MULTISPECTRAL AND HYPERSPECTRAL IMAGERY FOR SAFEGUARDS AND VERIFICATION OF REMOTE URANIUM MINES

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ABSTRACT

In this era of strengthened safeguards measures, and especially following the recent introduction of high-resolution satellite imagery by several commercial firms, the use of imagery is becoming more common as a cost-effective means to obtain information on uranium mining activities. Such imagery is relatively straightforward to interpret, and can be used to produce valuable information for safeguards purposes, e.g. image maps for comparison with member state declarations. In addition to these open sources, there are several unrestricted "research" satellite sensors available that can provide inspectors and regulators with additional tools that might be used to confirm operations, scheduling, movement of materials and other reported details.

As part of a co-operative project between the Canadian and Australian Safeguards Support Programs, very high spatial resolution panchromatic and natural colour (Red, Green, and Blue, or RGB bands) imagery of three operating uranium mines in Australia was examined [1]. This paper presents examples of the use of multispectral bands from IKONOS for multispectral classification and 220 bands from HYPERION for hyperspectral classification to demonstrate:

- terrain and vegetation classification;
- water usage (and by inference certain mining or milling operations); and
- geographic movements of ore material on a site by spectral discrimination.

The paper examines potential applications of the above findings with respect to safeguards verification of declared and undeclared activities.

SAFEGUARDS APPLICATION OF REMOTE SENSING

Uranium mines are often located in remote areas far from built up areas and are difficult or expensive to access. Satellite imagery can be of considerable aid to safeguards inspectors, by allowing for production of up-to-date independently produced maps that can be used to evaluate member state declarations and monitor reactor or mine operations.

Satellite imagery provides *synoptic*, *wide-area spatial coverage* on a more or less regular basis, subject to cloud cover for satellite visible-infrared (IR) imaging systems. In *remote or inaccessible areas*, satellite or airborne sensors may be the only practical way of gathering information, since it can provide access without administrative restrictions, on private land, across borders. Thus *trans-*

boundary analyses can be repeated at intervals, or after some event to provide temporal monitoring and *change analysis.*

In 2003, a wide variety of satellite data is available – from very high resolution panchromatic (black and white) imagery similar to aerial photography that is taken on demand; through lower spatial resolution multispectral (many colours – usually 4-20 spectral bands) imagery; with more spectral resolving power, thermal capability and a 30 year archive of the entire earth; to more recent radar imagery that can see through cloud and darkness; to hyperspectral (very many colours, 20 to 200 or more spectral bands) imagery capable of detecting very subtle colour variation.

This paper introduces multi and hyperspectral imagery – using examples of 4 band multispectral imagery from the IKONOS satellite launched by Space Imaging Inc. and 220 band hyperspectral imagery from the NASA satellite HYPERION. The multispectral IKONOS (launched by the American company Space Imaging Inc.) has much higher spatial resolution than HYPERION, with pixel spacing of 4 m compared to 30 m for the latter. This is a function of the physical limitations on transmission of data from the satellites - HYPERION sacrifices spatial resolution for more spectral bands. Both types of imagery provide the capability to distinguish and map different materials based on their colour, but hyperspectral imagery provides much more diagnostic capability. In its most highly developed form, now being widely used in mineral exploration, hyperspectral imagery offers the ability to make chemical measurements from space based on very subtle spectral absorption and reflectance features in the light reflected from water, vegetation, rocks and minerals.

EXAMPLES FROM RANGER MINE, AUSTRALIA

Ranger Mine is a large open pit facility covering about 500 hectares, located in Northern Territory, Australia 230 km east of Darwin. It opened in 1981 and produces about 4000 tonnes of uranium per year. At present, ore is being mined from an open pit to the east of Pit 3 (Figure 1). High grade ore is stockpiled just west of the processing plant, while low grade waste rock is stored elsewhere on the site. Once the uranium has been removed from the crushed ore during processing, the contaminated tailings from the milling process are pumped as slurry into the mined out Pit 1. Following precipitation of most of the suspended tailings in Pit 1, the tailings water is either pumped to the tailings dam for evaporation or pumped back for recycling in the process plant [2].

