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PETROLOGY AND GEOCHEMISTRY OF THE MONTGOMERY LAKE SHOWING: EVIDENCE OF IOCG-TYPE MINERALIZATION IN THE EASTERN LABRADOR TROUGH

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ABSTRACT

The Montgomery Lake Cu–Au showing is located in the Andre Lake map area (NTS 23I/12) in the eastern part of the Labrador Trough, where trenching and diamond drilling have recognized low-grade Cu and Au mineralization in strongly altered and brecciated graphitic shales of the Menihek Formation. Mineralization is associated with a zone of intense metasomatic alteration that occurs for >1.5 km in a linear belt parallel to the Walsh Lake Fault, a major crustal structure in the Labrador Trough. The mineralized zones are best exposed in a series of trenches, but similar mineralization has been recorded along the alteration trend.

Two generations of alteration are recognized. An early, widespread-scale alteration is characterized by almost complete albitization and silicification of the host shales and siltstones. This early alteration is synchronous with peak deformation during the New Québec Orogen but is not associated with any significant enrichment in Cu or Au. The second phase of alteration is associated with fracturing and hydrothermal brecciation of previously altered units, with fragments of quartz–albite in a matrix of carbonate–quartz–albite–chalcopyrite–pyrrhotite. This later alteration is associated with the main mineralization phase, in which hydrothermal breccias is significantly enriched in Cu, Au and Ag.

*The Montgomery Lake Cu–Au showing displays many features typical of Iron-Sulphide Copper Gold (ISCG) deposits, a group with strong affinities to Iron-Oxide Copper Gold (IOCG) deposits. These include: 1) early Na-metasomatism, overprinted by a later mineralizing event; 2) location of mineralization close to a major crustal structure (Walsh Lake Fault); 3) graphite-bearing host rocks that inhibit formation of magnetite-rich IOCG deposits; 4) association of mineralization with brecciation; and 5) identification of hypersaline, halite-bearing fluid inclusions. The ISCG deposits are typically spatially and temporally associated with magnetite-group IOCG mineral deposits (*e.g., *Cloncurry District); hence the identification of ISCG-style mineralization at Montgomery Lake may have wider implications for exploration in this part of the Labrador Trough.*

INTRODUCTION

The Montgomery Lake Cu–Au showing is located in the eastern part of the Labrador Trough, approximately 80 km east of the town of Schefferville, Québec (NTS map sheet 23I/12). It is hosted in metasedimentary and metavolcanic rocks of the Kaniapiskau Supergroup, which were deposited on the margin of the Superior Craton in the Paleoproterozoic, and subsequently deformed during the New Québec Orogeny. The Montgomery Lake showing was first discovered in the 1940s, but has only been the subject of sporadic and limited exploration since then (Moss, 1942; Love, 1967; Labonté *et al.*, 2009). Mineralization occurs in a zone of intense metasomatism that can be traced for more than 1.5 km. Swinden and Santaguida (1995) tentatively suggested that the Montgomery Lake showing represented orogenic-gold type mineralization. However, this genetic model does not explain many unusual features of the occurrence and the associated metasomatic alteration; hence this study was initiated to develop a more detailed genetic model.

The Geological Survey of Newfoundland and Labrador visited the Montgomery Lake showing in 2013, 2017 and 2018 as part of a regional study of the metallogenic evolution of the Labrador Trough (Smith *et al.*, 2018; Conliffe *et al.*, 2019). This report presents the results of field observations, as well as petrographic and geochemical studies of samples collected during this fieldwork. The aim of this work was to better characterize the alteration and mineralization styles at Montgomery Lake, and to compare it to other mineralization, hosted in zones of intense metasomatism, elsewhere in the Labrador Trough (*e.g.*, Romanet Horst, Corriveau *et al.*, 2014), as well as to global examples of Iron-Sulphide Copper Gold (ISCG) mineralization (*e.g.*, Cloncurry District, Australia, Mark *et al.*, 2006). This is followed by a short, critical discussion on the regional implications, including the potential of the Montgomery Lake and Andre Lake areas to host Iron-Oxide Copper Gold (IOCG) and affiliated deposit types.

REGIONAL SETTING

The Montgomery Lake area is located in the hinterland of the New Québec Orogen. The geology consists of a series of Paleoproterozoic supracrustal sedimentary and volcanic units formed on the margin of the Superior continent during initial rifting at ~2.17 Ga (Rohan *et al.*, 1993), and during the subsequent development of a long-lived marginal marine basin (Wardle and Bailey, 1981; Le Gallais and Lavoie, 1982; Clark and Wares, 2005). These supracrustal units are collectively known as the Kaniapiskau Supergroup (Wardle and Bailey, 1981; Le Gallais and Lavoie, 1982; Clark and Wares, 2005), and have traditionally been subdivided into three distinct cycles of sedimentation and volcanism separated by unconformities (Frarey and Duffell, 1964; Clark and Wares, 2005). However, Clark *et al.* (2006) showed continuous sedimentation occurred between Cycle 1 and Cycle 2, and therefore, the Kaniapiskau Supergroup can instead be subdivided into early rift-related sediments (Seward Group), passive margin to shallow-marine sediments (Swampy Bay, Attikamagen and Ferriman groups in western Labrador) and associated deeper water equivalents (Doublet Group), and foreland basin sedimentation and flysch related to the development of the New Québec Orogen (Rachel-Laporte Group and Tamarack River Formation). Recent detrital zircon data from the Menihek Formation at the top of the Ferriman Group indicate that it may also, in part, be related to sedimentation in a foreland basin (Corrigan *et al.*, 2019).

There are at least two main phases of magmatic activity; a ~2.17–2.14 Ga event associated with initial rifting and voluminous mafic magmatism (Wardle and Bailey, 1981; Rohan *et al.*, 1993), and a later phase of igneous activity from ~1.88 to 1.87 Ga (Findlay *et al.*, 1995; Bleeker and Kamo, 2018). This later phase of igneous activity includes gabbro sills of the Gerido Intrusive Suite (formerly Montagnais Gabbro; Bilodeau and Caron-Côté, 2018), as well as the mafic to intermediate volcanic and volcanoclastic rocks of the Nimish Formation (Findlay *et al.*, 1995). In the study area, all units of the Kaniapiskau Supergroup were deformed during the New Québec Orogen, recording the oblique convergence and collision of the Archean Superior Craton to the west and the Archean to Paleoproterozoic Core Zone to the east at between 1.82 to 1.77 Ga, during the Trans-Hudson Orogeny (Wardle *et al.*, 1990, 2002).

Recent 1:50 000-scale bedrock mapping of the Andre Lake map area has broadly subdivided the region into three lithotectonic zones, separated by west-verging thrust faults (Butler, 2019; Figure 1). The western zone consists of a sequence of supracrustal rocks of the Kaniapiskau Supergroup (Swampy Bay, Attikamagen and Ferriman groups) and is separated from the central zone by the Mina Lake Fault in the south and the Quartzite Lake Fault in the north (Butler, 2019). The central zone is underlain by generally north–south-striking rocks of the Kaniapiskau Supergroup, which form a north-plunging anticline (Snelgrove Lake Anticline, Wardle, 1979; Butler, 2019). The Snelgrove Lake Basement Complex (SLBC), comprising Archean orthogneiss with a margin of undeformed granite, is located in the centre of the anticline (Wardle, 1979; Butler, 2019). The SLBC is flanked to the west by rocks of the Seward, Swampy Bay and Attikamagen groups, with the contact between the SLBC and supracrustal rocks marked by a steeply dipping thrust (Wade Lake Fault). On its eastern margin, the SLBC is separated from the Seward Group by an inferred east-dipping thrust (Quartzite Lake Fault), with the Seward Group overlain by rocks of the Swampy Bay, Attikamagen and Ferriman groups. In the northern part of the central zone, rocks of the Ferriman Group are separated from deeper water sedimentary and volcanic rocks of the Doublet Group by the Walsh Lake Fault (Butler, 2019), a major thrust fault that can be traced for 100s of km to the north (Clark and Wares, 2005). Metamorphic grades of the Kaniapiskau Supergroup rocks in the central zone generally reached greenschist facies, with lower amphibolite-facies metamorphism recorded along the eastern edge of the SLBC (Butler, 2019). The Montgomery Lake showing and other areas discussed in this paper are located in the central zone. The eastern zone, which is separated from the central zone by the Ashuanipi River shear zone, consists of Archean orthogneiss and Paleoproterozoic tonalities of the MacKenzie River domain (James *et al.*, 1996; Butler, 2019).

