

# **Waste Identification and Characterization for the International Smelter Area Using CASI/SFSI Hyperspectral Remote Sensing Data**

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**D.C. Peters**

*Peters Geosciences, Golden, Colorado, USA*

**P.L. Hauff, W.A. Peppin, E.C. Prosh**

*Spectral International, Arvada, Colorado, USA*

**G.A. Borstad**

*G.A. Borstad Associates, Sidney, British Columbia, Canada*

**F.B. Henderson III**

*HENDCO Services, Nathrop, Colorado, USA*

**E.D. Dillenbeck, L.G. Closs, K. Lee**

*Colorado School of Mines, Golden, Colorado, USA*

**J.L. Thiros**

*Utah Department of Environmental Quality, Salt Lake City, Utah, USA*

**D.W. Coulter**

*Newmont Exploration Ltd., Englewood, Colorado, USA*

**D.A. Robbins**

*ASARCO, Inc., Salt Lake City, Utah, USA*

**K.W. Wangerud**

*U.S. Environmental Protection Agency, Denver, Colorado, USA*

## **ABSTRACT**

The International Smelter, 3 km east of Tooele, Utah, operated from 1910 to 1971 and consisted of copper and lead smelters, concentrators, and various other processing facilities as well as a large tailings disposal area. The site was reactivated for tailings disposal by the Carr Fork copper mine and mill from 1979 to 1981. Reclamation and revegetation of the smelter complex and combined tailings facilities was completed to the satisfaction of State regulatory agencies in 1989 (Braxton & Buck 1989). The site was converted to a wildlife reservation following reclamation. The smelter site is upstream of farming and residential areas near Tooele, and the town of Tooele gradually is growing east toward the tailings area.

However, areas of tailings were missed or not addressed by reclamation activities. Other areas within the smelter-concentrator complex are showing chemical resurgence from sulfidic wastes and metal-rich wastes that were only covered up by a layer of gravel during reclamation. The degree to which revegetation has been successful at the site and areas of missed or resurgent wastes were the primary topics of interest for a remote sensing analysis of the area.

Hyperspectral remote sensing was used at this site to identify mineralogical and vegetation differences that were indicative of unreclaimed and resurgent wastes. Specifically, the CASI (Compact Airborne Spectrographic Imager) and SFSI (SWIR (short-wave infrared) Full Spectrum Imager) sensors were flown together to provide reflectance data in the visible, near-infrared, and short-wave infrared ranges of the spectrum. Accuracy of image processing results (mineralogical classification) were confirmed through ground sampling and analysis with portable spectrometers. The results of this site characterization process and implications for environmental impacts and further remediation of the site were the focus of this presentation.

## 1. INTRODUCTION

This paper is a brief description of remote sensing work performed for the International Smelter site (also called the "Carr Fork Property") near Tooele, Utah, as part of studies for a National Aeronautics and Space Administration (NASA) Earth Observations Commercial Applications Program (EOCAP) project on "Application of Airborne Hyperspectral Data to Characterization of Mined Lands and Analysis of Associated Watersheds and Impacts for Environmental Management" (Contract #NAS-13-99004). We are unable to cover all the details of this project and related work in the space available, so please see [section 4](#) (Additional Information) on how to access web sites that can provide you with more information.

The EOCAP in general is designed to demonstrate remote sensing technologies that are on the cusp of commercialization and to advance the respective fields of these technologies through identification of advantages and pitfalls that need to be addressed before full operational use can be achieved. Our project in particular was designed to prove the applicability of airborne hyperspectral data to characterization of mine and mill sites and related wastes. The environmental industry in general has made little use of the capabilities of hyperspectral sensors and data, so the goal was to prove that critical and detailed characterization of sites and wastes can be performed reliably and more thoroughly using hyperspectral remote sensing than can be achieved using standard ground surveys alone.

