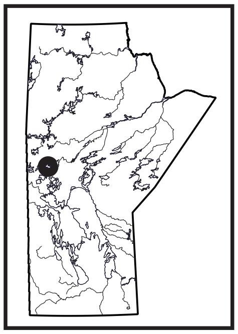
GS-3 Examination of exploration drillcore from the Reed Lake area, Flin Flon belt, west-central Manitoba (parts of NTS 63K9, 10): implications for the stratigraphy of the Fourmile Island assemblage and setting of VMS deposits

by S. Gagné



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Summary

Four weeks were spent examining recent and historical drillcore of Paleoproterozoic bedrock from the southern portion of the Reed Lake area and the sub-Phanerozoic area immediately to the south. A total of 44 drillcores were examined, documented and sampled to complement a set of 9 drillcores that were examined in 2013–2014. This work is a component of a larger project aimed at updating the geology of the Reed Lake area. The objectives of the drillcore examination program are to

- better document the stratigraphy of Paleoproterozoic supracrustal rocks in the Reed Lake area;
- investigate the geological setting of volcanogenic massive sulphide (VMS) deposits hosted by these rocks; and
- characterize the nature and intensity of associated hydrothermal alteration, which can serve as an important exploration tool.

Drillcores indicate that bimodal volcanic rocks of the Fourmile Island assemblage are more complex and diverse than previously thought. Drillcores from the western Reed Lake and Fourmile Island areas show that felsic volcanic and volcaniclastic rocks are much more abundant than shown on existing maps. These felsic rocks contain minor to moderate alteration (sericite, silica and chlorite) and show depositional facies varying from proximal to distal in relation to their volcanic edifice. Drillcore from the area of the Reed deposit and Cowan River zone also contains abundant felsic volcanic and volcaniclastic rocks, which are commonly altered. This alteration varies from weak and fracture controlled to strong and pervasive. Common alteration types include: chlorite, chlorite-carbonate and epidote-silica in mafic volcanic rocks; and chlorite, silica and sericite in felsic volcanic rocks. Depositional facies vary from proximal (flows and in situ breccias) to more distal (tuffaceous rocks). Distinct localized zones dominated by coherent felsic volcanic rocks, inferred to represent flows, with minor volcaniclastic rocks, may indicate felsic domes. In the Spruce Point deposit and eastern Reed Lake areas, the examined drillcores display weaker alteration and lesser amounts of felsic volcanic rocks.

The Dickstone and Reed deposits may reside at a similar stratigraphic horizon, as indicated by the very similar chemical signatures of associated felsic and mafic volcanic rocks. Volcanic rocks associated with the Fourmile Island deposit show distinctly different geochemical signatures, suggesting that they may represent a distinct stratigraphic horizon within the Fourmile Island assemblage favourable for VMS deposits. Further work is required to confirm this hypothesis and to determine the stratigraphic relationship, if any, between the hostrocks to the Fourmile Island deposit and those of the Dickstone and Reed deposits.

Andesitic and rhyolitic volcanic and volcaniclastic rocks were recognized in drillcore from most areas, suggesting arc or arc-rift depositional settings. In contrast, ocean-floor assemblages in the Flin Flon belt are typically monotonous and mafic-flow dominated, with only minor volcaniclastic rocks. The presence of bimodal volcanic and volcaniclastic rocks, moderate to intense alteration and local sulphide mineralization suggest that all of the Paleoproterozoic sections examined to date from the sub-Phanerozoic area south of Reed Lake have potential for VMS deposits.

Introduction

A multiyear field-mapping and compilation project was initiated in 2013 to expand the geoscience knowledge base of the Reed Lake area, a critical component for understanding the tectonic evolution of the Flin Flon belt (FFB) as a whole. The Reed Lake area is located in the central part of the FFB (Figure GS-3-1), which consists of a collage of distinct Paleoproterozoic (1.92–1.88 Ga) tectonostratigraphic assemblages and minor Archean crustal slices that were juxtaposed during 1.88–1.87 Ga intraoceanic accretion (Lucas and Stern, 1994; Stern and Lucas, 1994) to form the 'Amisk collage' (Lucas et al., 1996). Paleoproterozoic assemblages within the Amisk collage are subdivided into juvenile-arc, ocean-floor, ocean-plateau and evolved-arc (Figure GS-3-1; Syme and Bailes, 1993; David and Syme, 1994; Reilly et al., 1994; Stern et al., 1995a, b; Lucas et al., 1996). The Amisk collage formed the basement to widespread postaccretion magmatism between 1.87 and 1.83 Ga, which produced voluminous calcalkaline plutons and calcalkaline–alkaline volcanic rocks (Lucas et al., 1996). Younger sedimentary, and subordinate volcaniclastic and volcanic rocks (1.85–1.83 Ga Missi and Burntwood groups), were deposited

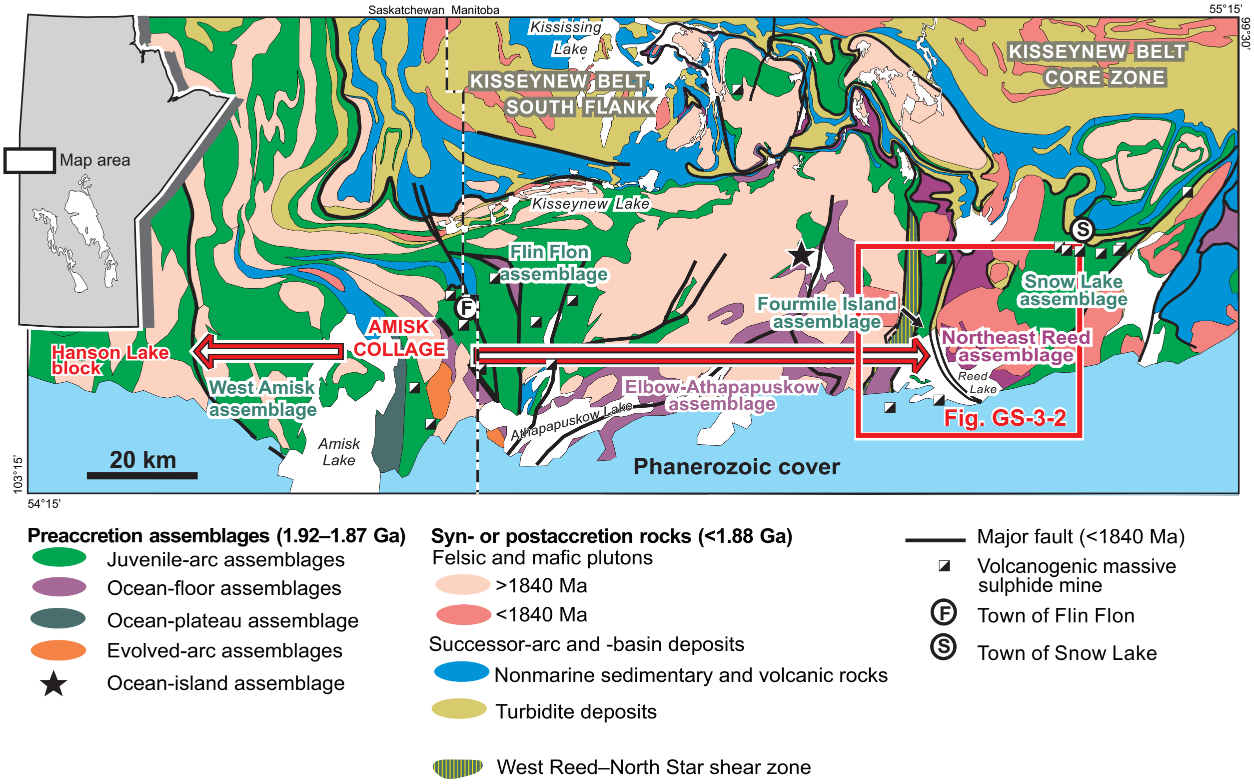

***Figure GS-3-1**: Geology of the Flin Flon belt, showing major tectonostratigraphic assemblages, plutons and volcanogenic massive sulphide deposits (modified from Syme et al., 1998). The box outlined in red indicates the location of the Reed Lake study area.*

contemporaneously with postaccretion ('successor') arc magmatism and deformation (Ansdell et al., 1995; Lucas et al., 1996).

