HYPERSPECTRAL REGOLITH AND ALTERATION MINERAL MAPPING OF THE KALGOORLIE-KANOWNA 1:100 000 SCALE MAPSHEET

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Summary
Accurately determining the surface mineralogy of the using remote spectral technologies, such as the airborne HyMap system, can complement conventional mapping methods for not only improving the efficiency and accuracy of geological and regolith maps, but in the delivery of a new range of alteration maps (metamorphic and/or metasomatic). To demonstrate this potential, a collaborative research and demonstration project was established to evaluate whether airborne and satellite spectral data could be processed to deliver a series of regolith and alteration mineral distributions for a 1:100 000 scale special mapsheet (2500 km^2) centred on the Kalgoorlie township. Data processed to date for the 26 HyMap flight-lines demonstrate that seamless maps can be derived for regolith mineral distributions (e.g. kaolinite abundance and crystallinity, iron oxide abundance and hydration state, hematite-goethite ratio, gypsum) and alteration mineral distributions (e.g. white mica abundance and chemistry [effectively the mica Al-content], talc, chlorite, amphibole). Field sampling, ground spectral measurements, XRD and geochemistry, is validating the accuracy of these mineral information products. The real significance or opportunity for these mineral information products is when they are incorporated into regolith and alteration mineral models. Previous models indicate that kaolinite disorder would be useful for mapping transported versus in situ materials. The associated laboratory study of field samples shows that the relative depth of the kaolinite 2160 nm absorption is correlated to changes in kaolinite crystal structure (that is, disorder), as shown in XRD patterns. The application of this parameter to the HyMap data broadly separates erosional from depositional areas and thus is consistent with the regolith model. Previous alteration studies (models) have shown that the white mica chemistry, measured using the wavelength position of the 2200 nm absorption, is useful for defining alteration zonation in the region, including within weathered ferromagnesian host rocks, which is a critical indicator for superimposed K-metasomatism.

Introduction
A 12 month MERIWA (www.doir.wa.gov.au/meriwa/) project, called "Regolith, Geology and Alteration Mineral Maps from New Generation Airborne and Satellite Remote Sensing Technologies" (Project Number M370) was established in mid-2004. The main remote sensing data used for the project are from the hyperspectral airborne HyMap (www.intspec.com) and the multispectral, satellite-borne ASTER (www.ersdac.or.jp/projects/aster/asterpro_e.html) systems. The vision is that project will herald a new generation of publicly available maps of regolith, geology and alteration mineralogy tiled across large parts of WA and Australia, showing mineral abundances and mineral physicochemistries at scales from 1:25 000 to 1:250 000. This new pre-competitive geoscience information will empower exploration geologists and regolith geoscientists to more effectively explore in terms of mineralogy and will complement their current use of conventional data sets including geochemistry, geophysics, aerial photography and Landsat satellite imagery. The collaborators/stakeholders involved in the M370 project include: CSIRO Exploration and Mining; HyVista Corporation; Geological Survey of Western Australia; CRC LEME; Placer Dome Asia Pacific and MERIWA. The Kalgoorlie-Kanowna 1:100 000 map area was chosen because it coincides with a special map release of this area by the GSWA; the wealth of existing data in the area; and because of the challenge for this new "surface sensitive"

technology to provide valuable information for more efficient exploration in deeply weathered (covered) environments.

Results

Twenty-six flight lines of airborne HyMap data were collected in May 2004 over an 11 day period and under very poor conditions (constant high-level cloud; drying ground and vegetation flush after significant earlier rainfall; variable sun angle). These data were delivered by HyVista Corporation (www.hyvista.com) to CSIRO as surface reflectance data. Processing to mineral information products was conducted using both ENVI™ (www.rsinc.com) and CSIRO's in-house "Stygosauras™" software.

Theoretically, 127 unique variables can be generated from HyMap's 126 spectral bands, but because of natural spectral variability of surface materials, typically 30-40 surface types can be discriminated. Of these, 15-20 components can usually be identified and mapped accurately and of these just a handful (1-3) will be critical for a given application. From previous studies of Yilgarn regolith spectral-mineralogy (Cudahy, 1992, 1997), kaolinite disorder is considered important for regolith materials classification, especially distinguishing transported from *in situ* materials, and even for determining weathered host rock composition (Figure 1). For example, soils and transported materials tend to have poorly ordered kaolinite in contrast to saprock and saprolite over felsic and mafic rocks which typically have moderate to well ordered kaolinite. The degree of iron substitution in the kaolinite helps separate weathered felsic from ferromagnesian rocks. Other clays may also be present depending on host rock composition.