The most contaminated wash-down and rain waters from the workshop areas, the power station and from the higher-grade ore stockpile areas are collected first in RP3 (Retention Pond 3), and then passed to RP2. Overflow from RP2 during the Wet season is collected in Pit 3 and dissipated during the Dry season by passing the water through a wetland. RP1 collects run-off from bush-land together with all water run-off from the base of the tailings dam wall and from all clean rock stockpiles in the area. This pond is essentially a sediment control pond and ensures that any disturbed soils in the RP1 catchment area are allowed to settle out in RP1 [2].

SPECTRAL EXAMINATION OF WATER AREAS

The reflectance of any water body is determined by the absorption and scattering of light from the water itself, and from dissolved and suspended particles. The surface water on a mine site provides important clues as to the operation of the mine, that are accessible to inspectors via multispectral and hyperspectral satellite remote sensing, and that are difficult to hide. As noted above, at Ranger the tailings are initially dispersed underwater and settled in Pit 1, then stored in the tailings pond. The area and colour of water bodies on the site are therefore an indicator of production. Simple aerial photography or black and white satellite imagery can show the aerial extent of the water in the tailings pits, but with even more digital processing of multispectral imagery, considerably more information can be obtained.

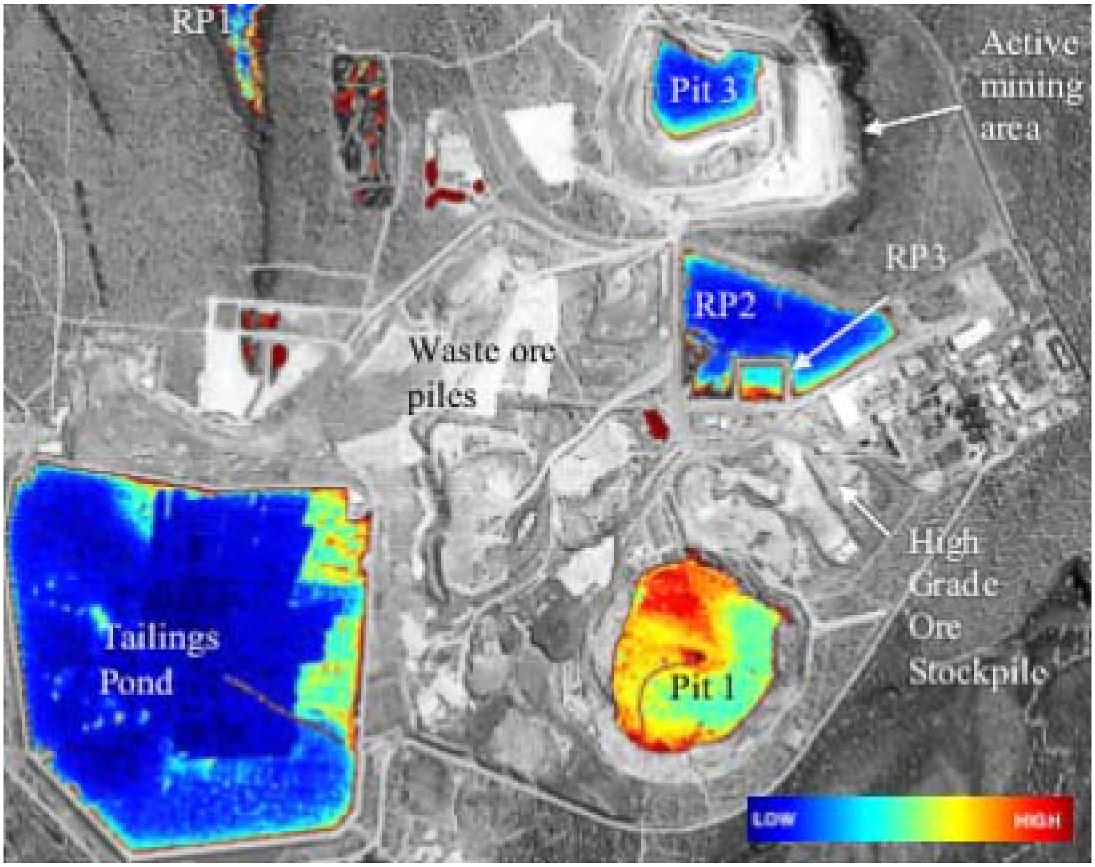

Figure 1. An IKONOS single panchromatic image [as black and white background] overlaid with colour to show the brightness of the water areas at red wavelengths, and interpreted in terms of turbidity and or water depth.

