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GEOSPECTRAL IMAGING

# Hyperspectral Core Imaging for VMS Deposits

- Volcanogenic hosted massive sulphide (VHMS) deposits are desirable targets for copper, zinc and lead in particular and sometimes with significant gold and silver credits. They are generally high grade, which makes even smaller deposits economically viable

- There are three types of VHMS deposit, those associated with felsic volcanics in back-arc settings (Kuruko type Zn-Pb-Cu), those associated with mafic volcanism in rift settings (Cyprus type Cu-Zn) and those hosted in sediments peripheral to volcanism (Besshi type Cu-Zn)

- Although forming syngenetically with volcanism via exhalation on the seafloor or sub-seafloor replacement, hydrothermal alteration is a feature of VHMS deposits. Alteration does vary between the different VHMS types, and also spatially in any deposit

- Of special interest in exploration is alteration of the hangingwall sequence, which can be used to target deeper mineralization. Chlorite and whitemica are typical alteration minerals in the hangingwall, with mafic minerals (talc, amphibole) and barite often forming proximal to mineralization. Distal propylitic alteration consists of carbonate, epidote, and quartz-albite

- Chlorite, whitemica and quartz are the main alteration phases formed in the deep feeder zone

- In some precious metal rich systems, advanced argillic (pyrophyllite, dickite and alunite) alteration may occur

# Introduction

Hyperspectral core imaging is of particular value given:

- It captures alteration mineralogy in situ and so textural relationships can be easily seen and mapped
- Since every pixel is imaged, quantitative counts of alteration minerals can be extracted (spectral modal mineralogy). The addition of the long-wave infrared (LWIR) adds anhydrous silicates, crucially calc-silicate minerals
- By extracting information related to absorptions or peaks the relative strength of spectral response provides a proxy for mineral abundance
- And by extracting absorption or peak positions, and shifts in those positions, the chemistry of alteration minerals can be examined and mapped
- By compositing the data, truly representative downhole plots can be output at any desired resolution

# Hyperspectral Core Imaging

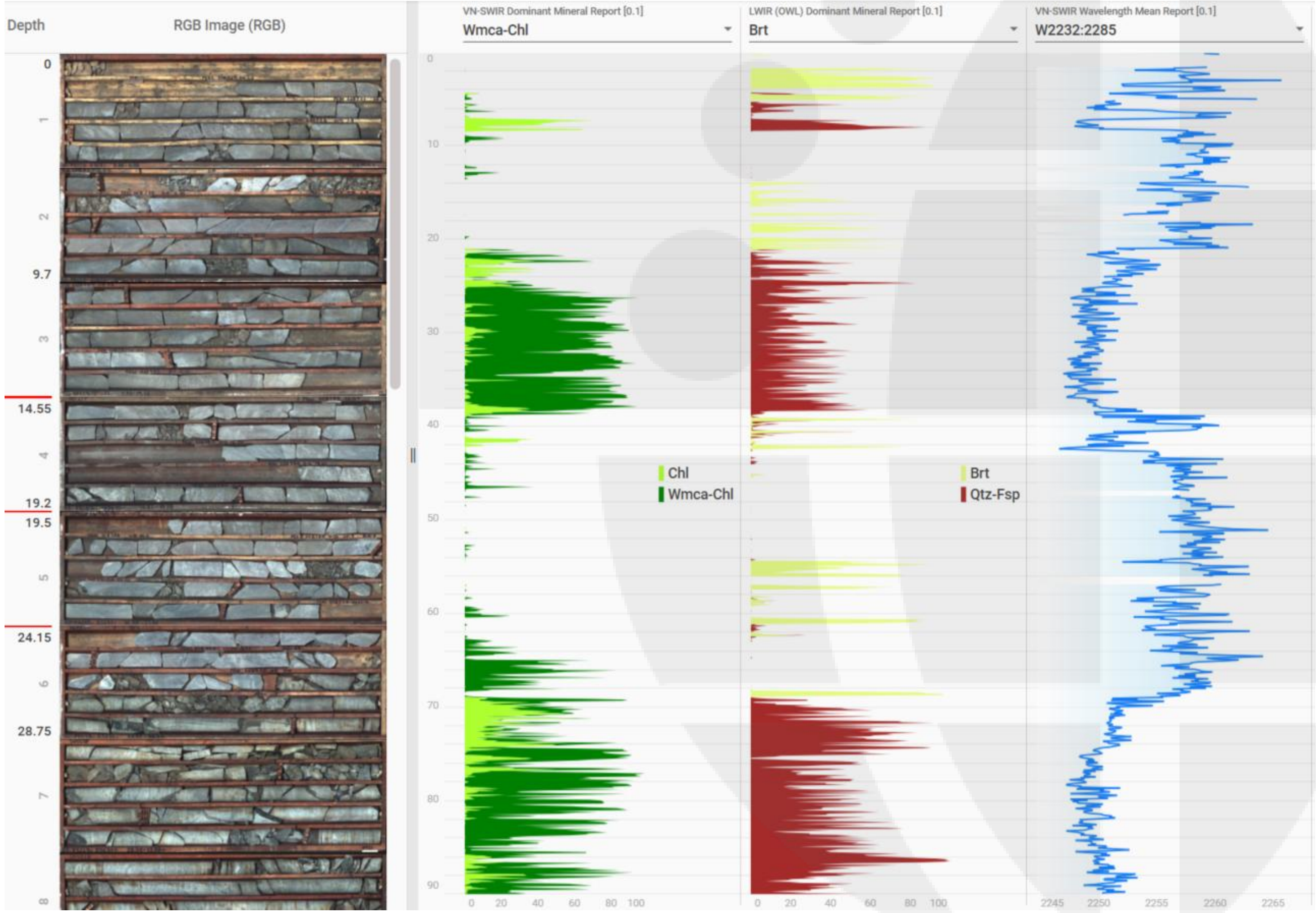
- There is a good body of literature on the use of spectroscopy in VHMS systems, mainly visible near-infrared (VNIR) and shortwave infrared (SWIR) using handheld (point) instruments. Of course the use of imaging retrieves the textural context of alteration minerals

