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WORLDVIEW-3 SATELLITE IMAGERY AS A TOOL FOR HYDROTHERMAL ALTERATION-MINERAL MAPPING: INSIGHTS FROM THE LONG HARBOUR GROUP, AVALON ZONE, NEWFOUNDLAND

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ABSTRACT

There is minimal documentation in the public domain on the application of satellite-acquired data for alteration mapping in Newfoundland, and, in particular, its application to exploring for hydrothermal alteration related to epithermal styles of mineralization. This is partly because most regions of Newfoundland lack sufficient outcrop exposure devoid of heavy vegetation cover, thus reducing the overall effectiveness of this technique. The Long Harbour Group of the Avalon Zone represents a unique area associated with abundant outcrop exposure and minimal vegetative cover, and hosts occurrences of epithermal mineralization.

A pilot study was initiated in 2021 to test the applicability of high-resolution, WorldView-3 satellite-acquired spectral data to evaluate a portion of the Long Harbour Group, covering some 272 km^2, for spectral signatures related to hydrothermal alteration. This study effectively identified a previously known area of advanced argillic alteration, in addition to identifying several new areas of interest, which have received little to no documented mineral exploration. Ground follow-up of these identified satellite spectral anomalies, utilizing a TerraSpec® Halo handheld spectrometer, has outlined a significant zone of white mica–pyrite alteration, 1 km in strike length, in addition to highlighting a zone of hydrothermal brecciation of possible low-sulphidation affinity. These results demonstrate the overall effectiveness of the high-resolution WorldView-3 satellite data for providing a cursory evaluation of remote areas of the Province, which, in turn, allow for detailed follow-up field investigations using minimal resources effectively.

INTRODUCTION

The Long Harbour Group of the Avalon Zone in Newfoundland is known to host both high- and low-sulphidation styles of epithermal mineralization (Sparkes, 2012; Sparkes and Dunning, 2014; and references therein). Given the prospectivity of the region, coupled with abundant outcrop exposure, a portion of the Long Harbour Group, covering an area 272 km^2, was chosen for a pilot study utilizing WorldView-3 satellite data to conduct hydrothermal alteration-mineral mapping (Figure 1). The satellite data, acquired on November 2, 2021, consists of three image strips across the area of interest, at a viewing angle ranging from 12.7–26.3°. Kongsberg Satellite Services (KSS) oversaw the acquisition of the satellite data, in addition to providing analysis and interpretation of the acquired satellite spectral data (a copy of the summary report provided by KSS can be found in Sparkes and Hinchey (2023)). This report identified a number of anomalous areas based on the presence of key alteration minerals as interpreted from the satellite data. These areas were investigated during the summer of 2022 by Geological Survey personnel, utilizing ground-based spectral measurements to evaluate the anomalous areas. This report provides a discussion of the findings related to this pilot study and the overall practicality of this technique to the region.

BACKGROUND

WORLDVIEW-3 SATELLITE DATA

The use of satellite data for mapping hydrothermal mineral alteration associated with mineralized systems is becoming commonplace with the improved resolution of sensors, having transitioned from the historical Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; 30-m resolution shortwave infrared (SWIR)) data to the more advanced WorldView-3 (3.7-m resolution SWIR) data. The usefulness of this technique in mapping the distribution of hydrothermal alteration minerals has been well established (*e.g.*, Kruse *et al.*, 2015; Sun *et al.*, 2017; Zhou *et al.*, 2017; Bedini, 2019). However, the technique is

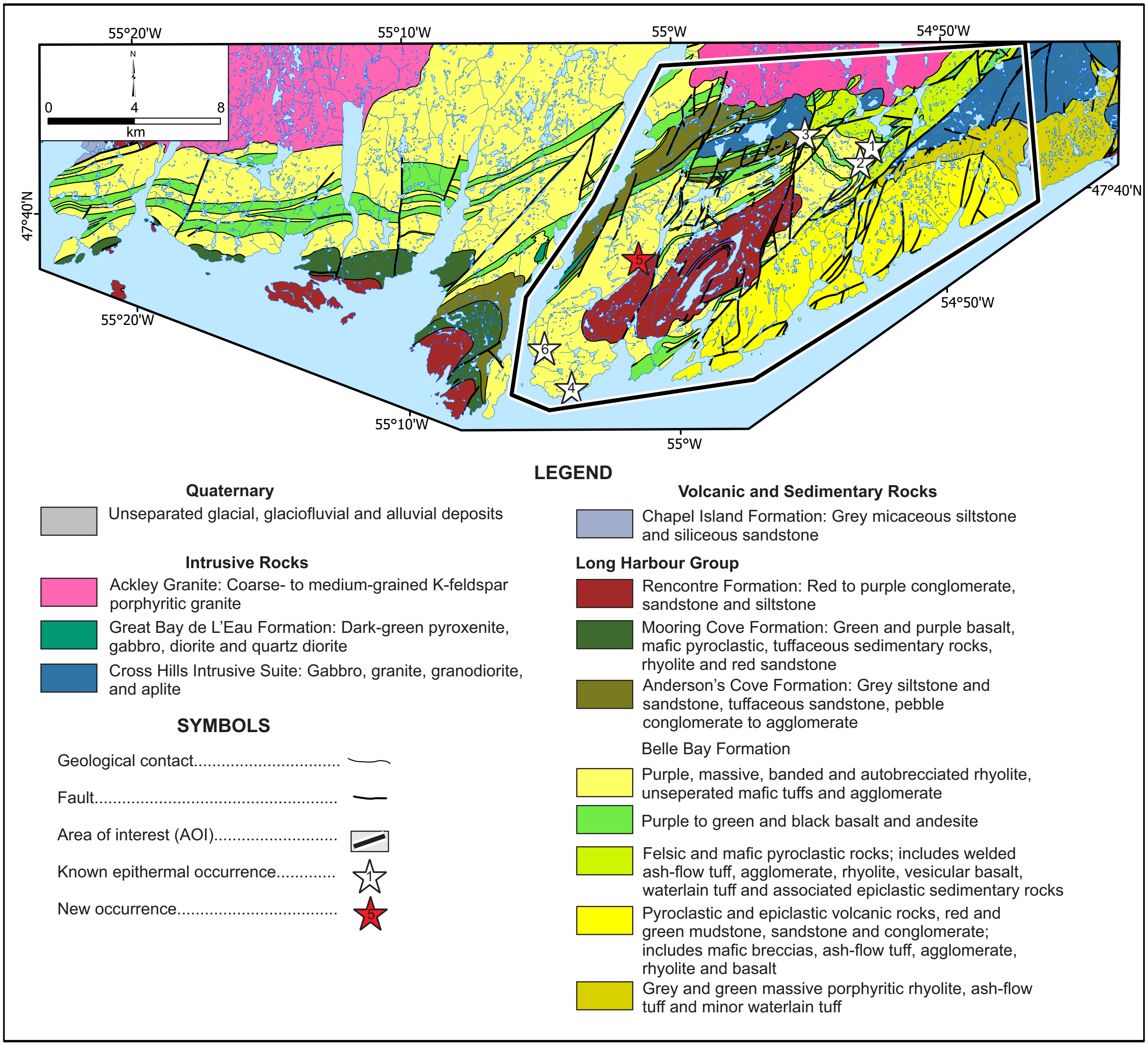

Figure 1. *Regional geology map outlining the distribution of the Long Harbour Group and the area of interest targeted for satellite-alteration mapping. Also outlined are the known epithermal occurrences. Labels for the occurrences are: 1) Gold Hammer; 2) Long Harbour Pyrophyllite; 3) 543 Trend; 4) Long Harbour Gold; 5) Femme Pyrite; and 6) Duck Hole. Bedrock geology modified from O'Brien* et al. *(1984) and O'Brien (1998).*

most commonly applied in areas having arid climates and minimal vegetative cover. Some work on the application of aerial alteration mapping in more northern environments, where the presence of lichen cover on outcrop is noted to affect the overall response of spectral signatures, has been published (Ager and Milton, 1987; Rivard and Arvidson, 1992; Bechtel *et al.*, 2002; Laakso *et al.*, 2015). Despite the affects of lichen cover, aerial alteration mapping has proved successful in outlining zones of hydrothermal alteration (*e.g.*, Laakso *et al.*, 2015), and does provide an effective tool to evaluate large areas of prospective geology for further detailed studies.

