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SHORT WAVELENGTH INFRARED SPECTROMETRY STUDIES OF SERICITIC ALTERATION ZONES, SOUTHERN BUCHANS–ROBERTS ARM BELT, NEWFOUNDLAND

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ABSTRACT

Numerous sericite alteration zones, locally associated with the development of VMS-style mineralization, are reported within various lithological groups of the southern Buchans–Roberts Arm belt (BRAB). The systematic collection of downhole short wavelength infrared (SWIR) spectrometry data has been used to further refine the mineralogy of these zones, to identify areas of intense hydrothermal activity. In numerous instances, a notable decrease of the Al-OH wavelength is observed with decreasing distance from mineralization, resulting in a mappable zonation of the white mica minerals phengite, muscovite and paragonite, based on the spectral data.

In addition, the use of SWIR spectrometry has locally identified the presence of pyrophyllite, dickite, kaolinite and alunite, proximal to zones of VMS mineralization. The recognition of advanced argillic alteration assemblages within these rocks potentially provides a new deposit model for the region, as well as highlighting the potential for precious-metal mineralization in association with the development of this alteration.

INTRODUCTION

Previous work has described the alteration zones, associated with volcanogenic massive sulphide (VMS) mineralization within the southern Buchans–Roberts Arm belt (BRAB), using the generic term sericite to classify zones of white mica alteration (Figure 1). In addition, rare occurrences of aluminous alteration (pyrophyllite, alunite) are reported proximal to the development of VMS mineralization (*e.g.*, Mary March prospect; Barbour *et al.*, 1989; Thurlow, 1999). The use of short wavelength infrared (SWIR) spectrometry enables the subdivision of these sericitic alteration zones into distinct mineral assemblages, as well as providing a means of identifying minerals associated with advanced argillic alteration (pyrophyllite, alunite, kaolinite, dickite). This information allows for a better understanding of the conditions (acidity, temperature) related to the development of these alteration zones. For example, the presence of muscovite is generally indicative of more acidic conditions compared to the presence of phengite, which is inferred to represent a neutral environment. The use of SWIR spectrometry to characterize the alteration assemblages, developed proximal to known occurrences of VMS mineralization, can define scalar variables that can be used to highlight characteristic alteration zones containing similar mineral signatures to such areas of known mineralization. When used in conjunction with structural analysis, these scalar variables can provide vectors to potential mineralization.

This study primarily focused on areas of known alteration occurring east of the main Buchans deposits (Figure 1). However, an orientation survey of select drillholes from the Buchans area was also conducted to establish the spectral characteristics of the alteration proximal to massive sulphide mineralization. The results presented provide the first systematic, downhole, SWIR-spectral data from drillcore targeting rocks associated with VMS mineralization within the southern BRAB, and builds upon previous work in the region (van Hees, 2011; Seymour *et al.*, 2015; Sparks, 2019). This downhole drillcore data enables the evaluation of spectral changes associated with the formation of individual alteration zones, and, in turn, can aid in identifying stratigraphic horizons with favourable alteration signatures for additional follow-up work. This study is preliminary and presents the results of initial sampling of select drillholes from known sericitic alteration zones; further refinement of the alteration mineralogy associated with these zones will undoubtedly occur with the collection of additional spectral data.

REGIONAL GEOLOGY

The geology of the southern BRAB, primarily confined to the area north of Beothuk Lake (formerly known as Red

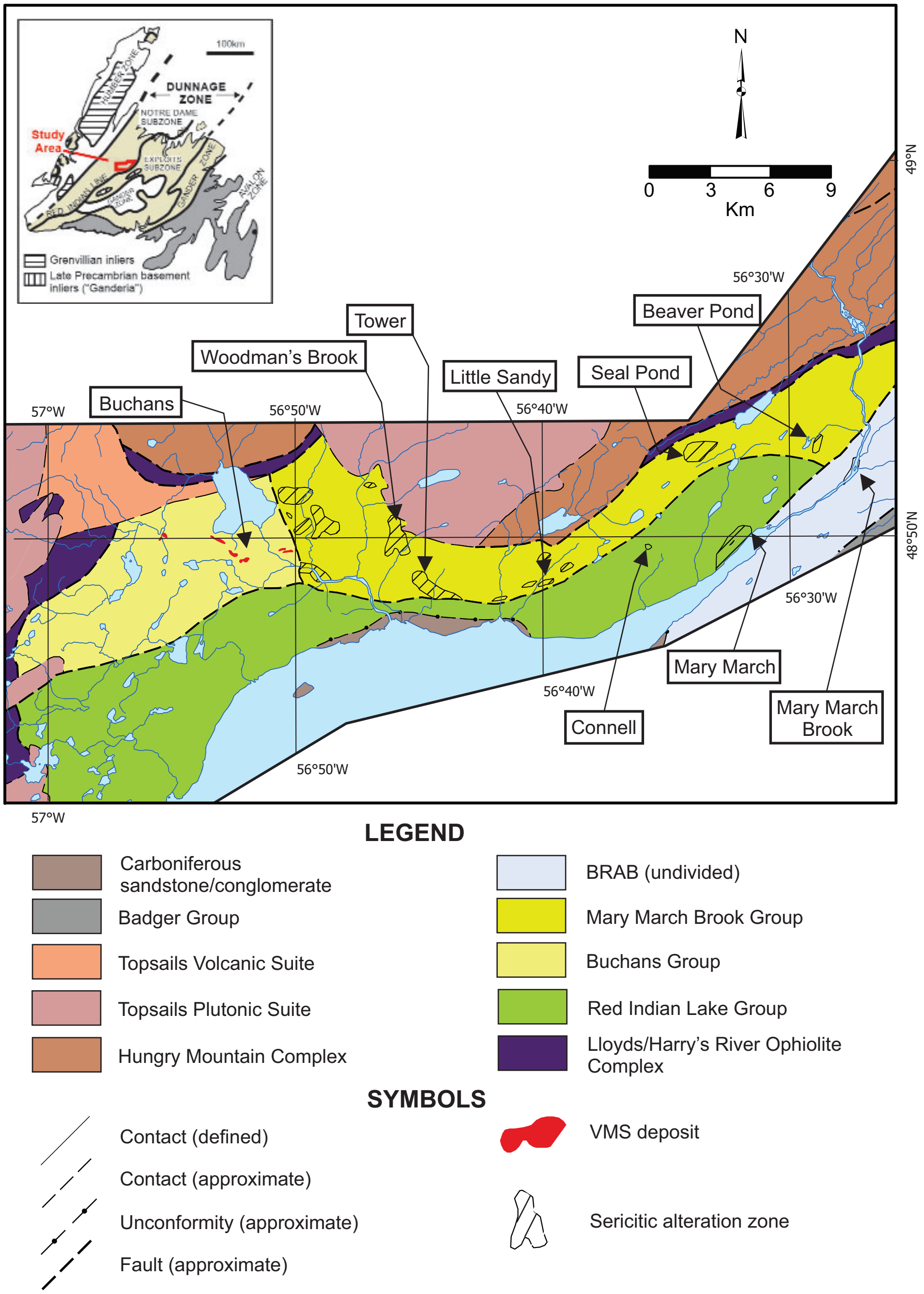

Figure 1. *Regional compilation map outlining the geology and location of select sericite alteration zones and Buchans VMS deposits; geology modified from Zagorevski* et al. *(2015). Note the sericite alteration zones are drawn to encompass drillhole collar locations that are reported to have intersected sericite alteration at depth. BRAB – Buchans–Roberts Arm belt.*

Indian Lake), has most recently been discussed by Zagorevski and Rogers (2008, 2009) and Zagorevski *et al.* (2007, 2015, 2016). From this work, the geology of the area has been subdivided into five units, consisting of the Lloyds/Harry's River Ophiolite and Hungry Mountain complexes, and the Buchans, Mary March Brook and the Red Indian Lake groups (Figure 1). Only the Buchans, Mary March Brook and the Red Indian Lake groups are discussed in detail, as they are host to known zones of sericitic alteration.

The Mary March Brook group consists of bimodal tholeiitic and calc-alkalic volcanic rocks. The formation of tholeiitic rhyolite cryptodomes and coeval island-arc tholeiitic basalts were accompanied by the deposition of rare polymictic debris flows and locally developed hydrothermal alteration and VMS mineralization (Zagorevski and Rogers, 2008, 2009). These rocks are conformably overlain by bimodal calc-alkalic volcanic rocks. The Mary March Brook group formed within a back-arc or intra-arc rift setting and has been dated at 461.5 ± 4 Ma (Zagorevski *et al.*, 2015, 2016). This group is host to localized VMS mineralization and sericitic alteration zones, and include Beaver Pond, Seal Pond, Little Sandy, Tower and Woodman's Brook prospects (Figure 1).

The Buchans Group structurally underlies the Mary March Brook group and is composed of calc-alkalic basaltic and rhyolitic rocks of continental-arc affinity, along with abundant granitoid-bearing conglomerate and debris flows (Thurlow and Swanson, 1987; Swinden *et al.*, 1997; Zagorevski *et al.*, 2015, 2016). Geochronological data from volcanic rocks within the lower stratigraphic levels of the group range from 465 ± 4 to 463 ± 4 Ma, whereas a felsic crystal tuff from stratigraphically higher in the sequence is dated at 462 ± 4 Ma (Zagorevski *et al.*, 2015). Granitoid clasts from within the debris flows of the Buchans mine area are dated at 464 ± 4 Ma (Whalen *et al.*, 2013), and a felsic volcanic rock located stratigraphically below one of the mineralized debris flows is dated at 471 ± 1.6 Ma (Sparkes *et al.*, 2021). The Buchans Group is well known for its VMS mineralization, which includes the past-producing Oriental, Lucky Strike, Rothermere and MacLean deposits. This VMS mineralization is inferred to have developed around *ca.* 465 Ma based on age constraints of units within the Buchans Group (Zagorevski *et al.*, 2016).

The Red Indian Lake Group is composed of tholeiitic mafic, and overlying calc-alkalic bimodal, volcanic rocks, with the two sequences locally separated by polymictic conglomerate (Zagorevski *et al.*, 2006; Zagorevski and Rogers, 2008, 2009). Rocks at the base of this group are composed of island-arc tholeiities to back-arc basin basalts, along with minor felsic volcanic rocks, that are interpreted to have formed within a rifted-arc or back-arc-type setting (Zagorevski *et al.*, 2006). Rocks included within the Red Indian Lake Group have ages ranging from 465 ± 4 to 462 +2/-9 Ma (Zagorevski *et al.*, 2015) and host several notable VMS occurrences, which include the Mary March and Connell prospects (Figure 1).

Rocks located within the eastern portion of the southern BRAB remain poorly constrained, in part, due to poor outcrop exposure (BRAB undivided; Figure 1; Sparkes *et al.*, 2021). These rocks include structurally interleaved mafic and felsic volcanic rocks, and locally host sericitic alteration zones such as Mary March Brook (Figure 1). Preliminary examination of airborne geophysical data, coupled with limited field investigations, suggest the presence of a significant northeast-trending fault structure within this area. The current lack of data for rocks occurring to the east of this structural contact impedes their incorporation with established unit subdivisions for this area.

SERICITIC ALTERATION ZONES

The following summarizes previous work on select alteration zones noted to contain sericite alteration within the southern BRAB that were investigated as part of this study. These zones are discussed based upon distinct mineral groupings as identified from preliminary SWIR spectral data (*see* below).

Buchans

Preliminary SWIR spectrometry studies of the alteration developed proximal to massive sulphide mineralization in the Buchans area were carried out to characterize the sericitic alteration associated with known VMS mineralization (Henley and Thornley, 1981; Thurlow, 1981; Winter, 2000; van Hees, 2011). This work builds on the spectral data of van Hees (2011), but represents a more systematic collection of downhole spectral measurements taken from select drillholes that contain footwall rocks of the Lucky Strike deposit (H-08-3356; H-08-3407; Moore *et al.*, 2009), and select stratigraphic intervals from the overlying felsic volcanic rocks of the Buchans River Formation (Buchans Group) proximal to the Rothermere deposit (H-817; Buchans Mining Company unpublished drill log). For a detailed description of the exploration history of the area, the reader is referred to Moore and Butler (2016).

Early x-ray diffraction and microprobe work by Henley and Thornley (1981) noted the phengitic affinity of white mica alteration within the upper stratigraphic levels of the Buchans Group, whereas white micas developed in footwall rocks contained chemical values more indicative of muscovitic compositions. From their study, illite was the most abundant clay reported within the felsic volcanic rocks, along with lesser illite–montmorillonite, montmorillonite and montmorillonite–chlorite. Finally, Henley and Thornley (1981) also noted that chlorite alteration displayed higher magnesium contents proximal to mineralization. Similarly, microprobe work conducted by Winter (2000) indicted that the examined sericite alteration in the area was defined as muscovite based on its chemical composition, and that Mg-rich chlorite formed proximal to mineralization.

The first reported SWIR work in the Buchans area was by van Hees (2011), who noted the predominant phengitic nature of the sericite alteration within the hangingwall rocks, and the muscovite-dominated signature of the main ore-horizon. From this work the dominant minerals identified in the Lundberg deposit, which represents the stockwork mineralization beneath the Lucky Strike deposit, included chlorite, illite (hydrated muscovite) and quartz. However, this spectral work only utilized select core samples, and spectral results were manually interpreted, thus limiting the overall number of spectra that could be processed.

Mary March

Outside of the main Buchans area, the Mary March alteration zone has received the most intensive mineral exploration, which first began in the early 1980s; however, it was not until the late 1990s that the first significant mineralization was identified. The alteration zone is defined by forty-three drillholes, which outlines one of the most significant zones of hydrothermal alteration developed within the study area (Figure 1). For a detailed description of the exploration history of the area, the reader is referred to Oosterman (2015). The following summary focuses on work conducted within the southwestern part of the alteration zone.

Abitibi-Price first conducted exploration in the area of the Mary March prospect in the early 1980s, which resulted in the discovery of numerous boulders of altered and weakly pyritic volcanic rock (Barbour and Thurlow, 1981). This area was investigated through various geophysical surveys along with the first drilling, which targeted a weak IP anomaly (Thurlow *et al.*, 1982). Building on the work completed by Abitibi-Price, BP-Selco explored the area from the mid-1980s to the early 1990s, conducting an airborne geophysical survey, along with various ground geophysical and geochemical surveys and diamond drilling (Thurlow *et al.*, 1987; Woods, 1988a; Barbour *et al.*, 1988, 1989, 1991; Woods *et al.*, 1988; Desnoyers *et al.*, 1992). One of the most notable outcomes from this work was the identification of a large base-metal soil anomaly in the area of the Mary March prospect (Woods *et al.*, 1988). As part of this exploration program, trenching was carried out that identified the first presence of high-sulphidation related alteration (alunite) associated with anomalous Au, Hg, Cd, Mo and Zn (Barbour *et al.*, 1989).

