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VMS-STYLE MINERALIZATION IN THE KETTLE POND FORMATION, GLOVER ISLAND (NTS MAP AREAS 12A/12 AND 13)

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ABSTRACT

The Kettle Pond Formation on Glover Island in western Newfoundland is part of a thick sequence of Cambro-Ordovician ophiolitic rocks and associated cover rocks that are correlated with similar rocks on the Baie Verte Peninsula. The Kettle Pond Formation is predominantly interbedded mafic and felsic volcanic and volcanoclastic units and minor sedimentary rocks. Previous exploration on Glover Island has concentrated on orogenic gold deposits in the Kettle Pond Formation, and little work has focused on the potential for VMS-style mineralization, despite possible correlations with VMS-prospective belts, elsewhere in Newfoundland. This study highlights the VMS potential of the Kettle Pond Formation, combining geological and petrographic descriptions with lithogeochemistry and short wavelength infrared (SWIR) analysis.

Mafic tuffs show a wide range of geochemical compositions, ranging from island-arc tholeiites to MORB signatures, which is consistent with formation on a juvenile oceanic island volcanic arc associated with episodic intra-arc rifting. Felsic tuffs and quartz-feldspar porphyritic (QFP) rhyolites have geochemical characteristics typical of FIV-type rhyolites, indicating they formed via *crustal melting of basaltic material at shallow crustal levels (<10 km). These lithogeochemical signatures demonstrate that the Kettle Pond Formation has geochemical characteristics favourable for the formation of VMS-style mineralization.*

*A number of VMS-style mineral occurrences are hosted in the Kettle Pond Formation on Glover Island. The most extensive zone of VMS-style mineralization is reported from the Rusty Trickle area, where stringer-style sphalerite–chalcopyrite mineralization is associated with a zone of intense hydrothermal alteration in deformed QFP rhyolites (grab samples up to 12.9% Zn, 1.58% Cu, 1.16% Pb and 15.6 g/t Ag). Hydrothermal alteration is characterized by Na-depletion, enrichment in Mg, K, Ba and Hg, and high Ba/Sr, Hg/Na_2O, AI and CCPI values. SWIR analysis of white mica records a shift to more phengitic compositions (>2210 nm) in the alteration zone. These alteration signatures are characteristic of hydrothermal alteration associated with VMS mineralization and are similar to alteration zones at other VMS deposits in central Newfoundland (*e.g.*, Lemarchant and Boundary deposits). The metal content and host lithologies at Rusty Trickle are typical of bimodal mafic VMS deposits.*

Other VMS-style mineral occurrences in the Kettle Pond Formation include the Glover Island North and Glover Island East showings. These showings consist of thin (<2 m) massive to semi-massive sulphide units interbedded with altered felsic to mafic tuffs and minor black shales. These sulphide occurrences have low, but anomalous, base-metal and silver contents and are not associated with intense hydrothermal alteration as observed at Rusty Trickle.

INTRODUCTION

Glover Island is a large (39 x 5 km) island situated at the southern end of Grand Lake in western Newfoundland, approximately 30 km southeast of Corner Brook. It is predominantly underlain by a sequence of Cambrian to Ordovician ophiolitic rocks and associated cover rocks (Knapp, 1982; Cawood and van Gool, 1998; Szybinski *et al.*, 2006), which formed in a narrow tract of ocean volcanic arcs between the Laurentian continental margin and the Dashwoods microcontinent (Waldron and van Staal, 2001; van Staal *et al.*, 2007). These rocks are inferred to represent the southern extension of the Baie Verte Oceanic Tract (BVOT) of the Baie Verte Peninsula (van Staal *et al.*, 2007). The BVOT is host to numerous economic VMS occurrences, including the Rambler Ming Mine (M&I resources of 23.4 Mt at 1.64% Cu, 0.32 g/t Au and 2.52 g/t Ag as of December 2017, Rambler Metals and Mining Ltd.), as well as past producing mines at Tilt Cove, Rambler and Betts Cove. However, previous studies on Glover Island have focused on the potential for orogenic gold mineralization (Barbour *et al.*, 2012; Conliffe, 2021). Base-metal occurrences were reported in some of these studies, but the potential of Glover Island to host significant VMS-style base-metal deposits is underexplored.

The current study focusses on the VMS potential of the Kettle Pond Formation in central Glover Island (Figure 1), which forms part of a broader study investigating the mineral potential of the Glover Island and Grand Lake area. Central Glover Island has been covered by a number of recent high-resolution geophysical (magnetic, EM) surveys (Basha *et al.*, 2001; Ingram *et al.*, 2009), which have identified a number of geophysical anomalies that correspond with known VMS-style occurrences (Figure 2). This study includes detailed descriptions of these occurrences based on field mapping, relogging of historical drillcore, petrography, lithogeochemical data of outcrop and drillcore samples, and short wavelength infrared (SWIR) data collected during fieldwork in 2019 and 2021. These data are evaluated and discussed in the context of known VMS-style mineralization systems elsewhere in Newfoundland and globally, and this research will aid in future mineral exploration surveys on Glover Island and other VMS-prospective belts in Newfoundland.

GEOLOGICAL SETTING

Glover Island is located on the boundary between the Humber and Dunnage zones of the Newfoundland Appalachians (Williams, 1979), which are separated by the Baie Verte Brompton Line–Cabot Fault Zone (BCZ), a major crustal-scale lithotectonic boundary in the Canadian Appalachians (Williams and St. Julien, 1982; Brem, 2007). Rocks of the Humber Zone are restricted to the west coast of the Island (Figure 1). They form part of the Corner Brook Lake Block (CBLB) and consist of strongly deformed schists of the South Brook Formation (Knapp, 1982; Cawood and van Gool, 1998) overlying basement gneisses of the Corner Brook Lake Complex (~1.5 Ga, Cawood *et al.*,

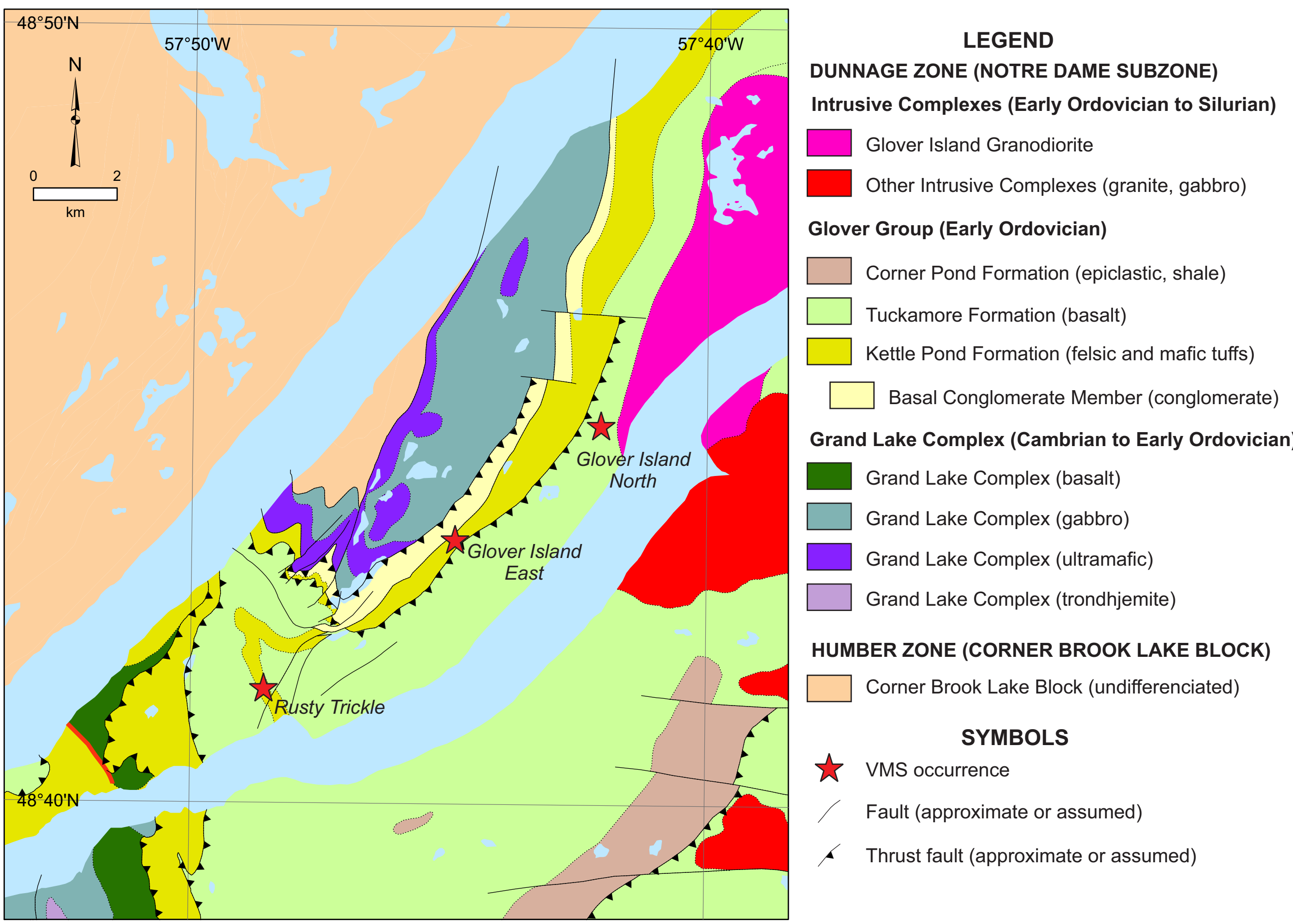

Figure 1. *Geological map of the Glover Island and Grand Lake area, compiled from published geological maps (Whalen and Currie, 1988; Whalen, 1993; Cawood and van Gool, 1998; Szybinski* et al.*, 2006) and detailed geological maps in industry assessment reports (Coates* et al.*, 1992; Barbour* et al.*, 2012).*

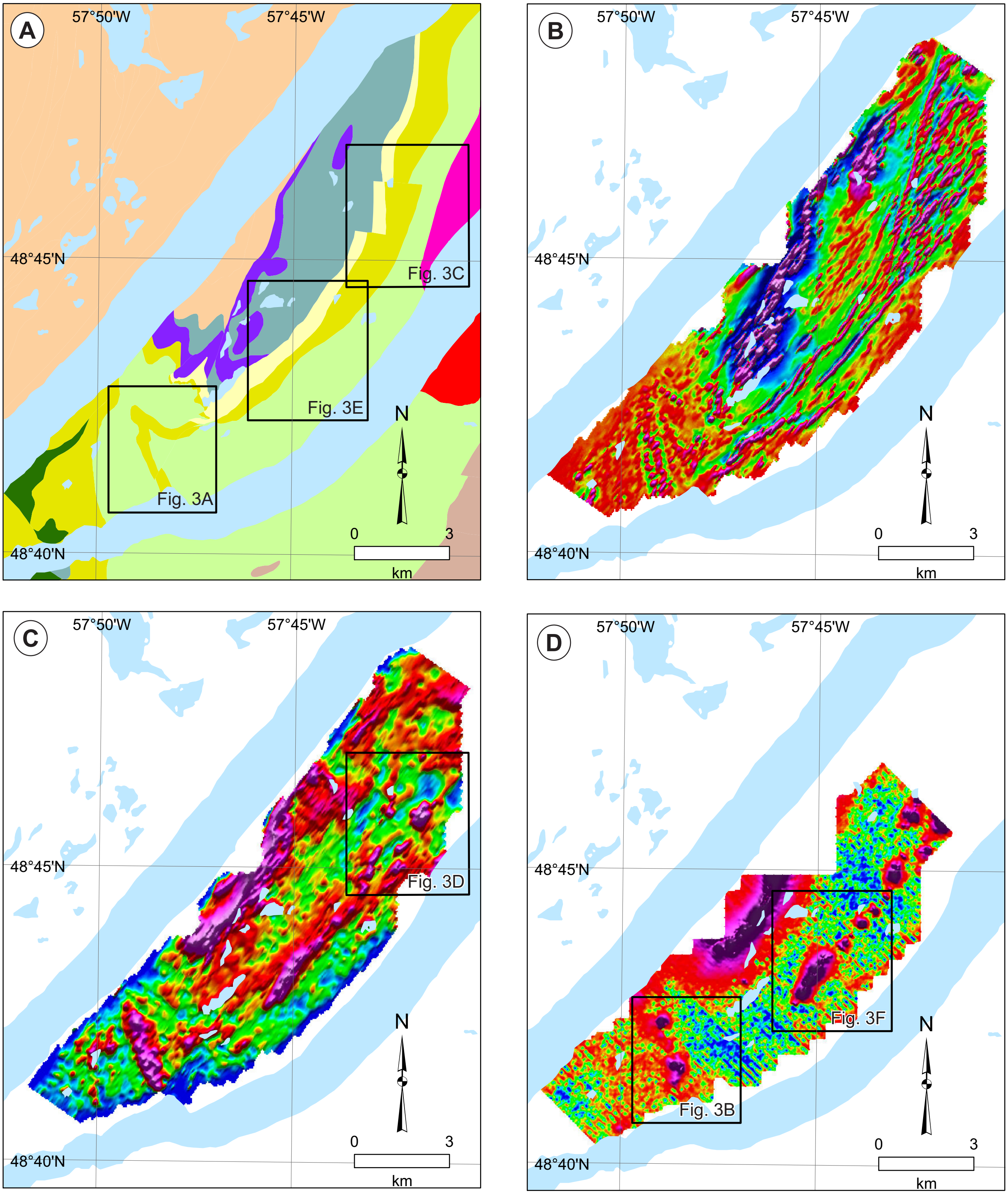

Figure 2. *Geological and geophysical maps of the Glover Island showing EM anomalies associated with known massive sulphide occurrences (*see *text for details). A) Simplified geology map, legend as in Figure 1; B) Aeromagnetic data (first vertical derivative) from the Glover Island area (data from Basha and Frew, 2001); C) DIGHEMV frequency-domain EM survey (data from Basha and Frew, 2001); D) Versatile Time Domain Electromagnetic (VTEM) survey (data from Ingram* et al.*, 2009).*

1996). The CBLB is interpreted to represent an allochthonous terrane transported to its current location by significant (>400 km) orogen-parallel strike–slip motion after the Taconic Orogeny (Brem, 2007; Lin *et al.*, 2013), or a basement domain on the distal margin of eastern Laurentia (Hodgin *et al.*, 2021).

Rocks to the east of the BCZ form part of the Notre Dame Subzone of the Dunnage Zone, a series of continental and oceanic arcs, back-arc basins and ophiolites of peri-Laurentian affinities (van Staal *et al.*, 2007). On Glover Island, a sequence of ophiolite rocks known as the Grand Lake Complex is structurally overlain by oceanic to back-arc volcanic, volcaniclastic and sedimentary successions collectively grouped together as the Glover Group (Knapp, 1982; Cawood and van Gool, 1998; Szybinski *et al.*, 2006). These rocks have been correlated with ophiolitic and associated volcanic and sedimentary cover rocks of the BVOT on the Baie Verte Peninsula, and together are interpreted to have formed in a narrow tract of ocean volcanic arcs between the Laurentian continental margin and the Dashwoods microcontinent (Waldron and van Staal, 2001; van Staal *et al.*, 2007).

