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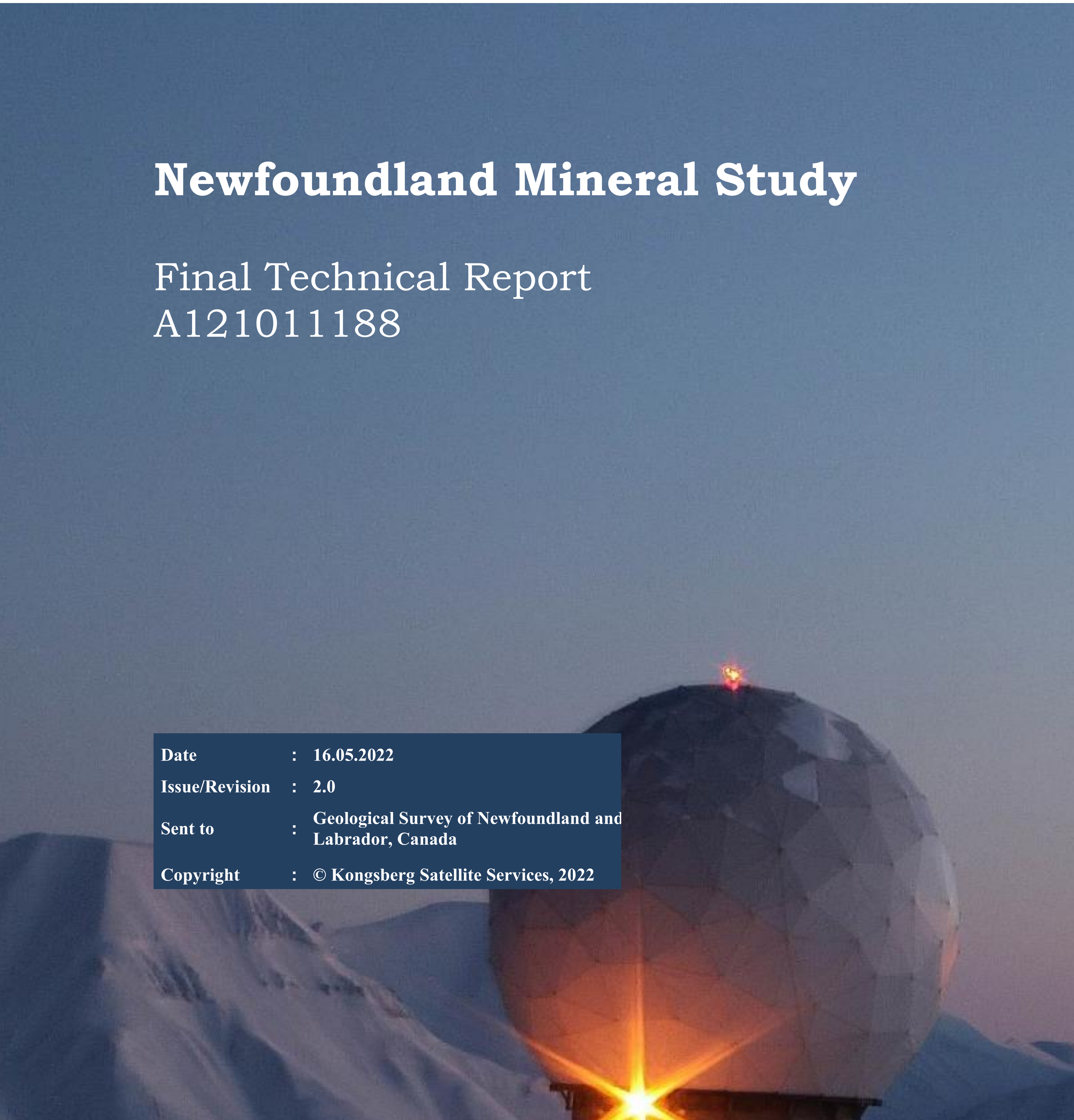

Newfoundland Mineral Study

Final Technical Report
A121011188

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1. INTRODUCTION & SCOPE

This report has been prepared for the Geological Survey of Newfoundland and Labrador, Department of Industry, Energy and Technology under contract A121011188. This report details the data, approach and interpretation of the minerals and geology across an area in Newfoundland, Canada along with the deliverables provided.

2. AREA OF INTEREST

The area of interest encompasses a region of 272km^2 in Newfoundland, Canada. The area is characterised by extensive outcrop, steep in places, waterbodies and extensive vegetation in some areas. The area is sparsely populated but roads and tracks are present, as are recent workings.

Figure 1 Area of interest outline (white) in the area of East Harbour, Newfoundland

3. DATASETS USED

The requirements laid out by the Geological Survey focused on the use of WorldView-3 satellite imagery. In addition to that, KSAT also used supplementary data described below.

3.1. WorldView-3

The WorldView-3 imagery was acquired on 2nd November 2021 across all 16 spectral bands (plus panchromatic). The image collection was completed in one day from 3 image strips across the area. The data is delivered in the OR2A (ortho-ready) product level meaning the data is radiometrically and geometrically corrected and map projected but not terrain corrected. Subsequent processing was then applied by KSAT.

The data was cloud, haze and snow free with viewing angle range of 12.7 – 26.3°. The imagery is considered to have good quality.

Image processing applied to the WorldView-3 varies depending on how the data is being used within the study.

The flow diagram in figure 2 shows the two processing chains applied to the data, both of which start with Orthorectification. The *Imagery for basemap* process provides the baseline reference data, this is the highest spatial resolution but only in a limited number of bands. It is used for visualisation and interpretation of features such as faults, folds and for overlaying results.

For the mineral processing, which is at the heart of this study, additional processing is applied to prepare the dataset for the mineral processing approach presented in section 4.2.

A summary of the processes applied to the data are presented below:

- **Orthorectification:** also known as terrain correction was applied to correct the line-of-sight distortion from the viewing angle of the satellite to the ground. The DEM used for this correction is described in the supplementary datasets and was provided by Geological Survey of Newfoundland and Labrador.
- **Pansharpening:** this is where the highest spatial resolution band, a panchromatic band, is merged with the multispectral bands to provide an enhanced multispectral dataset at a spatial resolution which matches that of the panchromatic band. There are many options of pansharpening algorithms, but KSAT use the UNB (University of New Brunswick) algorithm, which is considered an industry standard and helps to retain the spectral quality of the multispectral imagery when it is merged with the panchromatic band.
- **Enhancement and Mosaicing:** image contrast tables are enhanced and optimised for viewing and the input data is then combined using mosaicing techniques where images can be combined together, colour balanced and be consistent across multiples of scenes.
- **Layerstack:** where all the spectral bands are stacked together into one single dataset for analysis and resampled to the SWIR resolution. The reason for this is because the SWIR has the majority of information of interest to a geological study and it is important to retain the spectral quality of this data as much as possible.
- **Trim data:** as extent of VNIR and SWIR sensors are not the same, trimming them to a common extent aids the analysis

- **Atmospheric correction:** There are many different forms of correction that can be applied including both relative and absolute corrections. In the absence of reference atmospheric information and as the data used still has a limited number of spectral bands a relative reflectance correction was applied. In this case an Internal Average Relative Reflectance (IARR) approach was considered. This approach uses the average radiance spectrum of the entire scene and calculates the ratio of the average spectrum with all pixel spectra. The assumption is that this average spectrum is representative of the solar irradiation spectrum.

For optimal analysis each strip of WORLDVIEW-3 is analysed separately in the mineral process. Whilst mosaicing is an option, with different viewing angles, even on the same day as in this case, it can lead to mixed pixels which could provide false positives. To retain as much spectral integrity as possible the data is therefore handled in its original strips. As such the output of the processes described above and in figure 2 are:

- Imagery for mineral process: 3 strips of 3.7m corrected 16 band images named Eastern, Middle and Western.
- Imagery for basemap: single 0.3m spatial resolution mosaic in natural colour (bands 5, 3, 2)

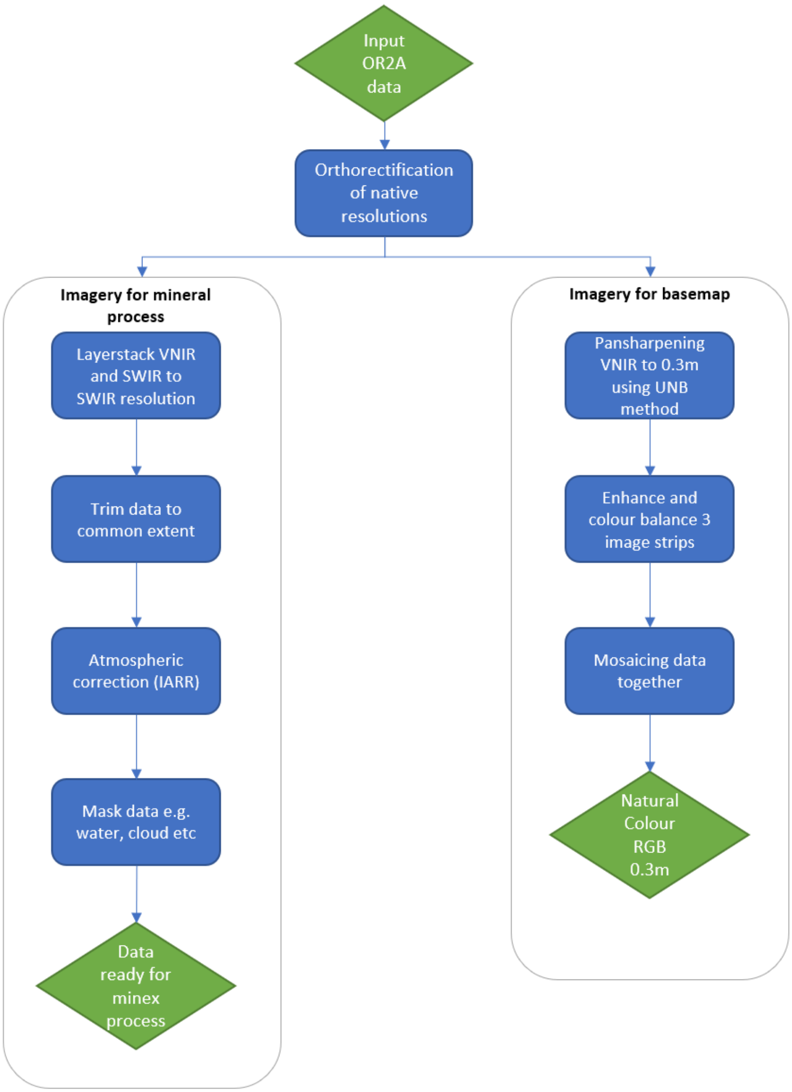


Figure 2: WorldView-3 processing workflow

3.2. Supplementary datasets

3.2.1. ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has long been used in support of mineral exploration using satellite sensors since its launch aboard the satellite Terra in December 1999. Whilst ASTER was not requested by the Geological Survey of Newfoundland, KSAT's approach to mineral exploration includes this step as an initial screening tool. The processing and results of which are also included in this report.

ASTER data is provided from USGS as L1T Precision Terrain Corrected product and is subsequently atmospherically corrected prior to further analysis.

The date of the imagery was 17th October 2001 and had haze and cloud partially occluding some of the area however it represented the best quality image in the available archive.

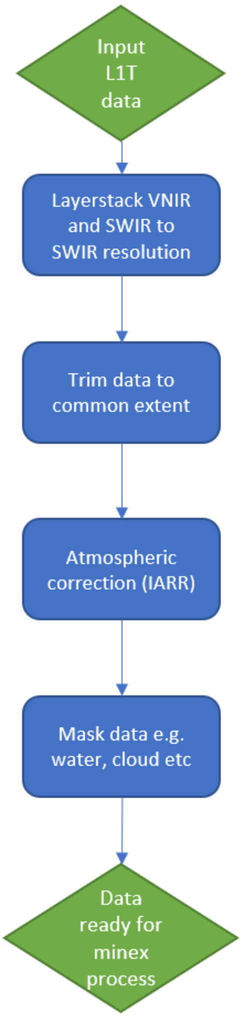


Figure 3: ASTER processing workflow

Image processing steps, shown in figure 3, echo the process indicated in section 3.1.

The output of this approach is a 30m spatial resolution 9 band data stack covering the VNIR and SWIR portions of the spectrum which is then the input into the mineral processing described in section 4.

ASTER collects imagery across three sensors a Visible Near Infrared (VNIR), Short Wave Infrared (SWIR) and Thermal Infrared (TIR). However since April 2008 there has been a failure on the SWIR detector which has rendered it unusable so the imagery after this point, whilst still collected in VNIR and TIR cannot be used for mineral analysis as the SWIR is missing hence all imagery for such studies are prior to April 2008.

3.2.2. Digital Elevation Model

Provided by the Geological Survey of Newfoundland and Labrador, the DEM is available at 10m grid. DEM_NFLD_GMD_10m. It is understood this product's source data were all collected over multiple years but all contracts had to meet the requirements of the Geological Survey. The raster DEM was created from the Mass Points, Breaklines, and Vector Drainage delivered by these contracts. It was this data that was used to terrain correct the data and support the interpretation.

3.2.3. Maps and Other

Other datasets provided by the Geological Survey directly or through their portal include the following which were used to support the analysis and provide background context.

- https://gis.geosurv.gov.nl.ca/geofilePDFS/WBox038/001M_0227.pdf
- Map 95-016
- 95-16.pdf (gov.nl.ca)
- 001M_0227_BWMap8459_Terrenceville.pdf (gov.nl.ca)
- https://www.gov.nl.ca/iet/files/98-02.pdf
- Waterbodies
- Known mineral occurrences in the area

In addition a structural and geological mapping exercise, undertaken by KSAT, was completed to provide context when presenting the results.

3.2.4. Band spacing between ASTER and WorldView 3

WORLDVIEW-3			ASTER	
#	Band name	Wavelength (nm)	Band #	Wavelength (nm)
1	Coastal Blue	425		
2	Blue	480		
3	Green	545	1	556
4	Yellow	605		
5	Red	660	2	661
6	Red Edge	725		
7	NIR1	832.5	3	807
8	NIR2	950		
9	SWIR1	1210		
10	SWIR2	1570		
11	SWIR3	1660	4	1656
12	SWIR4	1730		
13	SWIR5	2165	5	2167
14	SWIR6	2205	6	2209
15	SWIR7	2260	7	2262
16	SWIR8	2330	8	2336
			9	2400

Table 1: Band numbering and associated central wavelengths for ASTER and WorldView-3

4. PROCESSING APPROACH

Mineralogical studies from satellite data can include a number of processes. The approach taken by KSAT is stepwise to provide a logical analysis. In some areas this process is adapted to best suit the specific environment.

The standard methodology is summarised below.

Visualisation: Optimising the imagery to enhance geological features is often the first step in the analysis. There are specific colour composites (or visual band combinations) that can be used to highlight different features based on their reflectance and absorption patterns of the features of interest. This is of most importance where we have data that extends past what we see naturally with our eyes (the visual portion of the spectrum) allowing us to enhance features we would otherwise not see naturally. This type of visualisation can provide the first indication of different geological and sometimes of hydrothermal areas of interest.

