

## Site Characterization of Mine Tailings at the INCO Copper Cliff Tailings Impoundment Area using *casi* Imagery\*

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### ABSTRACT

Hyperspectral imagery from the Compact Airborne Spectrographic Imager (*casi*) in the visible and near infrared was used to characterize mine tailings at the INCO Copper Cliff tailings impoundment area. The objective of the study described in this paper is to evaluate the usefulness of high spatial and spectral resolution data and analysis techniques for characterizing and monitoring such sites. Flight data were acquired in late August 1996 in 72 contiguous 9 nm wide spectral bands from 400 nm to 950 nm along with a detailed ground survey. The ground survey involved a visual characterization of the site and collection of ground truth spectra using a GER 3700 spectrometer operating between 400 nm and 2500 nm. Images were classified using a spectral matching technique. The site is well characterized by this technique and independent ground data support these results.

### 1. INTRODUCTION

The reduction of acidic drainage from mine tailings sites and their environmental restoration is a growing concern for many mine operators. When exposed to air and water, tailings oxidize and produce sulfuric acid which liberates the heavy metals already in great amount in the tailings (University of Missouri, 1997). Because of their high level of contamination in heavy metals and other toxic substances related to mining exploitation, it is difficult to revegetate such sites. One of the techniques used to revegetate mine tailings is to spread lime to reduce the level of acidity and thus allow certain tolerant species to initiate the process of revegetation. The success of mine tailings revegetation greatly depends on the quality of monitoring the tailings in order to ensure an efficient process on a long term basis.

The objective of the study was to evaluate the usefulness of high spatial and spectral resolution data and their analysis techniques for characterizing and monitoring mine tailings sites. Hyperspectral remote sensing offers data from sophisticated sensors that provide the

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level of spectral and spatial detail necessary to discriminate different types of surfaces such as vegetated areas, limed areas, exposed tailings, and any mixture of these surfaces.

Hyperspectral imagery from the Compact Airborne Spectrographic Imager (*casi*) in the visible and near infrared was used to characterize the mine tailings site at the INCO Copper Cliff tailings impoundment area in Sudbury. This site was chosen because of its well initiated revegetation program by INCO company (INCO Ltd, 1997) and earlier work conducted by Singhroy (1995a, 1995b, 1997). It contains a large variety of mine tailings, different levels of vegetation regrowth, as well as limed and non-limed areas. The image was classified using spectral matching.

## **2. METHODOLOGY**

### Ground survey

The ground survey included a visual characterization of the site and the collection of field spectra using a GER 3700 spectrometer operating between 400 nm and 2500 nm. Spectra of oxidized and non-oxidized (fresh) mine tailings of different composition (pyrite, pyrrhotite), green and dry vegetation, lime, straw, and rock were collected in August 1996. These spectra as well as the visual assessment were used to validate the results of the image classification.

### *casi* imagery

High spatial and spectral resolution *casi* data were acquired in the visible and near infrared and calibrated to radiance. Flight data were acquired on August 24, 1996 in 72 contiguous 9 nm wide spectral bands covering a wavelength range from 400 nm to 950 nm. The radiance data were multiplied by a factor of 1000 to achieve digital counts. Prior to the data analysis, a roll correction was applied using the navigation data to remove first-order geometric effects due to aircraft motion.

### Preclassification processing of image data

In order to reduce the number of bands and thus the redundancy in the data, a Minimum Noise Fraction Transformation (MNFT) was performed on the data cube. This transformation gives similar results as Principal Components but, besides reducing the amount of data, it also reduces their noise content (Research Systems Inc., 1997). For the Copper Cliff mine tailings site, the first four components as well as the 6th and 7th MNFT features were kept for classification purposes. The 5th MNFT feature displays strong noise and, therefore, was not used in the classification.