The Cambrian to Early Ordovician Grand Lake Complex on Glover Island consists of a lower sequence of altered ultramafic units overlain by a series of massive to layered gabbros. The upper part of the gabbro sequence is intruded by numerous small trondhjemite bodies, dated by Cawood *et al.* (1996) at 490 ± 4 Ma (U–Pb zircon). This portion of the Grand Lake Complex is interpreted to represent the base of an ophiolite complex (Knapp, 1982; Cawood and van Gool, 1998). A sequence of relatively unaltered and undeformed sheeted dykes, pillow lavas and gabbros occur on the southern end of Glover Island and in the southwestern Grand Lake area, and these are intruded by large trondhjemite and tonalite plutons east of Grand Lake (Figure 1; Szybinski *et al.*, 2006). Geochemical analysis suggests that this sequence represents the upper portion of the Grand Lake Complex on Glover Island (Knapp, 1982).

The Early Ordovician Glover Group is in fault contact with the Grand Lake Complex, but is interpreted to represent the cover sequence to the ophiolite (Knapp, 1982; Szybinski *et al.*, 1995, 2006; Cawood and van Gool, 1998). The Kettle Pond Formation represents the stratigraphically lowest part of the Glover Group, and is divided into a lower conglomerate unit (Basal Conglomerate Member) overlain by felsic to mafic volcanic rocks (Szybinski *et al.*, 1995). Numerous plagioclase-porphyritic mafic sills and dykes intrude the Kettle Pond Formation. The upper contact of the Kettle Pond Formation is marked by the disappearance of felsic volcanic units (Szybinski *et al.*, 1995; Barbour *et al.*, 2012). The Tuckamore Formation overlies the Kettle Pond Formation and is composed of a thick (<5 km) sequence of dominantly pillow basalts and plagioclase-porphyritic flows, with minor red to purple shales, iron formations, massive sulphides and interstitial jasper (Knapp, 1982; Szybinski *et al.*, 2006). The uppermost unit in the Glover Group is the Corner Pond Formation, which occurs to the east of Grant Lake. It is composed predominantly of felsic epiclastic (graded conglomerate to fine-grained siltstone) units with minor rhyolites, pillow basalts, shales, chert, and carbonate rocks. A black shale near the top of the Corner Pond Formation contains Laurentian graptolites spanning the *P. fruticosus* and *D. bifidus* biozones (Williams, 1989), indicating a mid-Floian (477.7 to 470 Ma) age (Loydell, 2012).

The Glover Group is intruded by a number of late-stage intrusions, including the Glover Island Granodiorite (440 ± 2 Ma; Cawood *et al.*, 1996) on the northeastern side of Glover Island and by gabbros and diorites that are included in the 435 ± 1 Ma Rainy Lake Complex (Whalen *et al.*, 2006). These intrusions display arc-like geochemical signatures (Whalen *et al.*, 2006), and are possibly related to the final stages of northwest-directed subduction of Ganderia below the Notre Dame Subzone (Whalen *et al.*, 2006). On the northern end of Glover Island, Carboniferous sedimentary rocks of the Deer Lake Basin unconformably overlie the Glover Group (Cawood and van Gool, 1998).

Rocks of the Grand Lake Complex and the Glover Group have experienced regional greenschist-facies metamorphism (Knapp, 1982; Cawood and van Gool, 1998). Four main phases of deformation have been identified, representing a complex deformational history from the Ordovician to the Carboniferous (Knapp, 1982; Szybinski *et al.*, 1995, 2006; Cawood and van Gool, 1998; Barbour *et al.*, 2012). D_1 deformation is responsible for a regionally penetrative S_1 fabric with common mylonitization, which is strongly developed in the Grand Lake Complex and Kettle Pond Formation on Glover Island, but decreases in intensity to the east (Barbour *et al.*, 2012). S_1 fabrics were subsequently folded during D_2 and D_3 deformation, resulting in spectacular mesoscopic folds with chevron, cuspate-lobate and ptygmatic styles developed parasitic on decametre- to kilometre-scale folds (Barbour *et al.*, 2012). D_4 deformation consists of high-angle faults, which formed in an extensional environment, potentially during the Carboniferous movement on the BCZ (Cawood and van Gool, 1998).

PREVIOUS WORK

The first geological mapping in the Glover Island–Grand Lake area was completed by Riley (1957) as part of a regional-scale mapping project of the Red Indian Lake area. Knapp (1982) completed a Ph.D. thesis on the Glover Island–Grand Lake area, and identified and described most of the map units shown in Figure 1. More detailed regional mapping by the Geological Survey of Canada resulted in the publication of geological maps of NTS map areas 12A/12 and 13 (*see* Whalen and Currie, 1988; Whalen, 1993; Cawood and van Gool, 1998; Szybinski *et al.*, 2006).

Mineral exploration on Glover Island has mostly focused on the gold potential of the area (summarized by Barbour *et al.*, 2012; Conliffe, 2021). Gold mineralization was first reported in the mid-1980s, and subsequent exploration led to the discovery of 15 gold occurrences in the Tuckamore Formation close to the contact with the Grand Lake Complex, with a strike length of >7 km (Barbour *et al.*, 2012). Exploration by various companies from 1985 to 2012 included airborne and ground geophysics, prospecting, soil sampling, geological mapping, trenching and diamond drilling (summarized by Barbour *et al.*, 2012). Based on this, Puritch and Barry (2017) reported a NI 43-101 Indicated Mineral Resource for the Lunch Pond South East zone of 58 200 oz. gold (1.03 Mt at 1.76 g/t Au) with additional Inferred Mineral Resources of 120 600 oz. gold (2.08 Mt at 1.81 g/t Au).

Exploration for VMS-style base-metal deposits on Glover Island began in the late 1970s, based on regional exploration by Hudson's Bay Oil and Gas Limited (HBOG). This work included geological mapping, soil geochemistry and airborne and ground geophysical surveys on Glover Island (Dean, 1977; Lassila, 1979a, b), and was successful in identifying a number of EM anomalies that were subsequently tested by 10 shallow (<85 m) diamond-drill holes in three locations (Rusty Trickle, Glover Island East and Glover Island North). Although drillholes in all three locations intercepted altered mafic and felsic volcanic rocks with some stringer and massive sulphide mineralization, base-metal values from assayed intervals were low (<200 ppm Cu + Zn) and further work was not recommended (Lassila, 1979a, b). However, detailed relogging and resampling of select drillholes in 1983 identified intervals of altered felsic and mafic tuffs with elevated Zn (up to 681 ppm), Ag (up to 30.2 g/t) and Ba (up to 11 400 ppm), resulting in a recommendation for further exploration and drilling on these targets (McHale and Tuach, 1983).

New Island Minerals Limited carried out prospecting, trenching, soil geochemical surveys and VLF-EM magnetometer surveys over the Glover Island North occurrence (French, 1995; Ralph and French, 2002). Two massive to semi-massive sulphide occurrences were identified, but assay results for base metals were low (<1000 ppm combined Cu, Zn, Pb). Numerous unsourced massive sulphide boulders were also found nearby along a small road, with assay values from float up to 4.7% Cu, 0.45% Zn and 58.4 g/t Ag (French, 1995).

In 1998, a new VMS-style base-metal occurrence was reported from the Rusty Trickle area (Barbour and Hodge, 1998). Between 1998 and 2000, geological mapping, soil geochemistry and ground geophysics (magnetics, IP, EM) identified a large zone of strongly silica–sericite-altered felsic tuffs with a minimum dimension of 150 x 550 m (Basha *et al.*, 2001). A number of grab samples from this anomalous zone returned values ranging from 0.5 to 12.9% Zn, 0.2 to 1.58% Cu, 0.15 to 1.16% Pb and 5.0 to 15.6 g/t Ag (Basha *et al.*, 2001).

A number of high-resolution airborne geophysical surveys have been flown over Glover Island as part of regional exploration programs (Basha *et al.*, 2001; Ingram *et al.*, 2009). Although these exploration programs were primarily focused on gold mineralization, they identified a number of anomalies coincident with known zones of VMS mineralization on Glover Island (Figure 2).

GEOPHYSICAL SURVEYS

Volcanogenic massive sulphide deposits are commonly characterized by a strong geophysical signature, with high-resolution magnetic and electromagnetic (EM) data commonly used during exploration for these deposits types (Morgan, 2012). Magnetic surveys are useful in determining the broad geological framework of an area, as well as identifying structural features or magnetite-destructive alteration typically associated with the footwall of VMS deposits (Morgan, 2012). Electromagnetic surveys can identify bedrock anomalies related to VMS deposits, due to the high conductivity of sulphide minerals (pyrite, pyrrhotite, chalcopyrite) relative to typical host rocks. However, care must be taken in interpreting these anomalies, as they can be indistinguishable from graphitic sedimentary rocks, or non-economic VMS deposits (Morgan, 2012). In addition, sphalerite-rich, sub-seafloor replacement-style mineralization may not be associated with significant EM anomalies.

Regional aeromagnetic and EM maps generated from surveys flown over Glover Island in 2000 and 2008 are shown in Figure 2. Aeromagnetic data (Figure 2B) correlates well with bedrock geology maps (Figure 2A), highlighting the highly magnetic ultramafic rocks of the Grand Lake Complex and the change in strike of the Glover Group volcanic rocks from northeast trending in central Glover Island to southeast trending in the Rusty Trickle area. In 2000, a DIGHEM^{V} frequency-domain EM survey was flown over Glover Island, which identified a number of large EM anomalies that were interpreted to represent bedrock anomalies (Figure 2C; Basha *et al.*, 2001). A helicopter-borne Versatile Time Domain Electromagnetic (VTEM) survey was flown in 2008 (Ingram *et al.*, 2009). Time-domain surveys generally transmit a much greater EM signal into the ground, and therefore are able to attain greater depth-penetration than frequency domain surveys. In contrast to the broad anomalies identified in the frequency domain survey (Figure 2C), the VTEM survey identified a number of smaller, more discrete anomalies in the Kettle Pond Formation of the Glover Group (Figure 2D), which are likely related to bedrock conductors. Although these anomalies correlate with known areas of VMS-style mineralization and alteration on Glover Island, no follow-up work has been done in these areas to date.

GEOLOGICAL CHARACTERISTICS OF VMS-STYLE OCCURRENCES ON GLOVER ISLAND

All known VMS-style occurrences on Glover Island are hosted in the Kettle Pond Formation, the lowermost member of the Glover Group. The Basal Conglomerate Member forms the lower part of the Kettle Pond Formation that outcrops extensively in central Glover Island (Figure 1). It consists of strongly deformed, clast-supported polymictic pebble to cobble conglomerate and matrix-rich polymictic conglomerates that grade upward into arenaceous schists with rare clasts (Barbour *et al.*, 2012; Plate 1A).

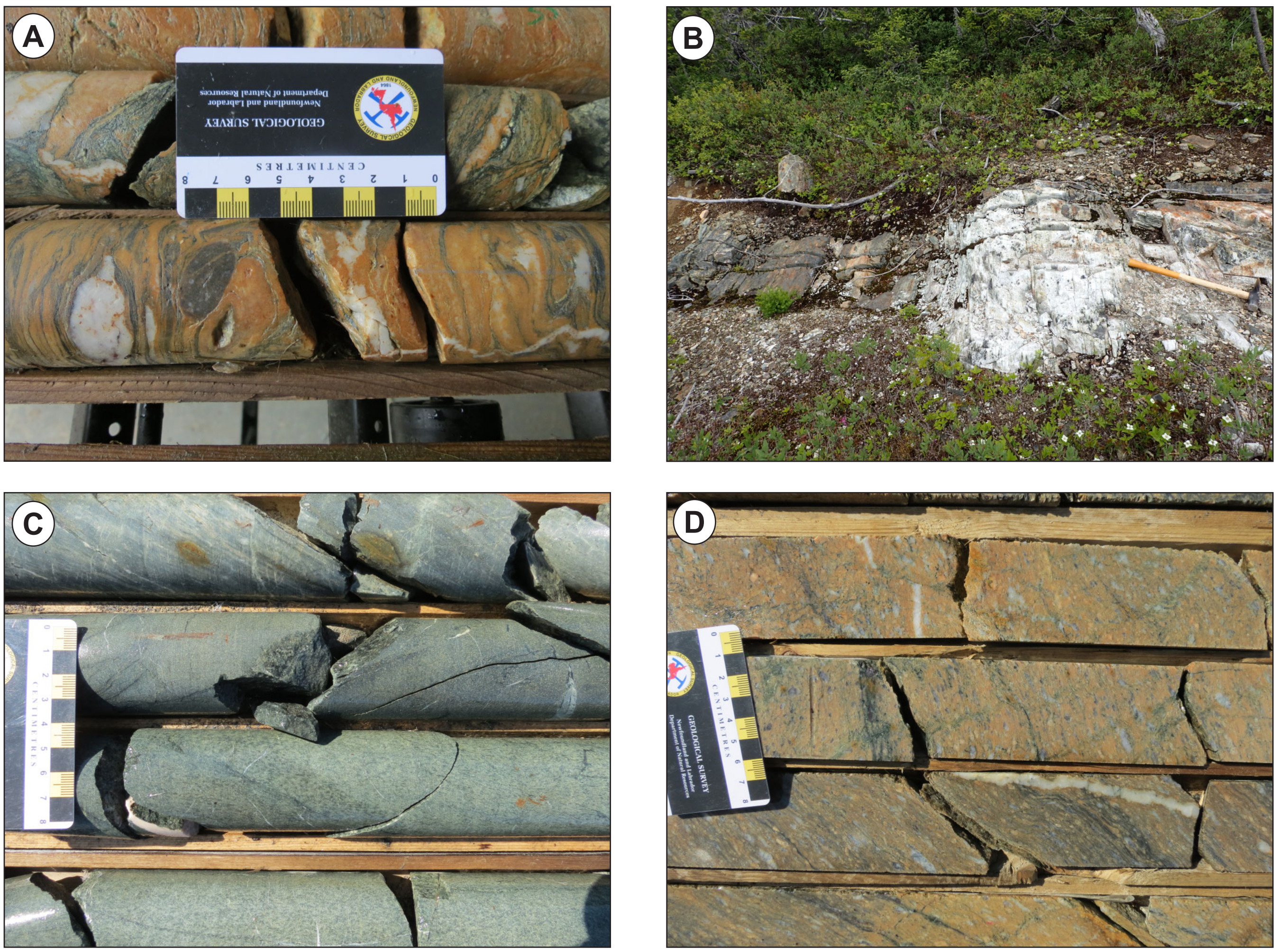

Plate 1. *Representative photographs from the Kettle Pond Formation. A) Strongly altered and deformed matrix-rich polymictic conglomerate from the Basal Conglomerate Member (drillhole LPN-2 @ 32.2 m); B) Interbedded mafic tuffs (left) and strongly altered felsic tuffs (right) exposed in trenched outcrop at the Jacomar showing; C) Fine-grained chlorite-altered mafic tuff (drillhole LPSE-11-57 @ 39.4 m); D) Typical moderately deformed and weakly altered QFP rhyolite (drillhole LPSE-11-57 @ 82.3 m).*

Above the Basal Conglomerate Member, the Kettle Pond Formation consists of interlayered, fine-grained mafic and felsic tuffs and volcanic rocks (Plate 1B) interspersed with thicker units of mafic volcanic rocks (Szybinski *et al.*, 1995; Barbour *et al.*, 2012). The mafic tuffs and volcanic rocks are strongly deformed and commonly form chlorite-rich schists (Plate 1C). Felsic rocks range from aphanitic felsic tuffs to quartz-feldspar porphyritic (QFP) rhyolites, and range in thickness from <1 to >30 m. The QFP rhyolites are host to orogenic gold mineralization on Glover Island, which is associated with intense albite–carbonate alteration that obscures many primary volcanic features (Conliffe, 2021). A thick (>100 m) sequence of distinctive QFP rhyolites occurs at the southern end of Glover Island (Plate 1D). This unit has been identified in drilling at the Lunch Pond South East gold deposit (Barbour *et al.*, 2012), as well as at the Rusty Trickle showing. The volcanic rocks are interlayered with minor, thin (<2 m) massive sulphide, black shale, chert, iron formation, and reddish-grey hematitic chert units (Szybinski *et al.*, 1995). These are interpreted as synvolcanic exhalites, which are commonly associated with VMS-deposits, and indicate seafloor hydrothermal activity (Galley *et al.*, 2007; Slack, 2012).

