Emerging technologies and the future of geotechnical instrumentation

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ABSTRACT: This paper discusses the results of two recent case studies in which high-tech prototype instruments were used. The first case study describes the results of a ground-based hyperspectral imaging tool used to map the geology of an open-pit mine highwall. The second case study outlines the use of interferometric synthetic aperture radar and how this type of radar can be used in a variety of geotechnical situations. These case studies are part of an on-going research project at the National Institute for Occupational Safety and Health's (NIOSH) Spokane Research Laboratory. The project objective is to implement engineering controls and design methods in order to reduce the number of injuries and fatalities associated with slope failures at mining operations. Project personnel are hopeful that these new developments in technology will lead to better geotechnical monitoring and design in slope stability and other important areas of rock mechanics.

1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), Spokane Research Laboratory is involved in research to improve methods for detecting conditions in open pit mines that could lead to catastrophic slope failures. Since 1995, 33 miners have died in slope failure accidents at U.S. mines. Better methods for monitoring and design are needed to ensure the safety of mine workers. This paper highlights two emerging technologies that could potentially be adapted to improve mine safety. Applications to rock mechanics issues related to surface and underground mining, petroleum, geological, civil engineering and geohazards monitoring are also included.

2 HYPERSPECTRAL IMAGING

A contributing factor in many slope failures is the presence of mechanically incompetent, hydro-thermally-altered rock (Watters & Delahaut, 1995). Major structures are generally well mapped, but weak rock units may be much more difficult to identify and the degree of clay alteration is oftentimes difficult to determine by visual examination alone. Geologic maps can vary greatly in quality and detail due to the subjectivity of various geologists and the extreme complexity of many deposits. In addition, there are financial and practical limits to the number of samples that can be taken for geochemical or engineering analyses. Inevitably, a large percentage of data shown on geologic maps is subject to scrutiny. High turnover rates of engineers and geologists at many companies, financial and time limitations, and unfamiliarity with complex formations can contribute to crucial errors or omissions on geologic maps.

2.1 Prototype Spectral Imager

NIOSH recently completed field tests of a prototype imaging spectrometer that was built by Carnegie Mellon Research Institute (CMRI). The purpose of the tests was to evaluate a new method for objectively mapping the geology of an open-pit mine from a distance.

Every material on the earth's surface reflects light in a characteristic pattern. The manner in which light of different wavelengths is reflected or absorbed by each material is known as its reflectance spectrum. By filtering light of specific wavelengths, images can be created that differentiate specific materials. Figure 1 illustrates examples of the spectral signatures of Neodymium Oxide and Kaolinite (Clark et al., 1998). A spectrometer is a device that collects these diagnostic spectral absorption features; identification of the minerals is then achieved by comparing the data to spectral libraries.

Field portable spectrometers are commercially available that can analyze light reflected from a single point, but the CMRI instrument is distinctive because it collects spectral reflectance data in a two-dimensional array. The instrument operates in the visible and near infrared ranges and employs an acousto-optical tunable filter to control wavelength, a phase retarder to measure polarization signatures, and a digital camera linked to a laptop computer to capture data (Figure 2). The instrument is very robust since it has no moving parts, and is also field portable (Denes et al., 1998; Gupta et al., 1999; Sabine et al., 1999; McHugh et al., 2000).

2.2 Field Site Selection

Since the current configuration of CMRI's instrument is limited to the visible and near infrared ranges (0.45 – 1.0 μm), mineralization with diagnostic features within this particular spectral range was required for the field tests. For