### Classification using the Spectral Angle Mapper (SAM)

SAM is a spectral matching technique that classifies spectra on a pixel basis according to its resemblance to a reference or end-member spectrum. An end-member spectrum represents a pure pixel, which is composed of a single material (e.g. lime) rather than a mixture of two or more materials (e.g. lime, soil, and grass) (Boardman, 1995). Its spectrum represents a pure material and can be used as a reference spectrum for that specific material. Most pixels in an image are a mixture of many end-members. The SAM method uses an algorithm that calculates the spectral angle between the reference spectrum and the spectrum to be classified. It projects the spectra as vectors in space with a dimension that is equal to the number of bands (Research Systems Inc., 1997). Figure 1 shows a simplified two dimensional representation of the SAM method where two materials are compared using two spectral bands. SAM considers the direction of the vectors and not their length. Since the length of the vectors is related to the degree of illumination, SAM is not sensitive to illumination since only the direction of the vectors (colour) is taken into account when calculating the spectral angle. The resulting product of SAM classification is a series of angle images, one for each end-member, where each pixel is assigned an angle value. The smaller the angle, the more similar is the pixel spectrum to the end-member spectrum.

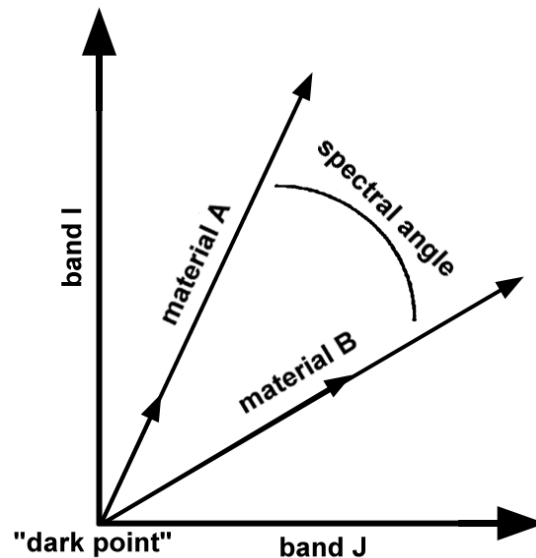


Figure 1. Two-dimensional example of the Spectral Angle Mapper (SAM)  
(Research Systems Inc., 1997)

#### End-member collection

End-member spectra were collected from the image data using the purest pixel determined by the Pixel Purity Index (PPI) (Research Systems Inc., 1997). Three end-members were chosen for the classification: mine tailings, lined areas, and vegetation. The grass and trees were incorporated into the same class (vegetation).

### **3. RESULTS AND DISCUSSION**

#### Colour composites and image spectra

Figure 2 shows a colour composite of the *casi* image acquired over the Copper Cliff mine tailings. The bands displayed are 737 nm in red, 676 nm in green, and 540 nm in blue. The end-members are identified in the image and are illustrated with a ground-level image.

