Environmental Site Characterization for the International Smelter Area and Bauer Mill, Utah, Using Hyperspectral Data

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Abstract-**Studies conducted under a National Aeronautics and Space Administration (NASA) Earth Observations Commercial Applications Program (EOCAP) project on applications of hyperspectral data to mine and mill wastes have helped advance the acceptance of this remote sensing technology among the mining and environmental communities in the United States. Our work addressed mineralogical and vegetation analysis of mine and mill waste areas as a means of identifying environmentally important materials, both wastes and background, that are critical to understanding which wastes and impacted areas may require remediation and those that do not.**

In this presentation, we discuss two case studies: the International Smelter area east of Tooele, Utah, and the Bauer Mill and tailings ponds north of Stockton, Utah. These two sites represent the approximate ends of the mill site reclamation spectrum. The Bauer Mill, active from about 1900 to 1974, is a completely unreclaimed site with mill foundations, assorted outbuildings and townsite, waste dump, and large tailings ponds. The International Smelter area, active from 1910 to 1971 and 1981 to 1983, consists of "reclaimed" (but not necessarily "remediated") and revegetated tailings ponds, building sites, mine dump, and slag dump. The potential impact of windblown tailings from the Bauer tailings ponds and on-site and potential downstream impacts of unremediated wastes at International were topics of interest during our investigations. Both processing facilities handled base and precious metal sulfide ores.

Airborne hyperspectral data were acquired for the study areas and classified through image processing to identify mineralogical distributions of interest for waste analysis. Ground sampling was performed to both guide the mineralogical classification and to perform accuracy assessment on the image processing results. At both study areas, it has been possible to accurately identify mineralogical associations indicative of wastes and to locate wastes of interest for environmental assessment. In some cases, such as eolian tailings outside of the Bauer site and probable tailings washouts outlying the International tailings dam, the full location and extent of these wastes were not identified prior to use of remote sensing.

The results of this project can be used by environmental and land management agencies to prioritize further site assessment and eventual remediation activities. Chemical relationships to mineralogy, identifiable through remote sensing, can be established and used to differentiate between potential or actual problem wastes and wastes that do not require significant characterization and/or remediation efforts.

I. INTRODUCTION

The NASA Earth Observations Commercial Applications Program (EOCAP) is intended to help advance remote sensing technologies from the experimental to the operational stage of use. Ultimately, in the case of our hyperspectral EOCAP project, the goal is to effectively target and guide further environmental ground studies, rather than relying on current typical practice, without benefit of remote sensing data, of grid or random sampling without prior comprehensive knowledge of site characteristics.

The NASA project work on our Utah sites ran in parallel with an U.S. Environmental Protection Agency (EPA)-sponsored project (called "The Utah Abandoned Mine Land (AML)-Watershed Hyperspectral Analysis Project") designed to demonstrate the capabilities of hyperspectral sensors and image processing to address land and environmental managers' needs for AML and watershed characterization. The EPA, Region 8 in particular for projects in Utah, is interested in application of hyperspectral remote sensing to sites under investigation to target and guide regulatory activities and make their efforts more thorough and efficient.

The airborne hyperspectral sensors used for this study were AVIRIS (Airborne Visible-InfraRed Imaging Spectrometer), CASI (Compact Airborne Spectrographc Imager), and SFSI (Short-wave infrared (SWIR) Full Spectrum Imager). Further information on these devices can be found at the sources noted in section IV of this paper.

Because of the limited space available for discussion in this proceedings paper, we will cover only highlights of our project work and results. Work at the Bauer Mill site is continuing by Eric Dillenbeck as part of a M.Sc. thesis at the Colorado School of Mines, with expected completion in late 2001 or early 2002. Sources for further information on both study areas are noted at the end of this paper.