PHYSIOGRAPHY

A large portion of the target area consists of well-exposed outcrop with minimal vegetative cover, aside from lichens. This is, in part, due to the alkalinity of the felsic volcanic rocks of the Belle Bay Formation (Plate 1). Whereas these felsic volcanic rocks, which are the primary host to

Plate 1. *Aerial view of the extensive outcrop exposure and overall lack of vegetative cover around the Long Harbour Gold prospect (white area just to the left of the helicopter).*

known epithermal-style mineralization in the area, are generally devoid of any significant vegetation, the mafic volcanic and siliciclastic sedimentary rocks in the area are heavily vegetated.

Topographically, the area consists of a moderately rugged terrain between sea level and 400 m elevation, and is transected by several prominent north-northeast-trending structural lineaments (Figure 2). Steep-sided ridges are commonly flanked by significant scree slopes that consist of local material derived from higher elevations (Plate 2).

GEOLOGY AND EPITHERMAL MINERALIZATION OF THE LONG HARBOUR GROUP

The Long Harbour Group is composed predominantly of subaerial alkaline to peralkaline affinity felsic volcanic rocks, and lesser mafic volcanic and siliciclastic sedimenta-

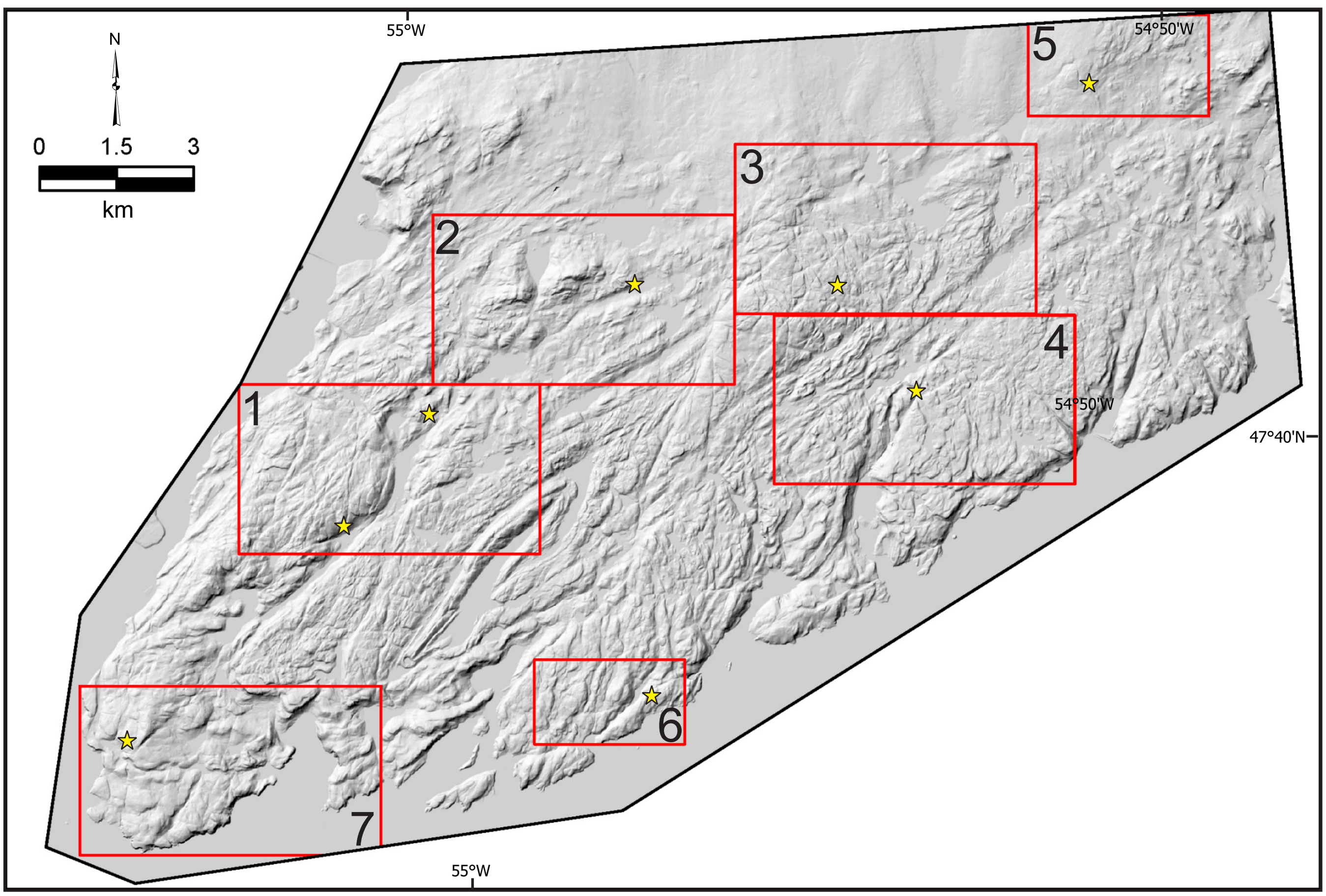

Figure 2. *Digital elevation model of the study area, with the relief shaded to highlight the southwest-facing slopes that were preferentially imaged by the satellite survey. Also outlined are the seven blocks noted to contain minerals of interest based on the satellite survey. The yellow stars represent the actual location of the satellite anomalies discussed in the text.*

Plate 2. *Steep-sided valley with well-developed scree slope derived from local material. Photo taken on the northeastern anomalous scree slope highlighted in Figure 3; photo taken looking southwest.*

ry rocks. The group is divisible into a lower volcanic sequence (Belle Bay Formation) and an upper volcanic sequence (Mooring Cove Formation), separated by the Anderson's Cove Formation (O'Brien *et al.*, 1995; Figure 1), a clastic sedimentary unit. Rhyolites from both the Belle Bay and Mooring Cove formations are dated at 568 ± 5 and 552 ± 3, respectively (O'Brien *et al.*, 1994). The Mooring Cove Formation marks the end of volcanism in the region and is, in turn, conformably overlain by siliciclastic sedimentary rocks of the Rencontre Formation, forming the stratigraphically highest unit within the late Neoproterozoic Long Harbour Group. The Rencontre Formation passes conformably up into micaceous siltstone and siliceous sandstone of the Early Cambrian Chapel Island Formation (Williams, 1971; O'Brien *et al.*, 1995).

In 2004, the first occurrence of epithermal-style mineralization within the Long Harbour Group was discovered at the Long Harbour Gold prospect (Figure 1), consisting of well-developed crustiform–colloform-banded chalcedonic silica veins and associated cockade breccias, locally assaying up to 5.2 g/t Au and 3.8 g/t Ag (Seymour, 2004a, b, 2006; Crewe and Seymour, 2007; Plate 3A, B). Here, the flow-banded rhyolite of the Belle Bay Formation, which hosts the low-sulphidation veining, is dated at 566.5 ± 1.9 Ma (Ferguson, 2017). Subsequent reconnaissance prospecting in the region, targeting anomalous selenium values in regional lake-sediment samples, resulted in the discovery of gold mineralization farther to the northeast at the Gold Hammer prospect, also hosted within felsic volcanic rocks of the Belle Bay Formation (Hussey, 2006; Figure 1). Here, stockwork-style chalcedonic silica veins, associated with phengitic white mica alteration, locally assayed up to 61 g/t Au (Hussey, 2006; Plate 3C). This mineralization is inferred to be of a low-sulphidation affinity, based on the observed vein textures and associated alteration (Hussey, 2006; Sparkes, 2012). Similar low-sulphidation veining and phengitic white mica alteration has also been identified approximately 3 km to the west of the Gold Hammer prospect, along a subparallel northeast-trending structural lineament known as the 543 Trend (Hussey, 2009). Here, chalcedonic silica veining and related cockade breccias are locally developed along with rare examples of chalcedonic silica banding that formed perpendicular to vein margins (Plate 3D). Vein textures, similar to those developed here, from the Rodalquilar gold deposit (Arribas *et al.*, 1995), are interpreted to represent the precipitation of amorphous silica in the near-surface environment, suggesting shallow levels of preservation within the overall epithermal system.

Prospecting approximately 1 km to the southwest along strike of the Gold Hammer prospect identified pyrophyllite–diaspore-advanced argillic alteration (Hussey, 2009; Long Harbour Pyrophyllite prospect, Figure 1; Plate 3E, F). This occurrence represents the first example of high-sulphidation-related alteration within the Long Harbour Group, and is traced for over 1.5 km along strike (Sparkes and Dunning, 2014). To date, no significant precious-metal mineralization has been identified in association with the high-sulphidation-related alteration of the Long Harbour Group.

