HyMap™ - Hyperspectral Mapping - GeoVision beyond the Visible

Introduction

Most geoscientists are familiar with the colorful LandSat imagery we have been provided with for almost 30 years. These multispectral data sets have allowed us to see the earth in colors not accessible to the human eye and hence allowed discrimination of previous, not distinguishable geological features. Technology has progressed and it is now possible to view the earth not only in a few, but hundreds, of different spectral channels over a wide wavelength range; and to map the surface composition based on the spectral signatures observed. We call that “hyperspectral sensing” and despite some attempts with satellite systems, airborne instruments are leading the way. An Australian designed and built sensor is one of the world’s outstanding performers and has delivered high quality data sets worldwide in over 27 different countries. Applications range from mineral mapping to environmental monitoring, geothermal prospecting to oil seep identification. From small scale targeting to large area mapping, HyMap has demonstrated its usefulness equally to geological surveys, environmental agencies and exploration companies.

When trying to convince the classic exploration geophysicist of the usefulness of a detailed mineral map for his exploration lease many seem skeptical and refer to hyperspectral as ‘only’ being a surface tool. However quite often surface mapping can reveal astonishing details about the presence of alteration minerals, their mineral chemistry and spatial distribution. With a high spatial resolution of down to 3m, structures like quartz veins or gossans can easily be identified and can highlight new, previously inaccessible exploration targets. Even in the highly weathered, regolith dominated Australian environment, HyMap has discovered structures and residual anomalies previously unknown to geoscientists, many of which are not present in the standard geological maps of the area.

For many exploration managers remote sensing data is still synonymous with large-area overviews rather than detailed, specific information related to an exploration issue. Often the data processing and interpretation skills are not advanced enough to extract the relevant information for the project. However, demonstration projects by CSIRO and Australian state mapping agencies lead the way and create insight into the potential uses of hyperspectral technology. If we can directly send the drill crew to a promising alteration / target / anomaly area and avoid ‘blind’ holes we may actually save money by investing in the right remote sensing technique. Having highly accurate mineral maps may actually allow us to correctly identify the exploration model to be used for a specific area. Hence acquiring HyMap data and getting the appropriate data processing done can prove to be quite a cost effective way to start an exploration project.

Hyperspectral data should also always be seen in conjunction with other geo-data sets, be it elevation models or magnetic data. The wise use of different information layers as part of the whole, is an important element of the recent revolution seen within the geosciences. Today, whole-earth models that combine seismic-extracted fault structures, spatially located geochemical information, magnetics, gravity, age-dating and field mapping information are used to assess exploration prospects and leases. Continuous surface information from hyperspectral imaging is simply one more vital building block for our exploration models.

HyMap™ Airborne Imaging Sensor

The HyMap sensor is an airborne imaging system that is used for earth resources remote sensing. It records a digital image of the earth’s sunlit surface underneath the aircraft (Figure 1), but unlike standard aerial cameras, the HyMap records images in a large number of wavelengths. Spanning the wavelength range from the 0.4 to 2.5mm (visible to shortwave infrared) spectral region (Figure 2), HyMap is an airborne spectrometer that detects and identifies materials by the spectral features contained in the recorded data.

The HyMap records an image by using a rotating scan mirror, which allows the image to build line by line as the aircraft flies forward. The reflected sunlight collected by the scan mirror is then dispersed into different wavelengths by four spectrometers in the system. The spectral and image information from the spectrometers is digitised and recorded on tape.

To minimise distortion induced in the image by aircraft pitch, roll and yaw motions, the HyMap is mounted in a gyro-stabilised platform. While the platform minimises the effects of aircraft motion, small image distortions remain. These residual motions are monitored with a 3 axis gyro, 3 axis accelerometer system (IMU – inertial monitoring unit). Dedicated geo-correction processing restores the full geo-location information and allows the creation of GIS ready products.

