4. REMOTE SENSING

DETECTION AND MONITORING OF ACID MINE DRAINAGE BY REMOTE SENSING
Beckett, P.J.; S. Pappin Willianen
Elliot Lake Research Field Station of Laurentian University Final Report to Northern Ontario Heritage Fund Corporation. p 67-80, 1996

LEVERAGING THE HIGH DIMENSIONALITY OF AVIRIS DATA FOR IMPROVED SUB-PIXEL TARGET UNMIXING AND REJECTION OF FALSE POSITIVES: MIXTURE TUNED MATCHED FILTERING
Boardman, Joseph W., Analytical Imaging and Geophysics, LLC, Boulder, CO
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings [Abstract only]

Much headway has been made by the direct application of the well-known signal processing technique of Matched Filtering to imaging spectrometry studies, especially applications involving detection and mapping of sub-pixel targets. The Matched Filter technique has long been used by electrical engineers for the detection of known signals in mixed backgrounds, especially in radio and radar applications. Its popularity derives from the proof that it is the optimal linear detector in such situations, maximizing the suppression of the background while simultaneously maximizing the target-to-background contrast. These dual properties make it appear to be the optimal detection method. However, in the case of the remote sensing mixed pixel case, it is most certainly not optimal. The underlying assumption of the "proof' used in radio and radar applications is one of unbounded superposition, Adding target signature in this case boosts the signal and one "hears" or "sees" the linear sum of the background and the target. This addition is wholly unbounded. In the imaging spectrometry case we have an undeniable and physically meaningful bound on the signal: every pixel is only 100% fill. As we add target material to a pixel it covers up some background, satisfying the unit-sum constraint. It does not add "area" to the pixel, as an additive radio signal adds "power" to its mixture, This simple but fundamental difference can be exploited to give an algorithm that then appears to have "super-optimal" performance, and shows the risk in a blanket application to remote sensing of techniques developed under different physical models and assumptions. We use these difference to our advantage in a technique called Mixture Tuned Matched Filtering (MTMF). MTMF combines the best parts of the Linear Spectral Mixing model and the statistical Matched Filter model while avoiding the drawbacks of each parent method. From Matched Filtering it inherits the advantage of its ability to map a single known target without knowing the other background endmember signatures, unlike traditional Spectra Mixture modeling. From Spectral Mixture modeling it inherits the leverage arising from the mixed pixel model, the constraints on feasibility including the unit-sum and positivity requirements, unlike the Matched Filter which does not employ these fundamental facts. As a result, MTMF can outperform either method, especially in cases of subtle, sub-pixel occurrences. In fact, using MTMF we have found a previously undetected and very subtle occurrence of ammonium minerals at the heavily studied site of Cuprite, Nevada! The MTMF method leverages the high dimensionality of AVIRIS data, using the high dimensional space to its advantage, to greatly increase
detectability and selectivity, Sub-lt routinely demonstrates single 3 to 5% abundance sub-pixel occurrences along with outstanding false-positive rejection and target selectivity. Question proofs of optimality.

GEOELECTRICAL METHODS FOR INVESTIGATING MINE DUMPS
Campbell, D.L.; D.V. Fitterman, U.S. Geological Survey, Denver, CO
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1513-1523, ©2000

The USGS has used direct current resistivity (DC), electromagnetic (EM), induced polarization (IP), and ground-penetrating radar (GPR) geoelectrical methods to study mine dumps. The results reflect lithology, pore water saturation, and dissolved solids in the pore water. If the pore water has a pH less than 5, conductivity maps can indicate acid generating potential. IP measurements can help distinguish mineralogy in mine dumps, especially concentrations of sulfide minerals. EM and DC can help locate acidic/high TDS groundwater associated with mine dumps. GPR methods failed at the sites studied in the West. These conclusions are augmented by those from the recent literature.

FINAL REPORT: A PROPOSED METHOD FOR THE DETECTION OF ACID MINE DRAINAGE IN ELLIOT LAKE MINING OPERATIONS USING SPECTRAL REFLECTANCE OF VEGETATION
Carlsson, D.
Ministry of Northern Development and Mines Project No 3110, 47 pp, 1993

MINERALOGICAL DIFFERENTIATION IN WEATHERING PROFILES OF LATERITIC NI USING AVIRIS DATA, IN NIQUELANDIA - GO, BRAZIL
Carvalho, Osmar Abilio de, Jr. (COTER - Excercito Brasileiro), et al.
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1999 JPL Airborne Geoscience Workshop Proceedings, 10 pp, 1999

Improvement of prospective optical remote sensing techniques is important on account of the increase in operational speed and the low cost of total coverage of wide areas. In spite of the advances obtained in the study of the way the minerals spectrum behaves, the multispectral sensor presents limitations in relation to an accurate mineralogical identification. The hyperspectral sensor has come to fill this blank. In intertropical conditions, even with the more complete information from hyperspectral sensors, collecting information from rocks and orebodies is, in some cases, very difficult due to the intense weathering process and the eventual vegetation cover. Not much is known about the hyperspectral data for geological mapping and mineral prospection in such areas and it is a wide field of research. Because supergenic accumulation is superficial and widespread in intertopical environment, it is more adequate for the use of this technique. Therefore, in this paper we try to evaluate the use of AVIRIS in the supergenic accumulation of lateritic nickel in Niquelandia town, Goias State, Brazil. More Info: http://makalu.jpl.nasa.gov/docs/workshops/99_docs/15.pdf

MINERAL MAPPING WITH IMAGING SPECTROSCOPY: THE RAY MINE, AZ
Clark, R.N. (U.S. Geological Survey, Denver, CO); J.S. Vance (U.S. EPA, Region VIII, Denver, CO); K.E. Livo (U.S. Geological Survey, Denver, CO); R.O. Green (Jet Propulsion Lab., Pasadena, CA)
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 9 pp, 1998

Mineral maps generated for the Ray Mine in Arizona were analyzed to determine if imaging spectroscopy can provide accurate information for environmental management of active and abandoned mine regions. The Ray Mine, owned by the ASARCO Corporation, covers an area of 5700 acres and is

situated in Pinal County, Arizona, about 70 miles north of Tucson near Hayden, Arizona. This open-pit mine has been a major source of copper since 1911, producing an estimated 4.5 million tons of copper since its inception. Until 1955, mining was accomplished by underground block caving and shrinkage stope methods (excavation by working in stepped series usually employed in a vertical or steeply inclined orebody). In 1955, the mine was completely converted to open pit method mining, with the bulk of the production from sulfide ore using recovery by concentrating and smelting. Beginning in 1969 a significant production contribution has been from the leaching and solvent extraction/electro-winnowing method of silicate and oxide ores. Published reserves in the deposit as of 1992 are 1.1 billion tons at 0.6 percent copper. The EPA, in conjunction with ASARCO and NASA/JPL, obtained AVIRIS data over the mine in 1997 as part of the EPA Advanced Measurement Initiative (AMI). This AVIRIS data set is being used to compare and contrast the accuracy and environmental monitoring capabilities of remote sensing technologies: visible-near-IR imaging spectroscopy, multispectral visible and, near-IR sensors, thermal instruments, and radar platforms. The goal of this effort is to determine if these various technologies provide useful information for environmental management of active and abandoned mine sites in the arid western United States. This paper focuses on the analysis of AVIRIS data for assessing the impact of the Ray Mine on Mineral Creek. Mineral Creek flows to the Gila River. This paper discusses our preliminary AVIRIS mineral mapping and environmental findings. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/98_docs/10.pdf

SPECTROSCOPY OF ROCKS AND MINERALS, AND PRINCIPLES OF SPECTROSCOPY
Clark, Roger N., U.S. Geological Survey, Denver, CO
Manual of Remote Sensing, Chapter 1
JohnWiley and Sons, Inc., New York. 1999 [This book chapter was produced by personnel of the U.S. Government; therefore, it cannot be copyrighted and is in the public domain.]