The satellite derived image map in Figure 2 confirms many of the details of the water management scheme referred to above and shown in Figure 1. Here, the brightness of water bodies on the Ranger mine site as recorded in the red band of 4 m resolution IKONOS image acquired on June 25, 2001 has been manipulated to show turbidity and or depth. The water brightness is shown in pseudo-colour (that is according to the rainbow scale shown in the insert), while the land areas are shown in black and white to provide the context of the water bodies.

Active sub-aqueous tailings dispersal at the time of imaging is made clearly evident by the bright plume in Pit 1, apparently issuing from a curved floating boom, while the linear features in the tailings pond are evidence of dredging of settled tailings after evaporation. The brightness of Pit 1 is an indication of very high particle content in these waters. Other water bodies on the site are darker, and therefore deeper with lower suspended solids.

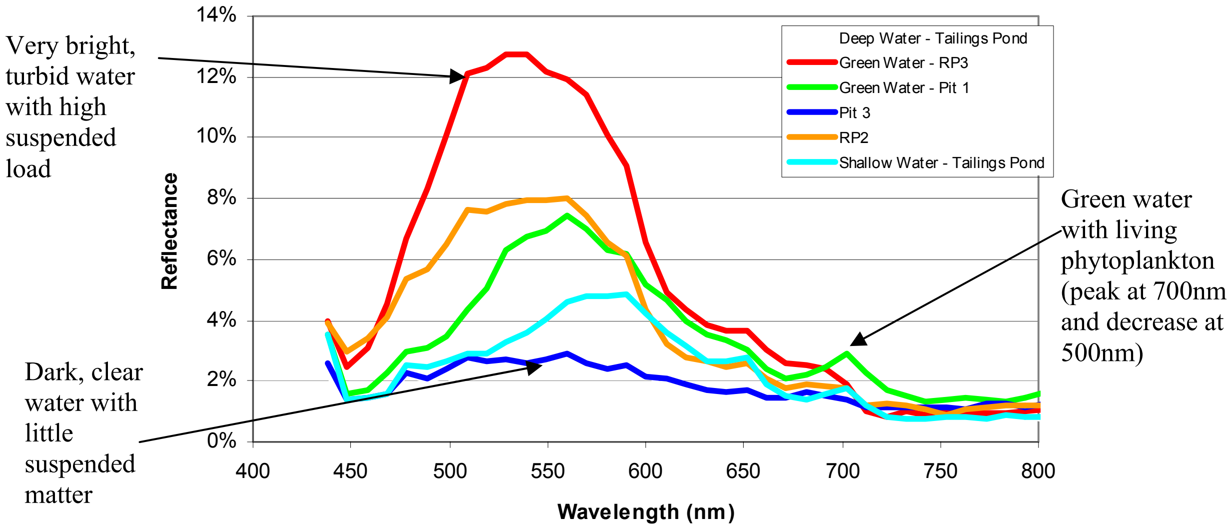

Figure 3. Reflectance spectra from the water bodies on the Ranger mine site, derived from HYPERION imagery.

With more colour information, we can take this analysis further. Figure 3 illustrates data from the hyperspectral sensor HYPERION on the American EO-1 satellite acquired on March 30, 2002. Here, spectra with 36 spectral bands derived from single points in each of the water bodies on the Ranger site are shown to illustrate the richness of the colour information in the water bodies. Water absorbs very strongly at wavelengths above 600 nm and thus all of these spectra converge at low reflectances at longer wavelengths. More or less white (equal at all wavelengths) scattering from suspended particles is responsible for increases in brightness at wavelengths below 600 nm, while absorption from phytoplankton and dissolved organic compounds is responsible for the decrease in reflectance at shortest wavelengths. While not shown here, mathematical optical models of absorption and scattering in water bodies can be used to derive quantitative measures of the suspended and dissolved particles as well as the presence of living phytoplankton (floating microscopic plants). These parameters can be used to infer the use of the water body and the rate at which water moves through it.

