PRELIMINARY INVESTIGATION OF ACID MINE DRAINAGE DETECTION USING *casi* DATA, COPPER CLIFF, ONTARIO, CANADA*

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ABSTRACT

The environmental impact of mine tailings is a nation-wide problem in Canada. Mine tailings affect the environment primarily through acid mine drainage (AMD). AMD contains toxic concentrations of metals and dissolved salts which can contaminate ground and surface water. There is a clear need for monitoring mine-tailing sites in order to ensure that damage to the environment is kept to a minimum. The availability of high spatial resolution hyperspectral airborne imagery, acquired by sensors such as the Compact Airborne Spectrographic Imager (*casi*), has greatly improved the potential for automated mapping of mine tailings. In this paper, we investigate the potential of *casi* data for use in AMD detection. Both constrained and unconstrained linear spectral unmixing was performed on summer 1998 *casi* data acquired over the Copper Cliff tailings area in Ontario, Canada. Preliminary results show that spectral unmixing of *casi* data can provide valuable information on the occurrence of AMD.

1.0 INTRODUCTION

Tailings are the waste products of mineral processing from mining operations. The negative effects of mine tailings include the loss of land-surface values, soil erosion, and air and water pollution. The environmental impact of mine tailings is a nation-wide problem in Canada. Up to 1994, there were 41,000 hectares (410 km^2) of mine tailings in Canada (CANMET, 1994). The increasing demand for metals and the ability to develop lower-grade ores economically in the future could lead to further accumulation of acidic tailings. Tailings from copper (Cu), zinc (Zn), nickel (Ni), gold (Au), and uranium (U) mines contain sulphide minerals. When tailings are in contact with oxygen and water, these sulphide minerals will oxidize and generate acid (Lévesque *et al.*, 1997a; MEND, 1999). Acid-mine drainage (AMD) will dissolve the residue metals in the tailings thus causing ground- and surface-water contamination. These dissolved metals and low pH conditions can have detrimental effects on the health of plants and animals.

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There is a clear need for monitoring mine-tailing sites in order to ensure that damage to the environment is kept to a minimum. Mapping the extent of mine tailings and their change over time is an essential component of mine-tailing monitoring and inventory. Various remote sensing data have been used for this purpose. However, because of the relatively coarse spatial and spectral resolutions of traditional satellite data, it is difficult to identify and map complex surfaces such as mine tailings. The availability of high spatial resolution hyperspectral airborne imagery, acquired by sensors such as the Compact Airborne Spectrographic Imager (*casi*), has greatly improved the potential for automated mapping of mine tailings. In this paper, the use of *casi* data for AMD detection is investigated through a case study at the Inco Copper Cliff mine, Ontario, Canada.

2.0 STUDY SITE

The study site is located at Inco Limited's Copper Cliff tailings area, Ontario, Canada (Figure 1). This site was selected because it has the largest acid-generating tailings in Canada, approximately 5,500 acres (22.3 km^2) (Puro *et al.*, 1995). It contains a range of mine-tailing lithologies with different levels of vegetation regrowth. The major surface-cover types are fresh tailings, oxidized tailings, tailings-retention ponds, lime, and vegetation. This area has been experiencing extensive revegetation activities. To date, 838 hectares of tailings have been limed, fertilized and seeded, and 340 hectares are permanently covered with water in the form of containment ponds (Yearwood, 1998). In addition, a considerable amount of research has been undertaken over this area which provides valuable information on the site (De Vos, 1995; Lévesque *et al.*, 1997a, 1997b, and 1999; McGregor, 1998). Results of these previous studies will assist in image interpretation.