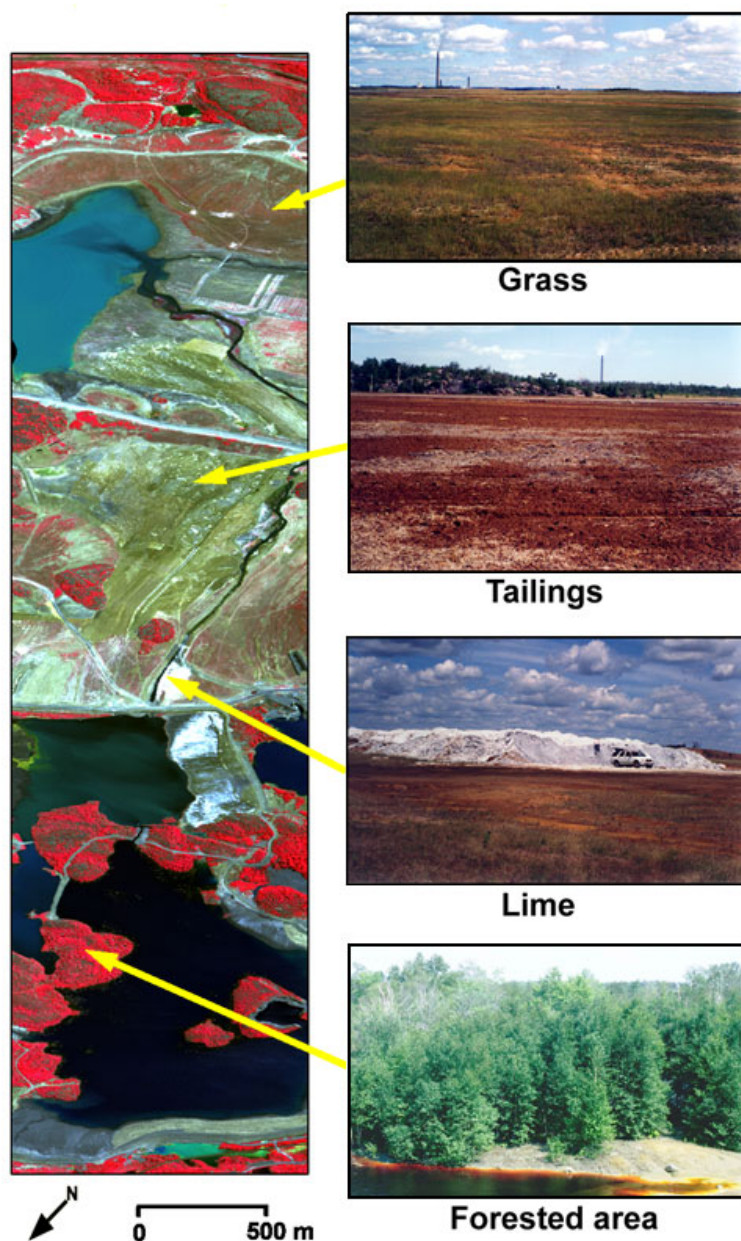


Figure 2. Colour composite (*casi* bands 737nm, 676 nm, 540 nm) showing the three end-members. Note that in the analysis, grass and forested area form one end-member (vegetation).