The HyMap system has been designed to operate in aircraft that have standard aerial photo-ports. The angular width of the recorded image is 61.3 degrees or about 2.3 km when operating 2000m above ground level. Typically, the spatial resolution achieved with the HyMap is in the range of 3 to 10m.

Figure 1: HyMap data acquisition.

Figure 2: Example for ground reflectances from a spectral library and HyMap spectral channel positions.
Hyperspectral Processing

The HyMap sensor acquires reflected surface radiation, which needs to be calibrated and corrected for atmospheric absorption to derive reflectance. Reflectance is then used for spectral signature analysis and comparison to spectral libraries of known materials (Figure 2). Using calibration parameters obtained in the laboratory, the initial digital numbers are converted to ‘radiance at sensor’ in ‘mW/cm² sr nm’ radiance units. Different atmospheric correction algorithms have been published such as AtCor, ACORN and FLAASH and can convert the ‘radiance at sensor’ into reflectance using atmospheric model parameters and information such as sun angle, location and time of the survey.

Unlike other geophysical airborne sensors where the calibrated units can be used directly in the data interpretation stage, post-processed reflectance data from HyMap are only the first step in the information extraction process. Though color composites of selected spectral channels do give a first indication about surface material properties (see Figure 3), the major power when using hyperspectral data comes when dedicated processing is applied. The data can be used to qualify the spectral properties of different surface materials and derive spectral indexes and spectral component maps. A spectral index utilizes the common spectral properties of a group of surface materials such as the dominant 2.2 µm spectral absorption of the clay group minerals. Based on surface-extracted spectral signatures, dedicated component maps can be derived, as shown in figure 3 where ‘mineral’ maps are shown. Another commonly used methodology builds on initial principle component like MNF transformations, which leads to semi-automated detection of spectrally different materials (Huntington and Boardman, 1995). Other ways of extracting the information in the data include monitoring an exact wavelength position of a spectral feature, such as that of the white mica minerals (e.g. muscovite), tracking its wavelength position shift and then deriving a so-called mineral chemistry map. In addition, various ‘mineral’ maps can be combined into alteration zone maps, such as advanced argyllic or epithermal. In a geological exploration model, these important pieces of information can lead directly to zones of higher exploration relevance and hence reduce exploration expenses.

In a similar way such processing techniques allow information extraction for other applications such as oil seep mapping (figure 4) or environmental monitoring (figure 5). Different water constituents or vegetation components can be separated, vegetation stress monitored or multitemporal comparisons obtained.

Hyperspectral Application Examples

The development of the HyMap sensor was inspired by the mapping needs of mineral explorers. Success in the mining industry with handheld spectrometers such as the PIMA complimented successful development of the large-area airborne scanners that utilised similar technology. These first airborne scanners from Integrated Spectronics eventually led to the HyMap series of sensors. They combine accurate, point-scale mineral identification from reflectance spectroscopy with the large-area mapping ability afforded by airborne scanning technology. The result is high fidelity, continuous surface information including mineral identification, lithology separation, vegetation classification, manmade material identification and a myriad of other material identifications and discriminations.

Significant contributions to Australian and international exploration programs have been made in the past ten years from airborne hyperspectral imaging and many prominent companies such as DeBeers, Falconbridge/Noranda and PlacerGold count on hyperspectral data for their exploration programs. Cudahy et al., 1999, have investigated the alteration systems around Panorama in Western Australia and successful mica chemistry mapping was demonstrated, while Bierwierth et al., 2002 demonstrated the distinct ability to identify and map gold indicator minerals such as pyrophyllite in the unforgiving regolith-dominated northern Pilbara region of WA. Other prospecting in remote regions of South America is benefiting from recent data fusion projects, which involve large-area satellite reconnaissance followed by specific prospect-scale mapping with airborne hyperspectral.

In addition to mineral exploration, geothermal resource prospecting has also become a ‘hot’ topic for hyperspectral scientists in recent years. Hyperspectral surveys in the western U.S. have served to define and refine geothermal exploration targets in several locales including expansion sites with previous production and green-field sites lacking current heat energy production.