RUSTY TRICKLE SHOWING

The Rusty Trickle showing represents the largest known VMS-style occurrence on Glover Island, and coincides with a number of discrete EM anomalies (Figure 3A, B). The mineralized zone consists of stringer-style Zn–Cu–Ag mineralization hosted in a 200–250-m-thick, north-northwest-trending, steeply dipping sequence of QFP rhyolites. These are conformably overlain by a sequence of fine-grained mafic tuffs and thin (<3 m) graphitic shales to the east, underlain by mafic tuffs and medium-grained gabbro sills to the west (Basha *et al.*, 2001).

The QFP rhyolites comprise abundant large (up to 3 mm) quartz and K-feldspar phenocrysts in a fine-grained matrix of quartz, feldspar, muscovite and chlorite (Plates 2A and 3A, B). Alteration is variable, ranging from strong silica–sericite ± chlorite ± carbonate alteration in the mineralized zone to moderate silica–sericite alteration more distal to mineralization. Late-stage Fe-carbonate alteration has also been recorded overprinting earlier alteration in drillcore (Plate 2B). The QFP rhyolites are moderately to strongly deformed and have a well-developed S_1 schistocity parallel to bedding, and tight isoclinal folding has been recorded in some areas (Basha *et al.*, 2001).

Outcropping sulphide mineralization at the Rusty Trickle showing occurs along a small brook, where mineralization has been traced for >80 m. Mineralization occurs as up to 20% stringer-style sulphide mineralization in strongly sericite–silica–chlorite–carbonate-altered QFP rhyolites, with sulphides composed of variable amounts of sphalerite, pyrite, chalcopyrite and galena (Plates 2C and 3C–E). These stringers are commonly deformed and recrystallized, and are aligned parallel to the regional north-northwest-trending S_1 schistosity. Grab samples from the mineralized trend assayed from 0.5 to 12.9% Zn, 0.2 to 1.58% Cu, 0.15 to 1.16% Pb and 5.0 to 15.6 g/t Ag (Basha *et al.*, 2001). A thin (>50 cm) exhalative mudstone layer is interbedded with the mineralization exposed in the brook. This mudstone is finely laminated, brown to black, graphite-rich and carbonaceous, with abundant euhedral pyrite and trace chalcopyrite and sphalerite (Plates 2D and 3F). The sulphides occur parallel to bedding and are commonly associated with fibrous barite crystals. This mudstone has elevated Zn, Ag and Ba contents, with up to 0.7% Zn, 5.7 g/t Ag and >1% Ba (Basha *et al.*, 2001).

Similar stringer-style mineralization has been recorded in outcrops up to 400 m southeast of the main mineralized trend, with ~10% sphalerite–chalcopyrite stringers and assay values up to 2.85% Zn and 0.38% Cu (Basha *et al.*, 2001). Dean (1977) recorded mineralized rhyolites from the southern shore of Glover Island, ~800 m southeast of the main occurrence, which assayed 0.4% Zn, 0.47% Pb, 0.11% Cu and 3.7 g/t Ag. Hudson's Bay Oil and Gas Limited also carried out diamond drilling ~300 m north of the main occurrence (Lassila, 1979a). Drillhole BR-3-78 terminated at 47.6 m in a sequence of strongly altered QFP rhyolites with 5–10% stringer-style pyrite and sphalerite mineralization (McHale and Tuach, 1983), with 30.2 g/t Ag over 1.5 m, 1.08% Ba over 3.26 m and 681 ppm Zn over 4.6 m (Lassila, 1979a; McHale and Tuach, 1983). Overall, these exploration results indicate that mineralized QFP rhyolites can be traced along strike at Rusty Trickle for more than 1 km.

GLOVER ISLAND NORTH SHOWING

Numerous thin (<2 m) massive sulphide units have been reported from outcrop and drillcore in the Glover Island North area (Figure 3C). The main Glover Island North showing occurs in outcrop in a small stream (Plate 4A) and traced along strike for at least 20 m northeast during trenching (Lassila, 1979b; French, 1995). Mineralization consists of semi-massive sulphides with up to 50% disseminated pyrite in strongly altered mafic and felsic tuffs (Plate 4B). Assay values in grab samples are generally low with a maximum of 580 ppm Zn, 397 ppm Cu and 1.1 g/t Ag (Collins, 1987). A large number of unsourced massive sulphide boulders are located over >1 km along a road to the north of the main showing (French, 1995). Although most of these boulders have low base-metal values (<0.1% Cu + Zn + Pb), one boulder assayed 4.7% Cu, 0.45% Zn and 58.4 g/t Ag (French, 1995).

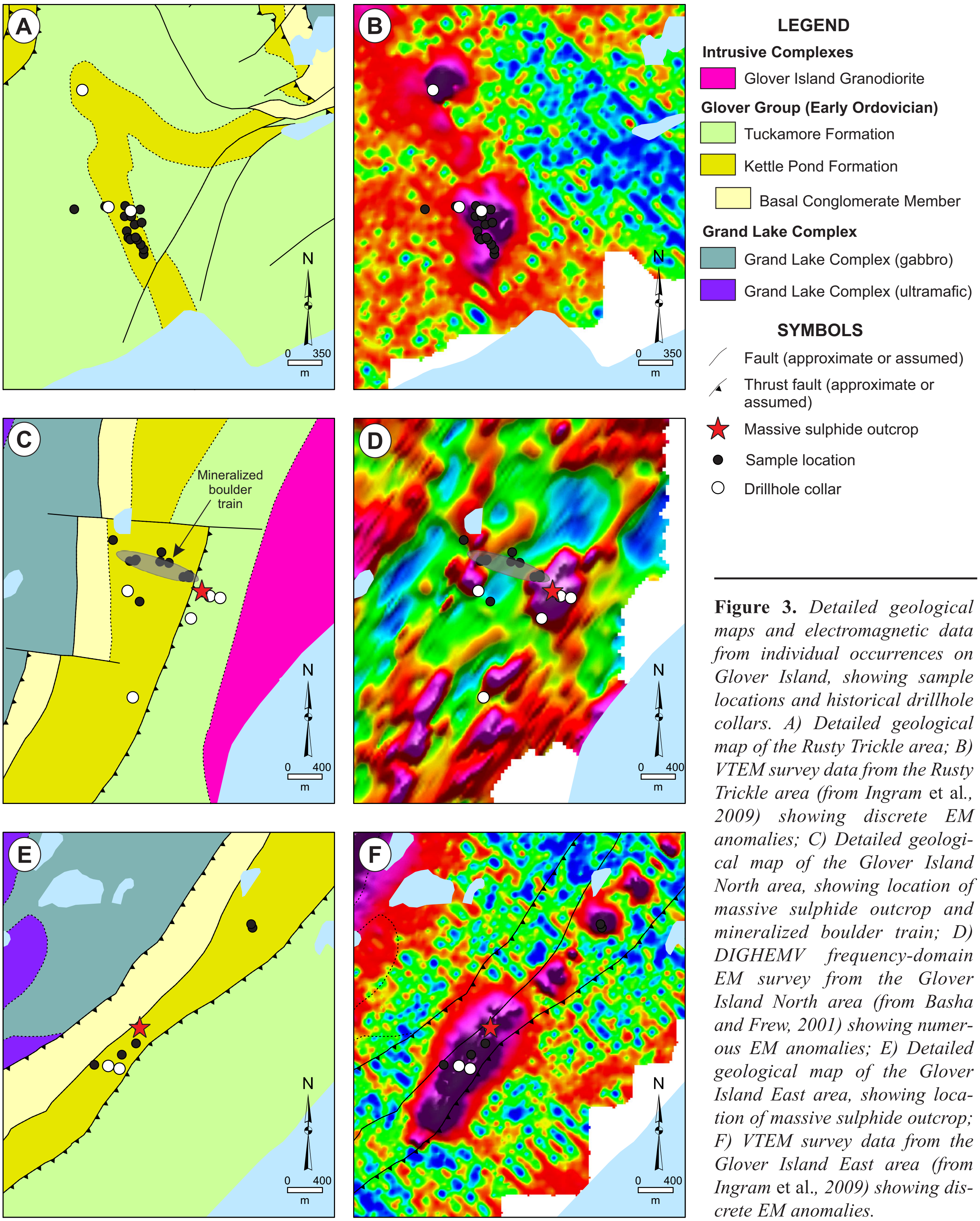

Figure 3. *Detailed geological maps and electromagnetic data from individual occurrences on Glover Island, showing sample locations and historical drillhole collars. A) Detailed geological map of the Rusty Trickle area; B) VTEM survey data from the Rusty Trickle area (from Ingram* et al.*, 2009) showing discrete EM anomalies; C) Detailed geological map of the Glover Island North area, showing location of massive sulphide outcrop and mineralized boulder train; D) DIGHEMV frequency-domain EM survey from the Glover Island North area (from Basha and Frew, 2001) showing numerous EM anomalies; E) Detailed geological map of the Glover Island East area, showing location of massive sulphide outcrop; F) VTEM survey data from the Glover Island East area (from Ingram* et al.*, 2009) showing discrete EM anomalies.*

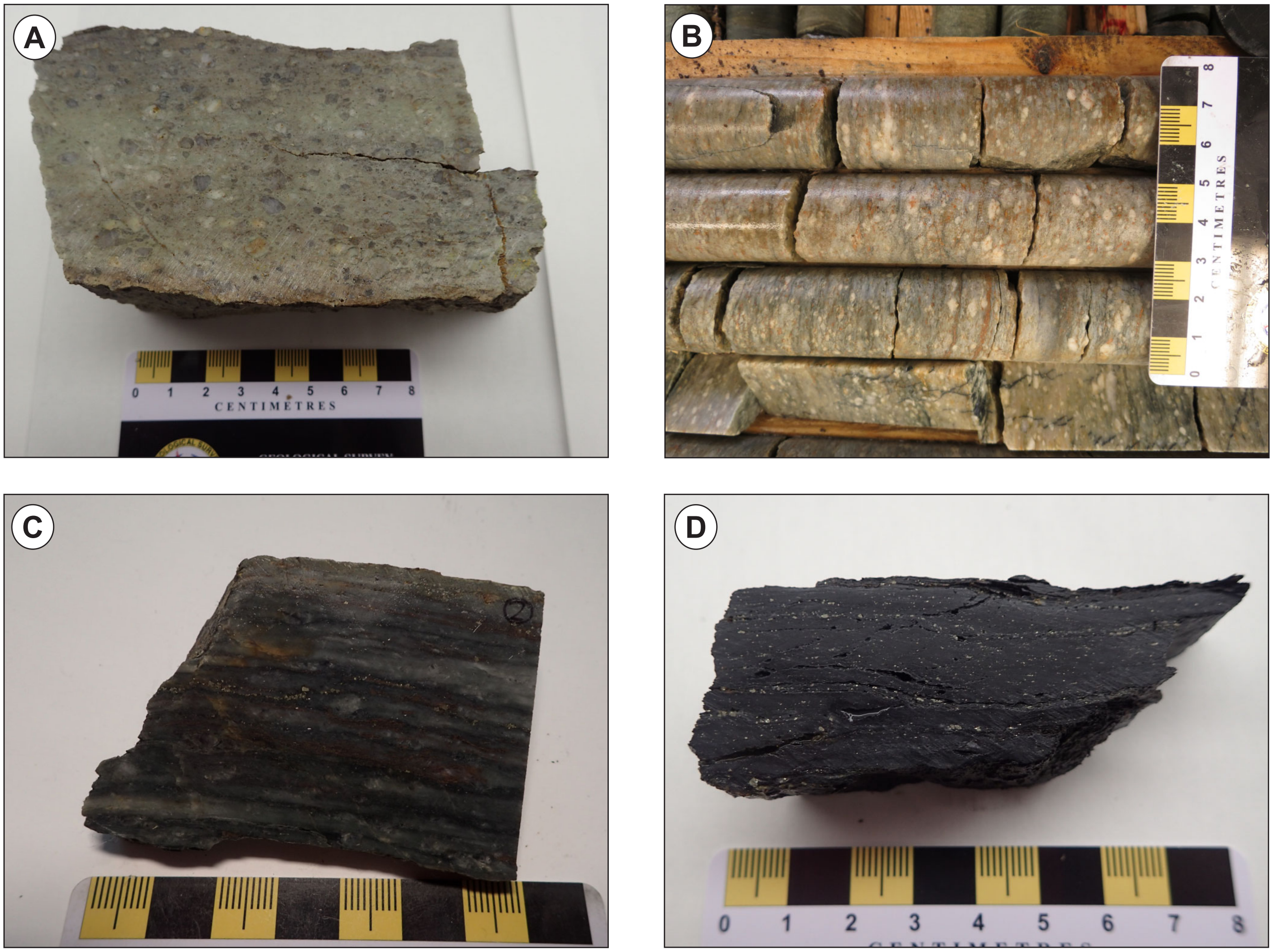

Plate 2. *Representative photographs of lithologies from the Rusty Trickle area. A) Moderately altered, unmineralized QFP rhyolite; B) Strongly altered QFP rhyolite with overprinting Fe-carbonate alteration (drillhole BR-3-78 @ 39.7 m); C) Mineralized QFP rhyolite with strong chlorite–sericite alteration and stringers of sphalerite and pyrite parallel to schistocity; D) Black graphitic shale with disseminated pyrite.*

In 1979, HBOG completed five shallow drillholes (total 306.3 m) on a number of EM anomalies in the Glover North area (Lassila, 1979b). These drillholes intersected interbedded mafic and felsic tuffs of the Kettle Pond Formation. Thin (up to 1.7 m), massive to semi-massive sulphide units are interbedded with felsic tuff units (Plate 4C), and minor chert and graphitic shale. The massive sulphides consist predominantly of pyrrhotite, with minor euhedral and brecciated pyrite overgrowing pyrrhotite (Plate 4D), and trace sphalerite, chalcopyrite and magnetite (Plate 4E). Lassila (1979b) reported low (<100 ppm) Cu and Zn values in the massive sulphide units. However, re-sampling indicates that many of the massive sulphides and interbedded felsic tuff and cherty shale units have elevated Zn (up to 1356 ppm), Cu (up to 508 ppm), Ag (up to 3.2 g/t) and Ba (up to 5796 ppm). All units are moderately to strongly deformed, and the massive sulphides are commonly brecciated and contain deformed, rounded to elongate clasts of the surrounding lithologies (Plate 4F). These fragments are interpreted to represent adjacent lithologies, which were incorporated into the sulphides due to differential brittle and ductile deformation during post-depositional tectonic movement (Durchbewegung textures; Marshal and Gilligan, 1989).