Significant stratigraphic, geochemical and isotopic differences between arc-volcanic rocks in the Flin Flon and Snow Lake areas (Stern et al., 1995a) suggest that these two segments of FFB formed in distinct tectonic settings (Lucas et al., 1996). The Reed Lake area represents a critical bridge between these two segments, as it lies at the boundary between the Amisk collage *sensu stricto* and the Snow Lake segment.

The Reed Lake area also includes the Fourmile Island assemblage (FIA), a bimodal succession of volcanic and volcaniclastic rocks of arc or arc-rift affinity that hosts several significant VMS deposits, including the currently producing Reed Cu-Zn deposit (Figure GS-3-2). Previous geological work (Leclair and Viljoen, 1997; Leclair et al., 1997) and geophysical data show that arc-affinity rocks extend south of Reed Lake beneath the Phanerozoic cover for a distance of more than 50 km. Therefore, a better understanding of the Reed Lake area may have important implications for base-metal exploration and is the goal of this drillcore examination program.

Previous work

Reconnaissance mapping of Reed Lake was completed at 1:50 000 scale during a joint Manitoba Geological Survey–Geological Survey of Canada project in the summer of 1995 (Syme et al., 1995b), and the results of follow-up geochemical and structural studies were presented by Syme and Bailes (1996). Prior to 1995, supracrustal rocks at Reed Lake were subdivided into mafic volcanic, volcaniclastic and sedimentary types (Stanton, 1945; Rousell, 1970). Preliminary Map 1995F-1 (Syme et al., 1995b) was compiled from older maps, including those of Rousell (1970) and Stanton (1945), and new data from the 1995 field season, resulting in a significantly improved understanding of the local geology. Morrison and Whalen (1995) reported the results of mapping of granitoid rocks in the NTS 63K10 area, west of Reed Lake; a simplified version of their map was included in Preliminary Map 1995F-1 (Syme et al., 1995b) and their complete work was presented in Morrison et al. (1996). The inland area north and east of Reed Lake was not remapped in 1995. In 2013, the northwestern Reed Lake area, including Rail, Sewell and Prieston[1] lakes, was mapped at 1:10 000 scale (Gagné, 2013a, b) and the inland area west of Reed Lake was subsequently mapped in 2014 at 1:20 000 scale (Gagné and Anderson, 2014a, b).

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[1] formerly Preaston Lake

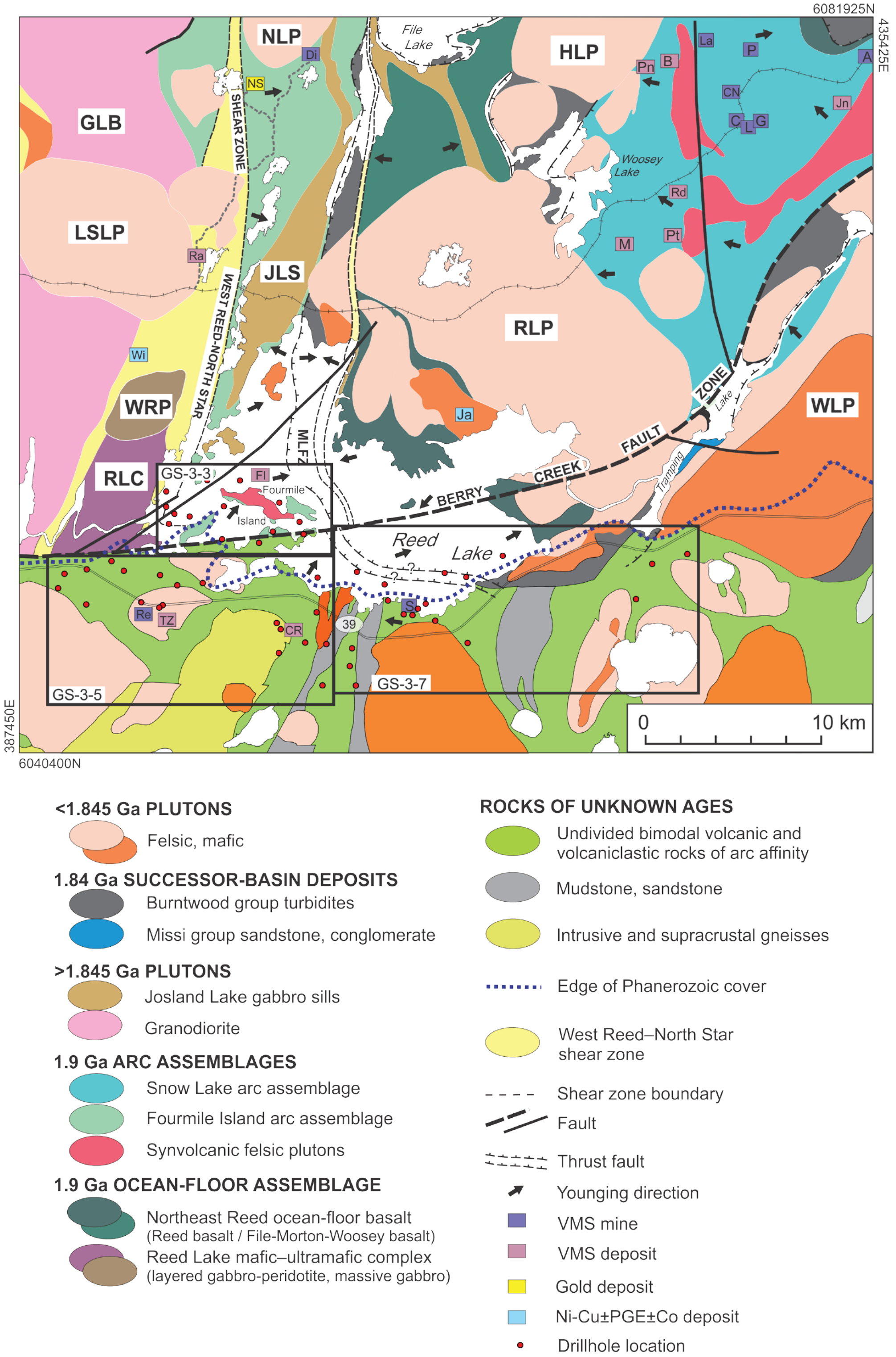

***Figure GS-3-2**: Generalized geology of the Reed Lake area (after Syme et al., 1995a) including the geology of the sub-Phanerozoic basement (Leclair and Viljoen, 1997; Syme et al., 1998). Boxes indicate the area covered by Figures GS-3-3, 5 and 7. Intrusive rocks: GLB, Gants Lake batholith; HLP, Ham Lake pluton; JLS, Josland Lake sills; LSLP, Little Swan Lake pluton; NLP, Norris Lake pluton; RLC, Reed Lake mafic–ultramafic complex; RLP, Reed Lake pluton; WLP, Wekusko Lake pluton; WRP, West Reed pluton. Structural feature: MLFZ, Morton Lake fault zone. Mines (active or closed) and deposits: A, Anderson; B, Bomber; C, Chisel; CN, Chisel North; CR, Cowan River zone; Di, Dickstone; FI, Fourmile Island; G, Ghost; Ja, Jackfish; Jn, Joannie; L, Lost; La, Lalor; M, Morgan; NS, North Star; P, Photo; Pn, Pen; Pt, Pot; Ra, Rail; Rd, Raindrop; Re, Reed; S, Spruce Point; Tz, Tower zone; Wi, Wine. Other: PGEs, platinum-group elements; VMS, volcanogenic massive sulphide.*

The southern shore of Reed Lake coincides with the northern extent of Phanerozoic platform sedimentary rocks of the Western Canada Sedimentary Basin. These rocks unconformably overlie the Precambrian basement and increase in thickness southward, ranging from a few metres to 30 m in thickness in the area immediately south of Reed Lake. Despite geophysical discoveries of significant base-metal mineralization in the sub-Phanerozoic basement in the 1960's and 1970's, the geology of this area was poorly understood. During NATMAP, the first regional map of the sub-Phanerozoic portion of the FFB was produced, by integrating high-resolution aeromagnetic and gravity data with drillcore information (Leclair et al., 1997). In the course of that same project, only a small number of drillcores from the area south of Reed Lake were examined. With the recent discovery of the Reed VMS deposit, industry has shown growing interest in gaining more detailed knowledge of the sub-Phanerozoic geology south of Reed Lake.