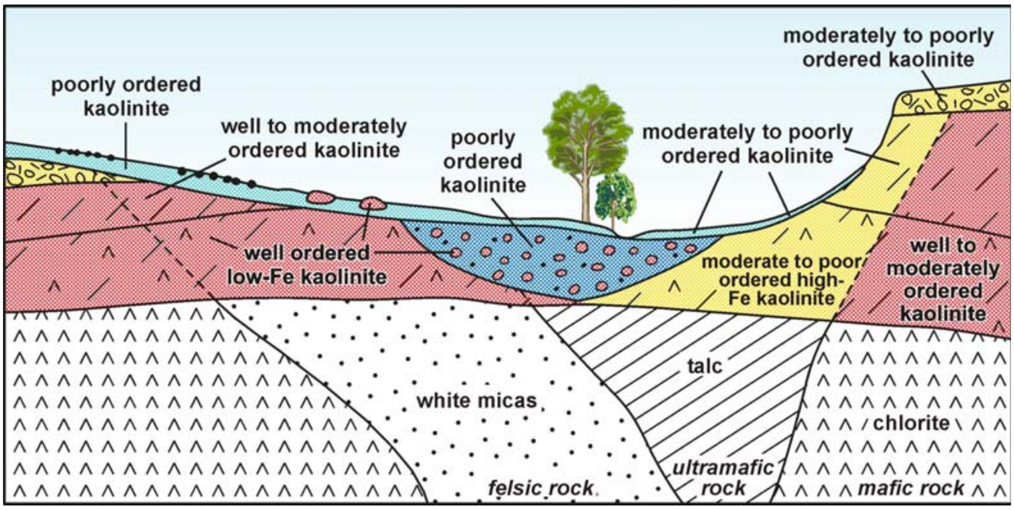

Figure 1: Schematic spectral-mineralogy regolith model for the Yilgarn focusing on kaolinite crystallinity (from Cudahy, 1997).

Cudahy (1997) established correlations between spectral parameters and XRD data that relate to kaolinite crystallinity. A similar correlation was found for the current M370 project, especially for the depth of the 2160 nm kaolinite absorption (Figure 2).

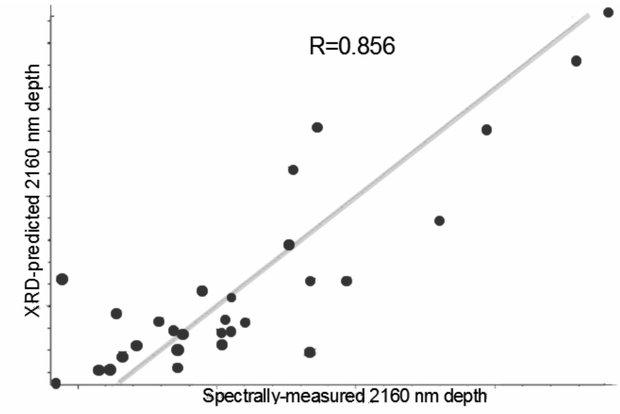

Figure 2: Partial least squares correlation established between a spectral parameter sensitive to kaolinite disorder, namely the depth of the 2160 nm absorption, and associated XRD data of field samples.

Even though HyMap has a spectral resolution of approximately 18 nm in the 2200 nm region compared with field spectrometers like the Analytical Spectral Devices Fieldspec Pro (www.asdi.com/products-FSP.asp), which has a spectral resolution of approximately 8 nm, there is little loss in precision when measuring the depth of the kaolinite 2160 nm absorption (Figure 3a) as a measure for kaolinite crystallinity. Cross-validation of the field spectral data and processed HyMap mineral maps is proceeding with due consideration given to problems in relating a single rock or soil spectral measurement with an integrated 5*5 m HyMap pixel and collocated using a GPS ground accuracy of 15+ m. Nevertheless, the emerging project results show correlation, albeit with some notable outliers (Figure 3b).

