HYPERSPECTRAL REMOTE SENSING

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1. METHOD

Mineral exploration is becoming increasingly difficult, especially in obtaining ground access to sensitive or remote areas. Remote geophysical methods can be used to advantage in such circumstances. Spectral remote sensing has the potential to provide the detailed physicochemistry (mineralogy, chemistry and morphology) of the Earth's surface. This information is useful for mapping potential host rocks, alteration assemblages and regolith characteristics. In contrast to the older generation of low spectral resolution systems, such as the Landsat Thematic Mapper with only six "reflected" bands, the new generation of hyperspectral systems enable the identification and mapping of detailed surface mineralogy using "laboratory-grade" spectroscopic principles (Clark, et al., 1990).

For example, many tri-octahedral silicates, carbonates and other minerals generate diagnostic absorption features in the 2300 to 2400 nm region. Only hyperspectral sensors, with tens of contiguous spectral bands across this wavelength range, can provide accurate measurement of the wavelength positions and geometries of the diagnostic mineral absorption features.

With the aid of hyperspectral remote sensing, an extensive range of minerals can be remotely mapped, including: iron oxides, clays, micas, chlorites, amphiboles, talc, serpentines, carbonates, quartz, garnets, pyroxenes, feldspars and sulphates, as well as their physicochemistries such as cation composition and long and short range order.

Geological remote sensing is performed through atmospheric windows where electromagnetic radiation (EMR) is allowed to pass without significant attenuation. The five atmospheric windows available for remote mineral mapping include the visible to near infrared (VNIR), the shortwave infrared (SWIR), the mid-infrared (MIR), the thermal infrared (TIR) and the microwave wavelength regions (Figure 1). The ultraviolet (UV) and far infrared (FIR) wavelength regions are not available. Of these five atmospheric windows, the VNIR, SWIR and TIR regions are most useful for mapping surface mineralogy because these wavelengths are sensitive to a wide range of diagnostic EMR-material interactions. In particular:

1. The mineral-spectral features in the VNIR are largely related to the transfer of electrons between energy levels of constituent elements, especially the transition metals Fe, Mn and Cr (Hunt, et al., 1971);
2. The mineral-spectral features in the SWIR are largely related to the overtones and combination tones of vibrations of octahedrally coordinated cations (typically Al, Fe, Mg) bonded with OH groups (Hunt and Vincent, 1968); and,
3. The mineral-spectral features in the TIR are largely related to fundamental vibrations (bends and stretches) of Si-O bonds in various structural environments (Lyon, 1965).
As a consequence, the VNIR wavelength region is useful for mapping iron oxides and oxyhydroxides (for example, hematite and goethite), the SWIR for dioctahedral and trioctahedral silicates (for example, kaolins, white micas, smectites, chlorites, amphiboles, talcs, serpentines) and the TIR for framework silicates (quartz, feldspars, garnets, pyroxenes and olivines). Carbonates and sulphates produce diagnostic spectral features at both SWIR and TIR wavelengths.

Combined use of the VNIR, SWIR and TIR atmospheric windows should therefore allow identification of a wide range of minerals necessary for most geological applications. For example:

1. The **VNIR** wavelength region is potentially useful for mapping gossans, rich in iron oxides and associated with weathered sulphide occurrences (Rowan, et al., 1977, Bladh, 1982, Buckingham and Sommer, 1983, Raines, et al., 1985, Fraser, et al., 1986, Townsend, 1987), as well as regolith characterisation (Cudahy, 1992);


3. The **TIR** wavelength region is potentially useful for mapping a range of exploration targets. For example, in more weathered environments, mapping silicification associated with epithermal/porphyry alteration (Gunnnesch, et al., 1994) may be useful. Similarly, Mn-rich garnets associated with Broken Hill style Pb-Zn-Ag mineralisation (Spry and Wonder, 1989) or Fe-rich garnets in Cu-Zn skarn systems (Harris and Einaudi, 1982) can be targeted. In less weathered terrains, pyroxene composition can potentially be used as an indicator for skarn deposits (Einaudi and Burt, 1982, Nakano, et al., 1994) whereas feldspars could be important in mapping granite host rocks or granite-associated mineralising fluids (Ishihara, 1981). For example, the Proterozoic Cu-Au-U mineralisation at Olympic Dam (Haynes, et al., 1995), rare earth mineralisation (Pollard, 1995) and Archaean lode Au deposits (Wyman and Kerrich, 1988) are all associated with specific types of granites.
2. **HYMAP SYSTEM**

The HyMap™ (Hyperspectral Mapping) system is an operational, airborne imaging VNIR-SWIR spectrometer designed and built by Integrated Spectronics Proprietary Limited (ISPL) (http://www.intspec.com). The features of the system include:

1. 450-2500 nm spectral coverage;
2. 128 spectral bands across three wavelength regions. The VNIR (visible-near infrared) region from 450-1400 nm has 64 bands, the SWIR-1 (shortwave infrared) region from 1400-1900 nm has 32 bands and the SWIR-2 from 1900 to 2500 nm has 32 bands;
3. bandwidths of 10-20 nm;
4. high signal to noise ratio for all bands (>500:1);
5. 3-10 m spatial resolution;
6. 61.3° degrees swath width;
7. on-board radiometric and spectral calibration;
8. operates in aircraft equipped with standard aerial camera ports; and,
9. 3-axis gyro-stabilised platform.

