FINAL REPORT

DEVELOPMENT OF RESEARCH INFRASTRUCTURE IN NEVADA FOR THE EXPLOITATION OF HYPERSPECTRAL IMAGE DATA TO ADDRESS PROLIFERATION AND DETECTION OF CHEMICAL AND BIOLOGICAL MATERIALS

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EXECUTIVE SUMMARY

This research was to exploit hyperspectral reflectance imaging technology for the detection and mapping variability (clutter) of the natural background against which gases in the atmosphere are imaged. The natural background consists of landscape surface cover composed of consolidated rocks, unconsolidated rock weathering products, soils, coatings on rock materials, vegetation, water, materials constructed by humans, and mixtures of the above. Human made gases in the atmosphere may indicate industrial processes important to detecting non-nuclear chemical and biological proliferation. Our research was to exploit the Visible and Near-Infrared (NIR) and the Short-wave Infrared (SWIR) portions of the electromagnetic spectrum to determine the properties of solid materials on the earth's surface that could influence the detection of gases in the Long-Wave Infrared (LWIR). We used some new experimental hyperspectral imaging technologies to collect data over the Non-Proliferation Test and Evaluation Center (NPTEC) located on the Nevada Test Site (NTS). The SpecTIR HyperSpecTIR (HST) and Specim Dual hyperspectral sensors were used to understand the variability in the imaged background (clutter), that detected, measured, identified and mapped with operational commercial hyperspectral techniques. The HST sensors were determined to be more experimental than operational because of problems with radiometric and atmospheric data correction. However the SpecTIR Dual system, developed by Specim in Finland, eventually was found to provide cost-effective hyperspectral image data collection and it was possible to correct the Dual system's data for specific areas. Batch processing of long flightlines was still complex, and if comparison to laboratory spectra was desired, the Dual system data still had to be processed using the empirical line method. This research determined that 5-meter spatial resolution was adequate for mapping natural background variations. Furthermore, this research determined that spectral resolution of 10um was adequate, but a signal to noise above 300:1 was desirable for hyperspectral sensors with this spectral resolution. Finally, we acquired a hyperspectral thermal dataset (SEBASS) at 3m spatial resolution over our study area in Beatty, Nevada that can be co-registered with the hyperspectral reflectance, LIDAR and digital Orthophoto data sets. This data set will enable us to quantify how measurements in the reflected infrared can be used to make inferences about the response of materials in the thermal infrared, the topic of our follow-on NA-22 investigation ending in 2008. These data provide the basis for our investigations proposed for the NA-22 2008 Broad Area Announcement. Beginning in June 2008, SpecTIR Corporation and Aerospace Corporation plan to fly the SpecTIR Dual and SEBASS in a stabilized mount in a twin Otter aircraft. This research provides the foundation for using reflected and emitted hyperspectral measurements together for mapping geologic and soil materials in arid to semi-arid regions.

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CHAPTER 1

Overview of the Grant Award

This final report summarizes research conducted under SC-O4-SC999B-PD00, a $2 million grant to the University of Nevada, Reno, including six tasks. Task-4 was to exploit hyperspectral image data for proliferation applications.

Project History

At the beginning of FY 2004, the University of Nevada, Reno (UNR) learned that it had received project funding amounting to $2,000,000 from a fiscal Congressional earmark to the DOE Office of Nonproliferation Research and Engineering (Code-NA). Originally UNR sought an earmark for funding to support sensor research being conducted by the Department of Chemical and Metallurgical Engineering. However, this earmark came out of the DOE NA-22 budget. In October 2004, UNR faculty were advised by e-mail from the Office of the Vice President for Research that there were opportunities to propose to do research for DOE’s NA-22 program, and that DOE program managers would be coming to UNR to hear presentations by faculty on research concepts. When the Arthur Brant Laboratory for Exploration Geophysics (ABLE) learned of the NA-22 interest in remote sensing, Dr. Taranik asked for the opportunity to present its current research on the applications of hyperspectral remote sensing. Our presentation in November 2003 was the last of the day, but received great interest from the DOE NA-22 program managers.

In March 7, 2004 ABLE received guidance from Code-NA on the mission of the office, the technology background and research goal, and research topics. ABLE decided that Topic 2c, Test and Evaluation for Chemical and Biological Detectors, would enable our group to make a significant contribution to the mission of NA-22.

March 30, 2004 ABLE submitted a pre-proposal white paper, entitled, ***"Development of Research Infrastructure in Nevada For the Exploitation of Hyperspectral Image Data to Address Proliferation and Detection of Chemical and Biological Materials, Topic 2C."*** In this pre-proposal to the UNR Vice President for Research we recommended:

- Exploring new procedures for chemical and biological spectral signature detection at the pixel and subpixel level using the next generation of hyperspectral sensors.
- Evaluating the effects of spectral, spatial and radiometric resolution of hyperspectral data for detection and understanding of foreign weapons of mass destruction programs.
- Producing training modules for training of analysts on experimental algorithms needed to analyze the data collected by tested sensors.
- Establishing new research in ABLE for spectral characterization of special chemical and biological materials.
- Creating a network of researchers who are capable of evaluating hyperspectral data to address the nuclear proliferation threat at the origin of source of fissile materials.

Comparison of Actual Accomplishments With Project Goals and Objectives

Pre-proposals were evaluated by UNR faculty, but our pre-proposal was not selected by the UNR Vice President for Research for transmittal to Code NA-22 for evaluation. However, Code NA-22 learned that we submitted a pre-proposal and asked UNR to send our proposal to them as well. Based on NA-22's evaluation of the ABLE pre-proposal, UNR was instructed to include our proposed effort in the FY 2004 research to be funded from Code NA-22. We submitted a finalized proposal on April 3, 2004 through the UNR Office of Research Services. Between April 3 and June 2, 2004 we began interacting with Bechtel managers at the Nevada Test Site (NTS). They steered our project towards supporting the DOE NA-22 program at NTS and collaborations with DOE's Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL) and with the Special Technologies Laboratory (STL) in Santa Barbara. On June 2, 2004, ABLE resubmitted a final revised proposal, with budget, to the UNR Office of Research on June 2, 2004. Eventually we were included in the Shrike Test at the Non-Proliferation Test and Evaluation Center (NPTEC). The UNR package of 6 proposals (Tasks) was sent in June 2004 to the DOE Project Officer, Jeff Lenhert, U.S. Department of Energy/NNSA, NNSA Service Center/AFAD in Albuquerque, NM 87135-5400 . The UNR proposed effort was awarded on September 28, 2004 and authorization for expenditure was approved by UNR's Office of Sponsored Projects for conduct of ABLE's research on October 28, 2004.

The focus of work changed as documented in the following Scope of Work:

1. Through our government contacts, acquire existing spectral libraries of man-made, tagging and non-proliferation-related chemical and biological materials and categorize them for completeness and applicability in future nuclear non-proliferation remote sensing studies.

Results: We developed collaborations with LANL, LLNL, PNNL and NSTec and attended NA-22 Shrike and Tarantula briefings, both at the NTS and in Washington D. C., to learn about existing spectral libraries and how they are being developed for the NA-22 mission.

2. Develop a laboratory spectral measurement capability for the Arthur Brant Laboratory for Exploration Geophysics (ABLE) and to support spectral library development for chemical, biological and other nuclear-related materials not present in existing spectral libraries. (Dr. Wendy Calvin)

Results: Dr Wendy Calvin developed both a laboratory and spectral measurement capability under this project along with funds from her other funded research. The instruments that were developed include: a new Analytical Spectral Devices (ASD) full-range spectrometer for field and laboratory applications. Dr. Calvin we also provided enhancements to her Thermo/Nicolet Nexus 6706 FTIR laboratory spectrometer for measurements from 0.8 to 50 um. The instrument has a smart collector and a Pike technologies DiffusIR attachment for reflectance measurements. An FT-Raman module was added in 2007 that uses a 1064 nm excitation laser for measurement of Stokes-only Raman scattering.

3. Through our DOE collaborators, coordinate with DOE National Laboratories to define information requirements for hyperspectral image data in support of detection of nuclear proliferation. (Dr. Jim Taranik)

Results: Dr. Herb Fry visited ABLE, gave lectures on the processing of hyperspectral data, installed and demonstrated his hyperspectral software for our researchers and agreed to participate in our research efforts. Through Dr. Gus Williams, we met Dr. John DiBenedetto of NSTec, who has visited our campus, our students have worked directly with John, both at UNR and at the NTS, and he agreed to be a collaborator on our projects. We met Travis White of LLNL at Shrike meetings and he agreed to be a collaborator with us as well. Finally, we have an active collaboration with PNNL in the area of signatures and evaluation of signatures.

4. Work with DOE collaborators and DOE National Laboratories to define information needs (targets) for hyperspectral data collection and/or analysis, and develop improved spectral signatures of important hazardous chemical and biological materials. (Dr. Jim Taranik)

Results: We worked with Dr. Gus Williams and Dr. Peter Munding to define how our hyperspectral remote sensing data might support the Shrike and Tarantula missions. We defined that airborne data collection before and after the July experiments, would have the least impact on the already planned experiments and agree to April and September overflights of NPTEC. Dr. Munding enabled us to get the necessary permission to overfly the NPTEC site and have access to the site.

5. Acquire HyperSpecTIR data at a variety of altitudes above mean terrain, conduct ground investigations and compare spectral information acquired over DOE-selected sites at the NTS and other targets selected by our DOE collaborators. Focus detection of targets at the pixel and sub-pixel level at varying spatial resolutions from 0.5 meter to 3 meters. (SpecTIR Corporation)

Results: We acquired several sets of hyperspectral data over the NPTEC site including SpecTIR HyperSpecTIR (HST-2, HST-3) hyperspectral data using two different aircraft (Cessna 206, Cessna 404). These overflights occurred in April, August and September of 206. We then acquired SpecTIR VS Dual data over the NPTEC and other sites for comparison. The HST overflights were marginal because the sensors were not adequately calibrated. However, the SpecTIR-VS Dual (ProSpecTIR, Specim Dual) overflight did yield some good data for analysis. We did investigate a variety of different sensors, having different spatial and spectral resolutions and determined that a ground-spatial resolution of 5 m and a spectral resolution of 10 nm are adequate for understanding the geological and soil variability of the background against which gases are imaged.

6. Analyze newly acquired hyperspectral data collected over NTS, and compare with previously acquired ground and aircraft-based information against DOE information requirements for detection of chemical and biological agents, and non-proliferation of nuclear materials. (ABLE Graduate Students)

Results: Five graduate students and two post doctorate students analyzed the hyperspectral data collected over the NTS NPTEC site and other sites having geological diversity. The reports of their investigations are contained in the various chapters of this final report. The results of their analysis identified the calibration problems with HST data and the promise of the new SpecTIR VS Dual hyperspectral system. Through this analysis the students and post doctorates have defined the useful spatial, spectral and radiometric resolutions needed to resolve ground cover types that are important in understanding background clutter in arid environments. They determined that a signal to noise ranging from a minimum of 300:1 was essential and 1000:1 would permit the discrimination of most spectral classes.

7. Develop graduate student training techniques and modules in chemical, biological and nuclear target detection with hyperspectral remote sensing data. (Dr. Jim Taranik)

Results: Graduate students, with different skills, abilities and knowledge of hyperspectral analysis techniques were utilized for the analysis of the hyperspectral image data acquired under this project. Those with extensive background in the Environment for Visualizing Images (ENVI) software, were challenged by the need to properly calibrate the data. Those students who lacked the principles and concepts of remote sensing behind the ENVI software, had difficulty learning it and ultimately applying it to the analysis of the hyperspectral data over NPTEC. These results are documented in Chapter 13 where the students who lacked remote sensing background documented their experiences in learning ENVI.

8. Establish a network of universities interested in training students and in the validation of hyperspectral data against DOE non-nuclear proliferation information requirements. (UNR, DRI Collaborator).

Results: During the conduct of this research we reached out to Brigham Young University, to Dr. Gus Williams and one of our researchers, Dr. Don Sabol, will be participating on the 18-month review of his program in Provo. Through Dr. Robert Porter, the former Chairman of the Board of the Earth Satellite Corporation, we prepared a cooperative agreement between UNR/DRI and Dartmouth (Dr. Richard Birnie), New Hampshire (Dr. Barry Rock), Rice University (Dr. Ersebet Meryni) and the University of Oklahoma that would lead to the development of a National Center for Hyperspectral Remote Sensing. At this time, the concept of such a National Center is still under discussion and securing private funding is a goal.

Figure 1. Arthur Brant Laboratory for Exploration Geophysics, showing four student workstations (back to back) and large format plotter at left wall. Each workstation has a full complement of the latest hyperspectral image processing software.

CHAPTER 2

Purchase and Installation of Project Equipment

By December 2004, the project was now funded at the University of Nevada, Reno and a series of tasks were accomplished as described in Progress Report 1:

1. Conrad Wright of SpecTIR Corporation attended the initial planning meeting in December 2004 for the July SHRIKE test at the DOE Nevada Test Site.

2. An Analytical Spectral Devices (ASD) Full-Range Infrared Spectrometer was purchased for field support and calibrated in the Arthur Brant Laboratory.

Figure 2. ABLE Spectroscopy Laboratory showing Thermo/Electron FTIR Optical Spectrometer in foreground and ASD Full-Range Field Spectrometer in the background.

3. The older existing ASD Spectrometer in the Arthur Brant Laboratory was sent for calibration to the ASD Laboratory in Boulder, Colorado.

4. Bids for a laboratory FTIR 0.4 – 50 micrometer precision spectrometer were received by Dr. Wendy Calvin and purchase negotiations were initiated.

5. Jim Taranik (PI) and Mark Landers (CEO of SpecTIR) met with DOE Program Managers and DOE Laboratory personnel in NNSA facilities on the NTS to define Task-4 contributions to the SHRIKE test in July 2005. As a result of these meetings, scientists from Los Alamos National Laboratory (LANL) plan to visit UNR to learn first hand about the capabilities of the Arthur Brant Laboratory and its staff. We anticipate that a cooperative program will develop with LANL that may include an internship at LANL for one of our graduate students.

CHAPTER 3

Project Initial Organizational Meetings

The next phase of the investigation was reported in Progress Report 2 and it covered the period January 1, 2005 to March 31, 2007. The following tasks were accomplished:

1. On January 27, 2005, Dr. James V. Taranik, the Project Investigator made a PowerPoint presentation at the Shrike Meeting at DOE's Las Vegas Headquarters on UNR's hyperspectral project and the capabilities of its investigators. During that meeting Dr. Taranik had discussions with Le Ann B. Tichenor, Project Manager Test and Evaluation; Dr. Richard J. Venedam, Principal Scientist; Dr. John A. Di Benedetto, Section Head of the optical Systems Development Group Special Technologies Laboratory; Jeffrey L. Hylden, Project Manager National Security Directorate, PNNL; and John Marcotte, Chief Scientist of ISR Programs Sierra Nevada Corporation.

