Quantifying downhole silicate mineralogy – HyLogger with thermal infrared

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SUMMARY

Thermal infrared spectroscopy (TIR) (6000 – 14500nm) has recently become available through HyLogger technology. Framework silicates such as quartz, feldspar, garnet, pyroxene and olivine have primary molecular responses at these wavelengths. With this new suite of minerals visible to the automated scanner, studies using semi-quantitative methods will be able to map key alteration vectors with which geologists are familiar. The Haylands Prospect, south of Morgan, South Australia offered the opportunity to demonstrate the capabilities of the new system mapping albite, quartz, microcline and carbonate in addition to chlorite and sericite offered by the shortwave infrared detectors. TIR spectroscopy can assist in delineating regional alteration systems, such as albitisation and K-feldspar alteration. Such alteration styles are a feature of many mineral systems, including regional alteration associated with iron oxide-copper-gold systems.

Key words: Thermal infrared spectroscopy, mineralogy, alteration, HyLogger.

INTRODUCTION

The CSIRO HyLogger™ for scanning drill core has recently been upgraded to incorporate thermal infrared (TIR) (6000-14500 nm) spectroscopy. The use of infrared spectroscopy in mineral analysis is not new. Conel (1969) published his work on understanding the infrared emissivities of powdered silicates, in particular, the behaviour of quartz. Logan (1973), Salisbury & Walter (1989) and Salisbury et al. (1991a) all published studies on mineral properties in the TIR. Salisbury et al (1991b) published the John Hopkins University mineral library with spectral measurements between 2100 and 25000 nm and cited works from the early 1950's.

Prior to the upgrade the HyLogger was restricted to the range of minerals that exhibited responses in the visible to shortwave infrared (VSWIR:380 – 2500 nm) which included phyllosilicates, carbonates and iron oxides. With the advent of TIR the framework silicates become visible including quartz, feldspar, garnet, olivine and pyroxenes. Within the extended spectral range of 8 to 12 microns the most intense primary features occur (Salisbury et al, 1991b).

Cudahy et al. (2009) demonstrated the use of the prototype thermal HyLogging system in its application to mapping plagioclase feldspar composition in Western Australia. Flint and Parker (1993) recognised that mineral systems across South Australia have an element of albitisation, which if mapped on a regional scale could reveal unknown mineralisation.

In this contribution we present preliminary results from TIR and VSWIR spectroscopy of a recently acquired drill core from South Australia and use the data to interpret stratigraphic relationships within the drill hole, with corresponding implications for understanding the styles of alteration and associated weak mineralisation.

DRILLHOLE DEL10ACD001

The drill core analysed in this study was recently acquired by Gold Fields Australasia Pty Ltd and part-funded by the South Australian Government's PACE initiative. The core was drilled at the Haylands Prospect, 20km south of Morgan on the western edge of the Murray Basin (Kitto and Mason, 2011). Drilling beneath the deep marine and fluviatile sedimentary cover of the Murray Basin recovered intensely deformed, greenschist facies, feldspar rich, volcaniclastic sediments and intermediate volcanic rocks believed to correlate with early Cambrian Truro Volcanics. The nature of these rocks including a thick zone of strong "potassic-like" chlorite-biotite-stilpnomelane-magnetite- hematite-carbonate meta-tuffaceous schist makes them ideal for investigation with a combination of VSWIR and TIR spectroscopy.

The initial aim of the work was to recover stratigraphic information on the nature of the volcanic/volcaniclastic rocks within the drillhole. We compare the feldspar composition obtained by TIR spectrometry and assayed results for Zr and Ce, as proxies for the andesitic or basaltic composition of the host rocks.

METHOD AND RESULTS

The HyLogger™ is a semi-automatic scanning spectrometer designed to measure diamond drill core trays with a minimum of sample preparation. Four instruments, a VSWIR spectrometer, a TIR spectrometer, a high resolution digital camera and a laser height profiler, are mounted on a cantilever frame over a robotic table. Each day the TIR spectrometer is calibrated against a hot and cold black body target and during the scanning of each tray both spectrometers subsequently scan a calibration strip for the VSWIR and TIR. The

HyLogger records 341 channels in the TIR with 25 nm resolution per spectra at a rate of 12 spectra per second with an IFOV of 12 x 8 mm taking a measurement every 4 mm along the core (Mason, 2011). Post-processing combines and registers all instruments such that each centimetre along the core two reflectance spectra – one VSWIR and one TIR are registered with the height measurement and the 0.1 mm resolution imagery.

