Integrating LiDAR Altimetry Data With Hyperspectral Data for Monitoring Mine Wastes.

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Abstract
In this paper we investigate the application of integrated hyperspectral and LiDAR data for the purpose of detecting and monitoring acid leachate around piles of waste rock from sulphide ores. The hyperspectral data provide spectral information permitting the identification of specific minerals in the target area while the LiDAR data provide accurate topographic information to create a digital elevation model. When integrated, the datasets can show the effects of terrain on the processes involved in the drainage of acid leachate. The study site is located near Sudbury, Ontario, Canada.

Introduction

Wastes from mining and smelting of sulphide ores can be an environmental hazard if the acidic leachate produced by surface oxidation seeps into the surrounding watershed. Enhanced concentration of heavy metals present in the leachate can also be detrimental to plants and animals in the affected areas. Many studies have examined procedures to mitigate these hazards (Canada Centre for Mineral and Energy Technology, 2001). However, constant monitoring is required in order to determine the effectiveness of these measures and to ensure the continuity of mitigation over time. Traditionally, monitoring has employed ground-based methods. Although highly effective, this approach provides very restricted spatial coverage. To cover larger areas, remote sensing imagery has been used. In particular, imaging spectroscopy or hyperspectral imaging is potentially useful as it allows identification of individual minerals based on their spectra and has been used in several studies (e.g. Shang *et al.*, 2000, 2002; Chevrel *et al.,* 2001; Swayze *et al.*, 2000).

Mines produce two distinct types of waste material: tailings, which consist primarily of sand-sized particles produced after rock crushing and mineral extraction, and waste rock comprised of boulders extracted from the mine that are considered to have no economic value. The waste rock is commonly stacked in piles on the surface. In this paper, the integration of hyperspectral data with a digital elevation model (DEM) derived from a LiDAR altimetry survey for monitoring leachate generation adjacent to sulphide-rich waste rock piles is investigated.

The Study Area

The study area is located near Sudbury, Ontario, Canada (Figure 1, inset). It includes the Frood-Stobie Mine in the east and the Murray Mine in the west. Both mines have been in operation since the 1880s. The Murray Mine is no longer active while the Frood-Stobie is still a productive mine. Nickel and copper ores are extracted from sulphide ores. Initial extraction was from open pits, but at Frood-Stobie current operations are underground only (Inco Ltd., 2001).

The Frood-Stobie area contains several open pits and sink holes. The largest open pit is located to the west of the mine buildings. Waste material from this pit was deposited on the rock pile to the east, which was subsequently used as an airstrip. The features of primary interest in this study are shown in Figure 1.

1. The Frood-Stobie Airstrip which contains 7.7 million cubic metres of waste rock excavated from the mining operations (Inco Ltd., 2001)
2. The Emergency Tailings pond, which contains approximately 2.2

million tons of tailings. These tailings were generated from the Frood-Stobie Mill which operated from 1967 - 1991. The pond is not currently being used but is available for emergency storage (Inco Ltd., 2001).

The Murray Mine area has several rock piles and an open pit. The pit has been flooded and is now a large lake at the site.

Data

Remote Sensing - Hyperspectral Imagery

Imaging spectroscopy or hyperspectral imaging records the spectral response of the Earth's surface to solar radiation. Spectral response is a function of molecular vibrations of electrons and chemical bonds in a molecule. When a molecule absorbs radiation at particular frequencies, this appears as inverted peaks or minima in the electromagnetic spectrum. The locations of these minima are unique for individual minerals. The spectra can therefore be used to identify these minerals. Minerals such as jarosite, goethite and hematite are produced during the oxidation of sulphide minerals. As the minerals are precipitated in environments of different acidity, their presence is an indication of the acidity of that environment. Individual endmembers, which contribute to the spectrum of each pixel are determined. In this investigation, linear spectral unmixing was used to separate the endmembers identified in the image and attempts were made to match these to known spectra from the United States Geological Survey (USGS) spectral library.