Spectroscopy is the study of light as a function of wavelength that has been emitted, reflected or scattered from a solid, liquid, or gas. This book chapter primarily discusses the spectroscopy of minerals, but the principles apply to any material. Reflectance spectroscopy is a rapidly growing science that can be used to derive significant information about mineralogy with little or no sample preparation. It may be used in applications when other methods would be too time-consuming or require destruction of samples. For example, imaging spectrometers are already acquiring millions of spatially gridded spectra over an area from which mineralogical maps are being made. It is possible to set up real-time monitoring of processes using spectroscopy, such as monitoring the mineralogy of drill cores at the drilling site. Research is still needed to better understand the subtle changes in absorption features before reflectance spectroscopy will reach its full potential. It may well take a decade before general software tools are available to allow reflectance spectroscopy to challenge other analytical methods in the commercial marketplace. However, spectroscopy is already an excellent tool for certain classes of minerals: clay mineralogy, OH-bearing minerals, iron oxides and hydroxides, carbonates, sulfates, olivines and pyroxenes. More Info:
http://speclab.cr.usgs.gov/PAPERS.refl-mrs/refl4.html

MAPPING OF ACID-GENERATING AND ACID-BUFFERING MINERALS IN THE ANIMAS WATERSHED BY AVIRIS SPECTROSCOPY

Dalton, J.B.; T.V.V. King; D.J. Bove; R.F. Kokaly; R.N. Clark; J.S. Vance; G.A. Swayze
U.S. Geological Survey, Denver, CO

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 5 pp, 1998

The Animas River Watershed is the site of a coordinated effort to characterize the extent and severity of environmental effects from acid water drainage. This water originates both from numerous abandoned mine sites that date as far back as the late 1800s, and from extensive areas of natural altered and mineralized outcrops. The headwaters of the Animas River are within the San Juan and Silverton calderas, which were responsible for creating large fractures and faults suitable for later mineralization. As part of the Abandoned Mine Lands (AML) Project of the United States Geological Survey (USGS), data were obtained over the San Juan Mountains and Animas Watershed using the Jet Propulsion Laboratory's Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS) and are being used in conjunction with field geologic mapping, geochemistry and geophysics to determine the relative extent of natural and anthropogenic sources of acid water runoff, and its effect on water quality in the drainage.
More Info: http://makalu.jpl.nasa.gov/docs/workshops/98_docs/12.pdf

MAPPING OF ACID-GENERATING AND ACID-BUFFERING MINERALS IN THE ANIMAS WATERSHED BY AVIRIS SPECTROSCOPY

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U.S. Geological Survey, Denver, CO

Science for Watershed Decisions on Abandoned Mine Lands: Review of Preliminary Results, 4-5 February 1998, Denver, CO
U.S. Geological Survey Open-File Report 98-0297, p 30, 1998

Visible-wavelength and near-infrared image cubes for the Animas River watershed from Hermosa, Colorado, to the headwaters at Animas Forks, Colorado, were acquired on June 18, 1996, by the Jet Propulsion Laboratory's AVIRIS (Airborne Visible and InfraRed Imaging Spectrometer) instrument in a 17-minute pass under cloud-free, late-morning conditions. These image cubes have been analyzed using the USGS Tricorder V3.4 implementation, an expert system that utilizes a database of over 300 laboratory spectra of end-member minerals and mineral mixtures to generate maps of mineralogy, vegetation coverage, and other material distributions from image cubes using both the spectral and spatial information dimensions. Major iron-bearing, phyllosilicate, clay, carbonate, alteration, and other minerals were identified along with several vegetation classes. Subtle spectral variations enabled discrimination between similar hydrothermal alteration products, resulting in highly detailed maps that were generated and field-checked during the 1997 field season. The maps reveal widespread distributions of anthropogenic as well as large localized outcrops of natural acid-generating mineral assemblages such as pyrite, jarosites, alunites, and goethite. Additionally, distributions of alkaline minerals such as calcite and dolomite were determined with sufficient precision to indicate a relation between acid-buffering assemblages and stream geochemistry within the watershed. Preliminary maps of mineral distributions were used as aids to field work by several teams during the 1997 field season, and improved maps of minerals of interest will again be utilized in the 1998 field season.

DISTRIBUTION OF ACID-GENERATING AND ACID-BUFFERING MINERALS IN THE ANIMAS RIVER WATERSHED AS DETERMINED BY AVIRIS SPECTROSCOPY

Dalton, J.B.; T.V.V. King; D.J. Bove; R.F. Kokaly; R.N. Clark; J.S. Vance; G.A. Swayze
U.S. Geological Survey, Denver, CO
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1541-1549, ©2000

Visible-wavelength and near-infrared multispectral image cubes for the Animas River Watershed from Hermosa, CO, to the headwaters at Animas Forks, CO, were acquired on June 18, 1996, using the Jet Propulsion Laboratory's AVIRIS (Airborne Visible and InfraRed Imaging Spectrometer) instrument. These image cubes have been analyzed using the USGS Tetracorder V3.4 implementation an expert system that utilizes a database of more than 300 laboratory spectra of endmember minerals and mineral mixtures to generate maps of mineralogy, vegetation coverage, and other material distributions. Major iron-bearing, clay, carbonate, and other minerals were identified along with several minerals associated with acid-generating hydrothermal systems including pyrite, jarosite, alunite and goethite. Additionally, distributions of alkaline minerals such as calcite and chlorite indicate a relation between acid-buffering assemblages and stream geochemistry within the watershed.

MAPPING THE DISTRIBUTION OF MINE TAILINGS IN THE COEUR D'ALENE RIVER VALLEY, IDAHO, THROUGH THE USE OF A CONSTRAINED ENERGY MINIMIZATION TECHNIQUE
Farrand, W.H.; Harsanyi, J.C.
Remote Sensing of Environment, Vol 591, p 64-76, 31 Jan 1997

Mining activities in and around the town of Kellogg, Idaho, have left ferruginous fluvial sediments contaminated by trace metals deposited on the banks and on the floodplain of the Coeur d'Alene River in northern Idaho. These contaminated sediments are amenable to detection and mapping by remotely sensed data. Data collected by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) were analyzed both to map exposed concentrations of these sediments and also to consider their mineralogic variability. The constrained energy minimization (CEM) technique was used as a processing tool to map the ferruginous sediments. The CEM maximizes the response of the target signature and suppresses the response of undesired background signatures on a pixel-by-pixel basis. CEM abundance images, produced using both laboratory and image data as the target signatures, were thresholded to produce a set of spectra dominated by the ferruginous sediment spectral response. Spectral subsections of this data set were analyzed using principal components analysis. Endmember image spectra were identified that represented, in most cases, known mineral phases. Recent studies have demonstrated that sediments in the Coeur d'Alene (CDA) River are highly enriched in trace metals such as Ag, Cu, Pb, Zn, Cd, Hg, As, and Sb.