PREVIOUS WORK

The Montgomery Lake showing was discovered in 1942 during regional geological mapping and prospecting by Labrador Mining and Exploration (LM&E; Moss, 1942). Mineralization was exposed in a number of trenches, with samples averaging 0.53% Cu and 0.6 g/t Au (80 samples, Moss, 1942). Two short (<60 m) diamond-drill holes were collared close to the trenches but failed to intersect similar mineralization at depth (Murdock and Moss, 1944). Subsequent soil and geophysical surveys (EM, magnetics, gravity and seismic) over the Montgomery Lake showing identified a number of additional anomalies (Crichton and Macpherson, 1959; Hogg, 1964). In 1966, follow-up geochemical and geophysical surveys expanded these anomalies, and 11 drillholes (totalling 1255 m) were completed in

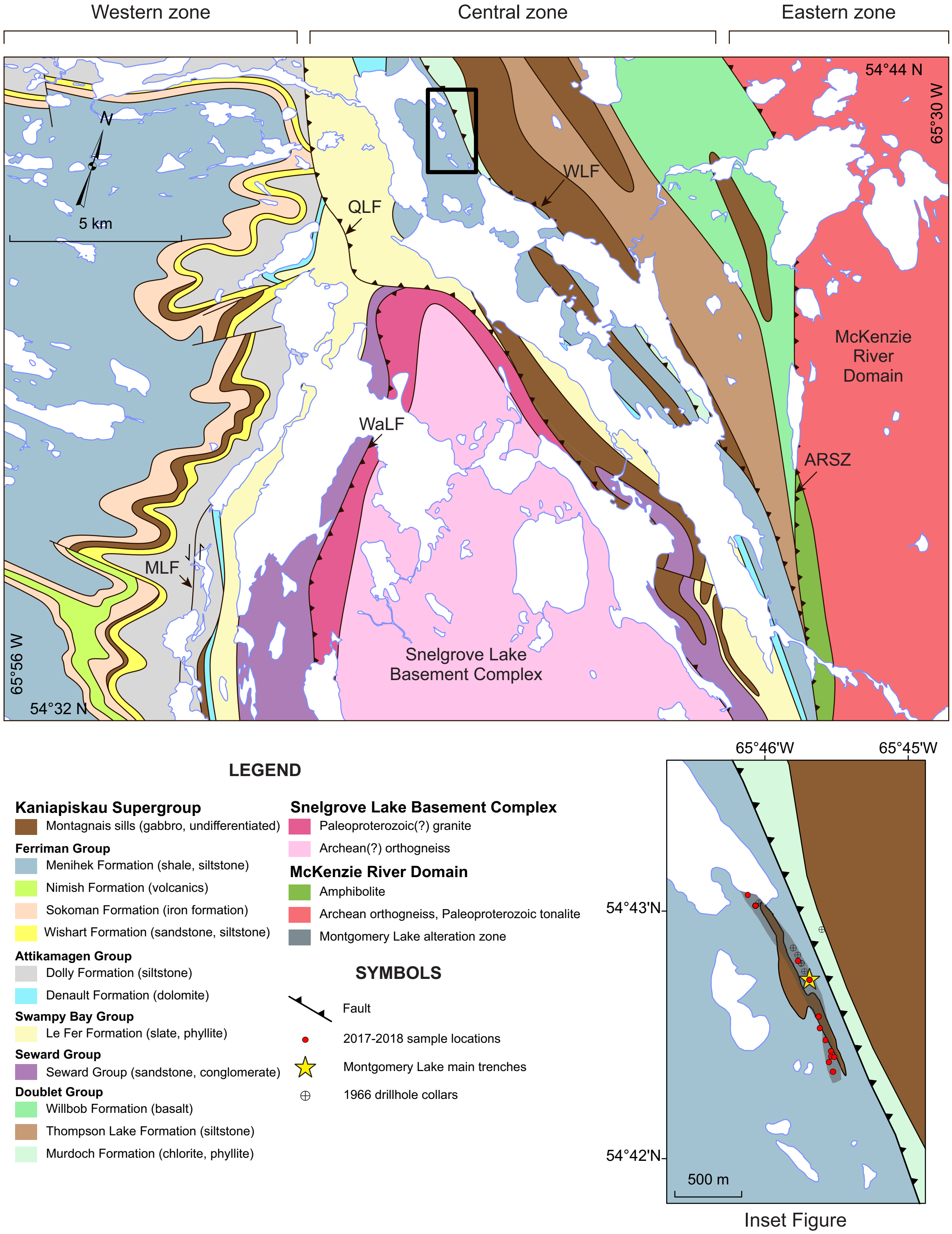

Figure 1. *Geological map of the Andre Lake map area (NTS 23I/12), adapted from Butler (2019). Inset map shows detailed geology of the Montgomery Lake area, including outline of the alteration trend, historic drillhole collars and location of the main showing and samples collected in 2013, 2017 and 2018. ARSZ=Ashuanipi River shear zone; MLF=Mina Lake Fault; QLF=Quartzite Lake Fault; WaLF=Wade Lake Fault; WLF=Walsh Lake Fault.*

the area of the showing (Love, 1967). Multiple drillholes encountered similar mineralization and alteration to that recorded in the trenches, with assays of 0.31% Cu over 14.5 m, 0.17% Cu over 25.5 m, 0.12% Cu over 36.1 m, 1.0 g/t Au over 1.5 m and 9.2 g/t Ag over 1.5 m (Love, 1967). No further work on the Montgomery Lake showing was carried out by LM&E.

In the early 1990s, the Geological Survey of Newfoundland and Labrador conducted regional metallogenic studies throughout the eastern Labrador Trough, with particular emphasis on known occurrences (Swinden, 1991). Based on this work, Swinden and Santaguida (1995) produced a report on the Montgomery Lake showing, including detailed trench maps and lithogeochemical studies. These authors concluded that the Montgomery Lake showing occurred within a zone of strongly metasomatised rocks, and suggested that the mineralization may represent an orogenic gold-type deposit. Further exploration in the Montgomery Lake area in the 2000s showed that this zone of metasomatised rocks continues along strike from the main showing for more than 1 km, and the altered host rocks are locally brecciated (Labonté *et al.*, 2009; Labonté and Kieley, 2009).

Most other base-metal exploration in the eastern Labrador Trough focused on syngeneic VMS-type sediment hosted mineralization (*e.g.*, Martin Lake showing) or Ni–Cu–PGE mineralization in gabbro sills (*e.g.*, Frederickson Lake showing). However, exploration by LM&E in the Andre Lake area identified a number of other, unclassified mineral occurrences. At the southern end of Andre Lake, two sulphide occurrences are reported in altered and brecciated shales close to the contact with gabbro sills (Kozela, 1960). Diamond drilling of EM anomalies identified in this area intersected similar mineralization having strongly altered and brecciated sulphide-rich zones (up to 90% sulphides over 10 m) and up to 0.17% Cu over 9.75 m (Love, 1961). Drilling of magnetic anomalies on Andre Island encountered strong potassic (biotite) alteration in strongly deformed and sheared sedimentary and volcanic units, with abundant magnetite and pyrrhotite, and minor Cu mineralization (Hogg, 1968). Prospecting along the shores of Andre Lake and Montgomery Lake has identified numerous Cu-enriched boulders (Labonté *et al.*, 2009), and an interpretation of a recent airborne magnetic and radiometric survey has identified a number of high priority base-metal and uranium targets close to known copper occurrences (Labonté and Kieley, 2009).

LOCAL GEOLOGY

The Montgomery Lake showing, located immediately west of the Walsh Lake Fault (Figure 1; Swinden and Santaguida, 1995), is hosted by shales and siltstones of the Menihek Formation, which is locally intruded by gabbros of the Gerido Intrusive Suite. Due to the pervasive intense alteration surrounding the mineralized zone, the host rocks types are often difficult to determine. The following descriptions are based on the least altered units in the Montgomery Lake area, as well as unaltered rock types along strike.

The Menihek Formation consists of thin-bedded shales and siltstones (Plate 1A), that were deposited in a shallow-water environment (Wardle, 1979). In the Montgomery Lake area, the Menihek Formation shales are commonly highly graphitic, particularly where shale layers are interbedded with altered and mineralized zones (Love, 1967). The gabbro sills are fine to medium grained and have subophitic textures. Love (1967), and Swinden and Santaguida (1995) demonstrated that the Montgomery Lake showing was located in a high-strain zone, apparently related to the Walsh Lake Fault. In places the rocks have a mylonitic texture, and two generations of folding have been recorded: an early generation of flat-lying recumbent folds that are refolded by later upright, asymmetric, west-verging folds with steep western and shallow eastern limbs (Swinden and Santaguida, 1995).

ALTERATION AND MINERALIZATION

The following description of alteration and mineralization in the Montgomery Lake area are based on field observations, hand-sample descriptions, petrographic analysis of 21 thin sections and short wavelength infrared (SWIR) spectral data (*see* Sparkes, 2019) from samples along the alteration zone.