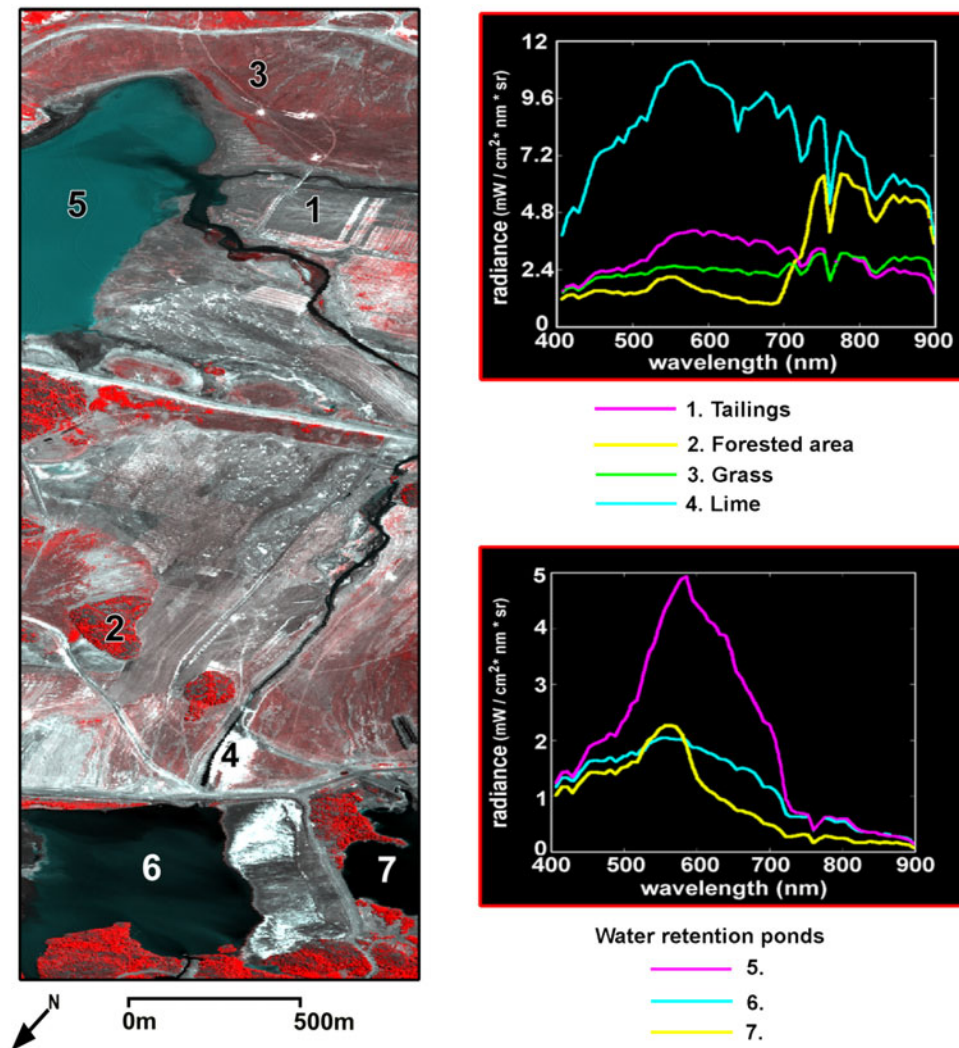


Figure 3. Colour composite (*casi* bands 737 nm, 684 nm, 684 nm) and spectra extracted from the *casi* image.

Figure 3 displays bands 737 nm, 684 nm and 684 nm in red, green, and blue, respectively. This colour composite facilitates the visual discrimination between vegetation (red), lime (white) and tailings (gray). Spectra of the three end-members were extracted from the image data (upper graph). The spectra were extracted from the tailings, forested area and grass (same end-member), and lime. Note the similar shape of the tailings and the grass spectra. As shown in the grass picture in Figure 2, the grass areas are composed of dry and green grass with patches of tailings which can explain their resemblance. The lime spectrum appears very bright in all wavelengths. The lower graphic shows the spectra of the three water ponds included in the image. Their different shapes and amplitudes indicate that contiguous spectra, as provided with hyperspectral data, allow a good discrimination between different water composition.

## SAM classification results

The images in Figure 4 display the similarity of each pixel spectra to the given end-member spectra. They should be compared to the images of Figures 2 and 3. Pixel values represent the spectral angle in radians measured from the end-member spectra. The lowest angle values represent the most similar pixel spectra to the end-member spectra and are displayed in red. The highest angle values represent the least similar pixel spectra to the end-member and are displayed in black. Any angle values in between are allocated a colour displayed in the colour scale as shown in Figure 4.

Figure 4 shows the mine tailings, lime and vegetation end-member images. Because no end-member was collected for water, it is normal that this class is not part of the results. The water bodies appear black in the three displayed end-member images. However, the three water ponds labeled as A appear as light blue in the tailings end-member image and black in the lime and vegetation images indicating that they relate slightly to mine tailings in their composition.

There is a pattern of two rectangular polygons that emerge in the centre part of the images (B) of the tailings and vegetation end-members. This pattern is not present in the lime end-member image but some lime is present in some parts of the area. It represents an area of seedling, partly limed, containing a very small amount of grass (light blue in vegetation image).

The C label shows a limed area where grass grows in different concentration over the lime. Note that this area appears black in the tailings end-member image indicating that the tailings surface is completely covered by lime and vegetation. The places where the vegetation end-member image displays a red colour (high amount of vegetation) appear black in the lime end-member image. The ground survey indicates that the amount of vegetation on these patches is high enough to cover the entire limed surface, thus showing a certain level of success in the revegetation process. The same thing is happening to a lesser extent in the D and E areas.

The area labeled as F shows a grass area. Compared to tree areas (G), grass areas do not cover as much ground as forested areas and are composed of dry and green grass so that the amount of green vegetation present in the pixels of these areas is less than in pixels of the forested areas. Thus, treed areas appear red while grass areas range from light blue to yellow and occasionally red as on the C area.

The area labeled as H shows an incursion of tailings into the grass area. This patch of tailings is mixed with lime as shown on the tailings and lime end-member images.

High lime content (I) is well expressed by the red colour in the lime end-member image except for the two J areas where the high lime content values are related to dry pyrrhotite tailings. This illustrates how hyperspectral imagery can be used to differentiate tailings surface features over large areas once validated through ground observation.