PRELIMINARY RESULTS FROM A COMPARATIVE MAPPING ANALYSIS IN THE TINTIC MINING DISTRICT USING AVIRIS AND ESSI-PROBE 1 DATA
Farrand, William H. (Farr View Consulting, Denver, CO); Robert D. Stewart; Larry Vance (Earth Search Sciences, Inc., McCall, ID)
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1999 JPL Airborne Geoscience Workshop Proceedings, 9 pp, 1999

In 1998, Earth Search Sciences, Inc. (ESSI) began commercial surveys using PROBE 1, a 128 channel, 0.4 to 2.5 mm, gyro-stabilized hyperspectral sensor built by Integrated Spectronics Propriety Limited. As part of the 1998 Utah Abandoned Mine Lands (AML) AVIRIS Watershed Analysis Project, EPA Region 8 encouraged participation by private sector remote sensing companies to demonstrate detection and analytical systems that could be utilized in future watershed analysis projects. On August 28,

1998, ESSI completed fourteen PROBE 1 flight lines over the Oquirrh Mountains and Tintic Districts using a light, twin engine aircraft. At the altitude flown in this survey, PROBE 1 data has 5 meter pixels, which is a significantly finer spatial resolution than the 17 meter pixel AVIRIS data collected using the ER-2 aircraft. The results of a preliminary comparative analysis are presented in this paper to compare the spectral and radiometric characteristics of PROBE 1 and AVIRIS data collected over the same region, illustrate the benefit of using PROBE 1's high spatial and spectral resolution data in the discovery phase of an AML watershed analysis project, and demonstrate that indicator minerals relevant to AML studies are readily recognizable in PROBE 1 data. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/99_docs/18.pdf

PRELIMINARY RESULTS FROM A COMPARATIVE MAPPING ANALYSIS IN THE TINTIC MINING DISTRICT USING AVIRIS AND ESSI-PROBE 1 DATA
Farrand, W.H. (Farr View Consulting, Denver, CO); R.D. Stewart; L. Vance (Earth Search Sciences, Inc. (ESSI), McCall, Idaho)
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Airborne Geoscience 2000 Workshop Proceedings, 9 pp, 2000

In 1998, Earth Search Sciences, Inc. (ESSI) began commercial surveys using PROBE 1, a 128 channel, 0.4 to 2.5 mm, gyro-stabilized hyperspectral sensor built by Integrated Spectronics Propriety Limited. As part of the 1998 Utah Abandoned Mine Lands (AML) AVIRIS Watershed Analysis Project, EPA Region 8 encouraged participation by private sector remote sensing companies to demonstrate detection and analytical systems which could be utilized in future watershed analysis projects. On August 28, 1998, ESSI completed fourteen PROBE 1 flight lines over the Oquirrh Mountains and Tintic Districts using a light, twin engine aircraft. At the altitude flown in this survey, PROBE 1 data has 5 meter pixels which is a significantly finer spatial resolution than the 17 meter pixel AVIRIS data collected using the ER-2 aircraft. Results of a preliminary comparative analysis are presented here to compare the spectral and radiometric characteristics of PROBE 1 and AVIRIS data
collected over the same region, illustrate the benefit of using PROBE 1’s high spatial and spectral resolution data in the discovery phase of an AML watershed analysis project, and demonstrate that indicator mineralogy relevant to AML studies are readily recognizable in PROBE 1 data. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/toc.htm

WHAT IS IMAGING RADAR?
Freeman, Tony, Jet Propulsion Laboratory, NASA Web Site

An imaging radar works very much like a flash camera in that it provides its own light to illuminate an area on the ground and take a snapshot picture, but at radio wavelengths. A flash camera sends out a pulse of light (the flash) and records on film the light that is reflected back at it through the camera lens. Instead of a camera lens and film, a radar uses an antenna and digital computer tapes to record its images. In a radar image, one can see only the light that was reflected back towards the radar antenna. The length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension. Synthetic
Aperture Radar (SAR) refers to a technique used to synthesize a very long antenna by combining signals (echoes) received by the radar as it moves along its flight track. Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of a camera, this would be the shutter opening; for radar it is the antenna. A synthetic aperture is constructed by moving a real aperture or antenna through a series of positions along the flight track. Parallel to the development of

spaceborne imaging radars, NASA/JPL have built and operated a series of airborne imaging radar systems. NASA/JPL currently maintain and operate an airborne SAR system, known as AIRSAR/TOPSAR. More Info: http://airsar.jpl.nasa.gov/techinfo.html

A NEW AND FAST METHOD FOR SMOOTHING SPECTRAL IMAGING DATA

Gao, Bo-Cai (Naval Research Lab., Washington, DC); Ming Liu (SAIC, Chantilly,VA); Curtiss O. Davis (Naval Research Lab., Washington, DC)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 10 pp, 1998

The Airborne Visible Infrared Imaging Spectrometer (AVIRIS) acquires spectral imaging data covering the 0.4- 2.5 µm wavelength range in 224 10-nm-wide channels from a NASA ER-2 aircraft at 20 km. More than half of the spectral region is affected by atmospheric gaseous absorption. Over the past decade, several techniques have been used to remove atmospheric effects from AVIRIS data for the derivation of surface reflectance spectra. An operational atmosphere removal algorithm (ATREM), which is based on theoretical modeling of atmospheric absorption and scattering effects, has been developed and updated for deriving surface reflectance spectra from AVIRIS data. Due to small errors in assumed wavelengths and errors in line parameters compiled on the HITRAN database, small spikes (particularly near the centers of the 0.94- and 1.14-|m water vapor bands) are present in this spectrum. Similar small spikes are systematically present in entire ATREM output cubes. These spikes have distracted geologists who are interested in studying surface mineral features. A method based on the "global" fitting of spectra with low order polynomials or other functions for removing these weak spikes has recently been developed by Joseph W. Boardman, who is also presenting a paper at this workshop. This paper describes another technique, which fits spectra "locally" based on cubic spline smoothing, for quick post processing of ATREM apparent reflectance spectra derived from AVIRIS data. Results born our analysis of AVIRIS data acquired over Cuprite mining district in Nevada in June of 1995 are given. Comparisons between our smoothed spectra and those derived with the empirical line method are presented. More Info: http://makalu.jpl.nasa.gov/docs/workshops/98_docs/18.pdf

COMPARISON OF UNMIXING RESULTS DERIVED FROM AVIRIS, HIGH AND LOW RESOLUTION, AND HYDICE IMAGES AT CUPRITE, NV

Goetz, Alexander F.H. (Center for the Study of Earth from Space/CIRES; Univ. of Colorado, Boulder. Dept. of Geological Sci.); Bruce Kindel (Center for the Study of Earth from Space/CIRES)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1999 JPL Airborne Geoscience Workshop Proceedings, 10 pp, 1999

The availability of low-altitude, high-spatial-resolution AVIRIS images and high-resolution HYDICE images over Cuprite, Nevada has provided an unprecedented opportunity to compare the radiometric quality, the ability to detect end-members and the application of matched filters to three different data sets in an area that is well understood mineralogically. An earlier paper (Goetz and Kindel, 1996) compared high-altitude AVIRIS and HYDICE data and showed that, even though there was a 36:1 ratio in pixel area, no new end-members appeared in the HYDICE images that were not seen in the lower resolution AVIRIS data. This result was not surprising in light of the fact that the signal-to-noise ratio (SNR) of the HYDICE data was much lower than that of AVIRIS. In this study, it was possible to remove the uncertainty associated with differing SNRs because the same AVIRIS sensor was used to acquire both high-resolution and low-resolution images. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/99_docs/25.pdf

COMPARISON OF UNMIXING RESULTS DERIVED FROM AVIRIS, HIGH AND LOW RESOLUTION, AND HYDICE IMAGES AT CUPRITE, NV

Goetz, A.F.H. (Center for the Study of Earth from Space/CIRES and Dept. of Geological Sciences, Univ. of Colorado, Boulder); Bruce Kindel (Dept. of Geological Sciences, Univ. of Colorado, Boulder)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Airborne Geoscience 2000 Workshop Proceedings, 10 pp, 2000

The availability of low-altitude, high-spatial-resolution AVIRIS (Green et al, 1998) images and high-resolution HYDICE (Basedow et al, 1995) images over Cuprite, Nevada has provided an unprecedented opportunity to compare the radiometric quality, the ability to detect end-members and the application of matched filters to three different data sets in an area that is well-understood mineralogically. An earlier paper (Goetz and Kindel, 1996) compared high-altitude AVIRIS and HYDICE data and showed that, even though there was a 36:1 ratio in pixel area, no new end-members appeared in the HYDICE images that were not seen in the lower resolution AVIRIS data. This result was not surprising in light of the fact that the signal-to-noise ratio (SNR) of the HYDICE data was much lower than that of AVIRIS. In this study, it was possible to remove the uncertainty associated with differing SNR's because the same AVIRIS sensor was used to acquire both high-resolution and low-resolution images. More Info: http://makalu.jpl.nasa.gov/docs/workshops/toc.htm

REMOTE SENSING ANALYSIS OF SURFACE WATER IN THE MINING AREA

Han, Zhen (Shandong Inst. of Mining and Technology, Shandong, China); Yang, Fengjie; Feng, Xianghua; Liu, Jiwei; Li, Yongqing; Lei, Liqing

Proceedings of the 1999 Optical Engineering for Sensing and Nanotechnology (ICOSN '99), 16-18 June 1999, Yokohama, Japan

Proceedings of SPIE, Vol 3740, p 212-215, 1999

This paper describes a rapid and economical method of monitoring mining area surface water. The authors tested the reflectance spectrum of waters affected by mine pollution in the Feicheng mining area and analyzed the curves to generate computer-processed images by TM computer-compatible tape. By combining routine monitoring methods and TM images, the researchers were able to comprehensively monitor and analyze the surface water of the mining area.