A zone of intense metasomatic alteration overprints the regional greenschist metamorphism, and has been traced for more than 1.5 km, southeast, along strike, from the southern shore of Montgomery Lake to ~700 m south of the trenches at the Montgomery Lake showing (Figure 1). The alteration zone is approximately 100–200-m wide, and is locally observed to be in sharp contact with unaltered shales and gabbros, and the alteration locally crosscutting bedding (Plate 1B). Quartz veins are rare except at the margins of the alteration zone where numerous small quartz veins are observed extending into relatively unaltered shales (Plate 1B).

The alteration zone is characterized by widespread and pervasive albitization, silicification and carbonitization, with the Menihek Formation shales completely altered to fine-grained quartz, albite and carbonate (Plate 2A, B) as well as minor muscovite and phengite (identified by SWIR analysis). Relict bedding is observed in places, and the altered shales have a beige to pale pink appearance (Plate 1C). The altered shales commonly have 1–5% disseminated

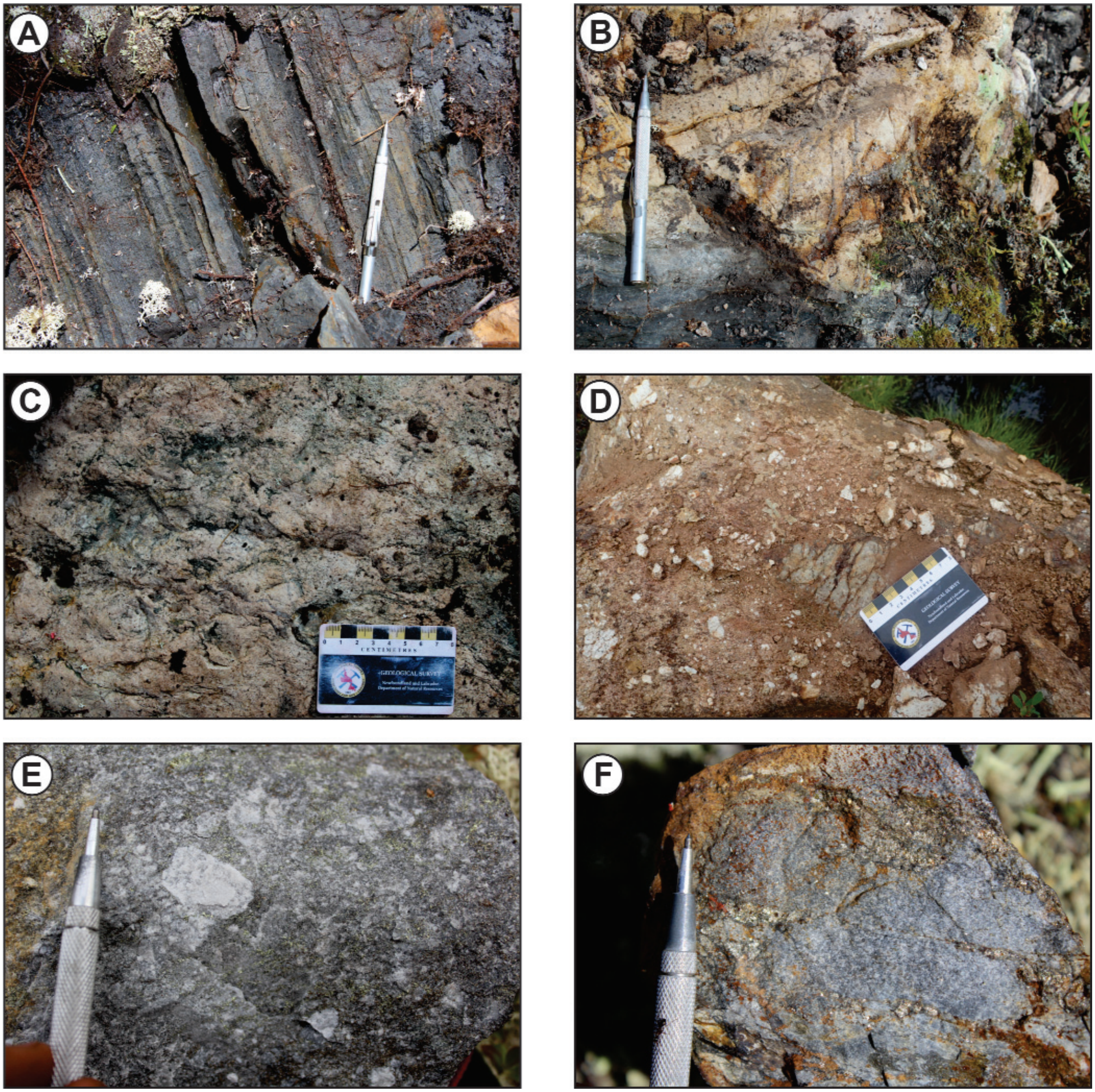

Plate 1. *Selected photographs from fieldwork in the Montgomery Lake area. A) Unaltered graphitic shales of the Menihek Formation; B) Contact between unaltered shales and albitized Menihek Formation, with minor quartz veining; C) Intensely metasomatized (albitized and silicified) Menihek Formation Shale; D) Hydrothermal breccia with angular fragments of albitized shale in fine-grained matrix (from mineralized boulders south of Montgomery Lake); E) Mineralized breccia with subrounded fragments of albitized shale in matrix of dolomite, albite and chalcopyrite (from main Montgomery Lake showing); F) Albitized shale cut by veinlets of pyrrhotite and carbonate.*

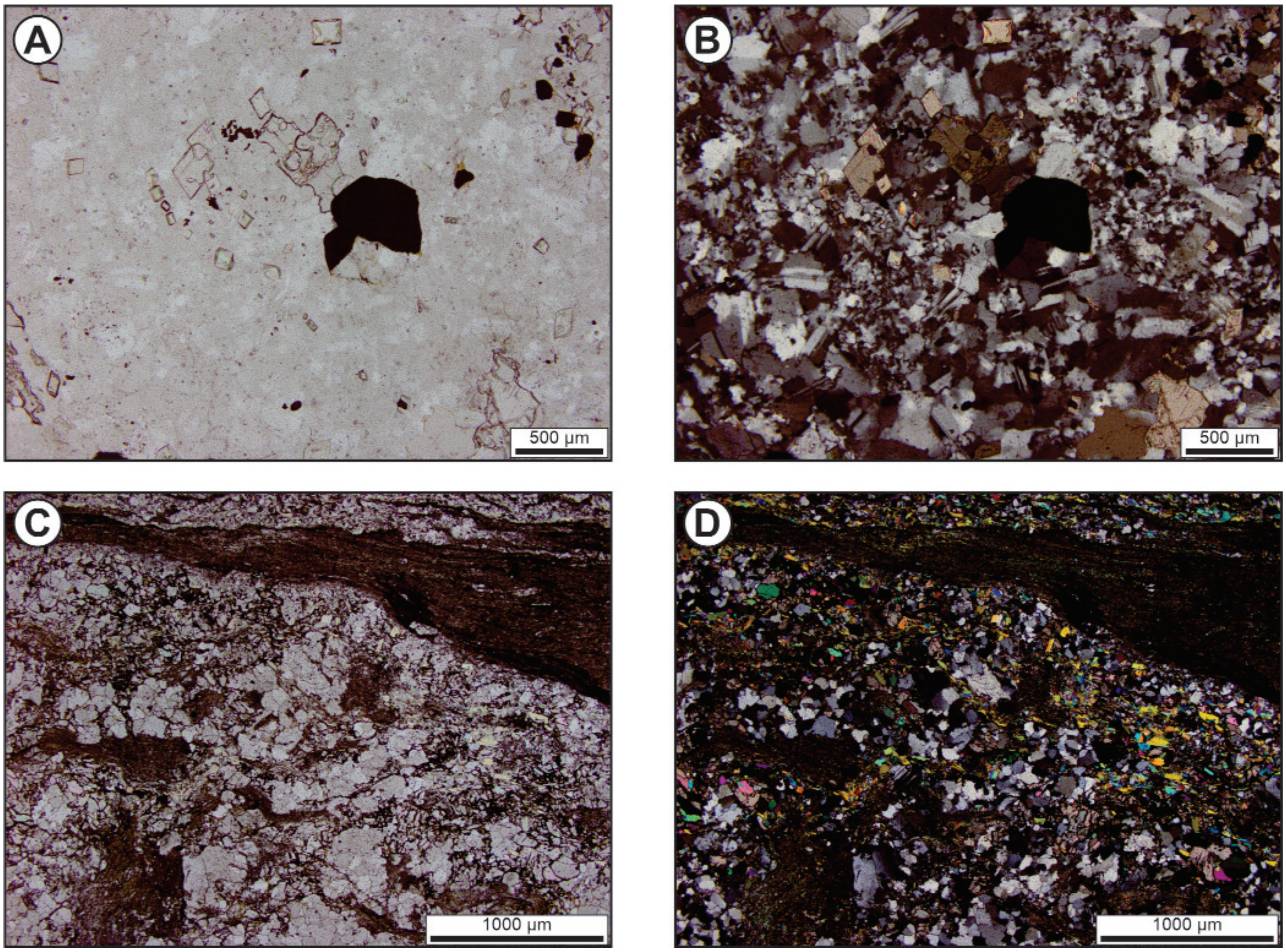

Plate 2. *Photomicrographs of altered samples from Montgomery Lake area. A) Albitized shale with fine-grained albite, quartz and carbonate and disseminated pyrrhotite (plane-polarized light, sample 17JC107A01); B) Same view as A, in cross-polarized light; C) Altered shale with fine-grained muscovite/phengite layer (plane-polarized light, sample 17JC110C01); D) Same view as C, in cross-polarized light.*

pyrite and pyrrhotite, minor hematite in some samples, and trace chalcopyrite. Localized sericitization of the shale units is also observed, with up to 50% muscovite and phengite (Plate 2C, D). Alteration of the gabbro sills is generally less pervasive, with the altered gabbros comprising fine-grained quartz, biotite, chlorite and Fe-carbonate and 1–10% pyrrhotite (trace chalcopyrite).