Geological framework of the Reed Lake area

The exposed portion of the FFB at Reed Lake contains several distinct panels of juvenile-arc assemblage, which are separated by major faults; some of these panels also contain ocean-floor assemblage, Burntwood group sedimentary rocks and plutonic rocks (Figure GS-3-1). The juvenile-arc assemblages are internally complex due to faulting and folding (e.g., Bailes and Syme, 1989), but are typically bimodal and include a wide range of arc-related volcanic, volcaniclastic and synvolcanic intrusive rocks (Bailes and Syme, 1989; Syme and Bailes, 1993; Stern et al., 1995a; Lucas et al., 1996; Bailes and Galley, 2007). Ocean-floor assemblages are composed mainly of mid-ocean-ridge–like basalt and related kilometre-scale, layered, mafic–ultramafic intrusions (Syme and Bailes, 1993; Stern et al., 1995b). Voluminous successor-arc plutons and coeval volcanic and sedimentary rocks, formed between 1.88 and 1.83 Ga, occur throughout the Reed Lake area and include the Schist–Wekusko assemblage, the Missi group and the Burntwood group. The Missi group is characterized by thick packages of fluvial-alluvial conglomerate and sandstone, whereas the basinal-marine Burntwood group comprises turbiditic greywacke, mudstone and rare conglomerate.

The western Reed Lake area includes a major (kilometres wide), regionally extensive zone of tectonite referred to as the West Reed–North Star (WRNS) shear zone, which was previously thought to juxtapose rocks of ocean-floor affinity on the west with rocks of juvenile-arc affinity (FIA) on the east (Syme F, 1995a, b). Rocks east of the WRNS shear zone are further divided into two domains separated by the Morton Lake fault zone: the FIA in the footwall and the Northeast Reed assemblage, Reed Lake pluton and Snow Lake arc assemblage in the hangingwall (Figure GS-3-2; Syme et al., 1995a, b; Syme and Bailes, 1996). The fault zone includes a panel of Burntwood group. A major east–west fault, the Berry Creek fault zone (BCFZ), truncates the southern part of Reed Lake near the northern limit of the Phanerozoic cover.

The Phanerozoic cover in the Reed Lake area typically consists of 1–2 m of Ordovician quartz-rich sandstone (Winnipeg formation) overlain by 12–25 m of Ordovician dolomitic limestone (Red River formation), atop of which generally sits several metres of unconsolidated glacial sediments and organic material. The Precambrian rocks beneath the Ordovician cover are weathered to depths ranging from 5 to 30 m.

Syme et al. (1995a) proposed that the exposed volcanic stratigraphy south of the BCFZ can be related in a general sense to that which lies to the north. However, direct correlation of units across the BCFZ is hampered by poor exposures at Reed Lake, Phanerozoic cover farther south, and the unknown sense and magnitude of its displacement.

Drillcore logging and whole-rock geochemistry

This paper provides a summary of observations made on drillcore in 2015, as well as previous field seasons (2010, 2013 and 2014). In addition to drillcore examination, a total of 492 samples have been collected to date for whole-rock chemistry, thin section petrography, Sm-Nd isotopic analysis and U-Pb radiometric dating.

The examined drillcores have been grouped into three domains based on geographic location and geological context: 1) the Fourmile Island and western Reed Lake area; 2) the Reed deposit and Cowan River area and; 3) the Spruce Point deposit and eastern Reed Lake area. Although the VMS deposit located north of Fourmile Island under Reed Lake has been called by many different names, it is herein referred to as the 'Fourmile Island deposit' to avoid confusion with the Reed deposit currently under production.

Fourmile Island and western Reed Lake area

The Fourmile Island and western Reed Lake area comprises a thick package of volcanic and volcaniclastic rocks that is truncated to the north by a layered gabbro intrusion, similar to the Josland Lake sills, and is intruded by tonalite–granodiorite at Fourmile Island. Syme et al. (1995a) proposed a stratigraphy for the FIA based on shoreline exposures on islands northwest and south of Fourmile Island. This area also contains the Fourmile Island deposit which occurs a few hundred metres north of the western end of Fourmile Island (Figure GS-3-2). The deposit is copper-rich and reported to contain 1.36 Mt grading 2.09% Cu (Bamburak, 1990). The mineralization consists of several stacked massive sulphide lenses hosted by felsic volcanic rocks (Mineral Inventory File 736, Manitoba Mineral Resources, Winnipeg). Rocks exposed on the islands surrounding this deposit are gabbro and ferrogabbro (Josland Lake sills) to the north and, to the south, on Fourmile Island, strongly epidotized andesite intruded by the Fourmile Island tonalite–granodiorite.

Fourteen drillcores were examined from this area (Figure GS-3-3). A series of drillholes (EEL-221, -223, -225, -228 and -232) and drillhole RAD-1 were collared on the western side of Reed Lake, in an area where few bedrock exposures exist. These short drillholes (100–150 m in depth) intersected a succession of felsic-dominated volcaniclastic rocks with minor intervals of intermediate composition. Felsic rocks vary from massive homogeneous lapilli tuff to crudely bedded ash tuff and quartz-rich crystal tuff (Figure GS-3-4a). Sericite alteration is pervasive throughout the rocks and varies from moderate to intense locally. Facies of intermediate composition or intervals of matrix-rich ash tuff typically contain abundant chlorite. Three drillholes (HO-10-02, EEL-423 and -424) were selected to obtain a section through the sequence hosting the Fourmile Island deposit. The two EEL drillholes (-423 and -424) were collared on the northern side of the island and intersected a succession dominated by mafic flows, with minor horizons of volcaniclastic rocks locally cut by gabbro and monzogabbro dikes. Minor horizons of sulphidic sedimentary rocks are also encountered in EEL-424. Drillhole EEL-423 intersected a lens of solid sulphide several metres thick, interpreted as part of the Fourmile Island deposit (Figure GS-3-4b). Neither EEL-424 nor EEL-423 intersected felsic volcanic rocks. The hangingwall of the sulphide lens appears unaltered, whereas the footwall contains pervasive, moderate to strong silicification. Drillhole HO-10-02 (>900 m core length; located on the southwestern side of Fourmile Island) intersected a well-preserved succession of intercalated aphyric andesite and quartz– and quartz-plagioclase–phyric rhyolite that did not contain any significant sulphide zones. The basalt forms thick successions (>150 m) of variably altered, massive to pillowed flows, with minor intervals of mafic breccia (Figure GS-3-4c). Quartz-epidote patches are common throughout the mafic rocks. The rhyolite forms thick (>300 m), massive to brecciated units, displaying variable silicification and sericitization (Figure GS-3-4d). Five additional drillcores (RAD-5, EEL-220 and 300, MBSL-13-01 and -02) from close to the BCFZ were examined. The EEL-220 and RAD-5 drillcores consisted mostly of strongly deformed intermediate to felsic crystal tuff to fine lapilli tuff, with weak to moderate sericite and chlorite alteration. Drillhole EEL-300 intersected a thick sequence of interbedded mudstone and siltstone, whereas the two MBSL drillholes intersected less deformed and altered intermediate to felsic volcaniclastic rocks (Figure GS-3-4e). The sequence of volcaniclastic rocks intersected by drillhole MBSL-13-02 was intruded by late tonalite that represents 45% of the section.