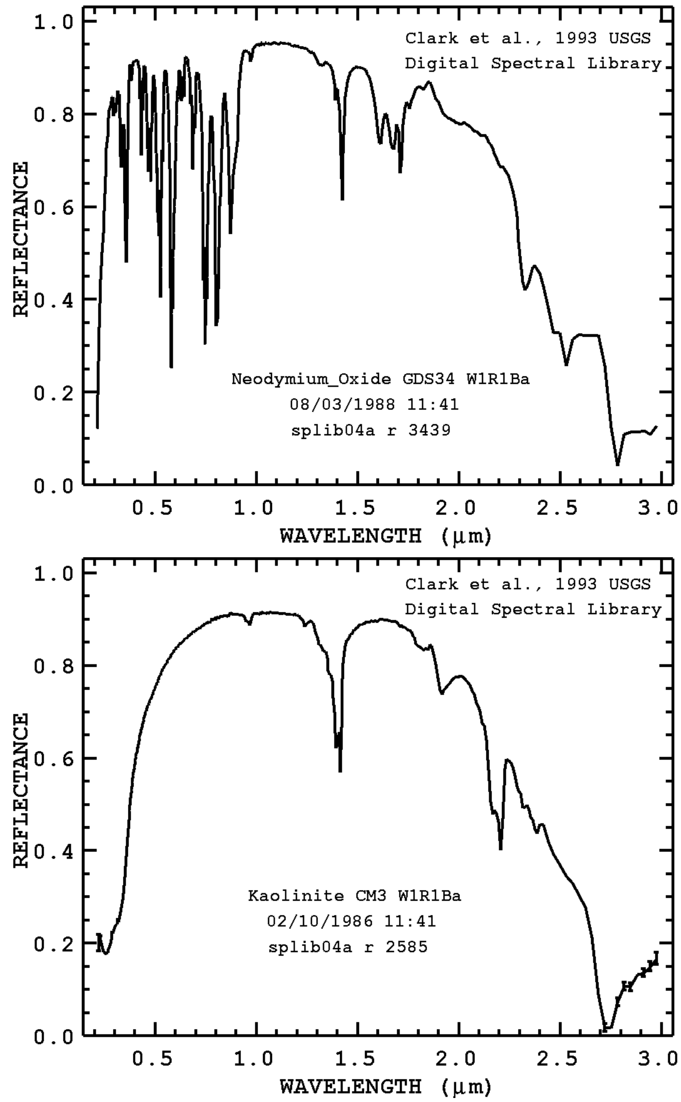

Figure 1. Examples of reflectance spectrum for Neodymium Oxide (top) and Kaolinite (bottom) (adapted from Clark et al., 1993)

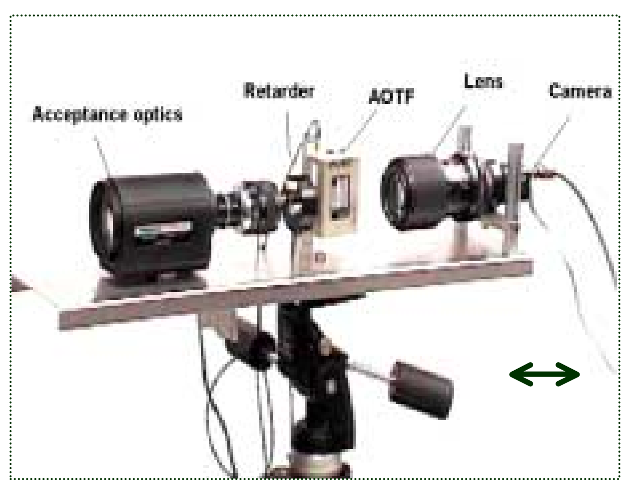

Figure 2. Spectro-polarimetric imager developed by Carnegie Mellon Research Institute.

this reason, the Mountain Pass Mine, which is approximately 60 miles southwest of Las Vegas, Nevada, was selected as the test site for the CMRI prototype instrument. The Mountain Pass Mine geology is comprised of rare-earth elements of the lanthanide series (cerium, lanthanum, neodymium, europium, and others), which have at least eight distinctive absorption features between 0.45 – 1.0 µm. Spectral data for the deposit were published by Rowan & others (1986; 1996) and Kingston (1993).

2.3 *Field Tests*

Twelve multispectral images -- including pit highwalls (Figure 3), outcrops, drill core from the ore zone, and hand samples -- were collected at the site. Supplemental images of hand specimens under artificial light sources were collected at CMRI to aid in calibration and evaluation of the instrument. Thin sections were made from both the ore and the host rock to assist with interpretation of the images.