In this paper, we will touch upon some of the methodology and results for the International Smelter area ([Figure 1](#)). Studies on one of the other Utah sites, the Bauer Mill, are discussed briefly in Dillenbeck and others (2001) in this book. Unfortunately, we are unable in this paper to show color images that are a critical part of the remote sensing technology and investigations for the International Smelter. Such images are available through the web sites discussed in [section 4](#).



**Figure 1.** Oblique aerial view of the International Smelter complex (except for tailings impoundments) in the late 1960s, looking to the south. Photograph from the Wilbur H. Smith Papers (MS563), Special Collections, J. Willard Marriott Library, University of Utah.

**Table 1.** Sensor specifications for CASI and SFSI and comparison with AVIRIS. "VNIR" refers to the visible and near-infrared range of the electromagnetic spectrum.

<i>Sensor</i>	SFSI-2	CASI	AVIRIS
Spectral Range	1220-2320 nm (SWIR)	403-914 nm (VNIR)	400-2500 nm
Bandwidth	5 nm	2 nm	10 nm
Swath Width	2 km	2 km	10.5 km
Number of Bands	240	15 selectable out of 100	224
Ground Pixel Size	4 m	4 m	17 m

## 2. DATA ACQUISITION AND ANALYSIS

The primary hyperspectral sensors used were the Compact Airborne Spectrographic Imager (CASI) and Short-Wave Infrared (SWIR) Full Spectrum Imager (SFSI) airborne systems (Table 1), which are flown together in a light aircraft, at an altitude of approximately 3,500 m above mean terrain. G.A. Borstad Associates performed all CASI and SFSI airborne data collection for this project. In addition to the data flown for use by our team for this NASA project, the entire Oquirrh Mountains area was flown in August 1998 with the Airborne Visible-InfraRed Imaging Spectrometer (AVIRIS), which is described in Table 1 for comparison with CASI and SFSI.

These data were available to our NASA EOCAP team as part of a parallel study known as the "U.S. Environmental Protection Agency (EPA) Region 8 Utah Abandoned Mine Lands (AML)-Watershed Hyperspectral Analysis Project", which involved demonstration of hyperspectral technology for EPA environmental analysis and monitoring purposes.

CASI and SFSI data for the International Smelter were acquired in October 1998. Initial calibration and rectification of these data were performed by G.A. Borstad Associates Ltd. as part of their work on the EOCAP project. Further analysis of the CASI data was performed by Borstad Associates to produce a vegetation classification of the study area. This vegetation classification proved to be especially valuable for full assessment of the International Smelter area because of the revegetated nature of much of the site.

Processing of the AVIRIS and SFSI data, and selected CASI data, for mineralogical analyses was performed by Spectral International and aided by review and other input and GIS work by Peters Geosciences. Other team participants had technical input to the site analysis process and/or background information and the GIS database for the study areas. ENVI was used for most image processing work and ARC/INFO and ArcView were used for all GIS work, with use of Adobe Photoshop and miscellaneous other software packages for other project-related work.