- Many of the alteration minerals, such as whitemica, chlorite, amphibole, carbonate, and talc are active in the SWIR. When present, the advanced argillic minerals are also all SWIR active

- The LWIR is a useful wavelength range, adding barite, quartz and albite in particular. In older deposits that have undergone metamorphism to produce minerals such as aluminosilicates, garnet, cordierite, staurolite etc. the LWIR is of real importance, and in conjunction with the SWIR helps to unravel the geological history

- In terms of the SWIR minerals, information about composition can be of key importance for vectoring, especially chlorite and whitemica

# Hyperspectral Responses within VHMS Systems




- The plots on the left show selected mineralogy and chlorite composition for a mineralized drillhole
- Mineralization occurs in two main horizons, from ~0-20 and ~40-60 metres. It is associated with barite, while peripheral alteration consists of chlorite and whitemica-chlorite mapped in the SWIR which coincide with a quartz-feldspar (albite) assemblage mapped in the LWIR
- Note the abrupt change in chlorite composition towards longer wavelengths in the mineralized zones, this shift is indicative of a more Fe-rich chlorite species
- Similar changes in chlorite composition have been detected in several unmineralized holes, suggesting that they have narrowly missed the target

# Chlorite Composition

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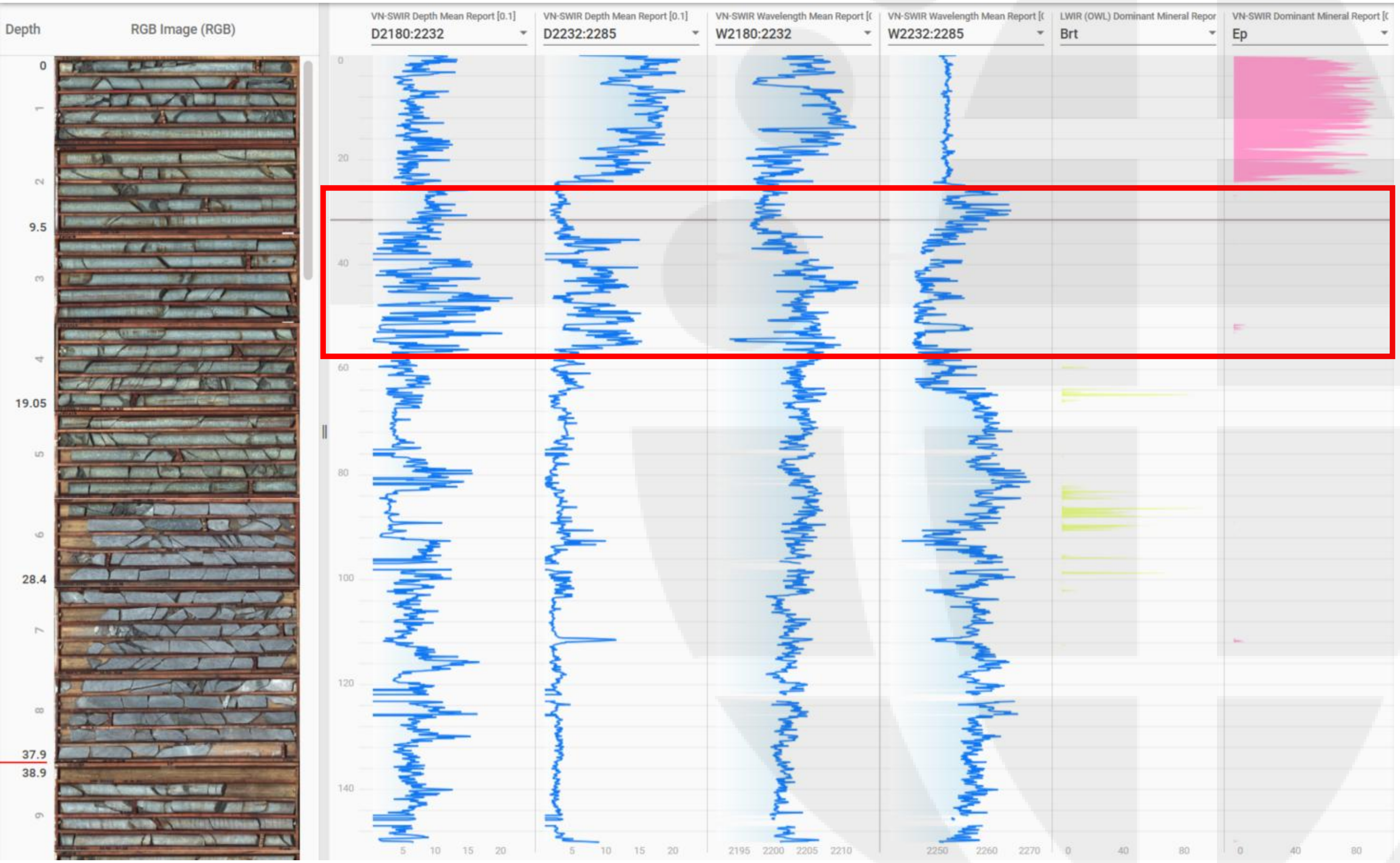


- The plots on the left show whitemica and chlorite abundance (the D plots) and composition (the W plots). Epidote mapped from the SWIR is shown, along with barite from the LWIR to show mineralized horizons. The hangingwall zone is outlined by the red box
- The unaltered volcanic has epidote, which vanishes in the hangingwall zone. Note the elevated chlorite and whitemica abundance in the hangingwall alteration, both of which show compositional changes (though more variable for chlorite). As expected chlorite associated with mineralization is strongly iron-rich
- These patterns, along with those shown for the LWIR in the next slide, can be transferred to unmineralized holes to investigate whether any may have been stopped prematurely in hangingwall alteration