HYPERSPECTRAL EVALUATION OF MINE WASTE AND ABANDONED MINE LANDS: NASA AND EPA SPONSORED PROJECTS IN IDAHO

Hauff, P.L.; N. Lindsay (Spectral International Inc., Arvada, CO); D.Peters; G. Borstad; W. Peppin; L. Costick; R. Glanzman

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1999 JPL Airborne Geoscience Workshop Proceedings, 10 pp, 1999

NASA and the EPA are sponsoring the Abandoned Mine Lands (AML) Project. Sites in Utah and Idaho are currently under investigation. This paper looks at the Idaho study and discusses the methods used. The objective of the study is to characterize and map the mine waste in the Couer d'Alene River Basin and the mine sites in the contributing drainage by locating and mapping areas of elevated lead and zinc concentrations and, if different, areas with low pH water (high iron). Cadmium and arsenic are secondary targets. The researchers are also examining whether or not stressed, dead, or dying vegetation could be used to map areas of high toxic metals and/or acidity. Hyperspectral data from AVIRIS, SFSI, and CASI are compared to the characterization results of field studies. The field studies were conducted using a wide

range of equipment to collect the following types of information: SWIR range reflectance spectra from rocks, soils, sediments, and vegetation; solar spectra for reflectance calibration and vegetation spectra; portable X-Ray Fluorescence (XRF) chemical analyses of the same; digital and film photographs of sample sites; and GPS coordinates for the sample locations and control points. More Info: http://makalu.jpl.nasa.gov/docs/workshops/99_docs/32.pdf

HYPERSPECTRAL EVALUATION OF MINE WASTE AND ABANDONED MINE LANDS NASA AND EPA SPONSORED PROJECTS IN IDAHO
Hauff, P.L. (Spectral International Inc., Arvada, CO (pusa@rmi.net)); N. Lindsay; D. Peters; G. Borstad; W. Peppin; L. Costick; Richard Glanzman
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Airborne Geoscience 2000 Workshop Proceedings, 10 pp, 2000

The utilization of remotely sensed hyperspectral data for the evaluation of mine waste and the classification of abandoned mine lands (AML) is rapidly becoming a routine, commercial technology. Spectral International has assembled a consortium of companies and consultants to provide evaluation and monitoring capabilities through hyperspectral surveys using AVIRIS (Airborne Visible InfraRed Imaging Spectrometer) and new generation airborne sensors such as CASI (Compact Airborne Spectrographic Imager) and SFSI (SWIR Full Spectrum Imager). Partly through the auspices of the NASA EOCAP program and the Environmental Protection Agency AML (Abandoned Mine Lands) Project, sites in Utah and Idaho are currently under investigation. This paper will present a preliminary look at the Idaho study and discuss the methods used. AVIRIS images and generalized analytical data
will be shown in this paper as the hyperspectral CASI and SFSI images and most of the analytical data have yet to be released by the EPA. The EPA has made a commitment to the use of hyperspectral methods in the evaluation of mine waste distribution in the Coeur d'Alene River Basin project. The area under investigation includes the lateral lakes area along the south fork of the Coeur d'Alene River from Rose Lake east to the Mission State Park, as well as the Canyon Creek and Nine Mile Canyon catchment areas and drainage. More Info: http://makalu.jpl.nasa.gov/docs/workshops/toc.htm

REMOTE MINERAL MAPPING USING AVIRIS DATA AT SUMMITVILLE, COLORADO AND THE ADJACENT SAN JUAN MOUNTAINS
King, T.V.V.; R.N. Clark; C. Ager; G.A. Swayze
Proceedings: Summitville Forum '95
Colorado Geological Survey Special Publication 38, p 59-63, 1995

Most naturally occurring and man-made materials absorb and scatter sunlight at specific wavelengths. The spectral information is a measure of how reflected sunlight interacts with a surface. It is these absorptions that produce the colors sensed by the human eye. For instance, absorption by plants produces the green color observed by the human eye. Just as every human has a characteristic thumb-print, each mineral and manufactured material has a unique spectral signature that is related to chemical composition, grain size, degree of crystallinity, or temperature of formation. Subtle differences in the reflectance spectra of minerals can indicate major differences in chemistry or some physical parameters. Spectral information can be gathered from laboratory samples, remotely sensed by aircraft or satellite systems, therefore providing a powerful mapping tool. Imaging spectroscopy is a mapping technique that uses remote sensing technology. The narrow spectral channels of an imaging spectrometer form a continuous reflectance spectrum of the Earth's surface, which contrasts with the 4 to 7 channels of the previous generation of imaging instruments, for example the Landsat Thematic

Mapper (TM) and Multispectral Scanner (MSS) instruments. Systems like Landsat can distinguish general brightness and slope differences in the reflectance spectrum of a surface. However, imaging spectroscopy has the advantage of providing compositional information based on the presence and position of absorption bands, as well as contributing data on brightness and slope. The system used to collect data for this study is the NASA Airborne Visible and Infra-Red Imaging Spectrometer (AVIRIS) instrument. AVIRIS acquires data in the spectral range from 0.4 micron to 2.45 microns in 224 continuous spectral channels. The instrument is flown in an ER-2 aircraft (a modified U-2
spy plane) at 19,800 meters (~65,000 feet). The swath width is approximately 11 kilometers and the swath length can be as great as 1000 kilometers. The image is composed of many data points, called pixels (614 pixels in an 11 kilometer swath width). Each pixel is a three-dimensional data point consisting of an X-, Y-, and Z- component. Each pixel represents a surface area (the X- and Y-components) approximately 17 meters square and contains information on the chemical and mineralogical character of the material (the Z- or spectral component). Spectra acquired by remote measurements are interpreted by comparison with laboratory spectra from well characterized samples.
An analysis algorithm called "tricorder" uses a digital spectral library of known reference materials and a fast, modified-least-squares method of determining if a diagnostic spectral feature for a given material is present in the image. The tricorder analysis compares continuum-removed spectra from the remotely sensed data to a database of continuum-removed spectral features from the reference spectral library. Multiple features from multiple materials are compared and the material with the closest match is mapped. The algorithm does not force a positive match, which makes if different from many other
algorithms in use. The tricorder algorithm attempts to map only minerals included in the reference database.

SPECTRAL BAND SELECTION FROM CASI DATA FOR MONITORING MINE TAILINGS SITE REHABILITATION
Lévesque. J.; T. Szeredi; K. Staenz; V. Singhroy
20th Canadian Symposium on Remote Sensing, Calgary, May 11-14, 1998

The authors examine the effect of varying bandwidth and number of bands on spectral unmixing results of Compact Airborne Spectrographic Imager (casi) data acquired over a mine tailings site. Quickbird, Ikonos, and Orbview, forthcoming high spatial resolution sensors with fewer bands and larger bandwidths, were simulated to determine whether the same unmixing results can be achieved as with the 68-band casi data.