Reed deposit and Cowan River area

Twenty-one drillcores from this area, which is mostly covered by Phanerozoic rocks, were examined and sampled (Figure GS-3-5). The sub-Phanerozoic basement consists mostly of bimodal volcanic and volcaniclastic rocks intruded by late gabbroic and granitic intrusions, and also includes the Reed deposit. Diamond drilling has intersected mineralization along a strike length of 430 m and to depths of 550 m below the surface, contained in three stacked lenses of variable orientation. Mineralization in this deposit is generally fine- to medium-grained, disseminated to solid sulphide consisting of pyrrhotite, pyrite, chalcopyrite, sphalerite and magnetite.

Two drillcores (RLD-002 and -003) of the Reed deposit were examined. Both drillholes cut through variably altered massive amygdaloidal andesite and andesite with minor autoclastic breccia (flow breccia), which are typically bleached and overprinted by silica-epidote alteration. Both drillholes also intersected two of the three main sulphides lenses that constitute the Reed deposit. The upper lens is sphalerite- and magnetite-rich and is capped by a layer of massive magnetite ~1 m thick. Below this lens, the two drillholes intersected silicified and chloritized aphyric basalt, locally cut by fracture-controlled alteration characterized by silica-rich cores and chlorite-rich margins. A lower, copper-rich lens of solid sulphide was encountered (Figure GS-3-4f) below the silicified basalt. The footwall of this lens in drillholes RLD-002 and -003 consists of chlorite-altered massive aphyric andesite that becomes less altered downhole (Figure GS-3-4g).

Drillcores TZ-08-01 and RD-07-06 from the Tower zone, ~1 km east of the Reed deposit, were also examined. These drillholes cored through a series of aphyric to quartz-phyric rhyolite flows that are intruded by lesser gabbro and diorite dikes. The rhyolite flows are mainly massive but include autoclastic breccia and lobe facies. Individual flows are not well defined in the drillcore, but variations in phenocryst populations suggest the presence of more than one flow. Rocks cored in TZ-08-01 display little or no alteration, whereas the base of RD-07-06 displays moderate to locally strong chlorite-epidote alteration.

Another nine drillcores (RLE-006, -011, -013, -020; RN-10-05, -06, -07; RAD-6 and R-96-1) from the vicinity of the Reed deposit were examined. These drillholes intersected mostly bimodal volcanic and volcaniclastic rocks cut by minor granitic and gabbroic intrusions. The volcanic facies vary from coherent flow, to autoclastic breccia, to poorly sorted lapilli tuff and well-bedded crystal tuff (Figure GS-3-4h). The variable distribution of the felsic volcanic and volcaniclastic rocks and their changes in thickness and depositional facies are suggestive of laterally restricted edifices or domes. These successions commonly display variable intensity of alteration,

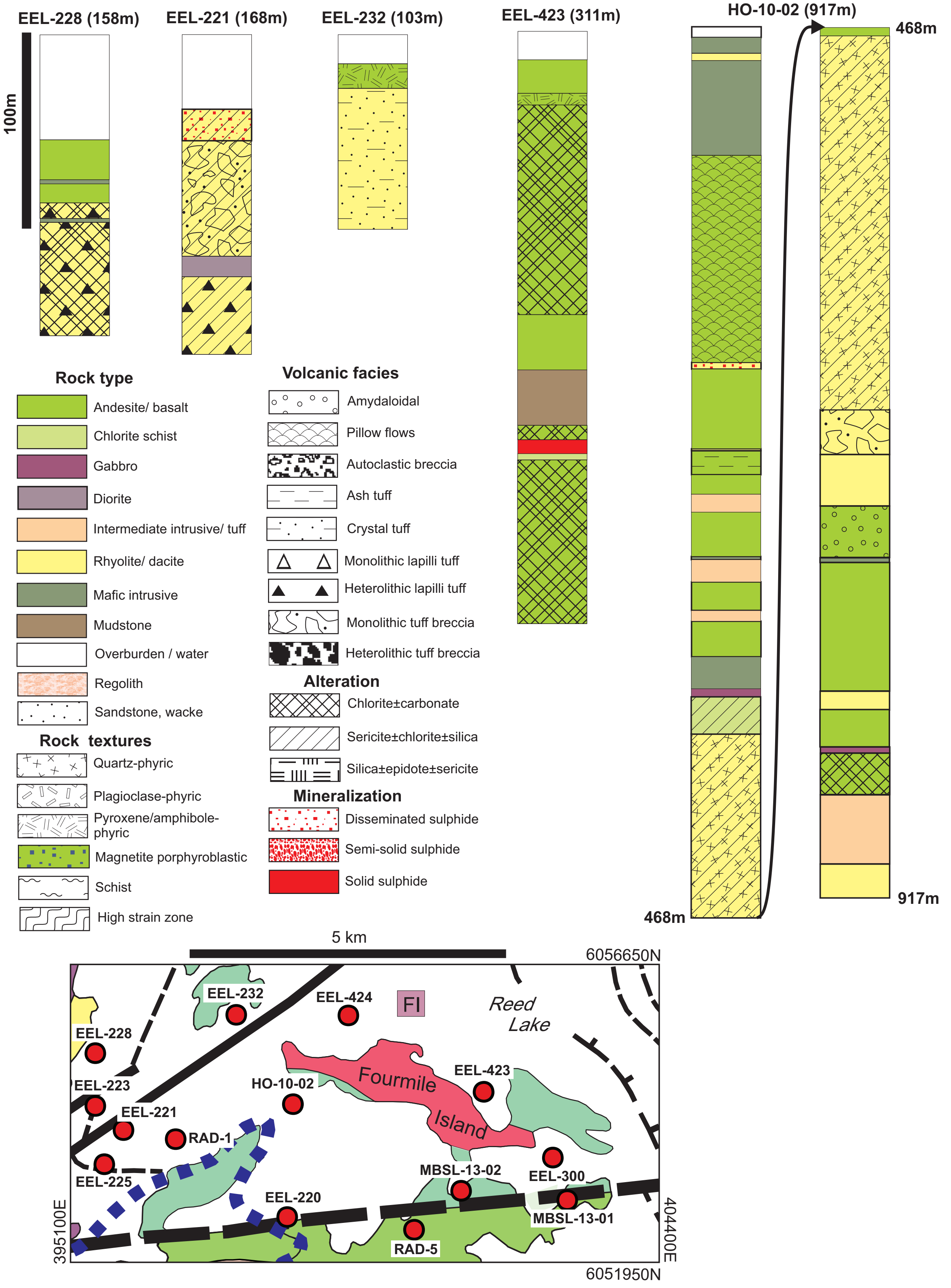

***Figure GS-3-3:** Schematic cross-sections of examined drillcores from the Fourmile Island and western Reed Lake area.*