RESULTS OF GROUND-BASED INVESTIGATIONS

The final contract report from KSS highlighted seven areas of interest; areas defined by the interpreted presence of key alteration minerals (Figure 2). Ground-based spectral measurements collected using a TerraSpec® Halo handheld spectrometer were subsequently processed using The Spectral Geologist (TSG™) software to obtain mineral identifications. Values within the spectral results, which include "Null", indicate no match within acceptable errors, and "Aspectral" values indicate poor-quality spectral measurements. As part of the evaluation of the white mica alteration developed in the area, scalars extract crystallinity and/or compositional information from the spectral data. One such scalar used is the illite spectral maturity (ISM) or white mica crystallinity scalar, which measures the overall ratio of the depth of the Al-OH absorption feature (~2200 nm) relative to the molecular water-absorption feature (~1900 nm). Values >1 are indicative of a more crystalline habit for white mica alteration and is indicative of higher temperatures of formation (AusSpec, 2008). Data tables containing the spectral data and related geochemical results, from sampling conducted as part of the ground-based investigations, are reported in Sparkes and Hinchey (2023). The following discussion of the satellite anomalies is organized according to

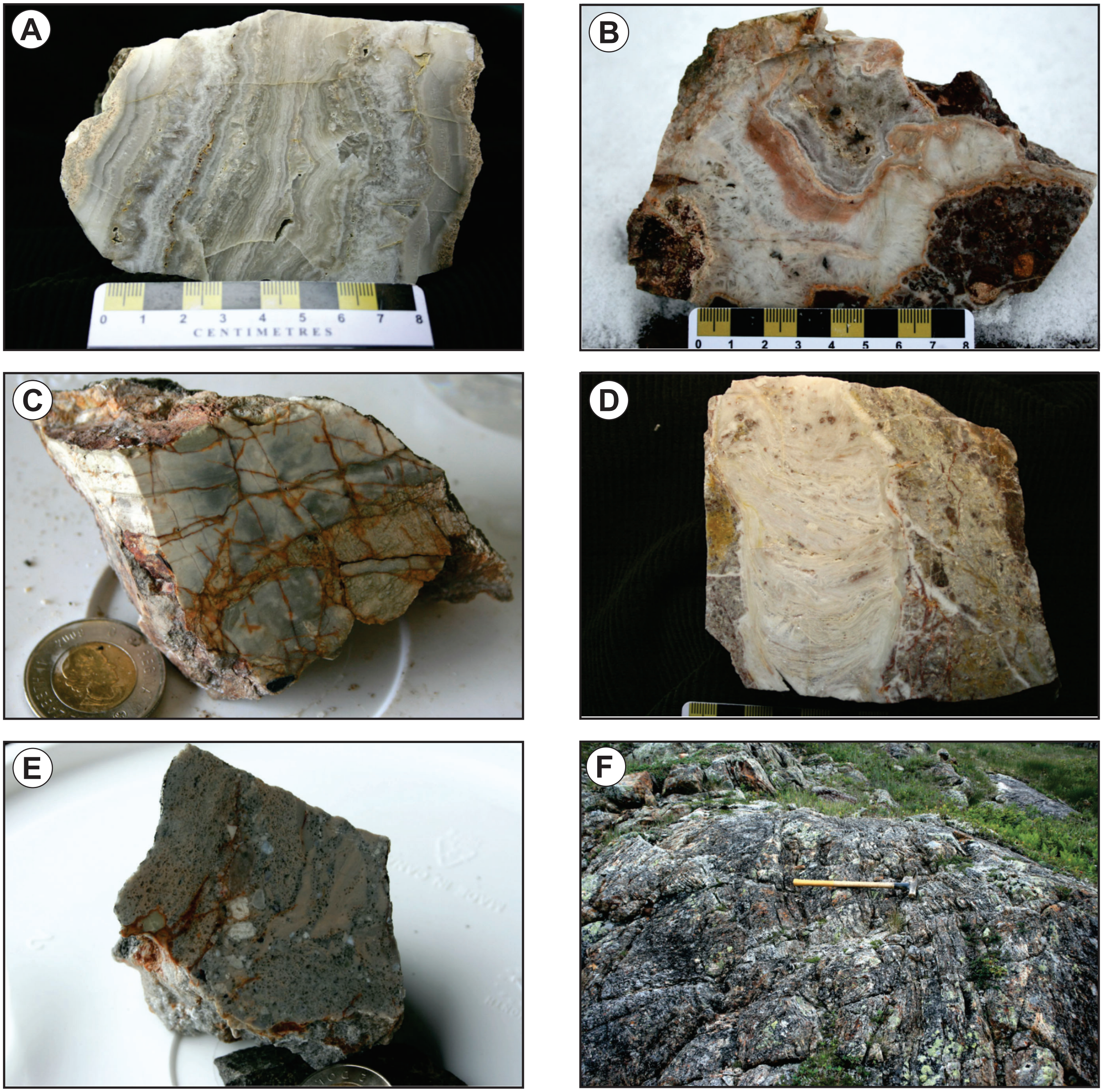

Plate 3. *A) Well-developed crustiform–colloform-banded, adularia-bearing, chalcedonic silica vein; Long Harbour Gold prospect; sample contains 1126 ppm F and 465 ppm Li; B) Adularia-bearing, chalcedonic silica vein displaying lattice-bladed textures indicative of fluid boiling; sample contains 5.2 g/t Au, 10 g/t Ag; Long Harbour Gold prospect; C) Chalcedonic silica vein displaying weakly developed banding; Golden Hammer prospect; D) Chalcedonic silica vein displaying high-level, silica slump features, and banding perpendicular to vein margins; 543 Trend prospect; E) Pyrophyllite-altered volcaniclastic rock displaying relic volcanic textures; Long Harbour Pyrophyllite prospect; F) Lichen-covered outcrop of pyrophyllite alteration hosted by flow-banded rhyolite; Long Harbour Pyrophyllite prospect.*

areas of similar alteration (*e.g.*, high-temperature and acidic vs. lower-temperature and neutral environments) and overall aerial extent, and is primarily based on observations made during the follow-up field investigations of these anomalies (Table 1). Note that the area of Blocks 2 and 4 shown on Figure 2 were not investigated because of time constraints and accessibility.

ANOMALY 1

Within Block 1, two separate anomalies were identified along a northeast-trending topographic lineament, with the most significant one located along a steep southeast-facing slope near the southern limit of the block (Figure 2). This anomaly represents a previously undocumented zone of potentially significant hydrothermal alteration marked by extensive gossanous weathering visible on aerial photographs, and is herein termed the Femme Pyrite occurrence. Here, rusty gossanous weathering extends for upwards of 1 km along strike (Plate 4). Satellite spectral data identified signatures for ferric iron and associated clays (alunite, pyrophyllite, muscovite, kaolinite, illite and montmorillonite).

Table 1. UTM location data for anomalies discussed in text (yellow stars in Figure 2)

Name	UTM Zone	Datum	UTM East	UTM North
Anomaly 1 South	21	NAD 83	647976	5278043
Anomaly 1 North	21	NAD 83	650105	5280485
Anomaly 3	21	NAD 83	657712	5283125
Anomaly 5	21	NAD 83	662880	5286897
Anomaly 6	21	NAD 83	654389	5275035
Anomaly 7	21	NAD 83	644143	5274216

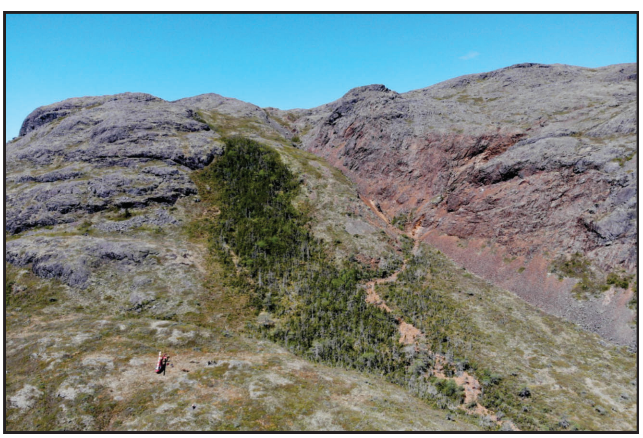

Plate 4. *Aerial view of the western extent of the 1-km-long gossanous alteration zone shown in Figure 3. Note helicopter for scale.*

However, the spatial distribution of these signatures is mainly confined to the scree slope developed along the northwest margin of the topographic lineament (Figure 3B–G).