Two sets of hyperspectral data have been collected over the study area. Airborne hyperspectral data were acquired in September 1998 by Earth Search Sciences Inc., using a PROBE-1 sensor. This sensor records data in 128 bands in the 400 to 2500 nm range. The bands have a nominal bandwidth of 11-22 nm. The spatial resolution of these data is 5 m.

In 2001, airborne hyperspectral data were acquired using the TRWIS III sensor. The sensor records data in 384 bands with bandwidths of 5-10 nm. Data were collected in the 400 to 2450 nm range at a spatial resolution of 4 m.

LiDAR

LiDAR is an acronym for Light Distance and Ranging. Airborne LiDAR altimetry is the technique of obtaining elevation data from an aircraft. A laser pulse is transmitted to the ground target area; the pulse is reflected and returned to the receiver. The receiver measures the travel time of the pulse and the distance traveled is determined. An on-board Global Positioning System (GPS) and an Inertial Navigation Systems (INS) determine the position and orientation of the laser pulses. By combining the information on the geometry of the laser instrument, the GPS and INS data, the x, y and z ground coordinates can be calculated for each laser pulse. From these values, a digital elevation model can be produced. In open, moderate-relief terrain, data accuracy is typically 15-25 cm in the vertical and 50 to 75 cm in the horizontal (Mosaic Mapping Systems Inc., 2001). The ground spacing for the data used in this study is 2 m.

In October, 2001, airborne LiDAR altimetry data were collected for the study site at the Frood-Stobie Mine. Mosaic Mapping Systems Inc., based in Ottawa, Ontario, surveyed an area of 25 sq. km. The data collected were used to create a 2-m grid of x, y and z values. A digital elevation model was then produced.

Data Processing and Analysis

Hyperspectral data were processed at the Canada Centre for Remote Sensing (CCRS) in Ottawa using ISDAS (Imaging Spectrometer Data Analysis System), a software system developed by CCRS (Staenz *et al.,* 1998). Additional processing was done using ENVI image analysis software developed by Research Systems Inc.

The LiDAR data were pre-processed by Mosaic Mapping Systems Inc. using the program Terrascan developed by 3D Laser Mapping Ltd. Further processing was undertaken using ENVI and ArcView 8.1 geographic information system (GIS) software from Environmental Systems Research Inc. (ESRI).

Results

Integrating the spectral response with topography serves to reveal the influence of terrain on surficial processes. Figure 2 shows a standard false-colour composite created from the PROBE-1 data, which has been draped over the LiDAR DEM at the Frood site (Area 1 in Fig 1). Preliminary analysis of the TRWIS III data over the Murray Mine site is shown in Figure 3. This image shows a map of the limonite endmember draped over the LiDAR DEM of the site (Area 2 in Figure 1). The image shows that the limonite concentrations are confined to the areas of the waste dumps and the mining property in general. The pixels identified as pure limonite (red pixels) are located primarily along the mine roads in the image. This phenomenon may result from the roads being an open, relatively flat environment from which the sensor is able to obtain a direct return. The slopes of the waste dumps, however, do not present a full surface to the sensor and the radiance return may be diminished. The large waste dump on the western side of this image, and north of the mine road shows a high concentration of limonite along the perimeter of the top of the pile, as well as on the southern slopes. The greater concentration along the slope surfaces may be attributed to surface flow of drainage over a larger surface area as compared to the percolation effect on the top of the pile. It may also be a consequence of different chemical processes at the top and along the slopes of the pile. The concentration of limonite is not apparent on the northern slopes of this rock pile and the cause has not been ascertained at this time. However, limonite is also evident on the eastern rock pile and in several other areas of the mine site.

Combining the spectral and topographic data may also permit monitoring of many other effects, for example:

1. The relationships between mineral concentrations and surface drainage.
2. Slope information, which may impact the distribution and drainage of deleterious materials on the surface.
3. Potential locations for wind-blown materials to settle.
4. The locations of vegetation in relationship to the terrain.
5. Slope stability for the rock piles.
6. Slope stability for revegetation efforts.
7. Investigation of basins and valleys, which may influence surface flow of acid drainage.
8. Structural information such as the location of faults.