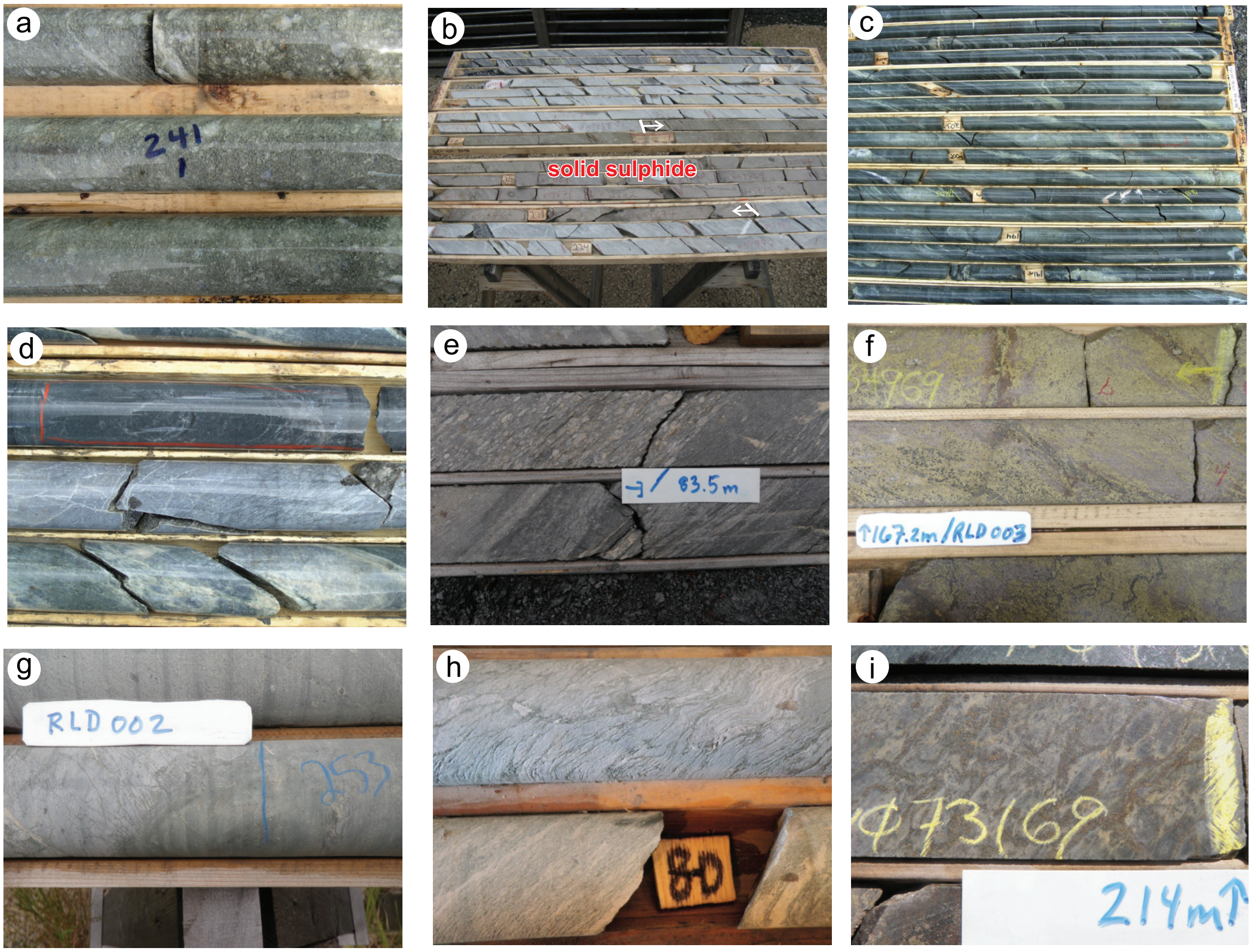

***Figure GS-3-4:** Drillcore photos: **a)** EEL-223, quartz-phyric felsic crystal tuff, with weak sericite alteration; **b)** EEL-423, solid sulphide lens of the Fourmile Island deposit; **c)** HO-10-02, variably altered massive andesite flows, bleached areas represent zones of moderate to strong pervasive silica alteration; **d)** HO-10-02, quartz-phyric rhyolite showing increase in silica-sericite alteration downhole (top to bottom of photo); **e)** MBSL-13-02, bedded heterolithic lapilli tuff and crystal tuff; **f)** RLD-003, solid sulphide (mineralogy here) from the Reed deposit; **g)** RLD-002, strong pervasive silica alteration (light grey, left side of photo) overprinting strongly chloritized andesite (grey-green colour, right side of photo) in the footwall of the Reed deposit; **h)** R-96-1, chlorite- and carbonate-altered, foliated mafic lapilli tuff; **i)** RLE-006, stringer-style sulphide veins in strongly silicified andesite.*

but overall are moderately altered. Types of alteration observed in the drillcore include chlorite-carbonate and epidote-silica in mafic volcanic rocks; and chlorite, silica and sericite±chlorite in felsic volcanic rocks (Figure GS-3-4i).

Eight drillcores (FB-79; R-96-5; RE-11-01, -02; RE-12-09, -11; MBSL-13-03, -04) from the vicinity of the Cowan River area were examined and relogged. Drillholes MBSL-13-03 and MBSL-13-04 intersected a fairly homogeneous and massive gabbro intrusion, whereas RE-11-01, -02, RE-12-09 and -11 cored through a thick succession of andesitic flows, with minor fragmental rocks. The mafic flows show fracture-controlled to pervasive chloritic and silica-epidote alteration that varies in intensity from weak to strong. Drillhole RE-11-01 intersected an interval of near-solid sulphide with a halo of strong chlorite alteration overprinted by silica-epidote alteration (Figure GS-3-6a). Drillholes R-96-5 and FB-79 both intersected felsic volcanic and volcaniclastic rocks that display weak to moderate sericite and silica alteration (Figure GS-3-6b, c).

Spruce Point deposit and southeastern Reed Lake area

Fourteen drillcores from the Spruce Point mine and southeastern Reed Lake areas were examined and sampled (Figure GS-3-7). These areas are characterized by three successions of bimodal volcanic and volcaniclastic rocks separated by sequences of mudstone and wacke 500–2000 m thick.

The past-producing Spruce Point deposit consisted of a series of copper- and zinc-rich sulphide lenses hosted

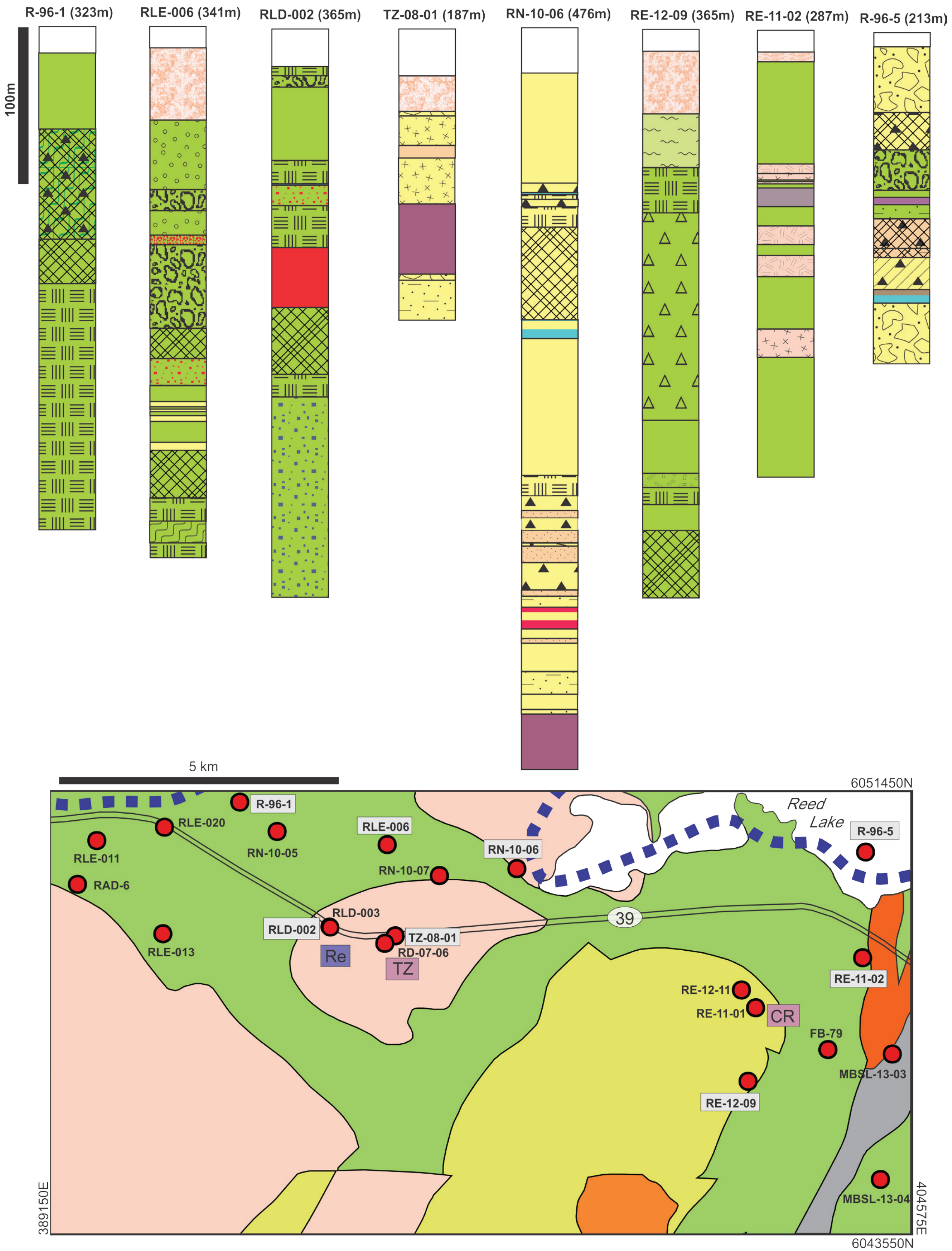

***Figure GS-3-5:** Schematic cross-sections of examined drillcores from the Read mine and Cowan River area. Legend same as for Figure GS-3-3. All cross-sections are drawn to the same scale.*