2. On March 9th, 2005, UNR project personnel participated in the NA-22 Project "Shrike" User Meeting at the NPTEC Classroom on the Nevada Test Site.

3. On March 11, 2005, Dr. Taranik held a project planning meeting at the Mackay School of Earth Sciences and Engineering for the NN-22, Task 4, Hyperspectral Imaging Science Group. This meeting included Mr. Tim Minor, Associate Research Scientist, Desert Research Institute; Dr. John Marcotte, Chief Scientist, Sierra Nevada Corporation; Mr. Tony Hoskins, Chief Flight Engineer, Sierra Nevada Corporation; Mr. A. J. Markow, Flight Engineer, SpecTIR Corporation; Dr. Amer Smailbegovic, Chief Scientist, SpecTIR Corporation and Conrad Wright, Manager of Operations, SpecTIR Corporation. The purpose of the meeting was to define the flight times, flight line orientations and ground truth acquisition for the flight over the Non-Proliferation Test and Evaluation Facility (NPTEC). During this meeting we defined the following:

    a. Schedule for preparation and testing of the SpecTIR HyperSpecTIR Sensor II for the Shrike mission.

    b. Schedule for integration of HyperSpecTIR into the external pod and check out flights with the Sierra Nevada Corporation's Cessna 404 aircraft.

    c. Decision to fly the 4th week in April 2005.

    d. Ground truth acquisition in support of the mission.

    e. Flight line coordinates for the mission, flight AMT and flight speed.

4. During the remainder of March, background information on the NPTEC was collected and several important conversations were held with project coordinators to obtain clearance for aerial data acquisition over the Nevada Test Site. Eventually a date of April 25, 2005 was approved.

CHAPTER 4

Preliminary Analysis of SpecTIR's HyperSpecTIR data over NPTEC

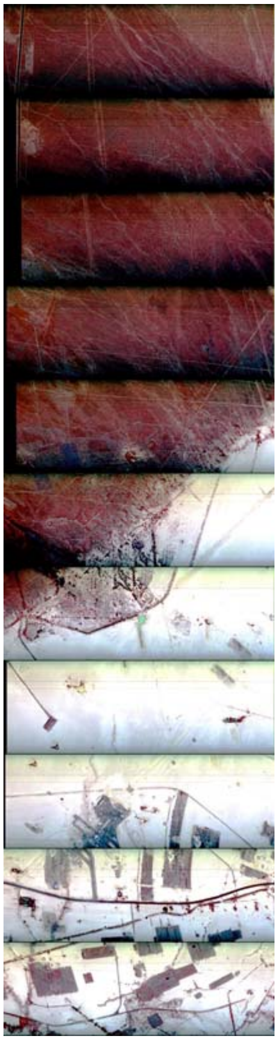
From April 1, 2005 to June 30, 2005, the following was accomplished as reported in Progress Report 3:

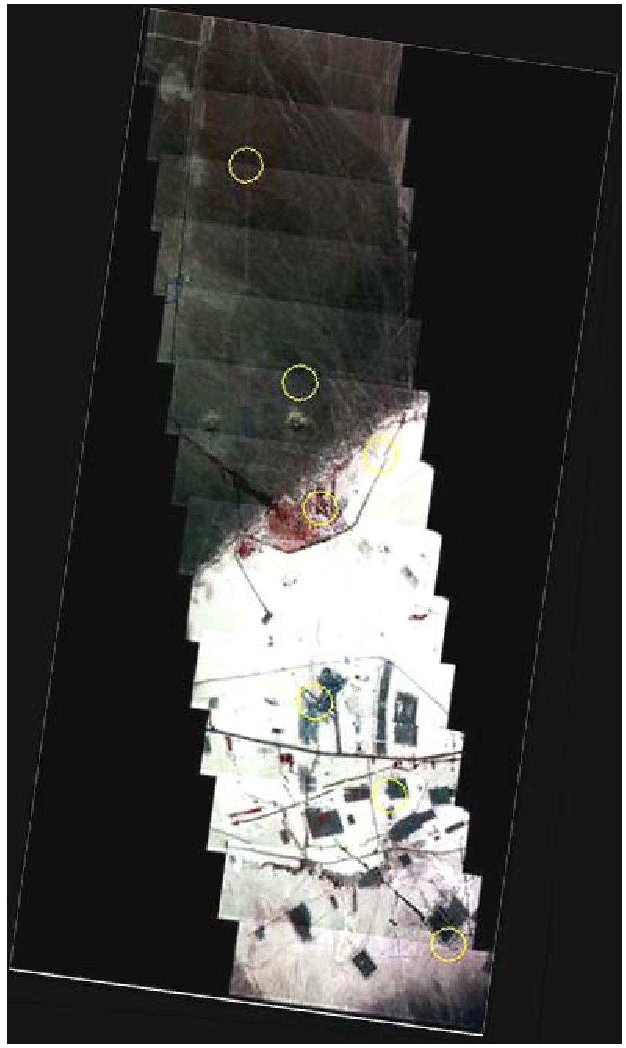
1. Hyperspectral data were acquired on April 26, 2005 at 2-meter spatial resolution over the Non-Proliferation Test and Evaluation Center (NPTEC). Five frames of imagery were preliminary analyzed using two different approaches:
    a. One student used standard Environment for Visualizing Images (ENVI) techniques to determine spectral end members (Morrow).

    b. Another student utilized software programs created by Dr. William Peppin of SpecTIR Corporation (Mahoney).

2. The dataset was collected over NPTEC by SpecTIR on April 26, 2005 by HST-2.

3. The students analyzing this data did not know there were calibration problems with the imagery. Preliminary analysis of the dataset indicated unexplained noise introduced into the data at time of acquisition. The noise was thought to be introduced either by vibration in the sensor pod or on-board electrical problems. Anomalous spikes were found to be inherent to the raw data. The effects of this problem are reduced dimensionality and limited ability to identify pure pixels. The noise manifested itself to a greater extent in the Short-Wave Infrared spectrometer, which is characteristically needs better cooling than that of the Visible/Near-Infrared spectrometer. These problems were not discovered until several months, after the analysis was done by students Mahoney and Morrow.





3a **3b**

Figure 3a – Original quick-look flight line data (3a) and manual mosaic not adjusted for bowtie imaging geometry (3b).

Analysis of April 2005 HST-2 Data by Sarah Mahoney and Blake Morrow:

For this project the main objective was to create a map, using the data provided by SpecTIR, of the Nevada Test Site. The Nevada Test Site (NTS) is a DOE installation occupying approximately 1,350 square miles (882,332 acres) in southeastern Nye County, Nevada about 65 miles (105 km) northwest of the City of Las Vegas[1]. SpecTIR acquired five scenes in April of 2005 over the Nevada Test site. Beginning in June of 2005, SpecTIR finished initial processing of the five scenes. These pre-processed scenes

[1] http://ndep.nv.gov/boff/ffco1.htm

were provided to us as 2-byte Band Interleaved by Line (BIL) files. These files were then imported into the remote sensing software program, ENVI, by standard ENVI processing (Blake Morrow), and by using some software programs created by Bill Peppin of SpecTIR, which allowed for bypassing the standard ENVI processing steps and instead going directly to endmember mapping (Sarah Mahoney).

Procedures:

Standard ENVI processing includes taking the input reflectance files into ENVI, performing the Minimum Noise Fraction (MNF), analyzing the MNF output, determining the dimensionality of the data, deriving endmembers from the data, performing the Pixel Purity Index (PPI), examining the PPI output, making a threshold Region of Interest (ROI) from the PPI output and importing this ROI to the n-Dimensional Visualizer (n-D Vis), creating classes of endmembers with the n-D Vis and exporting these classes to ROIs, performing endmember mapping on the original image using either the Spectral Angle Mapper (SAM) or Mixture Tuned Match Filtering (MTMF) methods or both, and finally investigating the mapped results and determining the identity of the spectral signatures found in the image.

The non-standard processing method involves using some batch processing software, designed by Bill Peppin of SpecTIR. The batch processing method allows for the retrieval of end products more quickly. The method, BatchDestripe, was the necessary first step in observing the data. This is because stripping occurs in this type of hyperspectral data acquisition and it is necessary to remove this variation in response across the image[2]. The output from running this program from file image_1 is "DS_image_1" and "DS_image_1.hdr". After destriping the data, another batch process was used, BatchPP. This program processes a suite of hyperspectral image files in BIL format. For each reflectance image the program performs an MNF transform, whose output is an MNF image, which is then used to find the outlier pixels. Only the bands whose eigenvalues indicate signal-to-noise equal to or larger than one are used to find the extreme pixels. The results of running the BatchhPP program are four files for each input file (image_1), "image_1PP" and "image_1PP.hdr", the ENVI-viewable image of extremal pixels, similar to the output of the ENVI PPI tool. "image_1PPLib" and "image_1PPLib.hdr", which contain some or all of the pixels found as an ENVI spectral library, sorted so that the "purest" endmember pixels are at the top of the list. BatchPP can be run on the previously destriped data, however, the removal of the striping from the original image distorts the spectra, therefore it is necessary to draw the pure pixels from the original image[3]. Another assignment was to compare the final processed images to each other. This helps make sure that the two methods are grabbing the same/similar pure pixels and also it can help us determine which method is more efficient.

[2] Peppin, Bill, BatchDestripe help file
[3] Peppin, Bill, BatchPP help file

Processing by Batch Methods:

The original file names are 04-2006-2005_017_*_pol, where the * indicates numbers 001 through 005. These files were all displayed using a false color composite (RGB). The bands that were chosen to represent Green and Blue were bands located in the green and blue spectrum, band 11 (549.9460 nm, green range) and band 4 (467.948 nm, blue range). The band chosen to represent Red was located in the vegetation range, band 34 (821.6370 nm). This was done so that when the image is displayed the red areas of the image will represent the vegetation in the image. The five files are shown in Figure 4.

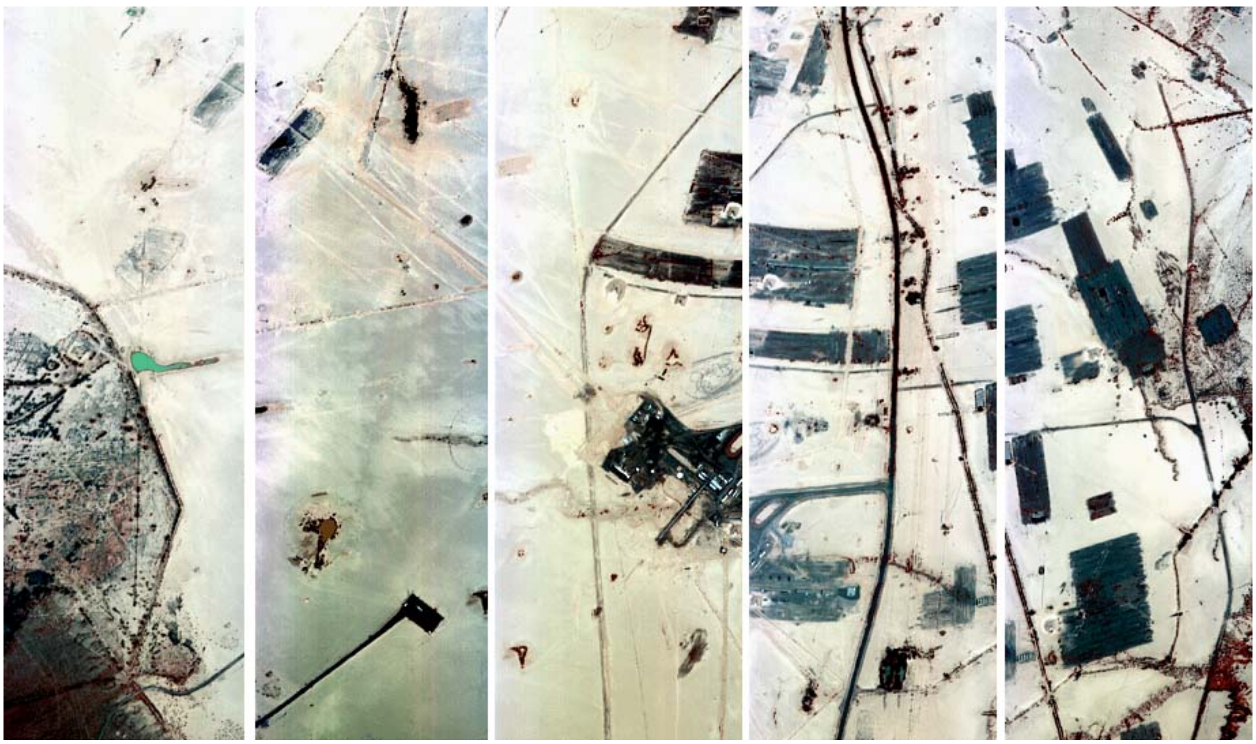


Figure 4: False Color Composite of all five images, showing vegetation in red

First, these files were placed into the BatchDestripe program. This program allows for all necessary files to be destriped at the same time, significantly cutting down on the processing time. After the destriping completed the output was five new files DS_04-26-2005_017_*_pol(hdr). These destriped files were then used as input into the second step, the BatchPP program. This program also allows for all files to be processed at once. The default settings were the most appropriate for this analysis so everything was kept at default except the entire VNIR-TIR spectral range was selected in the hope that it would make the analysis more accurate. Upon completion the result was two sets of files for each input file: DS_04-26-2005_017_*_pol_datPP(hdr) and 04-26-2005_017_*_pol_datPPLib(hdr).

The spectral library created for each of the images is sorted so that the "purest" endmember pixels are at the top of the list. The pixels are arranged as, C:(a) X:(b) Y:(d), where C(a) gives a measure of the purity of the pixel located at (X(b), Y(d)) in the image. The higher the number (a) the purer the pixel. An example of the created libraries is shown in Figure 5.