Copper mineralization has been recorded from a number of locations along the alteration trend. In the main trenches (Figure 1), mineralized rock containing up to 10% chalcopyrite has been recorded (*see* Swinden and Santaguida (1995) for a detailed trench map). Similar mineralization, with up to 5% chalcopyrite, has also been observed in a series of large (up to 10 m across) boulders or subcrops, located in an area of boggy ground ~50 m south of Montgomery Lake. Mineralization postdates the earlier albite–quartz–carbonate alteration phase in all locations. In the main trenches and boulders south of Montgomery Lake, mineralized material consists of rounded to angular clasts of previously altered (albitized and silicified) fine-grained host rocks in a matrix-supported breccia cemented by medium-grained albite, dolomite, quartz and chalcopyrite (± tourmaline), and minor pyrrhotite (Plates 1D, E and 3A–D). The abundance of rounded clasts in some areas gives the rock the appearance of a pebble conglomerate (Love, 1967; Swinden and Santaguida, 1995). However, the clasts are often angular, have ragged edges with evidence of dissolution in a hydrothermal fluid, and in places are clearly brecciated with albite–carbonate–chalcopyrite filling fractures in the clasts (Plate 3A, B), and therefore can be classified as hydraulic breccias with matrix-supported clasts in a hydrothermal cement matrix (Jébrak, 2010).

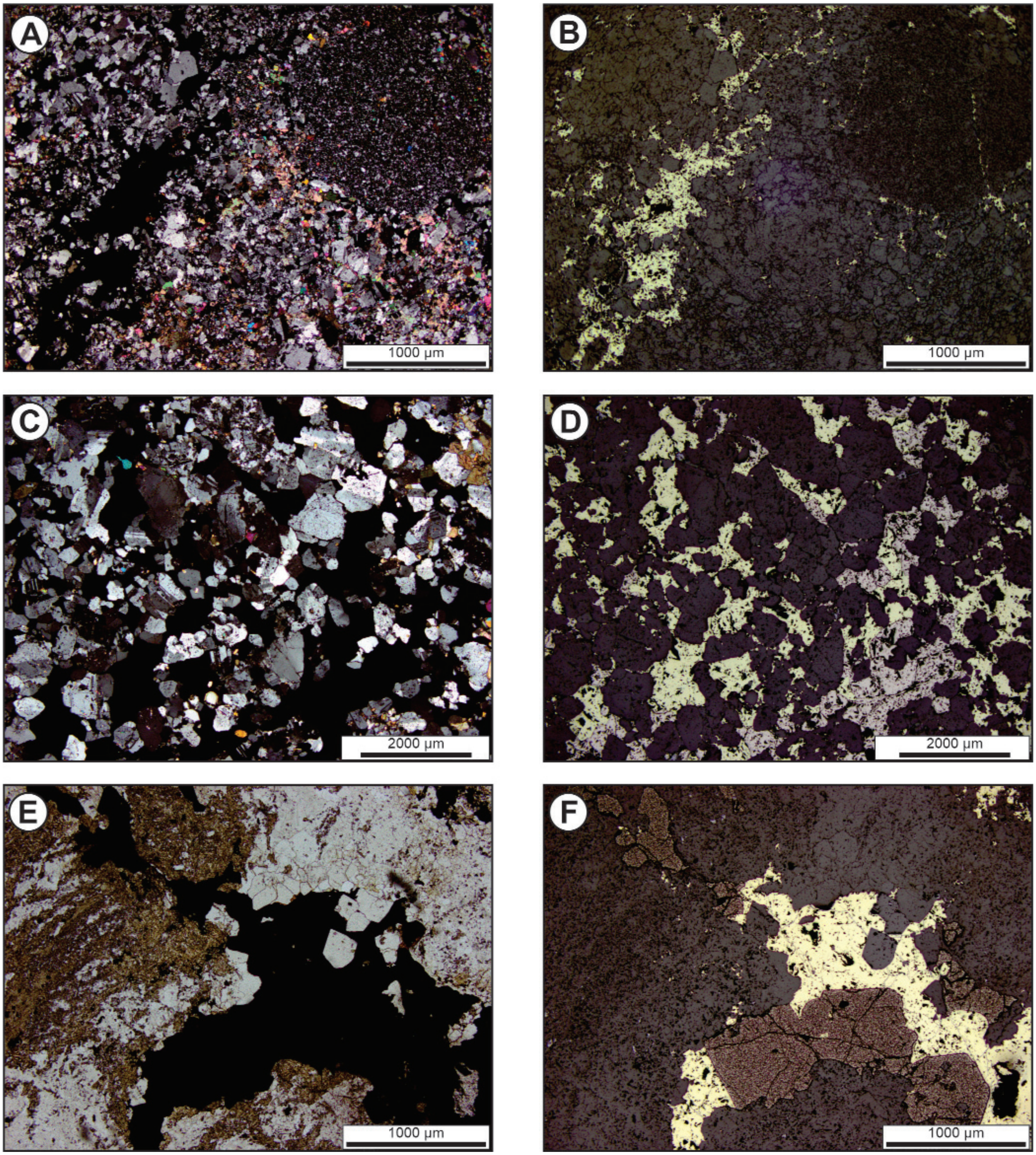

Plate 3. *Photomicrographs of mineralized samples from Montgomery Lake area. A) Mineralized breccia, with fine-grained albitized clast (top right) in matrix of albite, dolomite, chalcopyrite and quartz (cross-polarized light, sample 18JC001A01); B) Same view as A, in reflected light, showing disseminated chalcopyrite in matrix and filling fractures in albitized clast; C) Hydrothermal matrix with medium-grained albite, dolomite, quartz, chalcopyrite and pyrrhotite (cross-polarized light, sample 18JC006A01); D) Same view as C, in reflected light; E) Mineralized sample with abundant fine-grained tourmaline (light brown) cut by veinlet of chalcopyrite and pyrrhotite (plane-polarized light, sample 18JC002A01); F) Same view as E, in reflected light.*

During this study, mineralization was also identified in a series of outcrops ~300 m south of the main trenches, close to the contact with a relatively unaltered gabbro sill. This mineralization is characterized by abundant fine-grained black to dark-brown tourmaline (up to 20%) in altered and mineralized shales. Mineralization is fracture controlled with numerous stockwork veinlets of quartz–albite–pyrrhotite–chalcopyrite–tourmaline cutting fine-grained quartz–albite–tourmaline (Plate 3E, F). Similar pyrrhotite–quartz–carbonate-albite veinlets and trace chalcopyrite have been observed cutting albitized and silicified shales elsewhere along the alteration trend (Plate 1F).

SEM-MLA ANALYSIS

To further examine mineralogical compositions, two thin sections of mineralized samples (18JC001A01 from the main trench, and 18JC006A01 from mineralized boulders close to Montgomery Lake) were selected for Scanning Electron Microscopy-Mineral Liberation Analysis (SEM-MLA). Representative MLA false-colour images from both samples are shown in Figure 2 and the modal mineralogy is shown in Table 1.

Sample 18JC001A01 consists of ~50% subrounded clasts in a hydrothermal matrix (Figure 2A). The clasts consist predominantly of albite with minor quartz and dolomite, whereas the matrix consists of approximately equal proportions of dolomite, albite and chalcopyrite, and minor quartz and pyrite. Accessory minerals observed include hornblende, tourmaline, pyrite, pyrrhotite, rutile and apatite. A number of small (<25 µm) gold grains were also recorded, on the margins of, or inside, chalcopyrite grains.