Seventy-six spectral measurements were collected from the entire 1-km-strike extent of this alteration zone, along with nine samples for geochemical analysis. Spectral data collected from both outcrop and float from the adjacent scree slope, consists almost entirely of muscovitic white mica alteration based on ground-based spectral measurements (Figure 3A). The alteration is hosted within felsic volcanic rocks of the Belle Bay Formation, with rare evidence of relic flow banding observed in the host rock marginal to the alteration. Variations in the illite spectral maturity (ISM) along this trend indicate that most of the muscovite alteration has a moderate to high crystallinity as it contains minimal structurally-bound water features within the individual spectra. However, there is a zone characterized by ISM values of <1 at the western end of the alteration zone that is associated with the central core of a presumed fault structure (Figure 3A; Plate 5). Here, spectral measurements display pronounced water features indicating a more hydrous environment, potentially associated with greater fluid flow. Geochemical samples collected along the alteration zone failed to identify any precious- or base-metal enrichment. However, anomalous mercury values, generally ranging from 20 to 110 ppb, were obtained along the length of the alteration zone, with the most elevated sample occurring at the extreme northeastern end of the anomaly.

A second anomaly was identified in Block 1, along the same northeast-trending lineament, approximately 2.5 km to the northeast of the Femme Pyrite occurrence (Figure 2). Satellite data identified an increased abundance of clay signatures (pyrophyllite, kaolinite, illite and montmorillonite; Figure 4) hosted within felsic volcanic rocks similar to those noted above. Ground-based spectral data from this area indicate predominantly muscovite and lesser phengite, with most of the spectra displaying moderate to high ISM values (Figure 4A). Geochemical samples from this area failed to identify any notable values of interest, although minor anomalous gold (up to 43 ppb) has been reported from the area (Hussey, 2014).

ANOMALY 3

Anomaly 3 highlights the area surrounding the previously known Gold Hammer and Long Harbour Pyrophyllite occurrences and thus provides some confidence as to the overall effectiveness of this technique, despite the extensive lichen cover on outcrops in the area (Figure 2; Plate 3F). Satellite data indicate the presence of significant clay alteration (pyrophyllite, kaolinite, illite and montmorillonite). The overall abundance of pyrophyllite in the satellite data is

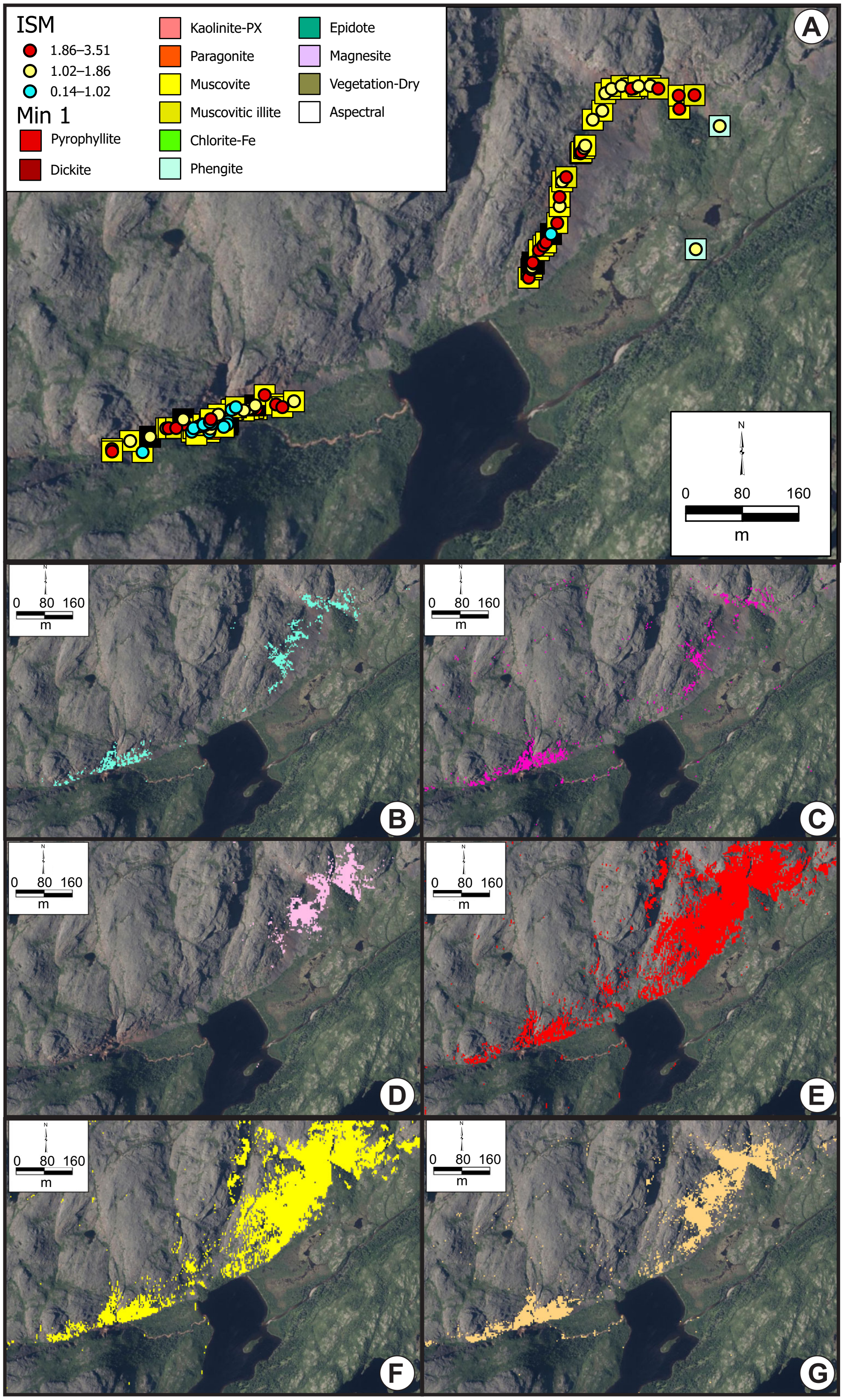

Figure 3. *A) Ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values along the Femme Pyrite alteration zone. Note the legend only pertains to Figure 3A; B) Satellite-interpreted spectral signatures of alunite; C) Satellite-interpreted spectral signatures of pyrophyllite; D) Satellite-interpreted spectral signatures of muscovite; E) Satellite-interpreted spectral signatures of kaolinite; F) Satellite-interpreted spectral signatures of illite; G) Satellite-interpreted spectral signatures of montmorillonite.*