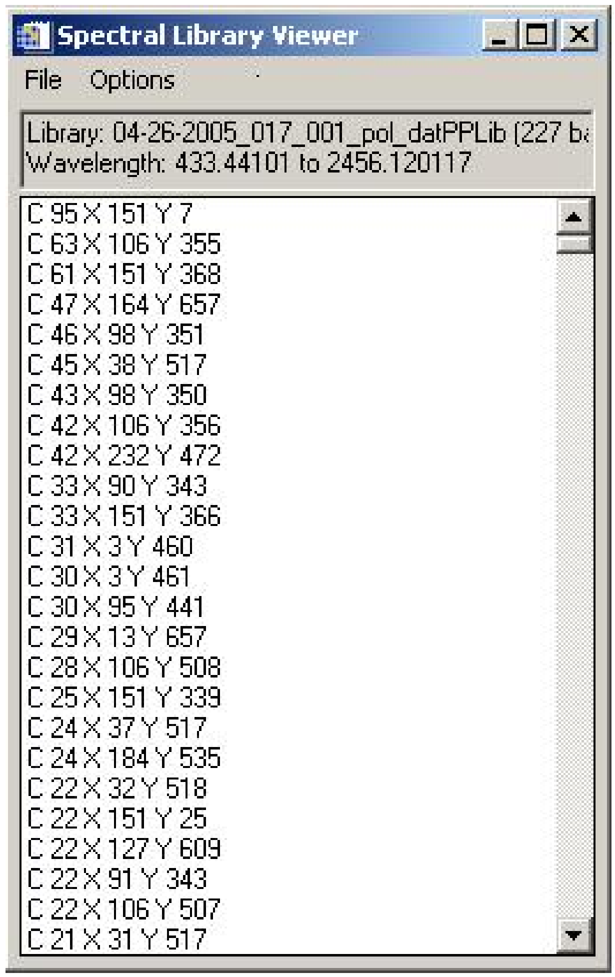
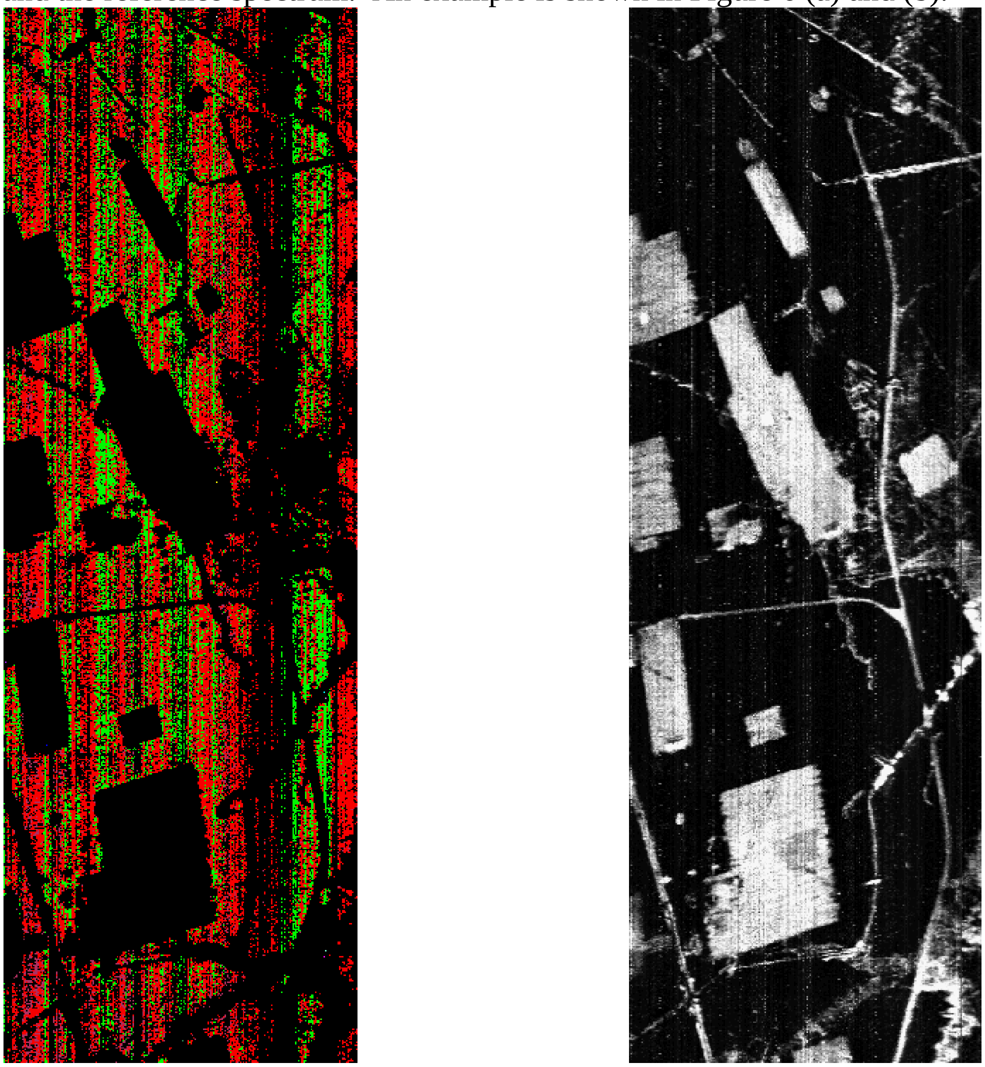


Figure 5: Spectral Library created from Image 001

An ROI was then created for each of the …_datPP files, the third step. The files had thresholds placed on them to obtain an ROI showing each of the hits in the (dark) PPI image. These ROIs were saved as DS_04-26-2005_017_*_pol_datPP.roi. The ROIs were then placed over the original image for which it was created and visually inspected to determine where the BatchPP process was picking up the most extreme pixels. Placing this ROI over the images and then inspecting the images…_datPPLib allows for quicker identification of the pure/real pixels as opposed to the noise. Upon identification of some pure endmembers from the spectral library, the fourth step is to perform spectral mapping. SAM was chosen to perform this analysis. After observing the spectral library of each image some pixels were chosen as representative of the scene. These pixels were then run through SAM. The output of running SAM is a classfile, best SAM match at each pixel, and a rulefile, actual angular distance in radians between each spectrum in the image and the reference spectrum. An example is shown in Figure 6 (a) and (b).



(a) (b)

Figure 6: Class file (a) and rulefile (b) of image 001

Darker pixels in the rulefile represent smaller spectral angles, meaning the pixels in those regions are more similar to the reference spectrum. The rulefiles are used for subsequent classifications using different thresholds to decide which pixels are included in the SAM classification image, meaning that the rulefiles have thresholds placed on them to find where each of the rulefiles had their most spectral matches. These thresholds were done for every image and ROIs were created from each rulefile for each image. The only factor that varied between images was the amount of pixels chosen from that particular images spectral library. The SAM output had x, number of rulefiles each, where x is the number of pure pixels selected from each spectral library. The ROIs created from the rulefiles were saved individually for each image as rulefile(x)_Thresh_unidentified_*, where (x) is the numbers 1 through the number of pure endmembers selected from the respective libraries. The ROIs were all saved together for ease of loading into ENVI as 04-26-2005_017_*_pol_SAM_allendmembers. Figure 7 shows these ROIs.

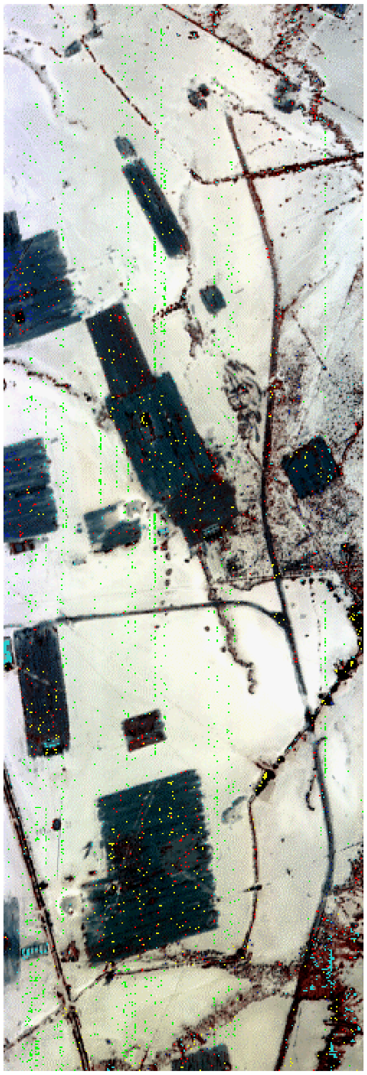


Figure 7: Image 001, with SAM mapped endmembers overlain on image.

Each dataset had a certain number of ROIs created from their rulefiles, unfortunately some of these rulefiles were representing the same spectra. Therefore, after processing each dataset via their rulefiles, it was decided that similar/same ROIs were to be the same color. The next thing that was done for this processing was to perform the MTMF mapping method. The MTMF mapping was used as a comparison to the ROIs obtained from the SAM method. The ROIs were compared for location and frequency. MTMF uses the same input as SAM from the spectral libraries. Upon comparing the two mapping methods, it was determined that SAM was grabbing more areas than the MTMF method. However, MTMF appeared to pick up some different endmembers than SAM in some cases, so all were used in subsequent processing. An example of an image overlain with the endmembers found from MTMF is shown in Figure 8.

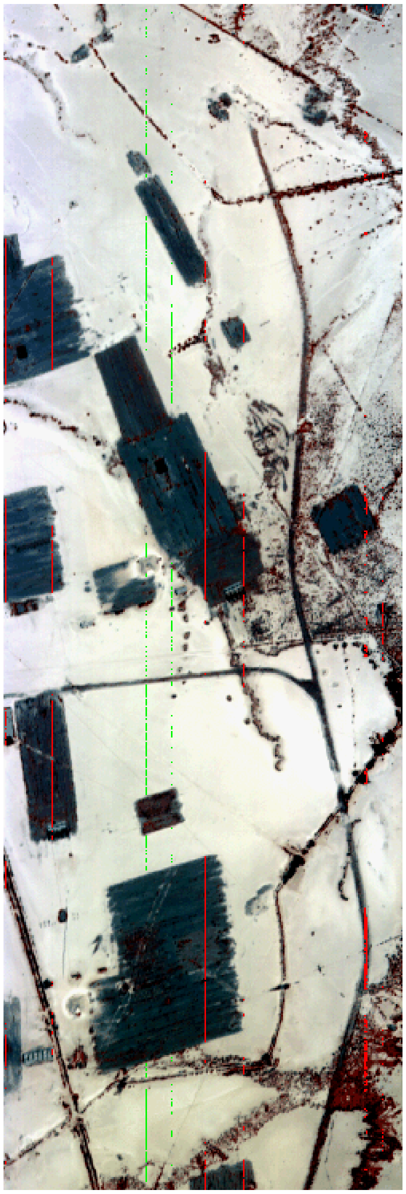


Figure 8: Image 001, with MTMF mapped endmembers overlain on image

The first three datasets were processed to MTMF without any incidents, however the fourth and fifth datasets had problems immediately. These datasets had water absorption spectral features that hadn't been taken out of the data even after all of the preprocessing. These water absorption features showed up on the edges of these two datasets. Therefore, the best answer was to resize the data, by taking off the edges. The two files were then saved separately as 04-26-2005_017_004_pol_resize and 04-26-2005_017_005_pol_resize. These files were then used as input into the previously described processing. Using the ROIs from the first run of SAM and approximately the fourth run of MTMF, a spectral library was created for each dataset, consisting of the mean spectra for each endmember. *Note: The endmembers that were the same in each dataset were combined, using the merge option from the ROI tool. The mean was then taken for each combined ROI and these average spectra were used as the input to the spectral library for each dataset.* All of the spectral libraries were then compared to determine the exact number of different endmembers between each of the five datasets. A total of twenty-one endmembers were used between the five datasets.

Upon comparison of the spectral libraries, it was determined that there were a total of eleven different endmembers between the five scenes. Some of the endmembers were present in only one scene, while others were present in multiple scenes. Spectral math was then used to break up the twenty-one endmembers into the eleven different endmembers. *Note: Some of the endmembers chosen were only initially present in one of the datasets.* The spectral math averages were then placed into a new spectral library. This new spectral library was then used as the input spectra for another run of SAM, minus the spectra that are vegetation. *Note: The vegetation spectra were taken care of by other means, which will be described shortly.* This was done in the hope that the scenes could be mapped more extensively than the previous runs of the spectral mapping. For dataset one, five endmembers were found out of the ten endmembers input, datasets two, three and four had seven out of ten, and dataset five had six out of ten. Each input endmember was assigned a color for ease of mapping between scenes. An example of this new SAM scene is shown in Figure 9.

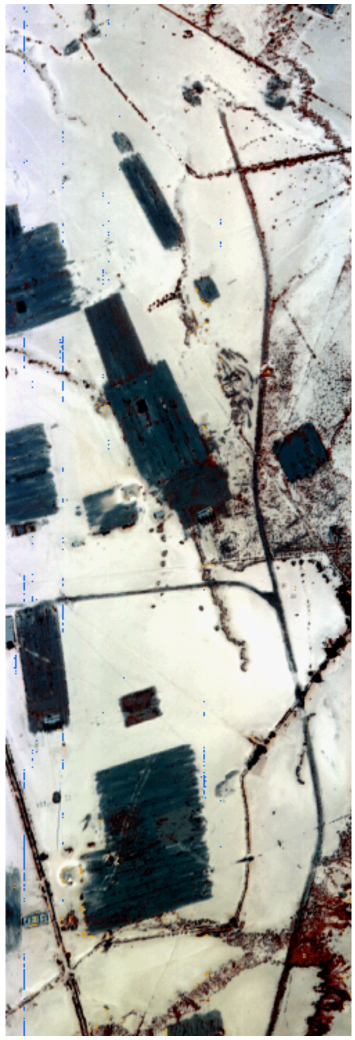


Figure 9: Image 001, with the five endmembers found from final run of SAM

The next thing that was done was to use band math for each scene to ratio the vegetation spectra. A band in the “chlorophyll trough” was ratioed to a band in the “red edge” for an example vegetation spectrum, for each of the datasets, the ratioed bands were Band 20 (656.1390 nm) to Band 31 (786.0650 nm). The output of doing this is a new gray-scale image, which is also the vegetation-index for each image. This gray-scale image, which is similar to the rulefile output of running SAM, is processed the same way as the rulefiles and thresholds are found for each image. An example vegetation index image is shown in Figure 10.