GLOVER ISLAND EAST SHOWING

The Glover Island East showing outcrops in a brook on the eastern side of Glover Island and is coincident with a large EM anomaly in the Kettle Pond Formation (Figure 3E, F). Mineralization consists of a series of massive to semi-massive sulphide beds (0.3 to 2.2 m thick) interbedded with mafic to felsic tuffs and graphitic shales (Plate 5A, B), all

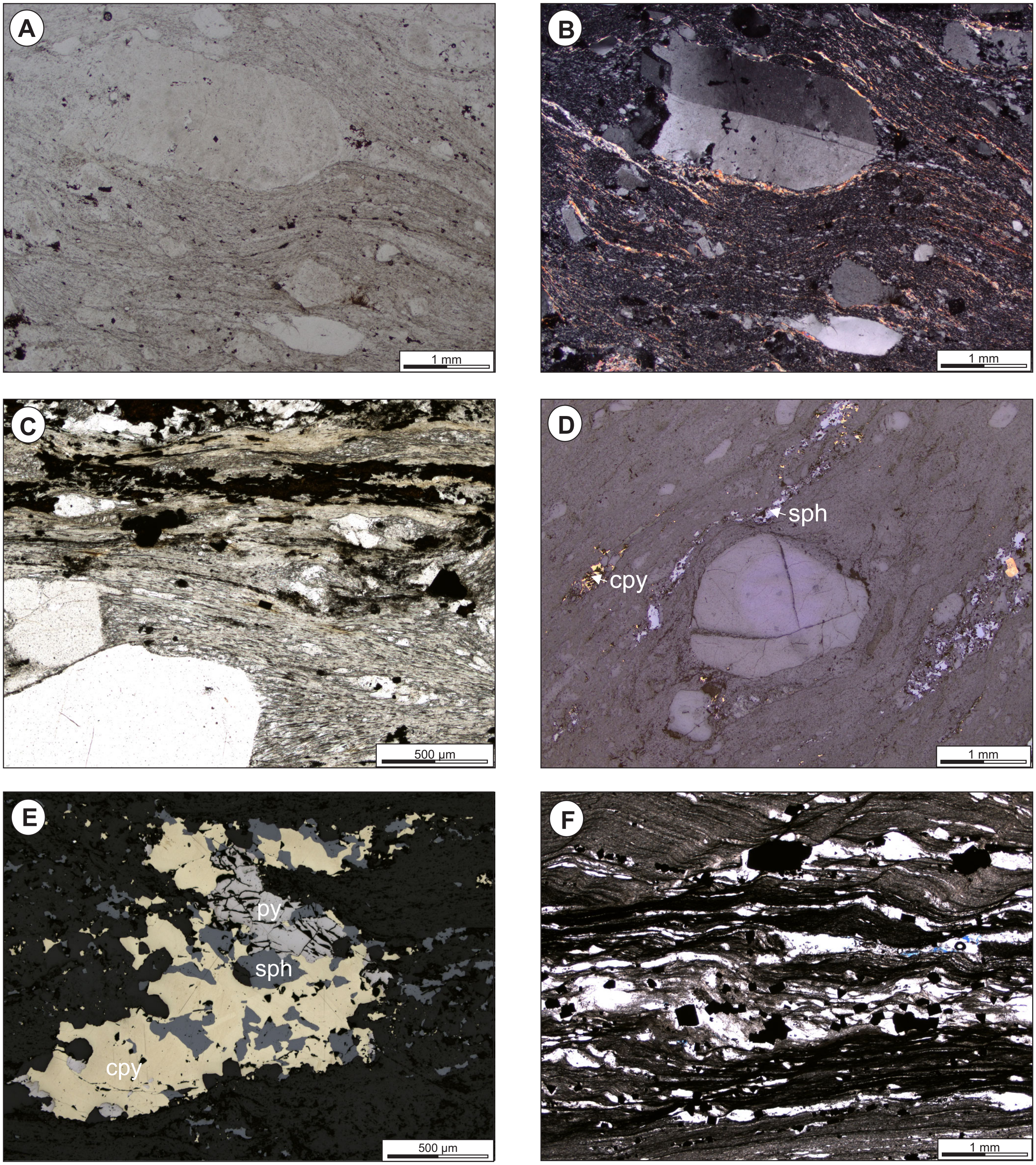

Plate 3. *Representative photomicrographs from the Rusty Trickle area. A) Typical QFP rhyolite with large feldspar and quartz phenocrysts, strong S1 schistocity and moderate sericite alteration (plane-polarized light, sample 21JC009A01); B) Same view as A), in cross-polarized light; C) Mineralized QFP with strong chlorite and sericite alteration (plane-polarized light, sample 21JC016A01); D) Mineralized QFP with sphalerite (sph) and chalcopyrite (cpy) in stringers parallel to S1 schistocity (reflected light, sample 19JC034A02); E) Sphalerite (sph), chalcopyrite (cpy) and pyrite (py) in mineralized QFP rhyolite (reflected light, sample 21JC016A02); F) Black shale with layers of pyrite and barite parallel to bedding (plane-polarized light, sample 21JC017A01).*

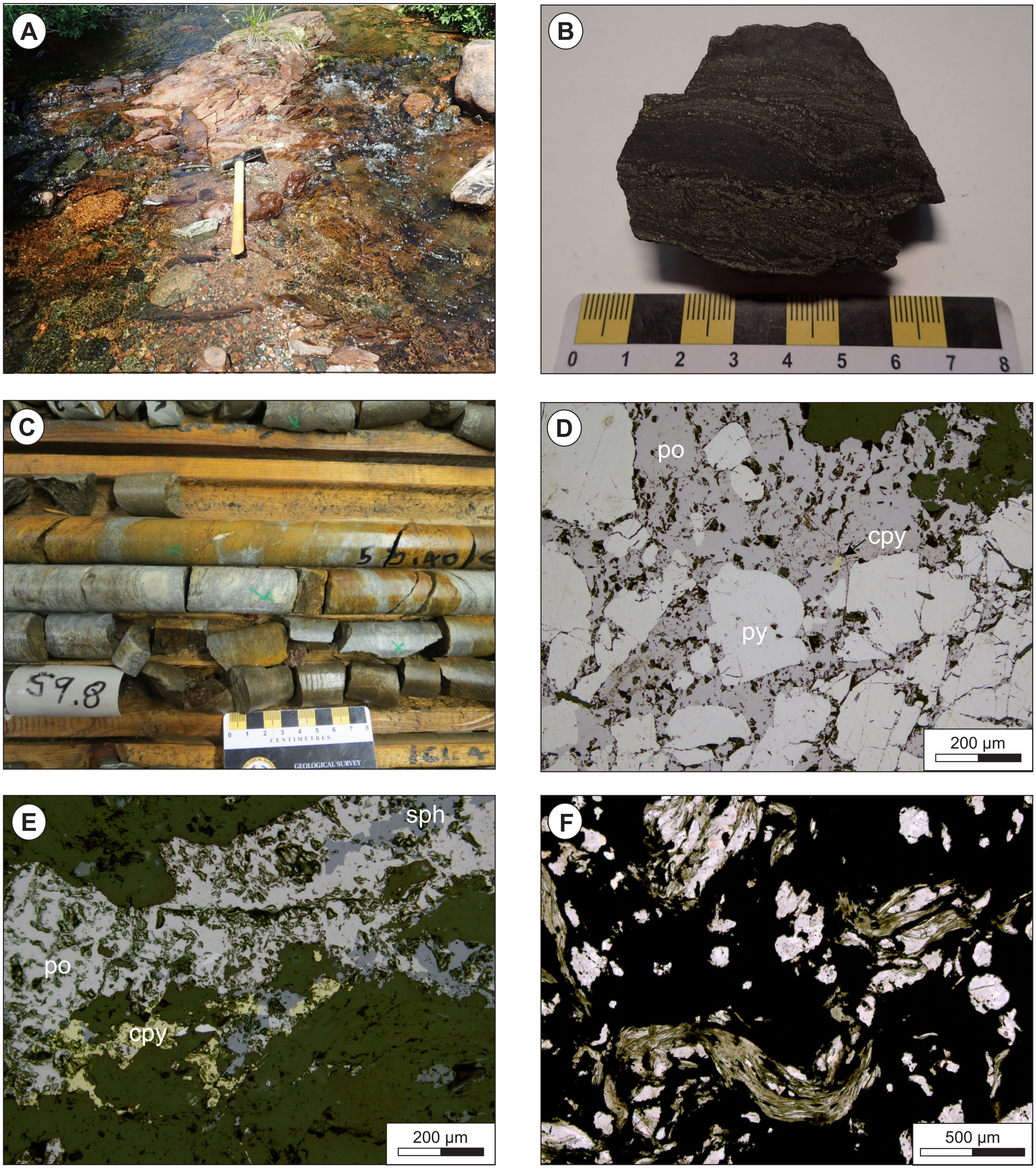

Plate 4. *Representative photographs and photomicrographs from the Glover Island North area. A) Semi-massive sulphide outcrop in brook; B) Semi-massive sulphide with pyrite and minor pyrrhotite in shale matrix; C) Interbedded altered felsic tuffs and semi-massive sulphides (drillhole RL223-1-78 at 56.6 m); D) Euhedral pyrite (py) in massive pyrrhotite (po), with trace chalcopyrite (cpy) (reflected light, drillhole RL223-1-78 at 74.8 m); E) Pyrrhotite (po), chalcopyrite (cpy) and sphalerite (sph) in semi-massive sulphide layer (reflected light, drillhole RL223-2-78 at 36 m); F) Massive sulphide with deformed elongate shale clasts forming Durchbewegung textures (plane-polarized light,, drillhole RL223-1-78 at 36.6 m).*

cut by plagioclase phyric mafic dykes (Lassila, 1979a). Channel samples from across the massive sulphide beds are anomalous in Zn, Pb and Ag, with assay values up to 1300 ppm Zn, 800 ppm Pb and 11 g/t Ag over 2.2 m (French and Wilton, 2005). Massive sulphides consist predominantly of fine-grained pyrrhotite overgrown by large euhedral pyrite crystals (Plate 5C), with trace chalcopyrite, galena and sphalerite grains (Plate 5D). The massive sulphides also include numerous elongate to rounded shale and silicate fragments (Plate 5B), which generally align parallel to the regional S_1 fabric and represent Durchbewegung textures formed during regional deformation (Marshal and Gilligan, 1989).

Two diamond-drill holes have targeted VMS-style mineralization to the south of the main occurrence (Figure 3E; Lassila, 1979a). Both drillholes intersected a sequence of mafic volcanic rocks with lesser shales and silicic tuffs. A number of thin (>1 m) massive to semi-massive sulphide horizons are interbedded with shale and felsic tuff units, with low base-metal values (<200 ppm Cu + Zn; McHale and Tuach, 1983). However, a sequence of interbedded silicic tuffs, graphitic shales and semi-massive sulphides in drillhole BR-6-78 contains elevated Ba, with assays up to 1.14% Ba over 1.5 m (McHale and Tuach, 1983).

LITHOGEOCHEMISTRY

METHODOLOGY

Samples for lithogeochemical analysis were collected from the three known VMS occurrences (Rusty Trickle, Glover Island North and Glover Island East) in the Kettle

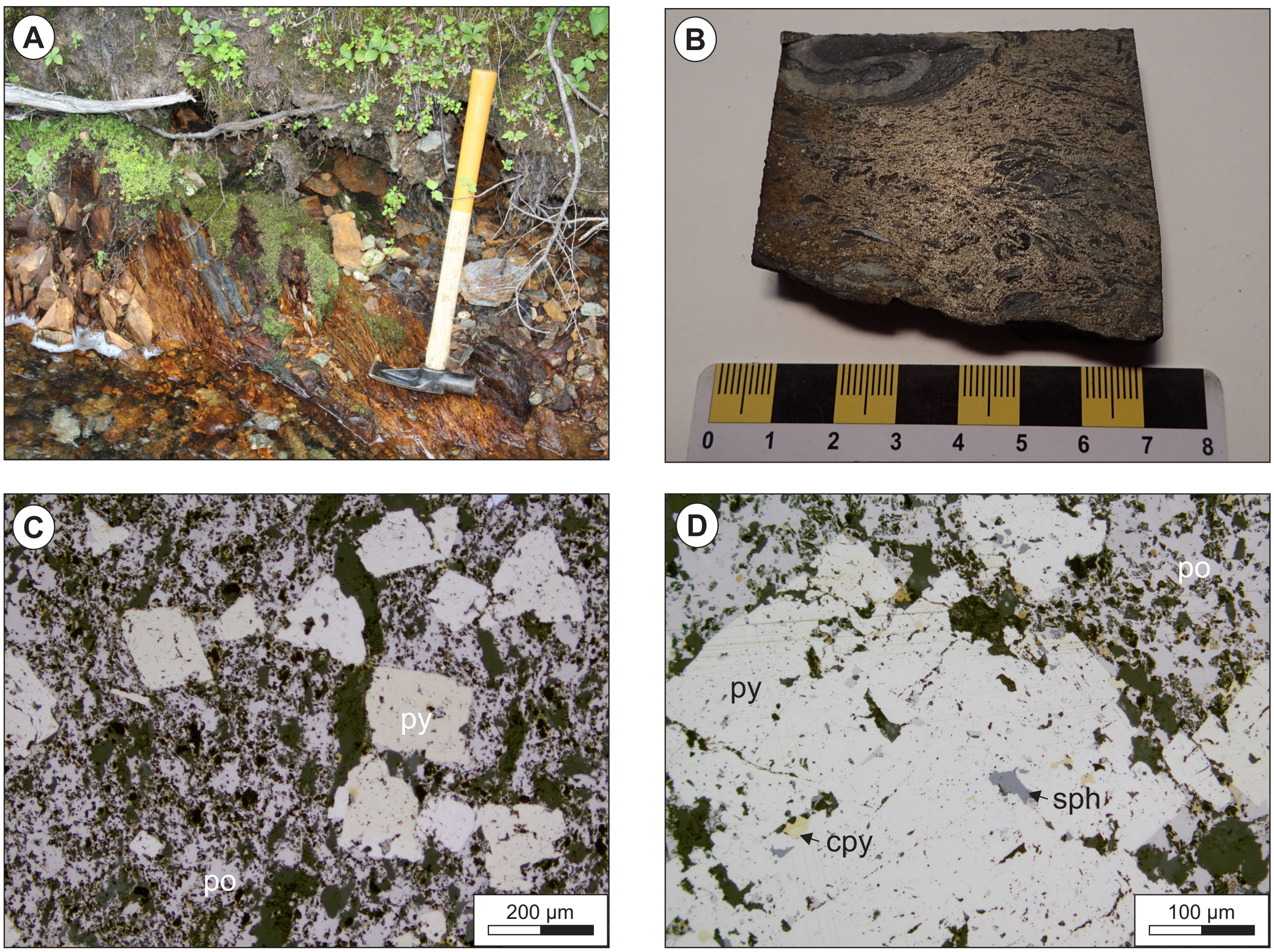

Plate 5. *Representative photographs and photomicrographs from the Glover Island East area. A) Massive sulphide outcrop interbedded with intensely altered shale and tuff; B) Massive sulphide with deformed shale clasts forming Durchbewegung textures; C) Euhedral pyrite (py) in massive pyrrhotite (po), with trace chalcopyrite (reflected light, sample 19JC029C03); D) Massive sulphide with chalcopyrite (cpy) and sphalerite (sph) inclusions in euhedral pyrite (py) (reflected light, sample 19JC029C03).*

Pond Formation, and are representative of all main rock types present. In total, 103 samples were analyzed, including 41 outcrop samples, 11 samples of massive sulphide boulders from the Glover Island North area, and 51 drillcore samples from the Government of Newfoundland and Labrador Core Storage facilities in Pasadena and Springdale. The geochemical data from these samples will be published later in an upcoming Open File report.