ENVIRONMENTAL STUDY OF THE BONANZA MINING DISTRICT, COLORADO USING AVIRIS AIRCRAFT, SATELLITE, AND TERRAIN DATA
Live, K. Eric; Ken Watson; Dan H. Knepper, Jr.; Susanne Hummer-Miller
U.S. Geological Survey, Denver, CO
Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 7 pp, 1998

The objective of this study was to describe the mineralization, altered rock, and mining impacts on the environment of the Kerber Creek drainage within the Bonanza Mining District, Colorado, using several types of remotely sensed data. Several types of data sets were analyzed, including imagery, map data, and point data. These data were assembled into a coregistered database where features were correlated between layers visually and/or combined through masking. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/98_docs/34.pdf

DIGITAL DATA FOR WATERSHED CHARACTERIZATION OF ABANDONED MINE LAND

Martin, E. Paul, U.S. Geological Survey, Denver, CO

Science for Watershed Decisions on Abandoned Mine Lands: Review of Preliminary Results, 4-5 February 1998, Denver, CO

U.S. Geological Survey Open-File Report 98-297, 1998

The USGS produces a number of standard digital products that represent base cartographic, elevation, and image information in support of a wide range of applications. In some applications, these data act strictly as a reference or background cover, and in some cases, these data are integrated with scientific information to form a knowledge base for subsequent analysis and decision making. Both cases apply to the USGS Abandoned Mine Land Project in order to characterize the watersheds. A digital elevation model (DEM) provides an array of elevation values that represent the terrain. When brought into a geographic information system, the software can transform the grid values into a shaded relief topographic view. While certain features are easily discernible, the DEM does not present a true picture of the ground features. A digital orthophoto quadrangle (DOQ) yields a clear view of these ground features. The DOQ is an image product derived by differential rectification from a perspective aerial photograph or other remotely sensed image data. Image displacements caused by camera tilt and terrain relief are removed. The DOQ combines the image characteristics of a photograph with the geometric qualities of a map. The DEM and DOQ in concert render a unique representation in which both the elevation and natural and cultural features are accentuated. The DOQ provides a source from which to ground truth existing vector data (for example, a digital line graph's (DLG) spatial location) or from which to compile new cultural and natural features. The combination of DEM and DOQ with DLGs (or other vector data) draped over the landscape gives a comprehensive watershed view. With the addition of more detailed scientific information and coverages (for example, water-quality data, dump-site characteristics, and geology), one now has the watershed information from which to perform more detailed analysis within the geographic information system or other modeling software.

WATERSHED CHARACTERIZATION FROM THE AIR: APPLICATION OF GEOPHYSICAL TECHNIQUES TO WATERSHED CHARACTERIZATION IN THE BOULDER RIVER WATERSHED, MONTANA

McCafferty, A.E.; B.D. Smith, U.S. Geological Survey, Denver, CO

Science for Watershed Decisions on Abandoned Mine Lands: Review of Preliminary Results, 4-5 February 1998, Denver, Colorado

U.S. Geological Survey Open-File Report 98-297, 1998

During December 1996 and October 1997, two airborne geophysical surveys were flown over parts of the High Ore, Cataract, and Basin Creek drainages. The primary objectives of the surveys were to 1) provide subsurface information on ground-water flow and physical-property patterns to aid in prediction of possible contaminant pathways to and from proposed repository sites, 2)characterize the conductivity and magnetization of shallow geologic units to aid in identification of metal-rich rocks contributing to the metal loads in the High Ore, Cataract, and Basin Creek drainages, and 3) provide site-specific information for remediation and/or risk-assessment issues.

MINERAL MAPPING USING PARTIAL UNMIXING AT RAY MINE, AZ

McCubbin, I. (Univ. of California, Santa Barbara. Geography Dept.); R. Green (Jet Propulsion Lab., California Inst. of Technol., Pasadena, CA); H. Lang; D. Roberts

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 4 pp, 1998

Imaging Spectroscopy enables the identification and mapping of surface mineralogy over large areas. This study focused on the use of Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data for environmental impact analysis over Ray Mine, Arizona. Using the Spectral Angle Mapper (SAM) algorithm in conjunction with AVIRIS data makes it possible to classify surface materials that are indicative of acid generating minerals. The improved performance of the AVIRIS sensor since 1996 provides data with a high enough signal-to-noise ratio to characterize multiple image endmembers (>5). In this study, we used SAM to map minerals associated with mine-generated waste--jarosite, goethite, and hematite--in the presence of a complex mineralogical background. Currently, the EPA's Advance Measurement Initiative (AMI) is using remote sensing instruments such as AVIRIS to collect data that can be used for detection of pollutants prior to their release by mining operations. These releases tend to be associated with natural disasters and open pit processes, even though the mine operator has attempted to prevent release under normal conditions. Imaging spectroscopy could provide the mineral extraction industry a new synoptic tool for monitoring mining
operations. Enhanced monitoring will allow for better understanding of the materials present within an open pit mine. The availability of spatial data of specific locations of high-risk materials could contribute to the prevention of future unnecessary accidents. Furthermore, the synoptic view offered by remote sensing can provide the mining industry an improved understanding of the surface geology within a region of interest for exploration or mine development. This type of AVIRIS-based target endmember determination has been used to identify and characterize acid-generating materials
associated with hard rock mining. More Info: http://makalu.jpl.nasa.gov/docs/workshops/98_docs/35.pdf

THERMAL INFRARED MULTISPECTRAL SCANNER (TIMS)
National Aeronautics and Space Administration, Dryden Flight Research Center, Web Site Information

NASA Stennis Space Center, the Jet Propulsion Laboratory (JPL), and Daedalus Corporation have developed the Thermal Infrared Multispectral Scanner (TIMS) for exploiting mineral signature information. The TIMS is a Daedalus multispectral scanning system using a dispersive grating and a six element mercury cadmium telluride detector array to produce six discrete channels in the 8.2 to 12.2 micron region. Used as an airborne geologic remote sensing tool, the TIMS acquires mineral signature data that permits the discrimination of silicate, carbonate and hydrothermally altered rocks. The instrument belongs jointly to the NASA Stennis Space Center and JPL. The TIMS is flown on the C-130, ER-2, and the Stennis Learjet aircraft. More Info: http://www.dfrc.nasa.gov/Projects/airsci/general/er-2/tims.html

AVIRIS: AIRBORNE VISIBLE INFRARED IMAGING SPECTROMETER
National Aeronautics and Space Administration, Jet Propulsion Laboratory, California Inst. of Technology, Pasadena, CA. AVIRIS Project Web Site

AVIRIS is an acronym for the Airborne Visible InfraRed Imaging Spectrometer. AVIRIS, a project of NASA's Jet Propulsion Laboratory, is a world class instrument in the realm of Earth Remote Sensing. It is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels or bands with wavelengths from 400 to 2500 nanometers (nm). A NASA ER-2 airplane, which is a U2 plane modified for increased performance, flies the instrument at approximately 20 km above sea level, at about 730 km/hr. The main objective of the AVIRIS project is to identify, measure, and monitor constituents of the Earth's surface and atmosphere based on molecular absorption and particle scattering signatures. Through measurement of the solar reflected spectrum, a range

of scientific research and application is being pursed using signatures of energy, molecules, and scatterers in the spectra measured by AVIRIS. Mineralogy, soil types, environmental contaminants, and geological substrates are just a few of the areas under study. More Info: http://makalu.jpl.nasa.gov/

PRELIMINARY INVESTIGATION INTO THE USE OF SPECTRORADIOMETRY TO DETECT ACID MINE DRAINAGE STRESS IN VEGETATION IN ELLIOT LAKE, ONTARIO
Pappin, S., P.J. Beckett and G.M. Courtin
Proceedings, 16th Canadian Symposium on Remote Sensing, Sherbrooke, Quebec. p 799-804, 1993

UNMIXING OF SIMULATED ASTER DATA WITH APPLICATIONS FOR THE ASSESSMENT OF MINING IMPACTS IN CENTRAL GERMANY
Reinhaeckel, G. (DLR Institut fuer Optoelectronik); B. Zhukov; D. Oertel; A. Mueller; P. Strobl
Imaging Spectrometry IV
Proceedings of SPIE, Vol 3438, p 345-354, 1998

The multi-sensor multi-resolution technique (MMT) was used to unmix simulated ASTER data. The simulation was performed using airborne spectrometer data of the open lignite mine Zwendkau in the Central German lignite mining district. The unmixing of low resolution ASTER thermal IR images with the reflective bands allowed for significant improvement of the spatial resolution. The radiometric accuracy was estimated using reference images and extracted pixel spectra. In comparison to other techniques, the MMT preserves the radiometric information in the TIR. Therefore, the spectral information can be used for a mineralogical analysis of the dumped material.