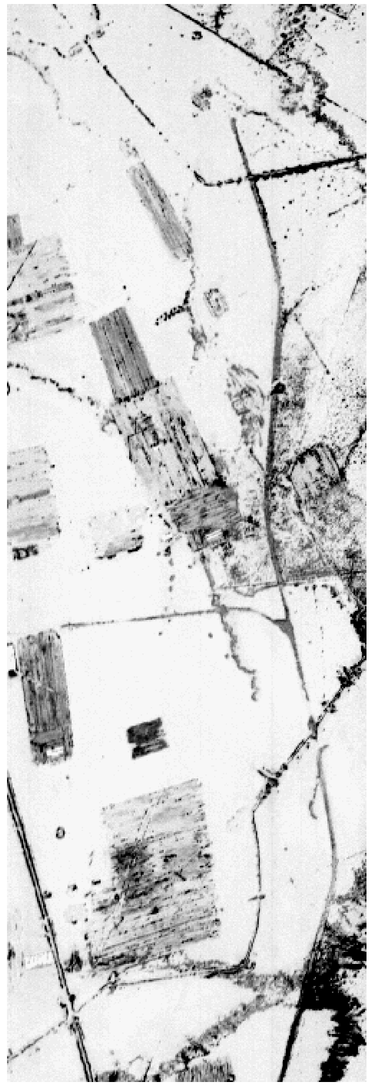


Figure 10: Band ratioed image of dataset 001.

This vegetation-index threshold was then made into an ROI. The ROI created from each dataset for the vegetation-index was then placed onto each scene, along with the ROIs created from the new run of SAM. *Note: The vegetation-index ROI and SAM endmember mapping ROIs were then saved as a final ROI together for each dataset. They were called:*
04-26-2005_017_001_pol_SAM_new_10_endmembers_5_actual_vegetation_index
04-26-2005_017_002_pol_SAM_new_10_endmembers_7_actual_vegetation_index
04-26-2005_017_003_pol_SAM_new_10_endmembers_7_actual_vegetation_index
04-26-2005_017_004_pol_resize_SAM_new_10_endmembers_7_actual_vegetation_index
04-26-2005_017_005_pol_resize_SAM_new_10_endmembers_6_actual_vegetation_index

An example of this new scene with the new SAM ROIs and the vegetation index is shown in Figure 11.

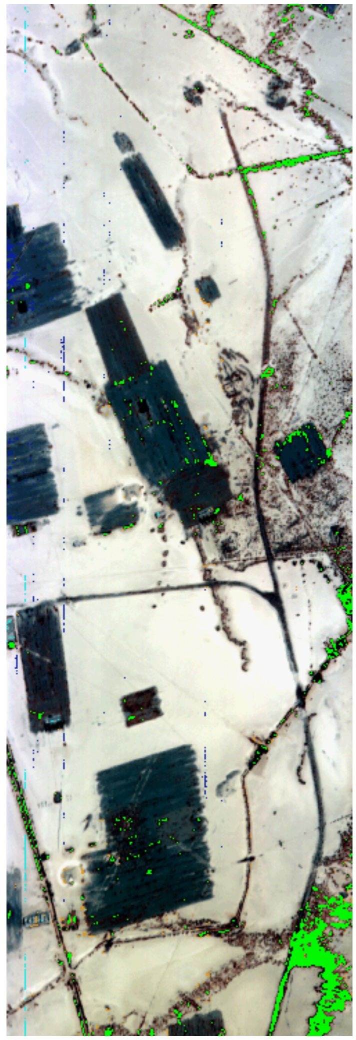


Figure11: Image 001, with the five endmembers found from final run of SAM, along with the vegetation index overlain on the image.

After all the ROIs were placed on their respective scenes an ENVI 24 bit image file was saved for each, 04-26-2005_017_*_pol_(resize)_prerectification, where * represents numbers one through five, and where four and five are resized. This ENVI file is then used as the input file for georeferencing each scene by the supplied GLTs. The output of this georeferencing is, 04-26-2005_017_*_pol_(resize)_postrectification_2, again where four and five are resized. These _postrectification images are then used as the input into the georeferenced mosaic of all five datasets. Before this mosaic can be completed the black areas surrounding each image were taken out, using the “cutline” method. This is a necessary step because if the dark areas are not taken out a dark area will show up on top of the previous images loaded. Once this “cutline” annotation file is completed for each scene it should be a smooth transition between each image in the mosaic. This final mosaic, 04-26-2005_017_all_pol_postrectification_mosaic_cutline_2, is shown in Figure 12.

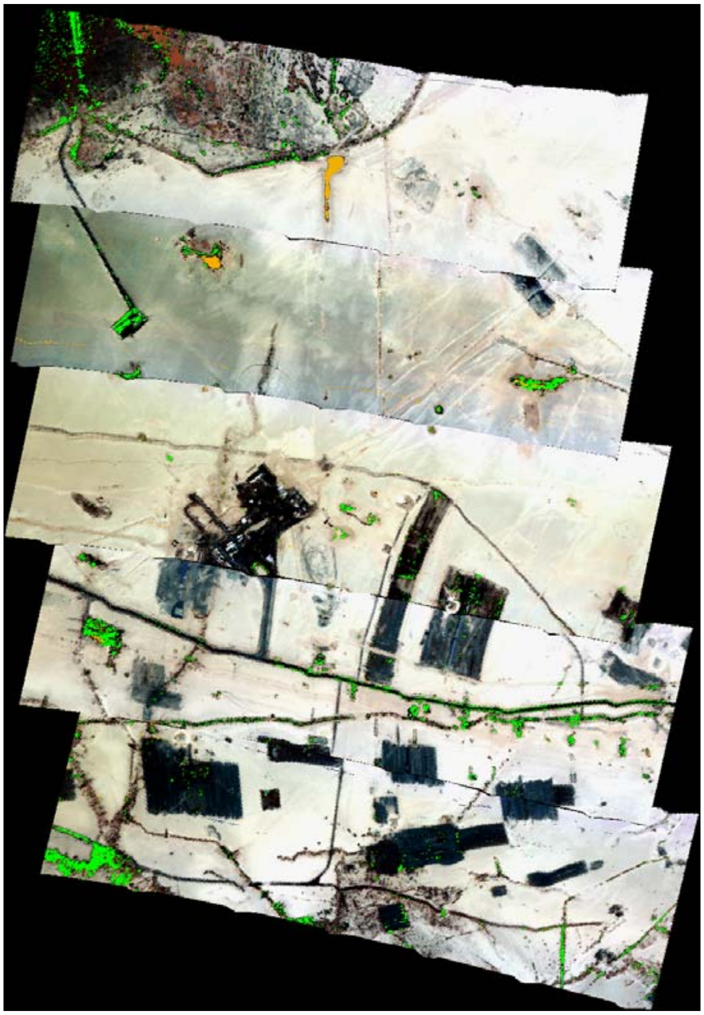


Figure 12: Georeferenced Mosaic over the Nevada Test Site

You can see from the figure that even though the scene is registered by the GLTs, the images don't line up at every point. This was the final processing step for the datasets. The next thing that was needed was to analyze the data to determine the spectral nature of each endmember.

Analysis:

The eleven dominant endmembers found in the scenes were analyzed to determine the components of each spectral endmember. The first thing that was done was to break the endmembers into groups. One of the groups was generally called the "clays", another was called the "unknowns", and the final group was called "vegetation". Figure 13 (a) shows the clay group, (b) shows the unknowns, and (c) shows the vegetation, which includes the vegetation indexes created for each image as well as the vegetation spectra created from the spectral math. This spectral math vegetation feature (s1+s2+s3+s4+s5+s6) was not used as input into SAM, because the vegetation indexes were created.

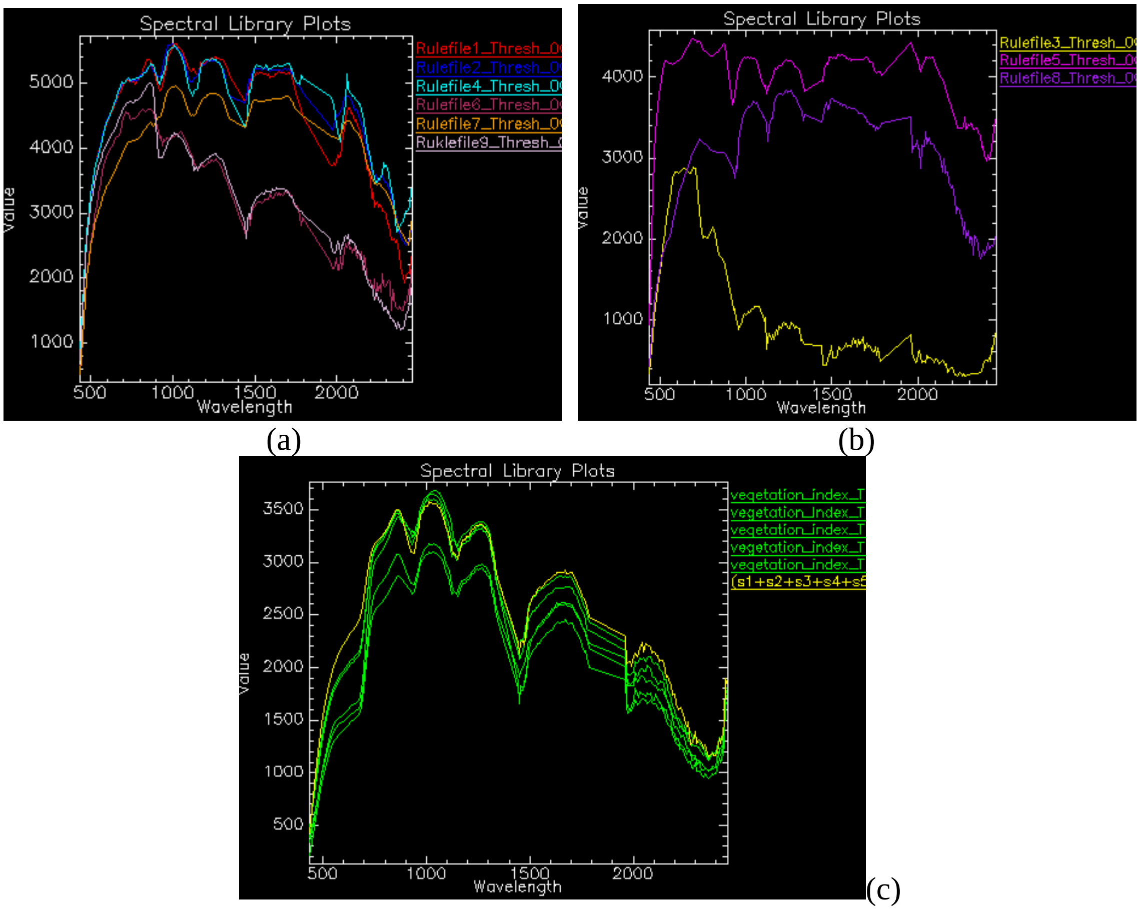


Figure 13: (a) Possibly Clay Spectra, (b) unknowns, and (c) Vegetation

Spectra,vegetation index and scene derived spectral math vegetation.

The “clays” can be further broken down into what they are possibly representing. Rulefiles 6 and 9, are possibly combinations of Illite-Smectite or just Illite. The evidence for this is shown in Figure 14.

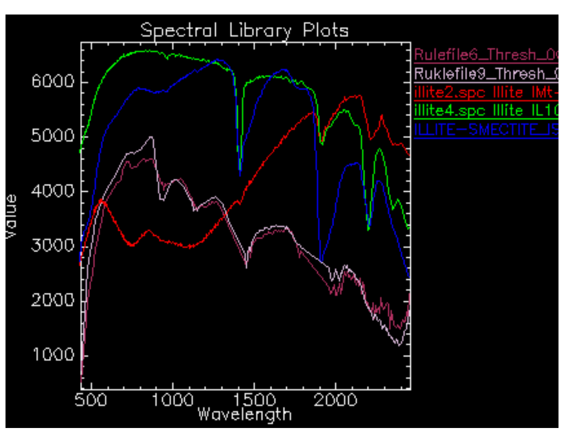


Figure 14: Rulefiles 6 and 9, with Illite library spectra taken from the USGS mineral library and Illite-Smectite library spectra taken from the IGCP_2 library.

These rulefiles don't exactly match the library spectra, but they have generally the same shape. Rulefile 7 is possibly a Muscovite. The evidence for this is shown in Figure 15.

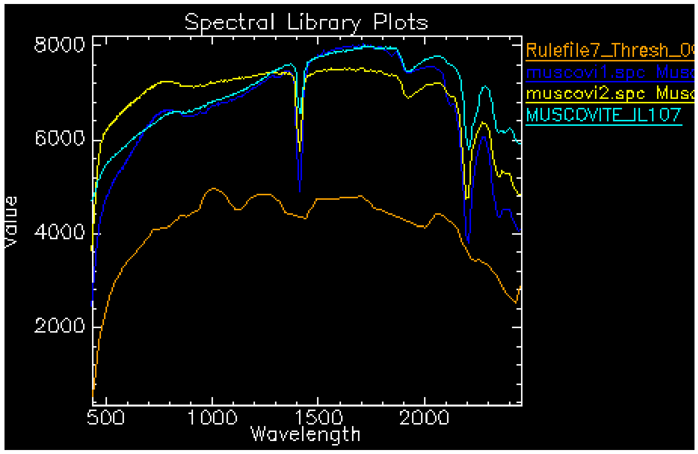
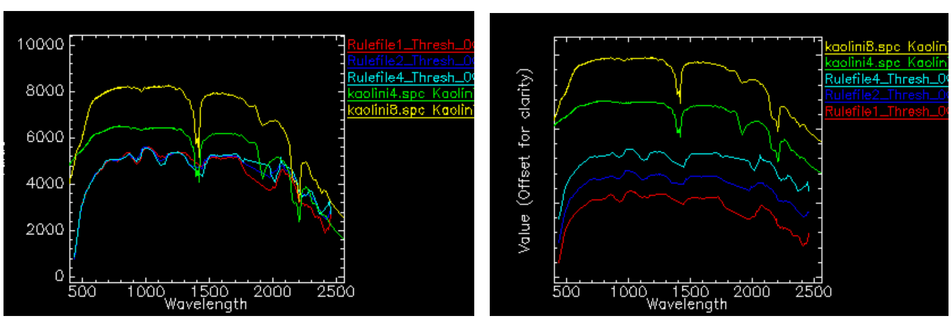


Figure 15: Rulefile 7, with Muscovite library spectra taken from the USGS mineral library and the IGCP_2 library.

Again these rulefiles don't exactly match the library spectra, but have the same general shape. Lastly for the clays, rulefiles 1, 2, and 4, are possibly types of Kaolinite. Figure 16 (a) and (b) shows these rulefiles.