# Hangingwall Alteration Mapping – (SWIR)

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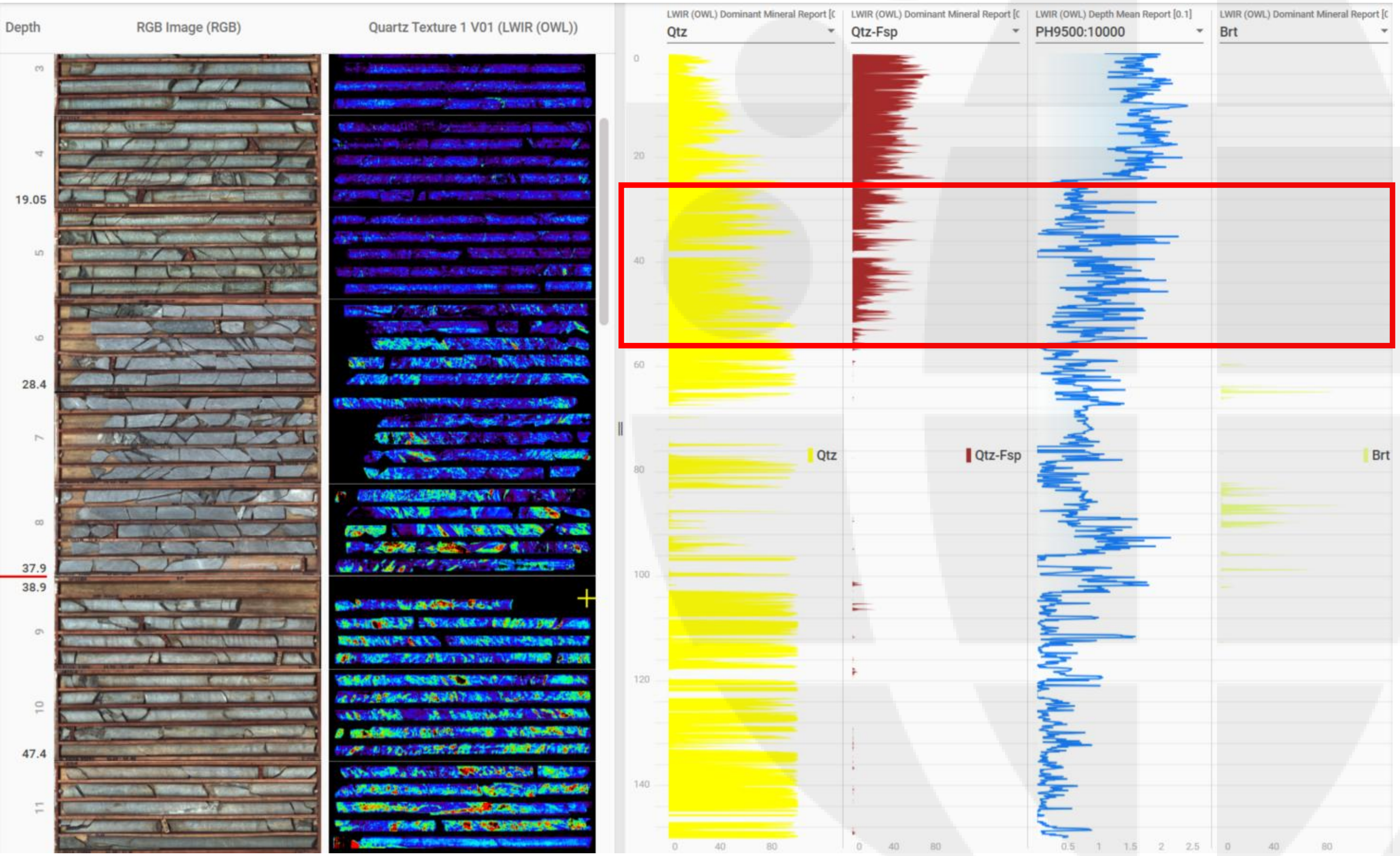
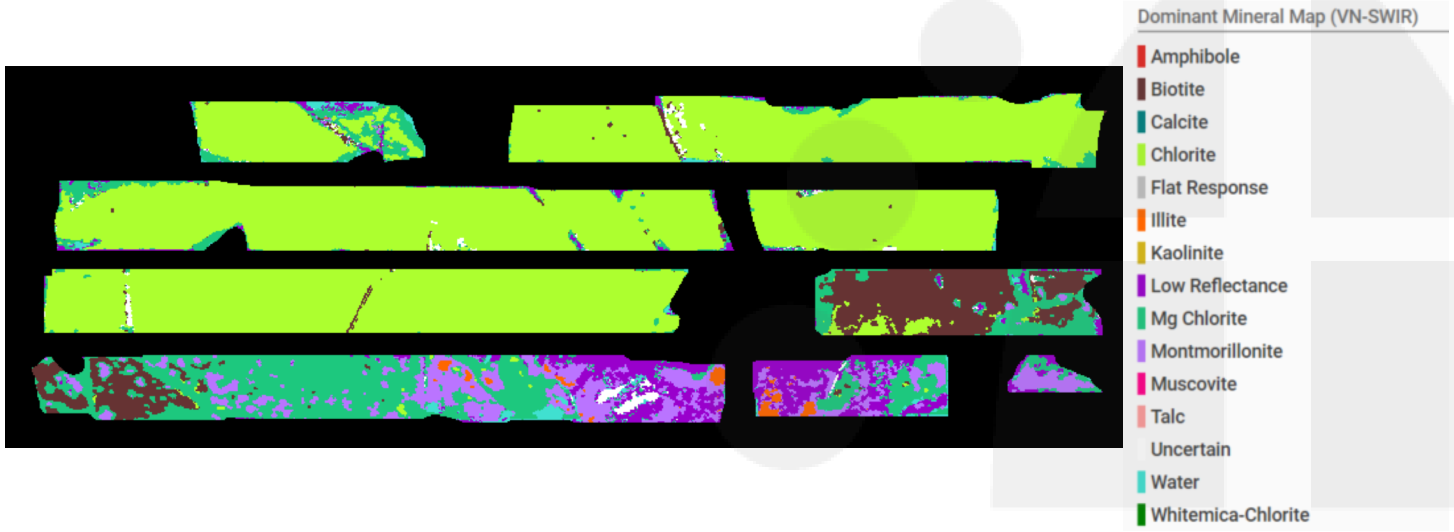
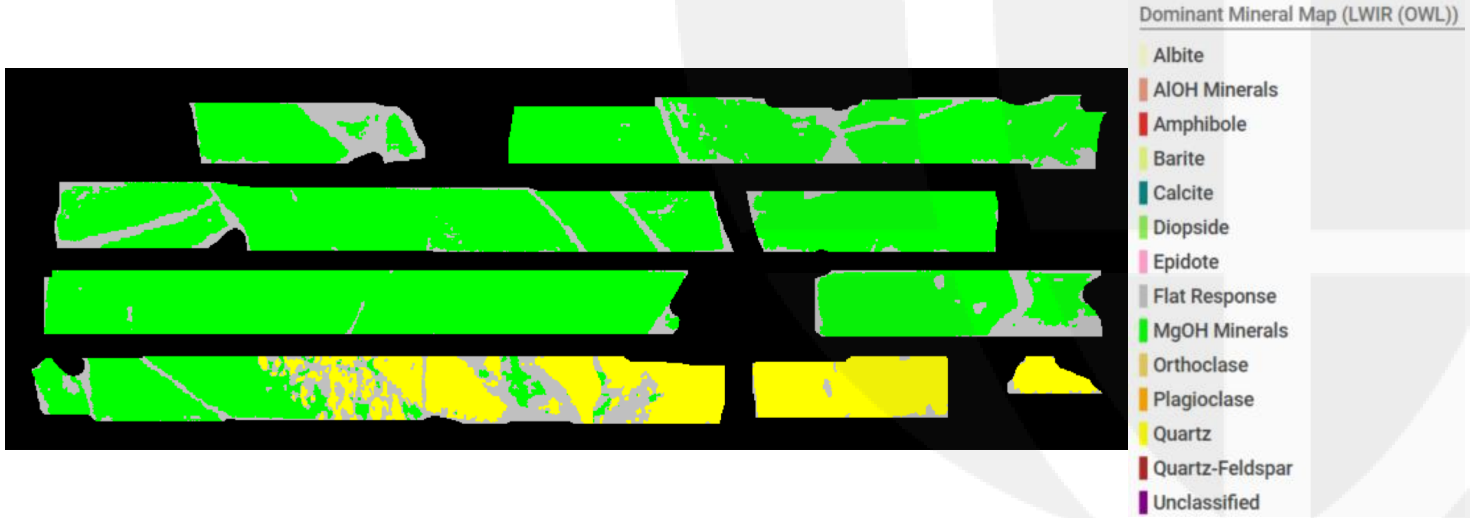