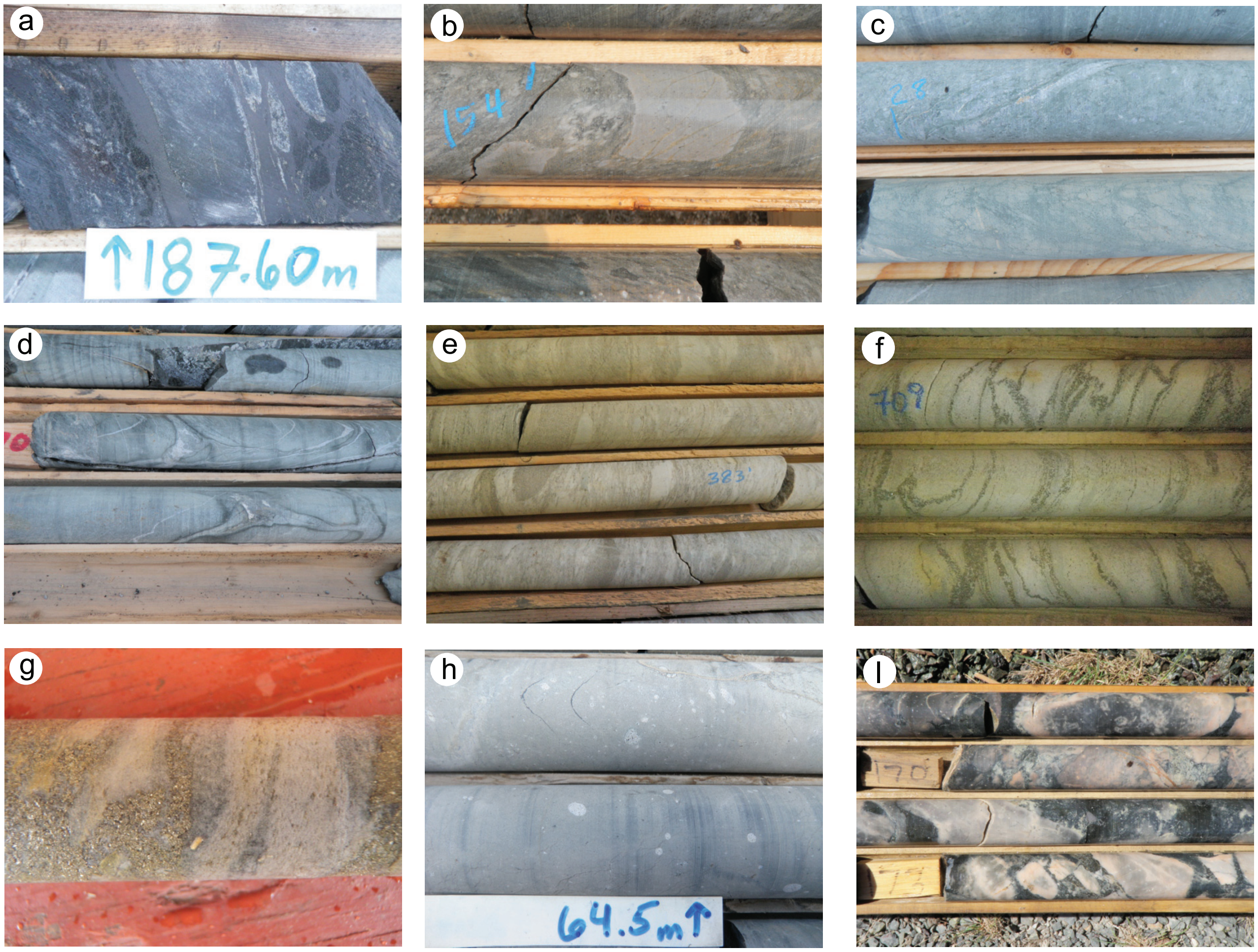

***Figure GS-3-6:** Drillcore photos: **a)** RE-11-01, magnetite-sulphide-quartz veins in altered footwall of solid sulphide mineralization from the Cowan River zone; **b)** R-96-5, poorly sorted bed of felsic lapilli tuff; **c)** R-96-5, moderate to strong silica-sericite-epidote alteration in fragmental felsic volcanic flow; **d)** FP-123, pillowed mafic flows displaying narrow selvages (dark green) and minor interpillow hyaloclastite; **e)** FP-110, weakly altered rhyolitic lapilli tuff from the footwall of the Spruce Point deposit; **f)** FP-110, stockwork of small sulphide veinlets in massive rhyolite from the footwall of the Spruce Point deposit; **g)** FP-110, close-up of a sulphide veinlet; medium-grey halo around sulphides represents strong silica alteration overprinting moderately sericitized rhyolite; **h)** FB-152, quartz-filled amygdules in massive andesitic flow **i)** FB-152, rhyolitic tuff breccia with moderately to strongly silicified clasts.*

by rhyolite breccia. The stratigraphic succession at the deposit is dominated by a sequence of felsic volcaniclastic rocks 200 m thick, which is interpreted to have been overturned (Fedikow and Lebydinski, 1990; Syme et al., 1995a). Three drillcores (FP-49, -110, and -123) of the Spruce Point mine horizon were examined. Drillhole FP-123 cored through the interpreted hangingwall of the deposit, which consists of a thick sequence of andesitic pillowed flows (Figure GS-3-6d), with minor intervals of autoclastic breccia, underlain by a thin sequence of aphyric rhyolitic fragmental rocks in the immediate hangingwall of the mineralized rhyolite. Drillholes FP-49 and -110 intersected footwall felsic volcanic rocks (Figure GS-3-06e) before encountering the mine horizon. The footwall consists of strongly and variably altered rhyolitic rocks, including fine-grained tuff, aphyric breccia and flows. The alteration consists of sericite-chlorite-sulphide, concentrated in the matrix of the rhyolite breccia (Figure GS-3-06f, g).

A series of four drillholes (FB-52, -53, -123, and -124) intersected a narrow zone of volcanic rocks bounded to the west and east by sedimentary sequences, and consisting of fine-grained mafic volcaniclastic rocks, which contain ash tuff and crystal tuff, with minor flow intervals.

Eight drillholes cored through the sequence hosting the Spruce Point deposit intersected mostly mafic volcanic and volcaniclastic rocks, with minor intervals of felsic volcanic rocks. Felsic volcanic and volcaniclastic rocks were most abundant in drillholes closest to the Spruce Point deposit. Alteration appears to be of lesser intensity and not as widespread as in the Reed mine and Cowan River area.