II. STUDY AREA SYNOPSES

A. International Smelter Area

The International Smelter site and surroundings were impacted by smelter and other beneficiation processes from 1910 to 1971. The smelter site contained a concentrator, copper smelter, lead smelter, and zinc smelter in addition to various support and processing buildings. A slag dump was built on the northeast end of the site. The tailings ponds extended down Dry Canyon, on the southwest side of the site, from the concentrator to approximately 1 km south of the hamlet of Lincoln and covered most of the western half of the site. A mine dump (from an abandoned copper mine) also is present at the northern corner of the site. Part of the tailings ponds were reused between 1981 and 1983 for tailings from the Carr Fork Mill, a copper mine and mill complex southeast of the smelter site. Along with the shutdown of the Carr Fork mine and dismantling of the mill, the International Smelter site and combined tailings facilities were reclaimed in the late 1980s. The area now is known as the "Carr Fork Project" and serves as a Utah Wildlife Reservation, a site for hunting and other recreational activities by the area's populace.

Because the International Smelter area had been "reclaimed," identifying the quality and completeness of revegetation and the reclamation process were the primary aspects of interest for investigation using the hyperspectral remote sensing data. Any wastes or environmental impacts identified through the remote sensing and ground studies would indicate probable chemical impacts from wastes and areas that had been missed by reclamation. A paper by Braxton and Buck [1] contained a "reclamation unit" map which served as a guide to most parts of the area that had been addressed by reclamation activities to some degree.

Most revegetation at this site has been effective or at least acceptable since the reclamation work was completed in 1989. However, resurgent sulfidic wastes and other unremediated wastes are damaging flora and fauna. In addition, "off-site" areas of tailings that were not addressed during reclamation need to be considered in further reclamation planning. Such wastes and their effluent have the potential to impact a downstream community during wet periods and already have impacted use of part of the site for pasture. Investigations also have begun on identifying, through the hyperspectral data, the extent of probable impacts from past smelter emissions on the nearby western flanks of the Oquirrh Mountains.

Basic results from our studies for this area include the following: 1) Not all of the tailings have been cleaned up or covered up at the International Smelter site, because tailings were observed and spectrally confirmed in a number of samples, and these sample areas likewise appear as "tailings" and potential mineralogical anomalies in the hyperspectral images, 2) although AVIRIS data show general distributions of minerals, the higher spectral and spatial resolution of the SFSI sensor provides the ability to better separate transitional, acid-drainage diagnostic mineral species, 3) acid-drainage associated minerals at this site include alunogen, jarosite, gypsum, and transitional kaolinites, 4) an important key to understanding geologically oriented image processing is understanding the spectral variability that occurs within mineral species, 5) probable impacts of past smelter smokestack emissions have been detected and preliminarily mapped with the hyperspectral images, and 6) the CASI data were very useful in mapping vegetation type and density which can be used both for wildlife habitat and revegetation analyses. Additional information on this study site can be obtained through the sources noted in section IV of this paper and in Peters et al. [2].

B. Bauer Mill Site

The Bauer Mill was one of the first large processing facilities in or near the Stockton mining district, the original lead-zinc-silver deposit discovery area in Utah. The mill was a beneficiation facility, so little or no smelting took place there. The sulfide nature of much of the ore processed from the Stockton District and elsewhere from the Western United States resulted in the tailings having a high component of pyrite and, therefore, an acidic nature. However, surface and ground water impacts on site are minimal concern because 1) the tailings ponds are in a closed basin, 2) the primary aquifer for the area is far below the bottom of the tailings impoundment with an apparent intervening aquaclude, and 3) the semi-arid nature of the area.

The tailings also have high arsenic and lead contents, with in-place tailings containing up to 7000 ppm As and 1.5% Pb among other heavy metals (based on analyses performed by EPA). The tailings ponds have no vegetation cover, so frequent strong winds in the area easily transport fine tailings off the site, dominantly to the north and north-northwest. A surface sample from north of the ponds, but without visible tailings present, contained 1800 ppm As and 4000 ppm Pb. In light of this contamination and its physical mobility, present recreational access and potential agricultural, residential, and light industrial use of the nearby area by the growing town of Tooele to the north causes this site to be of concern to local, county, and state officials. It appears that off-site ground water impacts from the eolian tailings, if any, have not been evaluated yet.