In the late 1990s, Phelps Dodge began exploration in the region. This work led to the discovery of two zones of massive sulphide mineralization, namely the Mary March and Nancy April prospects, which returned drillhole intersections of up to 10.1% Zn, 1.68% Pb, 0.64% Cu, 122.1 g/t Ag and 4.2 g/t Au over 9.63 m (Jagodits and Thurlow, 2000). As part of this exploration, the company conducted geochemical sampling of archived core, and included the Abitibi-Price drillcores in the southwestern portion of the alteration zone, near the trenching that exposed the high-sulphidation alteration. Samples from these drillcores locally returned values of up to 41 % Al_2O_3, indicating the aluminous nature of the alteration in this area (Thurlow, 1999).

In the mid-2000s, Candor Venture Corporation conducted drilling, along strike, to the southwest of the Abitibi-Price drillholes, in addition to conducting a geophysical survey over Beothuk Lake (Waldie, 2004a, b; Woods and Northcott, 2005). From this work, a narrow zone of semi-massive sulphide mineralization was intersected in drillcore, returning assays of up to 0.27% Zn, 0.05% Pb, 0.03% Cu, 4.7 g/t Ag and 162 ppb Au over 1.6 m (Waldie, 2004b).

Tower

The Tower alteration zone occurs within the Mary March Brook group. This area was first investigated in the 1940s, and has received intermittent exploration since that time up to the mid-2000s. During this period, eleven drillholes have been completed, which, combined with surface sampling, outline an alteration zone extending for up to 2.7 km along strike.

Abitibi-Price was the first to conduct reconnaissance drilling in the area of the alteration zone in the early 1940s and again in the late 1970s. Then in the mid- to late 1980s, BP-Selco conducted additional follow-up work consisting of reconnaissance drilling and various geophysical and geochemical surveys, which identified an alteration zone locally associated with anomalous base-metal enrichment, coincident with the inferred trace of a regional structural contact (Thurlow *et al.*, 1987; Barbour *et al.*, 1990, 1991; Desnoyers *et al.*, 1992). Alteration in the area is developed proximal to the regionally extensive Airport fault, which represents a major post-mineralization thrust that emplaces rocks of the Mary March Brook group over the Red Indian Lake Group (Thurlow *et al.*, 1992; Winter, 2000; Zagorevski *et al.*, 2016; Figure 1).

Noranda evaluated the Tower area during the 1990s, and refined the distribution of the sericitic alteration and overlying soil anomalies containing base-metal enrichment, outlining a zone with an approximate strike length of 1.2 km (Squires, 1994a; Banville *et al.*, 1998a, b). Compilation work, as part of these investigations, highlighted values of up to 1.2% Cu over 1 m near the southeastern limits of the alteration zone, and prospecting in the area returned samples with up to 1.3% Zn and 1.0% Cu (Banville *et al.*, 1998a). Samples from the alteration zone collected as part of this work were submitted for whole-rock geochemistry and were noted to contain a "Duck Pond" alteration signature (*e.g.*, elevated Hg/Na_2O and Ba/Sr ratios). Basal till sampling to the east of the alteration zone highlighted the presence of a copper–lead–zinc anomaly proximal to the area of recently discovered pyrophyllite alteration (Banville *et al.*, 1998b; *see* below).

During the late 1990s and the early 2000s, Buchans River Limited, in a joint venture with Billiton Exploration Canada Limited, furthered investigations in the area through various geophysical surveys and diamond drilling (Saunders *et al.*, 1999, 2000a, b, c; Wallis, 2001). Results from this work identified a prominent IP anomaly associated with the approximate outline of the alteration zone, in addition to intersecting elevated zinc and barium in drillcore, with intersections returning up to 2.1% Zn and 2.2% Ba over 1 m (Saunders *et al.*, 2000c)

Beaver Pond

The Beaver Pond alteration zone represents the most northeastern occurrence of sericite alteration developed within the Mary March Brook group (Figure 1). Early exploration was conducted during the 1980s and 1990s by various companies, these include: Abitibi-Price (Barbour, 1982, 1983, 1984, 1985a; Kilty and Dvorak, 1982; Thurlow, 1985a), BP-Selco (McKenzie and Hoffman, 1986; Poole, 1986; Poole *et al.*, 1987; Woods, 1988b), Noranda (Squires *et al.*, 1992; Graves and Squires, 1992; Squires and Marenghi, 1993), and Teck (Pickett and Scott, 1992). The Beaver Pond alteration zone was initially identified as a chargeability anomaly from an IP survey conducted by BP-Selco during the late 1980s (McKenzie and Hoffman, 1986). This geophysical anomaly was further highlighted by a soil survey that identified a significant Zn anomaly in the area (Poole *et al.*, 1987). Two drillholes tested the target, which intersected variably silicified and sericitized felsic volcanic rocks, locally hosting stringer sulphide mineralization with anomalous base- and precious-metal enrichment. The best results from this zone returned 0.6% Cu, >1.0% Pb, >1.0% Zn, 98 g/t Ag and 0.72 g/t Au over 0.03 m (DDH BJ-083; Thurlow *et al.*, 1987). Similar styles of alteration were also intersected in drillcore approximately 2.5 km to the northeast (McKenzie and Hoffman, 1986), along a coincident regional magnetic low, which extends northeast from the Beaver Pond area.

Celtic Minerals conducted work in the area in the 1990s and 2000s. This included an IP survey that confirmed the existing anomaly (Greene and Thurlow, 1997a; Stuckless *et al.*, 2009). Around the same time, the area was re-evaluated by Noranda, who conducted compilation work and additional basal-till sampling (Sheppard, 1997; Noranda Mining and Exploration Incorporated, 1998). Xmet Incorporated investigated the area along strike to the southwest of the Beaver Pond alteration zone and drill-tested a geophysical conductor and an area of anomalous soil geochemistry, some 3 km southwest of the Beaver Pond area, but no significant alteration was identified (Yeomans, 2011).

Mary March Brook

The Mary March Brook alteration zone is located approximately 2 km southeast of the Beaver Pond alteration zone (Figure 1). This alteration zone occurs within a structurally complex area of undivided rocks of the BRAB and is located beneath the location of mineralized boulders discovered in Mary March Brook, from which grades of up to 14.4% Zn, 9.3% Pb and 0.17% Cu have been reported (Pickett and Scott, 1992). Early exploration work during the 1980s and 1990s included much of the same work that covered the Beaver Pond area (*see* above).

The alteration zone was first drilled in 1992 (Pickett and Scott, 1992), and subsequent drilling was conducted in 1997, 2000 and 2001 by Vinland Resources (Chislett, 1997; Graves, 2000, 2001). In total, this zone has been tested by nine drillholes, spanning approximately 1.4 km of strike length, from which some 30 assays have been reported, with the best intersection returning 0.07% Cu over 0.4 m (Pickett and Scott, 1992). Locally, intersections of up to 65 m of sericitic alteration have been reported (DDH BJ-97-007; Graves, 2000). However, no assays are reported for most of the drillholes from this zone, despite having intersected sericitic alteration that has been sampled, based on visual inspection of the drillcore.

Seal Pond

Similar to the Beaver Pond area, the Seal Pond alteration zone is hosted within felsic volcanic rocks of the Mary March Brook group (Figure 1). This alteration zone is currently defined by 14 drillholes, and has a strike length of approximately 1.8 km.

The first reported exploration in the Seal Pond area was by Amoco Canada Petroleum during the late 1970s, but no significant results were identified (Donovan, 1978). In the mid-1980s, Abitibi-Price carried out geophysical surveys and limited diamond drilling on the Seal Pond prospect (Barbour, 1985b; Thurlow, 1985b; Thurlow and Barbour, 1985a). Then, in the mid- to late-1980s, BP-Selco began exploration in the area (McKenzie and Hoffman, 1986; Barbour *et al.*, 1988, 1989), which continued up to the early 1990s (Pumphrey, 1990; Barbour *et al.*, 1991). This work included general prospecting and geological mapping, which identified local zones of pyritic alteration. Noranda commenced work in the area in the early 1990s, identifying several conductors from an airborne geophysical survey (Squires *et al.*, 1992). This was followed by a basal till-sampling program that highlighted anomalies, coincident with the geophysical anomalies (Squires, 1994b, c). Samples submitted for whole-rock geochemistry as part of this work were noted to display a weak Duck Pond alteration signature (*i.e.*, elevated Hg/Na_2O and Ba/Sr ratios; Squires, 1994b). Follow-up work on the anomalies continued up to the mid-1990s in the form of soil sampling, additional geophysical surveying and diamond drilling (Squires and McDonald, 1995; McDonald, 1995). Local intersections of sericitic alteration were accompanied by sulphide mineralization, which returned values of up to 3.25% Zn and 0.54% Cu over 0.1 m (Squires, 1996).

From the late 1990s to mid-2010s, Vinland Resources conducted exploration in the area, including geophysical and geochemical surveys, and diamond drilling, which defined the current extent of the alteration zone (Chislett, 1998, 2004, 2005a, b, c, 2006, 2007; Chislett and Graves, 2004; Chislett *et al.*, 2005, 2012; Chislett and Wilton, 2006). As part of regional compilation work by Altius Minerals in the mid-2010s, drillcore from the area was re-logged, noting narrow intersections of previously unsampled base-metal mineralization. The best intersections reported from this re-sampling included 13.45% Zn, 0.4% Cu and 2 g/t Ag over

0.2 m and 4.68% Cu, 0.4% Zn and 6.8g/t Ag over 0.25 m (Seymour *et al.*, 2015).

Woodman's Brook

Located to the northwest of the Tower zone, the Woodman's Brook alteration zone is outlined by fifteen drillholes, defining a zone over a 1.5-km-strike length in a north–south orientation and a width of up to 600 m (Figure 1). Similar to the Tower zone, this alteration is hosted within felsic volcanic rocks of the Mary March Brook group. Reconnaissance geological mapping, geochemical and geophysical surveys and drilling were conducted in the area during the early 1960s by the Buchans Mining Company and ASARCO (Swanson, 1962a, b, 1963, 1964); this work identified several anomalies for additional follow-up. In the mid-1980s, Abitibi-Price conducted geophysical surveys over the area (Thurlow, 1984; Barbour, 1985c). Then, in the late 1980s, BP-Selco conducted re-sampling of diamond-drill core in addition to geological mapping and limited drilling (Thurlow *et al.*, 1987; Barbour *et al.*, 1990).

Noranda investigated the area in mid-1990s, which largely consisted of compilation work (Arseneau *et al.*, 1995a). Subsequently, the area was explored by Newfoundland Mining and Exploration Limited, targeting intersections of silica–sericite alteration noted in historical drill logs (Tuach and Saunders, 1994). In 1995, the company conducted prospecting, mapping and an IP survey, the latter of which identified a strong chargeability anomaly coincident with a weakly mineralized Zn–Pb–Ag zone intersected in drillcore (Saunders and Scott, 1995). Follow-up drilling identified several intersections of pyritic alteration in association with base-metal mineralization (Saunders *et al.*, 1996). In the early 2000s, Buchans River Limited conducted additional geophysical and geochemical surveys (Saunders *et al.*, 2000a, b, c; Pettit, 2000a). Most recently, core from the area was re-logged as part of compilation work conducted by Altius Minerals in the mid-2010s (Seymour *et al.*, 2015).

This area was also investigated as part of a master's thesis examining alteration zones within the Buchans area (Winter, 2000). Results of the study outlined two zones of alteration at Woodman's Brook consisting of: 1) disseminated, stringer and vein pyrite and lesser sphalerite and chalcopyrite in association with chlorite–sericite alteration hosted within mafic volcanic rocks, and 2) quartz–sericite–pyrite alteration hosted within felsic volcanic rocks.

Little Sandy

The Little Sandy alteration zone is located approximately 4.5 km to the east of the Tower zone, and is hosted in intermediate to mafic volcanic rocks of the Mary March Brook group. These rocks are variably chloritized and silicified proximal to the development of copper-dominated stockwork-style mineralization. Although this area has been explored since the early 1940s, the first documented, publicly available work did not occur until the early 1970s. The zone is defined by twenty-seven drillholes distributed over 800 m of strike length, and contains a non-43-101 compliant resource estimate of 160 000 tonnes at 1.9% Cu (historical ASARCO documents).

The following is an abbreviated account of the exploration work conducted in the area. For a more in-depth summary, the reader is referred to (Moore *et al.*, 2013). The Little Sandy prospect was first discovered in outcrop by ASARCO and was subsequently drilled in the early 1940s, and again in the 1950s. During the late 1970s, Price Company Limited and ASARCO continued exploration in the area (Barbour, 1978; Pearce and Thurlow, 1979; Swanson, 1979), which was subsequently followed-up by Abitibi-Price in the early- to mid-1980s (Barbour *et al.*, 1983; Thurlow and Barbour, 1985a, b; Thurlow, 1985a), and by BP-Selco during the late 1980s (Thurlow *et al.*, 1987). Noranda investigated the area surrounding the Little Sandy alteration zone in the early- to late-1990s, completing compilation work, along with geophysical and geochemical surveys and limited diamond drilling (Graves and Squires, 1992; Squires, 1993, 1994a; Arseneau *et al.*, 1995b; Banville *et al.*, 1998a, b). During the same time, Newfoundland Mining and Exploration and GT Exploration also conducted work in the area, which largely consisted of compilation work and geochemical surveys (Saunders, 1997a, b). Buchans Resources Limited (formerly Buchans River Limited) has explored the area from the early 2000s until present, conducting various geophysical and geochemical surveys in addition to diamond drilling (Pettit, 2000b; Saunders *et al.*, 2000a, b, c; Reed, 2000; Woods, 2000; Saunders, 2001; Wallis and Barrett, 2001; Wallis, 2001; Harris and Woods, 2001; Moore *et al.*, 2008, 2013).

This work has outlined several zones of sericitic hydrothermal alteration within the immediate area of the Little Sandy alteration zone, which are associated with a prominent IP anomaly, extending for upward of 4.5 km along strike. However, only the immediate area of the Little Sandy prospect was evaluated as part of this study.

Connell

The Connell alteration zone is limited in extent, and is defined by seven drillholes and surface trenching that outline a zone extending approximately 200 m along strike. Here, exhalative-style mineralization is hosted within volcaniclastic rocks interbedded with siltstone and chert of the

Red Indian Lake Group. The alteration noted in association with the development of the mineralization consists of weak to moderate silicification or sericite ± carbonate alteration, locally accompanied by elevated levels of finely disseminated pyrite and rare chalcopyrite or galena (Squires, 1994d). Information regarding the previous work on the Connell prospect is limited, as much of this work occurred prior to the 1950s. The following exploration history is taken from Squires (1994d):

> "The Connell prospect was discovered in 1929 by Hans Lundberg during pioneering regional geophysical surveying (equipotential). Trenching of the equipotential anomaly led to the discovery of the ore lens which at the time returned 1.0 m of 0.20% Cu, 6.20% Pb, 31.30% Zn, 9.60 opt Ag and 0.09 opt Au (source – old Memo in Asarco files). Narrow massive pyrite and ore bands were intersected in drillholes 1929-2 and 1929-4 (no assays or core available from this drilling). In the early 1950s drilling returned 0.3% Cu, 11.9% Pb, 25.4% Zn, 4.6 opt Ag and 0.1 opt Au over 0.6 m (DDH RI-002) at approximately 20 m vertical depth below the original trench."