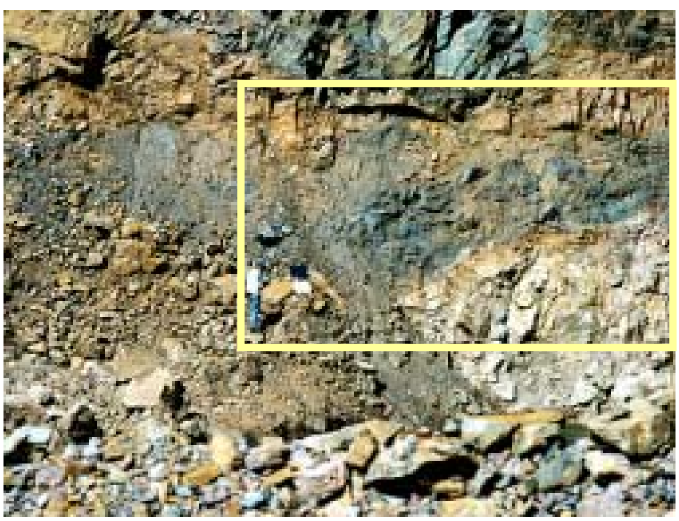

Figure 3. West highwall of the Mountain Pass Main Pit. Study area is outlined.

2.4 Analyses and Results

After the spectro-polarimetric images of the area were collected, substantial processing, filtering, and computer analyses were performed using ENVI software Spectral profiles were compared to data in the U.S. Geological Survey's Digital Spectral Library (Clark et al. 1993) to correlate the images with specific minerals. Detailed information regarding the spectral processing can be found in McHugh, et al., 2000. The results of the image analyses are illustrated in Figure 4. The white areas correspond to bastnaesite ore and the darker areas are waste rock or unclassified spectra.

Figure 4. Results from the CMRI spectro-polarimetric imager. Light areas correspond to ore; darker areas to waste or unclassified spectra.

The results from this field study successfully illustrate the capability of a field-portable imaging spectrometer to discriminate minerals within images of highwalls, outcrops, rock samples, and drill core. However, to effectively apply the AOTF-based technology to the characterization of alteration in rock masses caused by clays and other minerals, the instrument would need to be redesigned to extend into the shortwave and mid-infrared region of the spectrum. At this time, funding for this advancement in technology is not available at NIOSH or at CMRI.

There are many advantages to using spectral analyses for geologic mapping. First, spectral identification of minerals would remove the human error and subjectivity of trying to visually determine the degree of alteration in a rock mass. Secondly, workers would be able to map mine highwalls, or other inaccessible or precarious areas, from a safe distance. Finally, spectral analyses could be used to define faults, shear zones, and fracture systems in rock masses.

3 SYNTHETIC APERTURE RADAR

3.1 Overview of Technology

The second type of remote sensing technology that is being studied by NIOSH researchers is synthetic aperture radar (SAR). SAR is a type of ground-mapping radar that was originally designed to be used from aircraft and satellites. SAR can be used to generate high quality digital elevation maps and to detect disturbances of the earth's surface. A variation of SAR – Interferometric Synthetic Aperture Radar (also known as IFSAR or INSAR) – uses differences in successive SAR images to generate maps of displacements. One of the first applications that tracked ground motion without the aid of ground control points used Earth Resource Satellite (ERS-1) INSAR data to estimate ice-stream velocity in Anarctica (Goldstein et al., 1993). Although radar technology has been in widespread use since the 1940's, interferometric techniques have mostly been developed during the past decade. INSAR has also been successfully applied to produce the first displacement maps of ground movement caused by natural hazards such as earthquakes (Massonnet et al., 1993 & 1994; Zebker et al., 1994), volcanic activity (Massonnet, 1995), and landslides (Fruneau & Achache, 1996). This technique can also be used to monitor displacement of unstable slopes or landslides (Reeves et al., 1997; Sabine et al., 1999), and subsidence caused by the extraction of ground water, oil & gas, or minerals (Fielding, et al., 1998; Carnec, 1996; Stow 1996; Dixon, 1994). These pioneering studies have generated enormous interest in the Earth science community because they point to an entirely new way to study the surface of the Earth.