Within the Spectral Geologist™ (TSG) software used to process the data, modules exist for interpreting the mineralogy considered to contribute to the recorded spectra. A standard library within the program is used to mathematically model various combinations of two and three minerals to produce the closest match to the recorded curves. The results are not considered to be totally unambiguous and the software is under constant refinement but it is offered as an "Assistant" for the geologist performing the interpretation. Other sophisticated tools are provided to analyse the shapes of the curves and permit the development of fully calibrated batch scripts for extracting mineral information on a project basis.
Diamond drill hole DH 261383 DEL10ACD001 was scanned with HyLogger 3-3 in July 2011. Fig 1 shows the interpreted mineralogy provided by the automated software.

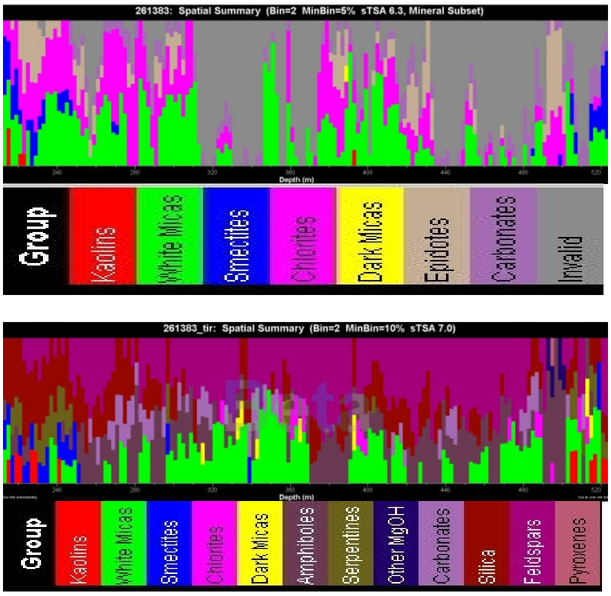

Figure 1. Mineral Group Summary plots for SWIR (upper) and TIR (lower). Note that large sections of hole could not be interpreted using the SWIR spectra alone and plotted as "invalid" in the upper plot. In the corresponding sections in the TIR the feldspars occupy those positions. (Left to right the scanned interval is from 212 m to 524 m down the drill hole)

The interpretive summary for the TIR is currently provided in "Beta" mode and is yet to be released as definitive product. Figs 2 to 6 provide insight into the complexities of interpreting TIR spectra.

Fig 2 illustrates the VSWIR and TIR spectra as delivered from post-processing of the recorded HyLogger data. Although the SWIR features are quite subdued there is a strong response in the visible caused by the green minerals.

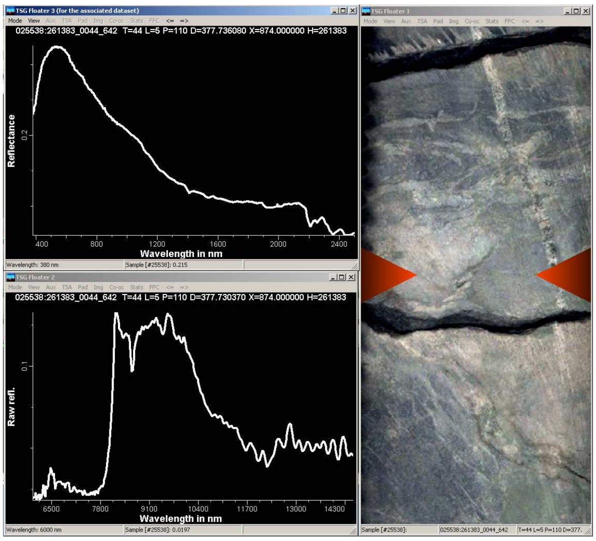

Figure 2. DEL10ACD001 377.74m. VSWIR and TIR spectra from core sample shown.

Three likely components of the TIR spectrum shown in Fig 2 are presented in Figs 3,4 & 5. The library spectra in purple have higher amplitude being pure samples.

