Dark Mica Composition as Mineralization Vector: Examples from Hyperspectral Core Imaging at the Cebolla Creek Titaniferous Magnetite Deposit, Gunnison County, Colorado, USA

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Abstract:

Dark Mica composition, as measured by hyperspectral core imaging, shows similar breadths of spectral variation with respect to the more commonly known White Mica and Chlorite variations, all of which are related to fundamental mineralization processes. Dark Mica spectral behaviour related to changing composition has not been successfully characterized in the past due to the poor sampling volumes, coarse field-of-view and low-fidelity bandwidths of typical single point spectrometers. Results from hyperspectral imaging of 200 feet of core from the Cebolla Creek Titaniferous Magnetite deposit in Gunnison County, Colorado indicate large spectral variation of the 2320nm composition feature (relating to mineralization). Located within the Iron Hill Carbonatite complex of the Powderhorn District (emplaced ~570 Ma), the Cebolla Creek deposit hosts Th, REEs, Cu and Nb in addition to the primary Ti and Fe mineralization. Eighteen separate minerals and mineral sub-species including Phyllosilicates, Carbonates, Amphibole, Pyrochlore, Iron Oxides, Hydrous Silica, REEs and potentially Perovskite were identified and mapped using hyperspectral data. The different species of Dark Mica at Cebolla Creek are characterised by wavelength shifts up to 16nm, ranging from ~2320nm to ~2336nm. Historical assay data (Cu, Fe, TiO_2, REE) integrated with the interpreted hyperspectral mineralogy and compositional variations, highlight mineralization relationships. Elevated TiO_2 and Fe assay values correspond to short ~2320nm wavelengths in Dark Mica (interpreted as Mg-rich Biotite), while low TiO_2 and Fe values correlate with the longer Dark Mica wavelengths (interpreted as Fe-rich Biotite). These results not only elucidate previously unknown mineralization vectors at a historic Ti-Fe deposit but also expose underutilized Dark Mica compositions for exploration in multiple ore deposit styles.

Introduction:

Hyperspectral core imaging of Dark Mica composition shows similar extent of spectral variation with respect to the more commonly known White Mica, Smectite, Chlorite and Carbonate compositional changes, all of which are related to fundamental mineralization processes. Dark Mica spectral behaviour related to changing composition has not been successfully characterized in the past due to the poor sampling volumes, coarse field-of-view and low-fidelity bandwidths of the typical single point spectrometers. Results from hyperspectral imaging of ~200 feet (~60m) of core from the Cebolla Creek titaniferous magnetite deposit in Gunnison County, Colorado indicate large spectral variation of the 2320nm composition feature that is diagnostic to Dark Mica. Located within the Iron Hill carbonatite complex of the Powderhorn District, the Cebolla Creek deposit hosts Th, REEs, Cu and Nb in addition to the primary Ti and Fe mineralization. The igneous rocks associated with this deposit are part of an alkaline complex emplaced ~570Ma ago into Proterozoic Powderhorn Granite (Figure 1).