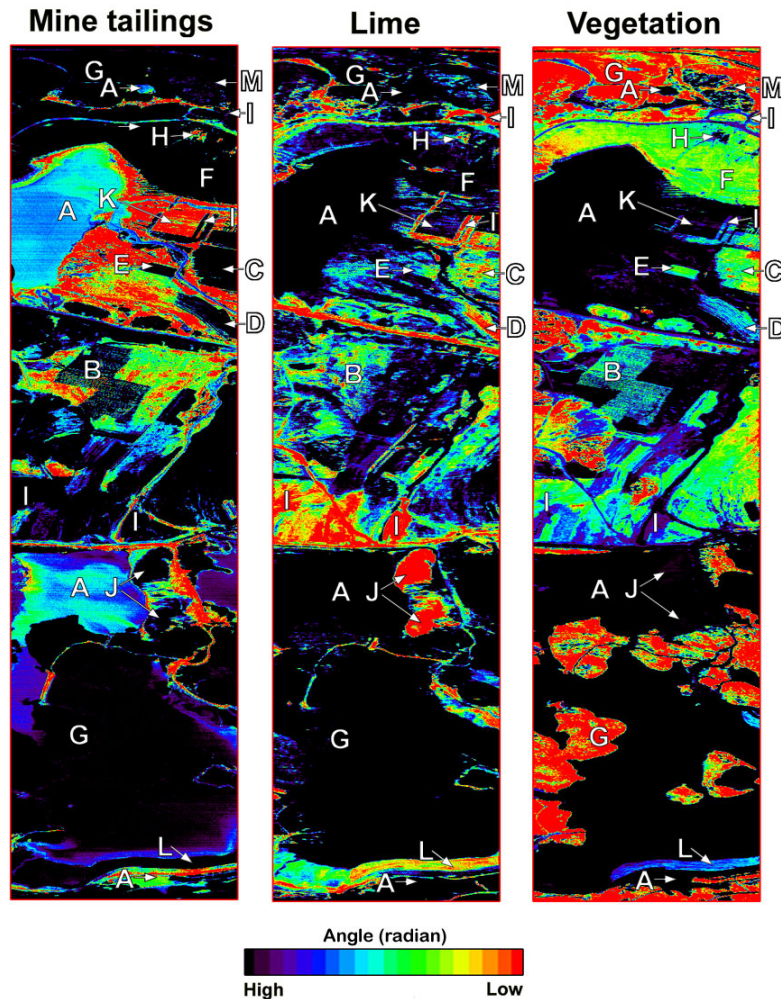


Figure 4. Results of the Spectral Angle Mapper classification.

Note the well defined tailings area surrounded by lime (K). It is also interesting to note that the roads are mainly composed of tailings and lime which shows the possibility that the contamination could be spread through human transportation means.

Vegetation and lime are mixed in area labeled L. This area appears as a band following the shoreline. From the ground observations this area is composed mainly of lime and straw, a material used to produce top soil organic matter and retain soil moisture. Straw is dry organic vegetation matter so it appears blue (low biomass) in the vegetation end-member image. The lime content is fairly high (mainly yellow) and no tailings (black) are seen through it.

The area of rock outcrop labeled as M was not chosen as an end-member. However, some of its surface is slightly covered by lime and vegetation. Since lime was not intentionally spread on this area, it suggests that airborne contamination from area to area can be present. This should be taken into account in future analysis.

## 4. CONCLUSIONS

This study has demonstrated the usefulness of hyperspectral *cas*i data to characterize mine tailings sites. Mine tailings, limed surfaces and vegetation can be well characterized assuming that ground observation is present to validate the results. The results thus far are promising. However, further investigation should be made to address the following issues: (1) results should be compared for end-members extracted from the image and those collected from the ground to see if the results can be improved; (2) other analysis methods such as spectral unmixing and matched filter should be investigated; (3) knowledge of the chemical composition of the water bodies on the Copper Cliff mine tailings site would help in deciding whether hyperspectral remote sensing can be used to estimate the degree of contamination of the water bodies on mine tailings sites as well as any leakage from the tailings areas; (4) end-member images should be calibrated so that different years of monitoring can be compared.

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