Oil and gas explorers have remained interested in the technology for many years and companies such as Shell and ChevronTexaco are known users. Detection of terrestrial hydrocarbon seepage is the most common application with practitioners measuring changes in soil composition, vegetation anomalies and direct hydrocarbon residue mapping. Recently, concerted effort towards detection and mapping of offshore hydrocarbon seepage has been made, especially at well-known seeps such as those off of Santa Barbara, CA,
USA. Detecting and discriminating seepage from other materials may help explorers to identify new regions of interest and to target areas for other complementary geophysical data collects. Hyperspectral imaging has also made significant contributions to environmental monitoring best-practices and has become a vital new research and application area. Work by Ong et al., 2003a demonstrated quantitative pH measurements made in mine regions plagued by acid drainage including the gold, silver, lead, zinc mine of Leadville, CO, USA and the abandoned pyrite mine of Brukunga, SA, Australia. Quantification of dust loading on mangroves surrounding BHP-Billiton Iron Ore’s iron ore handling facility at Port Hedland, WA was also accomplished and recent work by the USGS produced hyperspectrally derived asbestiform mineral maps relating to relative physical concentrations of said minerals around both the historic vermiculite deposits of Libby, Montana, USA and within the destruction of the World Trade Center.

In this article we would like to focus on three specific application examples:

* Mineral Exploration
* Hydrocarbon Seepage
* Environmental Baseline Mapping

**Figure 4a:** HyMap imagery used for offshore seepage mapping near Santa Barbara, California. Above: False color composite mosaic of the survey area highlighting different water constituents using spectral ratios in the visible and near infrared spectral region.

**Figure 4b:** HyMap imagery used for offshore seepage mapping near Santa Barbara, California. Below: Spectral component map of slick areas. The land, open water and kelp beds have been masked out deliberately and the remaining data spectrally processed to highlight variations within these components.

**Mineral Exploration:**

**Harts Range, NT - Australia**

The Northern Territory has been a region of increasing interest and prospectivity in Australia. Such areas as the Arunta inlier in the southern 1/3 of the state has garnered special interest in recent years due to its proven mineral resources (eg. the Tanami) and has subsequently been examined with extensive suites of geophysical and geochemical surveys. Synthesis and analysis of these data is on-going by Australian state and national entities including the NTGS and GA and by individual and JV’ed mining companies working in the region. The broad goal has been to expand the understanding of the complex genesis and geology of this region including characterisation of fluid movement in the Tanami and linking the Tanami and the Arunta more convincingly. Constraining the formation and occurrence of Cu-Zn-Pb deposits in the eastern Arunta has also been of primary interest. Several regions in the NT, including the rocks of the Harts Range in the eastern Arunta, have been flown with the HyMap. The eight lines of hyperspectral data seen in Figure 4 capture portions of the Riddock Amphibolite within the Harts Range Group in the northern part of the dataset, various gneisses, schists, amphibolites and granulites of the Strangways Metamorphic Complex within the central part of the dataset and extensive Proterozoic to Paleozoic aged schists and amphibolites in the southern part of the dataset. There are several exploration goals in this region of which determining possible Au and Cu prospectivity is paramount. Analysis of the hyperspectral data such as that shown in Figure 4 highlights new geological information about the Harts Range and has provided new insight into Cu-mineralisation and host-rock character to local exploration companies.

**Hydrocarbon Seepage:**

**Santa Barbara, California - USA**

The hydrocarbon seepage off of Coal Oil Point, Santa Barbara, CA is one of the largest and most active seeps in the world. It continues to be of great interest both to governmental bodies as well as universities and private resource companies including primary research done by the UC Santa Barbara Hydrocarbon Seeps Group. Researchers in this group estimate that approximately 100 barrels a day of crude oil seeps from the Santa Barbara region in addition to 100,000 m³ of gas per day. Tracking and quantifying this seepage has primarily been done with a combination of direct seep tent measurements and indirect sonar measurements. However the overall spatial distribution of the seeps on the ocean surface is less well-known, especially temporally. Spatial extent and seep-slick movements are important pieces of information towards understanding the dynamics of slicks and the behavior of seeps and slicks over time.