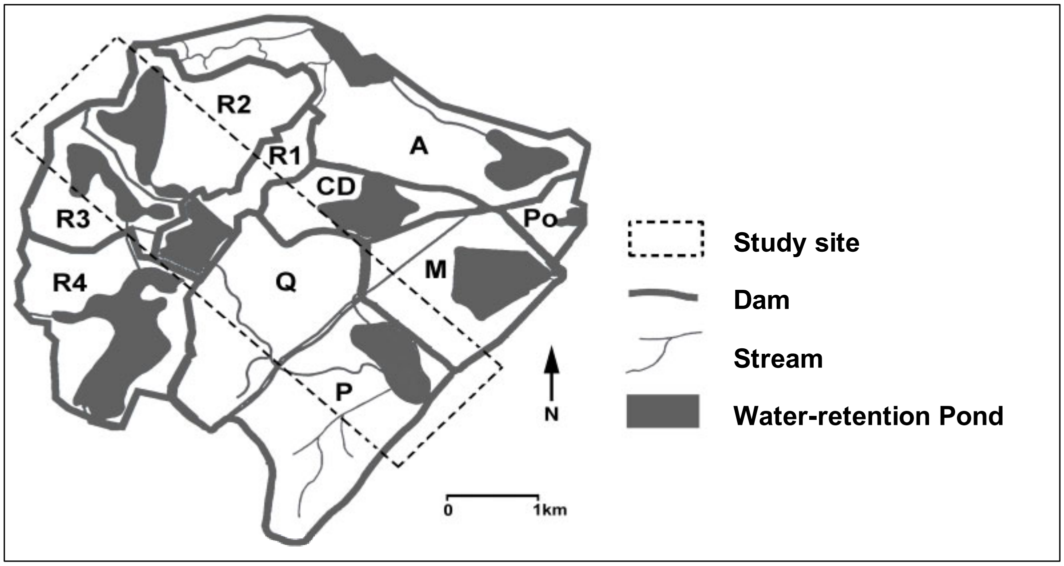


Figure 1. Map of the Study Area (Modified from Puro *et al.*, 1995)

3.0 DATA ACQUISITION AND PREPROCESSING

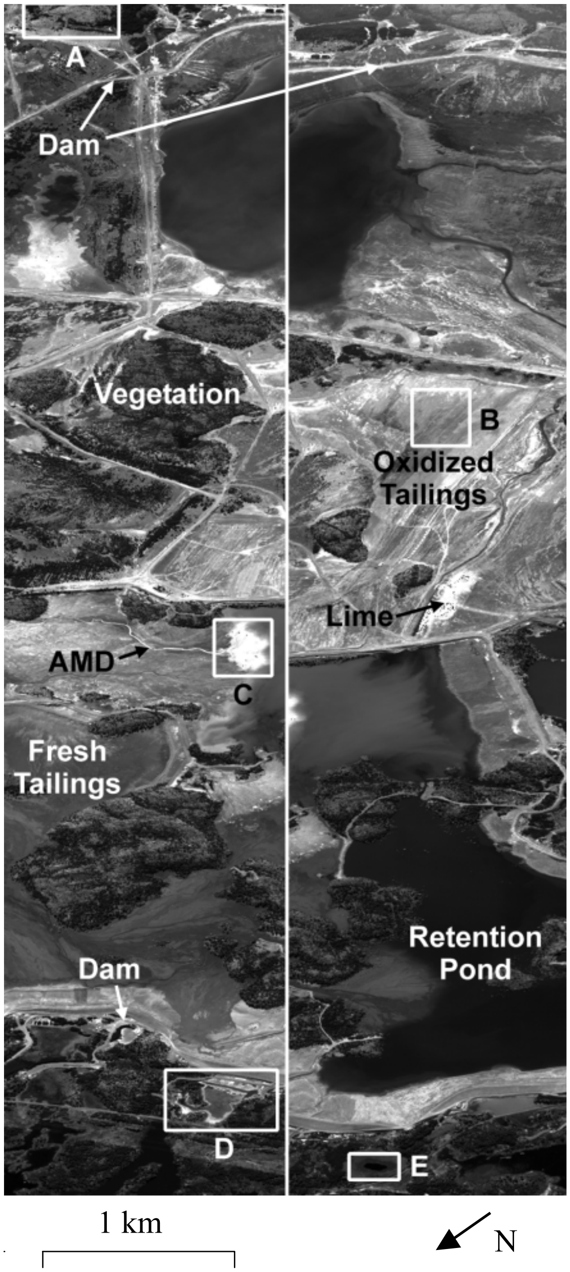
High spatial and spectral resolution *casi* data were acquired in spectral mode over the study area at 14:45 p.m. on August 19, 1998. The sky condition was clear, and the aircraft was flying at 2100 m above sea level (approximately 1800 m above the ground) heading 130 degrees from north. The data cover the visible and near-infrared regions of the electromagnetic spectrum, from 407 to 944 nm, in 72 contiguous bands. The bandwidth at FWHM (full width at half maximum) is 10 nm with a spectral sampling interval of 10 nm. The spatial resolution is 4 m by 4 m, resulting in a swath width of 1.6 km (406 pixels).