Band Ratios: This very common technique is a rapid way to assess an image and this can be applied to all data. Different ratios, designed based on the reflectance and absorption of the feature of interest, can be applied to the different datasets to extract broad mineral groups such as iron minerals, carbonates and clays.

Principal Components (PCA): This technique is specifically designed to reduce correlation between spectral bands to allow for improved separation of features. Such a lot of the information in a scene is topographically influenced. By using PCAs we can reduce the dependence on topography and other land features and highlight the features unrelated to both topography and other surface features such as vegetation. This can be used on any dataset, where the spectral resolution allows, and can be targeted to help extract the specific features of interest.

Spectral Mapping: is used to map specific and unique minerals (where possible) in more detail. This technique relies on a combination of spectral information e.g., the unique reflectance pattern of the feature of interest based on the number of spectral bands. Such information can be extracted directly from the image or from library of reference spectra of the minerals of interest. This is used to build on the earlier analyses described above and is typically applied to datasets such as ASTER and WorldView-3 to provide more information on potential target areas.

4.1. Vegetation and Mineralogy

Vegetation has a significant impact on geological mapping and the ability to extract mineral features of interest, particularly spectrally. The reason for this is because vegetation spectral response and that of, in particular, clay minerals, is very similar (figure 4) and vegetation can often mask these minerals from detection. In an area of extensive vegetation therefore vegetation can have impact the ability to extract features of interest and an adapted approach may be applied to optimise the extraction. More details on the approach used here is provided in section 4.2.

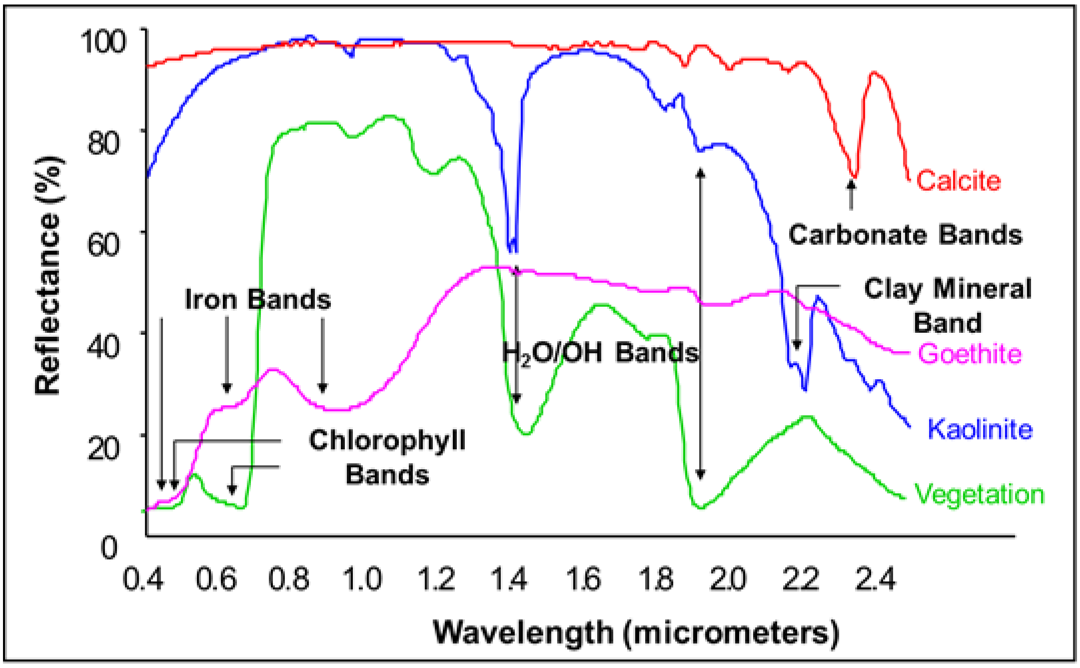


Figure 4: Spectral response of vegetation in comparison to key minerals. Taken from Alberta Geological Survey

4.2. Mineral Processing Methodology

The mineral processing approach is outlined in the following flow diagram (figure 5) which builds upon the descriptions provided in section 3 and earlier in section 4. All of these steps are applied to WORLDVIEW-3 whilst for ASTER the processing steps up to spectral analysis are applied.

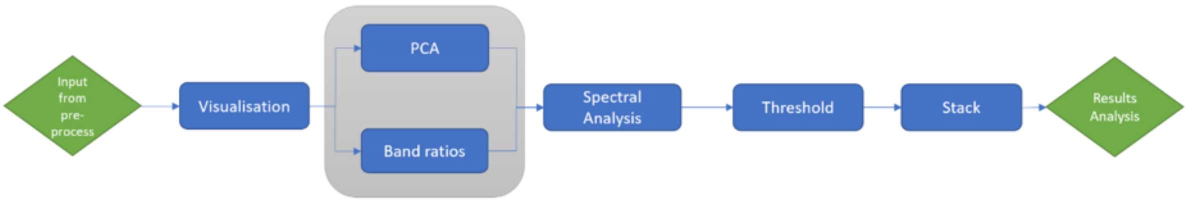


Figure 5: Flow diagram for mineral processing (minex) methodology.

The stepwise approach is advantageous to not only quickly identify potential areas of interest but to allow for an evidence-based approach that builds confidence in the repeated areas detected throughout the analysis, especially when those then correlate strongly within the geological context of the area.

A tabulated summary for the band ratios used and principal components combinations are summarised in tables 2 and 3. The band number used considers the full 16band range (ref section 3.2.4) of the WorldView-3.

Target mineralogy	ASTER spectral bands used	WorldView-3 spectral bands
Iron Oxide	2 / 1	5/2 or 5/3 or 7 + 1/8
Phyllic Alteration	5+7/6	13+15/14
Argillic Alteration	4/6	11/14
Adv. Argillic alteration	4+6/5	11+14/13
Carbonates	7+9/8	15/16
Ferrous iron	5/3+1/2	13/9

Table 2: Spectral bands used for the targeted mineralogy listed using band ratios

Target mineralogy	ASTER spectral bands used	WorldView-3 spectral bands
Kaolinite	1, 4, 6, 7	3, 11, 14, 15
Alunite	1, 3, 5, 7	3, 7, 13, 14
Illite	1, 3, 5, 7	3, 7, 13, 15
Chlorite	2, 4, 6, 8	5, 11, 14, 16
Pyrophyllite	2, 4, 5, 8	5, 11, 13, 16
Kaolinite and Smectite	1, 4, 6, 9	Not applicable

Table 3: Spectral bands used for the targeted mineralogy listed using PCA

4.3. Target mineralogy

The Geological Survey had a list of minerals of interest for identification as part of this project which were to include: Opal/Chalcedonic silica, Pyrophyllite, Diaspore, Alunite, Kaolinite, Montmorillonite, White mica, Chlorite, Epidote, Calcite, Illite, Hematite, Goethite, Jarosite and Iron Oxide Gossans.

However not all of these minerals are visible using WorldView-3 data.

For example Opal/Chalcedonic silica are best detected in the thermal infrared where silica response is most dominant. The separation of this mineral using only 8 bands in the short-wave infrared is limited as the similarity with other mineral spectra causes challenges with extraction. In addition, Diaspore is not easily separated from minerals such as montmorillonite, it is hoped that with the ability to extract other argillic and phyllic minerals as well as alteration haloes of groups of minerals provides valuable information for follow up even where these minerals are not included.

Whilst Epidote can be detected with satellite spectral analysis techniques, its subtle response signature when the signature is convolved to WorldView-3 spectral bands meant that it was not possible to identify Epidote within the area. Similarities in spectral response for iron oxides (hematite and goethite) can also make it challenging to identify subtle differences between them, however some differences were observed in this study.

A spectral plot (figure 6a) showing the spectral signatures of these minerals convolved to WorldView-3 spectral band widths is presented using the Jet Propulsion Lab (JPL) library spectral provided in the software ENVI (Environment for Visualising Images). Figure 6b zooms in to just the SWIR portion of the spectrum to focus on two advanced argillic minerals, Alunite and Pyrophyllite to highlight both the similarity and difference in these spectral. Despite similar absorption around 2180nm the subtle differences in reflectance around 2200nm does make it possible to separate Alunite and Pyrophyllite from each other using Worldview-3.

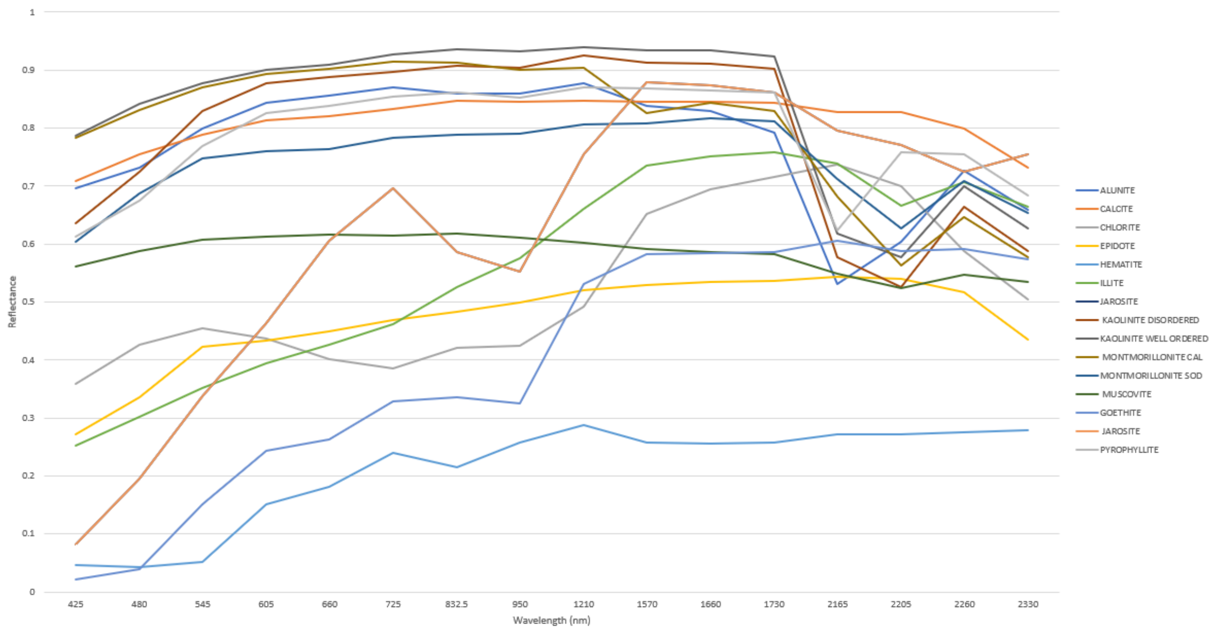


Figure 6a: Spectral response curves of requested minerals convolved to the wavebands of WorldView-3.

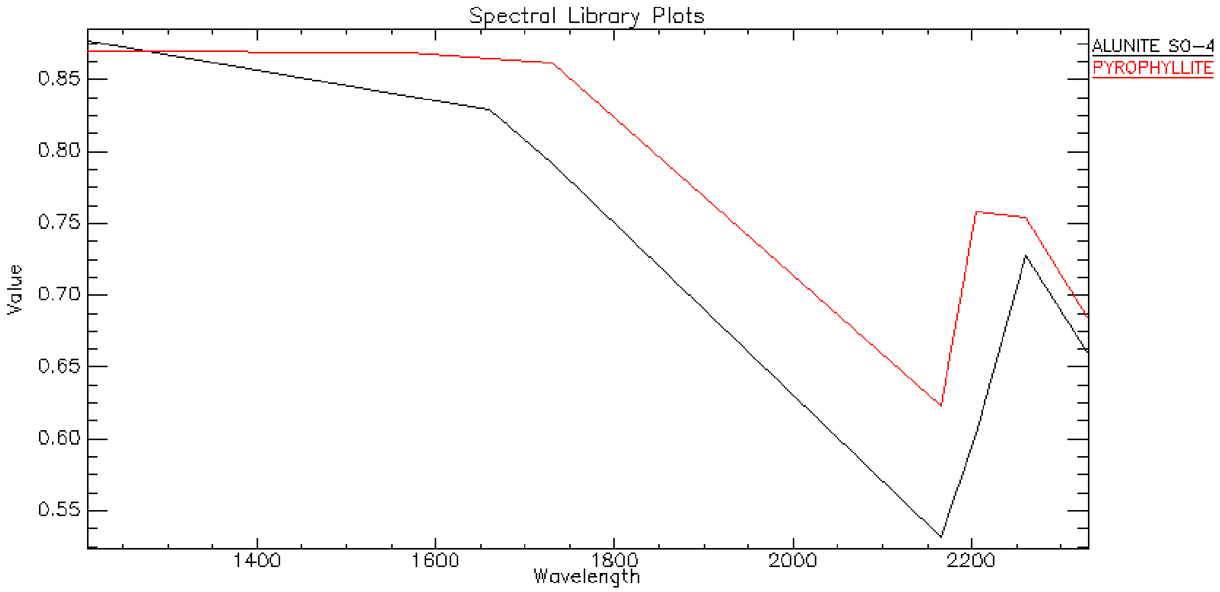


Figure 6b: Spectral response curves of just Alunite and Pyrophyllite convolved to the wavebands of WorldView-3 in the SWIR portion of the spectrum.

5. RESULTS

The following sections share results of the different stages of processing as part of building context and information across the area. The results are then discussed in detail in section 6 – Geological Context and Interpretation.

5.1. Visualisation

Visualisation uses the different combinations of spectral bands, afforded by the satellites, to highlight different features and make it possible to inspect the image in more detail prior to further analysis. For geological applications the inclusion of SWIR bands within the colour composite can help to understand information about the geological features present within the image that our outside of our normal visible range. For mineral exploration colour combinations such as bands 4, 6, 8 of ASTER have been used commonly to highlight potential mineralised areas which typically appear as bright pink features.

Figure 7 shows the ASTER data clipped to the area of interest, haze and some cloud is visible and the ASTER 4,6,8 image shows vegetation as darker red/brown colours and exposed areas appear white/blue. Examining the images further we start to see some potential areas of interest that appear as a subtle pinkish hue with the one present at site B possibly related to the haze present across the scene.