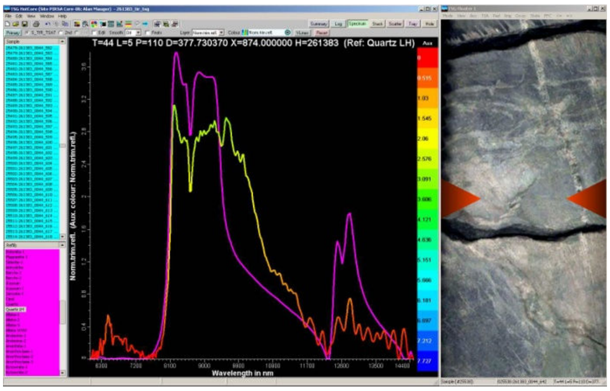

Figure 3: DEL10ACD001 377.74m. Library TIR spectrum for quartz (purple) compared to TIR spectrum of sample. (X-axis of the plot is wavelength 6000 nm to 14500 nm, left to right, Y-axis is normalised reflectance. The base of the arrows on the core image represents one spectral pixel – approx. 1 cm)

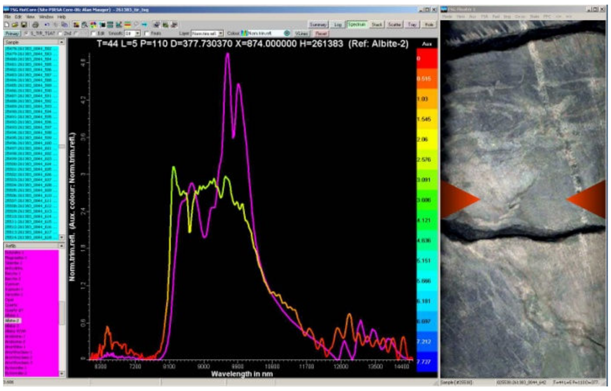

Figure 4. DEL10ACD001 377.74m. Library TIR spectrum for albite (purple) compared to TIR spectrum of sample.

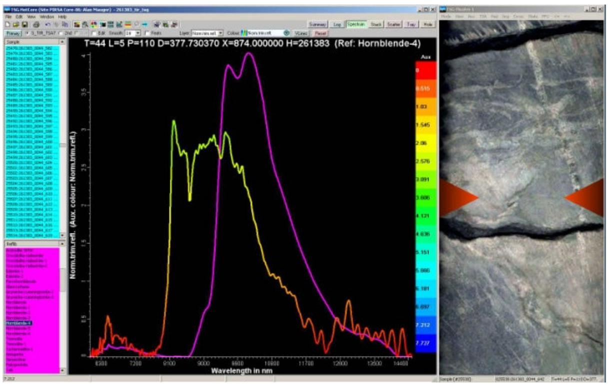

Figure 5. DEL10ACD001 377.74m. Library TIR spectrum for hornblende (purple) compared to TIR spectrum of sample.

The mathematical combination of 63% quartz, 19% hornblende and 18% albite library spectra best fit the observed data (Fig 6).

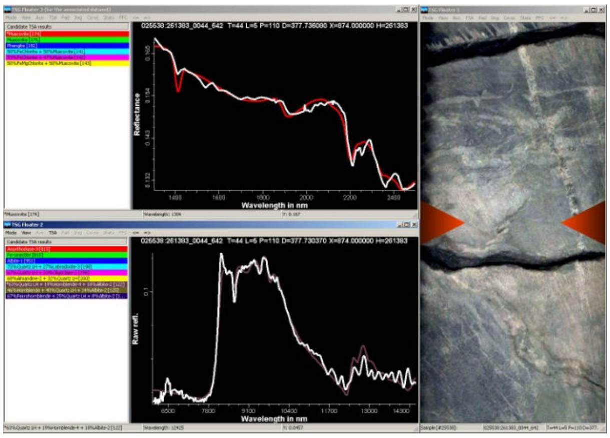

Figure 6. DEL10ACD001 377.74m. Interpreted mineral mixtures assigned using SWIR (upper, muscovite in red) and TIR (lower, quartz-hornblende-albite in brown) spectra.

The next sample shown in Figs 7 – 10 examines an albite rich specimen with carbonate and anorthoclase contributing to the spectrum.