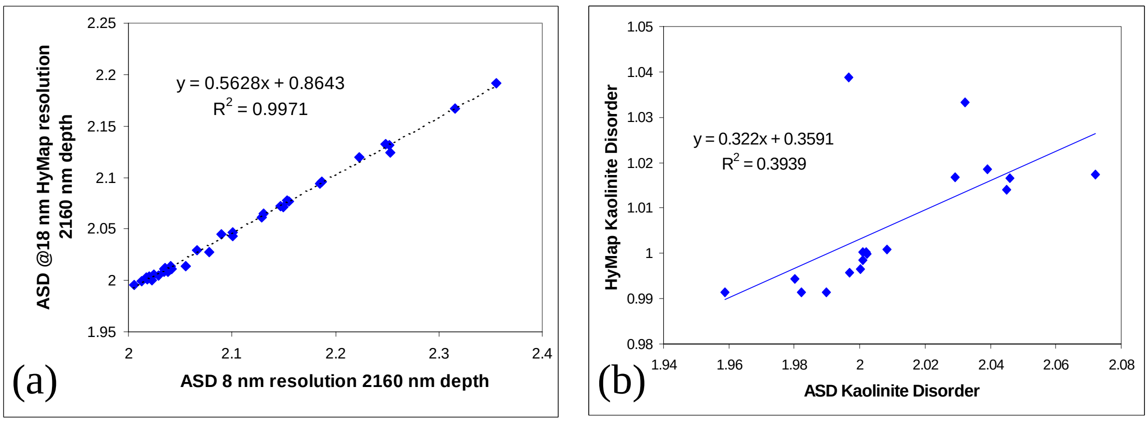

Figure 3: (a) Comparison of the measured depth of the 2160 nm absorption for field ASD spectra (8 nm spectral resolution) versus the same ASD spectra but convolved to airborne HyMap spectral resolution (18 nm) data; (b) Comparison of the measured depth of the 2160 nm absorption for actual HyMap data versus ground validation ASD results.

With the HyMap imagery processed to deliver both a measure of the kaolinite crystallinity (depth of the 2160 nm absorption) and the kaolinite abundance (depth of the 2200 nm absorption), with both products masked for white mica, green and dry vegetation and low albedo (dark) surfaces (e.g. shadow) and then draped over a high resolution digital elevation model (Figure 4), a pattern emerges that is consistent with the schematic model presented in Figure 1 and with the published regolith. That is, areas of saprolite and saprock show abundant well to moderately ordered kaolinite ("A") whereas soils and/or alluvium/colluvium comprise more poorly ordered kaolinite ("B"). Some anomalous areas, such as "C", comprise saprock over a white mica-rich felsic unit. The HyMap processed data show that this area contains little kaolinite of apparent poor to moderate crystallinity. From the schematic regolith-model in Figure 1, weathered felsic rocks should produce well-ordered kaolinite. This negative result is largely a function of unresolved spectral mixing problems and incomplete masking of Al-rich white mica which would theoretically degrade the 2160 nm feature to appear as a poorly ordered kaolinite. Clearly, more research is required to generate even more accurate mineral extraction methodologies.

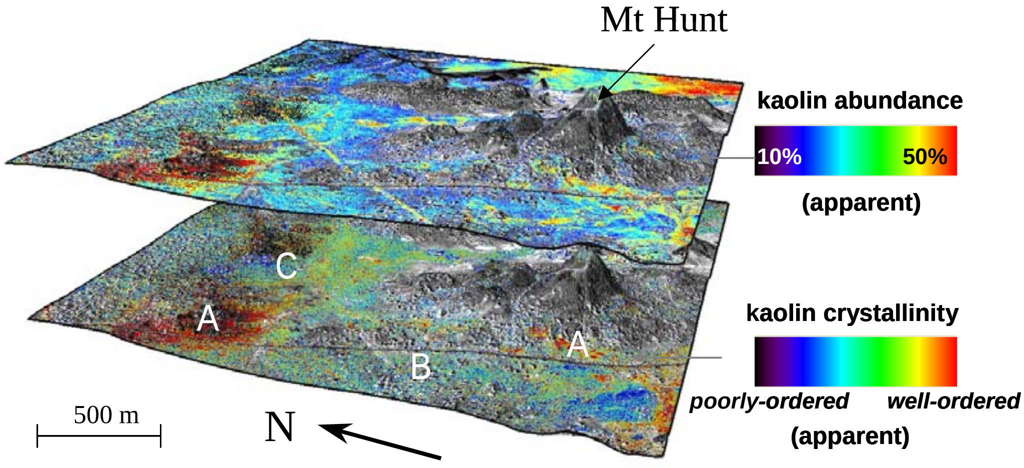

Figure 4: HyMap mineral maps of kaolinite abundance and kaolinite crystallinity draped over a DEM for the Mt Hunt area south of Kalgoorlie.