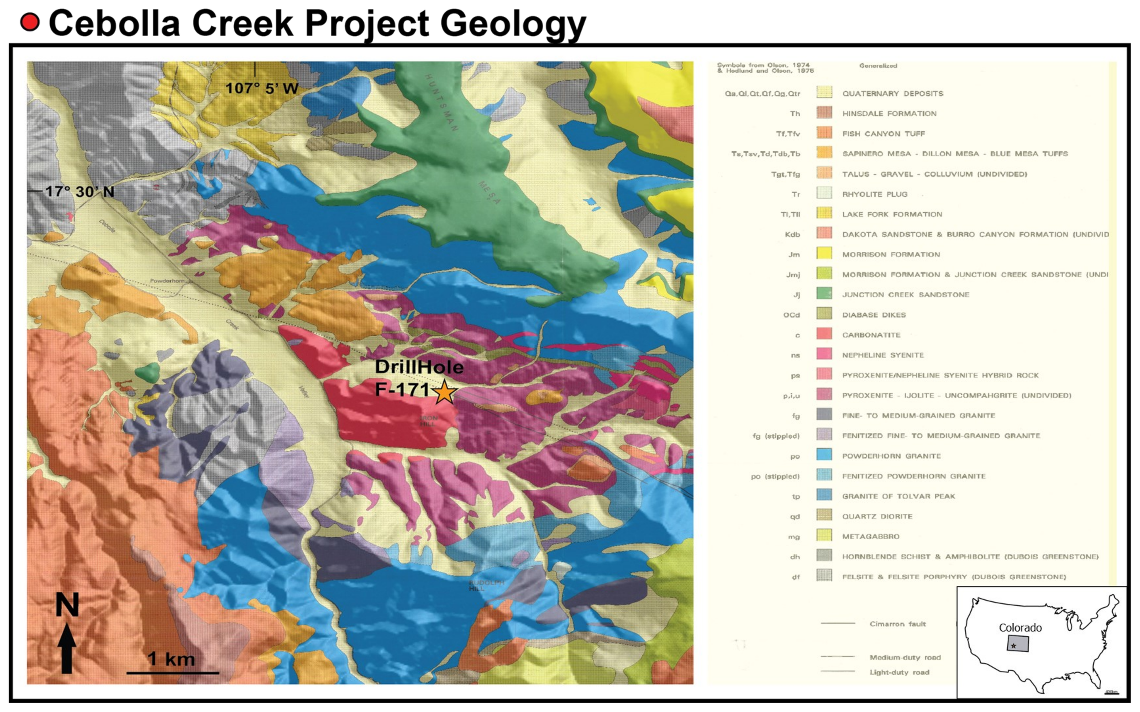

Figure 1. Location and regional geological map of the Cebolla Creek titaniferous magnetite deposit in Gunnison County, Colorado, USA.

Results:

The different species of Dark Mica at Cebolla Creek are characterised by wavelength shifts that range from ~2320nm to ~2336nm. Historical assay data (Cu, Fe, TiO_2, REE) integrated with the interpreted hyperspectral mineralogy and compositional variations, effectively highlight these mineralization relationships (Figure 2). Elevated TiO_2 and Fe assay values correspond to short ~2320nm wavelengths in Dark Mica (interpreted as Mg-rich end-member of the Biotite group), while low TiO_2 and Fe values correlate with the longer Dark Mica wavelengths (interpreted as Fe-rich end-member of the Biotite group). Mineral species can be used to partially track Fe, Mg and Ti within the ore deposit as well as to determine assemblages associated with Cu grade. These results emphasize previously unknown mineralization vectors at a historic Ti-Fe deposit, as well as introduce underutilized Dark Mica compositions for exploration in various ore deposit styles. Lastly, hyperspectral imaging successfully identifies minute instances of REEs in veins and groundmass, thus helping make geochemical sampling campaigns more efficient and targeted.

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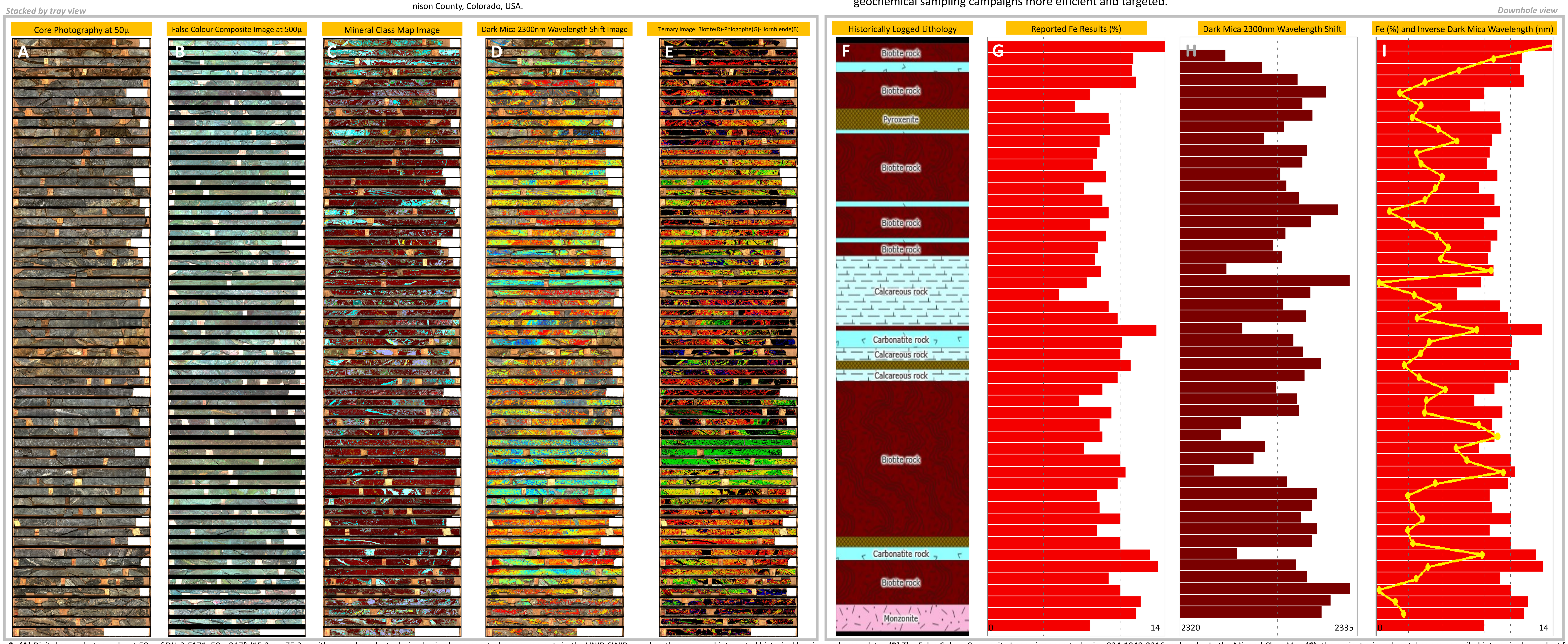