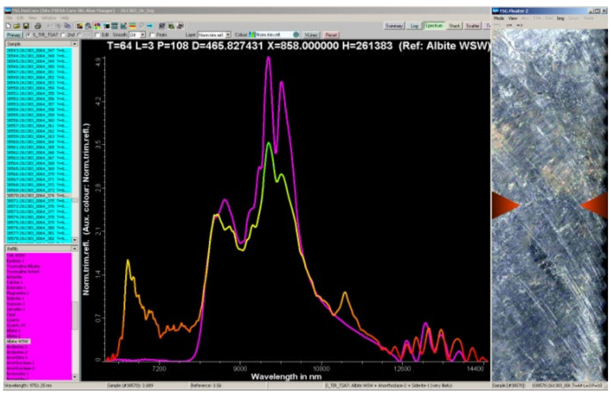

Figure 7. DEL10ACD001 465.83m. Library spectrum of albite (purple) compared to spectrum of sample.

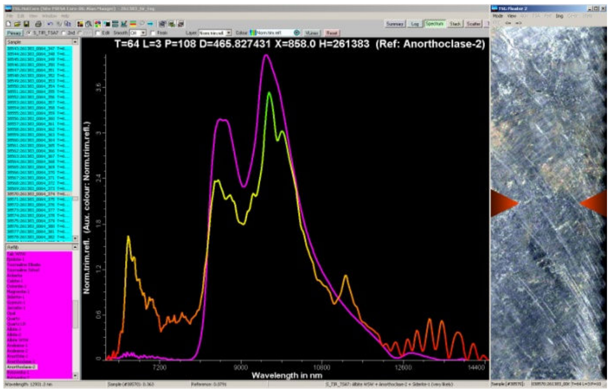

Figure 8. DEL10ACD001 465.83m. Library spectrum of anorthoclase(purple) compared to spectrum of sample.

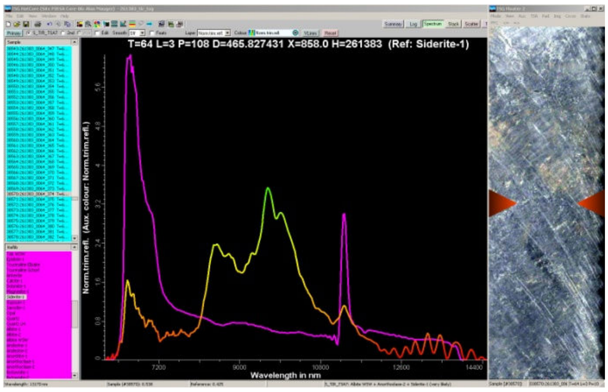

Figure 9. DEL10ACD001 465.83m. Library spectrum of siderite (purple) compared to spectrum of sample

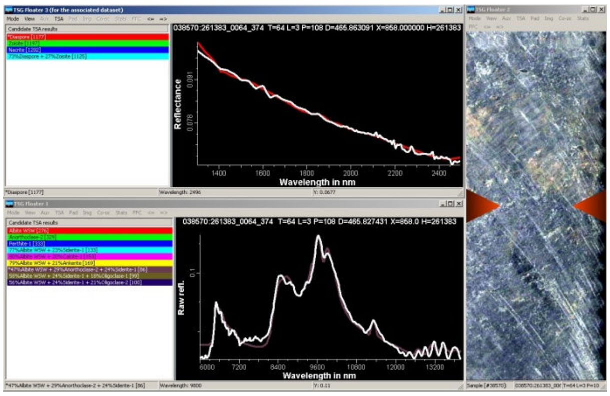

Figure 10. DEL10ACD001 465.83m. Interpreted mineral mixtures assigned using SWIR (upper, too high noise for accurate interpretation) and TIR (lower, albite-anorthoclase-siderite in brown) spectra.

Petrology has been described for several samples (Mason, 2010). The following Figs 11-13 provide an indication of the value of having both VSWIR and TIR spectra for the same sample as an aid to interpreting mineralogy. The figures (11-13) show the actual spectra (white), and the interpreted mineral mixtures (coloured) for that sample. It should be noted that zoisite is a member of the epidote family of minerals.

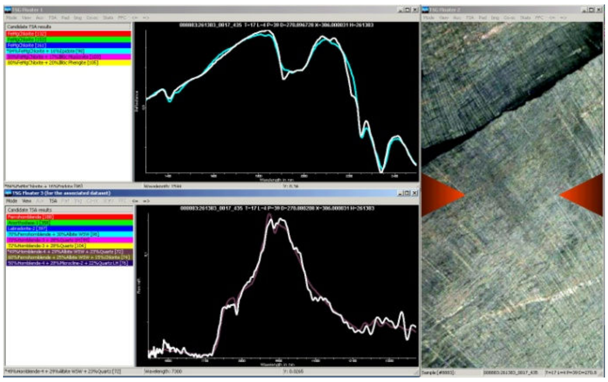

Figure 11. DEL10ACD001 270.9m. Petrology reports chlorite-zoisite-calcite-quartz as a metaferromagnesian porphyritic basalt/andesite. Spectroscopy reports chlorite-epidote-quartz-hornblende-albite.