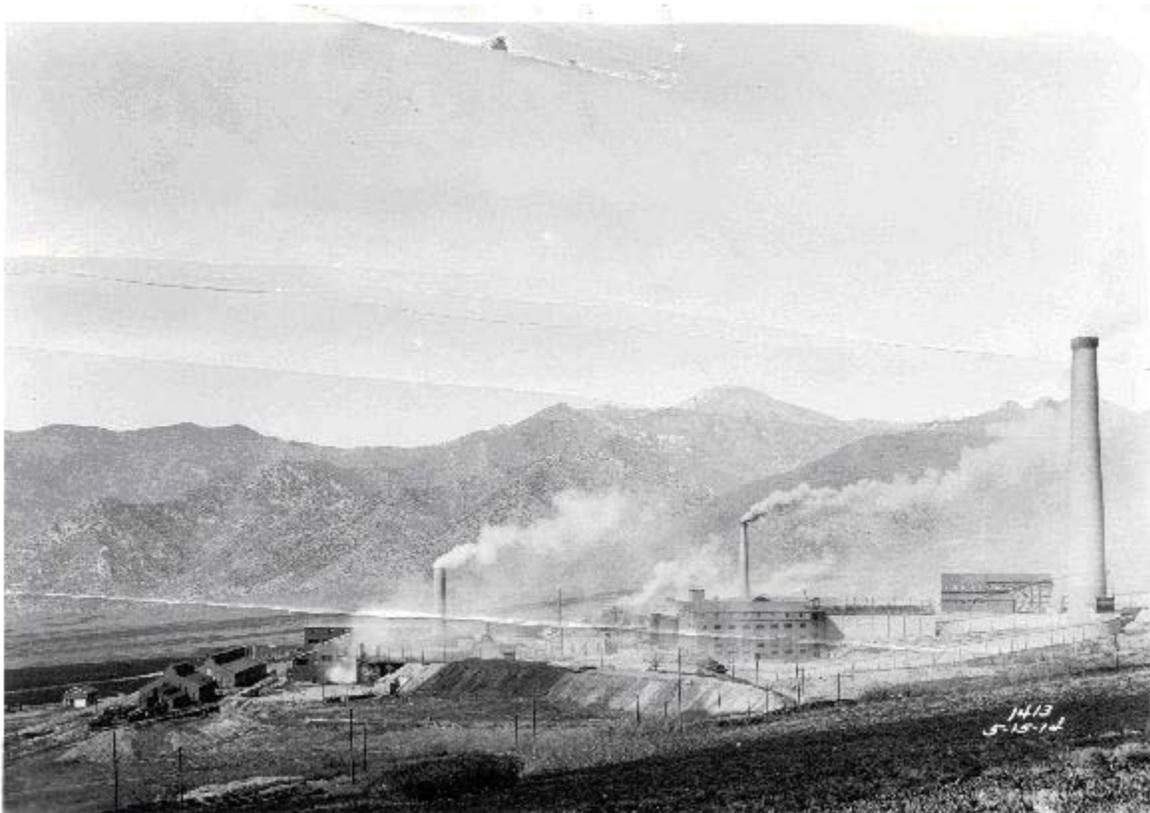
With respect to field work, the International Smelter area was visited and samples were collected to provide a representative set of mineralogical data both for the overall study area and for specific targets within the study area. Exhaustive sampling was not attempted, but major differences in mineral classifications (from the hyperspectral data) and physical features of study areas were examined within the limits available for the project. This resulted in approximately 100 sample sites being visited to date in the International Smelter area. The number of samples per sample site varied depending on the type of site and materials present. Only surficial materials were sampled. Samples are stored in sealable plastic bags to limit changes and prevent contamination of the samples. Ground photographs were taken at or near most sample sites to provide a visual record of site conditions that may be important for analysis of the hyperspectral data. GPS points were collected for sample locations for 1999 and 2000 field visits and subsequently corrected for system-based errors to provide locations that were reliable within the limits of the 4-m ground resolutions of the CASI and SFSI data.

Spectral analyses of the samples were performed with a PIMA II portable spectrometer (spectral coverage = 1200 - 2500 nm; internal light source) and an Analytical Spectral Devices "Hand-Held" portable spectrometer (spectral coverage = 300 - 1100 nm; solar or external light source). These devices provide detailed spectral coverage for most of the ranges covered by the airborne sensors used in this study. This allows detailed comparison of spectral mineralogy acquired both on the airborne scale and individual sample scale and the identification of significant mineralogical components that may be discriminable through processing of the hyperspectral data.

### **3. SELECTED RESULTS**

- 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, equally as important, there is present acid drainage from the smelter/concentrator complex along the Dry Canyon drainage, and potentially from the Northwest Dump. These sample areas likewise appear as "tailings" and potential mineralogical anomalies in the hyperspectral images.