Table 1. Modal mineralogy calculated from SEM-MLA analysis of mineralized breccias from the Montgomery Lake area

Sample	18JC001A01	18JC006A01
Mineral	Wt%	Wt%
Albite	62.53	39.31
Dolomite	17.82	26.46
Quartz	4.65	12.91
Chalcopyrite	9.87	5.71
Pyrrhotite	0.22	7.88
Pyrite	1.2	1.32
Tourmaline	0.94	2.49
Hornblende–Fe	1.52	1.08
Apatite	0.26	0.59
Rutile	0.3	0.36
Muscovite	0.02	0.45
Gold	0.01	0
Other	0.66	1.44

Sample 18JC006AO1 has a higher proportion of hydrothermal cement matrix, with silicified and albitized clasts making up <20% of the thin section (Figure 2B). Clasts display embayed margins and are commonly brecciated with chalcopyrite- and dolomite-filled fractures. The hydrothermal cement matrix consists of variable proportions of dolomite, albite, quartz, pyrrhotite and chalcopyrite with common tourmaline (2.5% wt. % of the sample) and accessory pyrite, hornblende, apatite, muscovite and rutile. Apatite is relatively coarse grained, with one grain >500 µm recorded (top left of Figure 2B). No gold grains were observed in this sample.

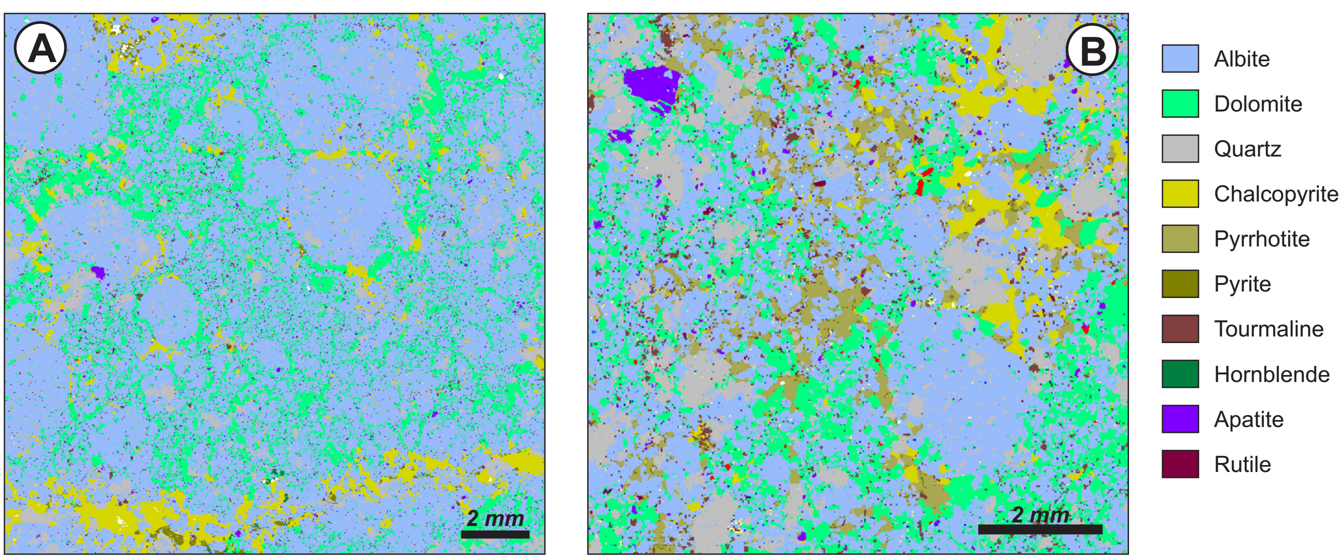

Figure 2. *False colour SEM-MLA images of mineralized breccias in the Montgomery Lake area. A) Sample 18JC001A01 from the main trenches; B) Sample 18JC006A02 from mineralized boulders close to Montgomery Lake* (see *text for details.)*

LITHOGEOCHEMISTRY

A representative suite of rock types from the Montgomery Lake area were analyzed for major and trace elements at the Geological Survey laboratory using the methods outlined by Finch *et al.* (2018). Additional analyses (for trace elements including Au) of selected samples were conducted by Maxxam Analytics. These samples are subdivided based on their presumed protolith, alteration type and presence or absence of Cu mineralization (>0.25% Cu) as follows: 1) unmineralized altered shale with strong albitization; 2) unmineralized altered shale with strong sericitization; 3) unmineralized altered gabbro; 4) mineralized hydrothermal breccia with abundant albite, dolomite and chalcopyrite/pyrrhotite; and 5) mineralized altered shale with abundant albite, tourmaline and chalcopyrite–pyrrhotite. Full geochemical data, methods and sample locations are included in Conliffe (2020).

All of the samples analyzed have been exposed to alteration processes, and therefore their geochemical composition may not reflect the composition of the unaltered protolith. During alteration, immobile elements such as Al, Ti, Zr, Nb and Yb are typically considered immobile (Barrett and MacLean, 1994). However, Montreuil *et al.* (2016) showed that in zones of intense metasomatism and alteration, elements that are generally considered immobile (*e.g.*, Al, Ti, Zr) can be significantly depleted or enriched. With the exception of a single sample of presumed gabbroic affinity, all samples are thought to represent similar protoliths (*i.e.*, Menihek Formation shales and siltstones). Binary plots of immobile elements (Al, Ti, Zr, Nb) show that these samples form two distinct groups (Figure 3). Ten samples display linear trends with R^2 factors of >0.9, indicating that they represent alteration of a similar protolith in a rock-buffered system (Barret and MacLean, 1994). In contrast, all other samples show no linear relationships, potentially indi-

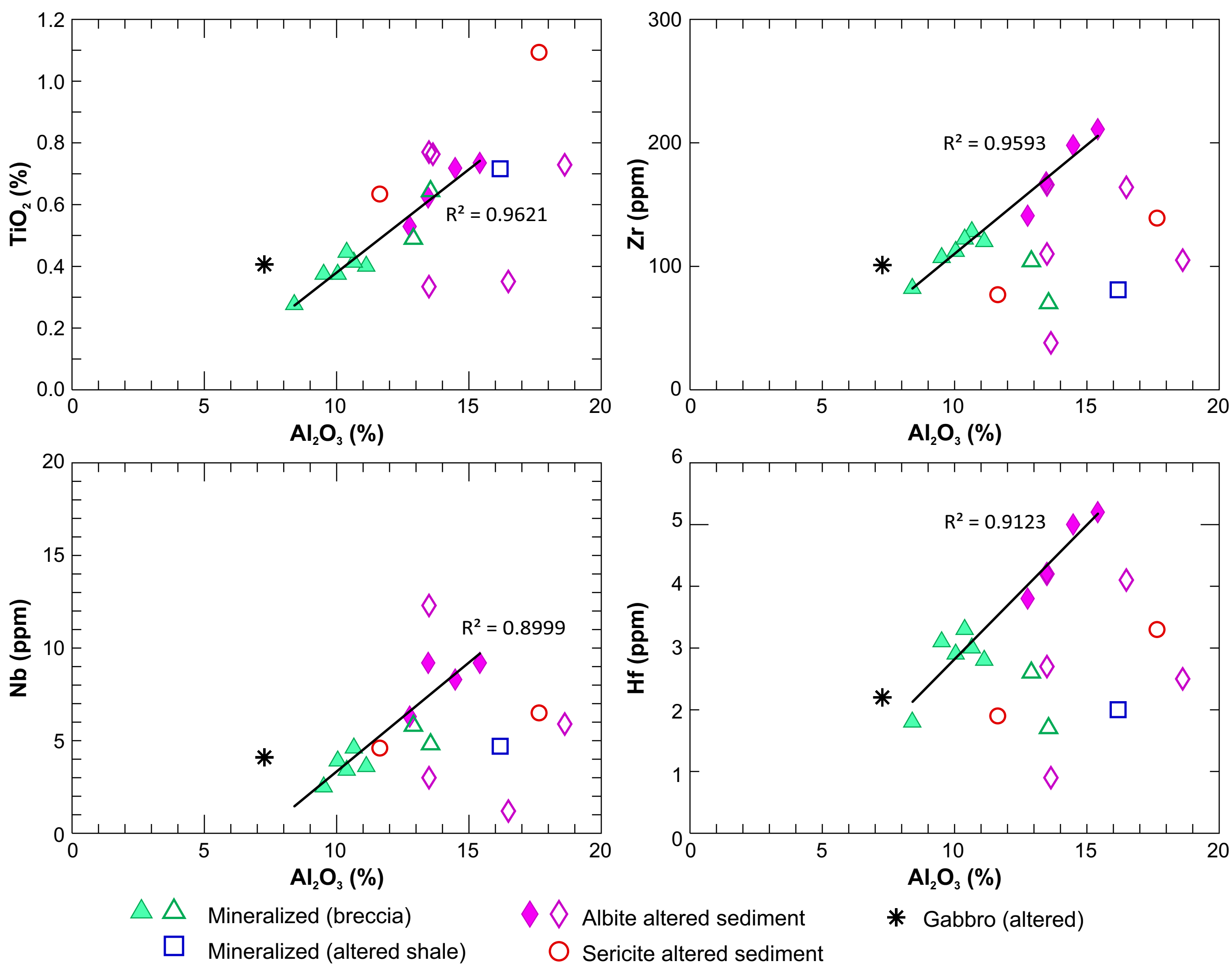

Figure 3. *Bivariate plots of Al_2O_3 vs. other immobile elements (TiO_2, Zr, Nb and Hf), showing variations between samples with constant immobile element ratios (solid symbols) and those with highly variable ratios (open symbols).*

cating variations in protolith, or intense alteration that resulted in mobility of elements typically thought to be immobile (Montreuil *et al.*, 2016).