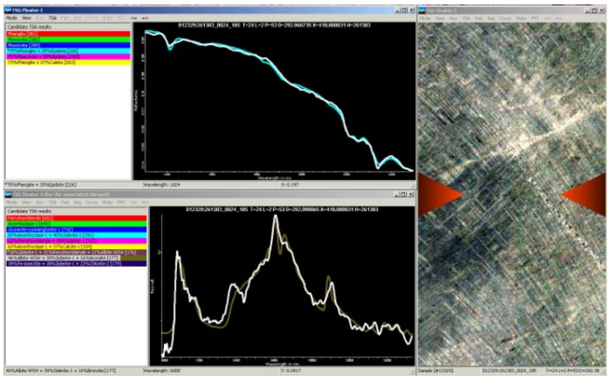

Figure 12. DEL10ACD001 292.96m. Petrology reports chlorite-zoisite-sericite-albite-calcite as a metaplagioclase porphyritic andesite. Spectroscopy reports epidote-phengite-albite-siderite-bronzite.

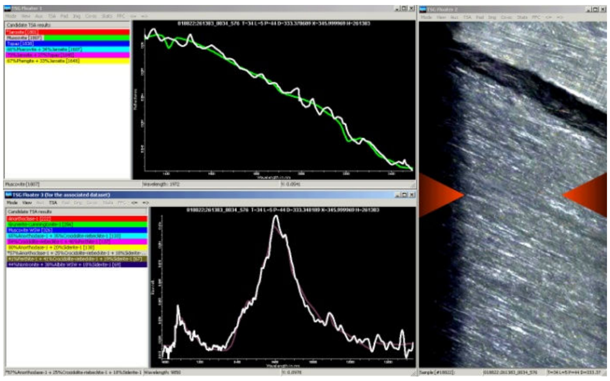

Figure 13. DEL10ACD001 333.37m. Petrology reports K-feldspar-stilpnomelane-muscovite-magnetite-chlorite-calcite as a metatuffaceous siltstone. Spectroscopy reports anorthoclase-riebeckite-siderite. The SWIR spectra had too high noise to accurately interpret. Stilpnomelane and magnetite are difficult to interpret spectroscopically.

Spot checks as demonstrated in these figs show that the spectroscopic interpretations can be corroborated by the petrographic studies within the limits of each technology. It should be noted that modal abundances as recorded in petrography bear almost no relationship to the mathematical proportions used to model the observed spectra. The measures of abundance derived from spectroscopy that are useful in exploration are computed by counting the centimetre intervals that contain the mineral of interest. In this way trends between adjacent drill holes can be established in such ways that mineralisation vectors can be developed.

LITHOLOGICAL FRAMEWORK FROM TIR DATA

The spectral data produces a picture of the feldspar abundance that can be linked to the petrographic descriptions and geochemical data of the host lithologies within this drill hole. Broadly the core recovered two sequences, an upper sequence of predominantly volcaniclastic sediments and a lower sequence of tuffaceous volcanics of basaltic to andesitic composition (Fig 14). The mineralised zone lies approximately at the boundary between these lithotypes, which may indicate some type of stratigraphic control on the alteration/metamorphic fluids which have transported the copper-gold-bearing fluids. The TIR data for albite shows a strong correlation with rock type. The lower sequence, predominantly basaltic, shows a greater albite content than the upper sequence. The modulation in albite content within the lower basalt/andesite sequence may correlate with individual volcanic flow horizons, and appears to correlate reasonably well with the bulk rock Zr data (ppm, 1m bulk composite samples). The geochemical data also shows a variable Zr content that likely corresponds to basalt (low Zr) compared to andesite (broadly, higher Zr).