Image preprocessing was performed prior to image analysis to convert the *casi* radiance data to reflectance data. The preprocessing steps include roll correction, reflectance retrieval, and post-processing of the data in the spectral domain. In the first step, the *casi* data were corrected for aircraft roll effects by calculating lateral pixel shifts for each line using the navigation data. However, the *casi* data were not corrected for pitch and yaw due to the lack of navigation data. The *casi* radiance data were then converted to reflectance data using the Imaging Spectrometer Data Analysis System's (ISDAS) surface reflectance retrieval procedure (Staenz *et al.*, 1998). This procedure, developed by Staenz and Williams (1997), is based on a look-up table (LUT) approach to remove atmospheric effects from the *casi* data. It takes into account the wavelength, pixel position, atmospheric water vapour, aerosol optical depth, and terrain elevation for the generation of the LUT. MODTRAN3 radiative transfer (RT) code was used to create the LUT. The parameters used to run the MODTRAN3 RT code are listed in Table 1.

Table 1. Input Parameters for the MODTRAN3 Run

Parameters	**Input**
Standard atmospheric model	Mid-latitude summer
Aerosol model	Continental (rural)
Date of overflight	August 19, 1998
Solar zenith angle	50.6 °
Solar azimuth angle	116.9 °
Sensor zenith angle	Variable
Sensor azimuth angle	Variable
Sensor altitude above sea level	2000 m
Platform heading	130°
Terrain elevation	300 m
Water-vapour content	1.2 g/cm^2
Horizontal visibility	50 km

Post-processing was then performed on the retrieved reflectance data using spectrally flat targets to remove artifacts due to calibration and atmospheric modeling (Staenz *et al.*, 1998). Subscenes from two adjacent flightlines (6 and 7) of the *casi* surface reflectance images are shown in Figure 2. The areas labeled will be reviewed in detail in Section 5.0 Results and Discussion.



Flightline 7 Flightline 6

Figure 2. *casi* Reflectance Images of the Study Site (band 35 centered at wavelength 661 nm)

4.0 METHODS

The study is intended to investigate the potential of *casi* data for detecting AMD. This issue is addressed by comparing the fraction maps with the ground survey results.

Spectral unmixing was performed on the sub-scenes (flightlines 6 and 7) of the *cas*i reflectance data in ISDAS. Both constrained and unconstrained linear-unmixing algorithms were applied. Linear unmixing is based on the assumption that the reflectance of a given target is the additive combination of the reflectance of each of the target components (endmembers) (Mustard and Pieters, 1987; Ben-Dor and Kruse 1995; Tompkins *et al.*, 1997). The unconstrained unmixing is abundance-free, and it can take on any value. Therefore, it represents the relative abundance of endmembers. The constrained unmixing provides the absolute abundance (Boardman, 1990).

Five endmembers were chosen for unmixing: water1, water2, oxidized tailings, lime, and vegetation. These endmember spectra were selected from the *casi* reflectance data. A principal component transformation was then conducted on all 72 bands of the *casi* reflectance data. The first three principal components (PCs) account for 98.8% of the total scene variance. These three PCs were used for selecting the endmembers. Endmembers are located at the extremities of the clouds of scatterplots using two of the PCs (Boardman, 1995; Lévesque *et al.*, 1999).

The locations of the five endmembers are shown in Figure 3. The spectra of the corresponding endmembers extracted from the *cas*i data are shown in Figure 4.

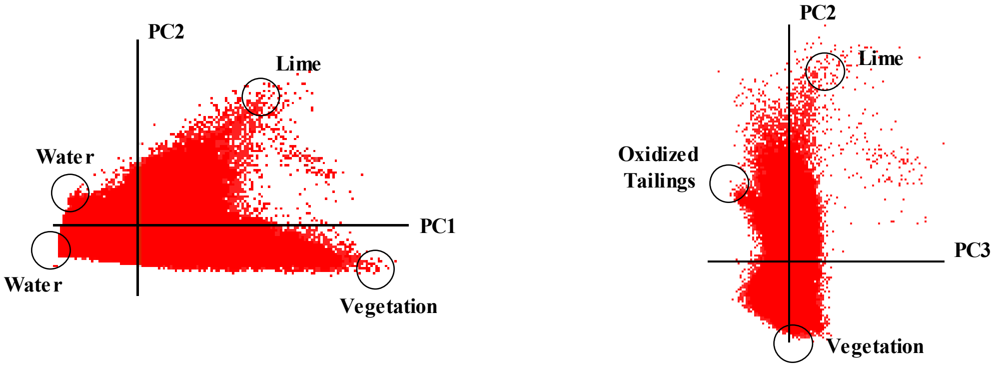


Figure 3. The Location of Endmembers on Scatter Plots of PC1 versus PC2 (left) and PC2 versus PC3 (right)