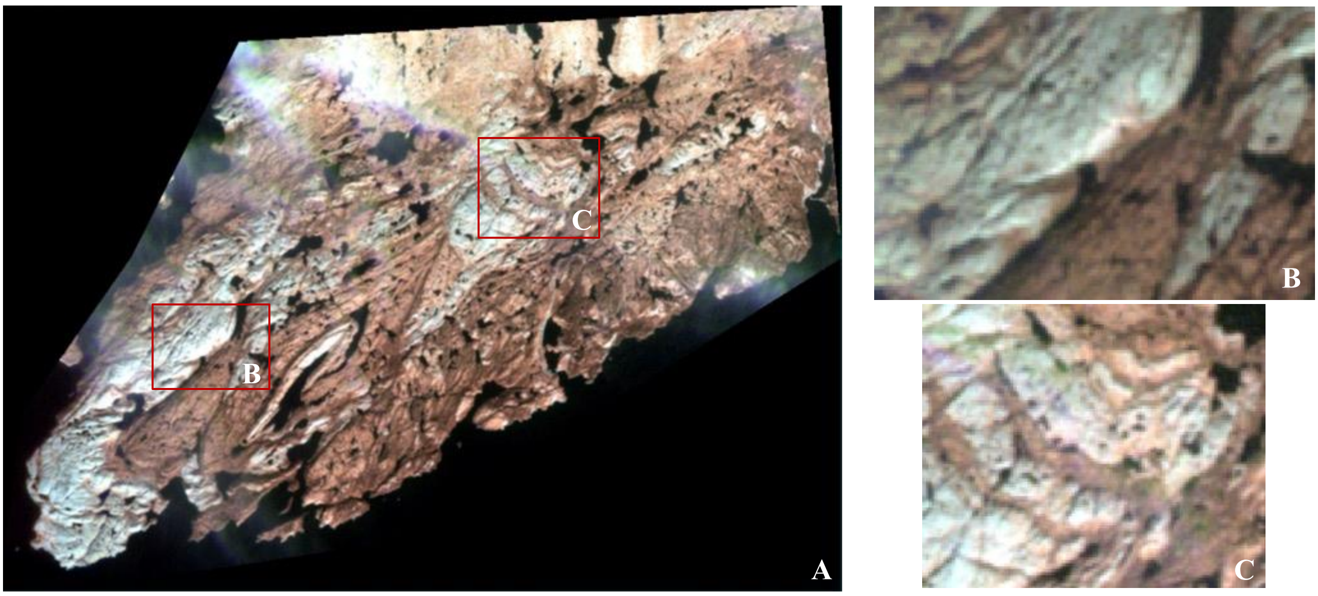


Figure 7: ASTER bands 4,6,8 RGB Colour composite showing alteration features in pink hue. A) Full image area with zoom areas marked B) Zoom location 1 and C) Zoom location 2

When compared to the WorldView-3 (figure 8) then the same features are seen, at higher spatial resolution, highlighted in similarly pink hue but the added detail provides a more defined extent. Likewise at Zoom area C, since this also appears in a pinkish hue on the WorldView-3 it adds more confidence that there is a possible area of interest here, not related to the haze across the ASTER image.

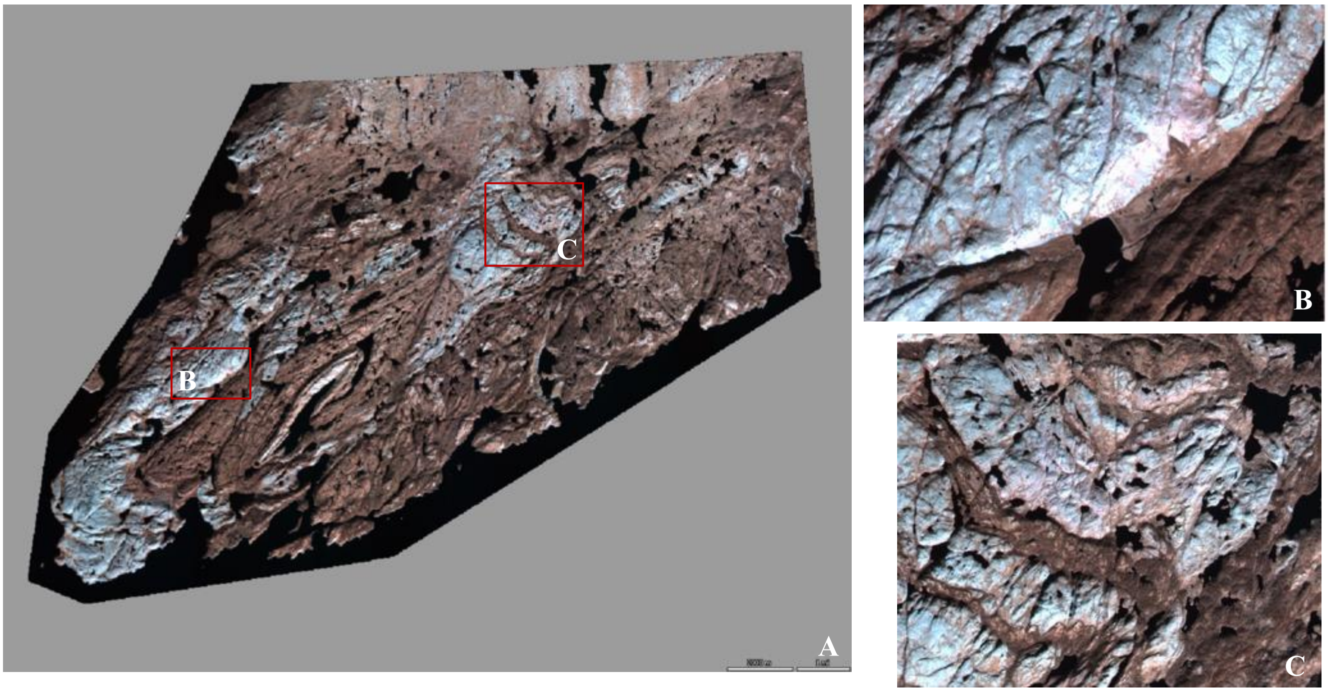


Figure 8: WorldView-3 bands 11,14,16 (as ASTER 4,6,8) RGB Colour composite showing alteration features in pink hue. A) Full image area with zoom areas marked B) Zoom location 1 and C) Zoom location 2

5.2. **Band ratios and Principal Components Analysis (PCA)**

The initial stages of analysis allow for the detection, even at a broad scale, of possible features of interest, and where there may be areas of interest to follow up more specifically with the spectral analysis. Sometimes also considered “broad band analysis” as it considers only a handful of input bands and can only broadly identify features of interest these techniques typically using just 2-4 bands, band ratios are invaluable for a rapid assessment of the types of mineralisation that may be present. Whilst a range of ratios and Principal Components may be run, they may not all show features of interest and not all are then valuable for onward interpretation. The ratios and PCA are discussed further in section 6 but are briefly shown here (for WorldView-3 only) for reference ahead of the analysis.

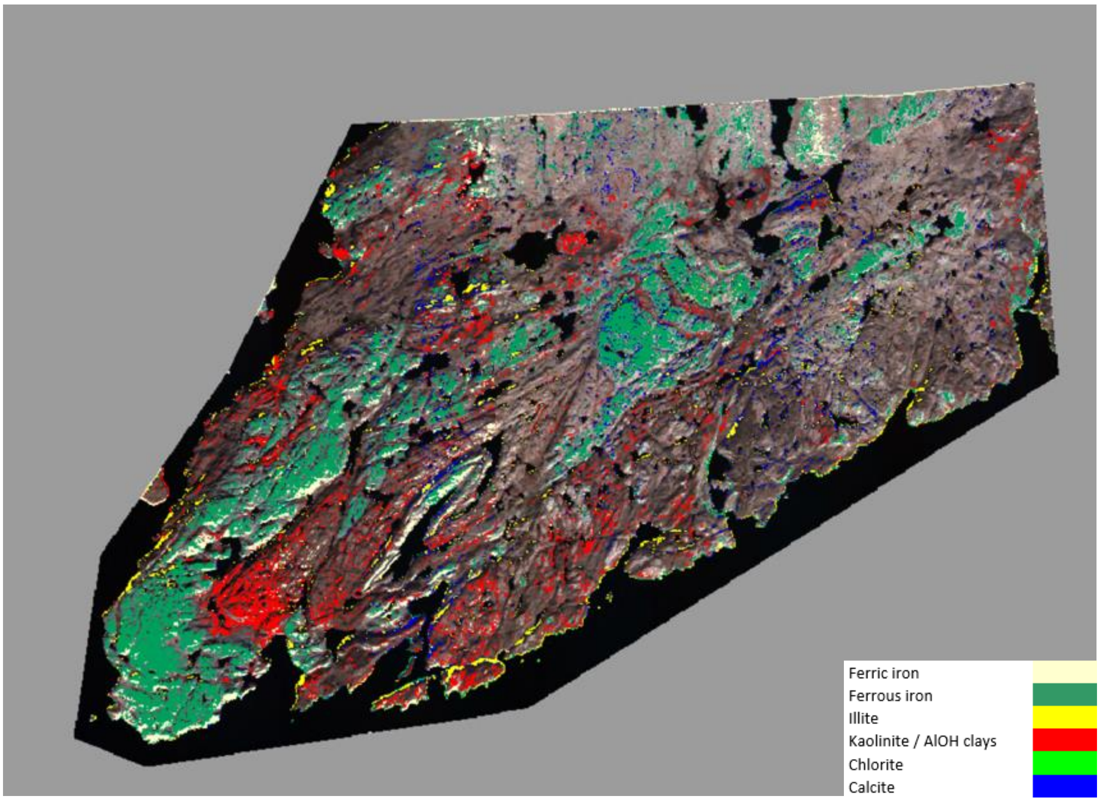


Figure 9: WorldView-3 band ratio results overlain on bands 11,14,16 (as ASTER 4,6,8) RGB Colour composite.

Figure 9 shows the band ratio results for WorldView-3 where it is clear that the clay ratios are closely correlated with the vegetated areas. This is not uncommon, as described in section 4.1 and can be a limitation of using some of the band ratios in vegetated areas. Whilst masking of the vegetated areas can also be applied to reduce the impact, this can reduce the detections that may exist over the area. What is clear however is a dominance of ferric and ferrous iron across the exposed areas with some advanced argillic minerals mapped (yellow) within these areas however there is a dominance for those features along the coastline and in shadowed areas which are likely false positive results.

Moving to the PCA (figure 10), which removes the dominance of vegetation and topography, then features are identified more clearly. By dampening down the effect of topography and other land cover, it is possible to more easily isolate different information of interest, particularly when using selective PCA – meaning spectral input bands that are selected specifically targeted for particular minerals. The results of these show significant improvement over the ratio where strong correlation with the visualisation features identified in section 5.1 are observed. In addition, some zonation is evident, in the areas previously seen during visualisation as well as in smaller areas close by not originally seen as part of visual inspection.

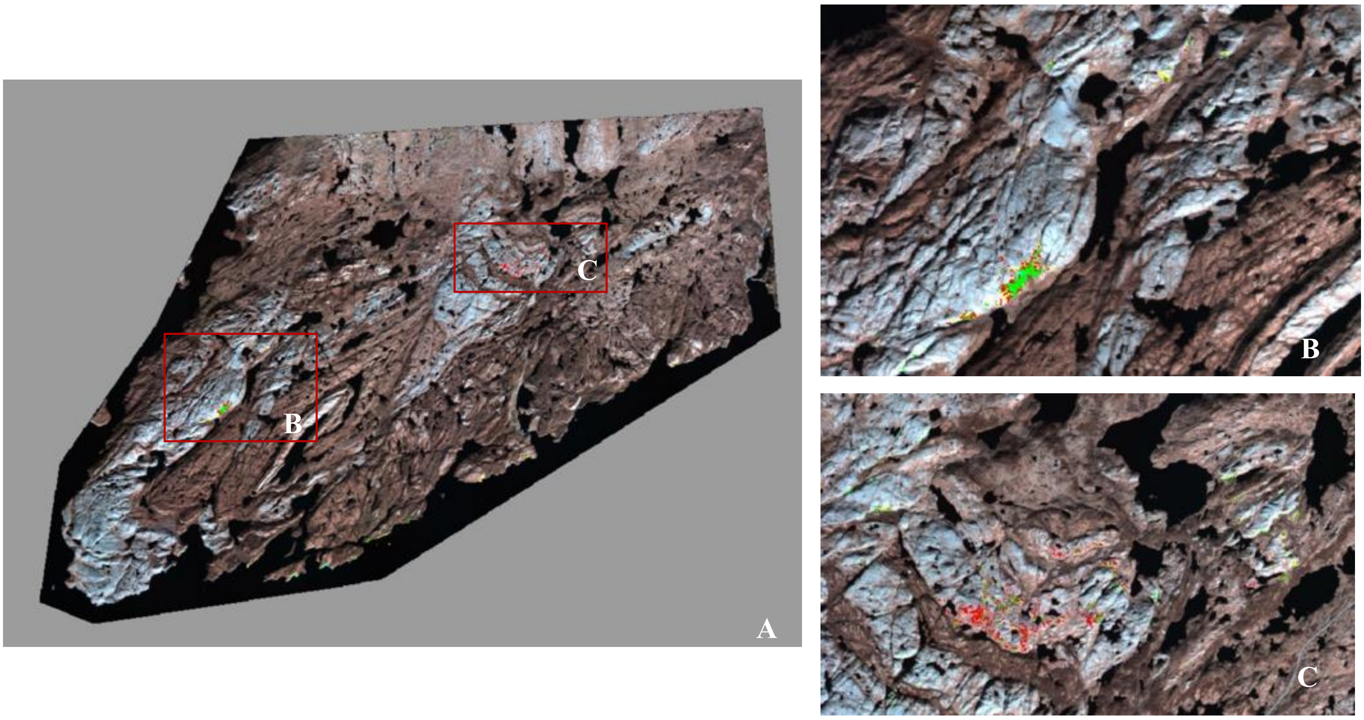


Figure 10: WorldView-3 PCA results overlain on bands 11,14,16 (as ASTER 4,6,8) RGB Colour composite. A) Full image area with zoom areas marked B) Zoom location 1 and C) Zoom location 2

5.3. Spectral analysis

The spectral analysis (figure 11) process follows the initial analysis and is designed to extract the purest pixels for analysis. On a 3.7m spatial resolution image the information is likely mixed in a pixel and the approach applied using the "Spectral Hourglass technique" in ENVI is designed to reduce correlation through a series of techniques to optimise the image for spectral analysis. The results then can include both image or library spectral end members, or a combination to best suit the area of interest. In this case the spectral analysis builds more evidence onto what was identified in the earlier analyses, particularly in the PCA, but makes it possible to separate out some more individual assemblages in more detail, were zonation of minerals is more defined, typical in hydrothermal alteration.

The results are discussed in more detail in section 6 in combination with the geological analysis.