- Although AVIRIS shows 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 that cannot be discerned as well in the AVIRIS images. Many of the failed revegetation areas and unreclaimed areas also are too small to be resolved adequately by the AVIRIS data.
- The most common infrared active minerals at the International Smelter Complex include smectite, illite, kaolinite, gypsum, calcite, and dolomite, with minor alunogen, jarosite, and selected copper sulfates. Aside from the exotic sulfates, these are the species most readily identified from the aircraft data.
- Acid drainage associated minerals at this site include alunogen, jarosite, gypsum, and transitional kaolinites.
- Gypsum can be a weathering product of sulfide, or SO<sub>2</sub> combined with carbonate, and is stable in a dry climate. Both input components are present at this site. The climate, however, is perhaps too humid to sustain extensive development of this mineral, except in areas of higher concentration of sulfide. This actually makes it a good pathfinder for the mine and mill wastes.
- Poorly crystalline kaolinite is the more common occurrence of kaolinite. It is also easier to explain its presence as a function of acidic ground water activity. Therefore, it would be expected to be present anywhere there is a possibility of sulfides or oxidized sulfides or SO<sub>2</sub> emissions. This appears to be the case as this material is particularly concentrated at the smelter complex where there are remnant sulfides, in drainages draining from the smelter complex, and on dumps and tailings piles.



**Figure 2.**View of part of the International Smelter complex, looking to the northeast in May

1914, showing smelter emissions blowing to the east and southeast toward the adjacent Oquirrh Mountains. Photograph from the Wilbur H. Smith Papers (MS563), Special Collections, J. Willard Marriott Library, University of Utah.



**Figure 3.** View of east flank (in background) of Pine Canyon (Oquirrh Mountains) in August 1999, showing denuded lower and middle slopes that are believed to have been impacted by emissions from the International Smelter complex. The slag dump for the smelter is in the middleground at left.

- Impacts of smelter smokestack emissions ([Figure 2](#)) have been detected and preliminarily mapped with the hyperspectral images. This issue of smelter emissions previously has not been addressed at this site. It is felt to be very important relative to the impact on the Pine Canyon area vegetation ([Figure 3](#)) from the past H<sub>2</sub>SO<sub>4</sub> generation at the site.
- An important key to understanding geologically oriented image processing is understanding the spectral variability that occurs with mineral species. If this is not addressed, then the image processing will produce inaccurate results.
- Certain applications may require only that the presence or absence of a mineral is verified and its detailed and accurate distribution may not be required to be known for a reconnaissance pass over an area that will be sampled in detail on the ground.
- In applications where the image data are tied to other information on the ground, such as distribution of toxic materials, the criticality of site specific spectral libraries and spectral variability is more apparent.

- Although the ground data may show the presence of a category of materials, there may not be enough of it in large enough concentrations and large enough areas to be detected from the air. This is a learning process to determine what the optimum parameters are for specific applications. This presents almost insurmountable problems with 17-m pixels (AVIRIS) and even significant problems with 4-m pixels (CASI and SFSI) ([Table 1](#)).
- Vegetation masks the soil signature and anything else with mineral spectral characteristics because the organic signature is strong. For the International Smelter area, where revegetation is extensive, the area must be studied in the negative sense (i.e., look for good mineral response of wastes as an indication of failure of revegetation).

#### 4. ADDITIONAL INFORMATION

The full details and results of this study, and related results for other Utah study sites, are too voluminous to cover in this proceedings paper. Therefore, readers are directed to the web site [www.pimausa.com](http://www.pimausa.com) for further information on the International Smelter study area and other work conducted under this NASA EOCAP project. Please click on the NASA icon at this web address for project information and how to obtain the reports for the NASA project. Further information on the NASA EOCAP program, including commercial partners, can be obtained from web site <http://www.crsp.ssc.nasa.gov/hyperspectral/hypermain.htm>.

#### 5. REFERENCES

Braxton, L.P. & B.W. Buck 1989. Reclamation of the Carr Fork Property, Tooele, Utah. In G.E. Cordy (ed.), *Geology and hydrology of hazardous-waste, mining-waste, waste-water, and repository sites in Utah*: 115-120. Utah Geological Association, Publication 17.

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