The earliest reported work on the Connell prospect includes that by MJ Boylen Engineering (Laughlin, 1967), with no further work reported until the 1990s, when Noranda initiated exploration in the area. The company conducted compilation work along with mapping, soil and basal-till sampling, and geophysical surveys along with limited drilling (Graves and Squires, 1992; Sheppard, 1996; Squires, 1994d; Banville *et al.*, 1998a, b). In 2012, the area was covered by an airborne geophysical survey conducted by Xstrata and Canstar (Wolfson, 2012), but no other work/reports is/are publically available.

SWIR SPECTRAL RESULTS

Initial investigations in the region consisted of thirty drillholes from eight sericite alteration zones plus limited examination of core from the Buchans area (Table 1). Based on preliminary SWIR spectral data, these zones of sericitic alteration have been further subdivided based on their white mica and aluminous alteration signatures. Four preliminary subdivisions are proposed for the sericite alteration zones, these are: 1) advanced argillic (Mary March, Tower), 2) phyllic–muscovite-dominated (Mary March Brook, Beaver Pond, Seal Pond, Woodman's Brook), 3) phyllic–chlorite-dominated (Little Sandy), 4) sub-propylitic (Connell; Figure 2).

The following discussion provides an initial description of the results from the orientation survey conducted at Buchans, along with a detailed description of the results from the various alteration zones investigated farther to the east. The SWIR data were generally collected at 3 m intervals using a TerraSpec® Pro spectrometer, and the mineralogical results represent the output from spectral software (The Sprectral Geologist (TSG™); version 8.0.7.4). This

Table 1. List of drillholes examined from each of the respective alteration zones along with the total number of spectra collected from each area

Alteration Zone	Drillholes Examined	Number of Spectra Collected	Notes
Buchans	H-08-3356; H-08-3407; H-817	128	Select intervals only
Mary March	BJ-065; BJ-066; BJ-067; BJ-068; BJ-069; BJ-073; BJ-074; BJ-077; BJ-078; MM-12-025; MM-14-033	549	
Tower	BR-2K-08-005; BJ-023	97	Drillcore and outcrop samples; select samples
Beaver Pond	BJ-083	38	
Mary March Brook	BJ-92-005ext; BJ-97-007	144	
Seal Pond	SP-95-001	66	
Woodman's Brook	BE-95-003; BJ-046	12	Select drillcore samples only
Little Sandy	BJ-013; BJ-016; BJ-021: BJ-022; LS-07-017; LS-94-001	149	
Connell	CP-93-001; RI-001	155	

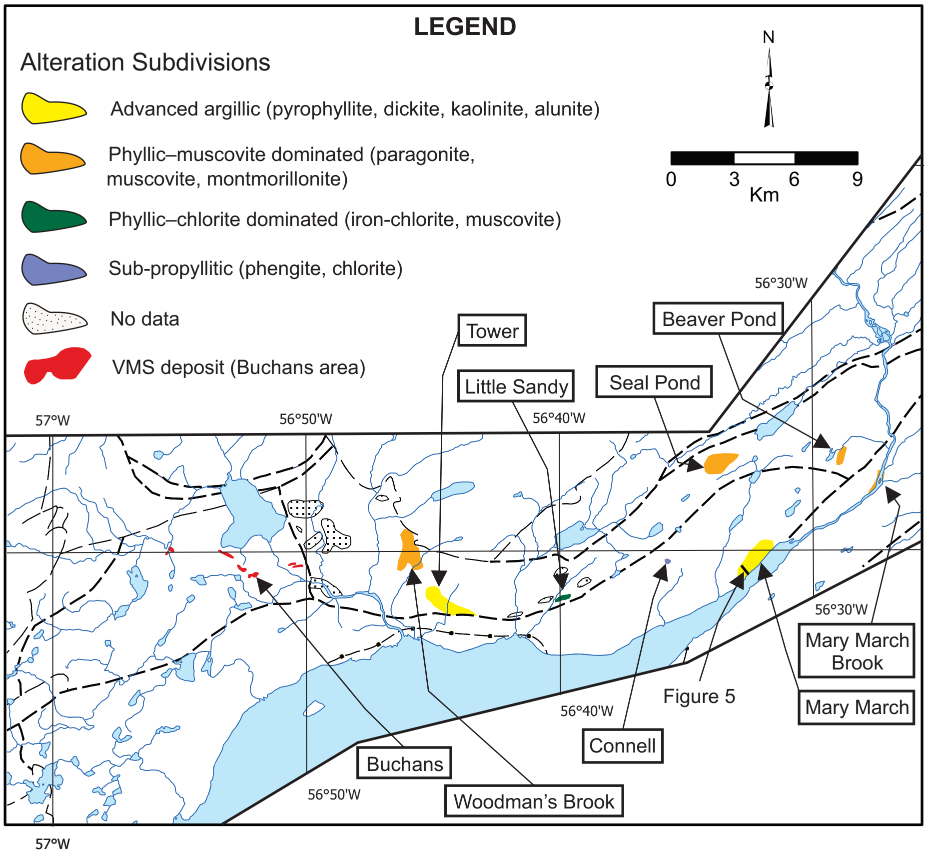

Figure 2. *Alteration zones subdivided on the basis of the most dominant aluminous or white mica alteration minerals associated with mineralization within previously identified sericitic alteration zones. (Legend for geological contacts (dashed lines) as shown in Figure 1.)*

software provides the two most abundant minerals present (Min 1 and Min 2) within individual analysis by comparing the spectral data against a reference library of known minerals. Within the following dataset the principal focus was to use the SWIR data to subdivide the previously described sericite alteration, primarily on the basis of the Al-OH absorption features associated with white mica minerals; these are: paragonite (2180–2195 nm), muscovite (2195–2215 nm), and phengite (2215–2225 nm; Pontual *et al.*, 1997). Illite variants of the above white mica minerals are expressed by the spectral software as either paragonitic illite, muscovitic illite, or phengitic illite.

BUCHANS DEPOSITS

Lucky Strike and Rothermere

As part of an orientation study within the Buchans area, select intervals from two drillholes (H-08-3356; H-08-3407; Moore *et al.*, 2009) were investigated using SWIR spectrometry to determine the mineralogy of the sericitic alteration developed within the footwall rocks of *in-situ* mineralization of the Lucky Strike deposit. Host rocks to this alteration consist of siliciclastic sediments and mafic volcanic rocks. From this data, the predominant footwall alteration developed immediately beneath the massive sulphide mineralization consists of muscovitic illite, siderite, montmorillonite and lesser chlorite (Plate 1A; Figure 3). In drillhole H-08-3356, the upper portion of the scanned interval (2–50 m) consisted of massive pyrite and abundant carbonate veining dominated by aspectral (no identifiable mineral signature) and siderite. Upon transitioning into the underlying siltstone interval, muscovite, muscovitic illite and siderite, along with lesser montmorillonite, become the predominate minerals (Figure 3). In drillhole H-08-3407, the scanned interval (130–165 m) targeted basaltic rocks, situated stratigraphically below those scanned in drillhole H-08-3356, hosting stockwork-style mineralization of the Lundberg deposit. Here, the sericite alteration developed within the basalt consists of muscovitic illite and montmorillonite (Figure 3; note the full extent of the mineralized intersection for DDH H-08-3407 shown in Figure 3 was not examined).

The third drillhole from the Buchans area (H-817; Buchans Mining Company unpublished drill log) targeted structurally repeated intervals of the same stratigraphic unit in the area of the Rothermere deposit, which represents an example of transported ore. The two intervals selected (110–145 m and 320–470 m) intersect three structurally repeated panels (based on industry logging), which contain a quartz-feldspar-phyric rhyolite unit of the Buchans Formation (Buchans Group). The first two structural panels (110–142 m and 320–427 m) are characterized by phengite and phengitic illite white mica alteration of the quartz-feldspar-phyric rhyolite, having Al-OH wavelengths between 2015–2025 nm. The lowermost structural panel (427–455 m), which consist of the same quartz-feldspar-phyric rhyolite and is proximal to mineralization, displays a distinct shift in its Al-OH wavelength (~2200 nm) and is dominated by muscovitic illite and lesser muscovite along with montmorillonite (Plate 1B–D; Figure 3).

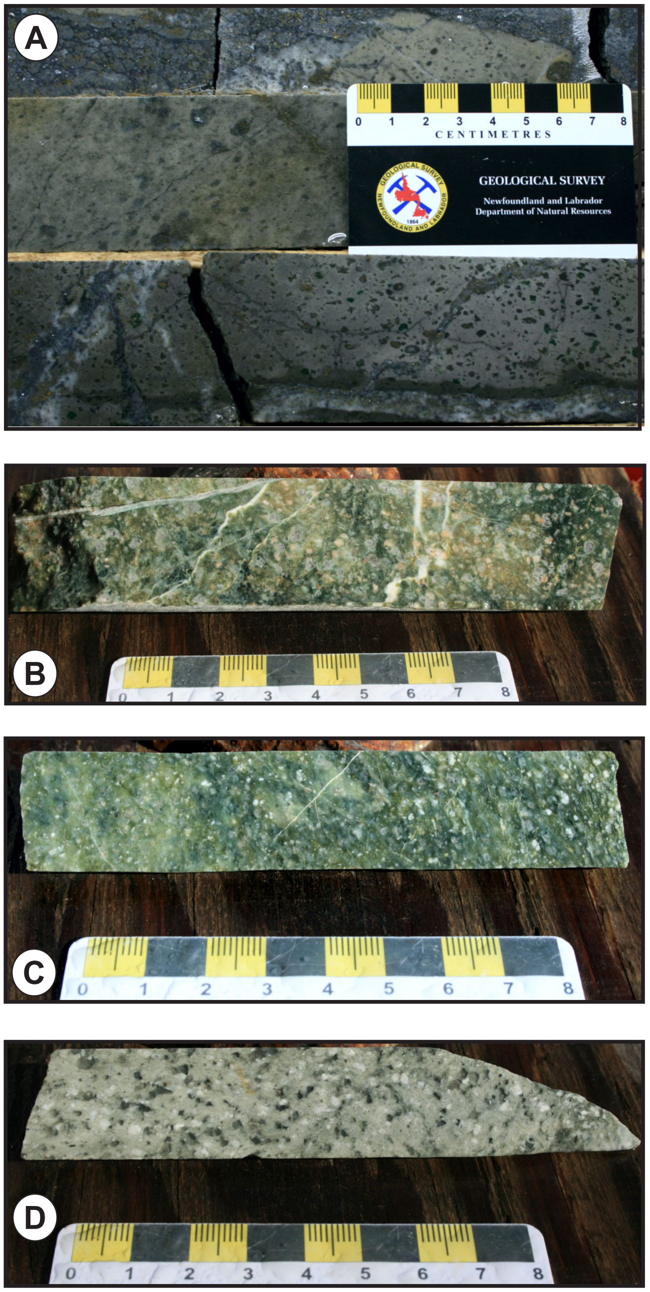

Plate 1. *Representative photographs of the Buchans area alteration. A) Green muscovitic illite alteration within footwall basaltic rocks of the Lucky Strike deposit; B) Quartz-feldspar phyric felsic volcanic unit, Buchans River Formation, containing phengite alteration, 130 m depth; DDH H-817; C) Quartz-feldspar phyric felsic volcanic unit, Buchans River Formation, containing phengitic illite alteration, 220 m depth; DDH H-817; D) Quartz-feldspar phyric felsic volcanic unit, Buchans River Formation, containing muscovite alteration, 380 m depth; DDH H-817.*

The SWIR data presented here support the findings of previous mineralogical investigations into the sericitic alteration of the Buchans area (Henley and Thornley, 1981; Thurlow, 1981; Winter, 2000; van Hees, 2011), and provide a detailed picture of its distribution. However, most of the chlorite identified within the SWIR spectral data is classified as Fe–Mg chlorite, contrary to the Mg-chlorite reported proximal to mineralization (Henley and Thornley, 1981; Winter, 2000). Given the predominance of muscovite in association with the development of the mineralization, this alteration is characterized as being phyllic dominated.

ADVANCED ARGILLIC ALTERATION

Mary March

Eleven drillholes were examined from the Mary March area, which largely focused on a section across the alteration zone near the area reported to contain high-sulphidation minerals (BJ-065 to BJ-074; Thurlow *et al.*, 1982; Barbour *et al.*, 1983). The SWIR data identified the presence of pyrophyllite, kaolinite and alunite in a number of drillholes, outlining two separate zones of advanced argillic alteration (Figures 4 and 5). The rocks hosting this alteration are inferred to be felsic, intermediate and mafic volcanic rocks along with lesser felsic intrusive units, but the exact nature of the protolith is difficult to determine given the intensity of the alteration. The western alteration zone (Figure 5) is largely dominated by muscovite and paragonite with lesser montmorillonite and rare pyrophyllite. Variations in the Al-OH wavelengths for drillhole BJ-065 progresses from an interval of muscovite (Al-OH ~2202 nm), into an interval of paragonite (Al-OH ~2196 nm) with localized pyrophyllite, indicative of more acidic hydrothermal conditions, then back into muscovite (Al-OH ~2198 nm) and finally ending in Fe–Mg chlorite (Plate 2A; Figure 4A). The eastern alteration zone (Figure 5) contains pyrophyllite, kaolinite and alunite (Plate 2B). Here, the advanced argillic alteration is underlain by mafic to intermediate volcanic rocks dominated by muscovite–phengitic illite, which is, in turn, intruded by felsic dykes dominated by phengite (Figure 4B). Both zones of advanced argillic alteration are enveloped within broader zones of muscovite or muscovitic illite, which transition outward into Fe–Mg chlorite or phengite-altered intermediate to mafic volcanic rocks.