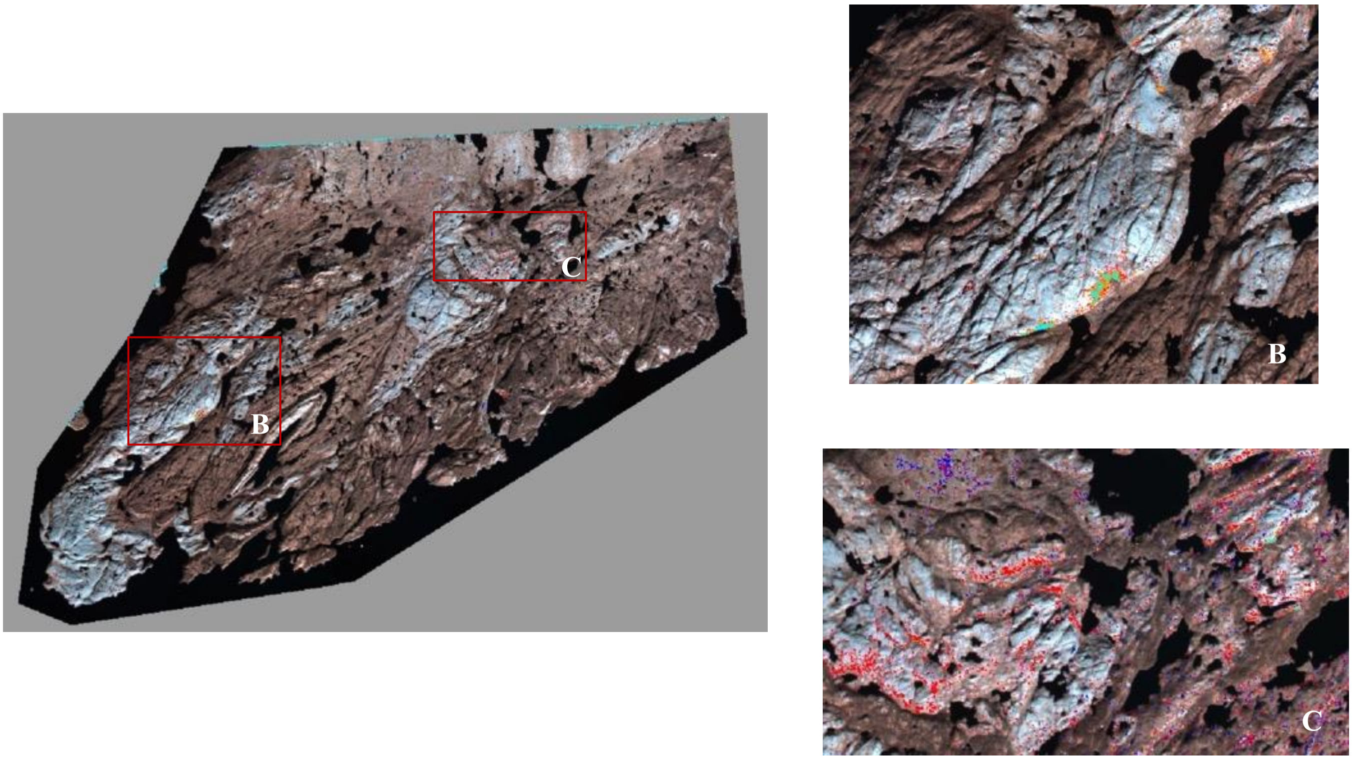


Figure 11: WorldView-3 Spectral analysis results overlain on bands 11,14,16 (as ASTER 4,6,8) RGB Colour composite. A) Full image area with zoom areas marked B) Zoom location 1 and C) Zoom location 2

6. GEOLOGICAL CONTEXT AND INTERPRETATION

The study area, which corresponds roughly with the Terrenceville 1M/10 map sheet around English Harbour, Newfoundland, lies within the Avalon Zone of the (Newfoundland) Appalachian chain that records the closure of the Iapetus and Rheic oceanic basins during the Early-Mid Palaeozoic. This section describes the results of the spectral analyses in geological context and will describe the results of both ASTER and WORLDVIEW-3-based mineral and alteration mapping.

6.1. Regional Geology

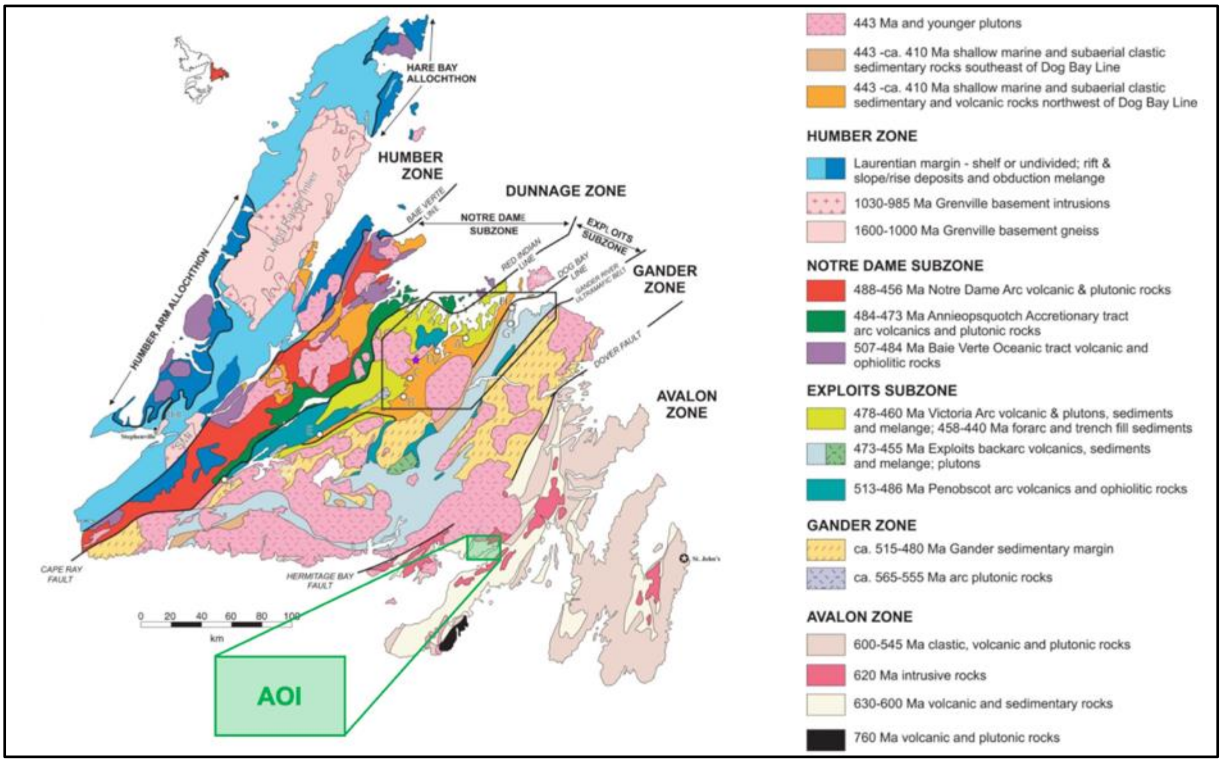


Figure 12: Geological summary map of the region. Approximate AOI is shown as green polygon. (Figure reproduced from www.eaglevision/ca/research/geology/)

The regional geology is shown in Figure 12, above that shows the aerial distribution of suspect terranes accreted to the margin of Laurentia; both the Avalon and Gander "zones" or terranes have Gondwanan affinity while the Dunnage and Humber are more associated with accretionary wedges formed above the subduction zone and the Laurentian continent respectively.

The Avalon Terrane can itself be divided into 3 zones – eastern, central and western zones (O'Brien et al 1984). The Eastern Avalon zone comprises Late Precambrian, prehnite-pumpellyite/Lwr greenschist metamorphic successions of alkaline volcanics and intrusive suites with overlying volcaniclastic and turbiditic units that are topped by shallow marine and terrestrial successions. The Central Avalon zone is similarly composed of volcanics and oceanic basalts at the base of the late Precambrian – Palaeozoic sequence and gabbros overlain by more turbidites and deltaic sequences, mafic and felsic volcanics and further marine sequences with weak metamorphism.

The Western Avalon zone contrasts with the Central and Eastern zones in that while it too shares the general volcaniclastic sequence: basalts and rhyolites overlain by thin fluvio-marine clastics and then peralkaline volcanics themselves overlain by latest Precambrian to Cambrian marine units; however, the NW part of the domain is intruded by granites of both Late Precambrian and Late Devonian age. The unit as a whole has been deformed and weakly metamorphosed and is unconformably overlain by late Palaeozoic sedimentary sequences. It is in this Western zone that the AOI lies, with the bedrock geology predominantly comprising the Precambrian Long Harbour Group and the Devonian Cross Hills Plutonic Suite and, further NW, the Ackley Granite.

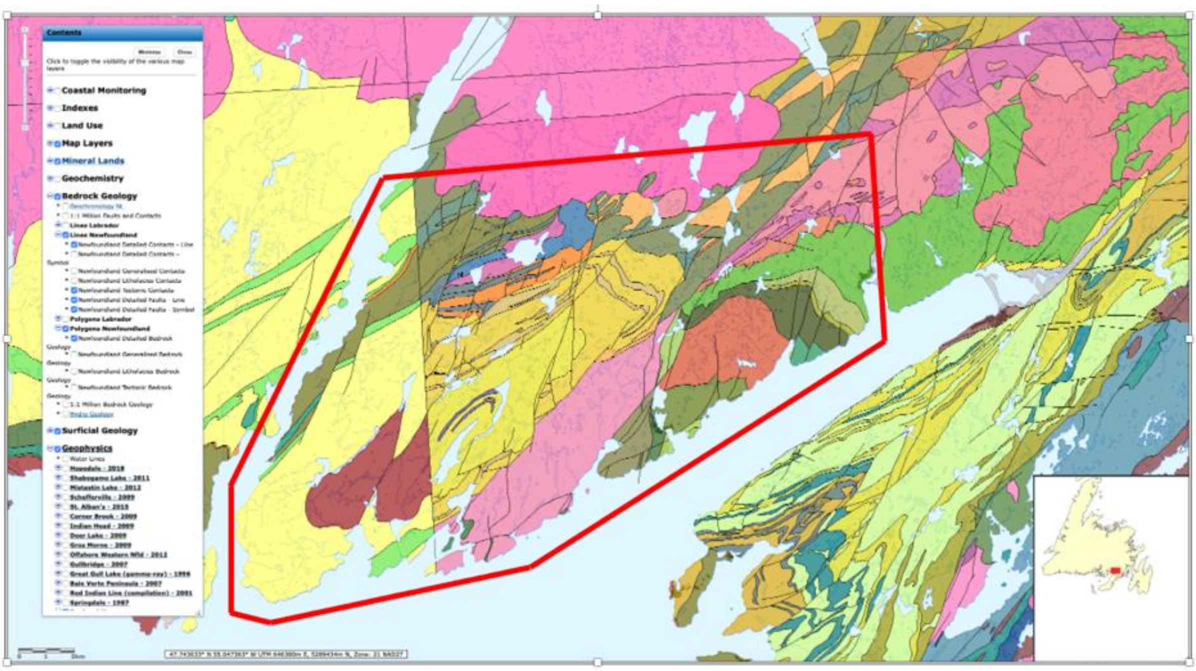


Figure 13: Geological map of the Study Area; approximate AOI in Red polygon (Source: Newfoundland and Labrador Geoscience Atlas, https://geoatlas.gov.nl.ca/Default.htm)

Structurally, the AOI consists of a number of ENE/NE – WSW/SW trending faults that control the coastlines – i.e., the South Shore Fault on the Northern Burin Peninsula and the North Shore Fault along the NW shoreline of Fortune Bay, both of which appear to join or are associated with the Terrenceville Fault. Further faults lie inland, chiefly the Cross Hills Fault, but many anastomosing and linked faults can be seen on the imagery and DEM. Several prominent synforms form, especially in the west, the Femme Syncline being the most prominent and, to the north, the Long Harbour Syncline. Tight antiforms are also present where the Femme Syncline plunges up, projecting above the Cross Hills Pluton. Relationships within the Long Harbour Group within and adjacent to the Femme Syncline infer the presence of NW directed thrusting and several locations indicate strike slip faulting both parallel and sub-parallel to the thrusts and other structural lineaments.

6.2. **Preliminary Interpretation**

Prior to examining the spectral anomalies derived from both the ASTER and the WORLDVIEW-3 data, interpretation on the Natural Colour FCC WORLDVIEW-3 data captured some 2,150 lake, pond and coastline polygons that would be used to mask out water bodies prior to spectral processing. Following this, a basic 1:10,000 scale fault/fracture interpretation was undertaken capturing some ~ 4,900 individual faults and fractures to provide some structural context to the results, which is shown in Figure 14, below.

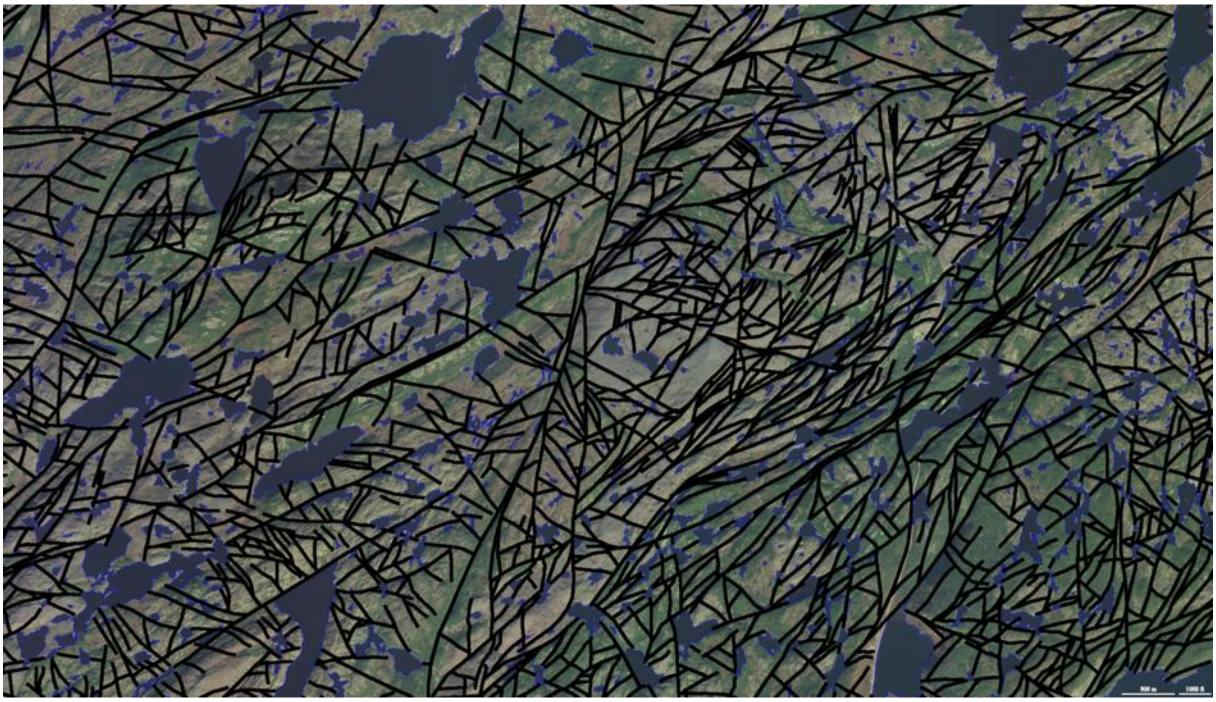


Figure 14: Extract from AOI showing fault network on NE plunge of the Femme Syncline. Two white scale bars sit in the SE corner of the image and are 500m (Left) and 1,000ft (Right) long.

The rationale for this exercise – which is neither specified in the deliverables, nor promised by KSAT – is to provide some context for the results. As exploration to the North of the AOI (e.g. by Newfound Gold Corp and Eagle Vision) has identified macro-scale hydrothermal alteration around faults and veins and that structure, chiefly around NE-trending dextral faults/shear zones (DEL Exploration, 2020), is a fundamental control on Au-Qz mineralisation, it was felt that a bit of context would be useful to explain and localise potential mineralisation scenarios. The full digital fault/fracture dataset is not included as part of this contract but details of this can be supplied if this is of interest. The same would apply to a refined version of the stratigraphic contacts derived from those shown on the Newfoundland and Labrador Geoscience Atlas (see Figure 6.2).