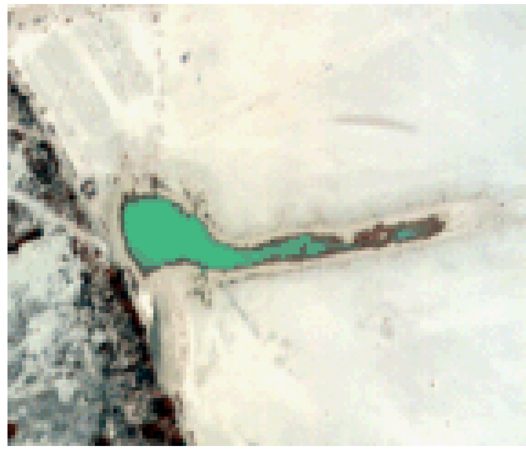
(a) (b)

Figure 16: Rulefiles 1,2 and 4 with Kaolinite library spectra taken from the USGS mineral library, (a) is the standard plot, while (b) is the stacked plot.

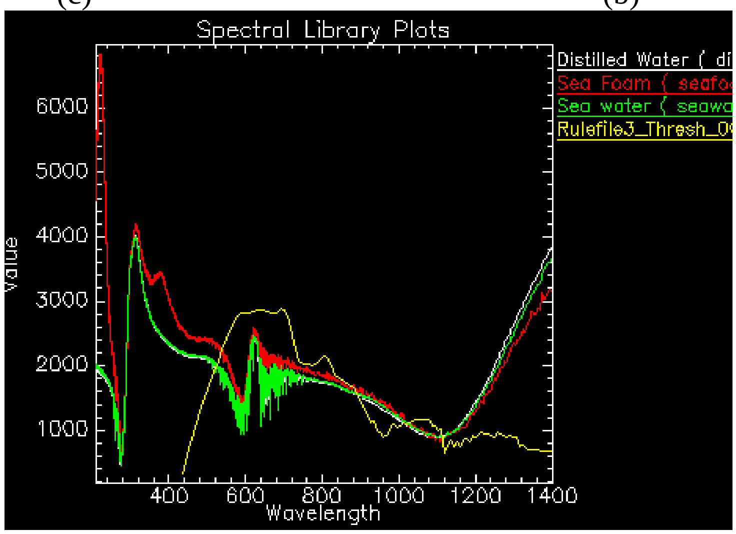
These rulefiles, don't match the library spectra exactly either, but if you look at the stacked plot for rulefiles 1, 2 and 4, the rulefiles appear to have a lot of the same absorptions as the Kaolinite library spectra, but with some slight shifts. These could also be another type of clay or combination of clays.

The "Unknown" spectra are the spectra that didn't appear to have any match with any of the library spectra observed. However, it was suggested that rulefile 3 from this analysis, is representing a water feature. The interpretation of the possible water feature is shown in Figure 17.

(c)



(b)

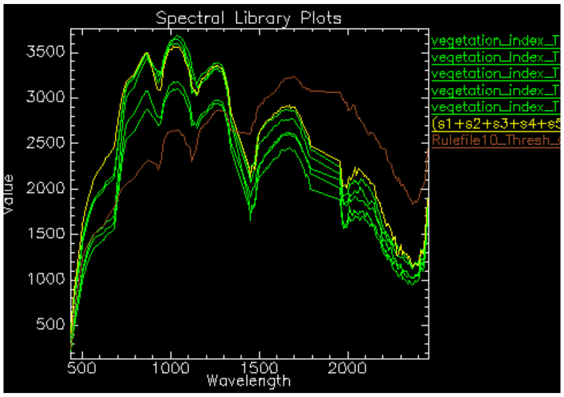


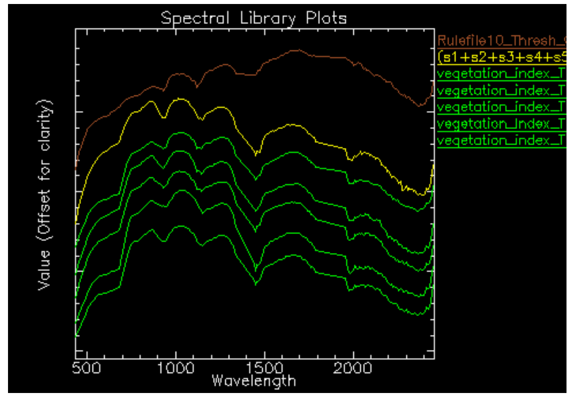
(c)

Figure 17: (a) rulefile 3 (shown in yellow) from image 005 and (b) RGB image of the same area. (c) Shows the spectral signature of rulefile 3 with the library water spectra from the John Hopkins University, water spectral library

Unfortunately this rulefile does not appear to be a water signature. Some reasons for this are that the rulefile, the yellow line in the graph, does not have a blue absorption feature associated with it, where blue light absorbs in the range of 440-490 nm. There is also a problem with but not limited to the region near 600 nm, where the water features have a trough, while the rulefile has a peak. Also, from the RGB composite image, the area this rulefile is located is colored in green, where the green light absorbs at 490-570 nm. This could mean that this area is a very green patch of ground, an algae (or a very polluted) pond or something else entirely.

It is still undecided on what kind of vegetation each spectra are representing, so all of the vegetation spectra are generally called “vegetation”. The reason that we know that all of these are representative of vegetation is because each of them has a distinctive trough at approximately 700 nm, and then a distinctive peak between 800 and 900 nm. This trough is called the "chlorophyll trough" and this peak is known as the "red edge". After observing the only remaining rulefile, rulefile 10, it was decided that this rulefile is also representative of vegetation. This rulefile can be shown with the rest of the vegetation spectra in Figure 18.





(a) (b)

Figure 18: Vegetation Spectra, vegetation index and scene derived spectral math vegetation, also rulefile 10 shown with the vegetation (a) normal plot, (b) stacked plot.

It was decided that rulefile 10 was also a vegetation signature after placing rulefile 10 into a plot with all of the vegetation indexes and the image derived spectral math vegetation. This similarity is a little hard to see from Figure 17 (a), but when you look at Figure 18 (b) it becomes apparent. Rulefile 10 has approximately the same shape as the rest of the vegetation, as well as a slight trough around 700 nm as well as a slight peak between 800 and 900 nm. This analysis is by no means definitive. All of these rulefiles could be entirely different combinations from what has been thought so far. This data is a little too noisy to make accurate identifications at this point.

CHAPTER 5

Acquisition of Hyperspectral Image Data over NPTEC I

From June 30, 2005 through December 2005 airborne hyperspectral image data was acquired over the National Proliferation, Test and Evaluation (NPTEC) center as described in Progress Report Number 4:

The August 31, 2005 data collection occurred during high temperatures at the NPTEC and inadequate cooling of the HyperSpecTIR-2 sensor (HST-2) resulted in degraded data in the VNIR portion of the spectrum. During this reporting period our analysts have been coordinating with the sensor specialists and analysts from SpecTIR Corporation to get an acceptable data set for analysis. No in-air problems were detected during data acquisition; the data was deemed to be 'good' once inspected by Spectir personnel. Unfortunately, the scanning lamp, an integral part of the spectral calibration components, burned out before an after flight calibration was taken. This rendered any post-flight calibration unusable. Before-flight calibration could have been applied, however, the original scanning lamp had burned out right before the flight, and the sensor was not characterized. Although different spectral and radiometric methods were applied to the dataset (empirical line formula, etc.) the data never displayed characteristics that appeared to reflect real ground signatures. The dataset was never sent to UNR as a reflectance data set and was not seriously utilized for analytical products.

1. Currently we are analyzing both the April 26, 2005 overflight with 2-meter resolution to evaluate the effects of seasonality on remote sensing observations at the NTS NPTEC facility. To assist with this comparison, the Bechtel Remote Sensing Laboratory at Nellis Air Force Base has provided a scene of experimental airborne digital camera data in GEOTIFF form. This data is:

    a. UTM zone 11,
    b. Data in meters
    c. Nptec_subset_20050721_utm84.tif

    These airborne digital data were provided by Brian M.Allen on December, 9, 2005, general shipping order number 2059108.

    One of the ABLE graduate students has been georeferencing both the April and September data sets for comparison purpose using the airborne digital data set. At the end of December 2005 we still did not have an acceptable spectral data set to mosaic from the September 30, 2005 flight.

2. On November 17, 2005 we participated in the Shrike Outbrief meeting at the Bechtel Remote Sensing Laboratory at Nellis Air Force Base and presented a PowerPoint point presentation.

3. In December 14, 2005 Dr. Taranik participated in the first planning meeting in Washington D. C., for the next phase of NPTEC research at NTS. This phase is called Tarantula and will involve rapid response in two different seasons. The following images summarize our progress during this phase of our work. Changes in soil moisture (dark to light areas) and changes in vegetation density (reddish brown areas and lack thereof) indicate drying out of the background and increasing senescence of vegetation.

4. Comparison between the April and September 2005 overflights of the NPTEC is shown below. These swaths from the SpecTIR HST display VISNIR channels acquired by the VISNIR focal plane in the spectrometer. The SWIR spectrometer focal plane could not be calibrated and was not useable.

Figure 19. HyperSpecTIR data acquired by Sierra Nevada Corporation, 4-26-05. Cessna 404 Twin Engine Aircraft flying at 2000 feet AMT, 2 meter data, HST-2 sensor, at 120 Knot speed, 483, 554, 648 nm, BGR, gaussian stretch.

Figure 20. HyperSpecTIR data acquired by SpecTIR Corporation, 9-28-05, Cessna 206 Single Engine Aircraft flying at 2000 feet AMT, 2 meter data, HST-3 sensor, at 80 Knot speed, Bands 479, 549, 656 nm, BGR, Gaussian stretch.

In 2005, we waited for acceptable hyperspectral data from SpecTIR Corporation acquired over the NPTEC in August 2005 and September 2005 but never did receive reflectance data that could be satisfactorily exploited. The following summary of the issues with HyperSpecTIR (HST) data acquisition, calibration and pre-processing explains the problems with the data. Based on interactions with DOE Laboratory scientists the thrust of our research changed to exploiting data we already had over Cuprite, Nevada and Virginia City, Nevada to demonstrate our techniques for processing and analysis of hyperspectral reflectance, and emittance image data, showing the types of background information that could be derived for the detection and analysis of solids.

During the last period we received digital camera data from a research and development prototype system from the Bechtel Nevada, Nevada Test Site GIS Group over the NPTEC. This data was used to rectify the acquired SpecTIR image data. Figure 1 shows the coverage of the 132MB image.

Figure 21. Digital camera imagery of NPTEC Facility provided by Bechtel Nevada, Remote Sensing Laboratory, Nellis AFB. nptec_subset_20050721_utm84.tif

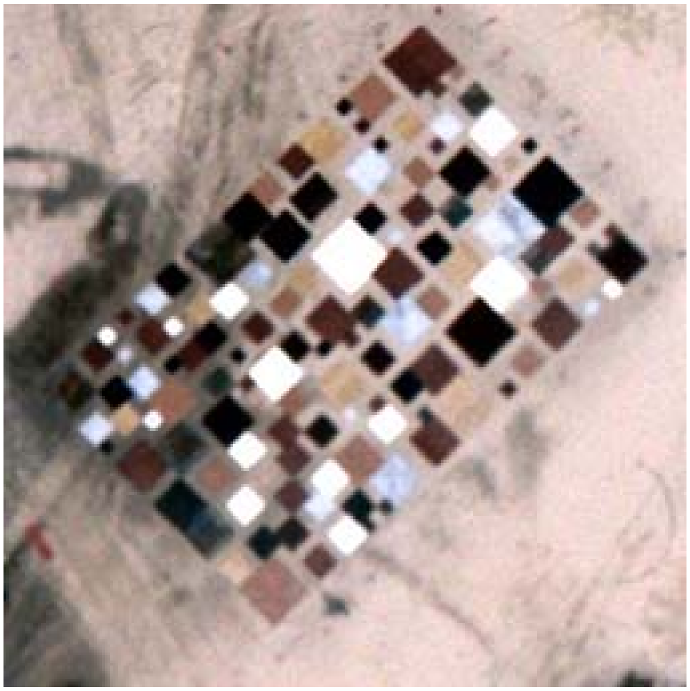


Figure 22. Digital camera subscene of spectral targets
at NPTEC. 399 pixels by 398 pixels.

Also during 2005, we received additional guidance regarding the thrust of our research. That guidance was in the form of a memorandum, listing research directions for DOE Code NA-22:

DOE NA-22 Research Emphasis for Chemical, Biological and Nuclear Detectors:

Bio
-Innovative detection techniques for non proliferation biological WMD detection
-Biological weapons production process indicators
-Detection of genetically engineered bio weapons
-Small, secure, inexpensive emplaceable bio sensors with low power wireless data exfiltration capabilities
-Multi and hyperspectral imaging of remote bio production effluents; Lidar techniques
-Other projects supporting detection of pathogens, naturally occurring or man made

Chem
-Micro- and/or nano-sensor technology for the detection of trace chemicals used in chemical agent production
-Collection systems for trace chemical species and gases
-small, secure, inexpensive emplaceable chem sensors with low power wireless data exfiltration capabilities
-Other projects supporting detection of chemical weapons production

-Multi and hyperspectral imaging of remote chemical effluents; Lidar techniques

Nuclear

-Detection of SNM via non nuclear effects
-Micro and/or nano sensor technology for the detection of radiation
-Material science for new photon emitters

CHAPTER 6

Acquisition of Hyperspectral Image Data Over NPTEC II

During the first quarter of 2006 ABLE research focused on acquisition of acceptable data over the NTS NPTEC facility using the HyperSpecTIR (HST) sensor developed by SpecTIR Corporation in Sparks, Nevada. This chapter describes the HST system and mission operations.