- The plots on the left show LWIR responses for the same hole as the previous slide, with the hangingwall outlined in red. Barite is used to show mineralized horizons
- Note the strong feldspar above the hangingwall, shown both as a mapped mineral (with quartz) and depicted by the height of the ~9800nm peak (the PH plot). Feldspar destructive alteration occurs in the hangingwall
- Note how the amount of quartz increases from the hangingwall through mineralization and into the footwall. A measure of quartz texture based on spectral shape is shown in the image, and it is evident that hydrothermal quartz is distinct from that in the unaltered volcanic
- The combination of this information with that extracted from the SWIR provides a powerful tool for exploration

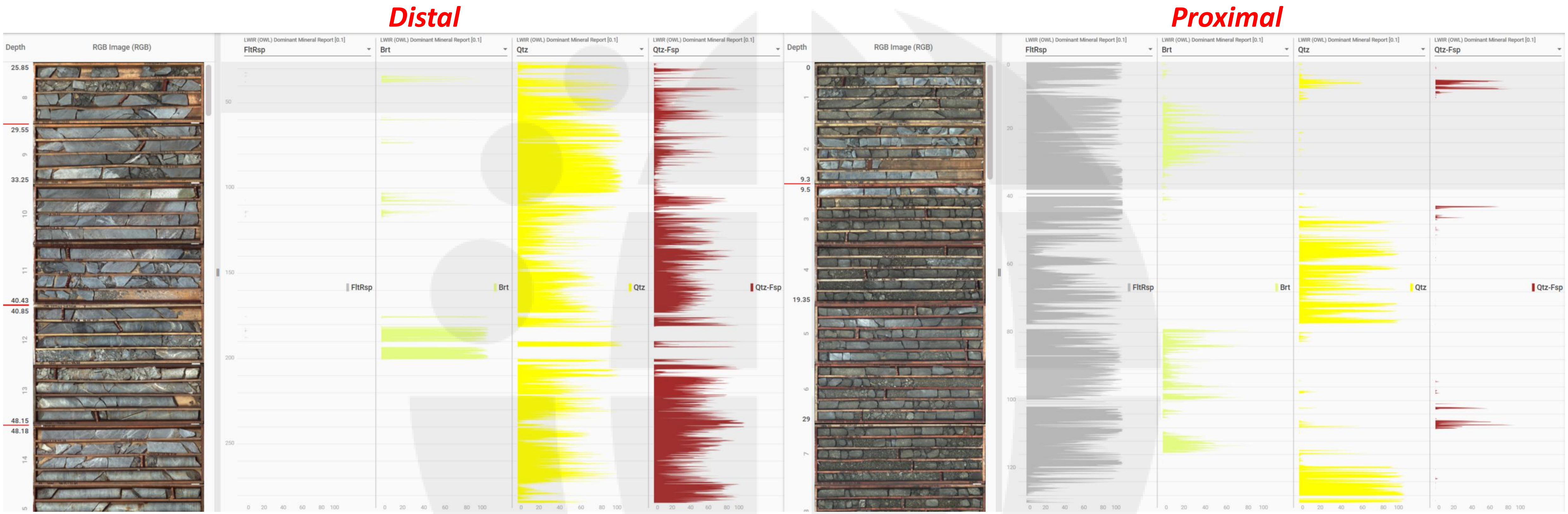
# Alteration Mapping – VMS (LWIR)




- The images on the left show mineral maps for the SWIR (top) and LWIR (bottom) in a box containing stringer mineralization
- Sulphides are expressed as “uncertain” in the SWIR, and “flat response” in the LWIR. Note that the LWIR is more sensitive to sulphides and so maps more
- Alteration associated with mineralization is shown in the SWIR to be biotitic, along with Mg-rich chlorite. The presence of strong silicification in this area is mapped by the LWIR, this has in places reduced the SWIR signal to the point where we can only map it as low reflectance and cannot extract mineral information
- Alteration adjacent to mineralization is strong chlorite (intermediate Fe-Mg composition), note that the LWIR has not separated biotite from chlorite

# Deep Stringer Zone Alteration




- The plots above are for two holes through the same mineralized zone
- Massive sulphides are specular reflectors in the LWIR, and so produce what we've termed a “flat” spectral response. Barite occurs with the massive sulphides within the orebody
- Distal to the orebody, barite defines the mineralized horizon but with very limited sulphides present
- Also note the amount of feldspar, which in the orebody has been almost completely altered but is still present in appreciable amounts distal to mineralization where alteration is less intense

# Alteration Mapping – VMS Section (LWIR)

## Conclusions

- Hyperspectral core imaging provides excellent data for VMS exploration
- The different alteration assemblages have distinctive mineralogical signatures that are spectrally responsive
- Spectral information is of especial use in the hangingwall, where recognition of this style of alteration and patterns within is of use in exploration to ensure that holes are not stopped prematurely
- Deep stringer zone alteration can be mapped, with mineralogical zonation
- The LWIR adds an additional dimension to alteration mapping, and is of special use in metamorphosed terranes