Samples were prepared at the GSNL geochemical laboratory in St. John's, where major-element, trace-element and rare-earth-element (REE)-analyses were carried out; the analytical methods are described in Finch *et al.* (2018). Additional analyses for trace elements including Au, Cd, Sb and As were conducted on selected samples by Maxxam Analytics (now Bureau Veritas) using Instrumental Neutron Activation Analysis (INAA). Analytical duplicates were inserted at a frequency of one in 20, with the duplicates selected at random. In addition, a selection of reference standards was analyzed, also at a frequency of one in 20.

IGNEOUS LITHOGEOCHEMISTRY

Geochemical data was collected for 57 volcanic rock samples from the Kettle Pond Formation, including 25 mafic tuff samples, 11 aphanitic felsic tuffs and 21 QFP rhyolites. All volcanic rock units sampled for lithogeochemical analysis have been variably affected by regional metamorphism/alteration and/or hydrothermal alteration (*see* below). This suggests that most major elements (except Al, Ti) and low-field-strength elements (LFSE; *e.g.*, Cs, Rb, Ba, Sr) are likely to have been mobile during alteration, and the application of these elements for whole-rock classification and deducing magma affinity will be compromised (MacLean, 1988; MacLean and Barrett, 1993). In contrast, elements thought to be immobile in hydrothermal fluids, such as Al, Ti, high-field-strength elements (HFSE; *e.g.*, Zr, Y, Nb) and the REEs (*e.g.*, MacLean, 1988; MacLean and Barrett, 1993) can be used to infer the primary magmatic and tectonic affinities of igneous rock types.

Mafic tuffs are sub-alkaline and plot in the basaltic field on the Zr/TiO_2 *vs.* Nb/Y plot (Figure 4A). They have tholeiitic to transitional affinities on the Th/Yb *vs.* Zr/Y magmatic affinity diagram of Ross and Bédard (2009). Although mafic tuffs have similar textures and mineralogy, they can be divided into three types based on their immobile-element geochemistry. Type 1 mafic tuffs are characterized by strong negative Nb anomalies and weakly negative Ti anomalies, and have flat to slightly light-rare-earth-element (LREE)-enriched profiles (Figure 5A), and plot within the volcanic-arc basalt field in tectonic discrimination diagrams (Figure 6). Type 2 mafic tuffs have less pronounced negative Nb anomalies, are relatively depleted in Th compared to Type 1 mafic tuffs, and have flat REE profiles (Figure 5B). These tuffs have geochemical characteristics of volcanic-arc basalts, back-arc basin basalts and normal mid-ocean ridge basalts (NMORB) on extended trace-element and tectonic-discrimination diagrams (Figures 5B and 6). However, there is significant overlap between the geochemical characteristics of Type 1 and 2 mafic tuffs. Type 3 mafic tuffs lack a Nb anomaly, display flat to LREE-enriched REE profiles (Figure 5C) and resemble enriched mid-ocean ridge basalts (EMORB; Piercey, 2011). These tuffs plot close to the fields of NMORB to EMORB basalts on tectonic discrimination diagrams (Figure 6).

Felsic rocks in the Kettle Pond Formation all display similar geochemical characteristics with high SiO_2 (73.2 ± 6.2% SiO_2) and low TiO_2 (0.22 ± 0.07% TiO_2) contents, and have tholeiitic to transitional affinities (Figure 4C; Ross and Bédard, 2009). Quartz-feldspar porphyritic rhyolites plot in the rhyolitic/dacitic field on the Zr/TiO_2–Nb/Y plot, whereas aphanitic felsic tuffs have variable Zr/Ti ratios, which indicate variable degrees of detrital contamination in these tuffs (Figure 4A). Extended trace-element plots show that these rocks have strong negative Nb, P and Ti anomalies (Figure 7), and QFP rhyolites also show slight LREE-enrichment with flat heavy-rare-earth elements (HREE) patterns and variable Eu anomalies (Figure 7).

The low Zr content (<185 ppm), Nb content (<5.2 ppm) and chondrite normalized La/Yb ratio (La/Ybcn generally <2) of felsic volcanic rocks are consistent with formation from post-Archean juvenile crust (Figure 8A; Piercey, 2009, 2011). On petrochemical affinity diagrams for felsic volcanic rocks, the samples plot in the field for Type IV rhyolites and to a lesser extent Type FIIIa rhyolites as defined by Lesher *et al.* (1986) and Hart *et al.* (2004; Figure 8B, C).

On the Nb *vs.* Y plot, the samples cluster close to the boundary between arc-type and ocean-ridge type felsic rocks (Figure 4B), which may indicate mantle or mafic-type (M-type) volcanic arc rocks derived from a mafic substrate (Piercey, 2011). This suggests that these felsic volcanic rocks formed due to shallow (<10 km), low-pressure melting of depleted tholeiitic basalt (Hart *et al.*, 2004). This melting likely occurred during rifting in an intra-oceanic island-arc setting on oceanic crust (Hart *et al.*, 2004), and suggests that they formed in an environment favourable for VMS formation (Hart *et al.*, 2004; Piercey, 2009, 2011).

SEDIMENT LITHOGEOCHEMISTRY

Sedimentary samples collected for geochemical analysis include four variably altered graphitic shales interbedded with, or within 5 m from, massive sulphide horizons or mineralized QFP rhyolites (proximal), one graphitic shale

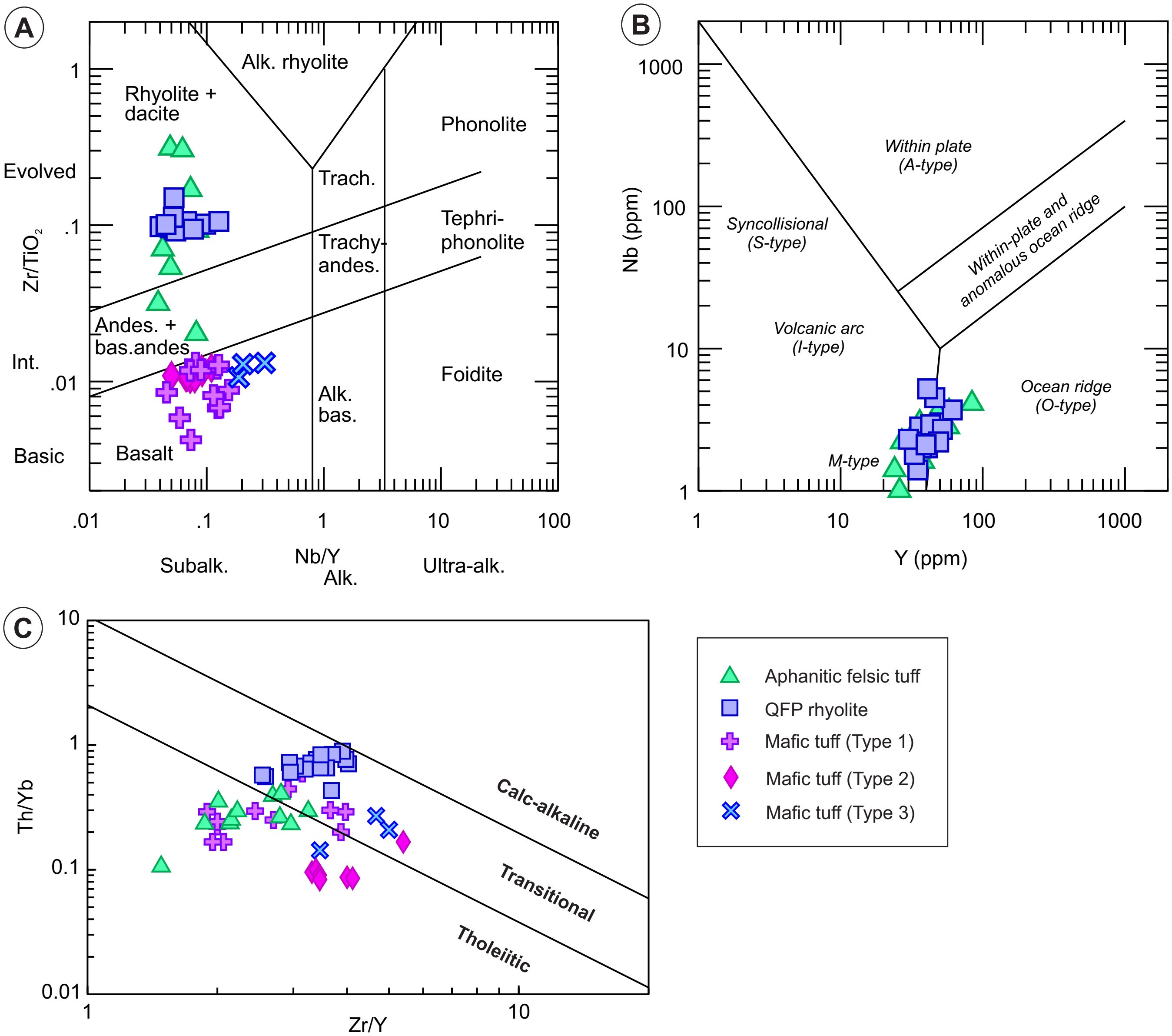

Figure 4. *Immobile-element plots for igneous rocks from the Kettle Pond Formation. A) Zr/TiO_2* vs. *Nb/Y rock discrimination diagram of Pearce (1996), modified after Winchester and Floyd (1977); B) Nb-Y diagram showing M-type affinities of felsic rocks (modified from Piercey, 2009). C) Th/Yb* vs. *Zr/Y magmatic affinity diagram of Ross and Bédard (2009), illustrating the tholeiitic to transitional affinity of igneous rocks.*

interbedded with altered felsic tuff (intermediate), and five mudstones interbedded with mafic to felsic tuffs with no spatial relationship to mineralization (distal).

The post-Archean Australian Shale (PAAS) normalized REE signatures of shales and mudstones are shown in Figure 9. Proximal mudstones are characterized by LREE-depleted signatures (La/Yb PAAS of 0.16 to 0.30), with positive PAAS normalized Eu anomalies (Eu/Eu* PAAS of 1.49 to 2.54) and small negative PAAS normalized Ce anomalies (Ce/Ce* PAAS of 0.76 to 0.90) (Figure 9A, C). The intermediate graphitic shale has a similar REE profile (Figure 9A), with a slightly more pronounced negative Ce anomaly but no positive Eu anomaly. The distal mudstones have variable LREE depletion (La/Yb PAAS of 0.11 to 0.54), but have no Ce anomalies and no, to weakly positive, Eu anomalies (Figure 9B, C).

The positive Eu anomalies in the proximal shales are consistent with precipitation of hydrothermal exhalites from high temperature fluids (>250°C) close to a volcanic vent (Lode *et al.*, 2015; Piercey *et al.*, 2018). The negative Ce

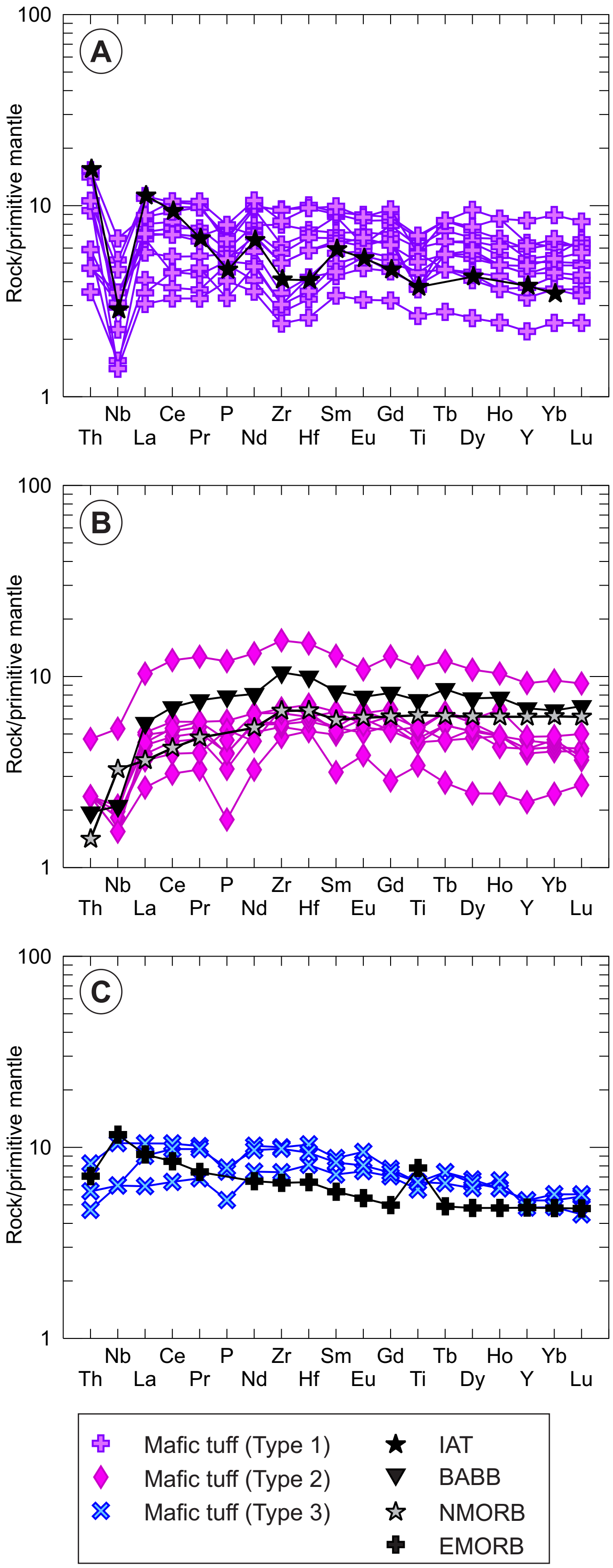

Figure 5. *Primitive mantle normalized extended trace-element plots for mafic tuffs in the Kettle Pond Formation (normalizing values from Sun and McDonough, 1989). Also included are typical primitive-mantle normalized values for island-arc tholeiite (IAT), back-arc basin basalt (BABB), normal mid-ocean ridge basalts (NMORB) and enriched mid-ocean ridge basalts (EMORB). Data from Sun and McDonough (1989), Stoltz* et al. *(1990) and Ewart* et al. *(1994).*

anomalies in these samples provide a proxy for redox conditions, suggesting that hydrothermal fluids were vented in a buoyant plume into an oxygenated water column (Lode *et al.*, 2015; Piercey *et al.*, 2018). This is supported by the elevated Ba content, indicative of barium sulphate (barite), of some proximal shales (up to 21 775 ppm Ba; Figure 9D). The lack of positive Eu and negative Ce anomalies in the distal mudstones suggest that they were deposited away from the active vent sites and/or have been significantly diluted by detrital material.