Conclusions

This preliminary study shows that the integration of a digital elevation model derived from LiDAR data with hyperspectral data can be useful in investigating acid leachate from mine waste rock piles. The effects of topography, slope and aspect can be examined and, combined with climatic and hydrogeological conditions, information on the weathering and drainage of acidic wastes may be obtained. This technique could provide useful methods for monitoring and mitigation of acid leachate from rock piles and at the mine site in general. This study will continue with additional detailed processing of the LiDAR and hyperspectral data over active and abandoned waste sites in the Sudbury area.

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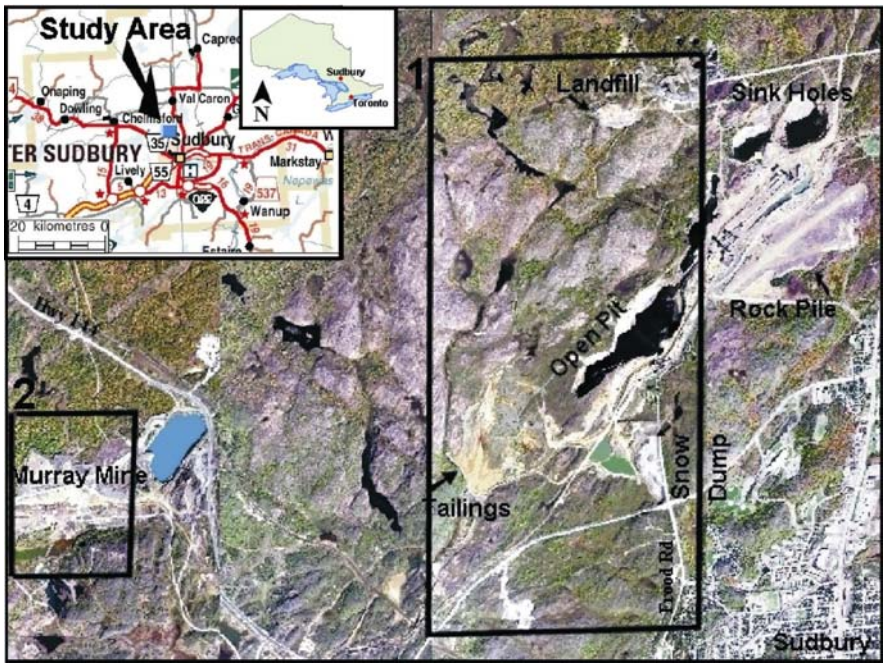

Figure 1: A natural colour composite of the Frood-Stobie Mine area derived from PROBE-1 hyperspectral data. Spatial resolution is 5 m. The inset shows the location of the study area.