Because the Bauer site is unreclaimed, it afforded the opportunity to assess unobscured mill wastes and their actual and potential impacts on their surroundings. Wastes were differentiated mineralogically from the surrounding background materials using the ground and hyperspectral data, and potential and actual on-site acid production and potential toxic metals releases could be established for the area. The extent and effects of the windblown tailings "plume" can be difficult to impossible to detect visually on the ground, outside of the area influenced by parabolic tailings dunes on the north side of the site, but easily can be identified through hyperspectral remote sensing. This

mineralogical information and resulting classification maps from the hyperspectral data ultimately will be useful to regulatory agencies for tracking tailings impacts and guiding ground studies necessary to fully evaluate the resulting heavy metal contamination from tailings.

Basic results from our studies (preliminary to completion of the M.Sc. thesis) for this area include the following: 1) analysis of ground samples shows that the tailings have a spectrally distinct signature from the surrounding valley fill materials and should be recognizable in hyperspectral imagery, 2) in-place tailings contain the SWIR-active minerals silica, smectite, and gypsum, and windblown tailings contain these same minerals, but also show the development of a kaolinite spectral feature, 3) carbonate was common in the ores processed at the mill, but was consumed due to the acidic nature of the tailings, with the excess calcium and sulfate combining to form the abundant gypsum now found in the tailings, 4) goethite, hematite, and jarosite (Fe^{3+} minerals) are present in the tailings at Bauer and can be used to map the tailings, 5) CASI and AVIRIS data provide similar distributions of Fe^{3+} minerals, but CASI classification maps are more geologically plausible and provide better mapping of complex mineral mixtures, and 6) all EPA geochemical samples of soil, tailings, and water that showed high levels of arsenic or low pH fall within the area of tailings defined by the hyperspectral Fe^{3+} mineral maps. Additional information on this study site can be obtained through the sources noted in section IV, in Dillenbeck et al. [3], and Mr. Dillenbeck at the above address.

III. SUMMARY

Study of the International Smelter area and the Bauer Mill site, using airborne hyperspectral remote sensing and related image processing techniques, has helped to not only guide further site characterization at these sites, but also to prove the value of application of detailed remote sensing for mill and smelter sites in general. The purpose of the EOCAP project was to advance hyperspectral applications to mine and mill wastes from the research stage to at least potentially operational use of the technology. The parallel EPA project helped prove the worth of the technology to EPA Region 8, and other segments of EPA, for providing information on Superfund and other sites that could not be obtained in any other way.

Ground studies as part of environmental site characterization cannot and should not be eliminated, if for not other reason than to verify remote sensing results for regulatory purposes. However, use of hyperspectral and ground spectral data, in advance of ground environmental sampling, can guide such studies toward addressing particular locations of potentially harmful wastes versus innocuous wastes. This will make ground studies much more efficient and ensure that all potentially harmful wastes are addressed, unlike what occurred with the past reclamation process at the International Smelter area.

IV. FOR FURTHER INFORMATION

Additional information on our Utah study areas can be found by clicking on the NASA logo at web site *http://www.pimausa.com*. Information on the CASI sensor and some related Utah and other vegetation studies can be found at *http://www.borstad.com*. Further information on the NASA EOCAP program, including commercial partners, can be obtained from the NASA web site at *http://www.crsp.ssc.nasa.gov/hyperspectral/hypermain.htm*. We also have prepared a CD of selected PowerPoint™ presentations and papers on our EOCAP work. This CD is available free upon request from Phoebe L. Hauff by writing to her at the address noted above or through her e-mail address (*pusa@rmi.net*). CDs of reports and data prepared for our EOCAP project also are available upon request, but have an associated nominal cost for reproduction, handling, and shipping.

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