METAL ASSOCIATIONS

Assay data from mineralized samples in the Rusty Trickle, Glover Island North and Glover Island East areas are shown in Figure 10. Mineralized samples were classified as those that contain >200 ppm combined Zn, Cu and Pb, which included 59 of the 103 samples analyzed during this study. In addition, assay data from 22 samples of mineralized QFP rhyolites and graphitic shale collected in the Rusty Trickle area by Basha *et al.* (2001) were included.

Samples from the Rusty Trickle area have elevated Zn, Cu and Ag contents, with 39% of mineralized samples having >0.5% Zn + Cu and up to 15.6 g/t Ag. These samples show a strong correlation between Zn and Cu contents (Pearson correlation coefficient value of 0.81) and are relatively enriched in Zn with Zn:Cu ratios generally >5 (Figure 10A). Samples from elsewhere on Glover Island have lower total base-metal and Ag contents, with a maximum of 0.17% Zn + Cu and 3.2 g/t Ag. No strong correlation between Zn and Cu contents is observed (Pearson correlation coefficient value of 0.44), but these samples generally have lower Zn:Cu ratios compared to the Rusty Trickle samples (<5; Figure 10A). These samples are also relatively enriched in Co and Ni compared to samples from Rusty Trickle (Figure 10C, D).

ALTERATION

Major-element lithogeochemistry from igneous rocks has long been recognized as an important tool in identifying hydrothermal alteration associated with VMS deposits

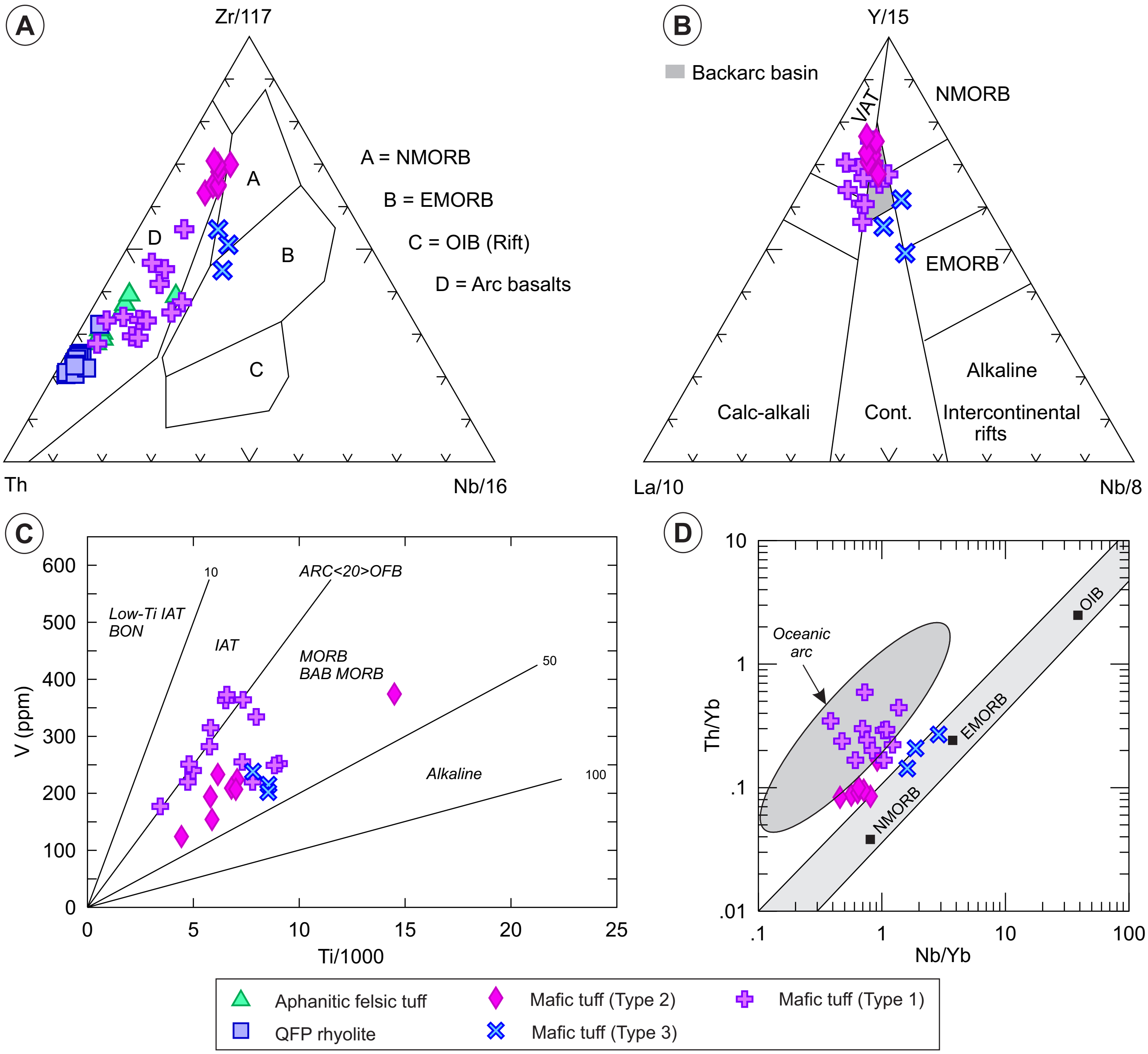

Figure 6. *Trace-element data for igneous rocks plotted on selected tectonic discrimination diagrams, showing petrochemical affinities. A) Th-Zr-Nb discrimination diagram from Wood (1980); B) Y-La-Nb discrimination diagram from Cabanis and Lecolle (1989); C) V* vs. *Ti plot from Shervais (1982); D) Th/Yb* vs. *Nb/Yb crustal input plot (after Pearce, 2008) showing MORB-OIB array and field for oceanic-arc rocks (adapted from Bruckner* et al.*, 2021).*

(Ishikawa *et al.*, 1976; Spitz and Darling, 1978; Large *et al.*, 2001; Piercey, 2009). During hydrothermal alteration, most major elements (except Al, Ti) and LFSE (*e.g.*, Cs, Rb, Ba, Sr) are likely to have been mobile (MacLean, 1988; MacLean and Barrett, 1993), and therefore can be used to identify zones of intense hydrothermal alteration. Similar studies from known VMS deposits in the Canadian Appalachians and globally have shown the applicability of these methods in exploration for these deposit types (*e.g.*, Hollis *et al.*, 2014; Buschette and Piercey, 2016; Cloutier and Piercey, 2020; Sparkes, 2020; Hollis *et al.*, 2021).

Geochemical data from this study have been combined with previously published exploration data from the Rusty Trickle showing (Basha *et al.*, 2001) to assess the hydrothermal alteration of igneous rocks at the Rusty Trickle (Figure 11A, C, E), Glover Island North and Glover Island East showings (Figure 11B, D, F). The QFP rhyolites from Rusty

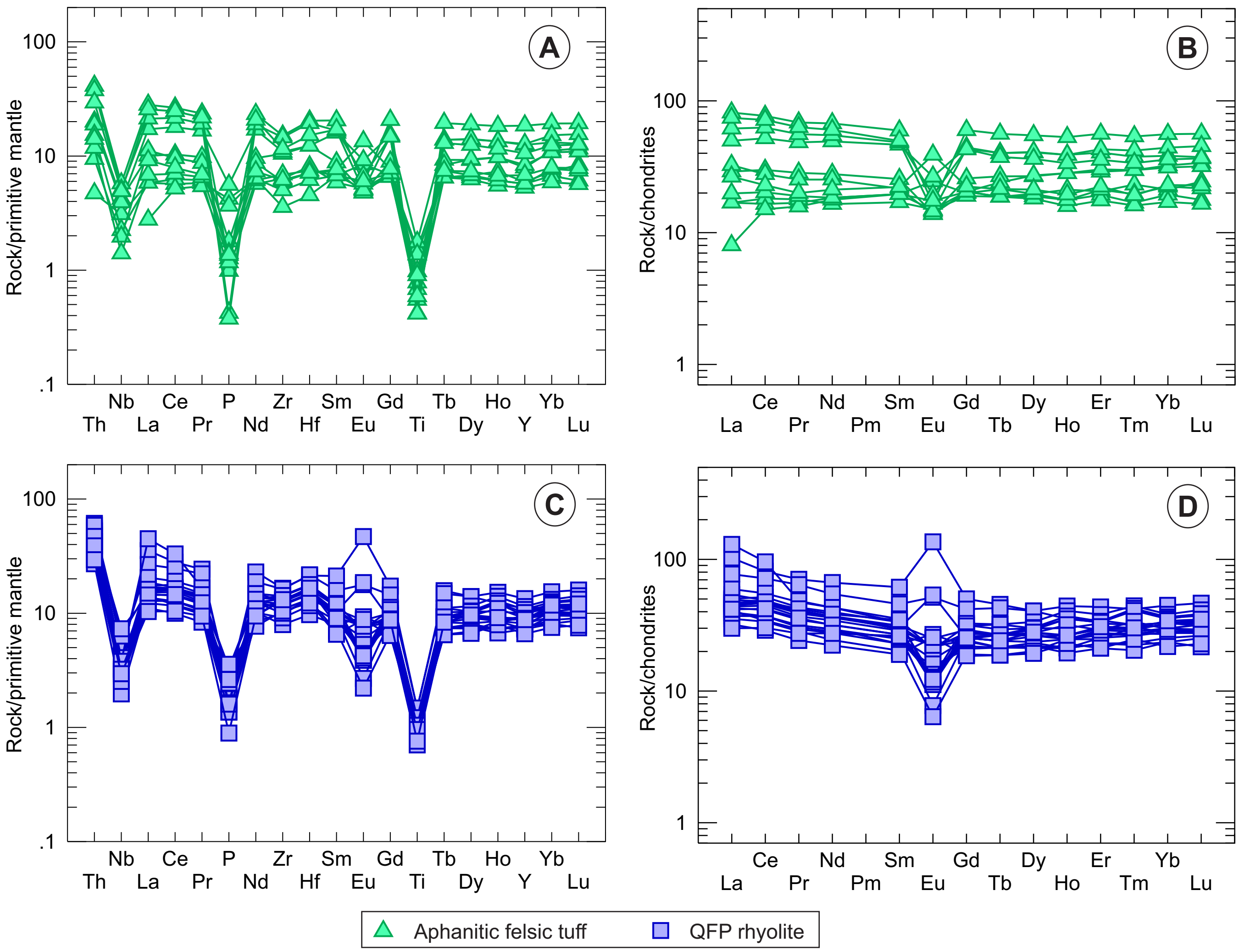

Figure 7. *Primitive mantle normalized extended trace element and chondrite-normalized REE plots for felsic rocks in the Kettle Pond Formation (normalizing values from Sun and McDonough, 1989).*

Trickle show a wide range of Na_2O contents (0.65 to 7.38% Na_2O), with some samples characterized by depleted Na (<2% Na_2O) and high Spitz-Darling index values (Al_2O_3/Na_2O >5; Figure 11A). A variable alteration pattern is seen when QFP rhyolites from Rusty Trickle are plotted on an alteration box plot of Ishikawa index values (AI = 100*(MgO+K_2O)/(MgO+K_2O+CaO+Na_2O); Ishikawa *et al.*, 1976) *vs.* chlorite–carbonate–pyrite index values (CCPI = 100*(MgO+FeO)/(MgO+FeO+K_2O+Na_2O); Large *et al.*, 2001; Figure 11C). These data show that some QFP rhyolites plot in the least altered field for rhyolites, or have low AI and CCPI values and plot close to the albite node, indicating diagenetic albitization (Large *et al.*, 2001). In contrast, more strongly altered QFP rhyolites plot in hydrothermally altered field and trend toward the chlorite–pyrite and sericite nodes (Figure 11C). This is typical of chlorite–sericite–pyrite alteration commonly seen in the footwall of VMS deposits (Large *et al.*, 2001) and is recorded close to mineralization in other VMS alteration systems in central Newfoundland (Buschette and Piercey, 2016; Cloutier and Piercey, 2020; Sparkes, 2020). A similar trend is seen on a plot of AI *vs.* Advanced Argillic Alteration Index values (AAAI = (100*SiO_2)/(SiO_2 + 10MgO + 10CaO + 10Na_2O); Williams and Davidson, 2004). This shows some QFP rhyolites trending toward the albite node and the more strongly altered rocks trending toward the muscovite node indicating robust sericite alteration (Figure 11E).