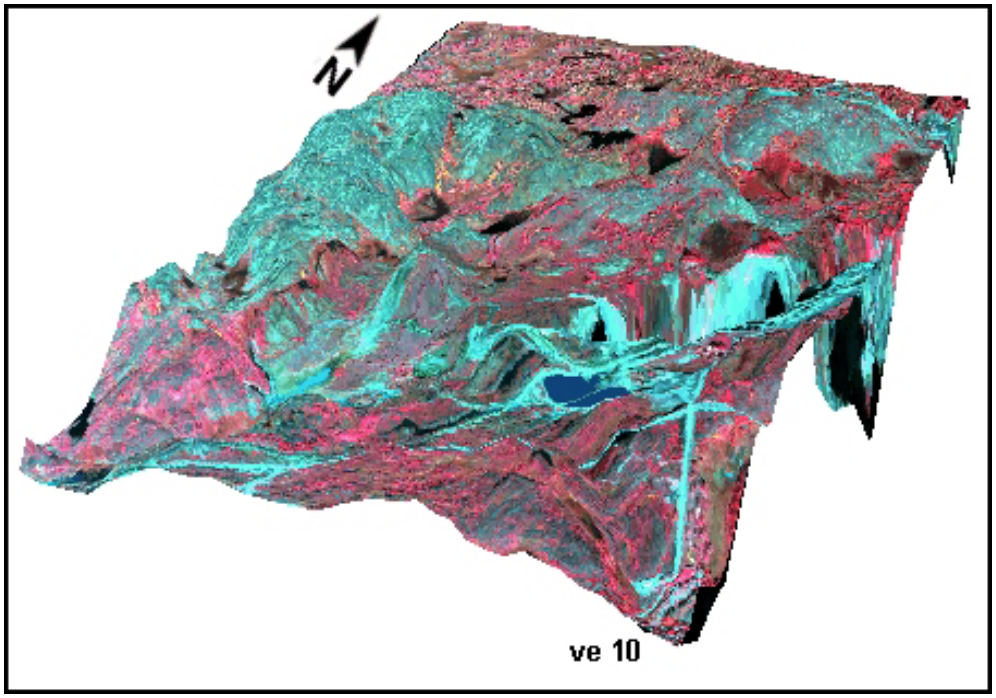

Figure 2: A standard false-colour composite of the PROBE-1 hyperspectral data draped over the DEM of the Frood-Stobie site. Vertical exaggeration is 10X.

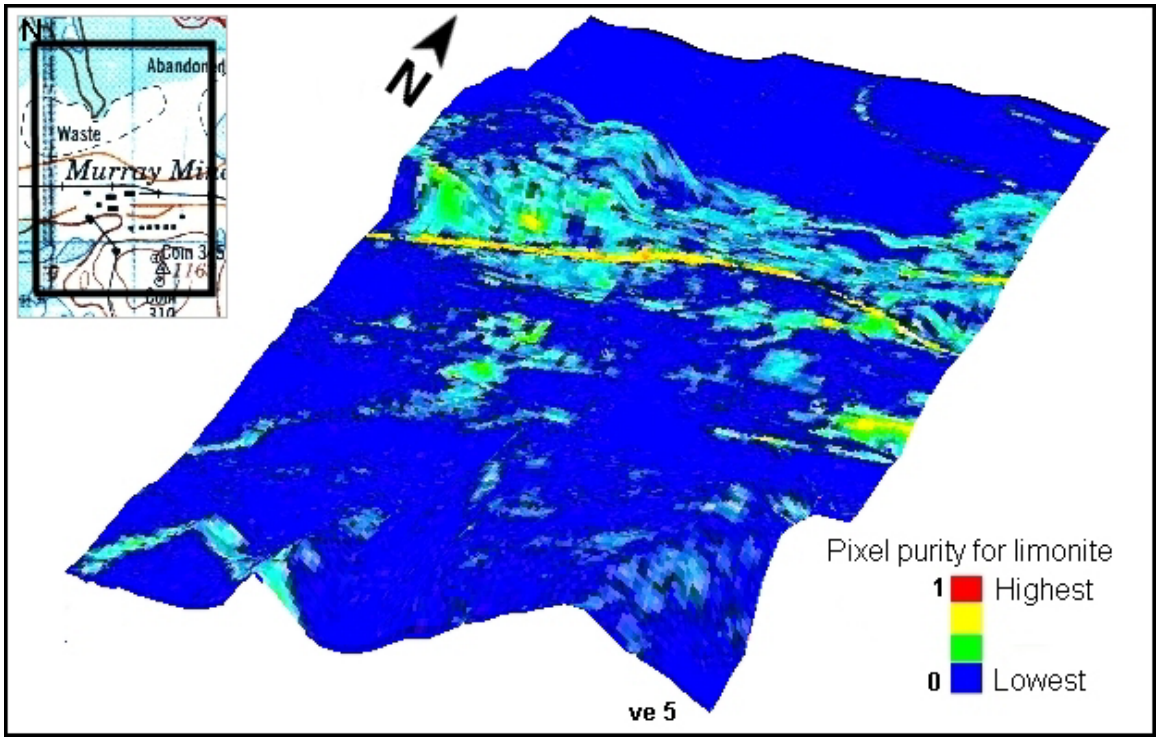

Figure 3: The limonite endmember draped over a DEM of the Murray Mine area. Vertical exaggeration is 5X.