Figure 2. **(A)** Digital core photography at 50μ of DH-2-F171, 50—247ft/15.2m—75.3m with several products derived using hyperspectral measurements in the VNIR-SWIR wavelength range, and integrated historical logging and assay data. **(B)** The False Colour Composite Image is generated using 924-1948-2316nm bands. In the Mineral Class Map **(C)**, the project mineral matches are compiled into a single product for a visual overview of data trends. In the Dark Mica 2300nm Wavelength Shifts Image **(D),** variations in the position of the 2300nm feature are captured using a rainbow colour table, cooler colours correspond to shorter wavelengths, and warmer colours to longer wavelengths. **(E)** The Ternary Image is a composite of three mineral matches, where the colour and their mixing are indicative of the minerals' distribution and spectral character. Downhole Lithology **(F)** is imported from a historical report by Rose and Shannon (1960). Historical Fe assay data integrated with the Dark Mica 2300nm wavelength shifts **(G-I)**, highlight certain mineralization relationship. Elevated Fe assay values correspond to short ~2320nm wavelengths in Dark Mica, while low Fe values correlate with the longer Dark Mica wavelengths.

Methods:

The detailed mineralogy for investigating the subtle chemical variations in Dark Mica is acquired using an automated hyperspectral core imaging system. The scanning measurements were performed with the Corescan HCI-3 system that was mobilised into the USGS Core Research Center in October of 2015 for one month. Thirty separate projects were scanned (totalling over 8700 feet (~2,650m) of core including the Cebolla Creek historical core collection. The HCI-3 operates across the VNIR and SWIR bands from 450—2,500nm at a spectral resolution of ~4nm and a spatial resolution of 500μm, resulting in ~50,000 pixels per foot (~150,000 per meter) of imaged drill core. The reflectance spectral signatures are compared to an amalgamated reference spectral library that consists of over 1,000 separate minerals and mineral sub-species. The signatures from these pixels are spatially referenced and tied to the original photography and hyperspectral data for all scanned material. The spatial referencing allows for detailed comparison with downhole geological information such as geochemical assays. Seventeen separate minerals/mineral groups, a mineral sub-specie and three separate mineral mixtures were identified and mapped using hyperspectral data. These include Phyllosilicates, Carbonates, Amphibole, Pyrochlore, Iron Oxides, Hydrous Silica, REEs and potentially Perovskite. Examples of Dark Mica spectral responses are captured in Figure 3.