The fault interpretation shows many ENE-WSE to NE-SE trending faults interpreted as strike slip, thrust and minor faults; synforms/antiforms and bedding/foliation traces are also interpreted (not shown in Section 6.3). Between the major fault strands, many smaller faults provide intersections and a network of faults that may help characterise the structural geological fault system and any mineralisation.

6.3. **ASTER spectral interpretation**

The basic spectral analysis of the ASTER data illustrates three or four findings of note.

Firstly, the Clay, Argillic Alteration and Phyllic Alteration mineral identification processing tend to isolate different lithologies rather than mineralisation: their signatures are ubiquitous and show where weathering may have locally produced soils and/or thin clay-rich patinas covering the bedrock. All three signatures appear in the same locations and are considered not indicative. This is evident in the Figure 15, below, that shows these three signatures superimposed on the Natural Colour composite image with the structural elements. The image shows all three signatures all overlap each other and the only areas not coloured are those with thick vegetation.

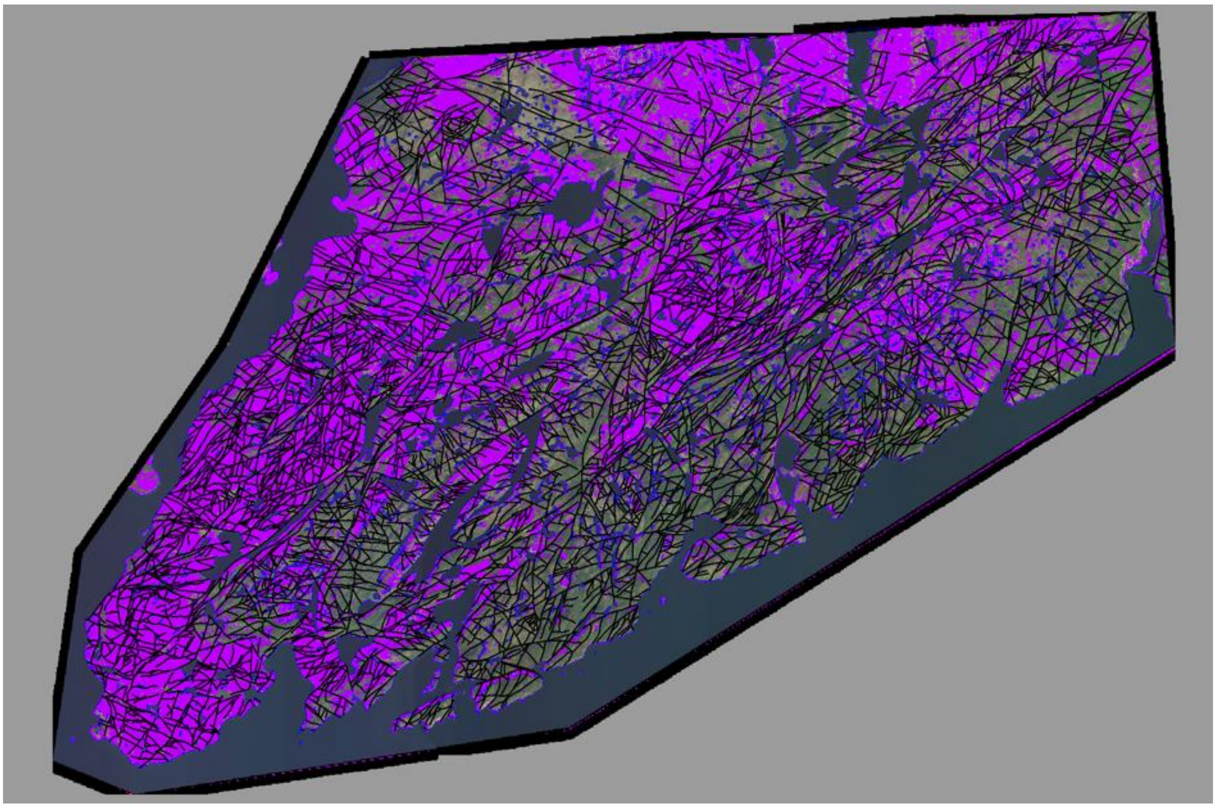


Figure 15: Clay, Argillic and Phyllic alteration signatures – signatures are all more or less coincident.

The second feature of importance is that the Ferric Iron, Ferrous Iron and Carbonate signatures show a bit more detail. The DEL Exploration (2020) report mentions that iron carbonates are the commonest alteration detected along with sericite. While these (ASTER) signatures are pretty course (30m resolution as opposed to 3.7m resolution proffered by the WorldView-3), some more diagnostic concentrations are evident.

Both the Ferrous Iron and Carbonate signatures again seem to map out non-vegetated outcrop and intensely vegetated outcrop respectively, but encouragingly, the Ferric Iron seems to correlate with the outcrop of granites – chiefly the Ackley Granite in the north of the AOI (see Figure 6.5, below). The Ferric Iron signature also seems to pick out a few anomalous areas throughout the AOI, but more especially concentrated in the centre and west of the AOI. While at first sight these may appear to be important, it is wise to exercise a degree of caution in that many of these sites appear to occupy SE-facing slopes, presumably in full sun in a morning image, so maybe due to increased illumination. The same Ferric signature also picks out the road from English Harbour to Grand le Pierre. But one area does stand out (see red box shown in Figure 16, below), but only when compared and viewed in conjunction with the WorldView-3 results reported on in the next section.

The main observation is that the ASTER data, with 30m resolution, is best as a regional screening tool in areas of reduced vegetation – where 30m pixels can pick up small bushes or trees, it will dominate the pixel/spectral response and cannot pick out small areas of bedrock soils or mineralisation that might be evident between the vegetation. WorldView-3 data, with its 3.7m resolution should offer a far more refined and resolvable dataset and is discussed below.

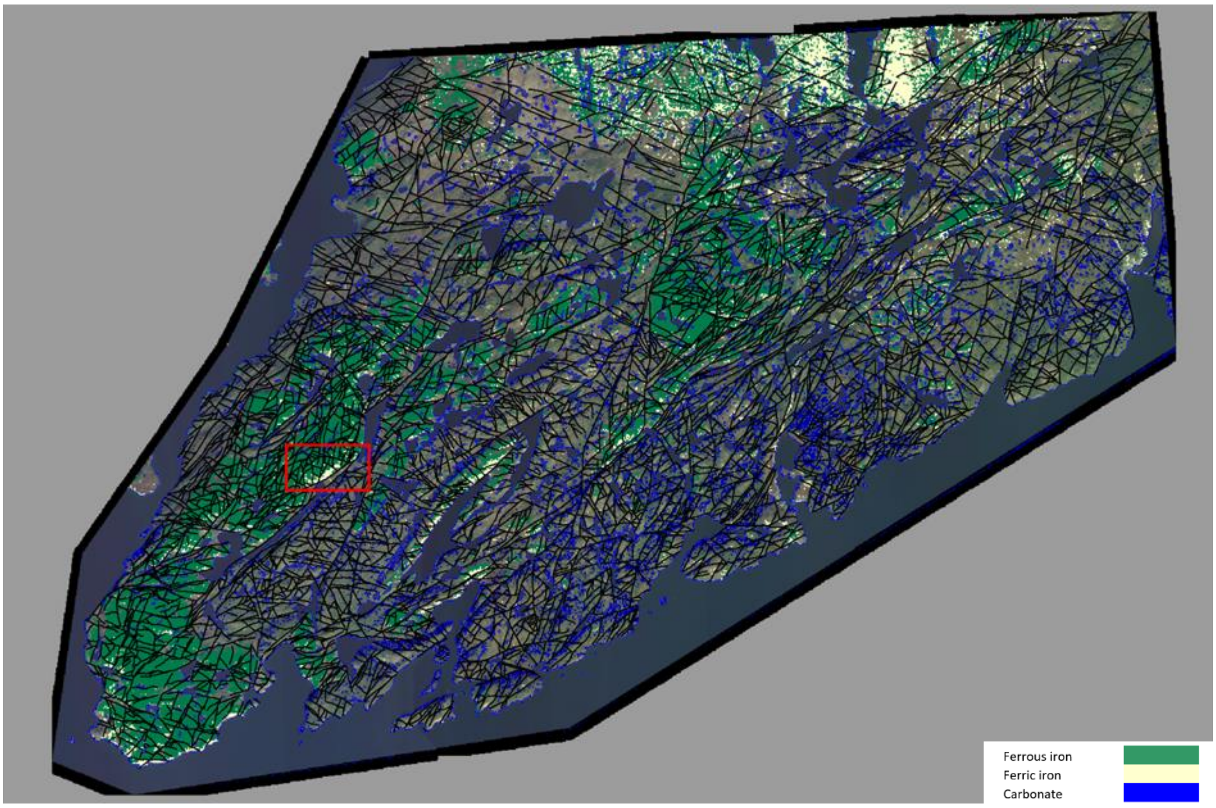


Figure 16: Green colours indicate Ferrous Iron signatures, blue the Carbonate and yellow, the Ferric Iron signature. NB the concentration of yellow within the red box and the yellow pixels in the North of the image that correlate with the Ackley Granite.

6.4. **WORLDVIEW-3 Spectral analyses**

The WorldView-3 data, having been processed and visualised, were then superimposed on the imagery and existing maps to see how the resulting mineral mapping visualisation may match the bedrock geology and known mineral occurrences in the mapping area. For this last task, the Terrenceville Map sheet (Map 84-59) was scanned and georeferenced. The map shows mineral locations from field work and several polygons depicting both 2% pyrite, sericite and gossans and 1-2% disseminated/stringer pyrite as a form of calibration exercise. Subsequently, the remainder of the data were examined to see where anomalies occurred. In this report, all the results are treated together in the form of 7 snapshots (Locations 1-7) across the AOI that show the relationships mentioned above – these are shown below in Figure 16, that sows where the snapshots lie in relationship to the AOI. The boxes are also supplied digitally to enable easy reference from report to digital database.

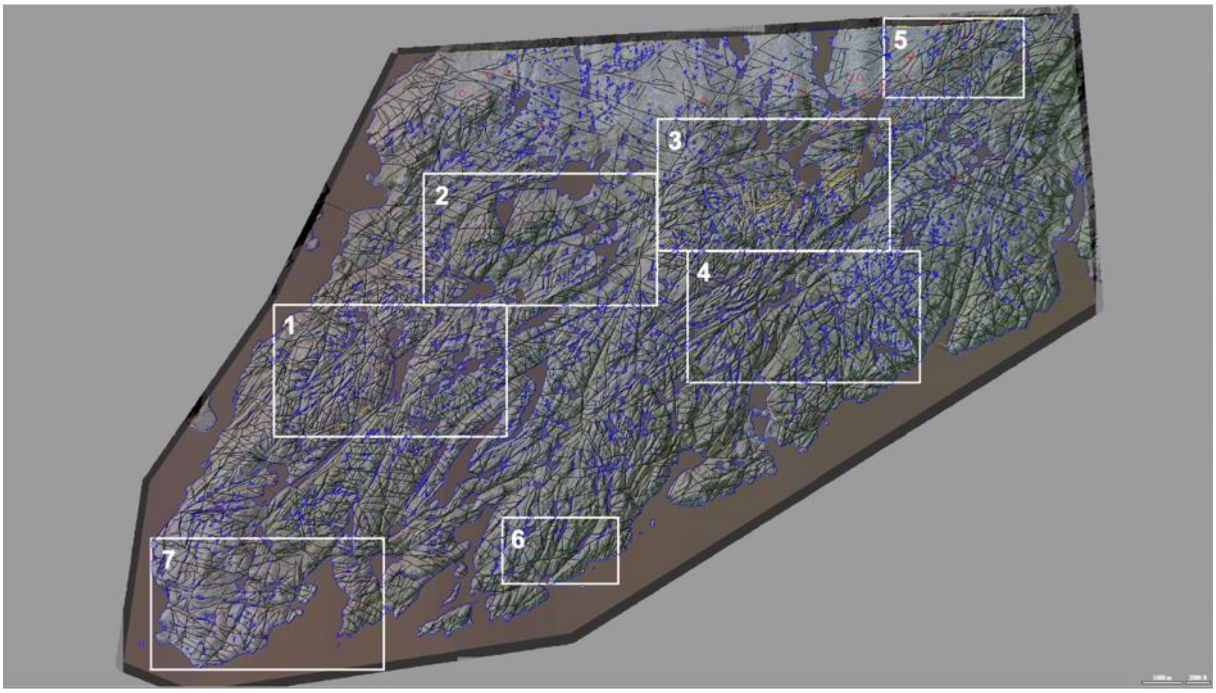


Figure 17: Location diagram showing where the subsequent numbered images lie within the AOI.

6.4.1. General points

The processing (band ratios, Principal components analyses and mineral mapping using spectral libraries (described in more detail in section 5 above) produce a suite of pixel-based relative mineral abundances indicative of specific clays, carbonates, ferric-ferrous iron and general alteration as well as specific minerals (e.g. hematite, goethite, montmorillonite, sericite etc). These are displayed either over the imagery (natural colour composite, as in Figures 14, 15, 16 and 17), an “Alteration Mapping Image” made to highlight alteration areas in pink using WorldView-3 bands that correlate with the ASTER 468/RGB Image or, lastly the 10m DEM) to see the spatial relationship to outcrop and structure from the faults mentioned above.

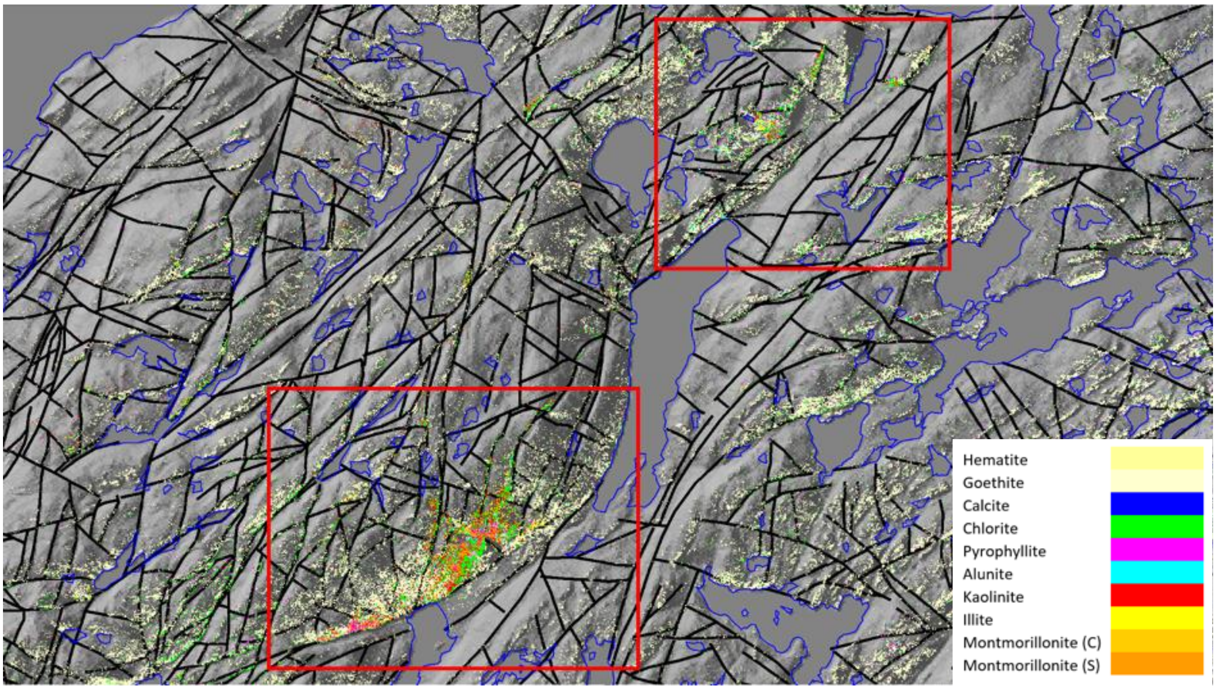
The hope is that they identify zones of enrichment and potentially, alteration haloes around significant leads. In addition, the results of all the analyses are “stacked” to see where high concentrations of multiple mineral signals overly each other. The latter produces a “traffic light” map that shows areas with moderate mineralisation in yellow (up to 4 minerals in the same location), orange (up to 6) or high mineralisation in red (up to 8), and highlights the most attractive zones for further analysis, presumably in the field.