MERGING REMOTE-SENSING IMAGES FOR GEOLOGICAL-ENVIRONMENTAL MAPPING: APPLICATION TO THE CABO DE GATA-NFJAR NATURAL PARK, SPAIN
Rigol, J. P.; M. Chica-Olmo
Environmental Geology, Vol 34 No 2/3, p 194-202, 12 May 1998

The Cabo de Gata Nfjar Natural Park in Spain has been affected by mining activities that were carried out up until ten years ago. The mining and waste-tip areas have been defined and a lithological discrimination carried out using various remote-sensing techniques employed to create high-resolution image documents on which the geological and environmental mapping of the area could be based. The merging of remote-sensing images with different spatial/spectral resolutions has become a highly useful tool, due to their increasing availability. The SPOT panchromatic and Landsat Thematic Mapper multispectral images are two of the most commonly used images in geological and environmental studies based on remote sensing. This paper analyses techniques for merging remote sensing image data based on Intensity-Hue-Saturation, Principal Component Analysis, Spherical Coordinates, High-Pass Filters and Color Normalized transform using SPOT panchromatic and Landsat TM data.

REMOTELY-SENSED MULTISPECTRAL REFLECTANCE VARIATIONS IN ACIDIC VERSUS NEAR-NEUTRAL CONTAMINATED COAL MINE DRAINAGE IN PENNSYLVANIA

Robbins, E.I.; G.L. Nord, Jr. (U.S. Geological Survey, Reston, VA); J.E. Anderson (Virginia Commonwealth Univ., Richmond, VA); C.A. Cravotta III, (U.S. Geological Survey, Lemoyne, PA); E.T. Slonecker (U.S. EPA, Reston, VA)

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1551-1559, ©2000

Remote sensing is being tested for its ability to identify the severity of impact on streams that are subjected to contaminated mine drainage (CMD) in the Southern Anthracite Coalfield of Pennsylvania. Airborne digital multispectral video images of acidic and near-neutral CMD are being compared with field spectra, water chemistry, mineralogy, and microbiology. Spectral differences in the visible region of the electromagnetic spectrum are caused by the presence of schwertmannite in the acidic precipitates and ferrihydrite in the near-neutral precipitates. The acidic CMD averages 1,500 mg/L sulfate and has bacteria coated with schwertmannite; the near-neutral CMD averages 87 mg/L sulfate and has bacteria coated with ferrihydrite.

MICROBIAL AND SPECTRAL REFLECTANCE TECHNIQUES TO DISTINGUISH NEUTRAL AND ACIDIC DRAINAGE

Robbins, E.I.

U.S. Geological Survey Fact Sheet, FS-118-99, 4 pp, 1999

New technology that allows above-ground measurements of reflected light is being tested to characterize mine drainage on the basis of the spectral properties of various iron minerals. Cooperative work between the USGS, the Army Corps of Engineers, and the Pennsylvania Department of Environmental Protection demonstrates that certain remote sensing tools can be used to differentiate between acidic and neutral waters because the iron flocculates in acid water have distinctly different spectral signatures from those formed in neutral water. A hand-held, field spectroradiometer produces graphical displays showing that the yellow-hued flocculates in acidic water have higher spectral reflectances than the red-hued flocculates formed in neutral water. An aerial technique using a 4-channel, digital multispectral video system (DMSV) can create digital composite images of the flocculates using specific wavelength filters. The images show a uniformly bright yellow or yellow-green signal above acidic water having yellow flocculates when the filtered video channels are combined in certain ways. The fact sheet is available at http://geology.usgs.gov/fact-sheets/1999.html

PRELIMINARY MATERIALS MAPPING IN THE PARK CITY REGION FOR THE UTAH USGS-EPA IMAGING SPECTROSCOPY PROJECT USING BOTH HIGH AND LOW ALTITUDE AVIRIS DATA

Rockwell, B.W.; R.N. Clark; K.E. Livo; R.R. McDougal; R.F. Kokaly; J.S. Vance
U.S. Geological Survey, Denver, CO (http://speclab.cr.usgs.gov)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Airborne Geoscience 2000 Workshop Proceedings, 11 pp, 2000

This paper presents the preliminary results of AVIRIS-based materials mapping in the region surrounding Park City, Utah. This work was performed as a part of the USGS-EPA Utah Abandoned Mine Lands (AML) Imaging Spectroscopy Project, in which spectroscopic imaging and analysis is being employed for watershed evaluation in areas of past and present mining activity. The objective of the project is to map surface mineralogy and vegetation type/vigor in five major mining districts in Utah with the

purpose of identifying sources and environmental effects of acid drainage. The Park City district, located approximately 35 km ESE of Salt Lake City, Utah, is of particular interest because Park City will be the site of the winter Olympics in 2002. The preliminary results presented here will be field checked during the summer of 1999. It is anticipated that these results will aid the other researchers in private industry and academia who are participating in the USEPA-sponsored Utah AML project. The results and detailed information regarding AVIRIS data calibration will be available online at the USGS Spectroscopy Laboratory web site. More Info: http://makalu.jpl.nasa.gov/docs/workshops/toc.htm

UTILIZATION OF AIRBORNE MAGNETIC, ELECTROMAGNETIC, AND RADIOMETRIC DATA IN ABANDONED MINE LAND INVESTIGATIONS

Smith, B.D.; A.E. McCafferty; R.R. McDougal, U.S. Geological Survey, Denver, CO

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1525-1530, ©2000

Magnetic, electromagnetic, and radiometric airborne survey data have been used in regional and local (drainage basin) scales. In a regional geoenvironmental assessment of the state of Montana, magnetic and radiometric data compiled from airborne surveys were used along with other digital geologic and geochemical data to prioritize mining districts for potential acid water generation. Probability ratio mapping was done in order to integrate the interpretation of many different digital data sets. On a more local scale, the Animas (CO) and Boulder Basin (MT) watersheds have been studied using helicopter geophysical surveys. The airborne geophysical surveys show many more structural features than the geologic maps. Combined interpretation of the geophysical data sets using the probability ratio method has resulted in identification of areas of alteration. Airborne radiometric data in the Boulder Basin area suggests that rocks with high potassium and thorium also have a high acid water buffering capacity.

EVALUATION OF CASI AND SFSI HYPERSPECTRAL DATA FOR ENVIRONMENTAL AND GEOLOGICAL APPLICATIONS: TWO CASE STUDIES

Staenz, K.; R.A. Neville; J. Lévesque; T. Szeredi; V. Singhroy; G.A. Borstad; P. Hauff

Canadian Journal of Remote Sensing, Vol 25 No 3, p 311-322, Aug 1999

The article reports on the evaluation of the Compact Airborne Spectrographic Imager (casi) and the SWIR (Short-Wave Infra-Red) Full Spectrum Imager (SFSI) for environmental and geological applications. Two case studies are presented: the first an identification of minerals at Cuprite, Nevada; and the second, an environmental characterization of a mine site near Sudbury, Ontario. The Sudbury site was evaluated using casi visible and near infrared (VNIR) (450 nm - 900 nm) data. SFSI SWIR II (9200 nm - 2400 nm) data were used for the Nevada site. Surface reflectances were retrieved prior to the application of spectral unmixing for the identification of specific materials and subsequent validation of the extracted information. The SFSI data showed clearly identifiable spectral features of the alteration minerals alunite, kaolinite, and buddingtonite. Generally good agreement was obtained between the mineral Classification map and data retrieved from the Airborne Visible/Infrared Imaging
Spectrometer (AVIRIS). Results derived from casi data demonstrated that vegetation, lime, oxidized tailings, fresh tailings, and water could be discriminated with spectral unmixing. Ground verification of the data also showed good agreement.

