Evaluating Minerals of Environmental Concern Using Spectroscopy

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***Abstract*--Imaging spectroscopy has been successfully used to aid researchers in characterizing potential environmental impacts posed by acid-rock drainage, ore-processing dust on mangroves, and asbestos in serpentine mineral deposits and urban dust. Many of these applications synergistically combine field spectroscopy with remote sensing data, thus allowing more-precise data calibration, spectral analysis of the data, and verification of mapping. The increased accuracy makes these environmental evaluation tools efficient because they can be used to focus field work on those areas most critical to the research effort. The use of spectroscopy to evaluate minerals of environmental concern pushes current imaging spectrometer technology to its limits; we present laboratory results that indicate the direction for future designs of imaging spectrometers.**

Keywords-Imaging Spectroscopy; acid-rock drainage; naturally occurring asbestos; World Trade Center dust

I. INTRODUCTION

Reflectance spectroscopy in the ultraviolet (UV) to the near-infrared (NIR) wavelengths is a useful tool for evaluating environmental contaminants at scales from hand specimens to those available from airborne and spaceborne remote-sensing platforms. In particular, use of airborne hyperspectral systems with hundreds of contiguous spectral channels substantially increases the certainty of mineral identifications compared to more widely used multi-spectral systems [1].

II. EXAMPLES

Acidic drainage from natural and mining-related sources can adversely impact the quality of ground and surface water and the health of riparian and wetland ecosystems. The task of identifying sources of acid-rock drainage is often costly and time consuming. Recent advancements in airborne sensors have allowed the development of screening tools for characterizing inactive mine sites. Airborne imaging spectrometers are now capable of measuring reflected light in hundreds of continuous channels and producing high-quality spectra. Such high-spectral-resolution data contain the spectral signatures of molecular absorptions, which can be diagnostic of specific minerals, thus providing a way to map their surface distributions. Imaging spectrometers have been used to evaluate mine waste at Colorado and Utah in the U.S., at Brukunga in South Australia [2], and at mines sites in Spain [3]. Laboratory and field leach tests of surface samples show that leachate pH is most acidic and metals most mobile in samples from the jarosite-bearing zones and that leachate pH is near-neutral and metals least mobile in samples from goethite-rich zones [4]. The U.S. Environmental Protection Agency estimates that mineral maps made from AVIRIS data at Leadville, Colorado accelerated remediation efforts by two years saving over $2 million in investigation costs. Imaging spectroscopy has also been effectively used to monitor Fe-oxide dust loads in mangrove habitats bordering mining-related facilities in Australia over seasonal climatic cycles [5].

Naturally occurring asbestos (NOA) minerals are a potential hazard to human health that are known to cause lung cancer, mesothelioma, and asbestosis. Chrysotile, a member of the serpentine group, and the fibrous forms of several amphiboles, including tremolite and actinolite are commonly occurring NOA minerals. In California, such minerals are predominantly, but not exclusively, found in serpentinite and ultramafic rocks, which are common in the Sierra Nevada, Coast Ranges, and Klamath Mountains. Given rapid urban and suburban growth in the state, it is increasingly important that these particular types of rocks be identified and mapped. This would provide information so that government officials could take appropriate advisory or regulatory action to protect the public from potential exposure to NOA that might result from physical disturbance of these rocks. AVIRIS data and the U.S. Geological Survey Tetracorder spectral identification system were successfully used to detect serpentine and tremolite-actinolite/talc in areas with up to 70 percent vegetation cover in some cases in El Dorado County in the foothills of the Sierra Nevada [6]. Serpentine mineralization was also detected outside of known exposures of serpentinite and ultramafic rocks, mostly as aggregate used to surface gravel roads. Differentiating fibrous from non-fibrous serpentine, distinguishing between amphiboles and talc, and determining if certain vegetation assemblages can help delineate areas of serpentinization are current research goals. If these goals are reached, it will be possible to further enhance the value of hyperspectral mineral maps used to show the potential for the presence of NOA in given areas.

Detection of hazardous materials in urban environments presents a challenge for current imaging spectrometers. On Sept. 17 and 18, 2001, samples of settled dust and airfall debris were collected from 34 sites within a 1-km radius of the World Trade Center (WTC) disaster site [7, 8]. Spectral and x-ray diffraction analyses of the field samples detected trace levels of serpentine minerals, including chrysotile asbestos in about two-thirds of the dust samples at concentrations below the detection level available using AVIRIS data. Results also show that the chrysotile content of the dust varies spatially and this may indicate that chrysotile asbestos was not distributed uniformly during the collapse of the buildings on 9/11. It may be possible that the relatively lower chrysotile content of the dust south of Ground Zero may reflect this area's proximity to Tower 2, which did not use chrysotile-bearing fireproof insulation. Spectra with a very high signal-to-noise ratio (28,000:1) were needed to estimate potential chrysotile content in the WTC dust down to levels below 1 wt%. The need for detecting concentrations of materials at this level and, perhaps, at even lower levels presents an extraordinary challenge for imaging spectrometers designed for emergency response. Laboratory spectroscopy was a necessary component of the spectral analysis of the WTC dust mainly because its sensitivity level extends well below that of current imaging spectrometers. Laboratory spectroscopy also allowed measurements of dust samples in spectral regions where atmospheric gases obscured reflected signal from the ground surface in the airborne data.

In the future, full-range UV-NIR (0.35 to 2.5 µm) high-spectral-resolution portable spectrometers with battery-operated light probes could be used to screen thousands of spots for asbestos or other types of contamination over large, potentially-hazardous areas in a matter of days. Software that automatically identifies materials could be used to search these spectra for contaminants, thus producing real-time results immediately after each spectral measurement. As more scientists become familiar with imaging spectroscopy and the sophisticated algorithms used to analyze hyperspectral and laboratory data, new applications for mapping minerals of environmental concern will undoubtedly be recognized and hopefully put to use.

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