Airborne hyperspectral seep mapping offers a new possibility of characterising seeps in an exploration area of interest. It offers the advantage of allowing spectral discrimination of seep components, which may not be separable with conventional techniques like radar. Initial analysis indicates that unlike the confusion imparted by such techniques as photography, multispectral and radar, hyperspectral has the ability to discriminate not only seep slicks from other biogenic materials, but may also track within-seep variability possibly due to chemistry, age, or thickness. The implications of this research may be far-reaching in time, especially for global seep detection and local seep variation studies. Figure 4 shows seamless data product mosaics of the 4 flight lines covering the area, with different seep-specific spectral components highlighted in the images.

**Environmental Baseline Mapping:**

**Ningaloo Reef – WA, Australia**

In times of increased environmental awareness, it becomes more important to have tools available to monitor environmental parameters such as water pollution, vegetation health, habitat biodiversity, invasive species and general human impact. Hyperspectral
monitoring offers an excellent possibility to regularly investigate conditions in sensitive areas and create highly accurate baseline maps over areas of high importance. One such area visited by the HyMap sensor in late 2002 is the Ningaloo Reef marine park in Western Australia, about 1200 km north of Perth. This area is not only one of Australia’s most precious marine habitats and protected areas, but has also been suggested for inclusion as a ‘World Heritage’ site. HyMap not only allows for monitoring various land surfaces and native vegetation habitats in the coastal karst areas, but it also penetrates the water and allows monitoring of the still pristine, but sensitive reef areas. Such a non-invasive remote sensing technique is the best way to keep an ‘eye’ on 100% of the protected area at a high spatial resolution, without extensive ground work and disturbance of the already fragile habitats. Figure 5 on the right shows a HyMap line acquired parallel to the shore near Turquoise bay with its colorful waters. The images below show an area near Yardie Creek flown perpendicular to the reef line showing both land and underwater features in the area. The clarity of these underwater features is remarkable and may allow spectral identification of the different reef components. Together with a spatial resolution of 3-5 m, HyMap offers the possibility for dedicated baseline mapping and regular monitoring of areas of such importance.

Conclusion

Hyperspectral mapping offers the geoscientist new possibilities for obtaining geo-information previously only available from extensive field work. The ability to spectrally map a variety of surface materials opens a range of applications. However the acceptance of the technology appears somewhat lacking in the geoscience community. This may be due to its ‘surface only tool’ capabilities, but more likely to a lack of education about the individual possibilities, the perceived complexity of the software needed to do the data processing and/or the shear number of spectral channels and multitude of possibilities for combinations of data products. People seem to want to have only 3 or 4 choices of products they can work with – HyMap offers many more – Which do I take? How do I know my processing was correct? But hyperspectral experts will understand how to process the data correctly and deliver the products required in a limited amount of time. With current advances in computer processing power and data storage capacity - data volume and processing speed is not an issue anymore.

We also see a trend in the geoscience industry to move away from the ‘We have to do it all ourselves’ mentality towards asking service providers for specific products – like a target map for one particular mineral in an alteration zone or a vegetation stress map over a contaminated field. Once the geoscientist knows what hyperspectral mapping can do for them without actually having to do it themselves, then we will see acceptance multiply. Like the magnifying glass for the field geologist, hyperspectral mapping is an essential part of the GeoVision we have for the future in earth monitoring.

Figure 5: HyMap imagery showing parts of the Ningaloo marine park. Above: True color composite mosaic showing the area around Turquoise bay. Below: Yardie Creek as seen with the HyMap. 5a) true color composite 5b) & 5c) different spectral end-member components highlighting various structures underwater (1) on land (2). B2 shows different vegetation components, whereas C2 shows the difference between specific clay (red) and carbonate (blue) dominated surfaces. (Note the water and land segments do not display the same spectral component, they were merged to save image space).