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Mine Tailings Characterization Using PROBE Data (Preliminary Results)

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***Abstract*-Acid Mine Drainage (AMD), caused by mine tailings, poses an environmental threat. AMD control is a major challenge facing the mining industries worldwide. An important initial step towards the reclamation of mine tailings sites is to identify the presence of sulphide-rich minerals and their spatial distribution. This study investigated the potential of hyperspectral PROBE data for mine tailings characterization over the Copper Cliff's tailings site in northern Ontario, Canada. The results indicated that PROBE data could provide information on locating oxidation zonations of the tailings. More importantly, it revealed that library mineral spectra could replace the scene-derived endmember spectra to unmix the PROBE image.**

I. INTRODUCTION

Tailings with high sulphide mineral content is a main source of acid mine drainage (AMD). When in contact with oxygen and water, the reactive sulphides oxidize and generate an acidic leachate that can act as an agent carrying heavy metals and dissolved salt, which can lead to environmental contamination. Long-term repetitive site characterization is urgently needed to monitor the evolution and migration of AMD. This will in turn mitigate its damage to the environment.

In earlier studies over the same test site, c*asi* data detected the occurrence of AMD through the association of oxidized tailings with iron oxides. This data can also be used to provide information on separating the oxidation zonations of the tailings through unmixing and spectral matching techniques [1]. However, the spectral coverage of *casi* data (400-900 nm) limited its capability in providing information that is unique to the short-wave infrared region.

This current study investigates the potential of high spatial-resolution hyperspectral PROBE data for detailed mine-tailing characterization and AMD detection. The rationale behind this study is to locate the spatial distribution of the acid-generating material and oxidized tailings, which are likely associated with low pH and heavy metals. The original ore-rock of this tailings site is rich in pyrite and pyrrhotite. With progressive oxidation, pyrite weathers first to jarosite, and then to goethite [2]. The spatial distribution of jarosite and goethite, therefore, provides a means to identify areas associated with low pH and high level of heavy metals. The data used are from three sources: PROBE imagery, X-ray diffraction analysis results of the tailing samples, and mineral spectra from the United States Geological Survey spectral library [3].

II. STUDY SITE

The study site is located at Inco Limited's Copper Cliff tailings complex, Ontario, Canada. It is the largest acid-generating tailings site in Canada, approximately 22.3 km^2, and has resulted from approximately 100 years of mining operations [4]. Through the years, the tailings areas have been partitioned using tailing dams. Some of the older inactive tailings have been subjected to intensive reclamation, typically liming and re-vegetation.

Tailings dumping is now restricted to the active tailings areas (R1 & R2), which are located at the northwest end of the tailings complex (Fig.1). This setting provides an excellent opportunity to study the evolution of tailings over time. Individual partitions within the tailings complex contain a range of mine-tailings compositions with different levels of vegetation re-growth. The major surface-cover types are fresh tailings, oxidized tailings, tailings-retention ponds, rock outcrops and vegetation. The average altitude is 300 m above sea level with an elevation range of 30 m.

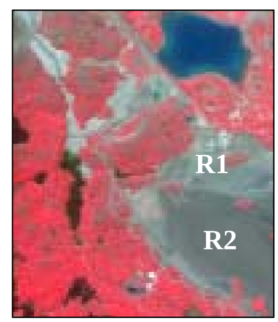

Figure 1. Sub-scene of the PROBE reflectance image. R (767 nm): G (629 nm): B (569 nm).

III. DATA ACQUISITION AND PROCESSING

Hyperspectral PROBE-1 imagery was acquired over the study site on July 8, 1999 from an altitude of 2400 m above ground level. The entire tailings were covered with four flightlines. The data were collected in 128 bands between 400 nm and 2500 nm. The bandwidth at full width of half maximum (FWHM) ranges from 13 nm to 20 nm with a sampling interval of 17 nm. The spatial resolution is 5 m by 5 m, resulting in a swath width of 2.55 km (512 pixels).