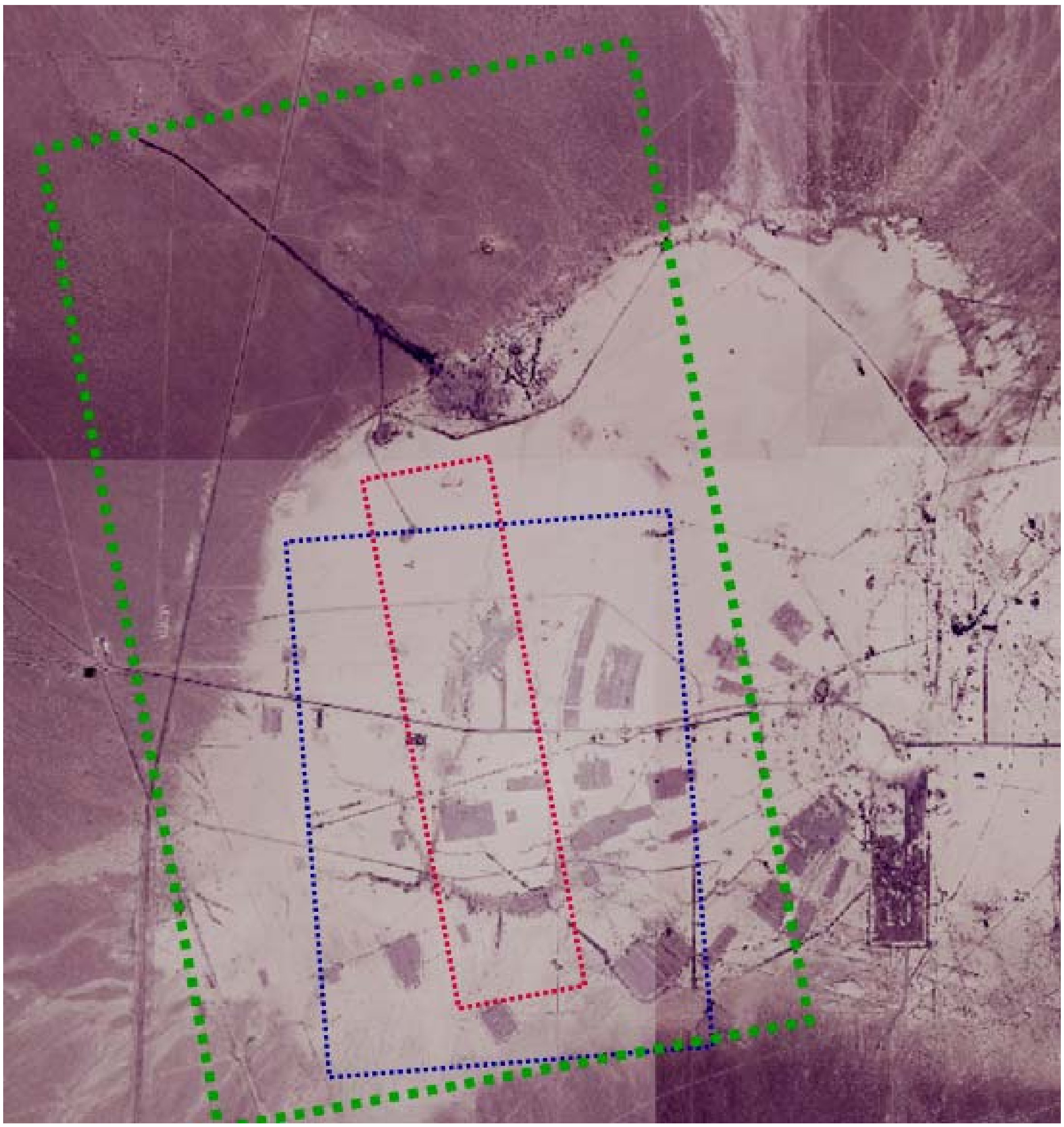


Figure 23. Showing coverages at 3m resolution, 2m resolution And 1m spatial resolution over the NPTEC acquired on September 28, 2005.

Description of HST Sensors

Figure 24. SpecTIR Corp, HST with Instrument Operator, Andy Rael

HyperSpecTIR Instrument Specifications

Spectral Channels/Range	227 bands, 450 - 2450 nm
IFOV Coverage	1.0 miliradian
GSD / GIFOV	0.5 m - 5 m
Swath	100 - 1024 Pixels (configurable)
Channel Width VNIR: SWIR:	8 - 12 nm (configurable) 9 - 10 nm
Image Length	Unlimited
Radiometric Digitization	12 bits (VNIR)/ 14 bits (SWIR)
Spectral Separation	Reflective Grating (VNIR & SWIR)
Scan Type	Cross-track whiskbroom area arrays (2 D)
Stabilization	Integral INS-controlled beam steering optics
Signal-to-Noise Ratio	900 peak
Geopositional Accuracy	dGPS, < 1 m error rating
Data Format	ENVI Compatible
Storage Media	DVD / Hard - Drives
Dimensions	33 L X 19 W x 16 H (inches)
Mass	105 Kg / 230 LBS
Power	1000 W nominal
Operating Platform	Variable

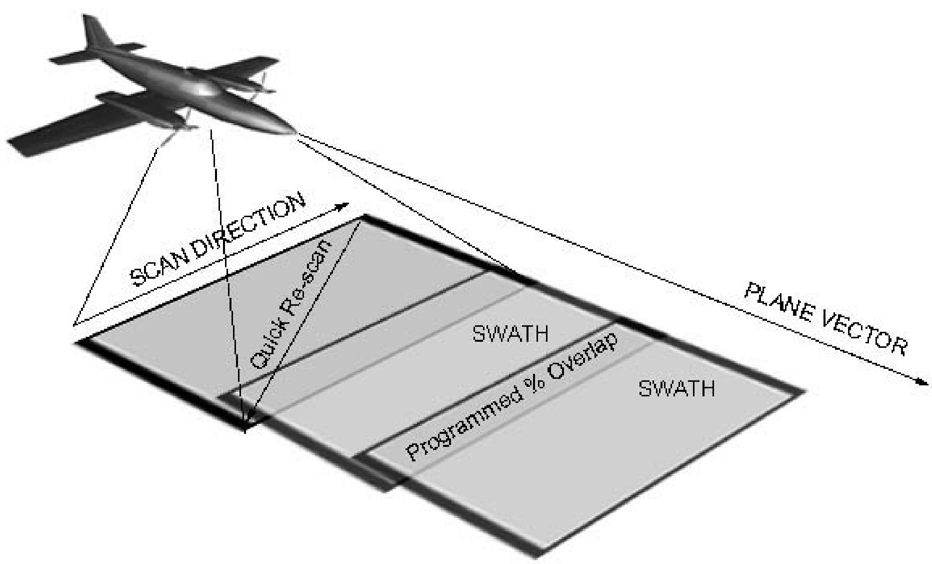


Figure 25. Imaging Geometry with HST Sensor.

Figure 26. Sierra Nevada Corporation Cessna 404 with instrument pod and showing installation of HST-2 instrument for April 28, 2005 overflight.

Figure 27. Cessna 206 used in August and September 2005

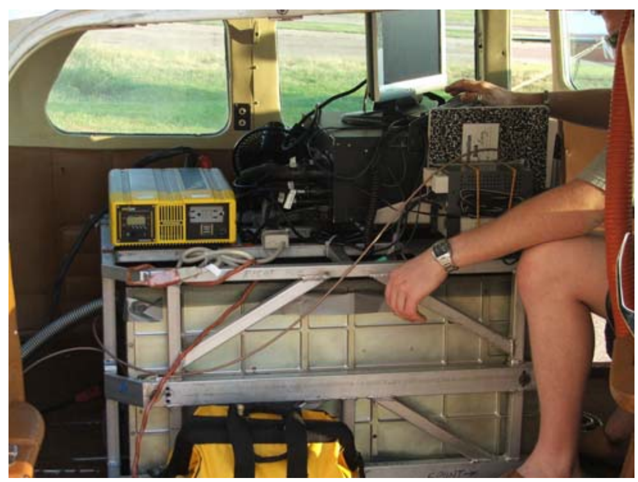


Figure 28. Installation of HST in 208 showing operator position.

Technical Specifications and Processing of HST Sensor Data

Each SpecTIR HST instrument is a different experimental imaging system with different characteristics and unique calibration procedures. The HST instruments were developed by electrical-optical instrument engineers, who were no longer with the company because they chose to not relocate to Reno. Calibration of these instruments is a complex process and the software utilized for this purpose was experimental and poorly documented. The HyperSpecTIR is a hyperspectral imaging spectrometer system with 2 spectrometers covering a combined range of 450 to 2450 nanometers. The visible and near IR spectrometer covers 450 to 900 nm and the SWIR spectrometer covers 900 to 2450 nm.

Light from the scene being viewed enters the view director and is first reflected off the roll mirror, then the pitch mirror and passes through the yaw corrector. Once through, the yaw corrector light is then passed through the shutter and then on to a dichroic, where light with wavelengths shorter than 900 nm gets reflected into the VNIR solid-state array, and light with wavelengths longer than 900 nm gets reflected into the SWIR array. The VNIR spectrometer uses a silicon charge coupled device (CCD) camera as its detector. The camera detector is a 1024 by 1024 array, of which 1024 by 288 pixels are used. The pixels are usually binned during normal operations. Typically the bin settings are 4 spatial pixels and 6 spatial pixels resulting in 256 by 48 pixels. For the VNIR array the spectrometer grating is about half the width of the 6-pixel binning. The VNIR camera is limited to a 3.5 ms integration time. That integration is about half of the 7.5 ms integration time used in the SWIR. The SWIR spectrometer uses a 256 by 256 MCT array that is cooled to 140 Kelvin. The focal plane array has four sections of 64 by 256 pixels that are read out using custom electronics.

Each spatial of the HyperSpecTIR has an instantaneous field of view (IFOV) of 1mR. The instrument views an entire line of 256 spatial pixels at once for its total field of view (FOV) which covers about 15 degrees. The field of view is aligned in the direction of travel and data is collected in a “whiskbroom” manner. This allows for the collection of varying spatial resolutions by reducing swath width. Dark and bright data are collected during each swath.

Calibration of HyperSpecTIR Instruments

There are four areas of calibration for the HST instruments: Spectral, Spatial, Radiometric and Pointing:

Pointing Calibration

The first portion of the pointing calibration is performed with a video camera mounted in the instrument. The pointing calibration involves setting the stabilization gains so the aircraft motion is properly compensated. The main part of this is accomplished with the output from a fiber optic gyro mounted in the instrument. The second half of the position calibration is adjustment of nadir.

Spectral Calibration

The next calibration performed is the spectral calibration of the two spectrometers. The spectrometers are calibrated by direct illumination from a Cary monochromator. The monochromator output is stepped through the entire range of the individual spectrometer's response, typically with 0.5nm steps.

Radiometric Calibration

The radiometric calibration is performed in two steps using several separate data sets. In order to produce consistency during later processing, the radiometric calibration performs several other operations other than a simple radiometric calibration. The first portion is the simple radiometric calibration which uses a 1kW FEL standard lamp. For calibration, several thousand swaths of data are collected and averaged, both with the lamp illuminating a spectralon target and with the lamp illumination blocked. A similar calibration is performed using an integrating sphere as a flat field to transfer the simple calibration to the rest of the spatial pixels. A bad pixel finder and gain massage correction is then performed. The gain massage correction alters the gain to fit the Savitsky-Golay bad pixel correction. Then a focal plane array correction is performed to correct for non-linear biasing of dark current detector response. This correction is facilitated by a small lamp placed inside the spectrometer.

HyperSpecTIR Data Processing

Radiance Processing

Radiance processing is done by averaging the dark current and subtracting them from the lowest digital numbers. The corrected focal plane array is then multiplied by the massaged gain. Bad pixel processing is then done to remove these pixels from the data.

Reflectance Processing

The HyperSpecTIR uses a two-dimensional focal plane array, which has some spectral smile as well as measurable spectral skew caused by misalignment between the slit, grating and the focal plane array. As a result, reflectance processing cannot be performed accurately with single spectral calibration. Instead, separate calibration must be applied for each pixel. The spectral calibration for each pixel uses atmospheric models derived using MODTRAN. Two atmospheric models are generated, one at nadir and one at the maximum view angle from nadir. The atmospheric correction for all pixels in between nadir and the maximum off nadir angle are interpolated. Several atmospheric parameters are needed for the correction: ground and sensor altitudes, water vapor content, carbon dioxide content and visibility at the surface (dust and aerosols estimated by a ground observer or the sensor operator). An initial estimate is made for all the parameters listed above, several points near nadir are averaged, and then the reflectance is calculated for those pixels. The reflectance is fit with a smooth curve through the area of interest and the residual (sigma) is calculated. The parameter of interest is then varied and the process is repeated until a minimum is found.

Polished Reflectance Processing

The basic assumption in polished reflectance processing is that reflectance from a single pixel is assumed to be slowly varying. A least-squares-fit is applied for each band in each spatial pixel, using equal weighting while avoiding the overlap bands and bands deep within any strong atmospheric band. Then, points are weighted by their distance from this initial smoothing and the process is repeated. Then, a gain frame is generated from the ratio of the smoothed to un-smoothed reflectance and that gain is applied to all the reflectance data.

Co-registration Processing

Co-registration processing is necessary for achieving agreement between the two spectrometers, for both the radiance data and the reflectance data. Each spectrometer has its own optical aberrations that must be corrected by re-sampling. Co-registration is performed on the SWIR spectrometer to match the VNIR spectrometer to a uniform grid. A linear interpolation algorithm provides the best results with the fewest overlap artifacts. Data are mirrored to reflect the actual geometry on the ground as it is generated in the instrument and the overlap bands are removed. Finally, the three spatial pixels on either side of the image are removed.

Georectification Processing

Georectification is performed in the Environment for Visualizing Images (ENVI) software. This process assumes the plane is traveling in a straight line at constant velocity during the acquisition of an imaging swath. A sensor altitude (GSD) is given and the amount of crab is determined from the magnetic heading recorded in flight.

Hyperspectral Data Acquisitions

The April 26, 2005 mission utilized SpecTIR's HST 2 instrument flown in Sierra Nevada Corporation's Cessna 404. The mission utilized SpecTIR's HST-2 instrument flown in SNC's Cessna 404 aircraft while the August 30, 2005 mission utilized SpecTIR's HST-3 instrument in SpecTIR's contractor aircraft, a Cessna 206. SpecTIR utilized the Cessna 206 because it could fly slower than the Cessna 404, and because SpecTIR engineers detected imaging problems that appeared to be related vibrations and/or electronic noise associated with SNC's pod. However, the true cause of these problems was never completely resolved.

Although, SpecTIR scientists have largely rewritten the software, they were not able to properly utilize it for calibration of the data acquired under this contract. Therefore, UNR/ABLE had to selectively try to utilize the best data from the three overflights in 2005. As a result of the data processing problems with the April data set, ABLE staff decided to use data acquired in September 28 and 30, 2005. SpecTIR discovered problems in calibration of the April 26, 2005 data set, notably affecting the Short Wave Infrared (SWIR) bands. Apparently, these problems were not as problematic in the Visible-Near-Infrared (VNIR) bands. This latter set of bands is more useful for vegetation analysis, therefore DRI chose to use only the VNIR bands for its analysis.