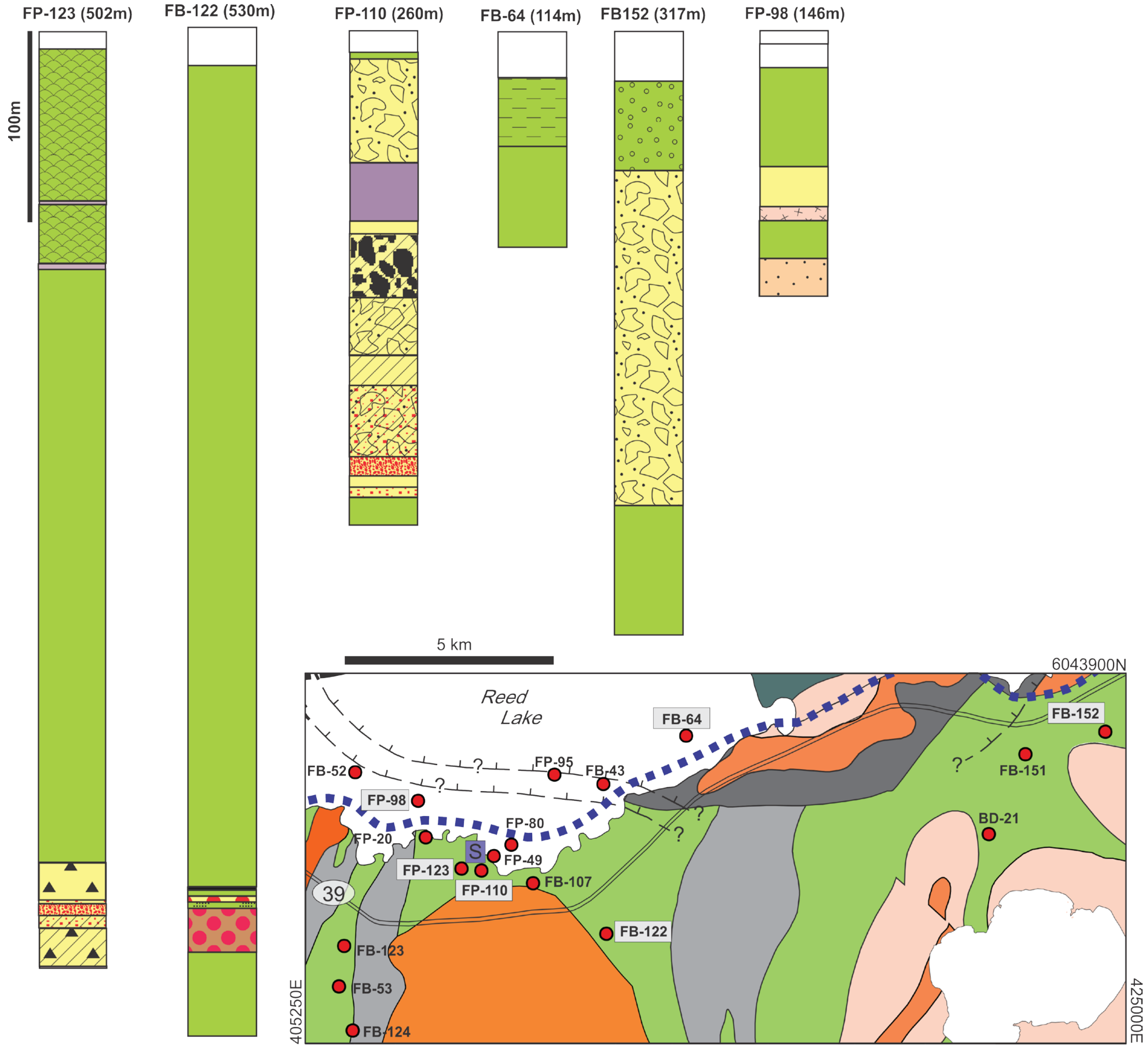

Figure GS-3-7: *Schematic cross-sections of examined drillcores from the Spruce Point mine and southeastern Reed Lake area. Legend same as for Figure GS-3-3. All cross-sections are drawn to the same scale.*

Finally, three drillholes (BD-21, FB-151, and -152) were selected to examine the volcanic succession in the sub-Phanerozoic basement east of Reed Lake and south of Tramping Lake. Drillhole BD-21 was cored through a bimodal sequence, with mafic flows overlying a sequence of strongly sericitized felsic tuff, which is underlain by mafic flows and monolithic mafic lapilli tuff.

Drillhole FB-151 encountered mostly mafic volcaniclastic rocks and, near the bottom, a narrow interval of felsic flow and monolithic felsic lapilli tuff. The upper 50 m of drillcore from FB-152 consists of amygdaloidal mafic flow (Figure GS-3-6h) followed by a thick (~175 m) interval of heterolithic felsic tuff breccia, with minor intervals of felsic lapilli tuff and crystal tuff (Figure GS-3-6i). The lower section of the drillcore consisted of aphyric massive mafic flow. The matrix of the felsic tuff breccia is weakly altered to chlorite-sericite and the felsic fragments are strongly silicified.

Geochemistry

One of the main objectives of the drillcore examination program is to obtain whole-rock geochemical data to characterize the trace- and rare-earth-element (REE) signatures of the rocks and help build a chemostratigraphic sequence for supracrustal rocks in the Reed Lake area. Both fresh and altered samples were collected; the latter will be used to characterize the intensity and type of alteration, and to test if this could be used as a vectoring tool for VMS-type mineralization.

Representative felsic and mafic volcanic rocks were collected from each examined drillcore. Samples collected in 2015 for whole-rock chemistry were submitted for analysis and results are pending. Results presented here are a compilation of previously published data (Syme et Bailes, 1996; Simard et al., 2010; Zwanzig and Bailes, 2010; Gagné and Anderson, 2014a) and unpublished data from both drillcore and outcrop of volcanic rocks in the Reed Lake area and sub-Phanerozoic area to the south.

All samples were trimmed to remove weathered surfaces, joints and veinlets; some samples may have contained minor amygdules. The trimmed samples were prepared in the Manitoba Geological Survey laboratory and analyzed using the '4Lithores' analytical package by Activation Laboratories Ltd. (Ancaster, Ontario). Major and minor elements were analyzed by inductively coupled plasma–emission spectrometry, and trace elements and REEs were analyzed using inductively coupled plasma–mass spectrometry. The sample suite of Syme and Bailes (1996) was re-submitted in 2013 for analysis using the '4Lithores' analytical package by Activation Laboratories Ltd.

Felsic volcanic and volcaniclastic rocks

In the following descriptions, the reference unit for felsic volcanic rocks in the Reed Lake area is taken as the Dickstone rhyolite (host to the Dickstone VMS deposit), which was described in detail by Bailes (1980) and Zwanzig and Bailes (2010). Bedrock mapping and sampling in 2013–2014 showed that the Dickstone rhyolite can be traced to the south over a distance greater than 25 km through the area west of Prieston and Sewell lakes, to the western shore of Krug Lake, and along the western shore of Reed Lake. This rhyolite displays remarkably uniform trace-element signatures characterized by slightly enriched heavy rare-earth element (HREE) profiles and small negative Eu anomalies on a chondrite-normalized trace-element diagram (Figure GS-3-8a). The Dickstone rhyolite signature on a primitive mantle–normalized incompatible trace-element diagram (Figure GS-3-8b) includes positive Th and negative Nb anomalies, and strongly depleted Ti (Zwanzig and Bailes, 2010; Gagné and Anderson 2014a). Samples from the vicinity of the Reed deposit (Tower zone) display a trace-element signature similar to that of the Dickstone rhyolite (Figure GS-3-8a, b).

However, some felsic samples collected from islands near drillhole EEL-232 in the western portion of Reed Lake, as well as from the Fourmile Island deposit (Simard et al., 2010), have trace-element signatures that are very distinct from that of the Dickstone rhyolite. The geochemical characteristics of these felsic rocks include lower REE contents and negative slopes on a chondrite-normalized trace-element diagram (Figure GS-3-8c). On a primitive mantle–normalized incompatible trace-element diagram (Figure GS-3-8d), the signature includes positive Th and negative Nb anomalies, strongly depleted Ti, and an overall negative slope. Although these chemical characteristics are distinct from the Dickstone rhyolite, they are nevertheless consistent with an arc or arc-rift depositional setting.

Mafic volcanic and volcaniclastic rocks

The reference units for mafic volcanic rocks in the Reed Lake area are taken as the Preaston andesite, which was described in detail by Bailes (1980) and Zwanzig and Bailes (2010), and the Northeast Reed basalt, discussed by Syme et al. (1995a) and Syme and Bailes (1996). Samples of mafic volcanic rocks collected from outcrop and drillcore (Syme and Bailes, 1996; Simard et al., 2010; this study) reveal three distinct geochemical signatures in the Reed Lake area. Samples from the western shore and islands in Reed Lake, and from the Krug Lake area, show Preaston-like signatures (type I), characterized by slightly enriched HREE profiles, with small negative Eu anomalies, on a chondrite-normalized trace-element diagram (Figure GS-3-8e). On a primitive mantle–normalized incompatible trace-element diagram (Figure GS-3-8f), the type I signature includes distinct positive Th and negative Nb anomalies, and depleted Ti. Three drillcore samples (from RLD-002 and RLD-003) from the Reed deposit show a very similar signature to that of the Preaston andesite (Figure GS-3-8g, h).