Industry assay data, from the limited sampling of the western alteration zone, returned weakly anomalous gold (20 ppb) and no significant base-metal mineralization. The bulk of anomalous zinc and gold in this area is concentrated within the adjacent muscovite–chlorite alteration, which locally returns values of up to 0.1% Zn, 0.1% Pb, 1 g/t Ag

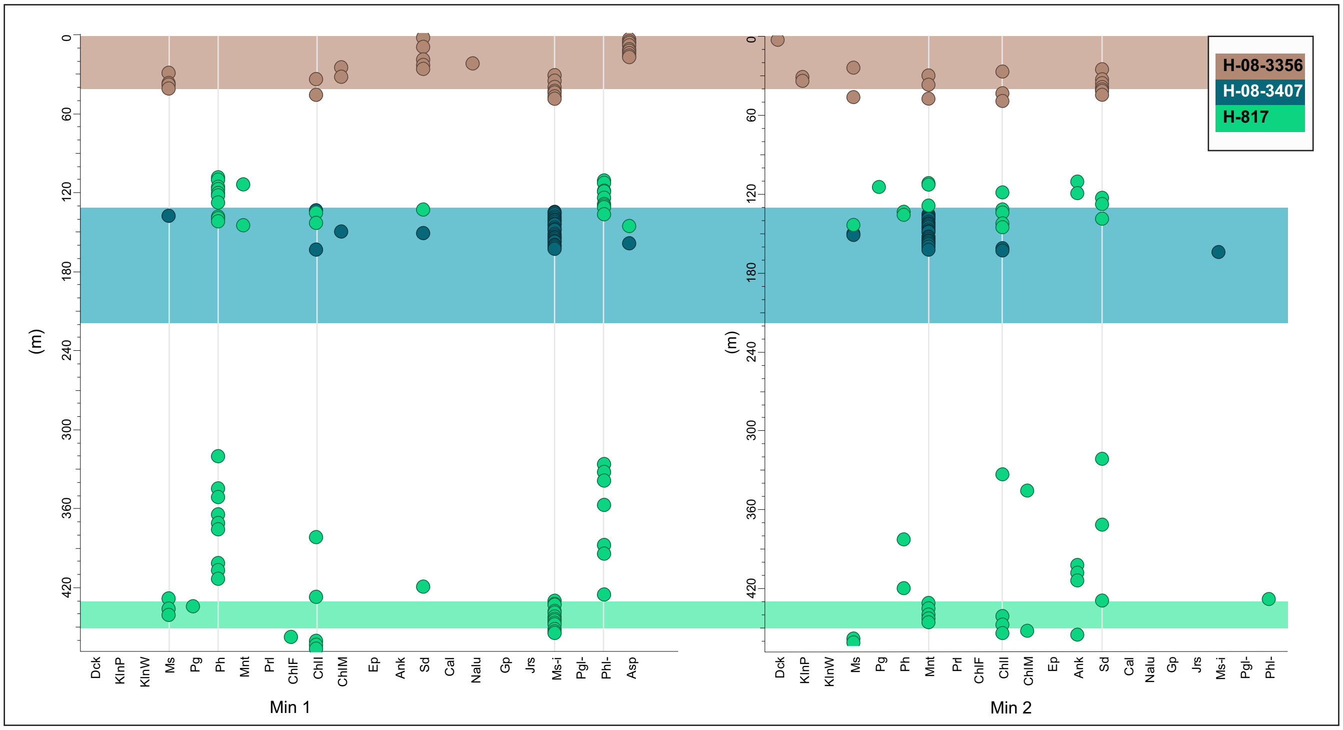

Figure 3. *Spectral results from select drillholes from the Buchans area (Min 1, 128 points; Min 2, 85 points). Shaded areas denote mineralized intervals colour coded to the corresponding drillhole. Note mineral abbreviations include: Dck – dickite; KlnP – kaolinite; KlnW – kaolinite; Ms – muscovite; Pg – paragonite; Ph – phengite; Mnt – montmorillonite; Prl – pyrophyllite; ChlF – Fe-chlorite; Chll – Fe-Mg chlorite; ChlM – Mg-chlorite; Ep – epidote; Ank – ankerite; Sd – siderite; Cal – calcite; Nalu – Na-alunite; Gp – gypsum; Jrs – Jarosite; Ms-i – muscovitic illite; Pgl – paragonitic illite; Phl – phengitic illite; Asp – aspectral.*

and 40 ppb Au over 2 m. (DDH BJ-068; Barbour *et al.*, 1988; Figure 5B, C). No assay data are available for the eastern advanced argillic alteration zone; however, this zone is proximal to the semi-massive sulphide mineralization intersected by Candor Venture Corporation occurring approximately 400 m to the southwest, which assayed 0.27% Zn, 0.05% Pb, 0.03% Cu, 4.7 g/t Ag and 162 ppb Au over 1.6 m (Waldie, 2004b).

In addition to the examination of the Abitibi-Price drillholes (BJ-065 to 074), select intervals from two, recent drillholes (2012-2014), were also examined for the presence of advanced argillic alteration. These holes intersect VMS-style mineralization developed at both the Nancy April (DDH MM-14-033; Oosterman, 2015) and the Mary March (DDH MM-12-025; Green and Wolfson, 2013) prospects, and are situated approximately 800 m to the northeast of the drillholes in Figure 5 (*see* Figure 6). The SWIR data collected from these two drillholes further support the presence of advanced argillic alteration within the area.

Drillhole MM-14-033, which is located along strike of the western alteration zone (Figure 5) discussed immediately above, contains similar styles of alteration. This drillcore displays a gradational transition from background Fe–Mg chlorite into an interval of muscovite–paragonite (~10 m core width) within intermediate volcanic rocks. This interval of white mica alteration is associated with minor base- and precious-metal mineralization assaying 1.2% Cu, 0.2% Zn, 4.9 g/t Ag and 0.4 g/t Au over 5.3 m (Oosterman, 2015). The muscovite–paragonite forms marginal to the main interval of pyrophyllite-bearing alteration, which extends from approximately 70 to 110 m depth (Plate 2C; Figure 4C). The lower contact of the pyrophyllite interval is marked by a sharp structural contact, separating it from underlying phengite dominated alteration inferred to be hosted within mafic volcanic rocks (Plate 2D; Figure 4C). The phengite–phengitic illite–Fe–Mg chlorite developed below the pyrophyllite alteration continues to approximately 200 m depth, where there is a sharp but gradational transition into an interval of Fe–Mg chlorite-altered mafic volcanic rocks; these rocks host stockwork-style mineralization assaying 1.0% Zn, 0.2% Pb and 2.9 g/t Ag over 93.7 m (Oosterman, 2015; Plate 2E, 2F; Figure 4C). The transition back into phengite-dominated alteration toward the bottom of the drillhole is associated with the emplacement of felsic intrusive rocks as seen

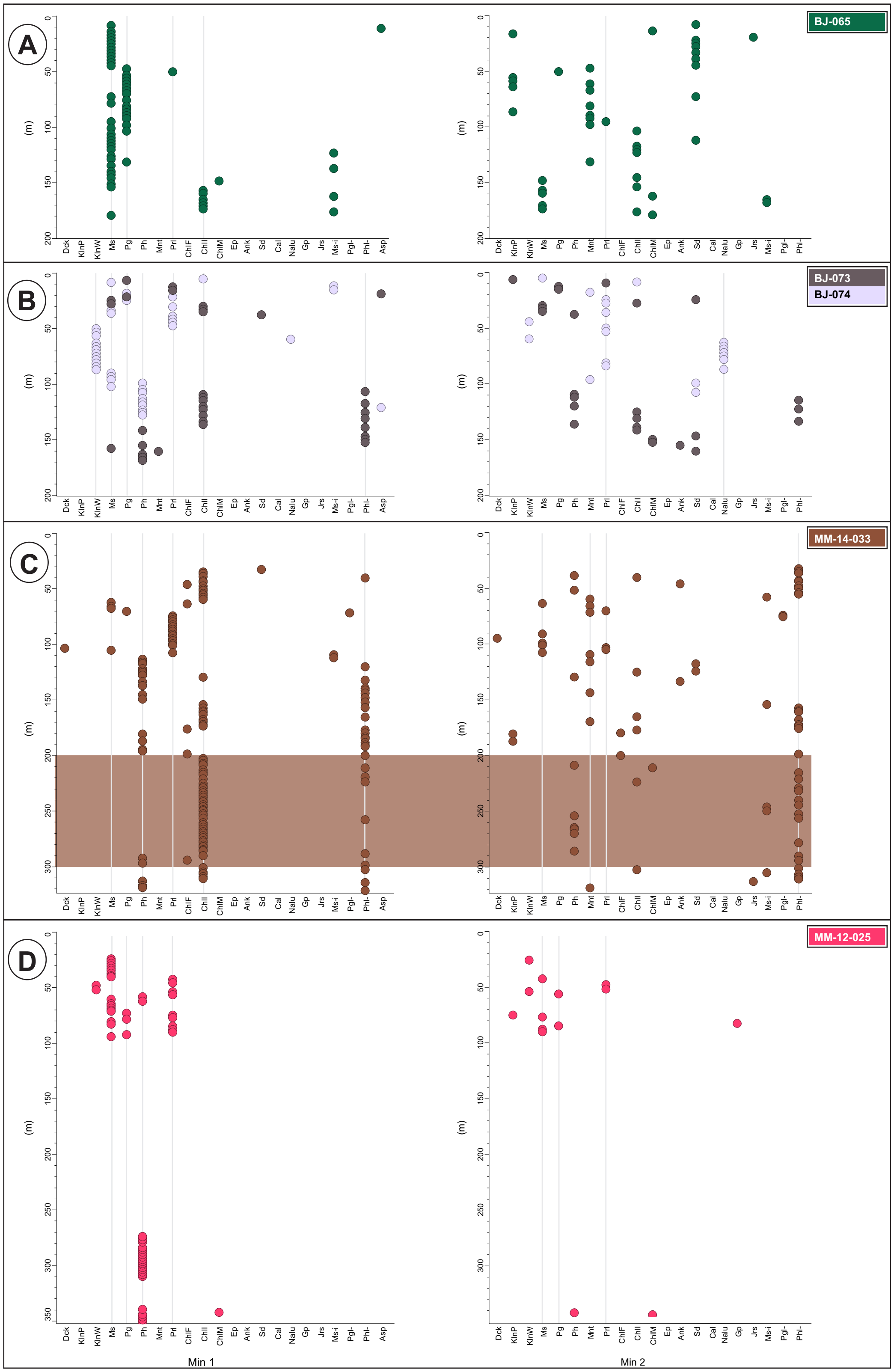

Figure 4. *Spectral results from select drillholes from the Mary March alteration zone. A) DDH BJ-065 (Min 1, 62 points; Min 2, 43 points); western alteration zone; B) DDH BJ-073 and BJ-074 (Min 1, 77 points; Min 2, 48 points); eastern alteration zone; C) DDH MM-14-033 (Min 1, 143 points; Min 2, 83 points); shaded area denotes the mineralized interval of the drillhole; D) DDH MM-12-025 (Min 1, 58 points; Min 2, 15 points). Refer to Figure 3 for mineral abbreviations.*

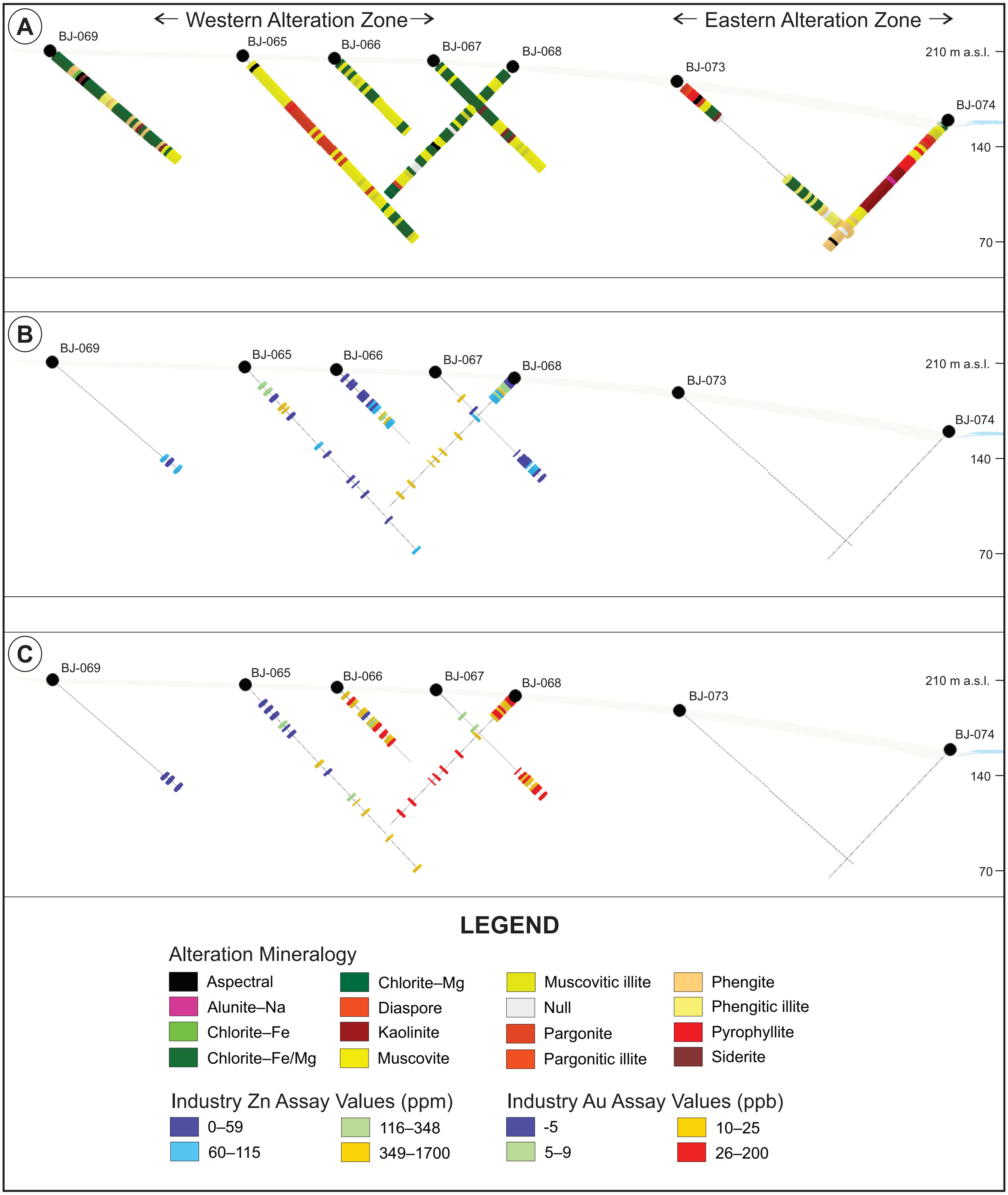

Figure 5. *Schematic cross-section through the southwestern part of the Mary March alteration zone. A) Drillholes colour coded to the spectral results of Min 1 in Figure 4; B) Available zinc assay values from industry data for the drillholes; C) Available gold assay values from industry data for the drillholes. Assay values from (Barbour* et al.*, 1988). For the location of the cross-section refer to Figure 2.*