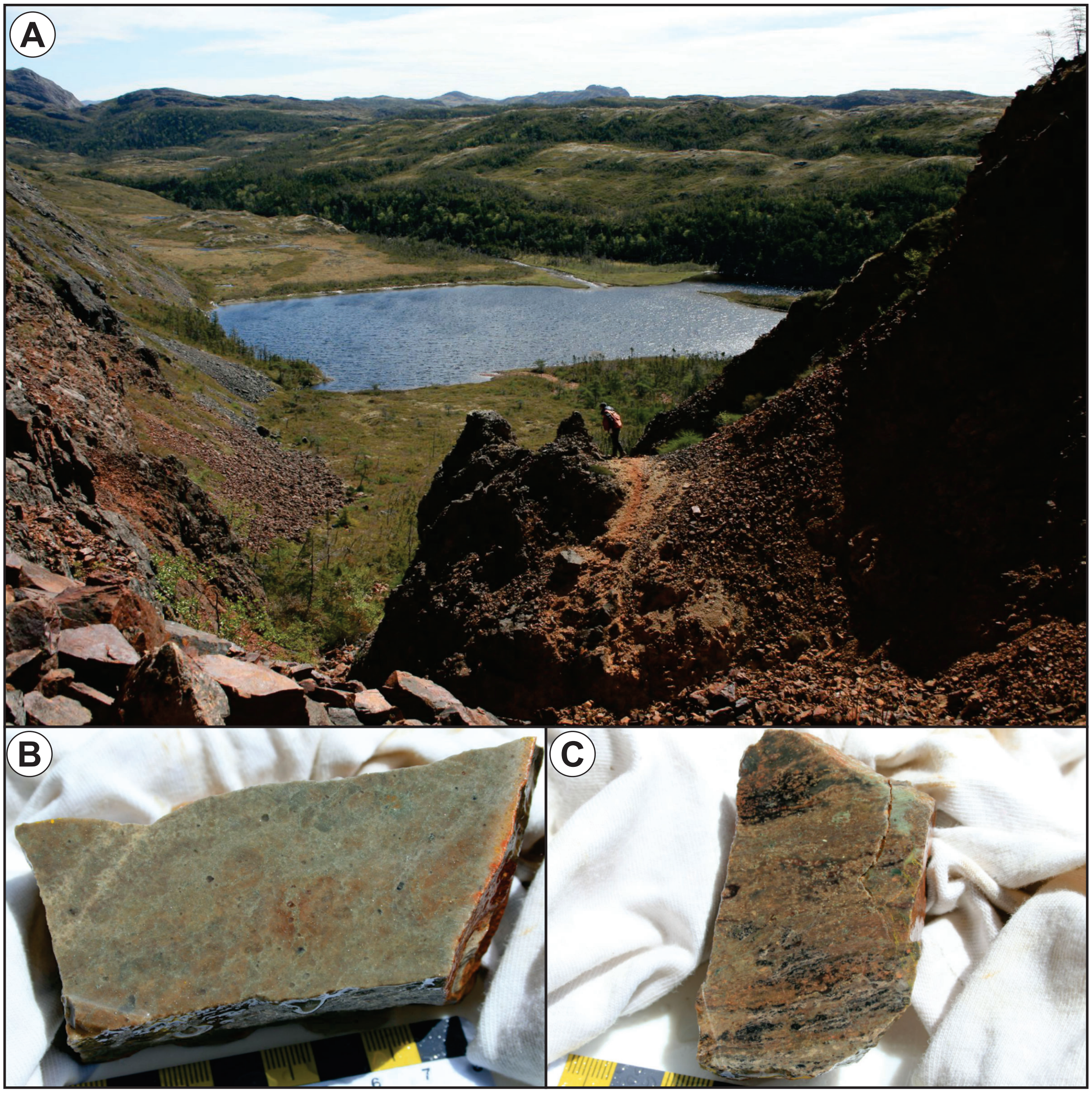

Plate 5. *A) Central core of the lineament hosting the development of moderate to strong white mica–pyrite alteration. Photo taken looking east-northeast from the western end of the gossanous alteration zone shown in Figure 3; B) Intense muscovitic white mica alteration developed within cataclastic breccia from the central core of alteration zone shown in (A); C) Weakly altered, phengitic white mica-bearing flow-banded rhyolite marginal to the alteration shown in (A).*

generally low, but the data does locally correspond well with previously identified pyrophyllite alteration in outcrop (Figure 5A, B). Kaolinite signatures from the satellite-interpreted data display the best spatial correlation with the known distribution of epithermal alteration in the area (*see* Figure 6 in Sparkes and Dunning, 2014). However, no kaolinite has been identified with ground-based spectral measurements. Similarly, satellite identified illite, and lesser muscovite, spectral signatures display comparable distributions to kaolinite, but at reduced abundances (Figure 5D, E). This area denotes the most intense zone of high-temperature hydrothermal alteration, and represents one of the few examples where the satellite data appear to be highlighting the alteration within actual outcrop as opposed to scree slopes adjacent to areas of hydrothermal alteration.

The epithermal alteration is hosted within felsic volcanic rocks and related volcaniclastic rocks of the Belle Bay Formation. Localized gold mineralization, of an inferred low-sulphidation affinity (Hussey, 2006; Sparkes, 2012), is associated with the predominance of phengitic white mica alteration as indicated by ground-based spectral measurements from the area of the Gold Hammer prospect (Figure 5A). However, the satellite data failed to display any signif-

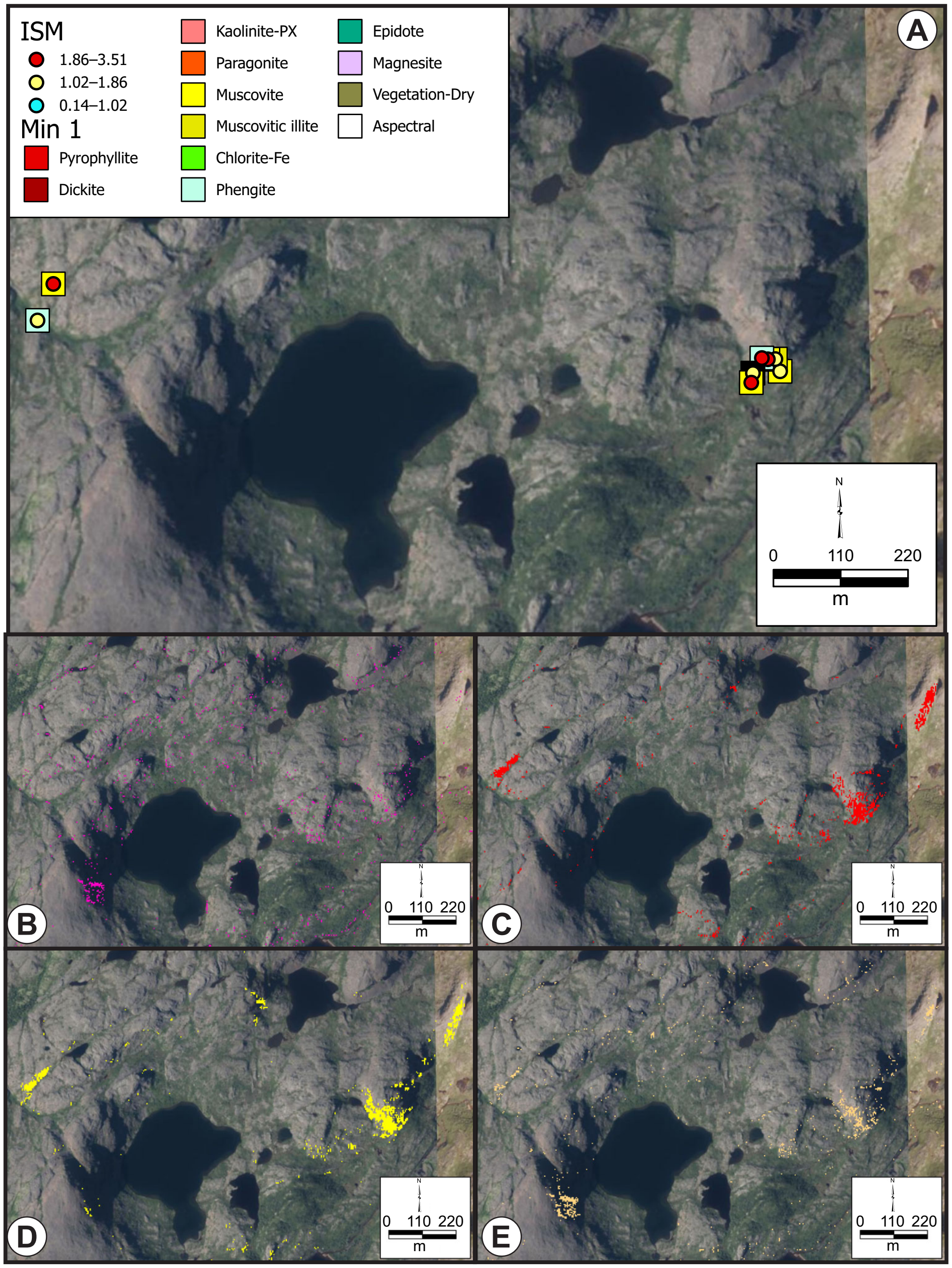

Figure 4. *A) Ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values along the northern anomaly in Block 1 (Figure 2). Note the legend only pertains to Figure 4A; B) Satellite-interpreted spectral signatures of pyrophyllite; C) Satellite-interpreted spectral signatures of kaolinite; D) Satellite-interpreted spectral signatures of illite; E) Satellite-interpreted spectral signatures of montmorillonite.*

icant clay signatures in the immediate area of the actual mineralized outcrop. The high-sulphidation-style alteration developed to the southwest at the Long Harbour Pyrophyllite prospect is more aerially extensive, and thus provides a more suitable target for satellite mapping. No significant mineralization has yet been identified in association with this alteration, aside from anomalous mercury and molybdenum occurring in silica–pyrite alteration (Sparkes and Sandeman, 2015).