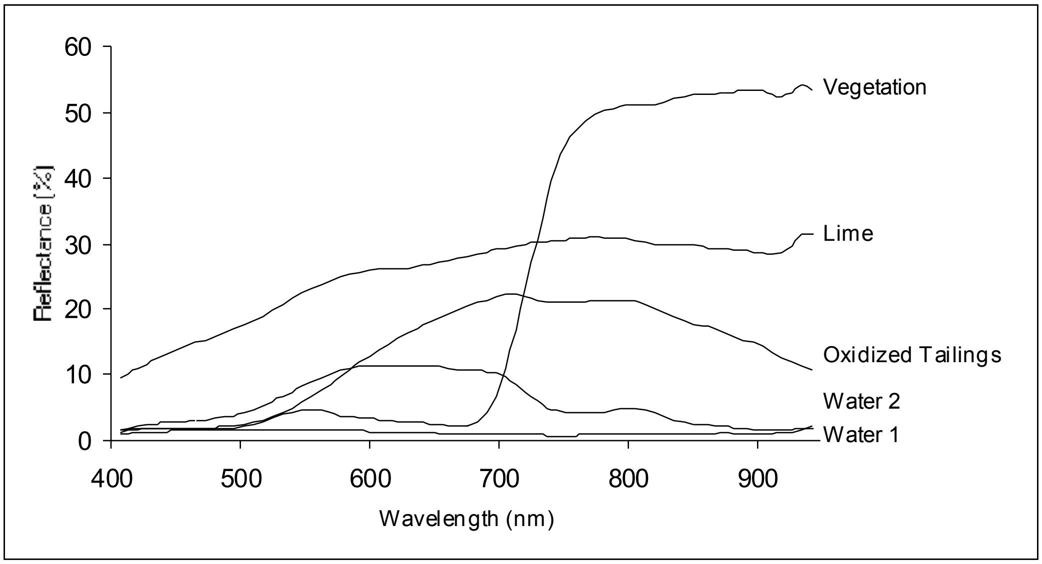


Figure 4. Endmember Spectra Derived from the *cas*i Imagery

5.0 RESULTS AND DISCUSSION

A fraction map for each of the endmembers was generated. Results derived from the constrained and unconstrained linear unmixing were compared visually. Overall, the constrained model produced more realistic fraction maps based on a comparison with ground inspections. More detailed verification will be conducted in the future. Among these maps, the ones showing oxidized-tailing fractions are of most interest; they are displayed in Figure 5. The fraction maps have been enhanced using linear contrast stretch for better visualization. Bright tones represent high fractions, and dark tones represent low fractions. Five areas labeled A, B, C, D, and E in Figure 5 (see also Figure 2) will be discussed in detail. These areas represent typical portions of the tailings and their surroundings.