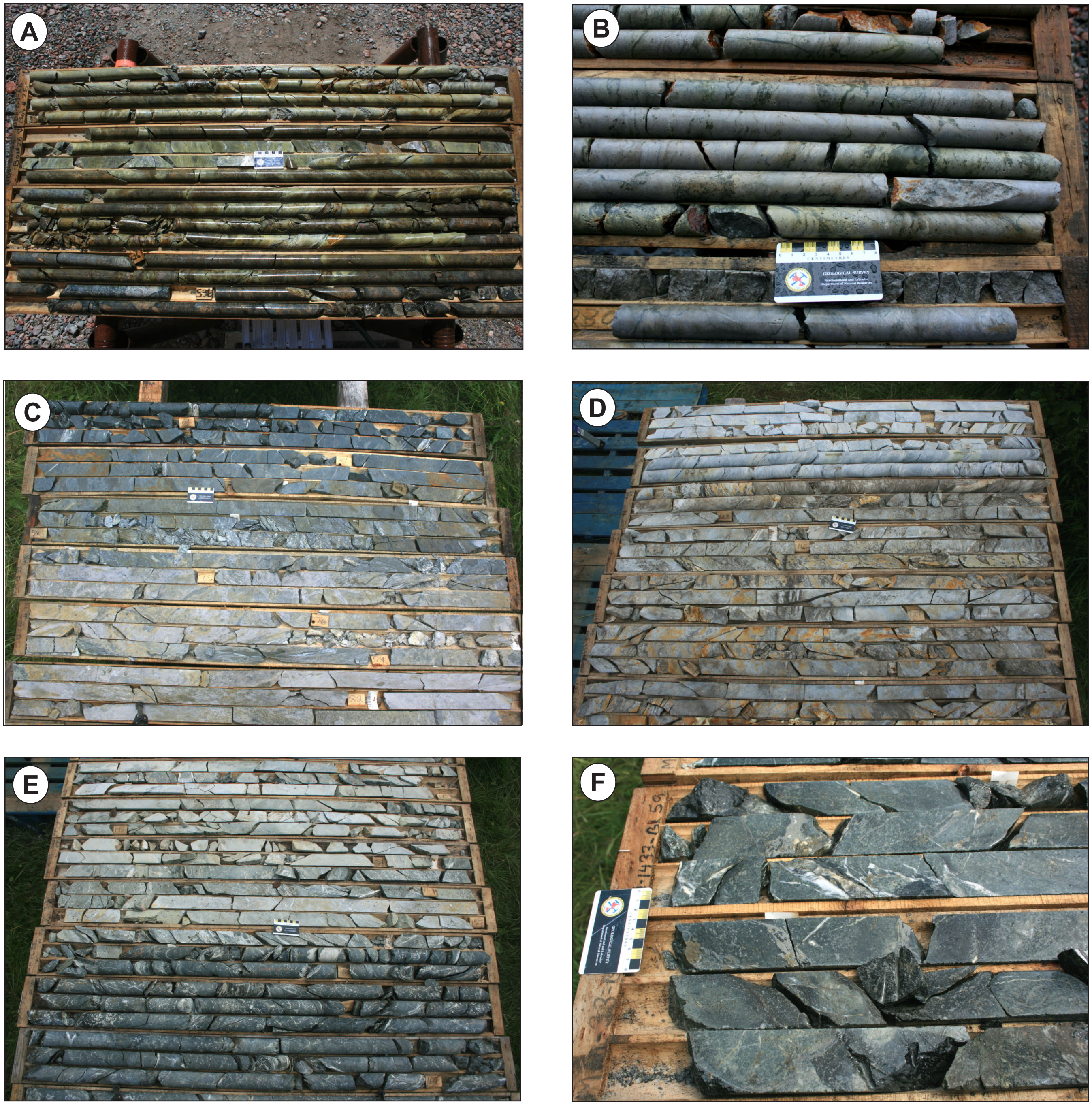

Plate 2. *Photographs from the Mary March alteration zone. A) Gradational transition from white mica into chlorite-dominated alteration; 158 m depth, DDH BJ-065; B) Kaolinite–alunite alteration with disseminated pyrite; 70 m depth, DDH BJ-074; C) Gradational transition from chlorite-altered intermediate volcanic rocks (top) through an interval of muscovite (middle) and then to pyrophyllite-dominated alteration (bottom); 60–80 m depth, DDH MM-14-033; D) Sharp transition from pyrophyllite-dominated (top; light-coloured alteration) to phengite-dominated (bottom) alteration; 110 m depth, DDH MM-14-033; E) Gradational transition from phengite- to chlorite-altered mafic volcanic rocks; 150 m depth, DDH MM-14-033; F) Zinc-rich stockwork mineralization in chlorite-altered basalt; 240 m depth, DDH MM-14-033.*

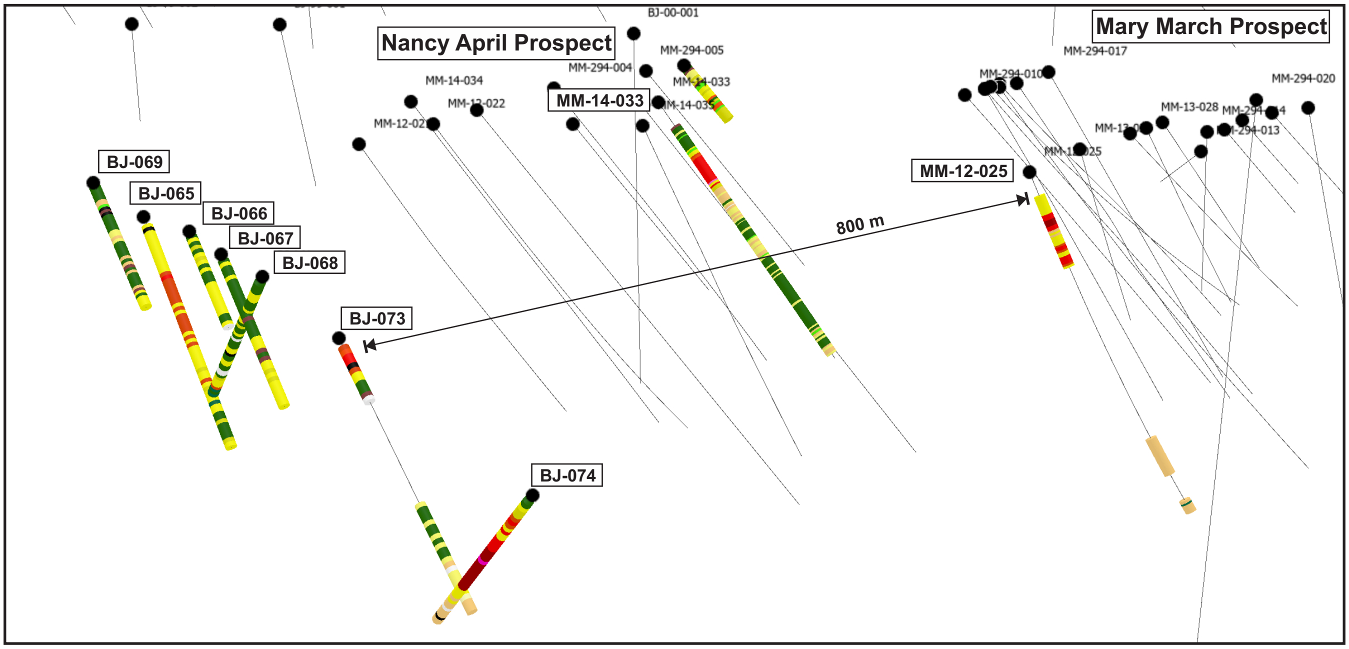

Figure 6. *Schematic 3-D model illustrating the location of drillholes analyzed within the Mary March alteration zone, colour coded to the spectral results of Min 1 in Figure 4; for the legend refer to Figure 5.*

to the southwest (BJ-074); these rocks have been sampled for geochronological study.

Drillhole MM-12-025, is located along strike from the eastern alteration zone (Figure 5) discussed above and is on the same section line as MM-14-033 (Figure 6). This hole is situated southwest of the main Mary March prospect and contains advanced argillic alteration (*N.B.* only portions of this drillhole were examined; 23-96, 274-310 and 340-350 m). The alteration observed within the examined intervals is inferred to be hosted within intermediate to felsic volcanic rocks, however, the exact nature of the protolith is difficult to ascertain due to the intensity of the alteration. This drillhole collared into muscovite-dominated alteration, which then grades into pyrophyllite–muscovite–paragonite and lesser kaolinite (Figure 4D). At the lower boundary of the pyrophyllite alteration, there is a gradational transition back to muscovite. The pyrophyllite, which is indicative of more acidic conditions, contains significantly less pyrite than the bounding muscovite alteration, but is locally crosscut by cm-scale quartz–pyrite-bearing veins. Toward the bottom of the drillhole, quartz–pyrite-altered, irregularly shaped, cm-scale fragments are contained within a light-green phengite-altered matrix. This alteration is crosscut by rare zinc-rich veins, locally returning values of 7.0% Zn, 3.9% Pb, 0.5% Cu, 90.5 g/t Ag and 198 ppb Au along with anomalous Cd and Hg over 0.16 m (Green and Wolfson, 2013). This relationship indicates that VMS-style mineralization locally overprints phengite alteration. No assay data are available for the advanced argillic alteration within drillhole MM-14-033, but the available data for drillhole MM-12-025 do not indicate any significant enrichment of base- or precious-metals within the advanced argillic alteration.

The known extent of the Mary March alteration zone corresponds to a distinct magnetic low in airborne geophysical surveys. Although the northeastern boundary of the alteration has been defined through drilling, the corresponding magnetic low extends for at least 900 m beyond the limit of current drilling in the southwestern part of the zone. This area of the magnetic low is locally coincident with anomalous gold in soil values (Woods *et al.*, 1988).

Tower

Within the Tower alteration zone, SWIR spectra collected from one complete drillhole, along with select representative samples from a second drillhole and surface outcrops, were utilized to classify the alteration zone. The drillhole surveyed in detail (DDH BR-2K-08-005; Harris and Woods, 2001) is located in the northwestern part of the alteration zone, whereas the representative samples from drillcore and outcrop come from the southeastern part of the zone. Results from the northwest part of the zone illustrate the predominance of Fe–Mg chlorite and muscovite within mafic and felsic volcanic rocks and associated volcaniclastic deposits (Figure 7). Anomalous base-metal values, reported from the limited sampling of the drillhole, highlight two intervals of zinc and lead enrichment located at approximately 30 and 80 m depth. The upper interval is dominated by Fe-chlorite–siderite–kaolinite–dickite, hosted within a felsic intrusive unit, whereas the lower interval is dominated by Fe–Mg chlorite–muscovitic illite–muscovite, and is hosted within siliceous felsic volcanic rocks (Figure 7; Plate 3A). Deeper down the hole (>150 m), dickite and kaolinite occur within an interval of more predominant muscovite alteration (Figure 7). However, no associated base-metal enrichment has been identified here, based on the limited sampling (two samples). The development of kaolinite may indicate increasing proximity to the Airport fault, as observed in the area of Little Sandy (*see* below).

Representative samples of drillcore from the southeastern portion of the alteration zone (not shown) contain paragonitic illite–montmorillonite, whereas outcrop samples contain pyrophyllite–dickite (Plate 3B). These samples are located proximal to the regional trace of the Airport fault and are hosted within what is inferred to be felsic volcanic

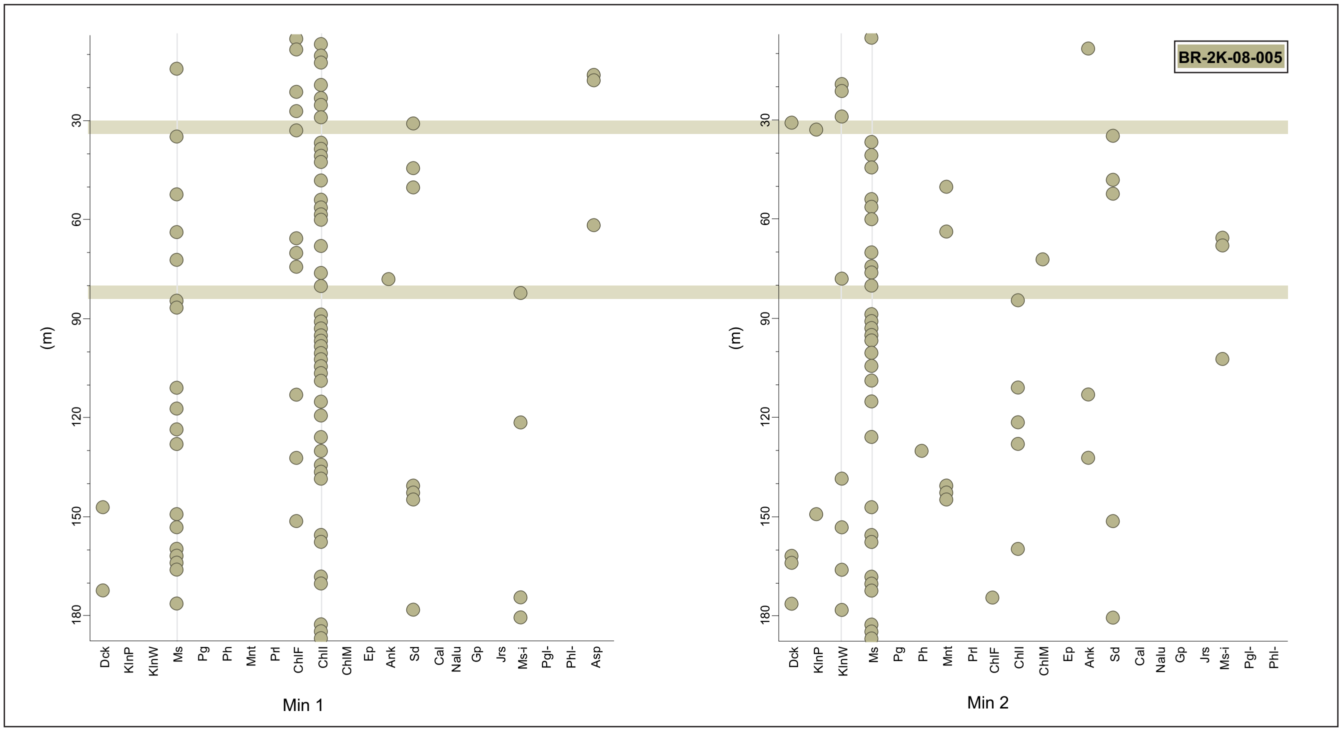

Figure 7. *Spectral results from the Tower alteration zone (Min 1, 90 points; Min 2, 68 points). Shaded areas denote mineralized intervals colour coded to the corresponding drillhole. Refer to Figure 3 for mineral abbreviations.*

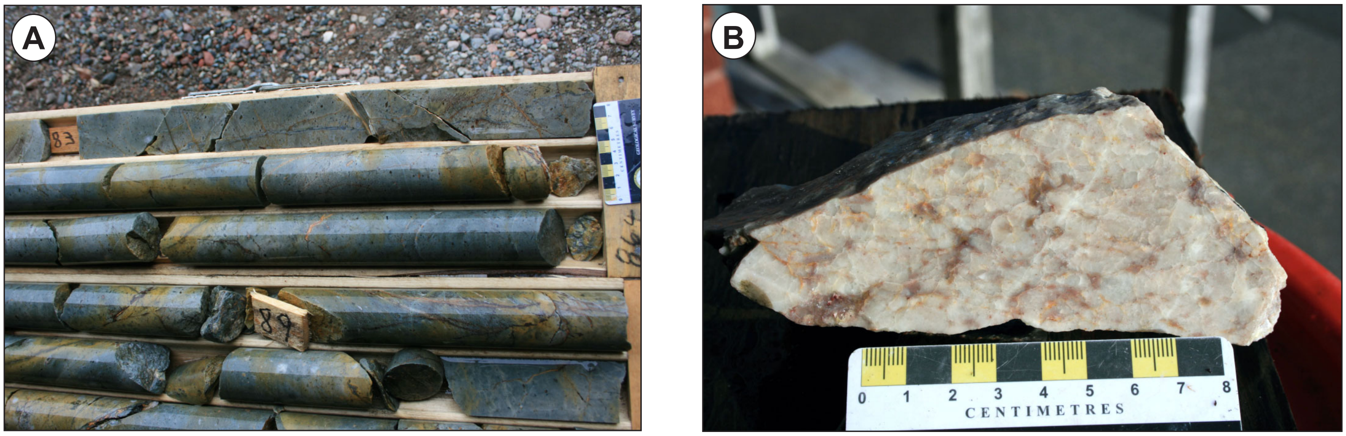

Plate 3. *Photographs from the Tower alteration zone. A) Muscovite-dominated alteration in association with anomalous base-metal mineralization, 85 m depth; DDH BR-2K-08-005; B) Pyrophyllite–dickite alteration in an outcrop sample from the southeastern portion of the alteration zone.*

rocks. The identification of pyrophyllite–dickite within the Tower alteration zone, coupled with the nearby paragonitic illite–montmorillonite from drillcore, forms the basis for classifying the zone as an example of advanced argillic alteration (Figure 2). However, this is preliminary, given the limited number of samples displaying this style of alteration. Further expanding the distribution of the advanced argillic alteration in this area will be the focus of future studies.