However, because the SpecTIR HSI instrument was inadequately cooled during the August 2005 flight, the August data were not properly calibrated. ABLE asked that the August 26, 2005 data be recalibrated, but did not receive this recalibrated data. The September 28 and 30, 2005 mission utilized SpecTIR's HST-3 instrument flown in SpecTIR's contractor aircraft, a Cessna 206. The collected data displays obvious calibration errors propagated throughout the data processing cycle. SpecTIR scientists have largely rewritten software intended to rectify calibration issues, although they were not able to properly utilize it for calibration of the data acquired under this contract.

Overflights of NPTEC facility of NTS, September 28, 2005 - September 30, 2005

HyperSpecTIR (HST) Image Data Collections over NPTEC

ABLE's original plan in acquiring hyperspectral image data over the Non-Proliferation Test and Evaluation Center (NPTEC) at the Nevada Test Site was to assess the effects of seasonality between springtime and late summer on the geologic, soil, and vegetation background, and to assess the types of background information derivable at different spatial resolutions over the NPTEC. This dataset was to serve as a scientific baseline and reference for the use of hyperspectral reflectance image data at NPTEC.

On September 28, 2005, SpecTIR Corporation, as a subcontractor to the Arthur Brant Laboratory for Exploration Geophysics (ABLE) at the University of Nevada, Reno (UNR), acquired four flightlines using their HST-3 sensor. The four flightlines were collected at differing spatial resolution of 3, 2, 1 and 0.5 meter Ground Instantaneous Field of View (GIFOV). One additional flight line was acquired on September 30, 2005 at 2-meter GIFOV. Hyperspectral image data were provided in 2-Byte Band Interleaved by Line (BIL) format. In each of four lines acquired on September 28, 2005 there were 43, 44 or 45 swaths of HST-3 data, each swath having 98.8 MB of radiance data. Thus, a total of 21.538 GB of data were georeferenced and analyzed. A software program, Environment for Visualizing Images (ENVI) was then used to perform advanced hyperspectral image processing to extract spectra from background cover types. Custom endmember extraction software created by Bill Peppin of SpecTIR was also used. The radiance and reflectance products were delivered in June of 2005 (for the April 26, 2005 data set) and in April 2006 (For the September 28 and 30, 2005 data set). These deliveries were delayed by a string of instrument calibration, radiometric pre-processing, and reflectance processing problems at Spectir Corporation. Residual effects stemming from these problems still remain in the hyperspectral reflectance image datasets preventing systematic hyperspectral analysis of the data. A full explanation of what caused these problems is documented in this progress report. Illustrations of the acquired image data follow.

The last NPTEC flight on September 28 and 30, 2005, utilizing the HST-3 series sensor, successfully collected data over the site. Again, the data was deemed to be good once quality-checked by Spectir personnel. Calibrations files were generated using a newly acquired calibration sphere. Once applied to the data, the radiance/reflectance product did not seem to be correct. Water absorption features were wildly out of character. The SWIR was particularly noisy. Once a thorough an analysis of the entire calibration process was initiated, it was discovered that the calibration sphere had incorrectly output half of the needed energy to characterize the sensor. In effect, less than half of the signal to noise ratio was attainable. An update to the sphere was ordered, but before the sensor could be scanned again, another scanning lamp burned out and, for all intensive purposes, rendered the data useless.

Summary of HST Sensor and Data Problems

1. April 26, 2005 Overflight: Excessive noise, mechanical vibrations and electrical instability with sensor in SNC Cessna 404 aircraft.

2. August 31, 2005 Overflight: Scanning mirror synchronization problems, inadequate focal plane cooling and calibration errors. Unusable data.

3. September 28 and 30 Overflights: Unrecoverable sensor calibration errors.

Analysis of September 28, 2006 HST Imagery of NTS, NPTEC site

Dr. Smailbegovic provided the following report on the 3m, 2m and 1m data acquired on September 28, 2006 over the NPTEC. The data was in MODTRAN V4R1 derived reflectance. Three known artifacts were known to occur in the data: spectrometer overlap near 960 nm, a large calibration error at 2200nm, and VNIR noise (data drops) in the 2m data. This evaluation involved the selection of a spectrally flat area present in all three data sets of about 36 square meters. The results are similar for the 1m and 3m data, but noise and attenuation of signal is present in the 2m data because of instrument overheating. Using the ENVI hourglass method, the 3m data set yielded 10 endmembers and the 1m data set yielded 11 endmembers. Most of the endmembers were found to be spectrally similar and having minor variations in intensity in the VNIR and SWIR. Statistical variance between the 1m and 3m “black” endmember composite is 17%. The analyzed 3m and 1m data is of marginal quality and usability was found to be limited to the VNIR. The 2m data was found to be unusable due to VNIR noise and failure of the SWIR focal plane due to overheating.

Figure 29. Aerial Photograph of NPTEC above and below a swath of HyperSpecTIR-2 (HST-2) 2-meter imagery collected on April 26, 2005 for comparison.

Figure 30. SPOT Image Showing 2m HST Flight Line of NPTEC

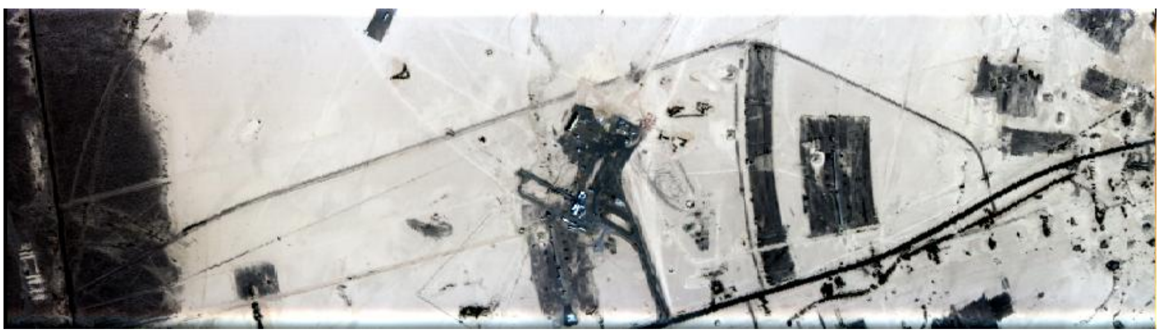


Figure 31. HST Frame 9-28-2005 003_004, Flight Line 3, 3-meter spatial resolution.

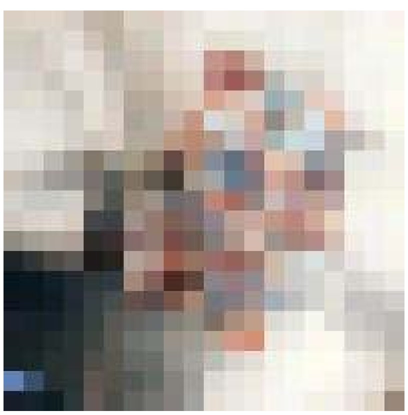


Figure 32. Zoom of clutter field
9-28-2005 003_004.

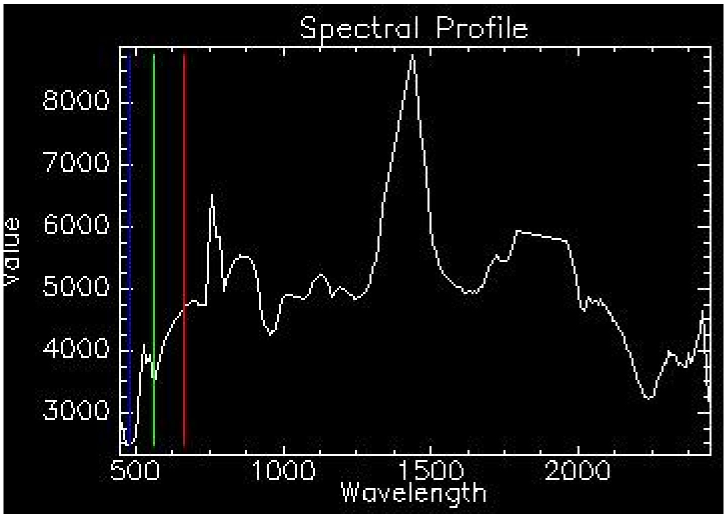


Figure 33. ENVI z-Spectral Plot of HST-3 data corrected to reflectance for 9-28-2005 003_004 zoom of targets.


Figure 34. HST Swath 9-28-2005 004_005, Flight Line 4, 2-meter

Figure 35. Zoom of clutter field,
Swath 9-28-2005 004_005

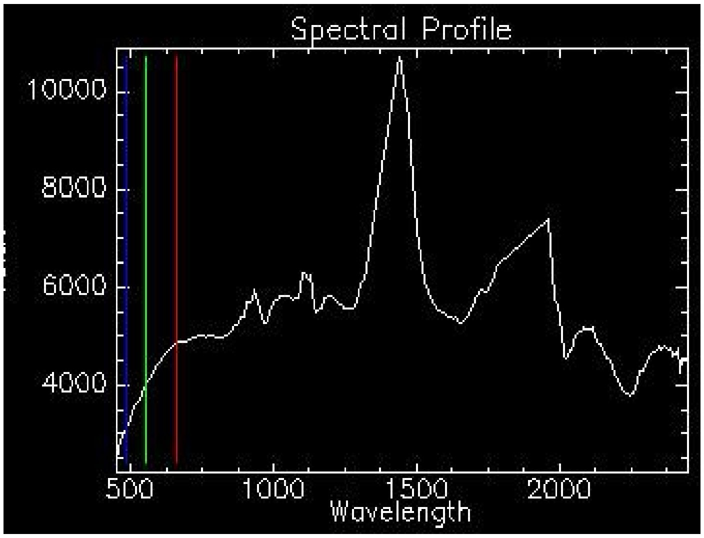


Figure 36. ENVI z-Spectral Plot of HST data corrected for reflectance
Swath 9-28-2005 004_005