A composite mineral map that features the HyMap-derived kaolinite crystallinity as well as a range of other regolith mineral products for the entire coverage of the 1:100 000 scale mapsheet is presented in Figure 5. This is one of two hardcopy products to be generated from the M370 project. This one being the "Regolith Mineral Map Theme" and the other is an "Alteration Theme" based on white mica chemistry. The important observation to be made from the kaolinite crystallinity product in Figure 5 and the existing published regolith landform map (second from the top series of tiles in the centre of the figure) is that red areas are essentially associated with erosional regimes (cyans and purples on the regolith map) and blue-cyan area associated with depositional areas (yellows and greens on the regolith map). Armed with this type of mineralogical information (not just kaolinite crystallinity but also iron oxide mineralogy and the presence of primary minerals), regolith mapping would in theory be more efficiently achieved for at least separating transported from *in situ* materials, especially when combined with a DEM and information about vegetation type (also from the spectral data and aerial photography) and radiometrics. Furthermore, within the erosional areas there is the potential to map mineral alteration including metasomatic minerals associated with hydrothermal Au and potentially base metal mineralisation. This has also been achieved with these HyMap data but is not presented in detail in this paper.

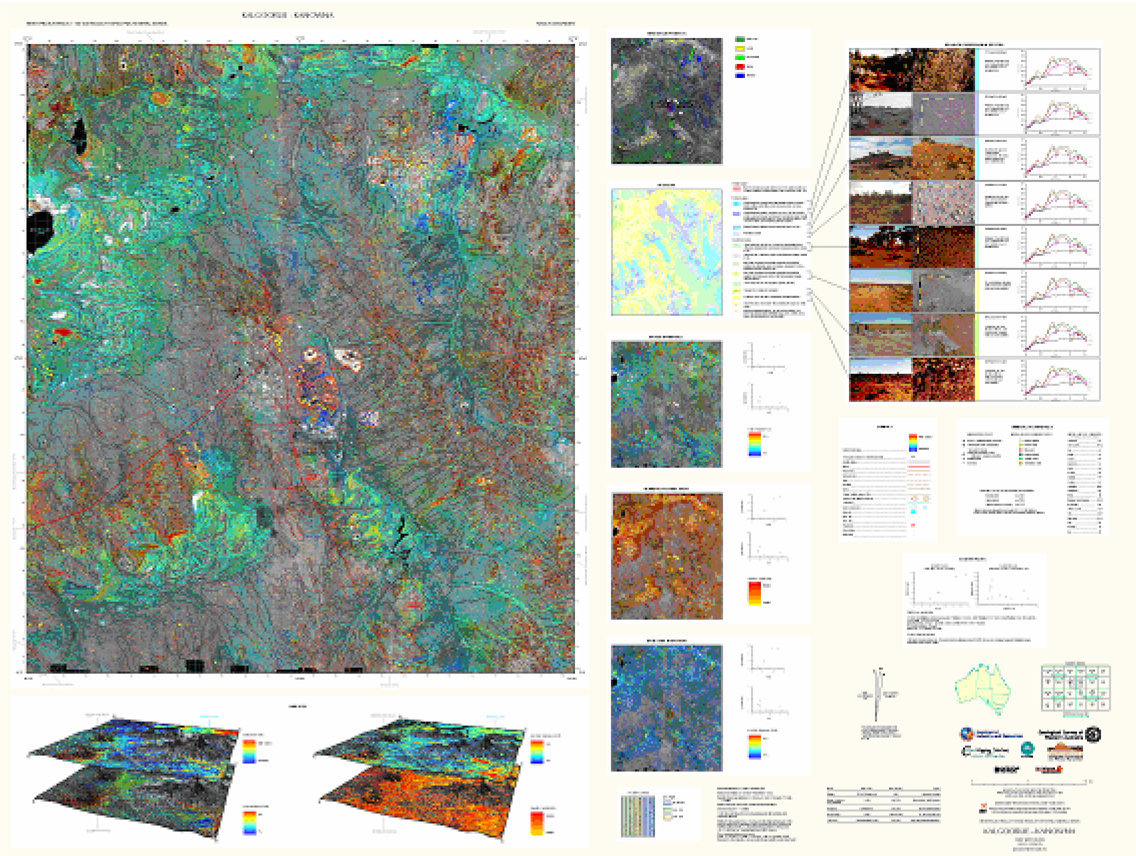

Figure 5: One of the final M370 project deliverables, namely the composite 1:100 000 mineral map for the Regolith Theme featuring kaolinite crystallinity.

Acknowledgements

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