The geographical distribution of altered QFP rhyolites and correlations with known mineralization at Rusty Trickle is shown in Figure 12. The main mineralized trend is clearly seen with strong enrichments in Zn, Cu and Ag (Figure 12A–C). The mineralized zone correlates with depletion in Na_2O (Figure 12D), elevated MgO, K_2O and Ba contents (Figure 12E, F) and high Ba–Sr ratios and AI values (Figure 12G, H). Mineralized samples also have high Hg contents

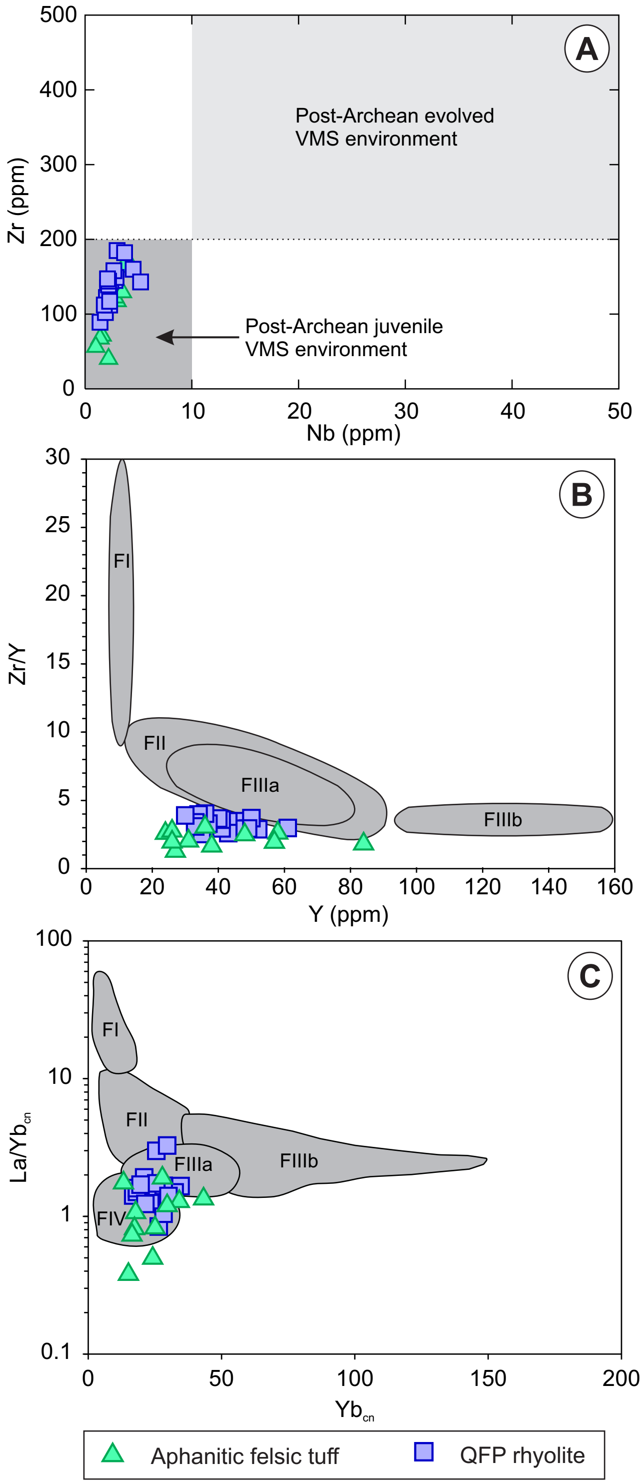

Figure 8. *Trace-element data for felsic rocks plotted on selected discrimination diagrams. A) Nb* vs. *Y tectonic discrimination diagram showing HFSE depletion typical of post-Archean juvenile VMS environments (adapted from Buschette and Piercey, 2016); B) Zr/Y* vs. *Y discrimination diagram of Lesher* et al. *(1986) showing low Zr/Y and Y contents typical of Type IV rhyolites (Hart* et al.*, 2004); C) La/Yb$_{cn}$* vs. *Yb$_{cn}$ showing felsic rocks have FIIIa and FIV affinities (from Lesher* et al.*, 1986; Hart* et al.*, 2004).*

(1650 to 2270 ppb) and high Hg/Na_2O ratios (349 to 2067). These signatures are typical of intense hydrothermal alteration halos and paleo fluid pathways associated with VMS deposits (Buschette and Piercey, 2016; Cloutier and Piercey, 2020).

Geochemical data from the Glover Island North and Glover Island East showings show a much lower degree of hydrothermal alteration. Most samples plot in, or close to, the least altered field on a Spitz-Darling plot (Figure 11B). On plots of AI *vs.* CCPI and AI *vs.* AAAI, the samples predominantly fall in the least altered to diagenetic alteration fields, and trend toward albite alteration (Figure 11D, F). This is consistent with these rocks not undergoing significant hydrothermal alteration related to VMS-mineralization. A similar trend of increased albite alteration is seen in orogenic gold deposits on Glover Island (Conliffe, 2021), indicating that this albitization may be related to hydrothermal fluid flow during gold mineralization, instead of being a diagenetic signature. Two felsic tuffs are depleted in Na (Figure 11B) and plot in the hydrothermally altered fields in an AI *vs.* CCPI diagram (Figure 11D). These samples are a Ba-enriched (11 719 ppm Ba) felsic tuff from Glover Island East and a strongly altered felsic tuff directly below a Zn and Cu enriched massive sulphide at Glover Island North.

SHORT WAVELENGTH INFRARED SPECTROSCOPY

METHODOLOGY

Hyperspectral data were acquired using outcrop samples from the Rusty Trickle showing, collected in 2019 and 2021, using visible/infrared reflectance spectrometry (VIRS) data collected on, and exported from, a TerraSpec® Pro spectrometer. Two to three measurements were taken on each sample to record intra-sample variations. The TerraSpec® Pro spectrometer was optimized every 30 minutes using a white standard reference material to reduce instrument drift. Spectral data was processed using the TSG™ Pro software program (*see* Kerr *et al.*, 2011 for complete details). The software facilitates estimation of the relative proportions of the two most abundant mineral phases within each sample (Min 1 and Min 2) by comparing the spectra to a spectral library in the TSG™ database. The location and depth of characteristic absorption features of SWIR-active alteration minerals were also calculated. These include the Al-OH absorption wavelength of white mica (2190–2225 nm) and the Fe-OH absorption wavelength of chlorite (2245–2265 nm), which are commonly used to track hydrothermal alteration associated with VMS-style mineralization (*e.g.*, Buschette and Piercey, 2016; Sparkes, 2019; Cloutier and Piercey, 2020; Hollis *et al.*, 2021).

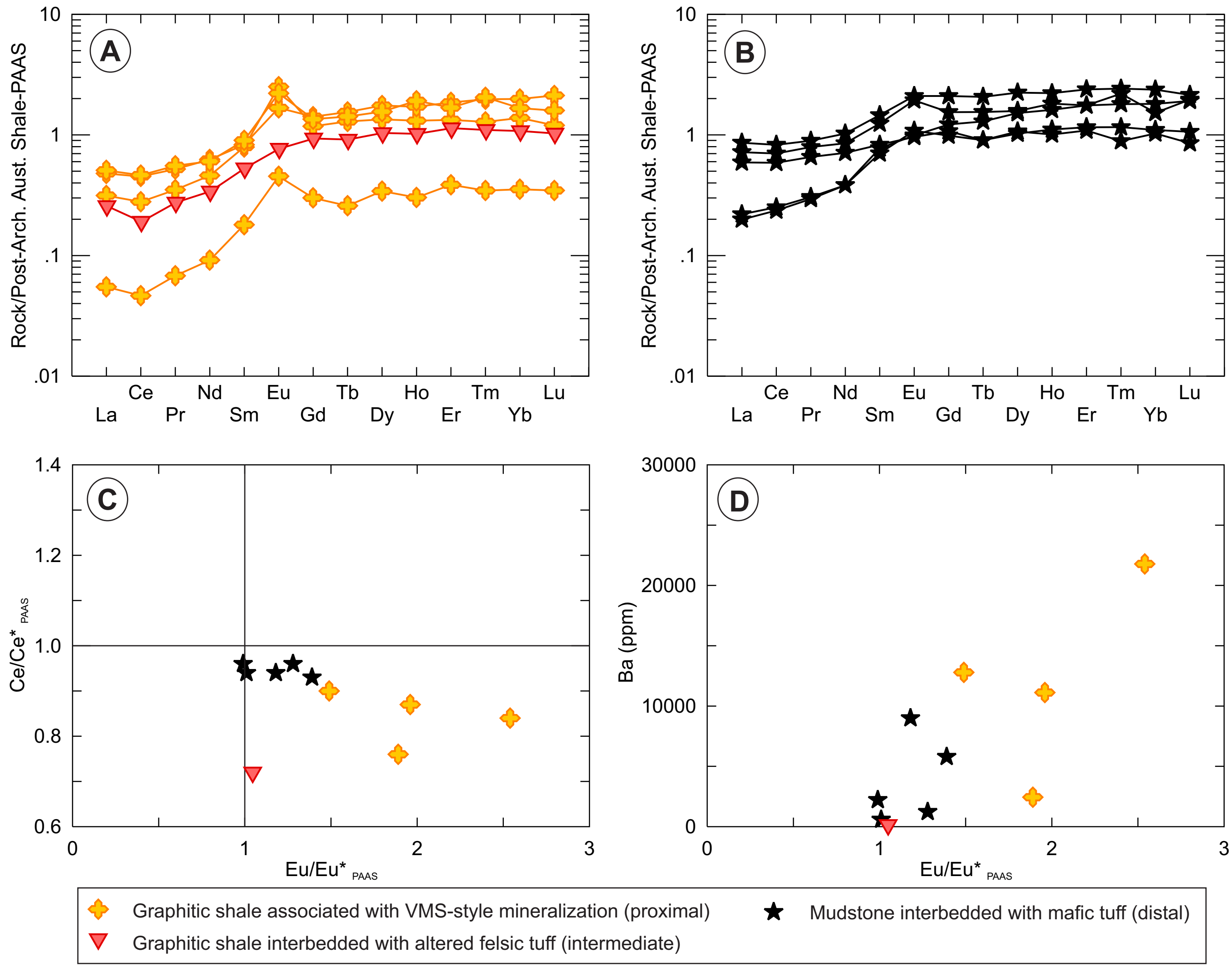

Figure 9. *A) PAAS-normalized REE plot of graphitic shales closely associated with massive sulphides and interbedded with felsic tuffs; B) PAAS-normalized REE plot of mudstones interbedded with mafic tuffs and not spatially associated with mineralization; C) Plot of PAAS-normalized Ce and Eu anomalies in graphitic shales and mudstones; D) Plot of Ba content vs. PAAS-normalized Eu anomalies. Normalizing values from Taylor and McLennan (1985).*

RESULTS

A total of 45 spectral measurements were collected from four unmineralized QFP rhyolites (<100 ppm Zn), nine mineralized QFP rhyolites (>100 ppm Zn) and three mafic tuff samples. The predominant alteration minerals identified in QFP rhyolites are muscovite and phengite, with Mg and Fe–Mg chlorite identified only in some of the mineralized samples. The Fe and Fe–Mg chlorite and minor phengite were the main alteration minerals identified in mafic tuffs.

The diagnostic Al-OH absorption wavelengths of white mica show clear variations in white mica chemistry between unmineralized and mineralized QFP rhyolites, with a shift toward phengitic (>2210 nm) white mica compositions in mineralized samples (Figure 13A). Mineralized samples are also characterized by a decrease in the depth of the Al-OH absorption wavelength feature (Figure 13A) and an increase in illite spectral maturity (Doublier *et al.*, 2010) or ISM (H_2O) compared to unmineralized samples (Figure 13B). This indicates that white mica in mineralized samples are more crystalline and formed at higher temperatures than white mica in the unmineralized samples. The increase in Al-OH absorption wavelengths in mineralized samples also corresponds to geochemical characteristics diagnostic of intense hydrothermal alteration (Figure 12I).

The Fe-OH absorption wavelength in chlorite at ~2250 nm shows a variation between chlorites, in unmineralized mafic tuffs and in hydrothermally altered and mineralized

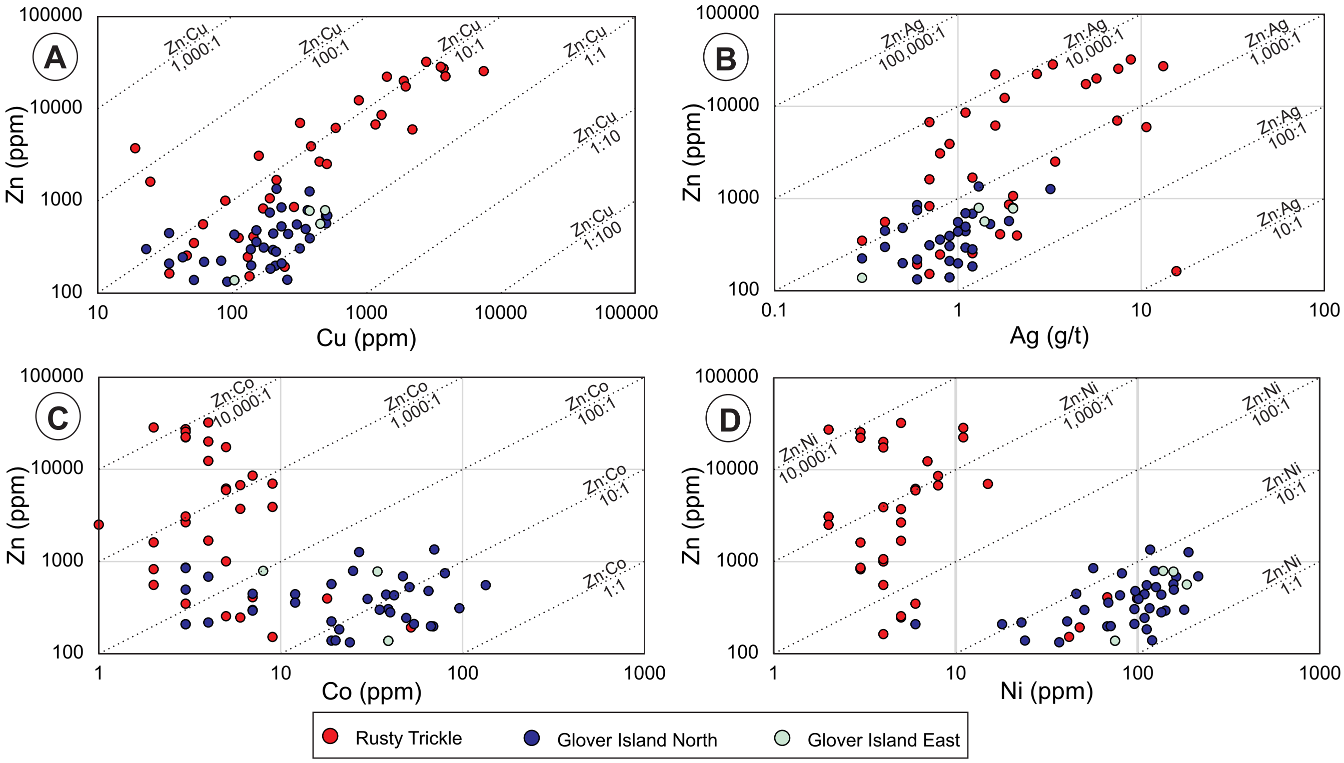

Figure 10. *Log-log plots showing correlations between zinc and selected trace elements from the Rusty Trickle, Glover Island North and Glover Island East areas (data from this study and Basha* et al.*, 2001).*

QFP rhyolites. Mafic tuffs show Fe-OH absorption wavelength positions from 2254.6 to 2255.9 nm, whereas mineralized QFP rhyolites show a slight shift to more Mg-rich chlorite with Fe-OH absorption wavelengths of 2249.4 to 2253 nm (Figure 13C). This shift corresponds to a decrease in the depth of the Fe-OH absorption wavelength feature in mineralized QFP rhyolites.

The progressive shift to higher Al-OH absorption wavelengths in white mica and lower Fe-OH absorption wavelength in chlorite, observed in mineralized QFP rhyolites at Rusty Trickle, is consistent with intense hydrothermal alteration during mineralization. Similar trends have been observed in other VMS deposits in central Newfoundland, including the Lemarchant Deposit (Cloutier and Piercey, 2020) and the Boundary Deposit (Buschette and Piercey, 2016).

SUMMARY AND CONCLUSIONS

The Kettle Pond Formation on Glover Island consists of a basal, clast to matrix-supported polymictic conglomerate overlain by a series of interbedded mafic to felsic tuffs interlayered with numerous thin (<2 m) massive sulphides, black shales, and synvolcanic exhalative units. It is host to a number of VMS-style mineral occurrences, including the Rusty Trickle, Glover Island North and Glover Island East showings. Detailed geological, petrographic and geochemical investigations have identified several features that are important in determining the prospectivity of the Kettle Pond Formation to host significant VMS-style mineral deposits. These include:

- Regional airborne geophysical surveys have identified discrete EM anomalies in the Kettle Pond Formation, which are located at, or close to, areas of known VMS-style mineralization.