Mineral Map Class Legend:

Aspectral	Kaolinite	REE: Ndm
Biotite	Magnetite	Saponite
Carbonate	Mg-rich Phlogopite	Quartz
Chlorite + Clay	Montmorillonite	Quartz + Carbonate
Fe Carbonate	Perovskite	Vermiculite
Iron Oxide	Phlogopite	White Mica
Hornblende	Pyrochlore	Undiffer. clay mixture

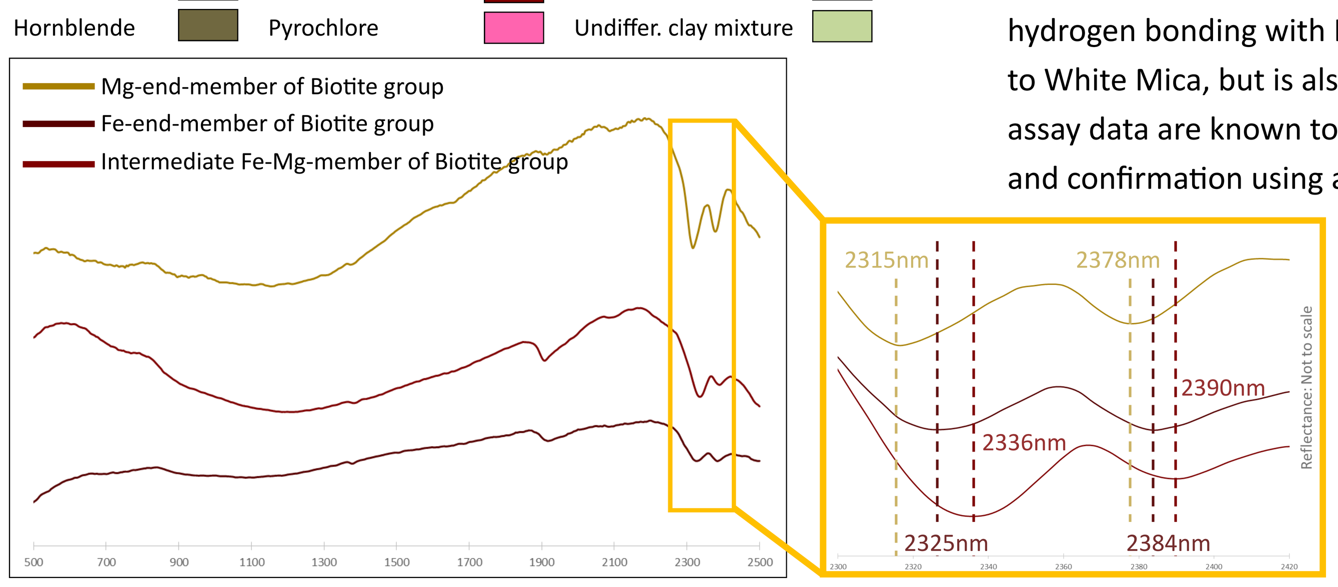
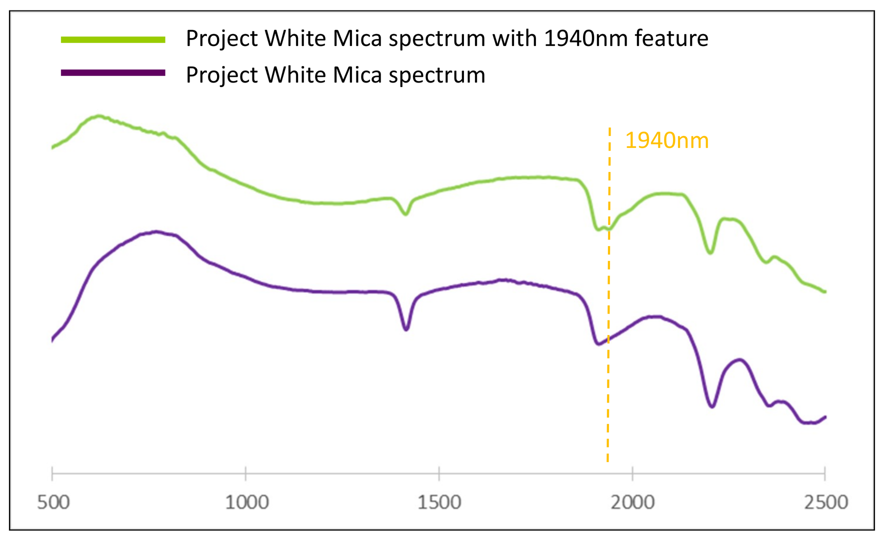


Figure 3. Examples of spectral reflectance responses of the Biotite group species with shifts of up to 16nm in diagnostic wavelength features between ~2300nm and ~2380nm. The OH stretch overtone at ~1400nm in Fe-end-member is often non-detectable because the band is suppressed by strong Fe absorption. Intermediate Fe-Mg specie is relatively low in Fe and the OH feature from 1377-1396nm is commonly weakly developed.