Tailings samples were collected at 21 locations through out the study site in summer 1998. The samples cover different tailings areas within the mining complex to include tailings of various mineral compositions and oxidation stages. Each sample was gathered from the top of the tailings surface. Reflectance of the tailings samples was measured in the laboratory using a GER 3700^{tm} spectroradiometer. The measured reflectance covers 400 nm - 2500 nm of the electromagnetic spectrum. X-ray diffraction analysis was also conducted to reveal the mineral composition of these samples.

PROBE radiance data were converted to reflectance using the surface reflectance retrieval procedure in ISDAS (Imaging Spectrometer Data Analysis System) [5]. This procedure, developed by Staenz and Williams [6], is based on a look-up table (LUT) approach to remove atmospheric effects. It considers the wavelength, pixel position, atmospheric water vapour, aerosol optical depth, and terrain elevation for the generation of the LUTs. The MODTRAN4 radiative transfer code was used to create the LUTs. Fig. 1 shows a retrieved PROBE reflectance image of the test site.

IV. Methods

The study is intended to investigate the potential of PROBE data for mine tailing site characterization. This was accomplished through partially constrained unmixing using library spectra as endmembers.

Usually, spectral unmixing is performed using image-derived endmember spectra. However, it is not always easy to find the interested pure materials in the scene. One of the reasons is that almost all tailing pixels are a mixture of minerals. Therefore, it is difficult to match the image-derived spectra with library spectra. Of course one could infer the presence of certain minerals by identifying their unique absorption features. However, this method is not always accurate or exclusive since very often there could be more than one mineral with the same absorption feature at the same wavelength. For instance (CO_3) has absorption feature at 2330 nm. However, both dolomite and calcite contain (CO_3). Therefore, it is more reliable to consider more than one absorption feature in order to detect the presence of the target minerals. Unfortunately, some of the absorption features could be obscured by the presence of other minerals. Therefore, some of the absorption features that are unique to certain minerals could be buried. To avoid this, we used pure mineral spectra from the USGS spectral library as the endmembers to unmix the scene.

A total of 20 endmembers were chosen to perform the unmixing. The selection of these minerals is based on those identified from the ground samples through X-ray diffraction analysis. The site also contains a fair amount of vegetation, straw (for the purpose of dust control and moisture retention), and water bodies. These targets are also included in the endmember list. The 20 endmembers are amphibole, calcite, chlorite, dolomite, goethite, gypsum, hematite, illite, Na-jarosite, K-jarosite, (K, H_3O)-jarosite, maghemite, magnetite, pyrite, pyrrhotite, quartz, forest, dry vegetation, water, and shade.

To accommodate the amplitude difference between the library spectra and the image data caused by different levels of illumination intensity, both the library spectra and the image data were normalized prior to the unmixing. Using the normalized PROBE reflectance data, partially constrained linear spectral unmixing was performed with the aforementioned 20 endmembers.

V. Results And Discussion

The results of the partially constrained linear unmixing were examined in the form of fraction maps. Endmember fraction maps permit the comparison of the variabilities of fractions of the endmembers in a spatial context. The resulting fraction maps discriminate among endmember minerals that are associated with different surface cover types such as fresh tailings, various oxidized tailings, vegetation, and water. Among the 20 endmembers, pyrite, pyrrhotite, gypsum, hematite, dolomite, jarosite, and goethite were of most interest. The spectra of these endmembers are shown in Fig. 2.

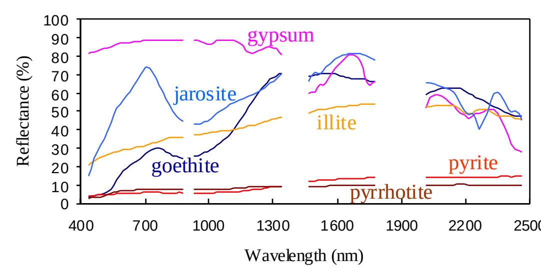

Figure 2. Selected mineral endmember spectra

A visual examination of these endmembers fractions provides some encouraging results (Fig. 3). For instance, based on known knowledge, pyrite is subject to oxidation easily; therefore, it should only appear in fresh/unoxidized tailings. The fraction map of pyrite provides evidence to this hypothesis. Furthermore, based on the ground samples, illite mainly exists in fresh tailings. The fraction map of illite also confirms to this finding (Fig. 3). The distribution of illite is localized and mainly confined to the active fresh tailings area in R2.