PHYLLIC ALTERATION (MUSCOVITE DOMINATED)

Beaver Pond

One drillhole (DDH BJ-083; Thurlow *et al.*, 1987) was examined from the Beaver Pond alteration zone, which is characterized by pervasive Fe–Mg chlorite and lesser muscovite accompanied by silicification, disseminated pyrite and anomalous base- and precious-metal mineralization. Based on the abundance of muscovite and lesser paragonite within the alteration, this zone is classified as an example of phyllic alteration (Figure 2). The alteration is developed within a lapilli tuff, consisting of cm-scale, subangular fragments predominantly consisting of weakly feldspar-phyric rhyolite; however, the type of host rock is difficult to determine due to the intensity of the alteration. Three intervals of anomalous gold–silver mineralization have been identified from the industry assay data for the drillhole. The first interval, occurring at about 60 m depth contains 130 ppb Au and 5.2 g/t Ag in association with muscovitic illite (Plate 4; Figure 8; Thurlow *et al.*, 1987). The second and third intervals occur at 100, and 110 m depth, returning 180 ppb Au and 4.8 g/t Ag and 725 ppb Au and 98 g/t Ag along with >1.0% Zn and >1.0% Pb and 0.6% Cu, respectively (Thurlow *et al.*, 1987). Both of these intervals are associated with Fe–Mg chlorite–paragonite (Figure 8). Spectral data from the drillhole illustrates a shift in the Al-OH wavelength from ~2200 nm to ~2196 nm below 90 m depth, in associa-

Plate 4. *Photograph of muscovitic illite alteration associated with anomalous gold (130 ppb); 60 m depth, DDH BJ-083, Beaver Pond alteration zone.*

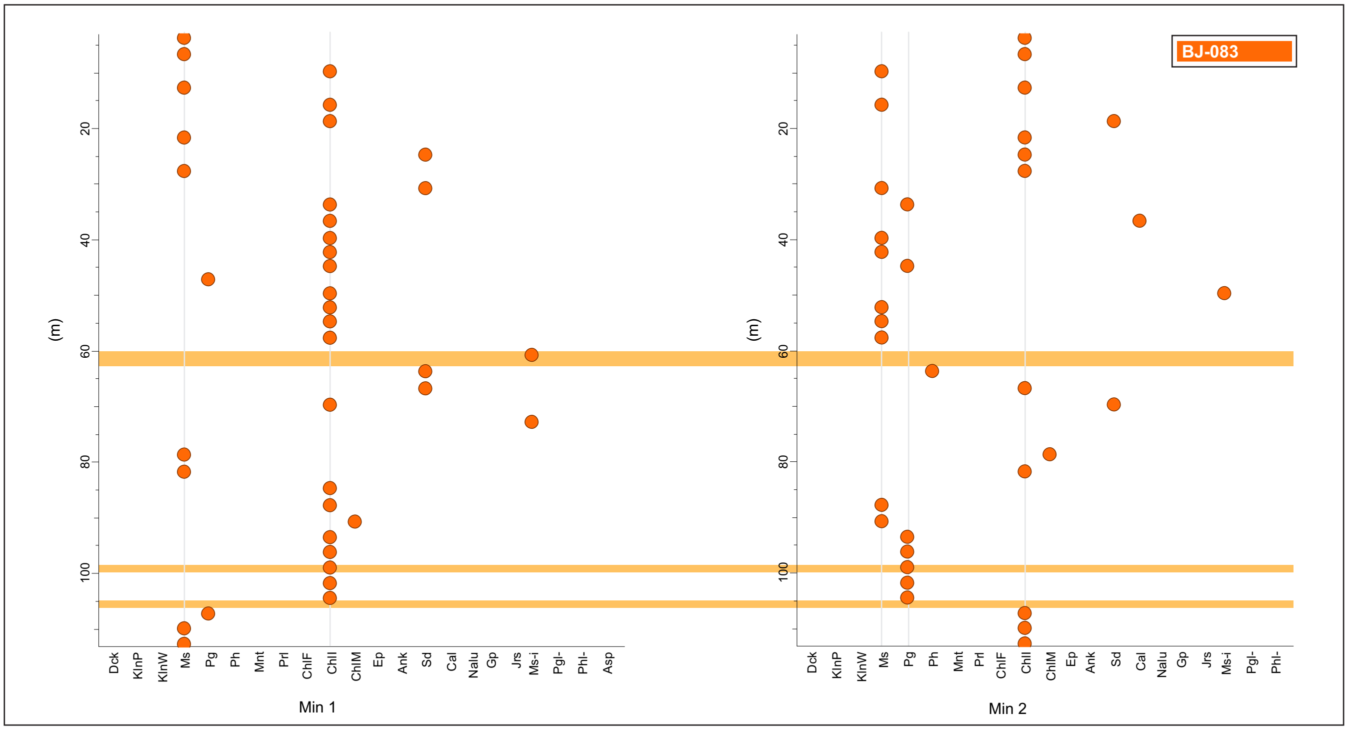

Figure 8. *Spectral results from the Beaver Pond alteration zone (Min 1, 38 points; Min 2, 35 points). Shaded areas denote mineralized intervals colour coded to the corresponding drillhole. Refer to Figure 3 for mineral abbreviations.*

tion with the development of paragonite alteration and increased silicification. This drillcore contains white mica–chlorite alteration for its entire length, with the best assay values occurring within 5 m of the end of the hole.

Mary March Brook

Two drillholes from the Mary March Brook alteration zone were examined; only one intersected visible sericitic alteration. Based on the abundance of muscovitic illite associated with hydrothermal alteration in the area, this zone is classified as an example of phyllic alteration (Figure 2). Within drillhole BJ-97-007 (Chislett, 1997), located in the northeastern portion of the zone, there are two intersections of visible sericite alteration. The first interval is located between 117–140 m, and is dominated by phengitic illite associated with a fine-grained felsic intrusive unit (Figure 9). Marginal to this interval, the alteration is dominated by Mg-chlorite–muscovite, developed between ~100–110 m, and potentially represents an alteration related to the emplacement of the felsic intrusive unit, but is not associated with any visually significant white mica alteration (Figure 9). The second interval of sericitic alteration is developed between 175–240 m, is dominated by muscovitic illite along with Fe and Fe–Mg chlorite (Plate 5), and is locally associated with the development of up to ten percent disseminated pyrite. Both intersections are hosted within similar fine-grained felsic rocks, and the observed shift in the Al-OH wavelength from ~2215 (117–140 m) to ~2205 (175–240 m) is inferred to reflect changes in the overall hydrothermal alteration, potentially indicating more acidic conditions associated with the lower interval. Below 240 m depth, the muscovite–phengite–Fe-chlorite–muscovitic illite spectral signatures are associated with a pink rhyolite unit, which does not display any significant hydrothermal alteration (Figure 9).

Plate 5. *Photo of muscovitic illite–chlorite alteration; 220 m depth, DDH BJ-97-007, Mary March Brook alteration zone.*

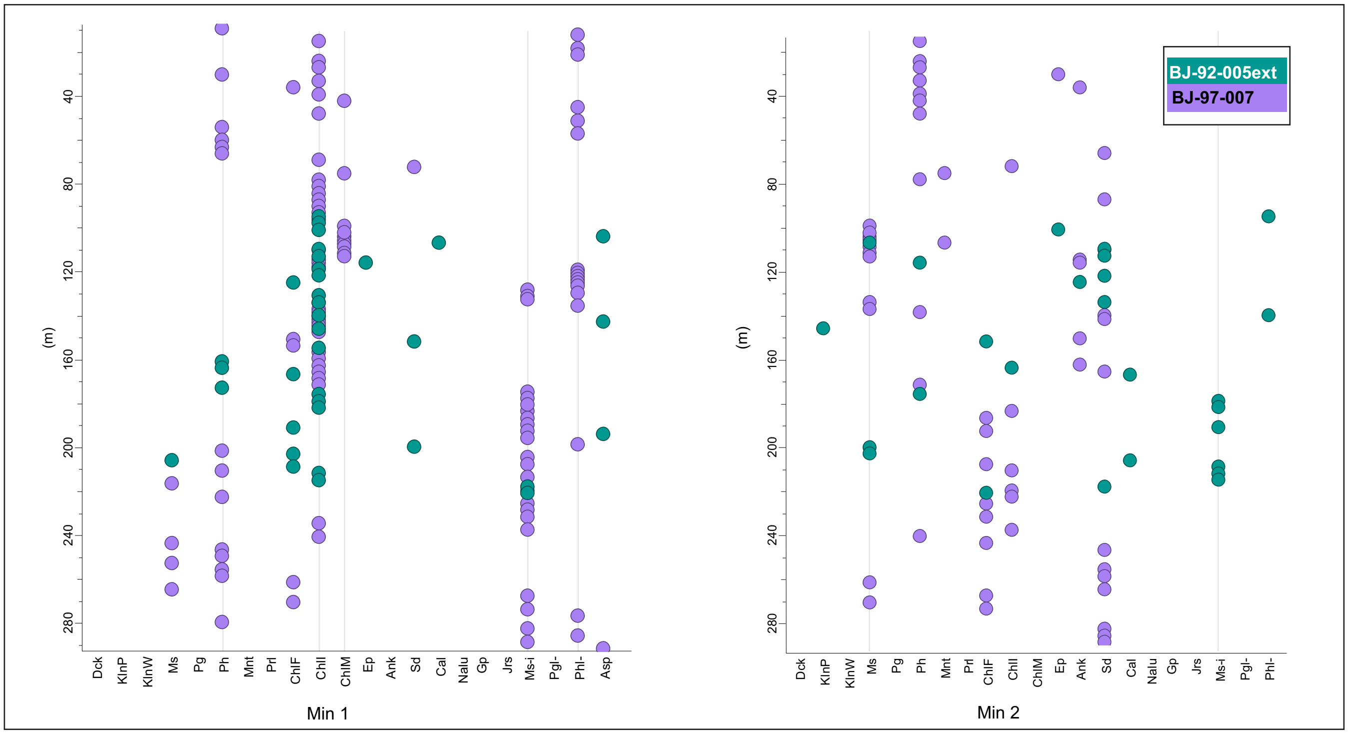

Figure 9. *Spectral results for select drillholes from the Mary March Brook alteration zone (Min 1, 144 points; Min 2, 87 points). Refer to Figure 3 for mineral abbreviations.*

Drillhole BJ-92-005ext was drilled in the southwestern part of the alteration zone, but failed to intersect any significant alteration; only the lower portion of this drillhole was available for examination. The Fe–Mg chlorite from 95 to 165 m characterize the background alteration signature of the variably vesicular, red to green mafic volcanic rocks (Figure 9). The Fe to Fe–Mg chlorite–muscovitic illite developed toward the bottom of the drillhole (165–220 m) is associated with a relatively unaltered quartz-feldspar phyric rhyolite unit.

Seal Pond

One drillhole was examined from the Seal Pond alteration zone, along with several surface grab samples collected from subcrop. Drillhole SP-95-001 is located within the central portion of the alteration zone (Squires, 1996). This drillhole is predominantly composed of moderately to strongly foliated felsic to intermediate crystal to lapilli tuff. The upper portion of the drillhole is dominated by Fe–Mg chlorite and lesser phengite, which persists to approximately 80 m depth (Figure 10). Below 80 m depth, Fe–Mg chlorite and muscovite dominate the spectral data, with muscovite becoming the predominant phase proximal to the disseminated and stringer sulphide mineralization (100 to 120 m depth; Plate 6; Figure 10). Similar to the Beaver Pond and Mary March Brook alteration zones, the Al-OH wavelength is observed to decrease from ~2214 nm within the phengite-dominated interval, to ~2200 nm within the area of mineralization and most intense muscovite alteration. The Fe–Mg chlorite–muscovite persists to approximately 170 m depth, below which the drillhole consists of more intermediate to mafic volcanic rocks that are dominated by Fe–Mg chlorite alteration (Figure 10). Based on the abundance of muscovite associated with mineralization, the Seal Pond alteration zone is classified as an example of phyllic alteration (Figure 2).