USING IMAGING SPECTROSCOPY TO COST-EFFECTIVELY LOCATE ACID-GENERATING

MINERALS AT MINE SITES: AN EXAMPLE FROM THE CALIFORNIA GULCH SUPERFUND SITE IN LEADVILLE, COLORADO

Swayze, G.A.(U.S. Geological Survey, Denver, CO); R.N. Clark; K.S, Smith; P.L. Hageman; S.J. Sutley; R.M. Pearson; G.S. Rust; P.H. Briggs; A.L. Meier; M.J. Singleton; S. Roth

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1998 JPL Airborne Geoscience Workshop Proceedings, 1998

The Leadville mining district, located at an elevation of 3000 m in the Central Colorado Rockies, has been mined for gold, silver, lead, and zinc for more than 100 years. This activity has resulted in the dispersal of waste rock and tailings, rich in pyrite and other sulfides, over a 30 square km area including the city of Leadville. Oxidation of these sulfides releases lead, arsenic, cadmium, silver, and zinc into snowmelt and thunderstorm runoff, which drains into the Arkansas River, a main source of water for Front Range urban centers and agricultural communities. The U.S. EPA, U.S. Bureau of Reclamation (USBR), contractors, and responsible parties are remediating the mined areas to curtail further releases of heavy metals into various drainage tributaries of the Arkansas River. Mineral maps made by the USGS from AVIRIS data collected over this ining district were used to focus remediation efforts by locating the point sources of acid drainage. More Info:
http://makalu.jpl.nasa.gov/docs/workshops/98_docs/49.pdf

IMAGING SPECTROSCOPY: A NEW SCREENING TOOL FOR MAPPING ACIDIC MINE WASTE

Swayze, G.A.; K.S. Smith; R.N. Clark; S.J. Sutley, U.S. Geological Survey, Denver, CO

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1531-1540, ©2000

Imaging spectroscopy is a relatively new remote sensing tool that provides a rapid method to screen entire mining districts for potential sources of surface acid drainage. An imaging spectrometer, Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS), measures light reflected from the surface in 224 spectral channels from 0.4 - 2.5 µm. Spectral data were used to evaluate mine waste at the California Gulch Superfund Site near Leadville, CO. Here, the process of pyrite oxidation at the surface produces acidic water that is gradually neutralized as it drains away from mine waste, depositing a central jarosite zone surrounded by a jarosite + goethite zone, in turn surrounded by a goethite zone with a discontinuous hematite rim zone. Leaching tests show that pH is most acidic in the jarosite and jarosite+goethite zones and is near-neutral in the goethite zone. The U.S. EPA estimates (U.S. EPA, 1998) that AVIRIS data have accelerated remediation efforts by two years and saved over $2 million in cleanup costs at Leadville.

INVARIANT SUBPIXEL MATERIAL IDENTIFICATION IN AVIRIS IMAGERY

Thai, Bea; Glenn Healey; David Slater
UC Irvine, Dept. of Electrical and Computer Engineering, Computer Vision Laboratory Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): 1999 JPL Airborne Geoscience Workshop Proceedings, 8 pp, 1999

The authors present an algorithm for subpixel material identification that is invariant to the illumination and atmospheric conditions. The target material spectral reflectance is the only prior information required by the algorithm. A target material subspace model is constructed from the reflectance using an image formation model, and a background subspace model is estimated directly from the image. These two subspace models are used to compute maximum likelihood estimates for the target material component and the background component at each image pixel. These estimates form the basis of a

generalized likelihood ratio test for subpixel material identification. Experimental results are presented that use AVIRIS imagery of a region of the mining district in Cuprite, Nevada, to demonstrate the utility of the algorithm for subpixel material identification under varying illumination and atmospheric conditions. More Info: http://makalu.jpl.nasa.gov/docs/workshops/99_docs/57.pdf

RAY MINE PILOT STUDY: ADVANCED MONITORING OF HAZARDOUS WASTE SITES: DISCRIMINATION AND SCREENING OF PROBLEM MINE AND EXTRACTIVE INDUSTRY WASTES

U.S. EPA; Consortium for International Earth Science Information Network (CIESIN)

The purpose of the Ray Mine pilot study is to develop and demonstrate advanced remote sensing-based methodologies for characterizing mining wastes, monitoring their effects on the environment, and assessing and communicating the risks associated with migration of pollutants during natural events. This project represents a pilot activity that includes cooperative work funded by EPA's Advanced Measurement Initiative (AMI) and NASA under their Geology and Natural Hazards Research Program (NRA). An associated stakeholders process has been funded by the EPA's Office of Policy, Planning and Evaluation and the EPA/ORD AMI. More Info: http://epawww.ciesin.org/raymine/

INTEGRATING AVIRIS IMAGERY AND FIELD SPECTRA FOR MINING SITE EVALUATION

Wawrzynski, A.L.; R.W. Marrs

Geological Society of America Abstracts with Programs, Vol 29 No 6, p 41, 1997

GIS and Airborne Visible Infrared Imaging Spectrometer (AVIRIS) were used along with field geology in two mining districts in Wyoming. The South Pass-Atlantic City area, a historical gold and iron mining district, presents extensive alteration, mineralization, and tailings. The extent of surface mineralization and transport of weathered tailings can be seen clearly on the AVIRIS imagery. The second area is the Copper King porphyry copper-gold deposit. The structure and extent of the mineralized ore body and associated alteration can be easily mapped from the imagery. Core samples from the deposit enable a ground truthing of the imagery and provide a spatial three-dimensional model of the deposit when a GIS is used to combine the imagery and field data.

APPRAISEMENT OF ENVIRONMENT REMOTE SENSING METHOD IN MINING AREA

Yang, F. (Shandong Institute of Mining and Technology); Z. Han; T. Jiang; L. Lei; C. Gong

Optical Remote Sensing for Industry and Environmental Monitoring

Proceedings of SPIE, Vol 3504, p 464-472, 1998

The monitoring and protection of the coal-mine environment is a developing profession in China. Sulfur dioxide, carbon dioxide, carbon monoxide, and other waste gases, which are put out by the spontaneous combustion or weathering of gangue, are an important source of atmospheric pollution. Smoke, coal dust, and powdered coal ash pollute the mining area and surrounding land under the influence of monsoon winds. The pH value of coal mine drainage water is low, and water for drinking, farming, and animal husbandry is affected. Remote sensing is being used as an environmental investigation method that is rapid and inexpensive to detect such phenomena as subsidence in mining areas. This paper appraises environmental monitoring of mining sites by different methods of remote sensing.

USING AVIRIS IMAGERY AND FIELD SPECTRA FOR THE EVALUATION OF MINING SITES

Wawrzynski, A.L.; R.W. Marrs, Dept. of Geology & Geophysics, Univ. of Wyoming, Laramie

Thirteenth International Conference on Applied Geologic Remote Sensing 1999

AVIRIS imagery was combined with field observations to evaluate two mining districts in Wyoming. The extent and intensity of alteration was successfully mapped using the imagery and the distribution of tailings and other waste products was defined and evaluated for mineral content. Interpretations of imagery, combined with field data and spectral analysis of samples and cores (using a hand held mid-infrared spectrometer), yields a more complete model of the ore body and associated alteration patterns. At the Copper King Mine in southeast Wyoming, the AVIRIS imagery was used to determine the lateral extent of the exposed ore body and the associated alteration. The ore body is a porphyry copper-gold deposit localized along and between east-west shear zones. Numerous core samples help constrain the model, from which a three dimensional view of the body was derived. The South Pass-Atlantic City area contains abundant tailings from historic mining. The AVIRIS imagery provides a way to determine the surface distribution of the mineralization, the surficial extent of the tailings, and to monitor movement of materials weathered from the tailings. The results of this study indicate that the tailings do not contain significant concentrations of acid producing minerals, and only minor occurrences of such minerals were found in the area. We are now examining waste products in the area of the ore processing operations and exploring potential environmental problems associated with these operations.