- Mafic tuff units have variable geochemical characteristics, ranging from island-arc tholeiite to MORB signatures. This intimate association of island-arc and rift-related mafic volcanism is consistent with development of a juvenile oceanic island volcanic arc with episodic intra-arc rifting; an environment favourable for the development of VMS deposits (Franklin *et al.*, 2005; Piercey, 2009; Hollis *et al.*, 2014).

- Aphanitic felsic tuffs and QFP rhyolites have tholeiitic affinities and geochemical characteristics typical of FIV rhyolites (*e.g.*, low Zr, Nb and La/Yb_{cn}). Geochemically similar tholeiitic Type FIV rhyolites are commonly associated with mineralization in post-Archean mafic-dominated (primitive) VMS environments (Hart *et al.*, 2004; Piercey, 2009, 2011). They are interpreted to have

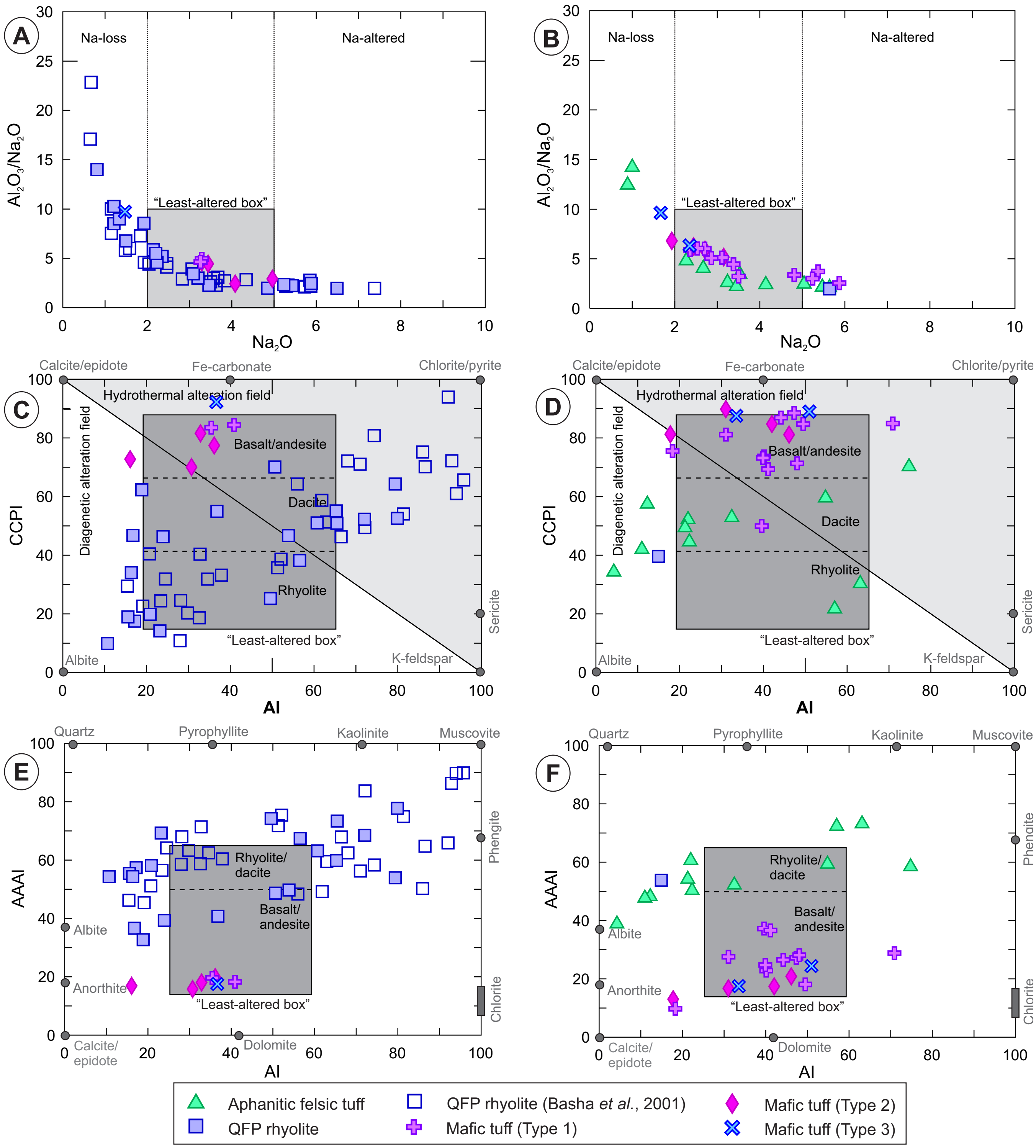

Figure 11. *Mobile-element plots for geochemical samples from the Kettle Pond Formation (data from this study and Basha* et al., *2001). A) Al_2O_3/Na_2O* vs. *Na_2O plot of samples from the Rusty Trickle area, with designations for least altered samples (modified from Spitz and Darling 1978); B) Al_2O_3/Na_2O* vs. *Na_2O plot of samples from the Glover Island North and Glover Island East areas; C) CCPI* vs. *AI alteration boxplot (adapted from Large* et al., *2001) with data from samples from the Rusty Trickle area; D) CCPI* vs. *AI alteration boxplot (adapted from Large* et al., *2001) with data from samples from the Glover Island North and Glover Island East areas; E) AAAI* vs. *AI alteration boxplot (adapted from Williams and Davidson, 2004 and Hollis* et al., *2021) with data from samples from the Rusty Trickle area; F) AAAI* vs. *AI alteration boxplot (adapted from Williams and Davidson, 2004 and Hollis* et al., *2021) with data from samples from the Glover Island North and Glover Island East areas.*

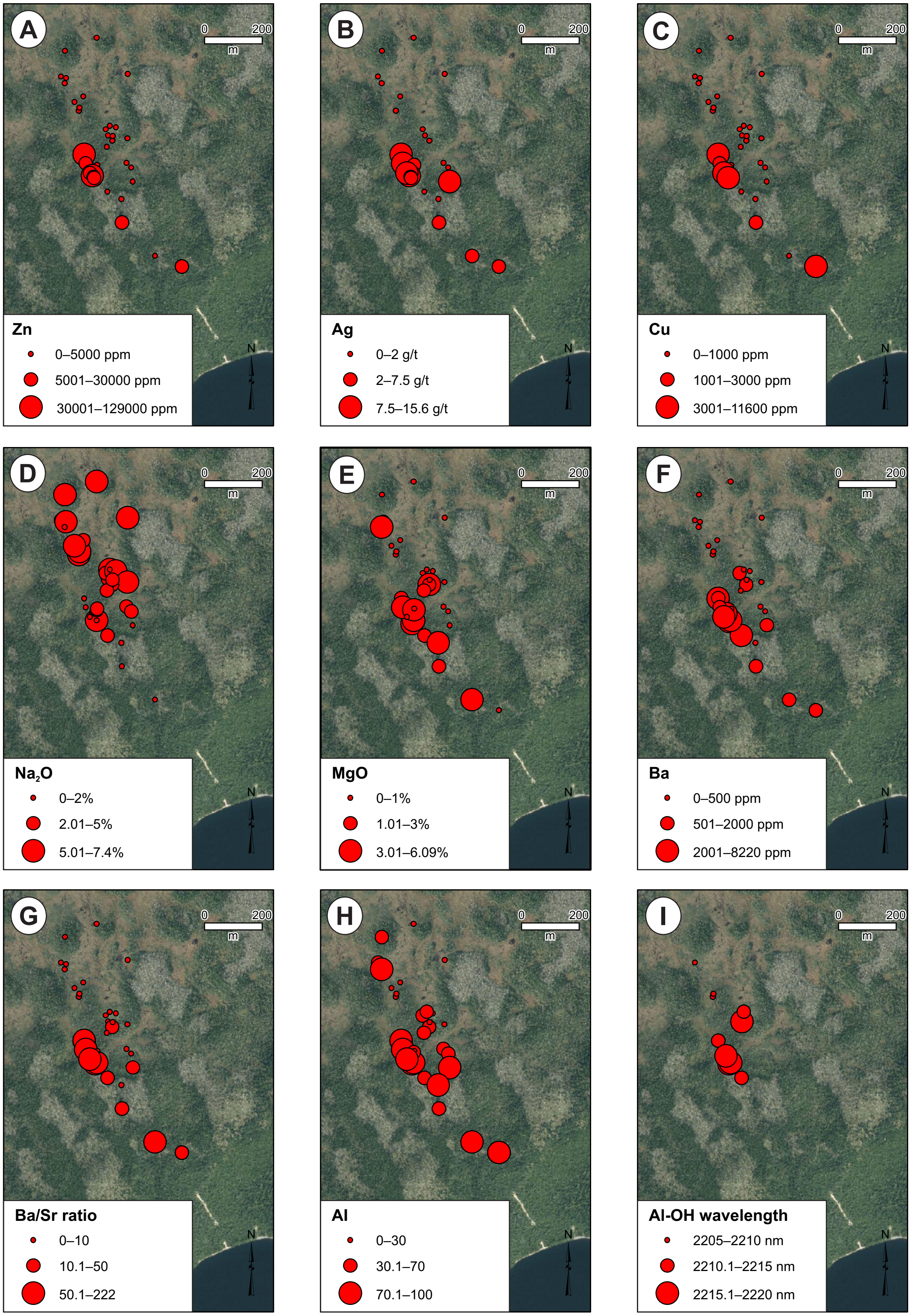

Figure 12. *Aerial photos of the Rusty Trickle area showing distribution of select metals (Zn, Ag, Cu), mobile major and trace elements (Na_2O, MgO, Ba), alteration indices (Ba/Sr, AI) and frequency of the Al-OH wavelength of white mica.* See *text for details.*

formed *via* crustal melting of basaltic material at shallow levels (<10 km), and these melts may have been an important heat source for driving hydrothermal circulation (Piercey, 2009).

- Sulphide-bearing black shales associated with VMS-style mineralization in the Kettle Pond Formation are characterized by high base-metal and Ba contents and strong positive Eu and negative Ce anomalies, compared to mudstones distal from mineralization. The geochemical signature of these mudstones is similar to vent-proximal mudstones at other VMS deposits (*e.g.*, Lemarchant Deposit; Lode *et al.*, 2015) and suggests that they precipitated from reduced high-temperature (>250°C) fluids vented into an oxygenated water column.

- Stringer-style Zn–Cu–Ag mineralization at Rusty Trickle is spatially associated with an alteration zone characterized by depletion in Na_2O, enrichment in K_2O, MgO, Ba and Hg, and elevated Ba/Sr, Hg/Na_2O, AI and CCPI values. The SWIR data show that compositions of white mica in the alteration zone shift more toward phengitic compositions (Al-OH absorption wavelengths >2210 nm) and chlorites have a Mg-rich composition with Fe-OH absorption wavelengths shorter than 2252 nm. Similar alteration patterns have been observed around other VMS deposits in central Newfoundland, and are attributed to intense alteration during the circulation of hydrothermal fluids (Buschette and Piercey, 2016; Cloutier and Piercey, 2020).

The metal content (Zn>Cu, high Ag) and geological setting (felsic rock-hosted mineralization in a thick package of dominantly mafic volcanic rocks) of VMS-style mineralization at Rusty Trickle is typical of bimodal mafic VMS deposit group (Galley *et al.*, 2007; Piercey *et al.*, 2015). Although no economic VMS-type mineralization has been recognized on Glover Island, this study has shown that the Kettle Pond Formation has geochemical characteristics favourable for the formation of VMS-style mineralization. The recognition of stringer-style Zn–Cu–Ag mineralization in a zone of intense VMS-style hydrothermal alteration at Rusty Trickle, highlights the potential of this area, which may warrant further exploration.

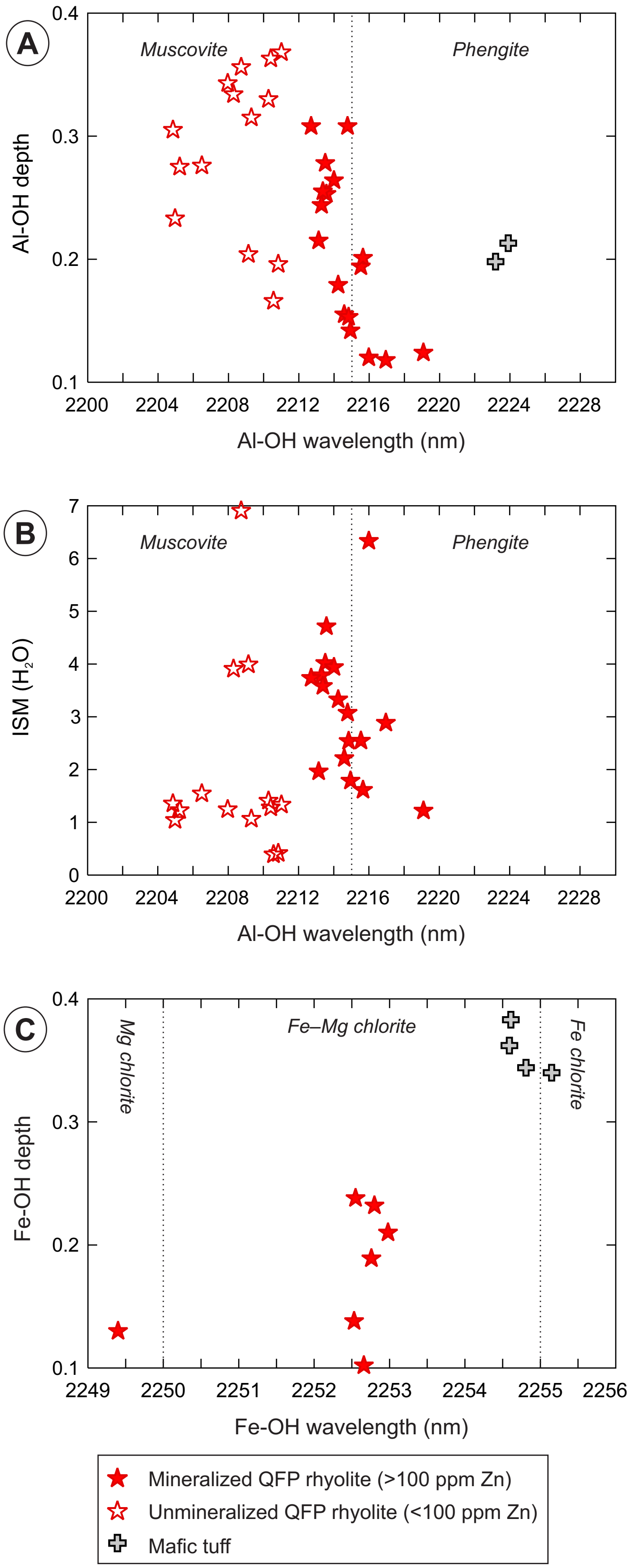

Figure 13. *SWIR data from outcrop samples in the Rusty Trickle area. Mineral species thresholds from Cloutier and Piercey (2020). A) Al-OH wavelength absorption (nm) vs. depth of Al-OH feature in white mica; B) Al-OH wavelength absorption (nm) vs. illite spectral maturity in white mica. C) Fe-OH wavelength absorption (nm) vs. depth of Fe-OH feature in chlorite.*

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