INSAR's have many advantages over current types of monitoring systems. Able to work in nearly all weather, an INSAR can acquire imagery through fog, mist, rain, haze, or cloud cover, and can operate day or night. Also, an INSAR can sample large areas for ground displacement, which gives them a tremendous advantage over survey networks, extensometers, and other instruments which sample movement on a discrete set of points. Recent developments in instruments such as prismless laser range finders partially address the problem of under sampling large areas for movement. However, the range and accuracy of these units can vary greatly depending on the reflectivity of the rock, the angle of the rock face, weather, and other factors.

3.2 Field Tests

The Microwave Earth Remote Sensing Laboratory at Brigham Young University (BYU) has recently designed and built a small synthetic aperture radar system capable of operating from light aircraft or

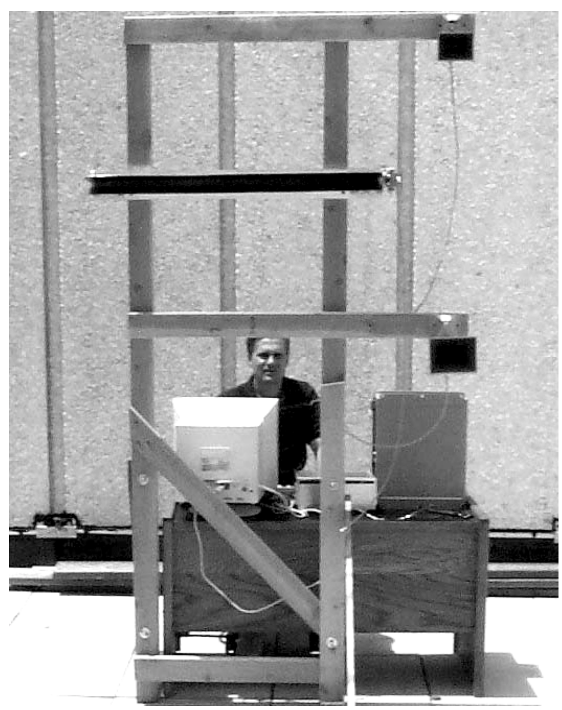

Figure 5. Photograph of the prototype interferometric radar system. The transmit antenna is seen in the center and the receive antennas are on the top-right and bottom-right.

from stationary ground-based locations (Thompson, 1998.) The prototype system, as seen in Figure 5, consists of a transmitter, two receivers, three antennas, and an embedded computer.

The first field tests related to geohazard monitoring using this instrument were performed by BYU for the Canadian National Railways (CN). The railways were interested in finding for a method to accurately detect rockfalls and washouts on railroad tracks before trains approached those dangerous areas. CN reports that approximately 20% of all their train derailments are caused by slope failures -- either rockslides or washouts (Figure 6. Arnold & Clegg, 1999). Corrective action requires a lot of time and can expose repair personnel to the risk of injury from additional falling debris. CN needed a system that could detect problems along the railroad track without having to send out personnel.

In the field tests for CN, the BYU interferometric radar system generated a terrain topography map accurate to within a few centimeters. Successive radar images were compared to watch for sudden changes in the topography caused by rockfalls or washouts along the track.

Figure 6. Rail track demolished by a slope failure.

The initial results from the CN railways tests were positive, and BYU researchers are confident that their system can be adapted to monitor highwalls at mines. Research and development needs to be completed and the prototype system is currently undergoing engineering tests. As soon as BYU has completed modifications to the instrument, NIOSH is planning to perform ground-based field tests of an open-pit highwall at an active mine site. An established survey network of prisms and GPS data will be used to calibrate the radar results.

4 CONCLUSIONS

Remote sensing, at the present time, cannot replace conventional geotechnical methods of investigation. However, emerging technologies such as hyperspectral imaging and interferometric synthetic aperture radar should not be ignored. The satellite versions of this technology are already widely used to monitor ground subsidence, landslides, volcanoes, and active faults. As computer technology continues to advance and processing speeds increase, integration of remote sensing tools into mining, petroleum, and civil engineering applications will also increase.

The potential benefits of using multiple remote sensing methods to better understand slope failures is merely one aspect of the current research to reduce the number of deaths caused by ground instability at surface mines. The NIOSH Slope Stability Hazard Recognition Team is pursuing many other options to minimize the dangers associated with surface ground control problems. Results of this research will hopefully benefit others involved in the study of landslides, rock falls, avalanches, volcanic activity, and other geohazards.

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