Mobile major elements, such as Na, K and Ca, show distinct variations depending on the dominant alteration style (Figure 4). Unmineralized samples dominated by early albitization and silicification have very low K contents (<0.75 wt. % K_2O) and generally have Na>Ca, which is consistent with albite as the dominant alteration mineral. In contrast, sericite-altered samples having abundant muscovite and phengite have higher K contents (up to 3.40 wt. % K_2O). Mineralized samples generally have low K contents and show an increase in Ca compared with unmineralized samples, which reflects the abundance of dolomite in hydrothermal breccia cement. A single tourmaline-rich mineralized altered shale sample (18JC002A01) has much lower Ca contents, reflecting the absence of carbonates. Montreuil *et al.* (2013) developed an IOCG alteration discrimination diagram for intensely metasomatised rocks using the molar ratio of major elements, which incorporates the alteration facies of Corriveau *et al.* (2010). When samples from this study are plotted, all samples of unmineralized altered shales plot close to the boundary between Na and Na–Ca–Fe (Mg) alteration (Figure 5). Mineralized samples cluster in the field for Na–Ca–Fe (Mg) alteration, and sericite-altered samples plot closer to the fields defined for potassic alteration (Figure 5).

Bivariate plots of metal values show a strong correlation between Cu contents and other metals such as Au, Ag and Zn (Figure 6). Although gold contents are generally low (<500 ppb), samples with >100 ppb Au correspond to high Cu contents (>1000 ppm Cu; Figure 6A). Copper contents also show a strong correlation with Ag and Zn contents, with R^2 values of >0.8 (Figure 6). However, there is no significant correla-

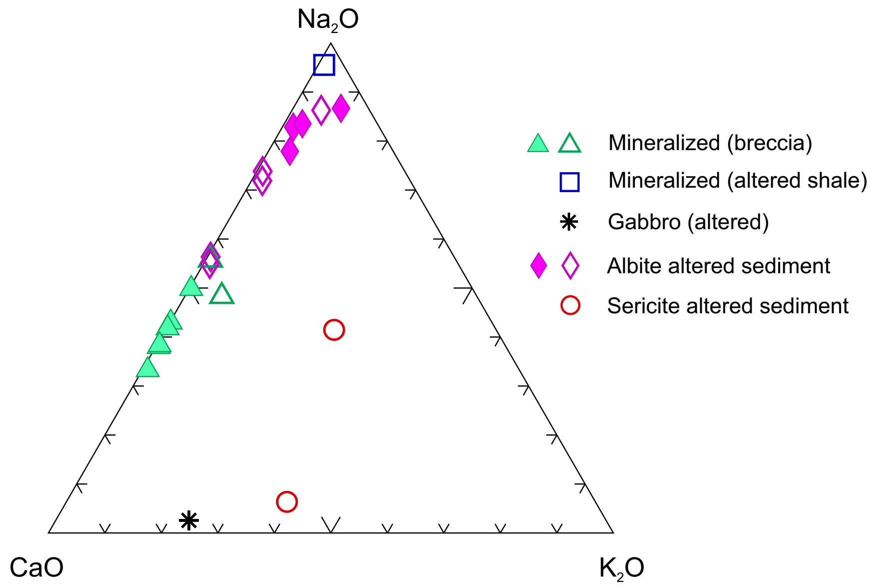

Figure 4. *Plot of Na_2O* vs. *CaO* vs. *K_2O of altered samples from the Montgomery Lake area. Filled symbols represent samples with constant immobile element ratios; open symbols represent samples with highly variable immobile element ratios (*see *text for details).*

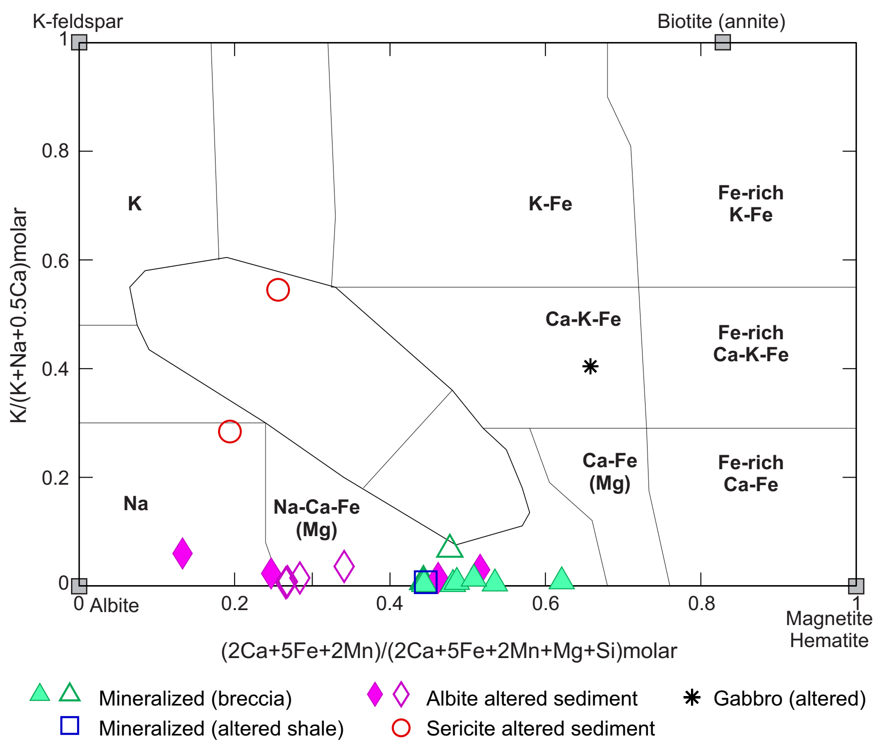

Figure 5. *Whole-rock geochemical data for samples from the Montgomery Lake area, plotted on IOCG alteration diagram of Montreuil* et al. *(2013), showing alteration facies defined by Corriveau* et al. *(2010). Filled symbols represent samples with constant immobile element ratios; open symbols represent samples with highly variable immobile element ratios (*see *text for details).*