Future Work:

In White Mica, a diagnostic absorption feature, due to water, occurs at ~1910nm. For instance, in White Mica species with bound H_2O in their crystal structure, such as Illite, this feature is deeper than that in Muscovite. It is suggested that the anomalous feature at ~1940nm in White Mica, observed in small clusters in various intervals in drillhole 2-F171 (Figure 4), is due to occurrences of F and the resulting hydrogen bonding with H_2O (Figure 5). This anomalous water feature is not unique to White Mica, but is also observed in Chlorite and Biotite, which from historical assay data are known to be F-bearing. These observations warrant further studies and confirmation using alternate analytical methods.



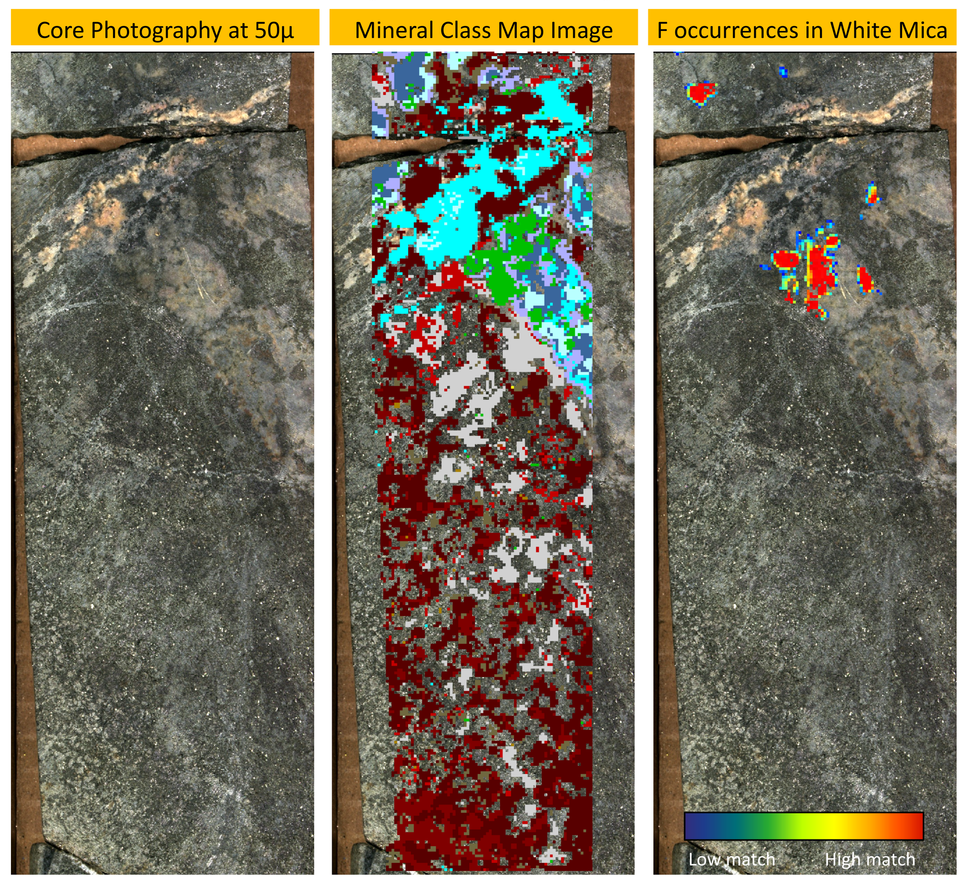


Figure 4 (above). Drillcore interval at 176.5ft/53.8m with an occurrence of F in White Mica, Chlorite and Biotite.

Figure 5 (left). Examples of project spectral reflectance responses of White Mica and White Mica with F in the H_2O structure. This feature, if present, is commonly seen as either a doublet in White Mica species or as a dominant feature in Chlorite and Biotite.