For example, in the absence of other information, using only the image data in Figure 2 and the spectral information in Figure 3, one could determine the water management on the site. From the observation that RP3 is the most turbid, one deduces that it is receiving fine particulate material that is still in suspension at the time of imaging. RP2 is less turbid, with less suspended material, suggesting that it is receiving less fine material, or that it receives water from RP3 after much of the fine material has been deposited. Note that the ‘green water’ in Pit 1 and RP2 has nearly the same reflectance at 580nm but differs both above and below that wavelength. That is, relative to RP 2, something in Pit 1 is absorbing near 500nm and scattering near 650nm, with a peak at 700nm. The spectral shape of the difference suggests that Pit 1 contains more living phytoplankton than RP2. This in turn supports the observation that the water in Pit 1 is receiving a fresh supply of plant nutrients, while RP2 is more stagnant.

SPECTRAL EXAMINATION OF THE SOILS, ROCKS AND ORE PILES

The colour of the soils, rocks and ore piles on the site can also be used to make deductions about the materials and interpret activities on the site. As observers of a landscape, we all do this naturally – making comparisons between the colour and texture of surfaces that we look at. In aerial photography, or true colour representations of satellite imagery, we deduce that the material at point A is the same as that point B because it looks the same. While such representations only use 3 colours (RGB), most satellite sensors have at least 4 (e.g. RGB plus near IR) and as many as 220 spectral channels. Using multispectral or hyperspectral classification techniques we can group the pixels in an image according to their spectral differences.

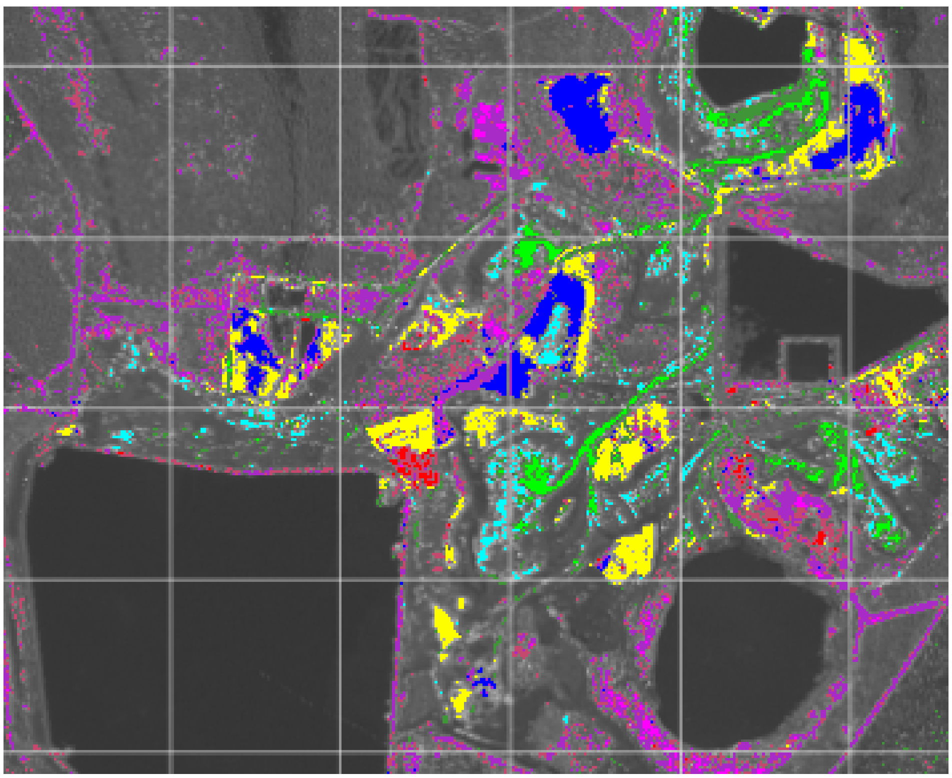

Figure 3. Multispectral classification of the soil, rock and ore piles on Ranger mine, using 4 spectral channels from IKONOS imagery.

Even with the limited number of spectral bands in IKONOS data, it is possible to separate the ore piles into classes that suggest similarities in ore type and in weathering, or where the material is coming from on the site, and perhaps how it is moving. In the 'unsupervised' classification in Figure 3, the unvegetated areas of the mine site are coloured according to their spectral similarity. Since only 4 spectral channels were used, the result is perhaps not that much different than one would have done with visual interpretation of just 3 colours (RGB) – but it does point out similarities that would not be evident using black and white imagery alone.

