860 Ma (N. Rayner, pers. comm., 2009). This indicates a depositional age at least 10 Ma younger than that of the underlying rhyolitic volcanic rocks. The geochronological and field evidence suggest that unit 5 is a tectonically transposed unit thrust on top of unit 4. However, it cannot be ruled out that the contact between units 4 and 5 is an unconformity that was tectonically reworked by late reverse-sinistral faulting.

Mafic intrusive rocks

Mafic dikes and sills commonly intrude units 1 to 4. Several types of mafic intrusive rocks have been recognized based on their petrographic characteristics: 1) amphibole gabbro, 2) plagioclase-pyroxene gabbro, 3) pyroxene-phyric gabbro, and 4) biotite schist interpreted as strongly metamorphosed and foliated undivided mafic intrusive rocks.

The amphibole gabbro and plagioclase-pyroxene gabbro form a >300 m thick composite dike and sill complex, which is intrusive into unit 3 and the contact between units 1 and 2 (Figure GS-4-2). On the surface, this gabbro can be traced for approximately 1 km along the shoreline of Trout Lake (Price, 1990; this study). The amphibole gabbro is black to metallic blue on the fresh surface; it contains acicular crystals of metamorphic actinolite (20–30%) up to 1 cm long (Figure GS-4-5e). The plagioclase-pyroxene gabbro is dark green, equigranular and rarely porphyritic (Figure GS-4-4g). This rock is composed of 5–15% clinopyroxene, 3–5% quartz and 80% plagioclase. Clinopyroxene and plagioclase are strongly replaced by chlorite and epidote, respectively.

Pyroxene-phyric gabbro, characterized by its distinctive strongly porphyritic texture with abundant (20–40%) coarse-grained (0.5–1 cm) clinopyroxene phenocrysts (Figure GS-4-4h), forms sills 1–30 m thick in units 3 and 4; the sills are dark green in colour, due to strong chlorite alteration, and commonly display chilled margins up to 2 m thick.

Biotite schist forms highly strained mafic dikes and sills in units 2, 3, and 4 (Figure GS-4-5f). These intrusions are 1–10 m thick, strongly foliated and contain 40–50% biotite. Biotite schist can locally be laterally traced into less deformed counterparts, such as pyroxene-phyric gabbro and plagioclase-pyroxene gabbro. This strain gradient suggests that biotite schist represents greenschist-facies recrystallized and deformed mafic intrusions.

Structural observations

A north-northwest-trending, northeast-dipping regional foliation is parallel to bedding and lithological contacts, and axial planar to early isoclinal folds (e.g., Figures GS-4-5c, -5d). The lithological contacts and north-northwest-trending foliation were dragged and reworked into north-northwest-trending reverse-sinistral and sinistral faults that are subparallel to stratigraphy. The hangingwall of these faults shows consistently north-northwest-directed tectonic transport. As the continuity of the volcanic units is not significantly affected, displacement along these faults was likely minor.

The only major lithological break related to the north-northwest-trending faults is the reverse-faulted contact between units 5 and 4 (Figure GS-4-2), which may, alternatively, represent an unconformity that was tectonically reworked. Shear-sense indicators are locally observed, which suggests that late normal-sinistral reactivation of the north-northwest-trending faults occurred.

Preliminary conclusions and future work

Stratigraphic and structural observations led to the following preliminary conclusions regarding the volcanic stratigraphy and structure of the Trout Lake VMS deposit:

- Hangingwall and footwall hostrocks of the Trout Lake VMS deposit can be subdivided into five different units on the basis of their lithofacies and petrographic characteristics; these units account for at least 1000 m of coherent stratigraphy.
- Graphitic argillite in unit 5 and unit 3 represent different stratigraphic rock types. Unit 5 is entirely dominated by siliciclastic rocks, is not interstratified with felsic volcaniclastic rocks, and is not intruded by syn- and post-volcanic felsic and mafic sills. Collectively, the field characteristics documented in this study, together with unpublished geochronological data, indicate that unit 5 rocks postdate volcanism. In contrast, unit 3 is interlayered with rhyolitic volcaniclastic rocks, and is intruded by felsic and mafic sills; it represents siliciclastic sedimentation coeval with volcanic activity. Units 3 and 5 are not fold- and/or fault-repeated stratigraphic levels.
- Synvolcanic siliciclastic rocks are not common in the Flin Flon, Callinan and 777 VMS deposits. The occurrence of synvolcanic argillite, as well as tectonically interleaved post-volcanic argillite, suggests that the Trout Lake deposit formed in a different depositional environment than its counterparts in the Flin

Flon area. The depositional setting of the Trout Lake deposit is currently under investigation.

- Syn- and post-volcanic felsic and mafic intrusive rocks strongly dissect the stratigraphy of the Trout Lake deposit, laterally disrupting the continuity of economically important horizons.
- The prevalent north-northwest-trending regional foliation is parallel to bedding and lithological contacts, and formed during early isoclinal folding. The Trout Lake mine lithological units and ore lenses have been affected by this folding event; however, at mine scale the overall lithological units show no evidence for structural repetition as previously proposed by some authors (e.g., Brown and Rusk, 2000).

Current work in progress includes 1) detailed geochemical investigation of the recognized lithological units to establish a chemostratigraphy for the mine; 2) U-Pb zircon geochronology of felsic volcanic rocks in units 2 and 4, and of the graphitic argillite in unit 3; 3) reconstruction of the depositional environment of the Trout Lake felsic volcanic rocks and associated Cu-Zn massive sulphide mineralization; 4) comparison of the Trout Lake stratigraphy with stratigraphic units elsewhere in the Flin Flon area; 5) correlation of the sequence of deformation events recognized in this project with those reported in previous investigations.

Economic considerations

Understanding the precise age, stratigraphic characteristics and tectonic setting of formation of the Trout Lake VMS deposit has major implications for current and future exploration. For example, the Flin Flon, Callinan and 777 VMS deposits formed during a restricted period of intra-arc extension (Syme et al., 1999; DeWolfe et al., 2009a, b; N. Rayner, in press). This space-time punctuated metallogenic event is intrinsically related to the geodynamic and tectonomagmatic history of the Flin Flon Belt. The stratigraphic characteristics of the Trout Lake VMS deposit are different than those of its southern counterparts, which indicates that the deposit likely formed in a different tectonic setting. The Trout Lake area has several felsic volcanic horizons that may include stratigraphic equivalents to the felsic rocks of unit 4, which host the massive sulphide mineralization. Continued work in the area will improve current understanding of the geological and geochemical characteristics of the Trout Lake deposit, leading to new opportunities for identifying other felsic volcanic horizons that are space-time equivalent to those hosting the Trout Lake VMS deposit, and which may host economically important mineralization.

Acknowledgments

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