SATELLITE AND AIRBORNE REMOTE SENSING TO DETECT HAZARDS CAUSED BY UNDERGROUND MINING

Kuehn, F.; G. Trembich; B. Hoerig
Federal Inst. for Geosciences and Natural Resources, Berlin, Germany

Thirteenth International Conference on Applied Geologic Remote Sensing 1999

Satellite and airborne remote sensing is used to detect hazards due to subsidence and collapse caused by mining. There are several abandoned underground lignite and potash mines in the area of investigation. Only parts of the abandoned lignite mine have been stabilized by backfilling with tailings or other material. Flooding of the potash mines has enlarged the mine cavities. Both have led to subsidence and the formation of collapse sinkholes. Detailed knowledge of the site is needed to assess the trends in time and space of surface destabilization and to minimize the hazards. Remote sensing has been used to supplement traditional geotechnical investigations. Special approaches to processing and interpreting satellite data (Landsat TM, Spot, IRS-1C) has contributed to locating unstable ground. Anomalous features observed on satellite images correlate with zones characterized by dense networks of tension fractures identified by traditional methods. Several airborne remote sensing systems have been used for special investigations at scales of 1:10,000 to 1:2000 (e.g., aerial photography, thermal scanning, laser scanning, airborne SAR). Remote sensing methods have been significantly improved by integration of laser scanning into the sensing system. Laser scanning revealed gentle depressions in the study area which -- associated with features suggesting fracturing -- indicated the early stages of subsidence. The efficiency of the applied methods was confirmed when a huge collapse sinkhole formed at these locations at the beginning of April 1998.

PRODUCTS FOR MONITORING AND PLANNING RECULTIVATION OF FORMER MINING AREAS IN EASTERN GERMANY, BASED ON AIRBORNE AND SATELLITE REMOTE SENSING DATA

Monika, N.; A. Kühnen, G.E.O.S. Freiberg, Freiberg, Germany

Thirteenth International Conference on Applied Geologic Remote Sensing 1999

Since the 17th century, lignite, and since 1949 uranium, have been mined in eastern Germany,

accompanied by the devastation of large areas of nature, ecosystems and human habitats. In the last few years great endeavors have been made to stop and to prevent further pollution as well as to renaturalise these areas. Positive aspects and developments can already be seen. In comparison, the negative consequences arising from underground ore mining seem to be not so dramatic on first view. In close cooperation with mining companies and relevant environmental and planning authorities, cost- and time-effective remote sensing products are being, and will continue to be, developed as useful tools for administration, planning, monitoring and recultivation of the vast mining areas in eastern Germany. This paper discusses the possibility of developing products for better and faster monitoring and planning recultivation activities in these former mining areas, based on high resolution airborne and satellite remote sensing data. On the basis of selected examples it will be shown how the status quo of a devastated mining area can be ascertained and documented, and how changes over time can be made visible and analyzed. Integrated into the remote sensing products will be additional data such as information from old mining maps, radiation measurements, or information gathered during on-site investigations. Based on these products, recultivation activities can be planned and simulated.

AN EVALUATION OF THE MODULAR AIRBORNE IMAGING SPECTROMETER (MAIS) DATA FOR ITS POTENTIAL IN ASSESSING THE REHABILITATION OF AN ABANDONED URANIUM-COPPER MINE SITE, NORTHERN TERRITORY, AUSTRALIA

Pfitzner, Kirrilly Sue, Northern Territory Univ., Australia

Thirteenth International Conference on Applied Geologic Remote Sensing 1999

Modular Airborne Imaging Spectrometer (MAIS) 64-channel scanner data covering the visible to short-wave infrared spectral region was evaluated for monitoring a rehabilitated uranium-copper mine site in northern Australia. Statistical analysis suggested data reduction from 64 original bands to 40 bands for processing. Merging of channels resulted in increased band variability and image sharpness that should prove useful when selecting bands for land cover discrimination. The image geometry varied for channels recorded by the visible near infrared (VNIR) and short-wave infrared (SWIR) spectrometers, as these were acquired on two separate flight runs. Spatial resolution varied within runs as well as between runs. Various registration models and resampling methods were trialed, with linear transformations in the VNIR and non-linear transformations in the SWIR providing optimal results. Assessments of spatial and spectral capabilities and limitations of MAIS data was required to ascertain the potential usefulness of this data set for future research into mine site rehabilitation assessment.

IDENTIFICATION AND CHARACTERIZATION OF FERRICRETES IN IMAGING SPECTROMETER DATA: APPLICATIONS TO ENVIRONMENTAL CHARACTERIZATION OF THE EARTH AND MARS

Farrand, W.H., Farr View Consulting, Westminster, CO

Lunar and Planetary Science XXX, Proceedings
Lunar and Planetary Institute, Houston (CD-ROM). Abstract #1936, 1999

Ferricretes are found on Earth at locations where waters that are highly enriched in iron emerge in springs. The iron precipitates out and cements existing colluvial materials. Ferricretes are the result of drainage from naturally occurring acidic metal-rich springs. Assemblages in which the iron-rich precipitate volumetrically outweigh the colluvium can be known as "ferrosinters." These unusual rocks are important for several reasons. Their presence in mineralized districts on Earth can be used as indicators of that mineralization and thus can be used as an aid in mineral exploration. For an area that has already been identified as a target for mineral exploration, the identification of ferricretes in the surrounding territory is

evidence of naturally occurring acid water run-off and thus is important data for environmental baseline assessments. Ferricretes and ferrosinters can also incorporate and entomb organic debris which can be used to date the deposit. The ferric oxides and oxyhydroxides that compose ferricretes have distinctive spectral signatures which are readily identified in airborne imaging spectrometer data such as is provided by NASA's AVIRIS instrument. Examples will be presented of the identification and characterization of these deposits in AVIRIS scenes collected over the Summitville Mining District in southwest Colorado and in the Virginia City District in Nevada. We will also show thermal IR spectra of these deposits and discuss their relevance to the analysis of Thermal Emission Spectrometer (TES) data currently being collected by the Mars Global Surveyor.

ENVIRONMENTAL CONTAMINATE DETECTION USING AVIRIS DATA AT RAY MINE, AZ
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Environmental Research Institute of Michigan, Ann Arbor, MI. 1999

Currently the EPA's Advance Measurement Initiative (AMI) is using remote sensing instruments including the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) to collect data that can be used to detect pollutants associated with mining operations at Ray Mine, AZ. Releases of these pollutants into the environment tend to be associated with natural disasters and/or processes, even though the mine operator has attempted to prevent release under normal conditions. Imaging spectroscopy could provide the mineral extraction industry and the EPA a new synoptic tool for monitoring mining operations. Ray Mine was selected as a demonstration site by AMI to evaluate the use of remote sensing instruments for characterizing and monitoring mine generated waste products. Data analysis techniques are the partial unmixing of endmembers that are indicative of mine generated acid waste using the mixture-tuned matched filter algorithm. This method maps image-derived endmembers that have been determined as "spectrally pure" and identifies all spectrally similar pixels within the scene. Spectrally pure within the image context does not correspond to spectrally pure reference endmembers from a spectral library. Model spectra, which are linear combinations of known minerals from available spectral libraries, have been generated to define the mixture that compose the image-derived endmembers. Preliminary results show that the mineral Jarosite, which is indicative of mine generated acid waste, is contained within the confinesof Ray Mine.

ELECTROMAGNETIC WAVEBAND IN ENVIRONMENTAL MONITORING
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Environmental pollution leads to changes in the electromagnetic radiant specific property of surface features that can be seen in the spectral variations of water, soil, and vegetation. This paper discusses the different categories of surface features, the spectrum variation caused by pollution, the optimum waveband applied to environmental monitoring of mining wastes, and suggestions for the selection of a sensor waveband and its design.