A drawback of the simple classification technique used in Figure 3 is that the separation partially reflects the brightness of the target. With more spectral channels, we can ignore the brightness of the target (and thus irrelevant factors like slope, aspect and illumination), and use only the spectral or colour information. In Figure 4, we ask "Where did the ore in the circle come from?" or at least "Which piles are similar?" In this analysis, we use hyperspectral information from HYPERION and

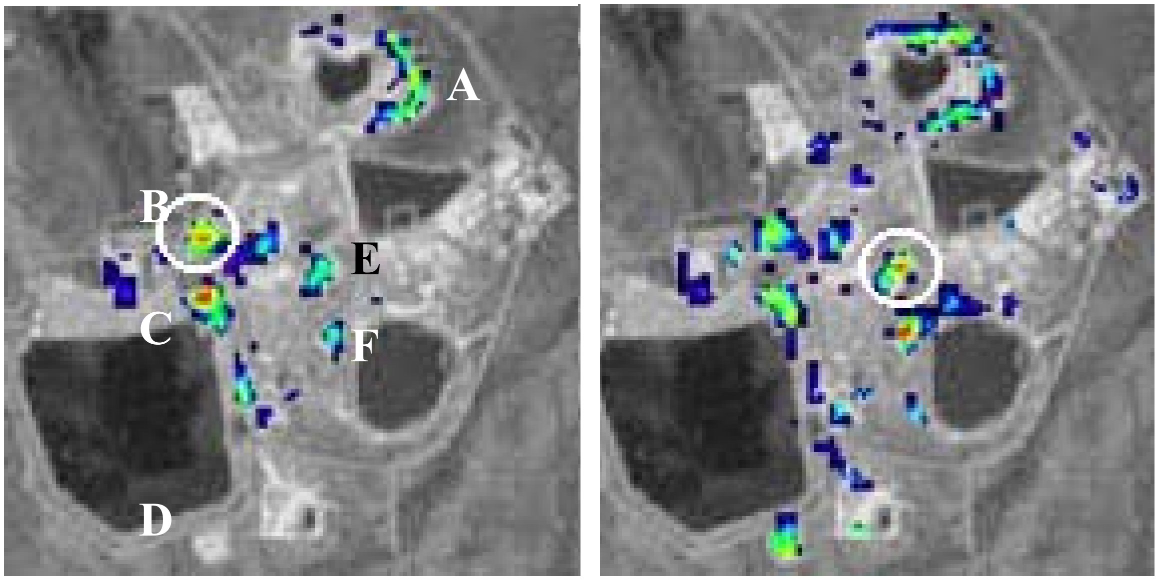

Figure 4. The mapped results of asking "Where does this ore come from?" of a hyperspectral HYPERION image, acquired March 30, 2002. The circled ore pile in the left panel is most similar to a pile at C, and at the active mining area eastern end of Pit 3 [A]. The ore pile circled in the right panel is most similar to that at F and several other locations B, C, D and the north and south sides of Pit 3 [A].

an analysis tool called the 'Spectral Angle Mapper' to compare each image pixel with a 'training' pixel (circled), and colour each one according to its spectral similarity to the training pixel. The spatially averaged result is shown in colour, overlaid on a black and white image of the mine to provide context. In the first case (B at left), three other waste rock piles exhibit decreasing similarity (B = C> A > E and F). In the second case, (E at right) is most similar to a neighbouring pile at F, but also to B, C, D and A. Note that B is most similar to the ore from the area of active mining at the east end of Pit 3 [A], whereas the pile at B is more similar to the rock exposed on the north and south side of Pit 3.

With care and appropriate pre-processing to adjust for atmospheric effects and other differences between sites, these analyses can also be carried out between widely separated target areas, thus providing insight into, for example, movement of materials from a mine to a processing plant.

CONCLUSIONS

The simple examples shown here illustrate the richness of the information contained in the colour of materials, and the utility of multispectral and hyperspectral satellite data for safeguards applications. The water bodies on a mine site are important indicators of the activities taking place, and are difficult to hide. Likewise, the vegetation, buildings, roads, exposed soil, rock and ore piles at a facility can all be spectrally interrogated to determine similarities and differences that may provide considerable insight into operations prior to inspection.

Note that all images in this paper have been grossly re-sampled in order to meet the required 500K file size for publication.

REFERENCES

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