As with the ASTER data, some analyses seem to have mapped lithologies – the Ferrous Iron (in the west) and the Calcite in the central east), for example, can be seen across the AOI – which is expected to some degree as they are common minerals. These can be considered to be "regional" or "background" data.

Lastly, the data also show that SE-facing slopes and SE-facing coastlines (presumably with cliffs) also show elevated values. These probably relate to them facing either the sun in the morning – and as such are preferentially illuminated, or are facing the sea, where sea spray and other wind-related fine-grained material collects and affects the spectral signals – these areas are treated with caution (see below).

6.4.2. Location 1: West of Gull Pond

The first and most prospective lead is described here and lies 3km WSW of Gull Pond. The terrain is rocky and hilly, with many large to medium sized ponds and lakes that lie within the Belle Bay Formation, characterised by rhyolites, mafic tuffs and agglomerates.



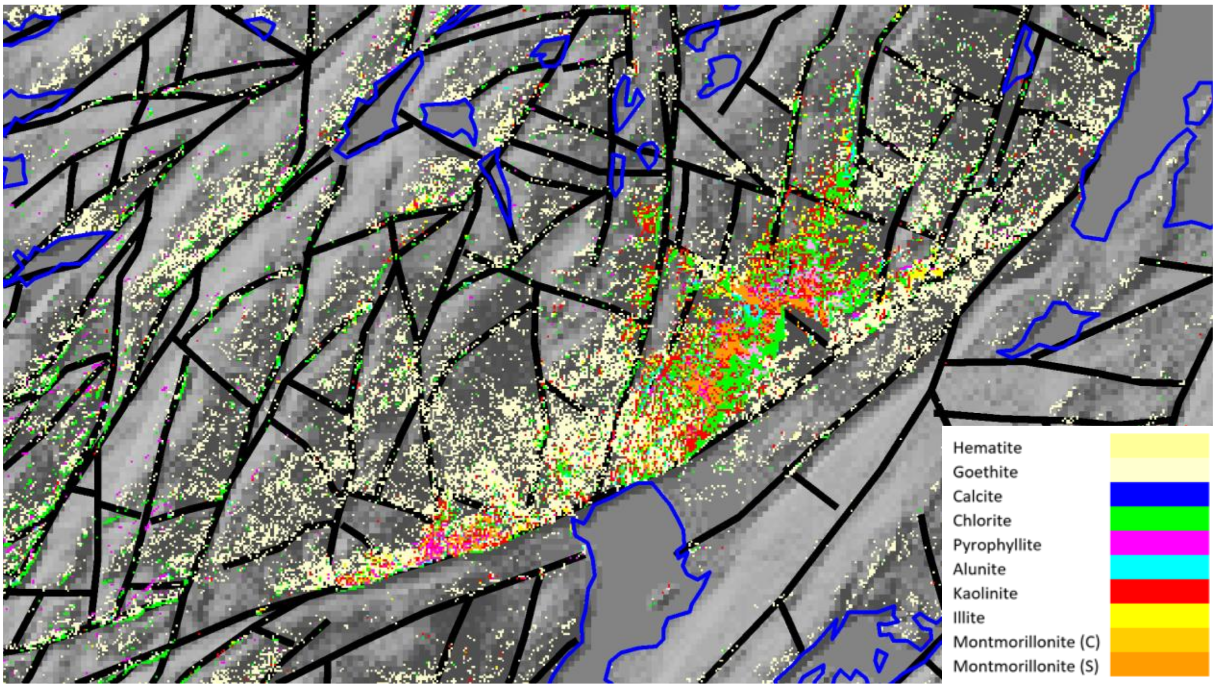


Figure 18: Location 1a, top, showing multiple and concentrated signatures in apparent alteration halo, (Ferric, Chlorite, Calcite, Illite, Kaolinite, Montmorillonite, Muscovite, Goethite, Hematite Pyrophyllite, Jarosite, and Alunite) West of the Femme Syncline. Red box shows extent of blow-up. Location 1b, immediately above) and "stacked" anomalies along and North of prominent fault: reds indicate 8 minerals in same location, oranges 6 and yellows, 4. NB two prominent haloes – the main halo in the centre and a smaller halo to the WSW of the main halo.

Much of the area shows Ferric Iron (light yellow colours in Figure 18), chiefly on SE-facing slopes (which appear to be facing the sun in the imagery collected) but also on hilltops.

The vast majority of the mapped mineralisation occurs in two locations, one in the central North of the area immediately NW of Gull Pond, on a SE-facing hill and hilltop, NW of a set of parallel NE-SW trending faults and the other WSW of Gull Pond on a prominent hill bound by an arcuate fault "bowing" to the SE. The smaller of the two, NW of Gull Pond, comprises three smaller concentrations of Ferric (light yellow), Chlorite (green), Illite (yellow), Kaolinite (red), Montmorillonite (orange) and Pyrophyllite (magenta pixels) in a crude halo in the (largest) westernmost cluster; smaller clusters lie to the NE, but neither have no discernible halos, but are associated with minor (NNE-SSW and WNW-ESE trending) faults.

The main anomaly, and the best lead mapped in the AOI, lies in the central South of Figure 6.7 and lies exclusively NW of a bow-shaped/arcuate fault that is concave to the NW, matching the shape of a hill whose steep side faces SE, with a gentler slope towards the NW. The Figure 17 (Location 1b) above clearly shows what appears to be a halo of different minerals comprising Ferric (light yellow), Chlorite (green), Calcite (blue), Illite (yellow), Kaolinite (red), Montmorillonite (orange), Muscovite (pink), Goethite (light yellow), Hematite (medium yellow) Pyrophyllite (magenta), Jarosite (light yellow), and Alunite (cyan) members, from outside (Ferric) to inside (Jarosite/Alunite. This does seem to fit a hydrothermal alteration halo model (see Figure 24, Section 6.4.8). Strands of mineralisation follow faults trending roughly N-S North of the main halo and many of the faults West of the halo also show chlorite pixels along the fault traces. A smaller and less well-developed halo also lies adjacent to the same fault some 300m further West. The entire anomaly (i.e. both together) measures 1.3 by 0.45 km.

6.4.3. Location 2: SE Bight Hills

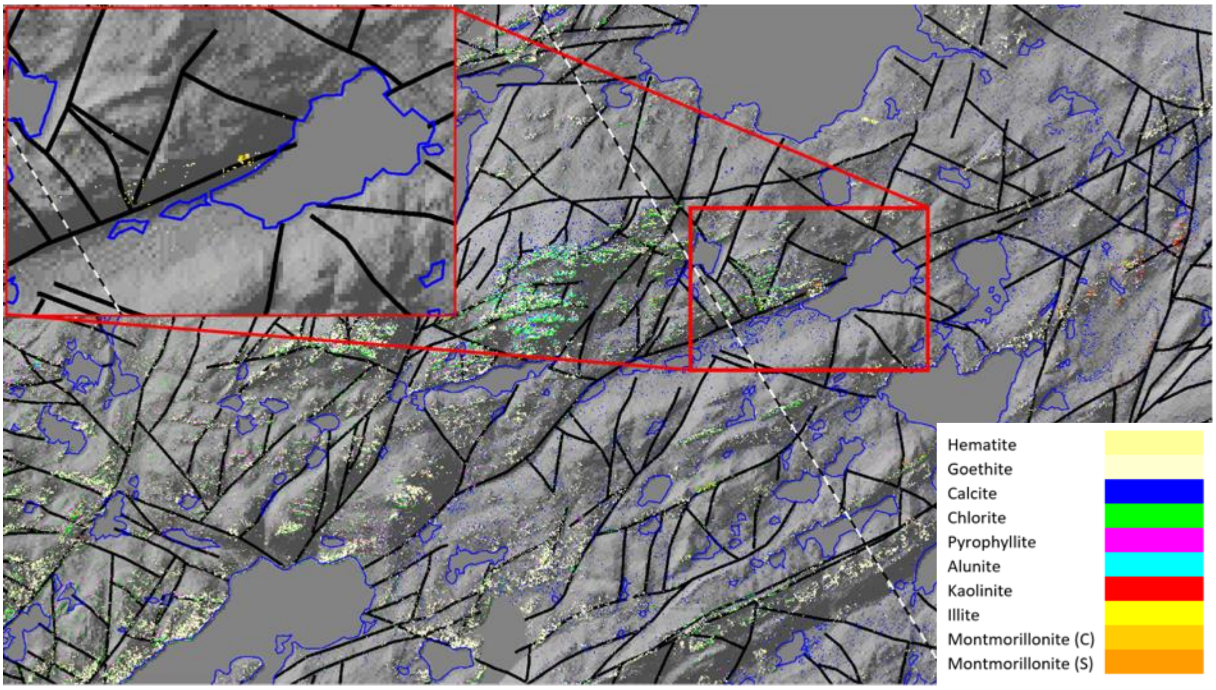


Figure 19: Location 2a, main image, showing multiple and concentrated signatures (Ferric, Pyrophyllite, Chlorite and Alunite) coincident with the SE Bight Hills (N of the Femme Syncline). Red box shows extent of blow-up (Location 2b, red box) and "stacked" anomalies along fault: oranges indicate 6 minerals in same location and yellows, 4. NB NE-SW-striking collection of Ferric, Chlorite and Kaolinite East of the red box.

Just to the North of Location 1, the SE Bight Hills lie NNW of prominent ENE-WSW trending faults and comprise members of the Precambrian Anderson's Cove Formation (sandstones and conglomerates, siltstones with occasional mafic flows) adjacent to granitic members of the Devonian Cross Hills Plutonic Suite. The terrain is formed of elevated ENE-WSW trending ridges that show Ferric, Chlorite, Alunite and Pyrophyllite. Some clusters seem fault-related and others more related to the bedrock itself. One particular cluster, 1.5km East of the main outcrop shows a tighter group with the addition of Montmorillonite (see Figure 19, 2a and 2b, above) and 6 or so different mineral species lie together along an ENE-WSW trending fault. However, as in many places, many of the signatures lie on SE-facing slopes that may be affected by direct sunlight and preferential reflection.

6.4.4. Location 3: Cross Hills Fault-Bark Pond

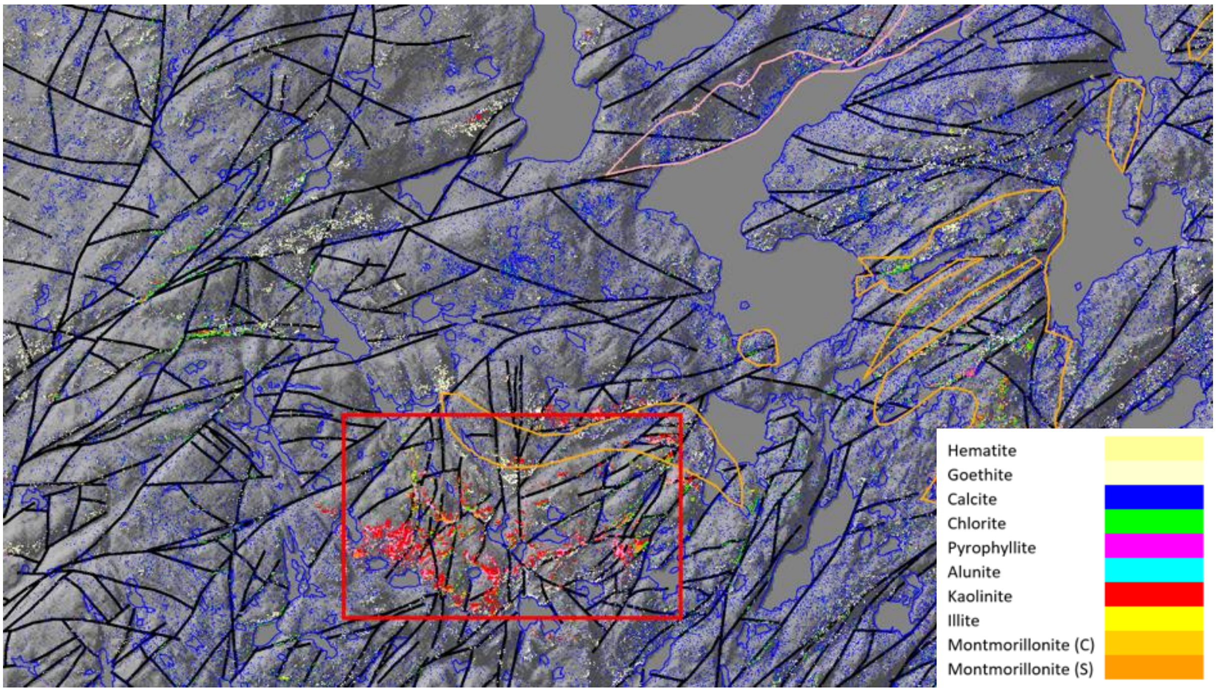


Figure 20: Location 3a, top, showing multiple and concentrated signatures (Kaolinite, Pyrophyllite, Montmorillonite, Chlorite and Illite) coincident with the previously mapped 2% Pyrite/Sericite alteration from field mapping (orange polygons). Red box shows extent of blow-up (Location 3b, immediately below). and "stacked" anomalies: reds indicate 8 minerals in same location, oranges, 6 and yellows, 4.

Location 3, an area North of the Cross Hills Fault and the Bark Pond, in the central northeast is dominated by the NE extension of the Femme Syncline, a broad structure with tighter antiforms on the flanks, sandwiched between NE-SW orientated faults. The synform is complex and smaller antiforms and synforms are superimposed on it, forming smaller structures commonly separated and associated with faults. The lithologies are dominated by rhyolites, felsite and tuffs of the Mooring Cove Formation in the centre (red box, Figure 6.9) and felsic/mafic pyroclastics (Snooks Tolt Member) or peralkaline granites intrusions of the Cross Hills Plutonic Suite. Previous mapping has established the presence of pyrite (~2% pyrite) and the spectral mapping confirms the presence of mineralisation in this locale. Figures 20 and 21 show these patterns: Kaolinite (red pixels) and pyrophyllite (magenta) dominate, but Montmorillonite (orange), Chlorite (green) and Illite (yellow) are present too in the centre, while smaller and tighter clusters are present 2.5km further East, some associated with ENE-WSW faults. Many of the clusters have up to 8 different minerals in the same location and these tie up with the previously mapped mineralisation zones (orange polygons in both Figure 6.9 and 6.10 and relate to the different lithologies present, whose outcrop patterns they mimic.