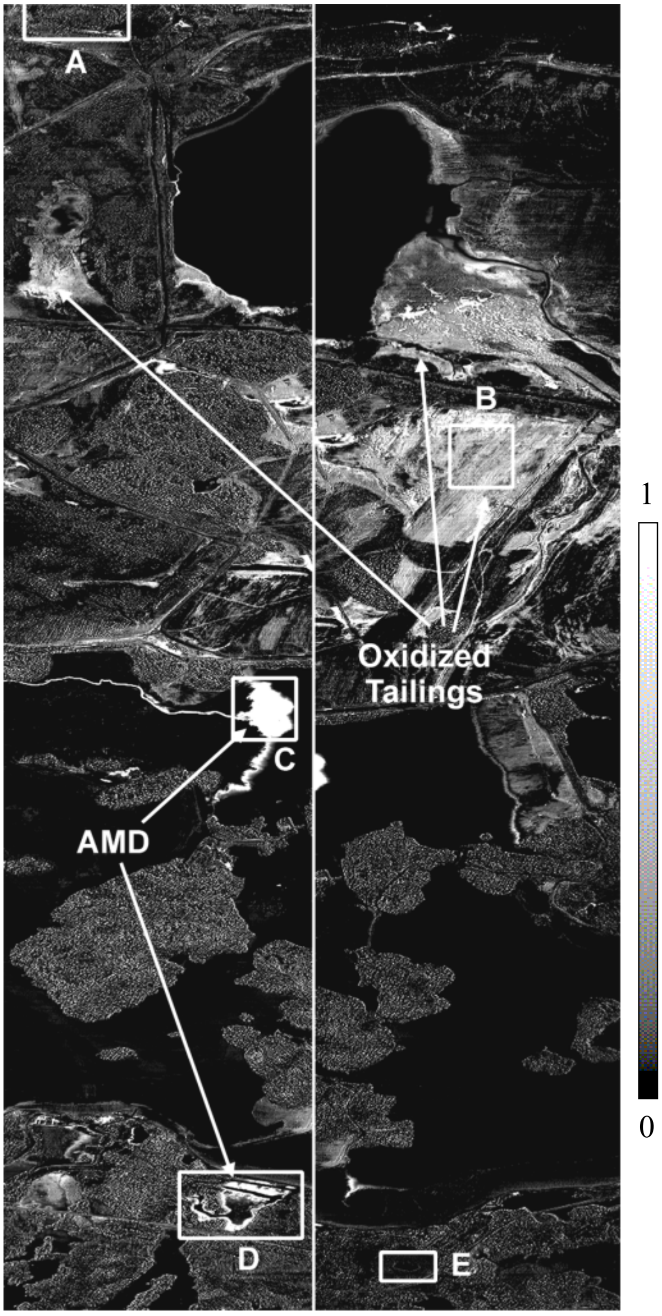


Figure 5. Oxidized Tailing (AMD) Fraction Map

Area A represents a rock outcrop with some vegetation cover. It is located beyond the tailings confinement area, southeast of the P tailings (Figure 1). On the map in Figure 5, the fractions are shown in mottled grey tones, with values between 0.0 and 0.2. They reveal the existence of oxidized tailings in this area. Since the prevailing wind in the area is from the northwest, the wind carries dust from the bare tailings and deposits it on the surface of the rock outcrop.

The bare oxidized tailings (Area B) are also well-defined. These areas have been limed, with no vegetation cover. In the fraction maps, they show as light tone with smooth texture.

Area C represents an extreme of AMD causing the tailings to appear in a rusty colour. It displays in solid bright tones in Figure 5 with fraction values of 0.7 to 1.0.

Area D is a tailings water-collection pond, located northwest to the dam that confines R2 and R3 tailings (Figure 1). It is also shown as bright tones due to its association with tailings water. However, its fractional values vary between 0.3 and 0.5, lower than area C.

Area E is a native water-body close to the R3 dam. There is no sign of AMD contamination or leaching from underneath the dam. Accordingly, the fractional values are close to zero. However, we do see some mottled grey tones in its neighborhood. This is very likely caused by airborne pollution.

6.0 CONCLUSIONS

This preliminary investigation has revealed that *casi* data can be used to detect acid mine drainage. It is a common belief that image data covering only the visible and near-infrared wavelengths are not capable of detecting mineral composition. This is because of the strong absorption features of minerals occurring in the shortwave-infrared region of the electromagnetic spectrum. However, due to the association of oxidized tailings with iron oxides, the occurrence of AMD can be inferred using iron oxide as an indicator. Iron oxides are featured as various shades of yellow, red, and brown colours in rocks, soils, and water (Schwertmann and Cornell, 1991). They can be identified using the visible and near-infrared portions of the spectrum as covered by the *casi* data used for this investigation (Kruse *et al.*, 1991). This study shows that *casi* can be used to recognize qualitatively the occurrence of AMD. For a future study, we will look at the relationship between oxidized tailings (AMD) and the *casi* response in a quantitative manner.

The results of this study will assist mining companies in monitoring the migration of AMD. By identifying possible affected sites, a more detailed survey can be conducted targeting these key areas in order to reduce time and cost. Accordingly, proper control can be applied to mitigate the negative impact of mine tailings on the surrounding environment.

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