Woodman's Brook

The Woodman's Brook alteration zone was not systematically surveyed; rather representative samples from the alteration zone were analyzed using SWIR as part of preliminary investigations of the area. These samples were collected from two drillholes, BE-95-003 (Saunders *et al.*, 1996) and BJ-046 (Buchans Mining Company unpublished drill log). Both drillholes were noted to intersect quartz–sericite–pyrite alteration in association with local base-metal mineralization (Winter, 2000). The alteration and mineralization are hosted within variably altered felsic volcanic rocks. Within drillhole BE-95-003, the best assay interval returned 2.6% Pb, 1.9% Zn, 0.1% Cu and 12.7g/t Ag over 0.5 m (108.2-108.7 m; Saunders *et al.*, 1996). Marginal to the mineralized intersection, felsic volcanic rocks are characterized by Fe–Mg chlorite–muscovite alteration, with an

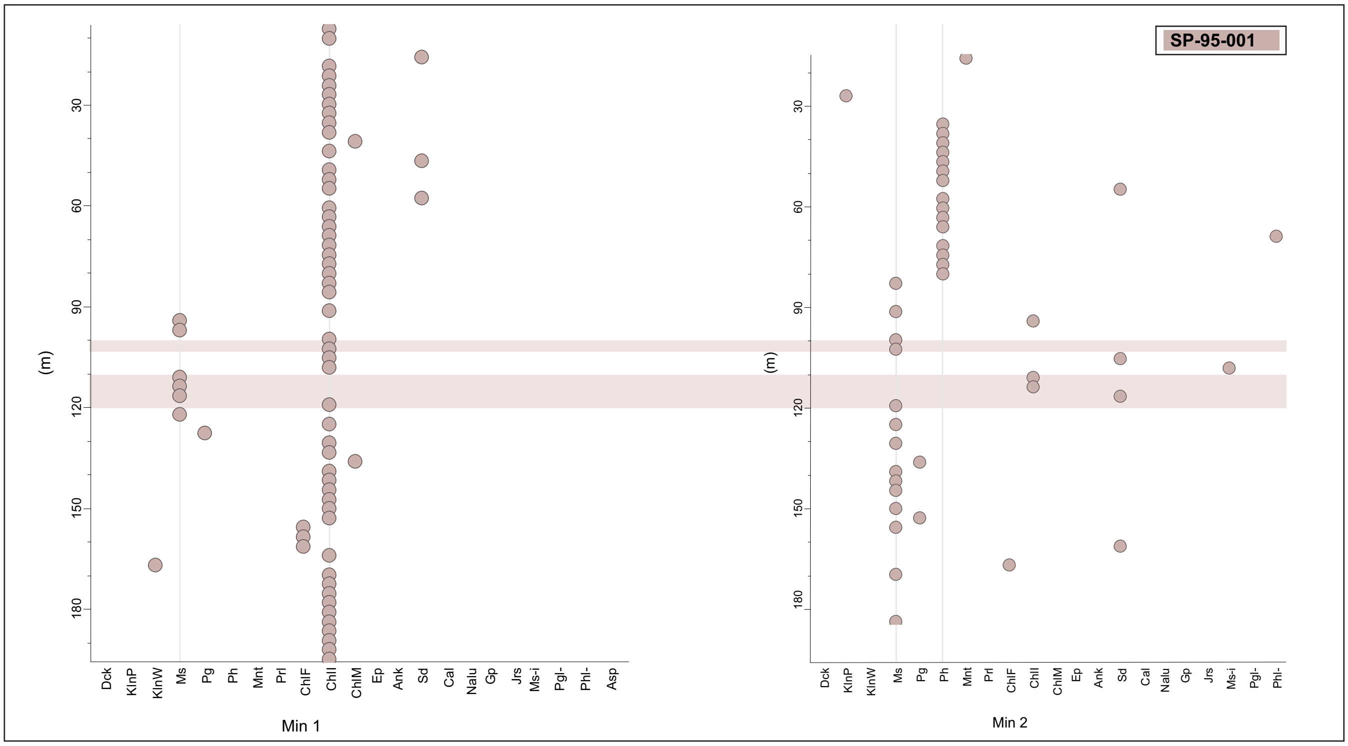

Figure 10. *Spectral results from the Seal Pond alteration zone (Min 1, 66 points; Min 2, 44 points). Shaded areas represent the main mineralized intersections colour coded to the corresponding drillhole. Refer to Figure 3 for mineral abbreviations.*

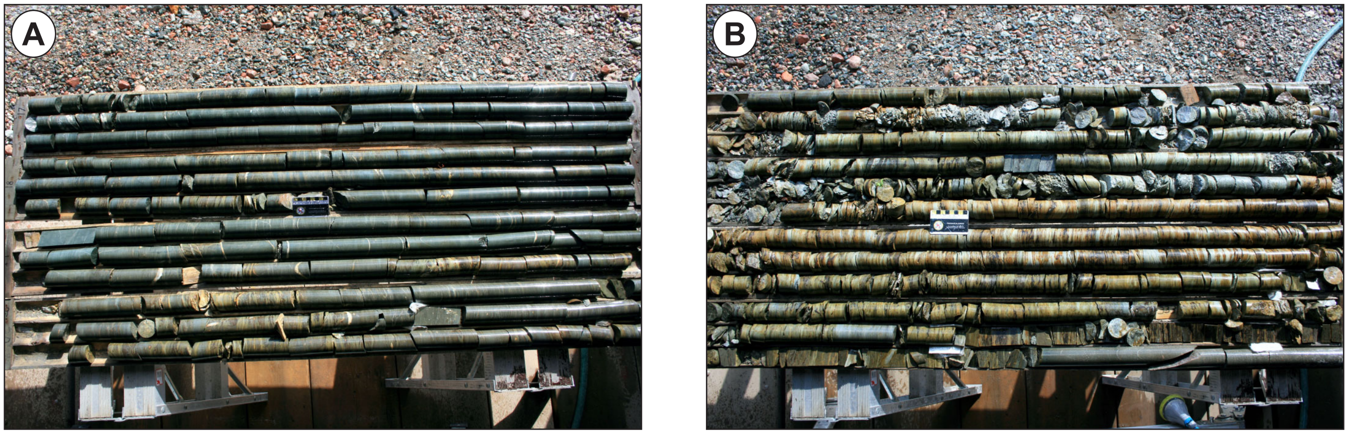

Plate 6. *Photographs from the Seal Pond alteration zone (DDH SP-95-001). A) Gradational transition from Fe–Mg chlorite–phengite (top) to Fe–Mg chlorite–muscovite (bottom) alteration within crystal tuff (83 m depth); B) Interval of well-developed muscovite alteration locally associated with anomalous copper mineralization (100 m depth).*

abrupt change to muscovitic illite–muscovite, marked by the intrusion of a distinctly quartz-phyric felsic unit (Plate 7A). Representative samples from both above and below the mineralized interval, which is associated with the white mica alteration, are dominated by muscovite based on spectral data (Plate 7B). Based on limited sampling and visual inspection of the drillcore, this alteration persists to the end of the hole. In drillhole BJ-046, located 275 m to the west of drillhole BE-95-003, four samples collected over a 150 m interval of alteration all contain muscovitic illite–muscovite based on SWIR data. This alteration is associated with similar base-metal mineralization, locally assaying up to >1.0% Zn, 0.8% Pb, 0.1% Cu, 27.6g/t Ag and 205 ppb Au over 0.1 m (Thurlow et al., 1987).

Based on geophysical surveys of the area, the Woodman's Brook alteration zone corresponds to an airborne magnetic low, an airborne EM high, and a local IP chargeability anomaly. Given the predominance of muscovite in association with the localized base-metal mineralization, this zone is classified as a zone of phyllic alteration (Figure 2).

PHYLLIC ALTERATION (CHLORITE DOMINATED)

Little Sandy

Six drillholes from the area surrounding the Little Sandy alteration zone were analyzed using SWIR spectrometry. Four of these drillholes are located proximal to the alteration zone (DDH BJ-013; BJ-016; LS-07-017; LS-94-001), whereas the remaining two are located to the southwest, outside of the alteration zone, and are proximal to the regional trace of the Airport fault (BJ-021; BJ-022). The entire length of drillhole BJ-013 is dominated by Fe–Mg

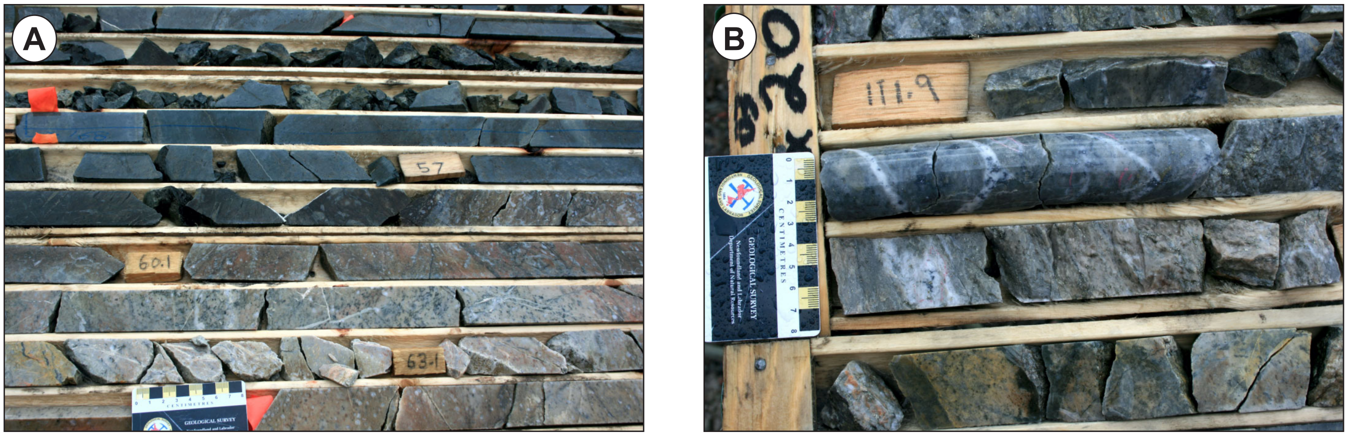

Plate 7. *Photographs from the Woodman's Brook alteration zone (DDH BE-95-003). A) Sharp transition from Fe–Mg chlorite–muscovite-altered felsic volcanic rock to a quartz-phyric, muscovitic illite-altered felsic unit (60 m depth). B) Base-metal-rich stockwork-style mineralization associated with muscovitic illite–muscovite alteration (112 m depth).*

chlorite, Fe-chlorite and lesser muscovite and paragonite primarily hosted within mafic volcanic rocks (Figure 11). The mineralized portion of this drillhole, located between 24 to 40 m, locally assaying up to 5.2% Cu, 0.5% Zn, 0.2% Pb and 62.4g/t Ag over 1.3 m (Pearce and Thurlow, 1979), corresponds with the development of Fe-chlorite–paragonite alteration. This mineralized interval is enveloped by Fe–Mg chlorite and lesser muscovite. Within drillhole LS-07-017, which undercuts BJ-013, only the mineralized interval (82 to 91 m) of the hole was analyzed using SWIR spectrometry; assays from this interval returned 1.8% Cu over 9.3 m (Moore *et al.*, 2008). This interval, composed of a rhyolite breccia, displays a similar signature to that in BJ-013, consisting entirely of Fe-chlorite along with rare paragonite. The remaining two drillholes from the alteration zone, LS-94-001 and BJ-016, are located 200 m to the southwest of the above drillholes, with LS-94-001 undercutting BJ-016. Both drillholes failed to intersect any significant mineralization and are dominated by Fe–Mg chlorite and rare Fe-chlorite (Figure 11); note only the lower portion of drillhole LS-94-001 was available for study.

Two drillholes, BJ-021 and BJ-022, located 0.5 and 1 km away from the Little Sandy alteration zone, respectively, intersect the inferred trace of the Airport fault. The upper part of drillhole BJ-021, representing the hangingwall, is composed of mafic volcanic rocks and is dominated by Fe–Mg chlorite, similar to that observed marginal to the Little Sandy alteration zone (Figure 11). At approximately 60 m depth, the drillhole intersects the inferred Airport fault, below which the drillhole is dominated by red to green siltstone characterized by phengite based on SWIR data. In addition, minor kaolinite appears to be developed proximal to the fault contact, extending upward into the hangingwall rocks for up to 35 m (Figure 11). The drillhole BJ-022 collars in red pebble conglomerate with spectral signatures dominated by kaolinite–montmorillonite. At approximately 50 m depth, the conglomerate is in sharp structural contact with mafic volcanic rocks displaying Fe- and Fe–Mg chlorite, kaolinite and lesser muscovite (Figure 11). These mafic volcanic rocks continue to 70 m depth, where there is a sharp contact with a felsic intrusive characterized by phengite–phengitic-illite alteration, which continues to the bottom of the drillhole.

SUB-PROPYLLITIC ALTERATION

Connell

Drillcore from the Connell alteration zone lack any significant visual evidence of hydrothermal alteration, supporting the inferred distal exhalative-style of mineralization, locally, identified in the area (Graves and Squires, 1992). Two drillholes were investigated using SWIR spectrometry, RI-001, which is located 100 m southwest of drillhole RI-002, which returned 25.4% Zn, 11.9% Pb, 0.3% Cu, 158 g/t

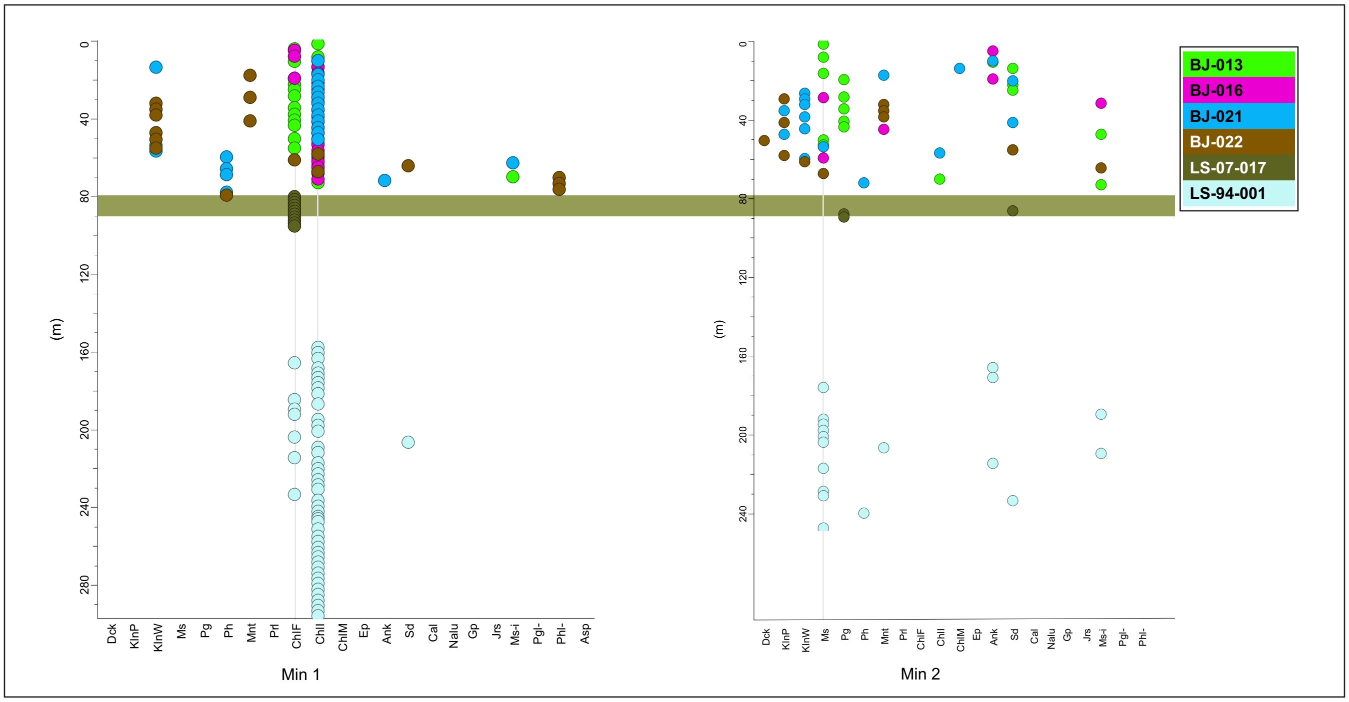

Figure 11. *Spectral results from select drillholes from the Little Sandy alteration zone (Min 1, 149 points; Min 2, 75 points). The shaded area represents the main mineralized interval colour coded to the corresponding drillhole. Refer to Figure 3 for mineral abbreviations.*

Ag and 0.3 g/t Au over 0.6 m, and CP-93-001, which undercuts hole RI-001 (Squires, 1994d). Spectral data from drillhole RI-001 is dominated by phengite to phengitic illite alteration, aside from one interval of muscovite–Fe-chlorite developed between approximately 30-45 m (Figure 12). The phengite to phengitic illite are developed within volcaniclastic rocks and interbedded siltstone, whereas the interval of muscovite–Fe-chlorite marks a felsic tuffaceous unit and lesser interbedded siltstone and chert hosting disseminated chalcopyrite; potentially representing the targeted exhalative horizon. Likewise, drillhole CP-93-001 is dominated by phengite to phengitic illite, along with intervals of Fe-chlorite and lesser Fe–Mg chlorite, and muscovite (Figure 12). The entire drillhole consists of felsic tuffaceous units interbedded with volcaniclastic and siliciclastic rocks, all of which lack any visual evidence of hydrothermal alteration or related mineralization.