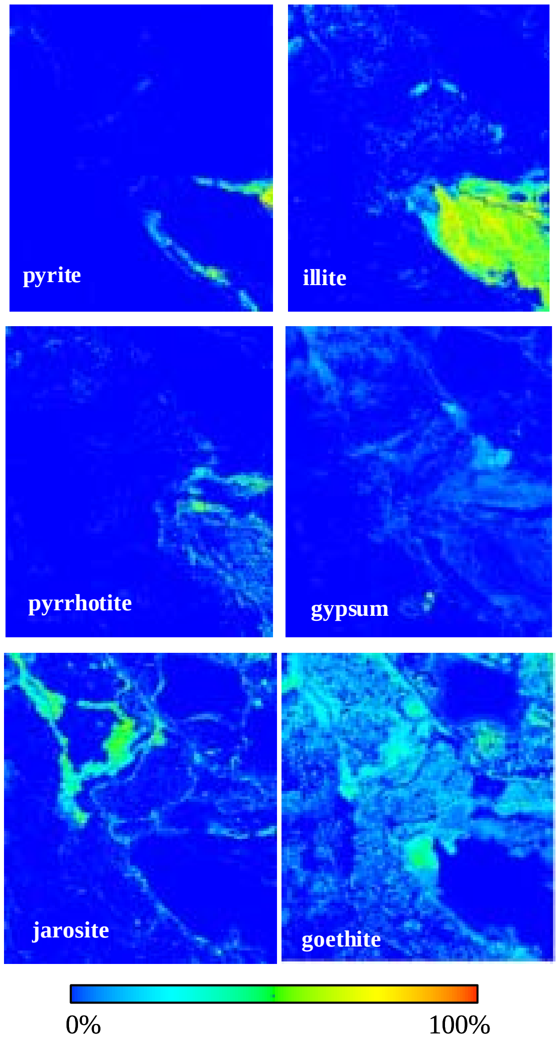

Figure 3. Fraction maps of selected minerals

From Fig. 3 we can see that the area with the highest concentration of pyrrhotite is in agreement with the known pyrrhotite tailings of the site, R1 area (Fig. 1). Gypsum, a type of sulfosalt, resulted from evaporation of the fresh tailings. Its spatial distribution aligns well with the ground survey. It can be found most commonly in area where frequent moisture change occurs. This area is likely linked with flooded plains adjacent to shallow stream and water retention ponds.

Jarosite and goethite are two common products of tailings oxidation, especially iron tailings. Jarosite is associated with the initial stage of the oxidation during which a strong-acid environment is present [2]. It usually coexists with more leachable heavy metals. Goethite, a more stable mineral, is formed in a less-acid environment and is associated with lower concentrations of leachable heavy metals. Fig. 3 reveals that the unstable jarosite appears mainly in areas close to the course of streams and the boundaries of ponds and dry land. These areas have access to both water and oxygen (essential oxidation agents). Therefore, the tailings oxidation process is most likely to occur. These are also the potential source of heavy metal and salt migration routes. The more stable goethite, however, has a much wider spatial spread. It poses less threat towards the environment compared to jarosite.

Overall, this experiment revealed the potential of PROBE data for mine tailing characterization. In addition to providing information on mine tailings extent, they can also distinguish oxidized tailings with different mineral composition. This will in turn provide valuable information when designing proper reclamation procedures.

VI. Conclusions

This study has demonstrated that PROBE-1 data can be used to provide information on locating oxidation zones of the tailings. More importantly, library minerals can be used as input spectra to unmix the image data instead of the scene-derived endmember spectra. This procedure has great value in identifying target minerals in both known and unfamiliar sites.

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