Weak kaolinite signatures identified in the satellite data to the east of the Gold Hammer prospect, and along strike to the northeast of the 543 Trend were also investigated (Figure 5A, C). Ground-based spectral measurements indicate that these areas are dominated by phengite and muscovite white mica alteration, respectively. The area east of the Gold Hammer prospect, characterized by low ISM values in association with chlorite and phengite alteration, suggests this is not part of the alteration system related to the high-sulphidation alteration farther to the west, based on its mineralogy. Ground-based spectral measurements from the anomaly to the northeast of the 543 Trend are muscovite dominated, and the observed alteration does not appear to be associated with any identifiable low-sulphidation related features.

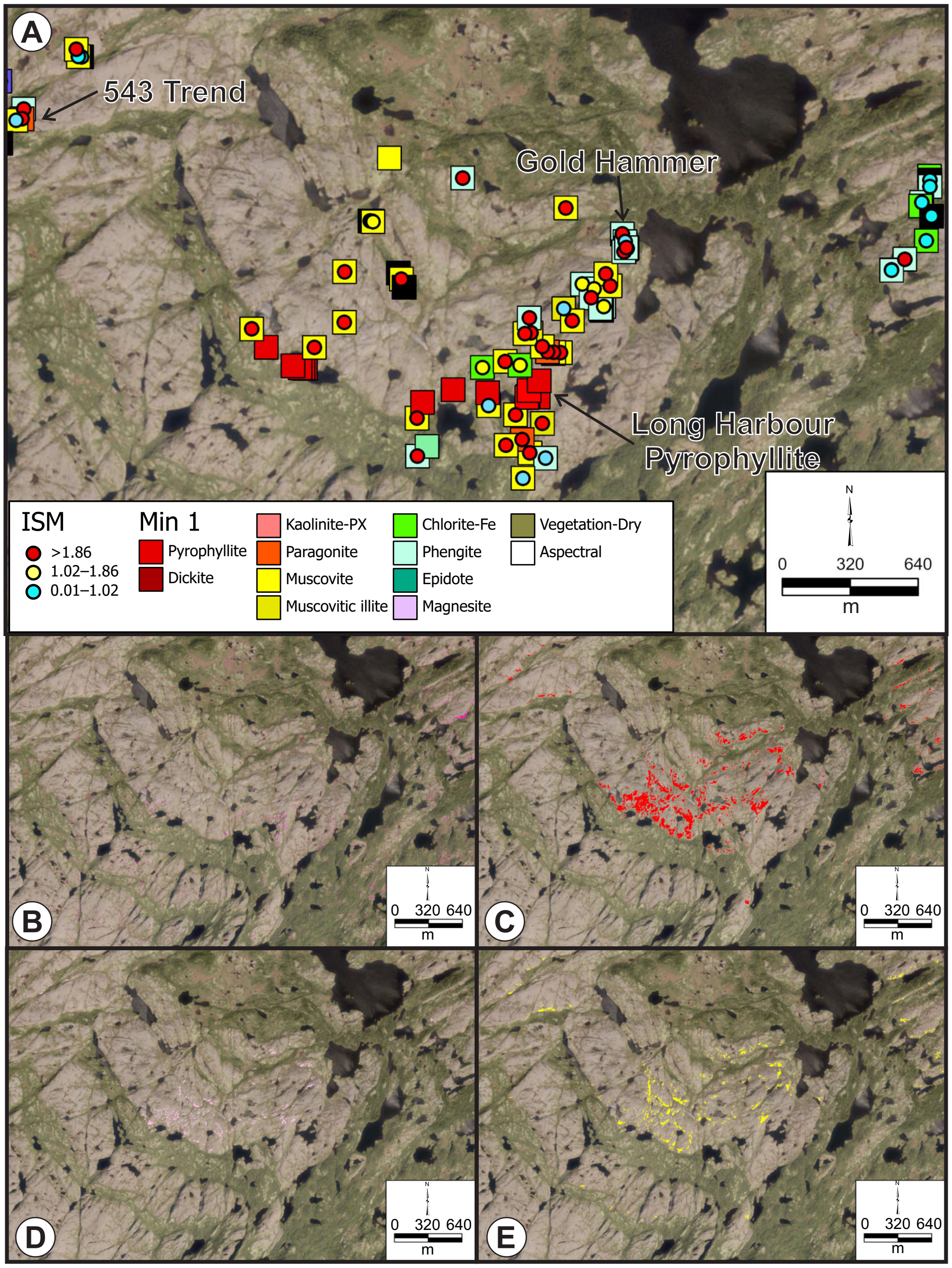

Figure 5. *A) Ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values around the Gold Hammer and Long Harbour Pyrophyllite prospects (Block 3, Figure 2); this map incorporates data from Sparkes* et al. *(2015). Note the legend only pertains to Figure 5A; B) Satellite-interpreted spectral signatures of pyrophyllite; C) Satellite-interpreted spectral signatures of kaolinite; D) Satellite-interpreted spectral signatures of muscovite; E) Satellite-interpreted spectral signatures of illite.*

ANOMALY 7

The area of Anomaly 7 in Figure 2, herein termed the Duck Hole prospect, is located proximal to a regional lake-sediment gold anomaly (11 ppb) to the immediate west. Satellite data for the area identified clay alteration (montmorillonite, kaolinite and illite) associated with a scree slope and proximal outcrop (Figure 6). This area contains a zone of silica alteration and related hydrothermal brecciation. Detailed examination revealed the presence of well-developed cockade breccia, locally with late chalcedonic silica infilling voids within the breccia matrix (Plate 6), along with rare lattice-bladed textures indicative of fluid boiling. This area potentially represents another occurrence of low-sulphidation-related epithermal features, and displays many textural similarities to the brecciation observed at the 543 Trend.

Ground-based spectral measurements are dominated by muscovite with low ISM values (Figure 6). Geochemical sampling produced anomalous silver, fluorine, lithium and weakly anomalous mercury, but failed to identify any enrichment of base or precious metals. However, sampling

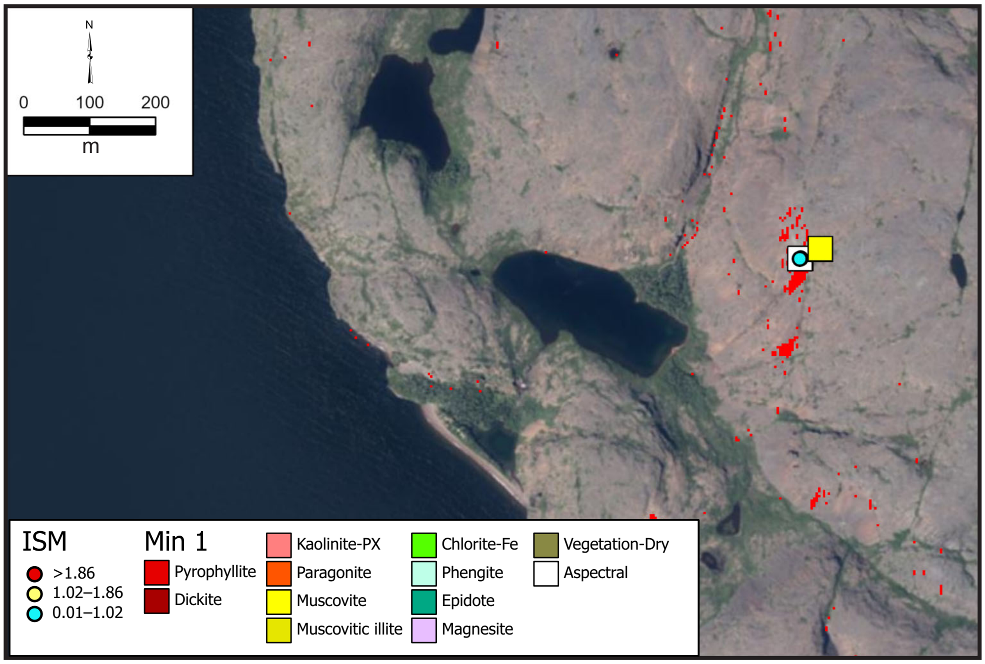

Figure 6. *Detailed aerial photograph outlining the distribution of the satellite data displaying a kaolinite spectral signature (shown in red) overlain by the results of ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values; Duck Hole prospect (Block 7, Figure 2).*