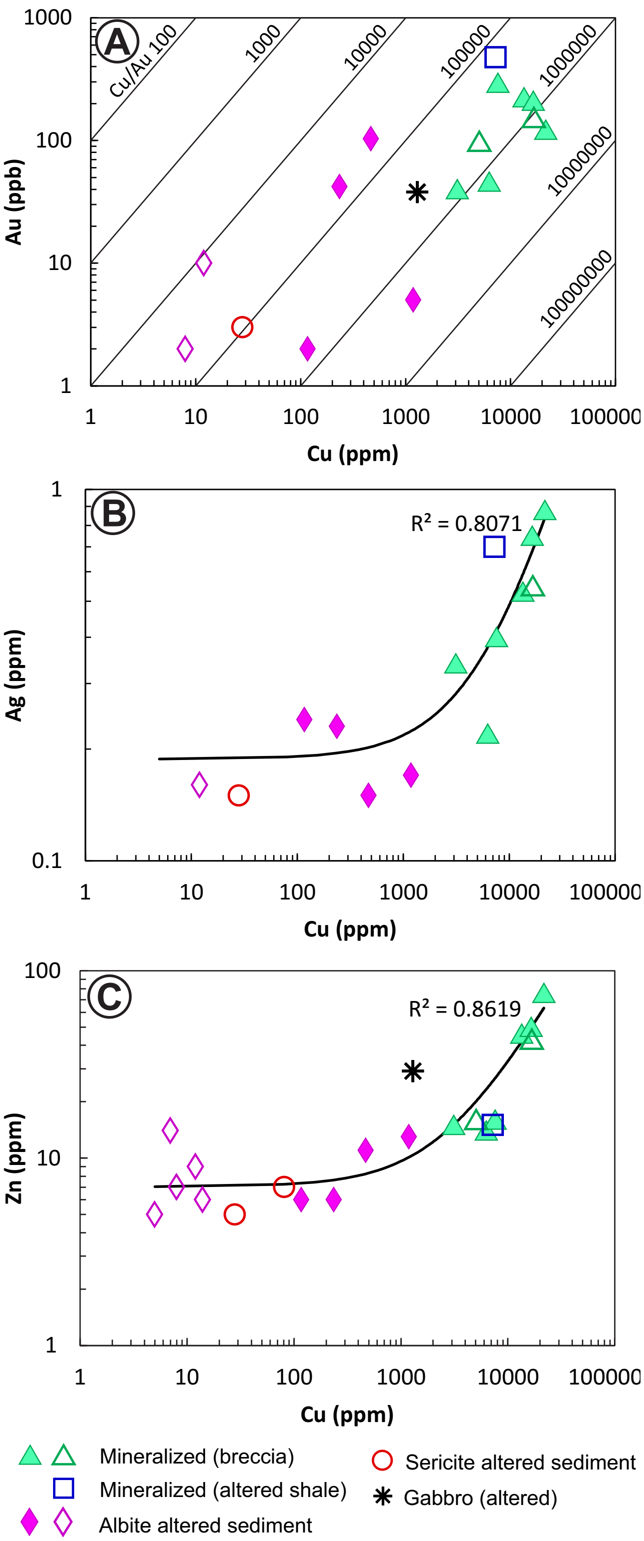

Figure 6. *Log-log plots of A) Cu* vs. *Au, B) Cu* vs. *Ag and C) Cu* vs. *Zn for samples from the Montgomery Lake area. Filled symbols represent samples with constant immobile element ratios; open symbols represent samples with highly variable immobile element ratios (*see *text for details).*

tion between Cu or Au contents with other metals that are commonly used as pathfinder metals in orogenic gold systems (*e.g.*, As, Sb). Rare-earth-element (REE) plots shows that samples with consistent immobile element ratios have relatively consistent profiles, with enrichment in light-rare-earth-elements (LREE) and negative Eu anomalies (Figure 7A). In contrast, samples with inconsistent immobile element ratios have much more variable REE contents, particularly in LREE (Figure 7B). This may reflect higher fluid-rock ratios, with LREE mobilized in the hydrothermal fluids.

DISCUSSION

The Montgomery Lake showing is located in a high-strain zone parallel to the Walsh Lake Fault, a major crustal structure in the eastern part of the Labrador Trough. Mineralization is associated with two main phases of alteration. The first stage of alteration is a widespread sodic-silicic alteration, which results in the almost complete albitization and silicification of the host shales and siltstones (local sericitization also observed). Primary lithological features are almost completely destroyed, but some relict bedding has been recorded (Labonté *et al.*, 2009). This alteration is associated with disseminated pyrite and pyrrhotite mineralization, but there is no significant enrichment in Cu, Au or Ag. Early alteration appears to be synchronous with peak deformation, with some altered units displaying intense deformation, whereas other units are relatively undeformed (Swinden and Santaguida, 1995).

The second phase of alteration is more localized in distribution, and is associated with fracturing and hydraulic brecciation of early alteration. Fragments of earlier alteration are commonly cemented by later dolomite, albite, chalcopyrite, quartz and pyrrhotite (± tourmaline, apatite), with enrichments in Cu, Au and Ag. Rare occurrences of quartz and carbonate veins are observed crosscutting earlier alteration, and may be related to this later alteration. Petrographic studies have identified fluid inclusions having abundant cubic and rhombic isotropic trapped minerals interpreted to be halite and/or sylvite crystals (Plate 4), which indicates that the later alteration, brecciation and mineralization was associated with high salinity (>> 20 eq. wt. % NaCl) fluids.

Swinden and Santaguida (1995) suggested that mineralization at Montgomery Lake was representative of orogenic-gold type mineralization, due to the strong structural control on mineralization and the local presence of carbonate alteration and possible fuchsite. However, the mineralization lacks many features typical of orogenic-gold type mineralization, with Cu>>Au, lack of quartz–carbonate veining, absence of CO_2-rich mineralizing fluids and pre-

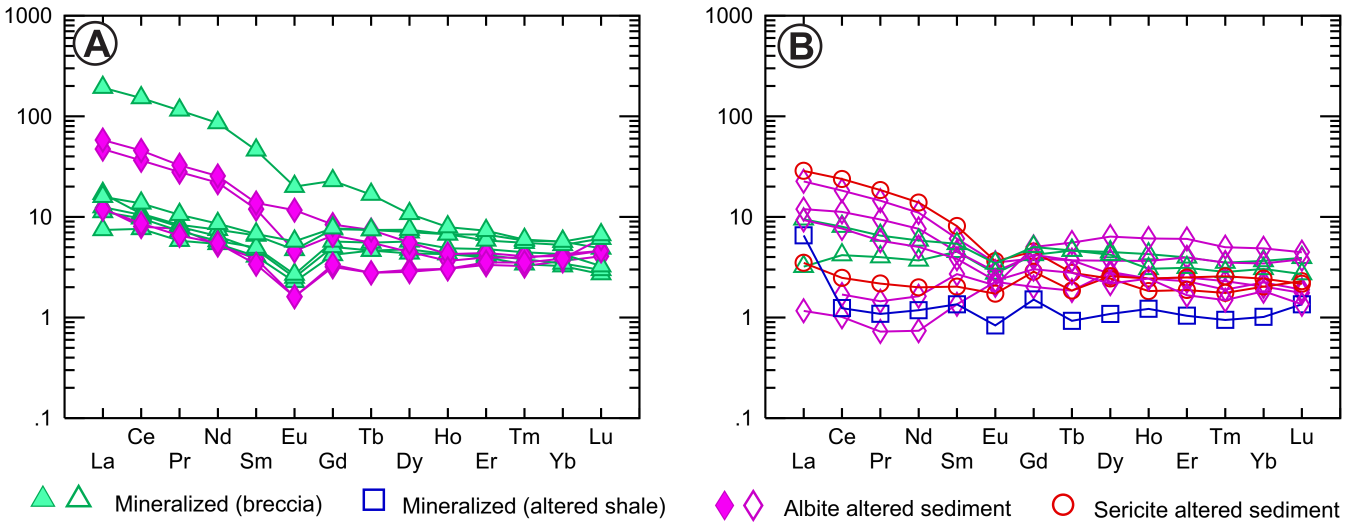

Figure 7. *Chondrite-normalized REE patterns for samples from the Montgomery Lake area (normalizing values from Sun and McDonough, 1989). A) Samples with constant immobile element ratios; B) Samples with highly variable immobile element ratios.* See *text for details.*

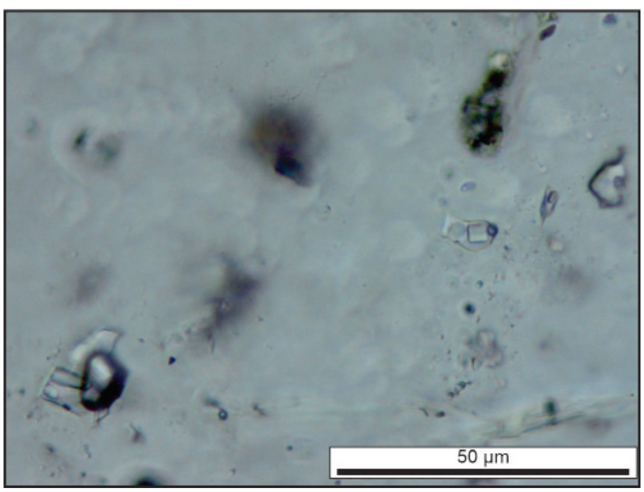

Plate 4. *Photomicrograph of quartz-hosted fluid inclusion in mineralized breccia, showing presence of abundant solid phases (possible halite?), potentially indicating hypersaline mineralizing fluids (sample 18JC006A01).*

dominance of sodic alteration; therefore alternative genetic models should be considered. The widespread Na-alteration, with more localized Ca–Na–Fe–(Mg) alteration associated with mineralization at Montgomery Lake is typical of Iron-Oxide and Alkali-calcic Alteration (IOAA) systems that have been associated with IOCG mineralization (Corriveau *et al.*, 2016). In addition, evidence of hydrothermal brecciation in the presence of hypersaline fluids and strong structural control of alteration and mineralization is typical of many IOCG mineralization systems (Groves *et al.*, 2010; Corriveau and Mumin, 2010; Williams, 2010). The lack of Fe-oxides associated with mineralization at Montgomery Lake precludes classification of this deposit as IOCG *senso stricto*. Based on the characteristic alteration and mineralization, the deposit can instead be classified as ISCG mineralization, a subset of IOCG-type deposits that do not have appreciable Fe-oxides (Haynes, 2000). The ISCG mineralization is hosted in relatively reduced rock types, such as carbonaceous and graphitic metasedimentary rocks (Mark *et al.*, 2006; Williams, 2010). Interaction between mineralizing fluids and the reduced host rocks is believed to inhibit the precipitation of Fe-oxides, and these deposits instead contain significant Fe-sulphides (pyrite or pyrrhotite) as the main iron-bearing mineral (Mark *et al.*, 2006; Williams, 2010). Diamond drilling at the Montgomery Lake deposit shows that the least altered shale units are highly graphitic (Love, 1967), which is consistent with the reduced environment typical of ISCG-type mineralization. Global analogies for this mineralization type include a number of deposits in the Cloncurry District, Australia (Krcmarov and Stewart, 1998; Habermann, 1999; Mark *et al.*, 2006) and northern Scandinavia (Ettner *et al.*, 1994; Lindblom *et al.*, 1996).