DISCUSSION

The collection of systematic downhole SWIR spectral data from drillcore hosting sericite alteration, has based on key mineral assemblages enabled the classification of four preliminary subdivisions; these subdivisions include: advanced argillic, phyllic (muscovite- and chlorite-dominated), and sub-propyllitic (Figure 2). The subdivisions highlight areas of more intense hydrothermal alteration (*e.g.*, advanced argillic) and provide measurable, scalar variables that enables the comparison of the various alteration zones. When used, in conjunction with detailed structural analysis to determine the effects of deformation on primary alteration patterns, these SWIR-defined scalar variables can potentially provide a means to vector toward areas of more intense hydrothermal alteration and potentially mineralization.

Development of white mica alteration in the form of phengite, muscovite and paragonite locally displays a spatial association with the hydrothermal mineralization. In most instances, a systematic decrease in the Al-OH wavelength is observed with decreasing distance from mineralization. Figure 13 highlights this by illustrating the downhole variation of the Al-OH wavelength for two select drillholes, one that has been structurally disrupted, and one that displays a primary alteration zonation. In Figure 13A, the Al-OH wavelength from a drillhole in the Buchans area shows a shift from phengite-dominated (2215–2225 nm Al-OH wavelengths), white-mica alteration within a structurally repeated, quartz-feldspar phyric rhyolite unit distal from VMS mineralization (110–142 m and 320–427 m), to more muscovitic illite-dominated (2200–2210 nm) alteration within the same unit, proximal to mineralization (427–455 m).

A second example, from a drillhole in the Mary March area, shows the continuous progression from muscovite alteration, and Al-OH wavelengths of 2200–2010 nm, into an interval of paragonite-dominated alteration (Al-OH wavelengths of ~2196 nm) along with rare pyrophyllite (not shown), then back into muscovite (2197–2202 nm), finally

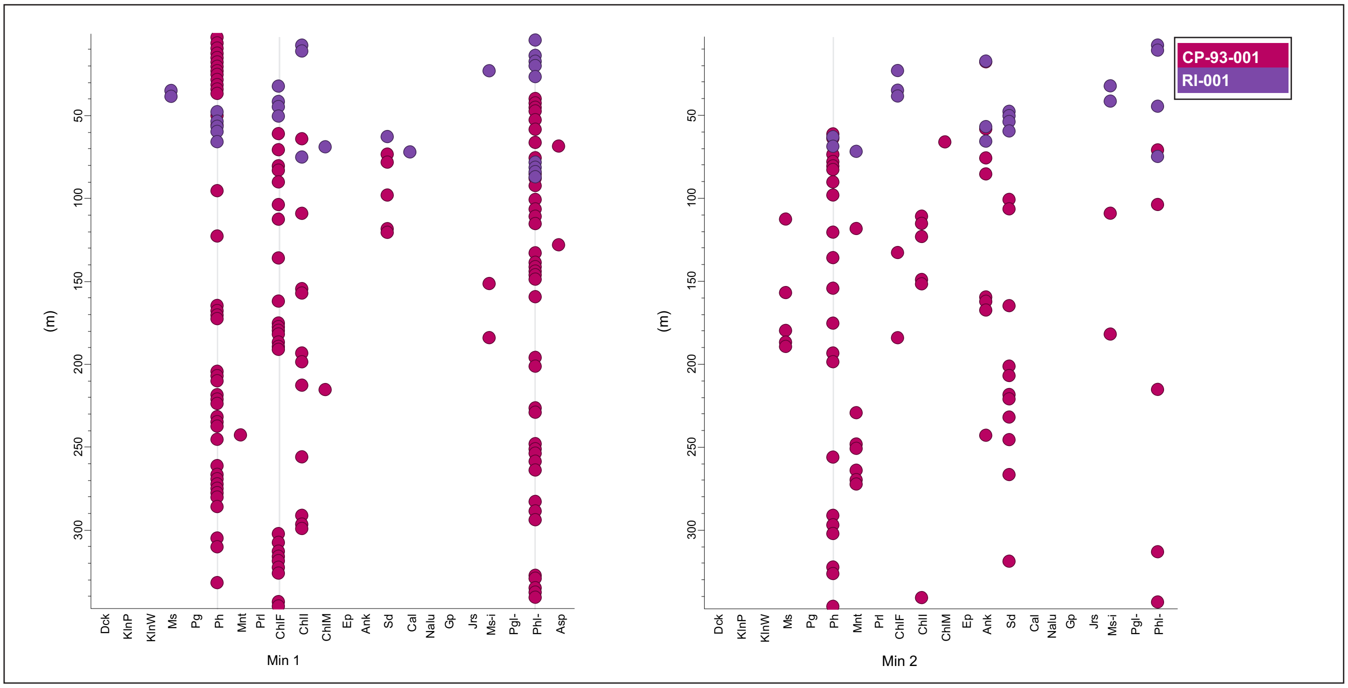

Figure 12. *Spectral results from select drillholes from the Connell alteration zone (Min 1, 155 points; Min 2, 93 points). Refer to Figure 3 for mineral abbreviations.*

ending in Fe–Mg chlorite–muscovite (2203–2208 nm; Figure 13B). Unfortunately, this particular drillhole did not contain any significant base- or precious-metal enrichment, but the interval of most intense alteration from 50 to 100 m is locally associated with up to 1.0% Ba (Barbour *et al.*, 1988). The zonation of white mica minerals illustrated in Figure 13B is inferred to be hosted within similar mafic to intermedite volcanic rocks, and highlights an area of hydrothermal fluid flow. Such information enables the mapping of scalar variations in SWIR data, and when used in conjunction with structural studies, can assist with vectoring toward more prospective zones within the overall hydrothermal system, generally represented by higher temperature, more acidic conditions, which is commonly associated with shorter wavelength white mica minerals (*e.g.*, muscovite, paragonite).

Preliminary investigations of several alteration zones in the region have identified the zonation of white mica minerals, locally associated with the development of base- and precious-metal mineralization (*e.g.*, Beaver Pond and Seal Pond). Such features can provide a means of mapping detailed variations in alteration mineralogy to assist mineral exploration programs in locating potential feeder zones to these hydrothermal systems. The distance that this zonation can be detected from potential mineralization, nor the direct effects of subsequent structural overprinting on the original distribution of alteration zones, has yet to be determined in the region. However, similar spectral shifts, such as those noted in association with VMS mineralization at the Nimbus deposit, are reported to occur up to 50 to 100 m distance from mineralization (Hollis *et al.*, 2021). Orientation studies, such those conducted here, are important when evaluation potential mineral zonation patterns associated with a given hydrothermal system, as opposite relationships to those outlined here have also been reported in association with VMS mineralization (*e.g.*, Buschette and Piercey, 2016; Cloutier and Piercey, 2020).

The application of SWIR spectrometry has highlighted the local development of advanced argillic alteration within two distinct geographical areas, namely the Mary March and Tower alteration zones. Previous interpretations of the development of this style of alteration in the Mary March area suggested the advanced argillic alteration postdated the formation of the VMS-style mineralization (Thurlow, 1999). However, given the close spatial association of the advanced argillic alteration with base-metal mineralization in two separate areas of the southern BRAB, suggests the possibility exists that this style of alteration is actually linked with the development of VMS systems in the area. Similar styles of advanced argillic alteration have been documented else-

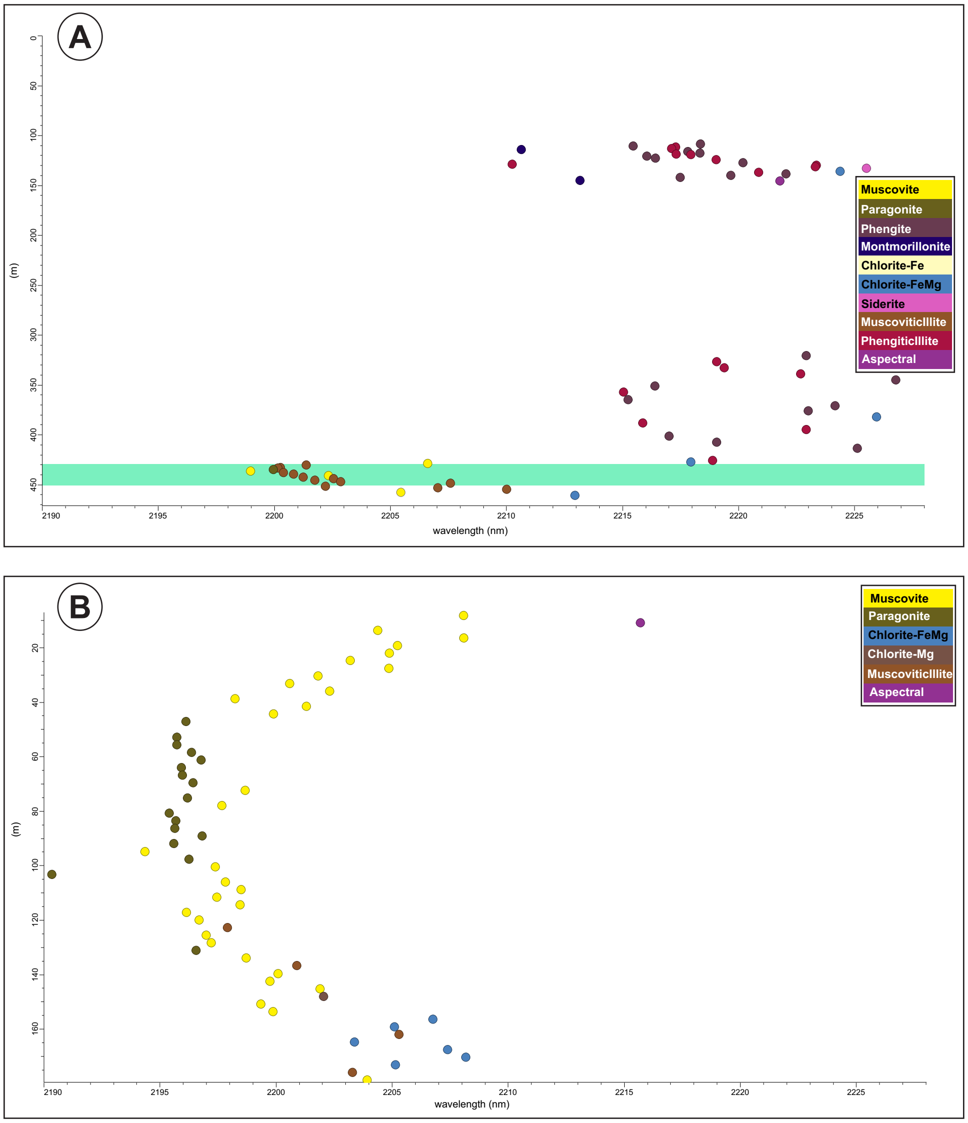

Figure 13. *A) Al-OH wavelength variation vs. downhole depth colour coded to Min 1 in Figure 3; Buchans Area, DDH H-817; B) Al-OH wavelength variation vs. downhole depth colour coded to Min 1 in Figure 4; Mary March area, DDH BJ-065.*

where in the region, where it occurs within footwall rocks related to VMS mineralization in the Tulks Volcanic Belt (Hinchey, 2011). Likewise, advanced argillic alteration has been noted in association with the development of VMS mineralization elsewhere around the world (*e.g.*, Sillitoe *et al.*, 1996; Hannington *et al.*, 1999; Scotney *et al.*, 2005). The recognition of transitional epithermal–VMS-style environments within the BRAB may provide insight to unsourced mineralized boulders potentially representing epithermal-related mineralization, located some 12 km northeast of the Mary March alteration zone. These boulders are noted to possibly contain tennantite–tetrahedrite and have assayed up to 16g/t Au and 58.4 oz/t Ag, 0.4% Zn and 0.1% Pb along with anomalous As and Sb (Greene and Thurlow, 1997b).

In typical epithermal environments, the development of alunite is generally associated with steam-heated alteration, representing a shallow, near-surface environment, which is locally host to gold mineralization. The development of alunite within southwestern portions of the Mary March alteration zone may indicate shallower levels of exposure, relative to the pyrophyllite-dominated alteration in more western portions of the zone. The measurement and interpretation of such variations in alteration mineralogy may aid in locating shallower, near paleosurface environments, which are prospective for the development of VMS mineralization, with interpretations being conditional on an interpretation that the alteration is indeed coeval with the development of VMS systems in the area. This advanced argillic alteration displays similarities to the hybrid bimodal-felsic VMS systems of Galley *et al.* (2007), and may provide a new model for some of the mineralization developed in the region.

The copper-dominated stockwork-style mineralization developed within the Little Sandy alteration zone is unique to the area, representing the only zone of Fe-chlorite-dominated alteration associated with this style of mineralization. However, similar relationships between Fe-chlorite- and copper-dominated stockwork mineralization have been noted farther to the northeast, in the area of the Gullbridge deposit (Sparkes, 2019). The close spatial association between the Tower and Little Sandy alteration zones suggests a potential genetic link between the two; this will be one of the focuses of future studies in the region.

Finally, based on the style of mineralization and related alteration, areas such as the Connell alteration zone represent more distal mineralizing environments. However, despite the lack of any significant hydrothermal alteration, the development of exhalative-style mineralization highlights the potential of the host stratigraphy for VMS mineralization. Untested anomalies, such as the anomalous zinc values noted in soil and basal till sampling along strike to the southwest of the Connell prospect represent potential targets for future exploration (Banville *et al.*, 1998a).

CONCLUSION

The systematic collection of downhole SWIR spectral data from previously reported zones of sericite alteration has enabled the subdivision of these zones. The use of white mica minerals to highlight zonations, in association with the development of alteration zones within the southern BRAB, when used in conjunction with structural studies, provide vectors toward hydrothermal feeder zones, generally associated with higher temperature, more acidic conditions, and potential mineralization. This study provides preliminary results, demonstrating the effectiveness of SWIR spectrometry in measuring scalar variations, in mineral compositions assisting with the identification of vectors that can be utilized to navigate in the structurally complex geological environment of the southern BRAB.

The identification of advanced argillic alteration within the southern BRAB potentially provides a new deposit model for the region. The occurrence of pyrophyllite alteration, proximal to VMS mineralization at the Mary March prospect, suggests the local development of highly acidic conditions in a vent proximal environment. The recognition of similar styles of alteration to that of the Mary March prospect within the Tower alteration zone, coupled with copper-rich stockwork-style mineralization at Little Sandy, highlight this area as a potential exploration target. Future work will focus on potential relationships between proximal alteration zones (*e.g.*, Little Sandy, Tower and Woodman's Brook) and attempt to constrain the timing of these events.

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