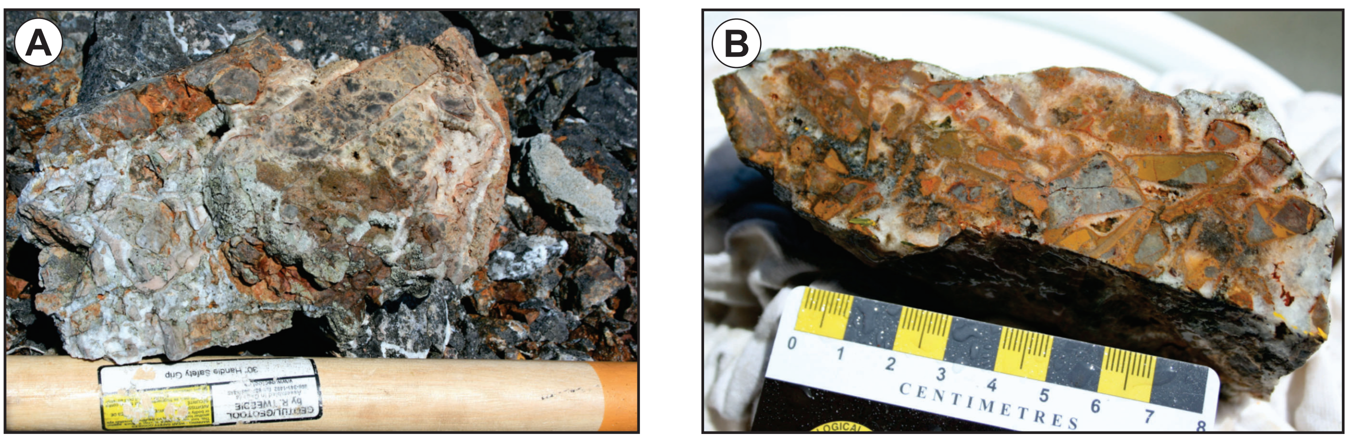

Plate 6. *A) Well-developed cockade breccia displaying fragments rimmed by white comb-textured quartz and late pale-pink chalcedonic silica, in-filling voids within the breccia matrix; Duck Hole prospect; B) Slabbed sample of the breccia displaying previously brecciated, chalcedonic silica-bearing fragments in a matrix of white comb-textured quartz.*

of similar rocks in the area by Cornerstone, approximately 500 m to the southwest, identified anomalous gold (up to 36 ppb), locally in association with elevated Zn (0.34 %), Cu (0.17 %), Pb (0.01 %), Sb (174 ppm), Ag (30.5 g/t) and Bi (46 ppm; Seymour, 2004a). The combined textural, geochemical and alteration features observed are supportive of the occurrence representing high-level features of a potential low-sulphidation affinity.

ANOMALIES 5 AND 6

In the northeastern study area (Block 5, Figure 2), an area with kaolinite and illite alteration signatures as noted in the satellite data, displayed a spatial association with a zone of gossanous alteration outlined by O'Brien *et al.* (1984). Ground-based spectra are dominated by muscovite alteration displaying moderate to high ISM values (Figure 7), hosted within felsic volcaniclastic rocks. In contrast, the spectra classified as "vegetation-dry" and epidote, associated with lower ISM values to the west in Figure 7, are characteristic of relatively unaltered mafic volcanic rocks. A single sample from the alteration zone collected for assay did not detect any elevated values of interest.

Anomaly 6 (Figure 2) represents an isolated anomaly of clay (alunite, pyrophyllite, montmorillonite, muscovite, kaolinite and illite) and chlorite alteration as identified by the satellite data (Figure 8). These signatures are associated with, and highlight, a southeast-facing scree slope; analogous to the setting observed at Anomaly 1. Ground-based spectral data are dominated by muscovite alteration hosted in flow-banded rhyolite, displaying moderate ISM values. A single assay collected from the zone only contained weakly anomalous mercury (65 ppb).

DISCUSSION

The use of WorldView-3 satellite data to conduct preliminary, regional-scale alteration-mineral mapping of part of the Long Harbour Group was successful in delineating new zones of hydrothermal alteration. However, despite the extensive outcrop exposure in the area, lichen cover does appear to reduce the overall effectiveness of

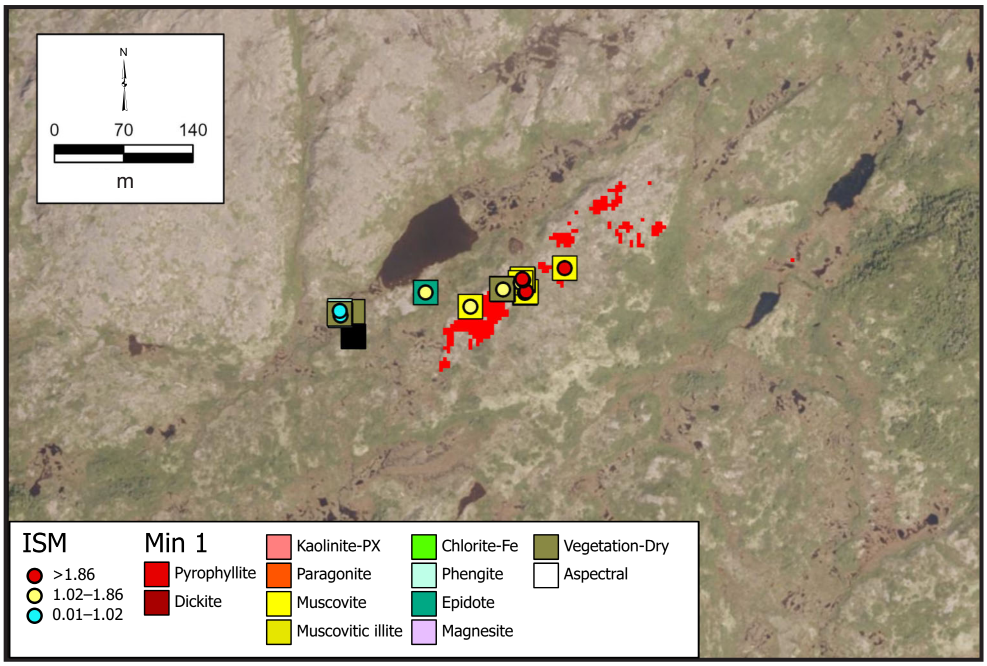

Figure 7. *Detailed aerial photograph outlining the distribution of the satellite data displaying a kaolinite spectral signature (shown in red) overlain by the results of ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values around the southwestern portion of Anomaly 5 (Block 5, Figure 2).*

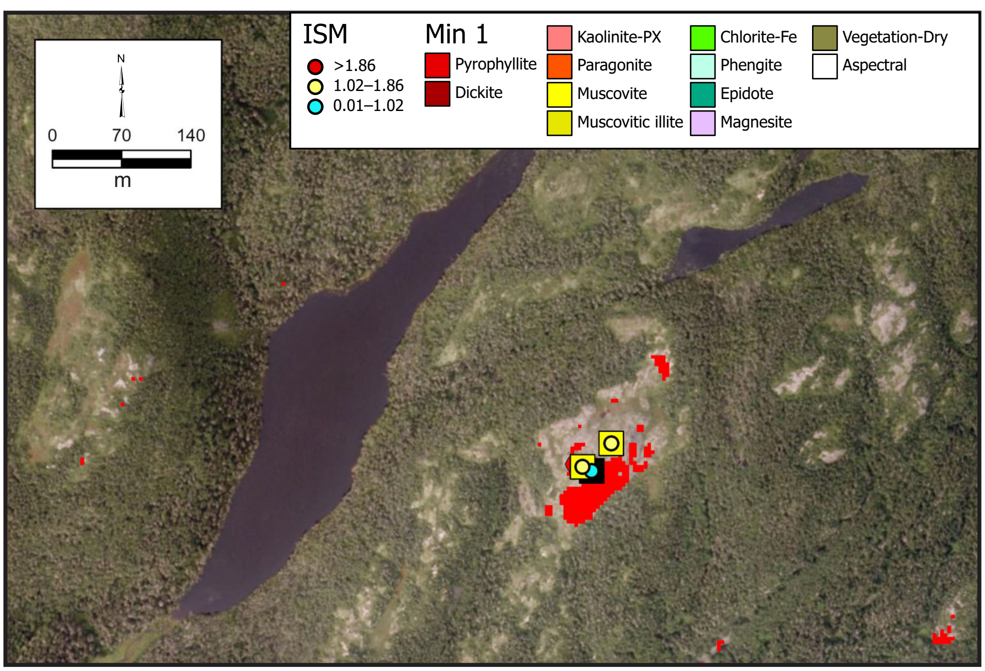

Figure 8. *Detailed aerial photograph outlining the distribution of the satellite data displaying a kaolinite spectral signature (shown in red) overlain by the results of ground-based spectral measurements displaying the mineralogy results from the TSG software (Min 1) and associated ISM values from Anomaly 6 (Block 6, Figure 2).*

this technique in detecting certain minerals (*e.g.*, white mica minerals).