Similar ISCG-type mineralization associated with sodic alteration has been reported from elsewhere in the eastern portion of the Labrador Trough, particularly from the Romanet Horst in Québec (Corriveau *et al.*, 2014; McLaughlin *et al.*, 2016). The Romanet Horst represents a similar geological setting to the Montgomery Lake and Andre Lake areas, with a northwest-plunging, fault-bound anticline consisting of an Archean basement complex overlain by rift-related and passive margin sediments (Konstantinovskaya *et al.*, 2019). Copper and gold mineralization at the Delhi-Pacific showing in the Romanet Horst is hosted in hydrothermal breccia consisting of albitized fragments cemented by a calcite–albite–pyrite–actinolite–biotite–chalcopyrite–titanite matrix, with diamond drilling intersecting 0.8% Cu, 0.34 g/t Au and 2.4 g/t Ag over 29.46 m (McLaughlin *et al.*, 2016). The Romanet Horst is also host to numerous other polymetallic (Cu, Au, U, Co, Mo) mineral occurrences within alteration facies typical of IOCG-type mineralizing systems (Clark and Wares, 2005; Corriveau *et al.*, 2014).

Based on the results of this study, a preliminary genetic model is proposed for mineralization at Montgomery Lake. Hydrothermal fluid flow was focused along major structures, such as the Walsh Lake Fault during the deformation associated with the New Québec Orogen. These fluids penetrated the graphitic shales and siltstones of the Menihek Formation along second- and third-order structures, and were responsible for the early albitization and silicification of the sediments and subsequent hydrothermal brecciation and mineralization. The heat required to drive this hydrothermal system may be associated with the emplacement of the large I-type De Pas Batholith at ~1.84 to 1.81 Ga (James and Dunning, 2000), which is located ~30 km to the east of the Montgomery Lake showing. The high salinity fluids may represent late-stage magmatic fluids, or alternatively fluids that have leached significant salts from evaporite horizons in the Denault Formation dolomites located in the eastern Labrador Trough (Zentemeyer *et al.*, 2011). Future research should focus on detailed fluid-inclusion and isotopic studies to better constrain the P-T-X conditions during mineralization, as well as boron isotope studies of tourmaline associated with mineralization to determine if the high salinity fluids were derived from magmatic or evaporitic sources.

EXPLORATION IMPLICATIONS IN ANDRE LAKE AREA

The recognition of ISCG mineralization and IOAA facies in the Montgomery Lake area has important implications for the mineral exploration potential of the eastern Labrador Trough. The ISCG mineralization typically occurs in clusters with other IOCG and affiliated deposits, *e.g.*, the Cloncurry District in Australia (Mark *et al.*, 2006) and the Romanet Horst in the Labrador Trough (Corriveau *et al.*, 2014; McLaughlin *et al.*, 2016). This is because hydrothermal systems associated with the intense metasomatism recognized at Montgomery Lake is expected to have been active over a regional scale, and the possibility exists that this hydrothermal system may have produced other affiliated deposit types.

Skirrow *et al.* (2019) identified a number of mappable criteria that can be used to determine if an area has potential to host IOCG-type deposits. These criteria were based on a "mineral systems" approach, which identifies a number of criteria that are important in forming ore bodies, including crustal architecture (fluid pathways), energy source to drive hydrothermal systems, source of metals and hydrothermal fluids, and development of ore-depositional gradients (Skirrow *et al.*, 2019). In the eastern Labrador Trough, the Montgomery Lake and Andre Lake areas fulfill a number of these criteria required to form IOCG deposits. These include the proximity (<30 km) to large scale I or A-type intrusions that may act as drivers for hydrothermal systems (De Pas Batholith), presence of large-scale crustal faults and shear zones that focus fluid flow (Walsh Lake and Quartzite Lake faults, Ashuanipi River shear zone), and potential magmatic and crustal sources of fluids, metals and ligands (iron formation, former evaporite horizons, mafic and ultramafic igneous rocks, sodic alteration zones).

The mineral potential of this area is also highlighted by the results of previous exploration efforts, with prospecting identifying anomalous Cu values (>0.1% Cu) in grab samples over >23-km-strike length from Montgomery Lake to the southern end of Andre Lake (Figure 8; Labonté *et al.*, 2009; Conliffe, 2020). These samples are also variably enriched in LREE, Ag, Au, Co, U and Ba, which is typical of IOCG-systems (Groves *et al.*, 2010; Barton, 2014). Additionally, four samples of biotite-altered shales were collected from the southern end of Andre Lake during fieldwork in 2017, with full geochemistry results available in Conliffe (2020). These show strong enrichments in Cu (up to 0.36%), Ag (up to 1.7 g/t), REE (up to 0.13% total REE) and Ba (up to 0.37%).

Labonté and Kieley (2009) reported on numerous unexplained and untested magnetic and radiometric anomalies in the Andre Lake area, and suggested that some of these may be related to IOCG-type occurrences. In addition, diamond drilling in the Andre Lake area in the 1960s intersected horizons of strong biotite–magnetite alteration, typical of the high temperature K–Fe alteration associated with many IOCG deposits (Corriveau *et al.*, 2010) as well as intervals of brecciated to massive pyrrhotite and magnetite with trace chalcopyrite (Love, 1961; Hogg, 1968). Although the data points to the overall prospectively of the area, and it is clear that the mineral systems approach provides an opportunity to create mineral potential maps for underexplored greenfield areas such as the eastern Labrador Trough, more baseline geological, geochemical and geophysical data are required to further develop these models.

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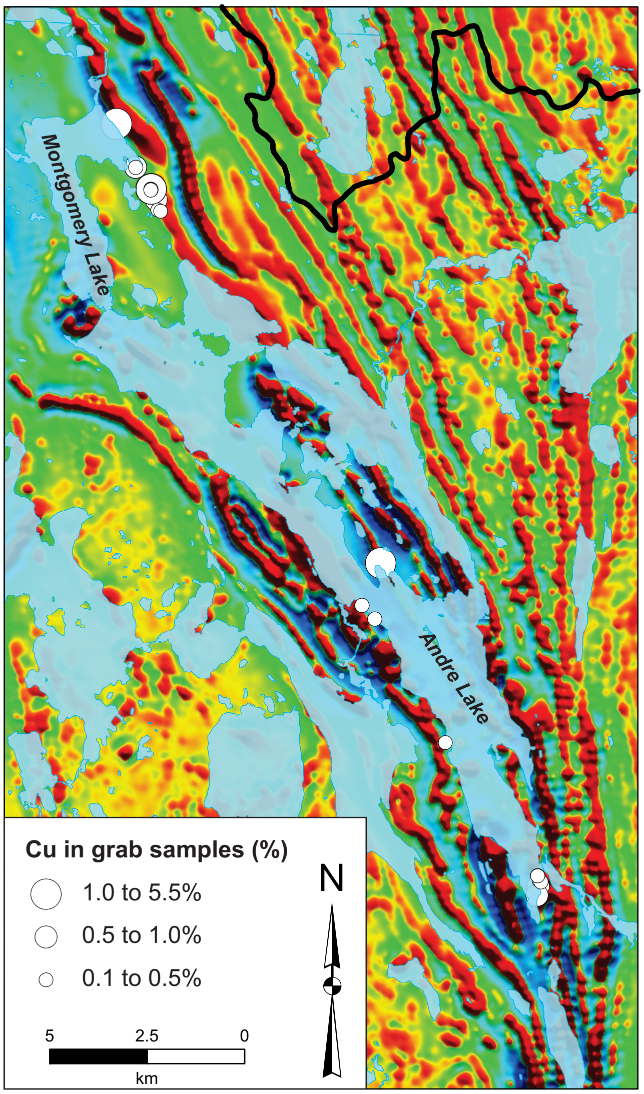

Figure 8. *Regional aeromagnetic map of the Andre Lake (2nd vertical derivative colour shade image), showing location of outcrop and boulder samples with anomalous (>0.1 %) Cu values (Labonté* et al.*, 2009; Conliffe, 2020).*

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