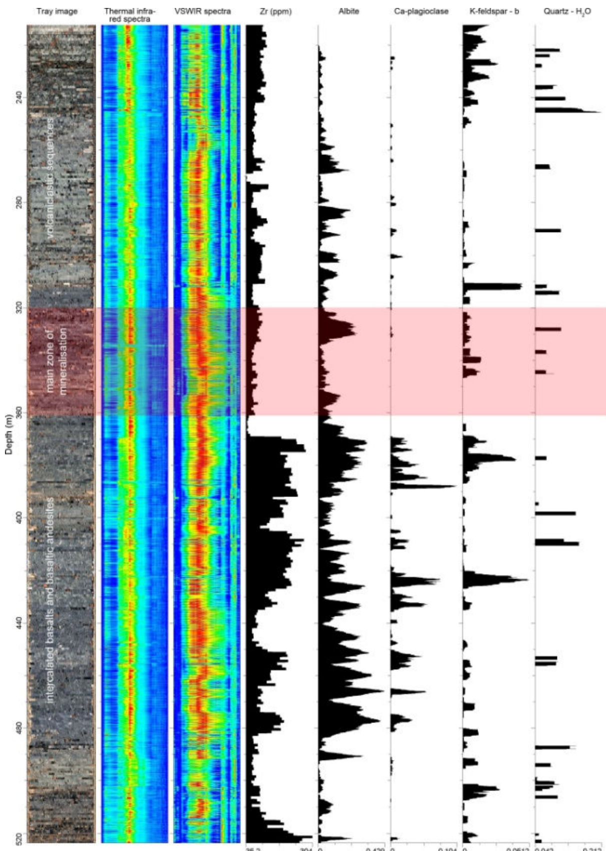

Figure 14. Interpreted down hole log for DE10ACD001. Columns from left to right are: image of the core, TIR spectrum, VSWIR spectrum, histogram of assay Zr values, histogram of TIR derived Albite, histogram of TIR derived Ca-Plagioclase, histogram of TIR derived K Feldspar and histogram of SWIR derived water bearing Quartz. 212m-524m scale provided on left. Zone of mineralisation highlighted.

The TIR data for K-feldspar is also interesting in that it shows two zones within the volcaniclastic horizon that are broadly enriched in K-feldspar (~220-250m and ~310-350). These intervals may represent strata of greater felsic clastic input within the sediment. The lower sequence shows greater variability in K-feldspar abundance; several peaks in abundance likely represent the more andesitic components of the volcanic sequence. We note also that some of the K-feldspar 'peaks' correspond to the late quartz-feldspar veins that contain weak sulphide mineralisation and appear to be late in the metamorphic paragenesis for the drillhole. These veins are indicated in Fig 14 by the hydrothermal quartz-only veins resolved in the SWIR. Further work where the TIR spectra were used to inform the SWIR interpretation enabled the extraction of veins of mixed quartz and calcite as well. The data show that the hydrothermal quartz occurs across all of the different lithological zones, which has implications for the style of mineralisation preserved within this drillhole and for the type of mineralisation that could be targeted at this prospect in future.

CONCLUSIONS

The automated interpretation of mixed spectra in the TIR is still in its infancy. The power of semi-quantitative analysis of framework silicate mineralogy is only now beginning to be realised. Logging of drill core in terms of silicate mineralogy offers a quantitative approach to core logging that can have benefits for erecting and correlating a stratigraphic system. As in the example shown here, such stratigraphy can be constructed using HyLogger in situations where grain size is small, and detailed petrographic evaluation would be required to develop a stratigraphic framework that could be correlated across drill holes within a tenement, for example.

Finally, we note that another major application for the TIR spectroscopy will be in delineation of regional alteration systems, for example albitisation, or K-feldspar alteration. Such alteration styles are a feature of many mineral systems, for example the regional alteration associated with iron oxide-copper-gold systems (Skirrow & Davidson, 2007). TIR scanning of drill core offers the opportunity to systematically acquire the significant volumes of semi-quantitative data required to map the distribution of regional and camp-scale alteration foot prints potentially providing vectors towards areas of more prospective alteration styles and hence mineralisation.

ACKNOWLEDGMENTS

CSIRO, AuScope, and the National Collaborative Research Infrastructure Strategic funding provided the technology and the finance to enable the Government Geological Surveys .of Australia to capitalise on the initial AMIRA funded research of 2002. Each State now owns, or has access to, a HyLogger-3 for the express purpose of scanning their drill core repositories and publishing the data over the internet. HyLogger™ and The Spectral Geologist™ are trademarks of CSIRO.

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