Scree slopes adjacent to hydrothermal alteration appear to produce the strongest signal response, possibly related to the abundance of clean rock surfaces that are devoid of lichen cover. In addition, the southeastern-facing direction of a number of the identified anomalous areas benefit from increased illumination given the sun angles associated with the late fall timing of the survey; thereby making them more susceptible to detection *via* satellite imagery. Limited field investigations of lichen-covered outcrops containing advanced argillic (pyrophyllite-dominated) alteration produced strong spectral responses even through the lichen cover. Similarly, the satellite data also highlighted alteration signatures associated with bedrock within this same zone of advanced argillic alteration, suggesting the spectral response of minerals associated with advanced argillic alteration are strong enough to be detected with WorldView-3 data, despite the extensive lichen cover masking the alteration.

High-sulphidation epithermal systems, which are characteristically associated with aerially extensive alteration haloes, represent good targets for satellite alteration mapping. This pilot study effectively outlined the extent of known advanced argillic alteration associated with the Long Harbour Pyrophyllite prospect (Anomaly 3). Although the exact mineralogy of this zone, as determined through ground-based analysis, differs from that interpreted from the satellite spectral data, the collection of the satellite data provided an effective tool for outlining areas for additional follow-up in the field. Similarly, the satellite spectral data was successful in delineating the large zone of alteration associated with the Femme Pyrite prospect (Anomaly 1). Preliminary investigations of the Femme Pyrite prospect failed to identify any diagnostic alteration minerals to definitively classify the style of alteration, however, the extensive muscovite–pyrite alteration, combined with anomalous mercury enrichment, are potentially indicative of high-level epithermal-style alteration.

In contrast to the high-temperature aerially extensive alteration patterns typically associated with high-sulphidation epithermal systems, low-sulphidation epithermal systems form at lower temperatures resulting in more aerially restricted alteration patterns; hence, the applicability of satellite data to identify alteration associated with the latter is limited. The reduced alteration footprint of such low-sulphidation systems is difficult to detect given the 3.7 m spatial resolution of the WorldView-3 SWIR data; a limitation that is enhanced even more when outcrops are covered/masked by lichen. The satellite survey failed to identify any significant anomaly associated with the low-sulphidation style alteration developed at the Long Harbour Gold prospect, aside from a very weak kaolinite signature coincident with a scree slope adjacent to the vein (Plate 1). However, the satellite data were able to delineate clay alteration (largely confined to scree slopes) that corresponds to the development of probable low-sulphidation-related brecciation and lattice-bladed vein textures at the Duck Hole prospect (Anomaly 7), thus illustrating that signatures related to these types of systems can be detected in some cases.

Ground-based spectral measurements throughout the area predominantly identified the presence of white mica alteration. Additional data derived from these spectral measurements reflect the composition and crystallinity of the white mica minerals. In general, muscovite and paragonite white mica alteration are indicative of more acidic hydrothermal conditions, whereas phengite is more typical of lower temperature, neutral hydrothermal environments (Halley *et al.*, 2015). The distribution of phengite within ground-based spectral measurements is largely confined to areas distal to the main zones of potential high-sulphidation-related alteration at Anomalies 1 and 3 (Figure 9). The regional distribution of the calculated ISM values for the white mica alteration also provides insight with respect to the overall crystallinity of the alteration. In Figure 9, the ISM values >1 (red and yellow circles) are preferentially plotted on top of lower values to illustrate the clustering of the inferred high-temperature white mica alteration with zones of more acidic, high-temperature, alteration associated with Anomalies 1 and 3. In contrast, the lower ISM values (blue circles) are predominantly associated with areas characterized by low-sulphidation-related features such as that developed in Block 7 and the western side of Block 3 (543 Trend; Figure 9).

CONCLUSION

The use of WorldView-3 satellite spectral data to evaluate part of the Long Harbour Group was successful in delineating several new zones of hydrothermal alteration. Although there is a notable discrepancy between the mineralogy interpreted from the satellite data and that determined from ground-based spectral measurements, the technique is effective as a regional tool for evaluating large tracks of land and highlighting areas for follow-up investigations.

High-sulphidation-related alteration zones, characterized by aerially extensive alteration, could be detected even through the extensive lichen cover of altered outcrops. More subtle features, such as discrete zones of kaolinite alteration identified with the satellite data, have the potential to be associated with the development of low-sulphidation systems. These alteration systems can be challenging to identify even when on the ground; hence the interpreted satellite anomalies should not be discounted.

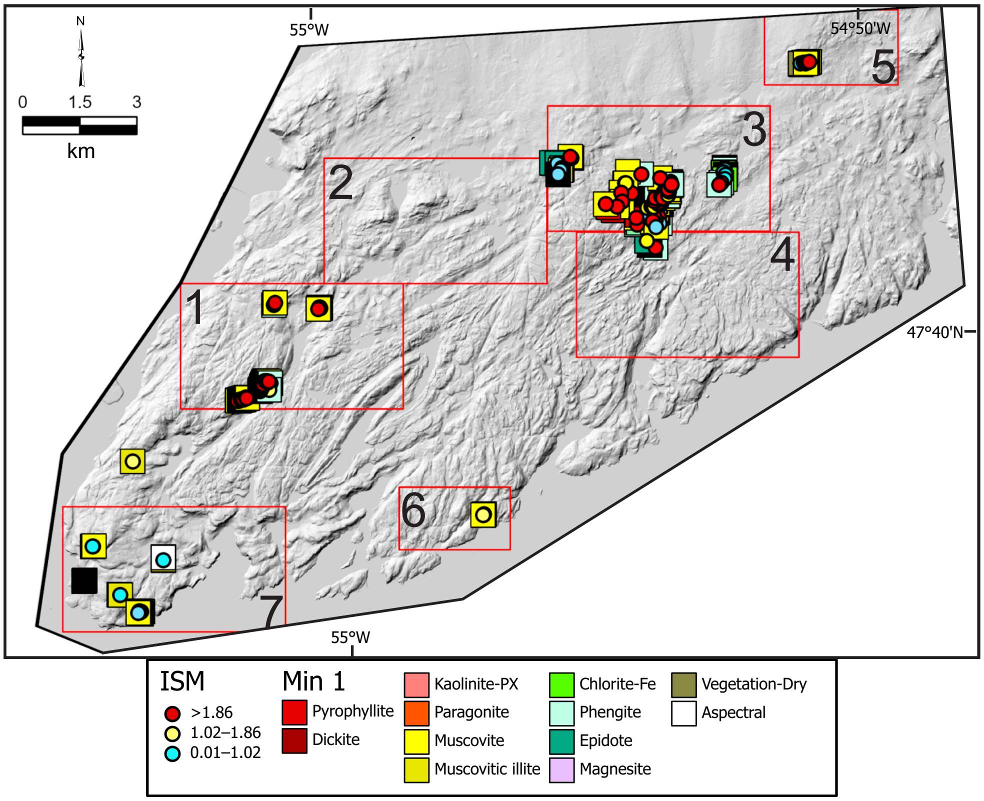

Figure 9. *Digital elevation model of the study area outlining the distribution of ground-based spectral measurements and associated ISM values.*

The improved resolution of satellite data now enables the targeting of areas that were previously not suitable for satellite mapping. The use of WorldView-3 satellite data enables the evaluation of large tracks of land at relatively high resolution. These data are ideally suited for cursory studies of remote areas, which then enable the effective targeting of regional studies utilizing minimal resources in the field.

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