3. **DATA PROCESSING**

The processing of airborne hyperspectral data to derive accurate surface compositional information involves the following steps:

1. Evaluation of the HyMap instrument stability and noise;
2. Generation of radiance at the sensor data (correction for instrument gains and offsets);
3. Evaluation and correction of radiance at the sensor data for atmospheric effects (both additive and multiplicative effects as well as wavelength-dependent and wavelength independent effects);
4. Evaluation and correction for surface scattering and shadowing effects (both wavelength-dependent and wavelength independent multiplicative effects);
5. Implementation of the above corrections to yield surface radiance (or equivalent), which is directly related to surface composition;
6. Spectral compression (to reduce the large volume of spectral data, much of which is highly correlated, to a size that can be efficiently processed);
7. Evaluation and generation of specific surface compositional products for comparison with the published mapping; and,
8. Georeferencing of the information products to a standard map base for inclusion into a GIS.
This chain of processing can take one of several paths depending on the user's requirements where consideration is given to speed versus accuracy. Two possible processing strategies are most commonly applied:

1. The first strategy is very rapid and uses a technique called log residuals (Green and Craig, 1985). In fact, this method generates mineralogically interpretable products within one hour after receiving the raw data. However, log residuals suffers from scene-dependency.

2. The second strategy involves full modelling of the atmosphere to yield surface radiance. This step is itself not time-consuming (1 hour per 4000 line run), though the subsequent steps of extracting the "scene-independent" mineral information products is very time consuming mainly because of current limitations in algorithms/software.

The software which is currently available for hyperspectral processing is largely written in IDL (Interactive Display Language) and includes ENVI (developed by Analytical Imaging and Geophysics (AIG at http://www.aigllc.com/) as well as ENVI "add-ons" written by CSIRO and stand-alone IDL-based packages like HYCORR, also written by CSIRO. Much use can be made of Microsoft EXCEL®, ERMAPPER®, ARCVIEW® and other imaging, statistical and GIS packages.

4. **DATA INTERPRETATION AND EXTRACTION OF MINERAL INFORMATION**

Information extraction follows data reduction to surface radiance (or equivalent). The type of extraction procedure again depends on the level of accuracy, confidence and reproducibility required by the user. As with the data reduction stage, simple methods like band ratios and log residuals can be used to good effect to derive image products that pertain to a compositional parameter of interest, though these types of methods often generate non-unique products. This is especially the case if a number of different materials generate significant spectral variation at those wavelength selected for the ratio (log residual) product.

Ultimately, whether it be ratios or more sophisticated techniques like partial unmixing (Boardman, 1993), the objective is to capitalise on that spectral information unique to the material of interest. This is non-trivial and no one method can yet be considered as truly reaching this much-desired goal.

Several information extraction methods can be used, including:

1. Band ratios;
2. Log residuals;
3. Curve fitting;
4. Supervised classification; and,
5. Partial unmixing.

Other techniques, like Mahalanobis Distances and Partial Least Squares (Haaland and Thomas, 1988), can also be considered.

5. **APPLICATIONS**

Hyperspectral remote sensing is a powerful tool for mineralogical mapping, regolith-landform mapping, and for a range of environmental applications. The spectral signatures of land surface, derived from imagery, can be used to identify and even quantify mineralogical entities of exploration significance. The spatial analysis of imagery can lead to improved mapping by more precise identification and subdivision of regolith-landform units. Environmental processes can be identified and monitored with high spatial resolution. Examples are shown in Figures 2-4.
Figure 2. An example for mineralogical mapping: a) RGB image derived from HyMap, overlain by mapped amphibolite units from the published 1:25,000 geological map. b) the imaged amphibole endmember, c) the imaged goethite-illite mixture endmember. The distribution of amphibolites is well mapped, and the weathering of amphibolites and dispersion of weathering products is clearly resolved.
Figure 3. An example for regolith-landform mapping. Iron-oxide endmember identified from HyMap data is imaged. High iron-oxide areas appear in the landscape as ferricrete rises (red colour, indicated with black arrows) dissected by drainage.

Figure 4. An example for environmental applications. The yellow lines show old drilling sites. They are invisible on aerial photography and hard to identify in the field, but are evident on HyMap imagery because of the significantly different mineralogy of drill spoil material from the natural surface materials.
6. **PROBLEMS, LIMITATIONS**

Because of current limitations in algorithms/software, many problems can be encountered during processing hyperspectral data. Hence, at the time of this study, no operational, scene-independent methodology is available. Hopefully the development of an accurate operational methodology in the future will provide a general solution.

What is lacking, are well-documented Australian geological case histories that demonstrate the potential of hyperspectral regolith exploration.

7. **SURVEY ORGANISATIONS**

A new generation of hyperspectral remote sensing systems is now becoming available for routine use by the mineral exploration community. These systems include the airborne HyMap, OARS, SWIPS, TIPS, SEBASS and AVIRIS systems and the spaceborne Hyperion, Orbview-4, ARIES-1 and NEMO systems. HyMap is operated by Integrated Spectronics Proprietary Limited (ISPL) ([http://www.intspec.com](http://www.intspec.com)).

8. **COSTS**

The cost of a hyperspectral survey largely depends on the volume and timing of data acquisition. Coordinating data acquisition campaigns of several projects for the same time can save as much as 50% of acquisition costs. Data for research purposes can often be obtained for much reduced price compared to commercial data. Cost of data is calculated as the sum of mobilisation costs plus price per line kilometer. The data is sold at various processing levels, which also influences the final cost. As hyperspectral techniques are in a rapid development, with constantly changing technology, it is best to contact the surveying company for details on actual costs.

9. **REFERENCES**