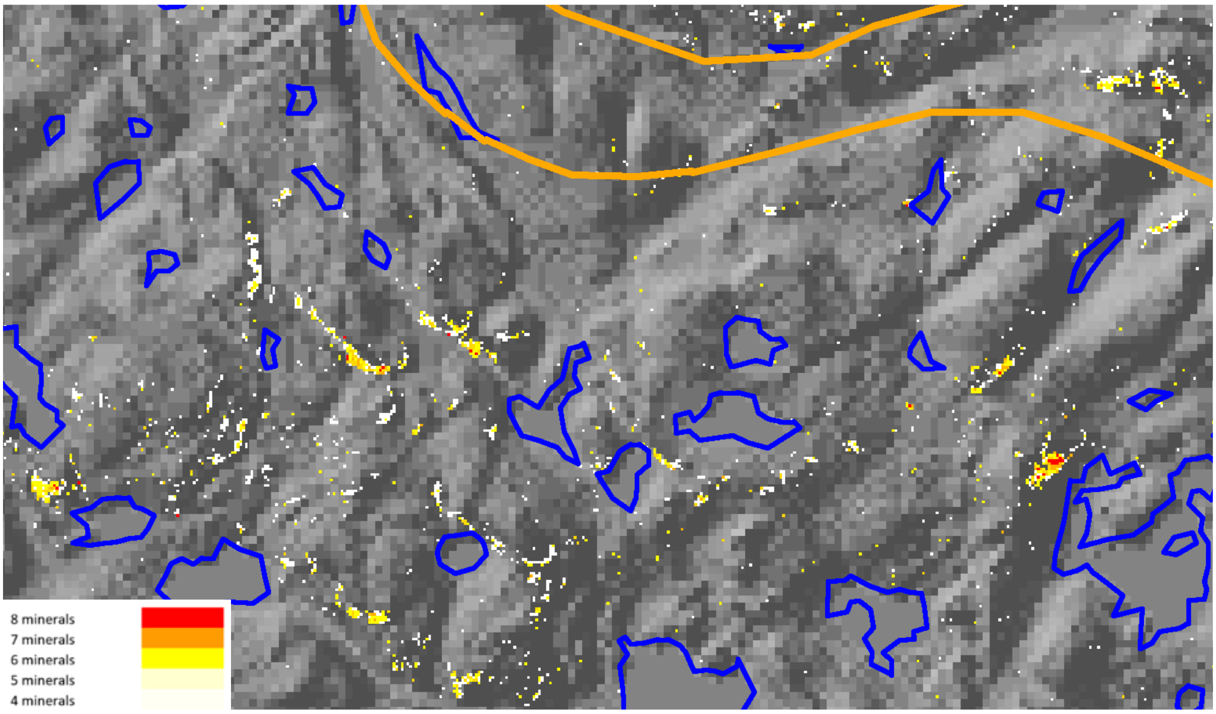


Figure 21: Area of Red box (in Figure 6.9) showing "stacked" anomalies: reds indicate 8 minerals in same location, oranges, 6 and yellows, 4. Waterbodies are shown by blue outlines.

6.4.5. Location 4: English Harbour East

The terrain north and inland from English Harbour East is dominated by the English Harbour East Formation that consists of (in this location) rhyolites, agglomerates and ash-flow tuffs. Faulting while developed, is not well organised, although ENE/NE-WSW-SW trending faults are evident, cross cut by NW-SE faults; but no one set dominates in the centre and SE. To the NW, prominent and ubiquitous, parallel to sub-parallel faults belonging to the Cross Hills Fault dominate and the fault resembles a fault zone rather than a single fault trace.

However, the signatures recorded by WorldView-3 data (see Figure 22, below) point to two apparently anomalous patterns (red boxes). The main body, which forms disseminated but locally clustered signatures of Kaolinite, Montmorillonite, Illite and Chlorite. Some relate clearly to faults but the majority relate directly to the bedrock. Weathered rhyolites will decay to clays, and the pattern may be lithologically controlled rather than to any focussed mineralisation.

The smaller red box (with blow up in NW corner) show a distinct and isolated cluster along a N-S fault that appears to splay off at a high angle from the Cross Hills Fault. Kaolinite, Montmorillonite, Chlorite and Illite are evident. The location marks a fresh cliff and a rock fall – whether this anomaly is simply due to the fresh-faced cliff and rock debris is unknown, but is worth checking in the field and is close to the road.

6.4.6. Location 5: Taylor's Mtn & Dick's Ponds

In the NE corner of the AOI, several NE-SW orientated linear zones that depict previously mapped areas of increased pyrite, sericite alteration, gossans and disseminated pyrite lie between Dick's Pond and Taylor's Mtn Pond, in the Snooks Tolt Member, which comprises dominantly felsic and mafic pyroclastics, tuff breccias, agglomerates, rhyolites etc.

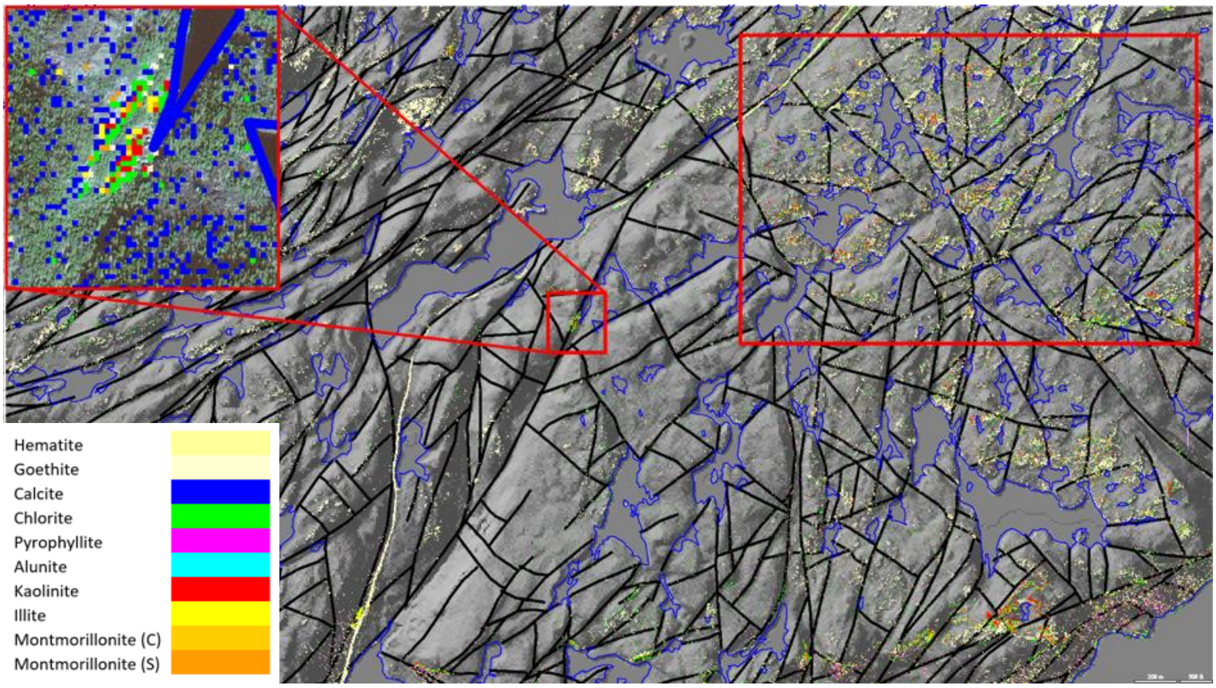


Figure 22: Location 4, showing (red boxes) multiple but disparate signatures (chlorite, Kaolinite, within the (orange) 2% Pyrite polygon (NE) and anomalous Kaolinite, Chlorite, Montmorillonite and Illite (central and in blown-up box) along fault.

The lesser mineralised disseminated pyrite zone lies NW of the more altered pyrite-sericite zone and displays some clumps of mineral signatures, especially along faults that may be mineralised. However, some caution is needed as these fault-guided troughs may contain more clay and humic soil that may obscure real signatures.

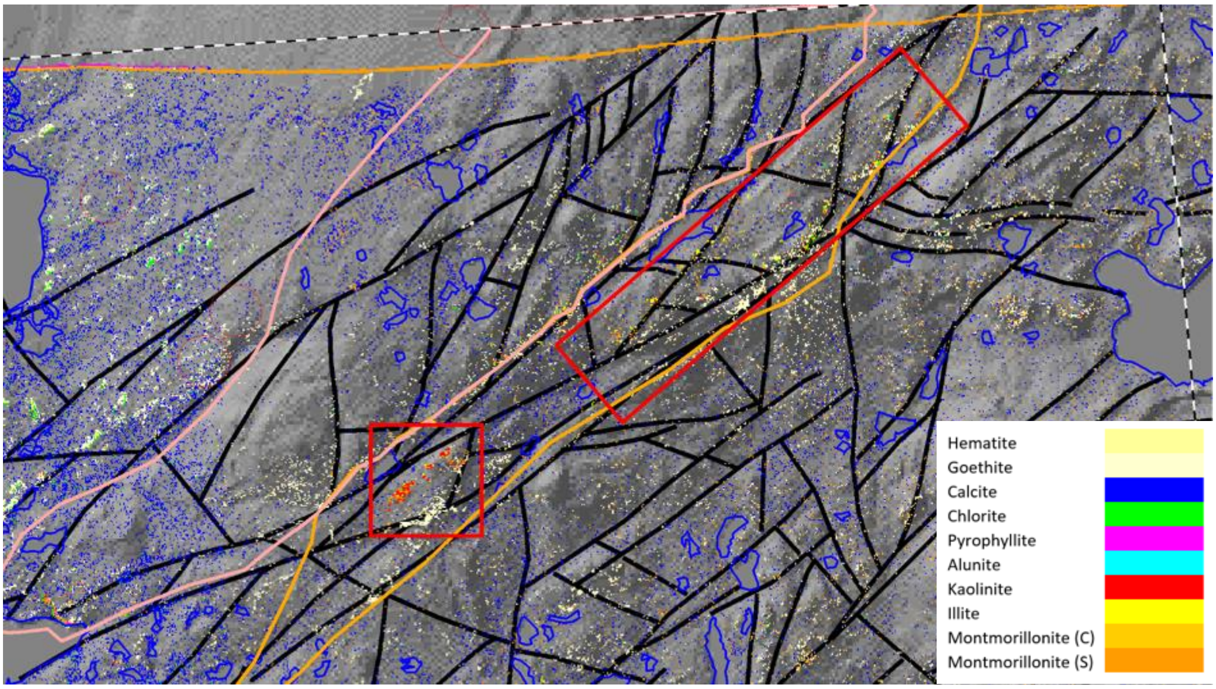


Figure 23: Location 5, showing (red boxes) multiple signatures within the (orange) 2% Pyrite polygon (NE) and anomalous Kaolinite (central SW).

However, further SE, within the more altered pyrite-sericite zone, more concentrated clusters of mineral signatures are noted, also preferentially lying within/alongside within fault zones. While Ferric Iron dominates, kaolinite, Alunite, Illite and Montmorillonite are also mapped. These are shown in the red boxes in Figure 23. The smaller box (centre-SW) displays a cluster of closely spaced Kaolinite-rich mineralisation associated with Montmorillonite and Chlorite.

The zone lies immediately NE of Location 3, along strike and slightly north of the Cross Hills Fault, the prominent FZ that runs ENE-WSW across the AOI (refer to Section 6.4.4, Location 3). The mineralisation along the faults and the juxtaposition of the two mineralised Pyrite zones indicates that these signatures are probably related to the Cross Hills Fault.

6.4.7. Location 6: New Harbour

This location lies next to the coast near New Harbour, where the bedrock is mostly comprises nits from the English Harbour East Member (red and pink ash-slow tuffs, tuff breccias and clastics). A minor antiform is indicated on the Terrenceville Geological map. Evident here is the Ferric Iron signature that is common in the west of the AOI, along with some minor Chlorite and Alunite concentrations, chiefly developed on the SE-facing slopes of ridges presumably relating the antiform; the predominance of the signatures on SE-facing slops may relate to increased insolation on these slopes or to the fact that there is more outcrop exposed in these locations.

Also evident is the development of strong Chlorite or Alunite signatures along the coast, which may point to the influence of wind-blown sea spray and clay-grade material along the coast, forming a thin veneer on the bedrock. However, this is uncertain, and should be field checked.

Of exploration interest is a small zone that has anomalous Ferric Iron, Chlorite and Kaolinite signatures (see red box in Figure 23); again, this relates to a steep slope/cliff and may be highlighted due the better outcrop exposure but may indicate some mineralisation.

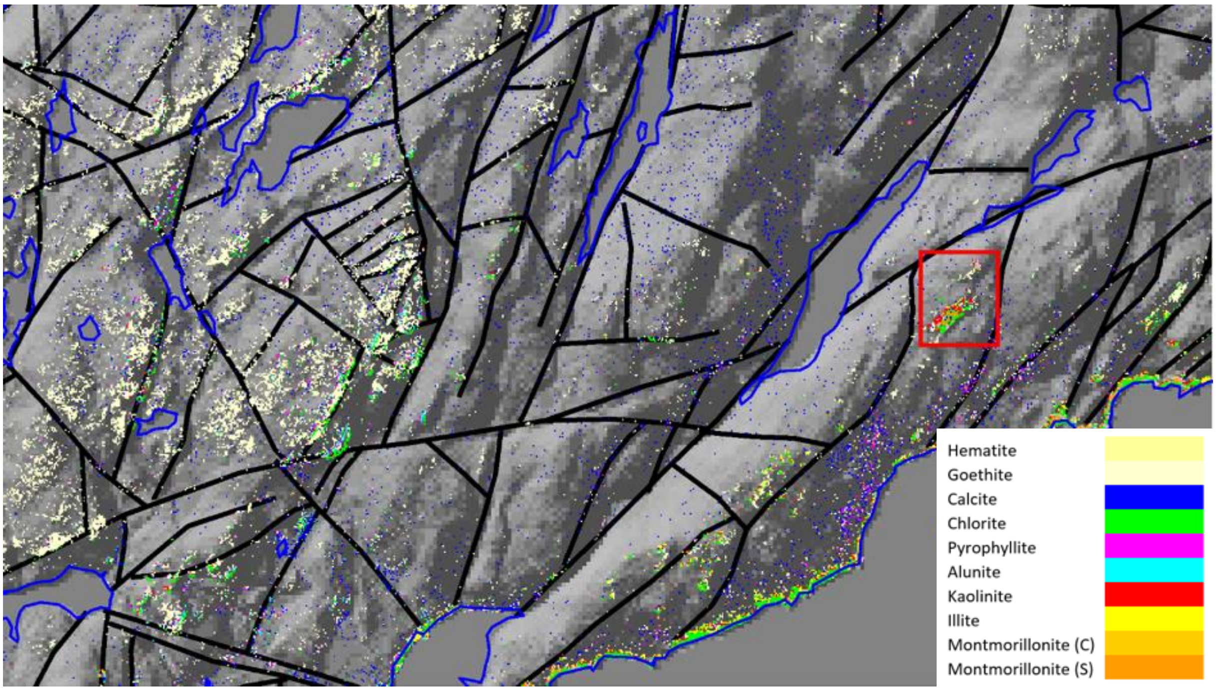


Figure 24: Location 6, showing prominent Ferric Iron signature and anomalous Kaolinite (red box).