Samples from the large island northwest of drillhole EEL-232, from drillholes EEL-423 and -424 (which intersected the Fourmile Island sequence), and from outcrop on an island north of Fourmile Island display a different trace-element signature (type II), characterized by depleted HREEs and small positive Eu anomalies on a chondrite-normalized trace-element diagram (Figure GS-3-8e, g). On a primitive mantle–normalized incompatible trace-element diagram (Figure GS-3-8f, h), the type II signature includes distinct positive Th and negative Nb anomalies, and slightly depleted Zr.

Three samples from outcrop south of the BCFZ, collected in the area between the collars for RAD-5 and R-96-5, as well as six drillcore samples from HO-10-02, EEL-423 and -424 show similar trace-element signatures (type III) that are distinct from the type I and II signatures. Mafic rocks with the type III signature display flat REE profiles on chondrite-normalized trace-element diagrams (Figure GS-3-8e, g). On primitive mantle–normalized incompatible trace-element diagrams (Figure GS-3-8f, h), type III rocks show distinct positive Th and negative Nb anomalies, and slightly depleted Ti.

Discussion

Whole-rock geochemical data suggest that the Dickstone and Reed deposits possibly sit at a comparable stratigraphic level, as indicated by very similar geochemical characteristics of both felsic and mafic volcanic

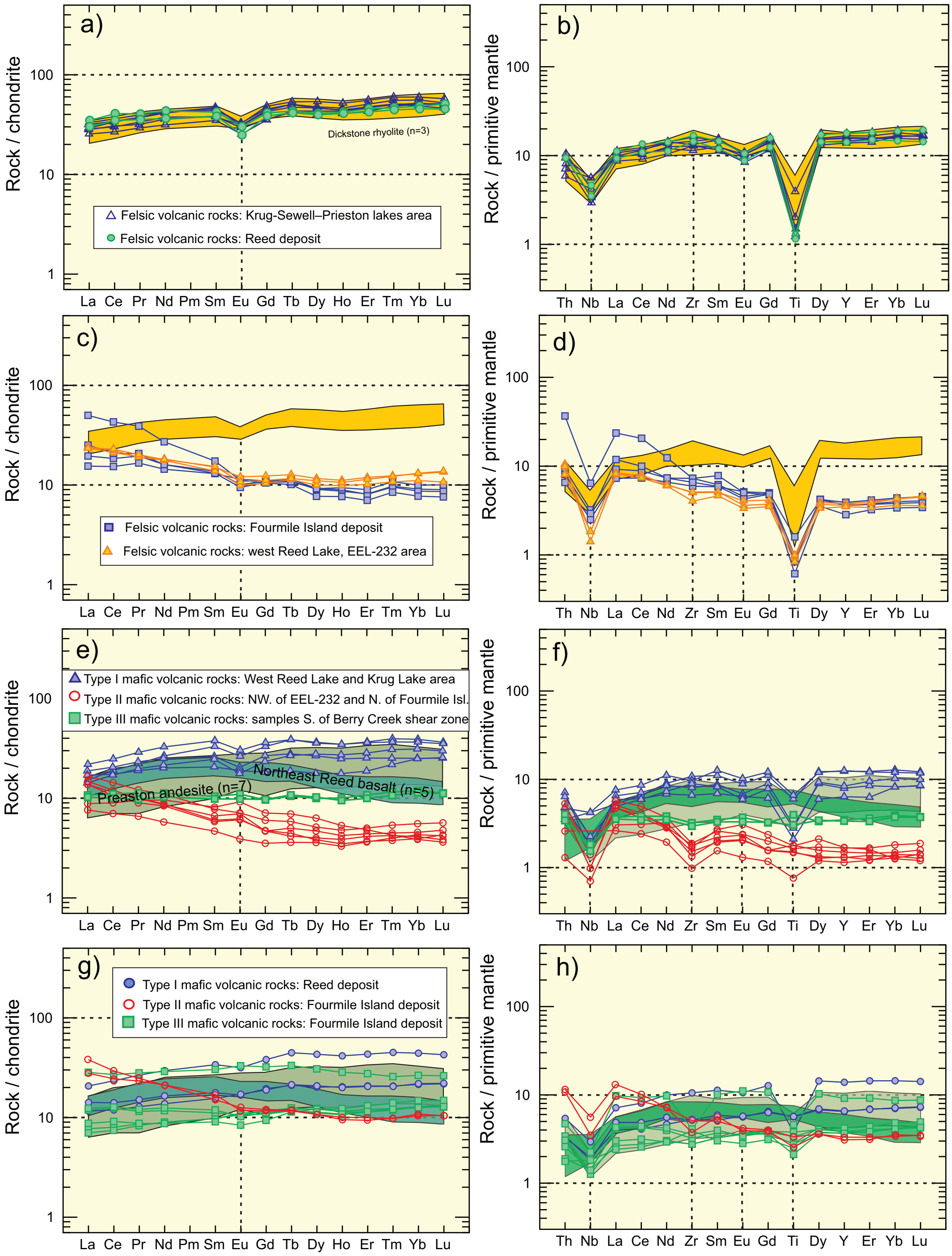

Figure GS-3-8: *Chondrite-normalized rare-earth-element plots (normalizing values from McDonough and Sun, 1995) and primitive mantle–normalized incompatible trace-element plots (normalizing values from Sun and McDonough, 1989) for rocks of the western Reed Lake area:* ***a)****,* ***b)****,* ***c)*** *and* ***d)*** *felsic volcanic rocks;* ***e)****,* ***f)****,* ***g)*** *and* ***h)****, mafic volcanic rocks.*

rocks associated with these deposits. Despite being located on the southern side of the BCFZ, of unknown net displacement, the Reed deposit lies almost along strike of the southern trace of both the Dickstone rhyolite and Preaston andesite (Gagné and Anderson, 2014a). Bailes (2010) presented geochemical data for volcanic rocks from the area of the Reed deposit and the Tower zone, which demonstrate a remarkable similarity to both the Dickstone rhyolite and Preaston andesite. Andesitic rocks from the Fourmile Island deposit have mostly type III signatures, with minor horizons showing type II signatures. None of the eight mafic samples from the Fourmile Island sequence show type I signatures. Coupled with the fact that felsic rocks associated with the Fourmile Island deposit display different trace-element signatures (Figures GS-3-8c, d), these observations point toward a distinct stratigraphic setting for this deposit. Further work is required to determine the exact relationship between rocks presenting different geochemical signatures. Considering the FIA consistently shows east-trending younging directions in the Reed Lake area, one possibility is that the sequence hosting the Fourmile Island deposit represents a higher stratigraphic level of the FIA (GS-3-2; Syme et al., 1995a, Figures GS-10-2, -3).

These preliminary data for volcanic rocks in the Reed Lake area suggest that it will be possible to refine the stratigraphy of the FIA using detailed whole-rock geochemistry. Follow-up sampling and analyses will further constrain the chemostratigraphy of the FIA sequence and the stratigraphic position of the various VMS deposits. Finally, by characterizing the stratigraphy of the FIA using whole-rock analysis, it may be possible to determine if the rocks north and south of the BCFZ can be correlated, thereby also providing insight on the sense of offset and displacement along the BCFZ.

Economic considerations

Bimodal volcanic and volcaniclastic rocks recognized in drillcore throughout the Reed Lake area indicate that the host successions were deposited in arc or arc-rift settings. The presence of moderate to intense, pervasive alteration and local sulphide mineralization suggest that all volcanic–arc assemblages in the sub-Phanerozoic basement of the Reed Lake area have potential for VMS mineralization; however, establishing the key criteria to target specific favourable horizons within these packages will be the focus of future work.

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