6.4.8. Location 7: Lobster Cove-Little & Big Conne

The rationale for the choice of Location 7 is to simply illustrate the effect of SE-facing slopes and coastlines. As the image below (Figure 25) shows, many of the slopes facing S or SE, preferentially illuminated by the sun, show elevated Ferric Iron signatures (light yellow colour); additionally, chlorite (green pixels) is abundant along some coastal stretches, presumably from salt in the sea spray that collects along the coast. Other disparate collections of assorted spectral signatures also lie by the coastline in the extreme NE of the image, adjacent to the two prominent bays: these too, are suspected of being influenced by marine processes. Note also the collection of Kaolinite in the red box that falls along the small extent of a N-S fault near the coast in the East of the image, in the Belle Bay Formation, characterised by rhyolites, mafic tuffs and agglomerates. A mineral deposit is described nearby – F110: Long Harbour No 6 (fluorine, NMI No 1M/11/Fl 020).

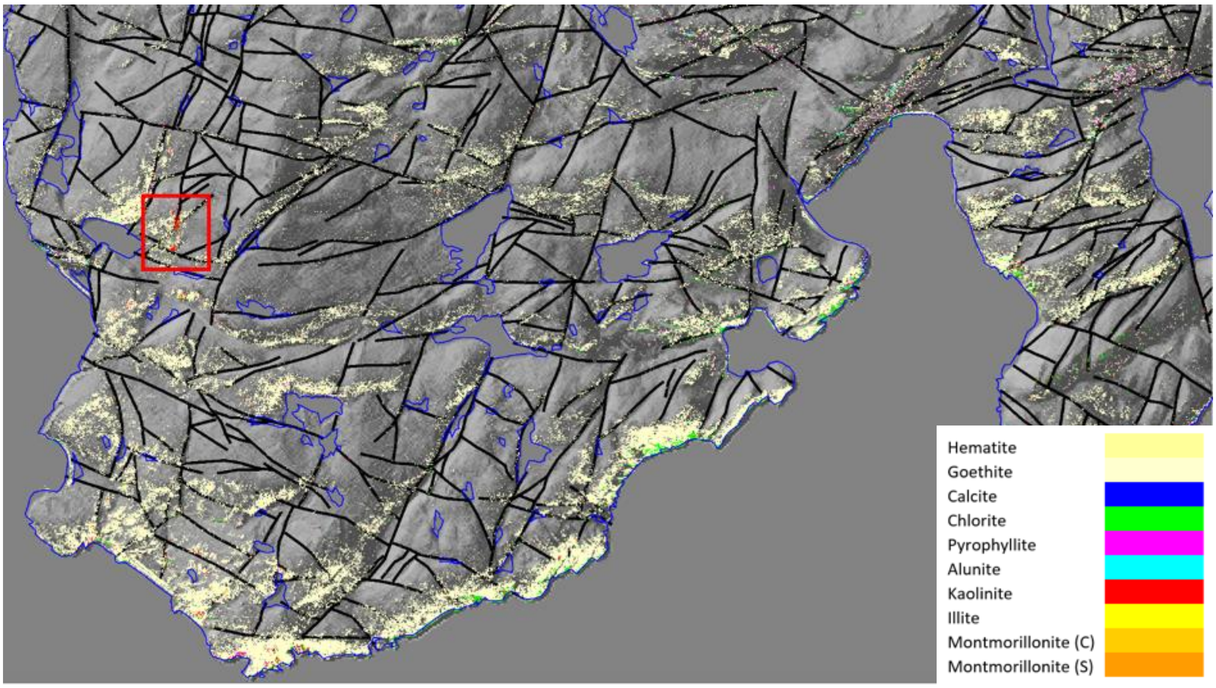


Figure 25: Location 7, showing prominent Ferric Iron signature and anomalous Kaolinite (red box).

7. CONCLUSIONS AND RECOMMENDATIONS

The processing applied to the data has allowed for the identification of a number of mineralisation zones present within the AOI.

The stepwise approach to processing ensures that confidence can be gained in the analysis where repeating areas are identified in subsequent steps.

The ASTER data whilst not a required data set for this study, provides context and support to the overall geological picture in this region and allows for baseline understanding of potential mineralisation to be identified, over and above, published areas of mineralisation provided through the Geological Survey.

The WorldView-3 adds value in detail and delineation of these features whilst also allowing the identification of smaller alternation zones not visible on ASTER owing to its resolution.

The analysis had led to the following main observations are:-

- The main lead, just west of the Femme Syncline appears to show alteration zoning with two prominent haloes that all lie directly NW of a bow-shaped, SE facing fault (intrusive-injected back thrust?). The haloes display a distinct zoning with ferric and clay (argillic and advanced argillic) around the margins with higher grade pyrophyllite and Alunite/Jarosite zones in the centre (see Figure 26 a and b, below)
- Other areas of potential lie at the NE plunge of the Femme Syncline, in conjunction with (but not exactly matching) previously mapped 2% Pyrite zone.
- Similarly, further to the NE, the previously mapped 2% Pyrite zone coincides with loosely clustered mineralisation with a prominent NE-SW strike, matching the pyrite zone.
- Smaller potential leads that will need to be assessed further in the field (with the leads mentioned above) are also identified, but are much smaller.
- Individual mineral localities marked on existing maps are hard to image, even with the WorldView-3.
- Other features of note are regional or background signatures more related to slope facing direction and closeness to the seashore and onshore wind-blown salt and clay material.
- ASTER data on its own are insufficient for detailed mapping at 1:20,000 scale.
- The WorldView-3 data is a valuable tool for providing detail and delineation to even smaller alteration areas, not afforded by the ASTER alone. Whilst only one image at one time of year was purchased, multi temporal analysis could also be considered, including summer scenes where the sun angle is more optimal. This could also be consideration for further study, characterisation and mapping.
- DEMs are crucial to understand the terrain.
- Further mapping could characterise and analyse the faulting with more precision and the lithostratigraphy could improve the existing maps and help further targeting of leads and prospects

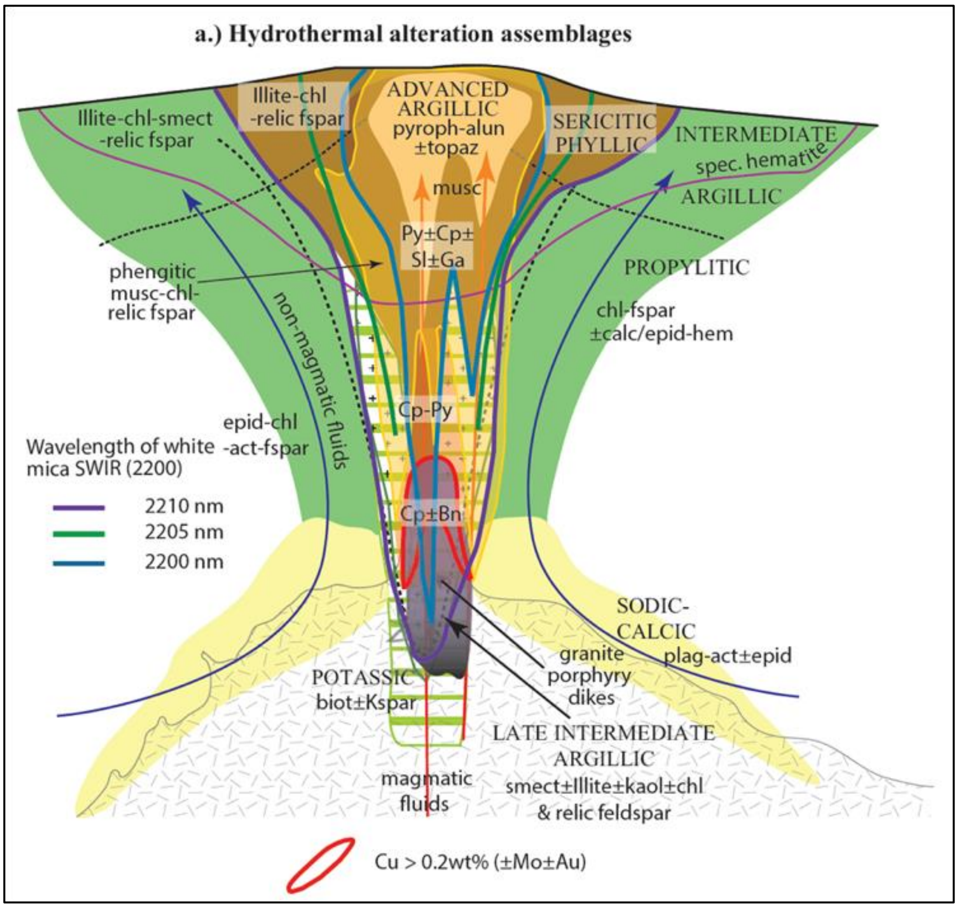
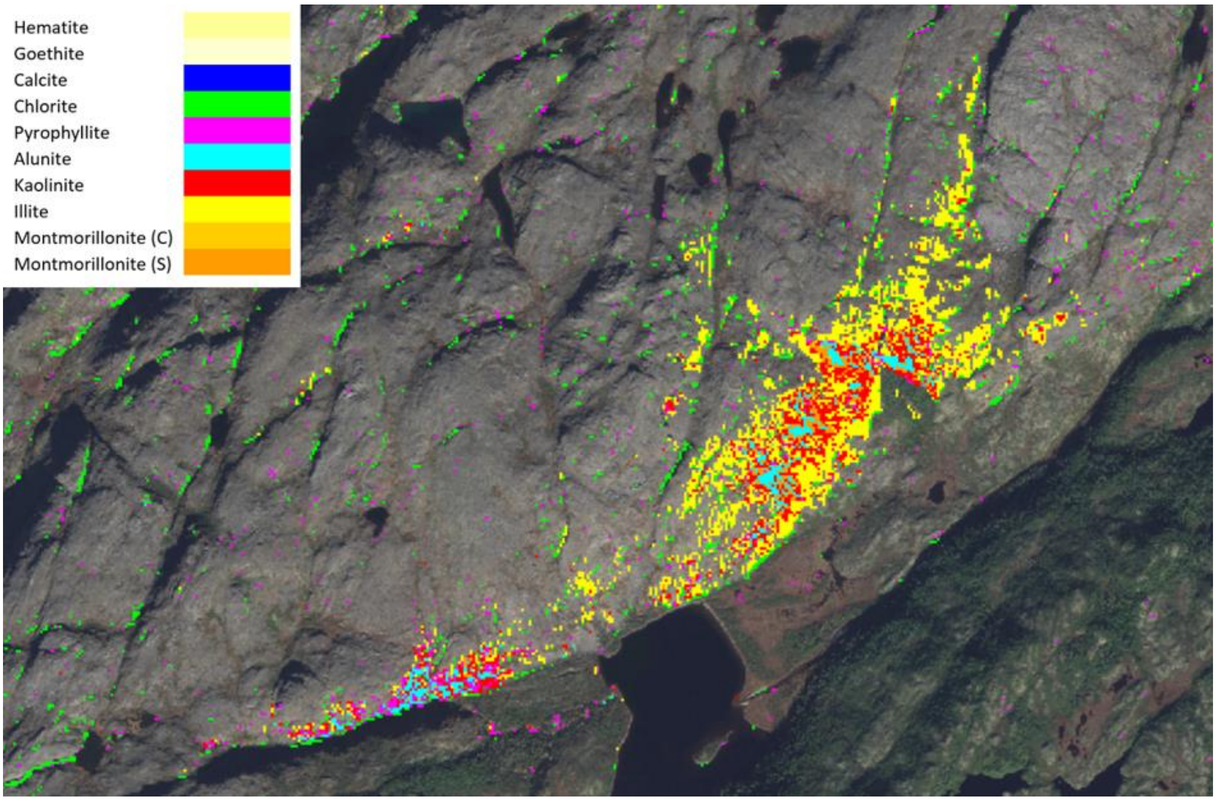


Figure 26 a, above): Alteration patterns (note the large orange advanced argillic alt = colour anomalies) in porphyry copper deposits (Halley et al., 2015); b, below): alteration halo developed west of Gull Pond (see section 6.4.2)



8. DELIVERABLES

The deliverables are listed below and are all provided in NAD83 Universal Transverse Mercator Zone 21 (T) and delivered via KSAT's delivery site.

The requirements for this tender requested shapefiles however as the output to the processing is raster, and to ensure no loss of information, the delivery of binary rasters, styled to each mineral is provided as an alternative. KSAT would be pleased to hear if these meet the need or discuss vector production if this is preferred.

In addition, the study called for a delivery of mineral layers with a degree of certainty for each specified mineral. KSAT presents a raster product with associated colour ramp to show low to high relative certainty to complement the binary mineral layers mentioned above.

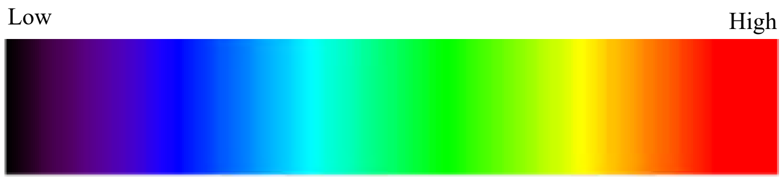


Figure 27 Relative abundance/certainty image colour ramp to show relative abundance of each mineral based on thresholded and optimised coverages. High abundance showing the estimated highest abundance of the minerals based on the thresholding applied. Each mineral is styled to the same approximate range for ease of comparison.

Note: as described in section 4.2 each strip of WorldView-3 was processed separately to retain the spectral integrity of the individual strips. The final combined raster is a merge of these layers into a single layer for ease of delivery and onward analysis.

The outputs have been compiled in an ESRI project file and styled as displayed in this report.

- Newlfoundland Mineral Study - ESRI Project file *(.mxd)*
  - Mineral layers *(geotiff)* – combined Middle, Eastern and Western into one file
    - Alunite
    - Calcite
    - Chlorite
    - Goethite
    - Hematite
    - Illite
    - Jarosite
    - Kaolinite
    - Montmorillonite Cal
    - Montmorillonite Sod
    - Muscovite (note only present on Western and Middle sections)
    - Pyrophyllite
    - Ferrous Iron (ratio product)
    - Ferric Iron (ratio product)
  - Mineral threshold / abundance *(geotiff)* – combined Middle, Eastern and Western into one file
    - Alunite
    - Calcite

        - Chlorite
        - Goethite
        - Hematite
        - Illite
        - Jarosite
        - Kaolinite
        - Montmorillonite Cal
        - Montmorillonite Sod
        - Muscovite (note only present on Western and Middle sections)
        - Pyrophyllite
        - Ferrous Iron (ratio product)
        - Ferric Iron (ratio product)
    - Focus areas (Figure 17 review boxes) *(shapefile)*
    - Basemap – ASTER 468 RGB image *(geotiff)*
- Report (this report) in Pdf

9. REFERENCES

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