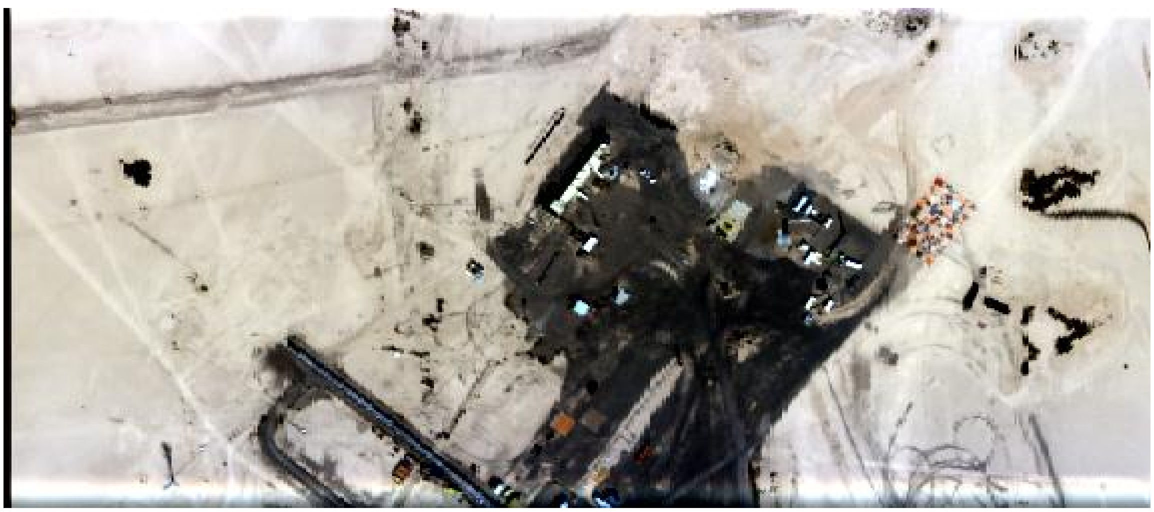


Figure 37. HST Swath 09-28-2006 005_013, Flight Line 5, 1-meter


Figure 38. Zoom of clutter field
Swath 09-28-2006 005_013

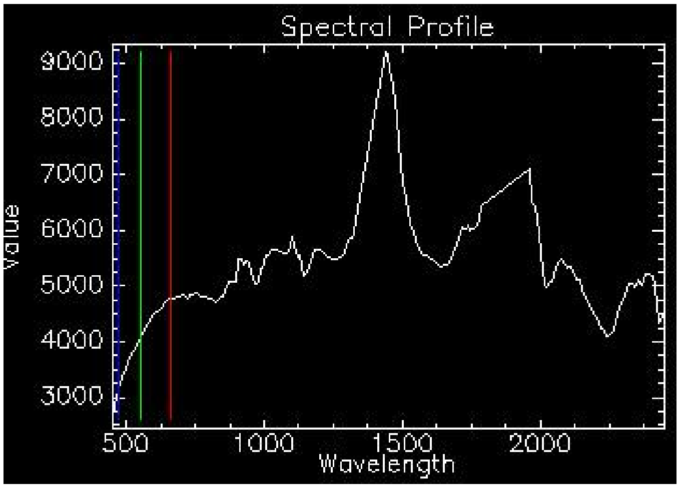


Figure 39. ENVI z-Spectral Plot of Zoom of Targets
Swath 09-28-2006 005_0013

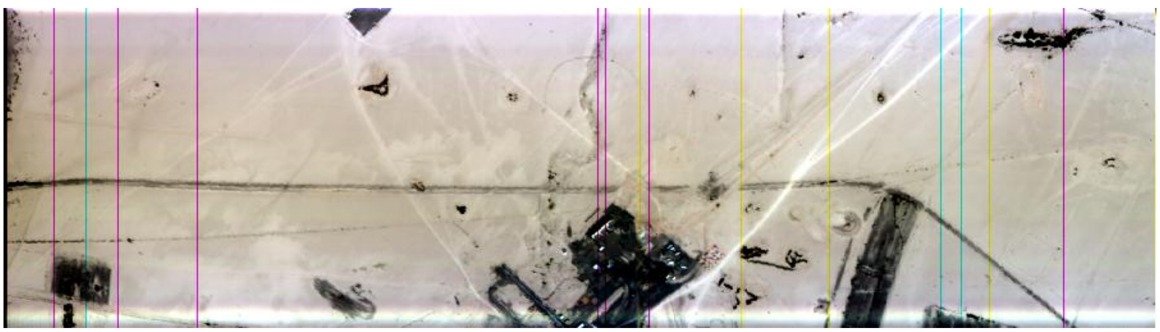


Figure 40. HST Swath 09-30-2005 022_006, Flight Line 1, 2m


Figure 41. Zoom of clutter field
09-30-2005 022_006

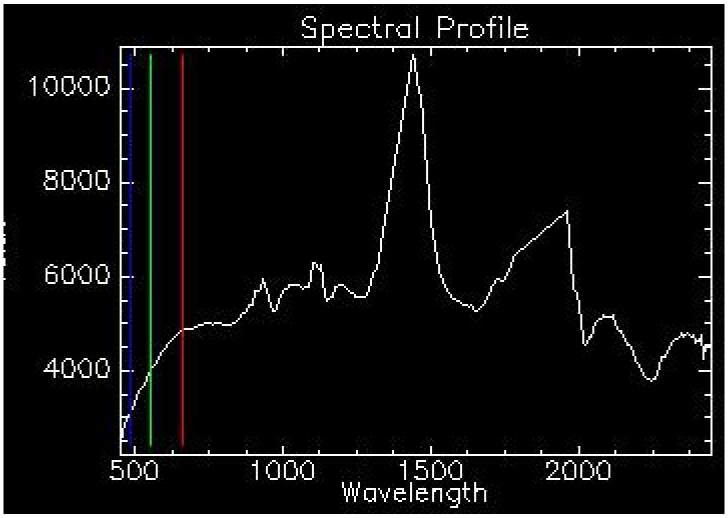


Figure 42. ENVI z-Spectral Plot of clutter field area
09-30-2005 022_006

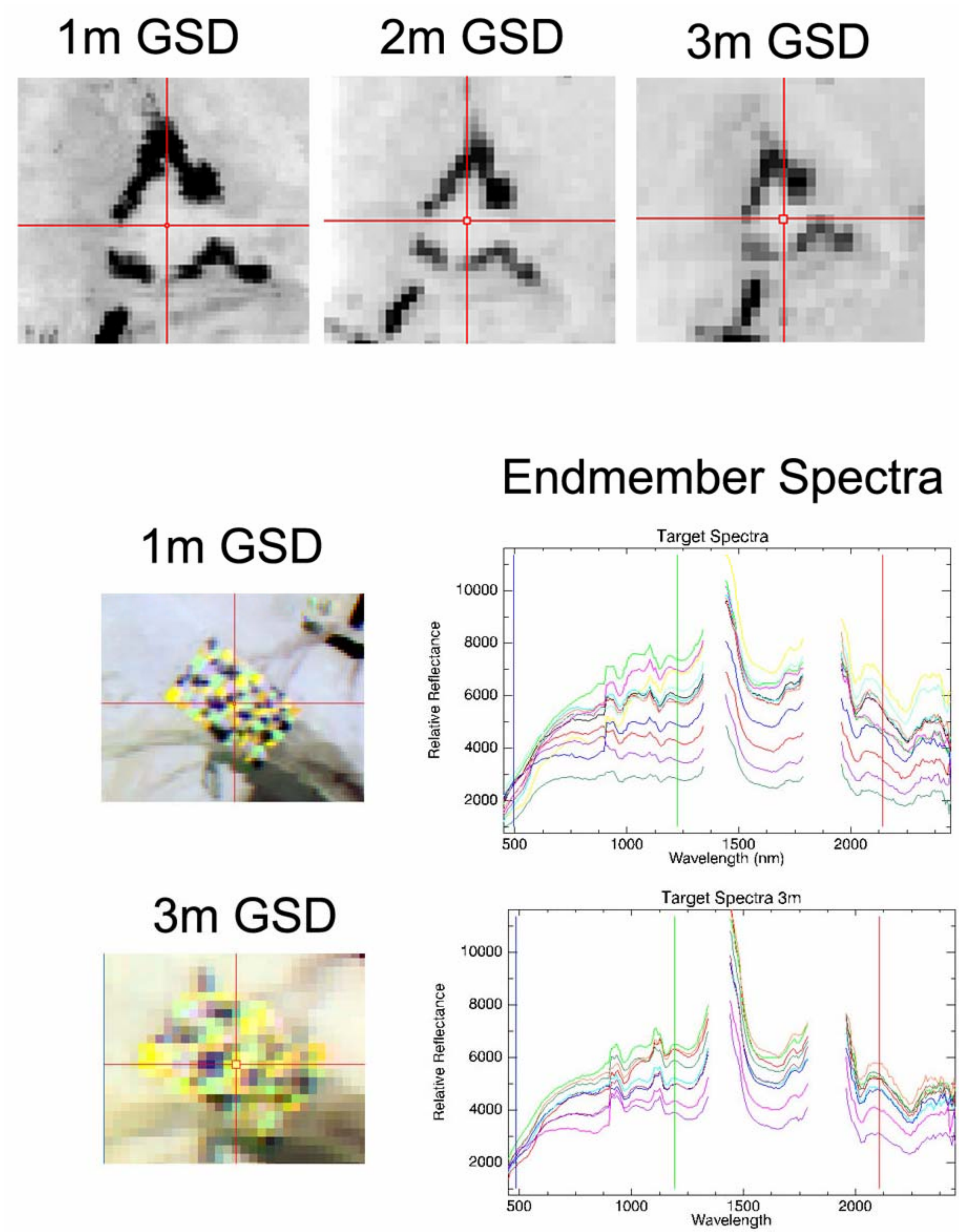


Figure 43. Analysis of HST-3 image data acquired over the NPTEC on 9/28/2005.

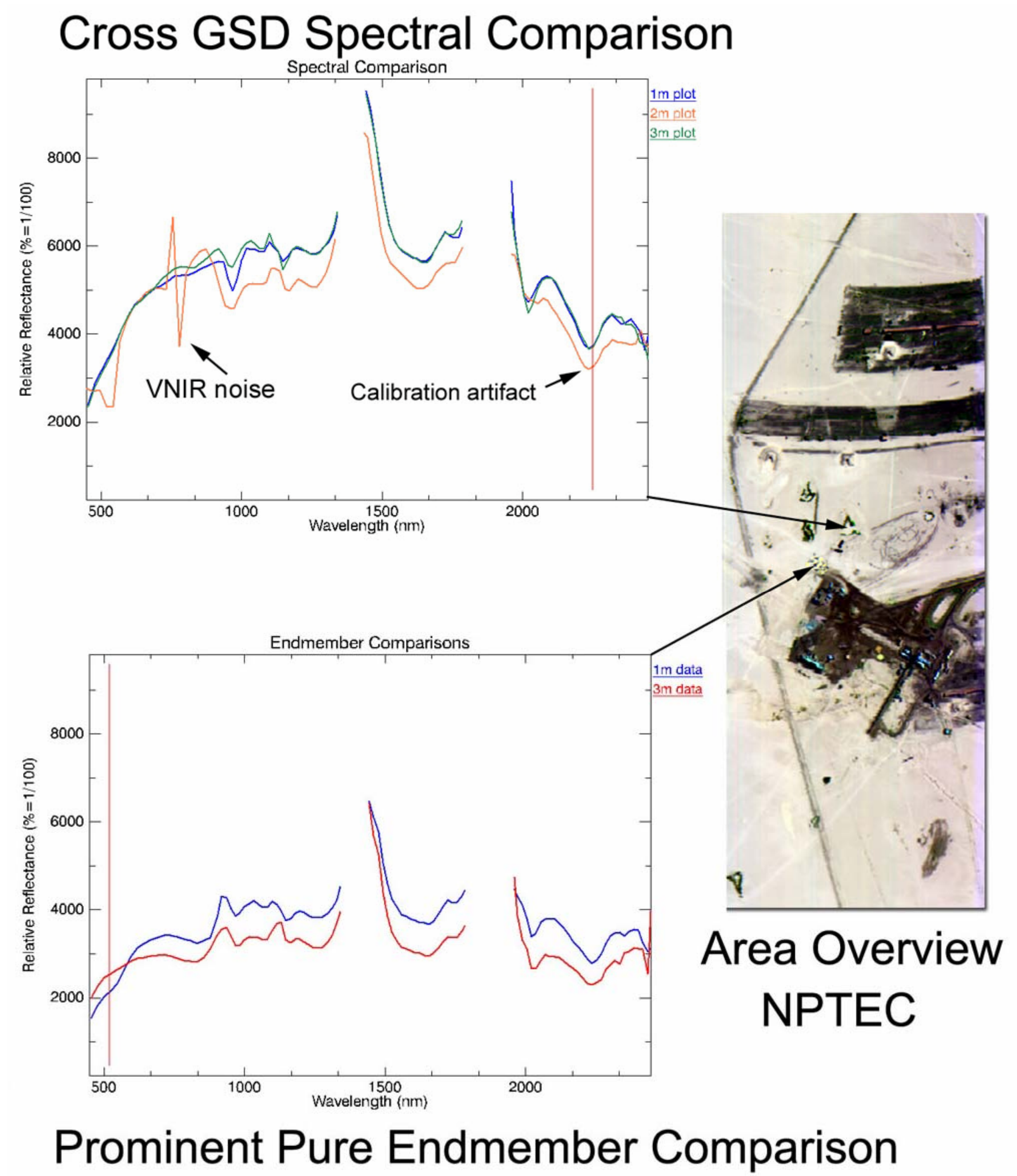


Figure 44. Evaluation of Ground Sampling Distance (GSD) and comparison of pure endmembers for HST-3 image data acquired on 9/28/2005.

41a.

41b

41c

Figure 45. Partial Mosaic of 0.5 meter HST-3 data (41a), Single swaths of 0.5 meter HST-3 image data, (41b, 41c). Coverage just missed the ground targets!

CHAPTER 7

Comparative Analysis of Hyperspectral Sensors

This chapter describes work done during the second quarter of 2006 when UNR was encouraged to work with DOE laboratory personnel, and notably personnel from the Special Technologies laboratory.

During 2005, ABLE received guidance from DOE and Bechtel-Nevada NA-22 program managers that encouraged us to work more closely with DOE's national laboratories that are working on the NA-22 hyperspectral program. Therefore, we began discussions with Dr. Travis White of Lawrence Livermore National Laboratory (LLNL), Dr. Herb Fry of Los Alamos National Laboratory (LANL), and Dr. John De Benedetto of the Bechtel Special Technologies Laboratory (STL) regarding our current work and our continuing work supported under contract to DOE Code NA-22. Those discussions culminated in the submittal of a now funded proposal to expand our research to evaluate background cover types with visible and near infrared (VISNIR), short-wave infrared (SWIR) and long wave infrared (LWIR) hyperspectral image data. We discussed collaborations of our graduate students with STL personnel at the Nevada Test Site, NPTEC during Tarantula. During this period in 2006, we agreed to organize visits to the Bechtel Special Technologies Laboratory, and to coordinate a visit of Dr. Herb Fry to the ABLE lab at UNR. Also, we discussed the possibilities of visiting with Dr. Travis White at LLNL and Dr. White suggested a possibility of collaboration on the DOE NA-22 Broad Area Announcement (BAA).

Problems with SpecTIR Corporation's HST sensors and their data, and pre-processing procedures, rendered all hyperspectral imagery over the NTS and NPTEC unuseable. Based on inputs from the DOE labs, we restructured our research effort to demonstrate the advantages of using hyperspectral reflectance image data to understand background conditions at the NPTEC. This restructuring involved:

1. Continue to investigate and understand the calibration and pre-processing issues with hyperspectral image data acquired by the SpecTir HST-2 and HST-3 sensors over the NPTEC.

2. Use existing hyperspectral reflectance data over Cuprite, Nevada acquired at 0.5, 1, 2, and 3 meter spatial resolutions to understand the influence of spatial resolution on hyperspectral signature analysis.

3. Use existing SpecTir HST, NASA AVIRIS high-altitude, NASA AVIRIS low-altitude, HyMAP, and SpecTir ProspecTIR Dual AISA image data to characterize the ability of various sensors to discriminate spectral endmembers important to background characterization.

4. Evaluate existing HST and ProspecTir data and SEBASS data acquired by ABLE over NPTEC, Cuprite and Virginia City:

    a. Understand the capabilities of SpecTir's new ProspecTir hyperspectral system.

    b. Exploit the synergy of using reflectance and emittance hyperspectral image data for analysis of background materials.

    c. Determine what VIS/NIR/SWIR hyperspectral image data provides that can be used to better understand what the LWIR provides for background discrimination and mapping.

5. Evaluate HST ground scan hyperspectral imagery of altered road cut on Geiger Grade, near Steamboat Springs, Nevada. Consider using HST ground scan data of mine pitwalls.

Specim's AISA Dual Eagle-Hawk SWIR Spectrometer System (Spectir's ProSpecTIR)

Both hyperspectral sensors incorporate a real-time downwelling irrandiance sensor (FODIS) integrated into the sensor heads.

The VISNIR sensor (Eagle) utilizes a Silicon Charge Coupled Device (CCD) progressive scan camera with 1024 (only 640 used) spatial and 256 spectral pixels for 2.3nm bandpasses (2X binning = 4.6nm, 4X binning – 9.2nm). Used dimensions 320 X 228 to match SWIR sensor. (12 bit camera)

The SWIR sensor (Hawk) utilizes a Mercury Cadmium Telluride (MCT) camera with passive cooler. 320 spatial and 254 spectral (246 used) pixels. 6.32nm or 12.64nm bandpasses. (14 bit camera)

Figure 46. ASIA Dual Hyperspectral Sensor System (ProSpecTIR)

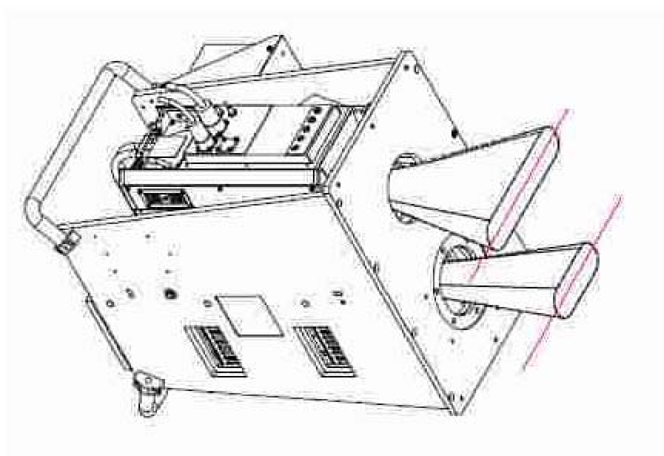


Figure 47. ProSpecTIR Dual Sensor system showing alignment configuration of sensors.

Table 1

AISA Dual Sensor	Specifications	
Spectral range	**VNIR 400-970 nm**	**SWIR 970-2450 nm**
	Total 400-2450 nm	
Spectral resolution	VNIR 2,9 nm	SWIR 8,5 nm
Spectral binning options # spectral bands Spectral sampling/band	VNIR none 2x 4x 244 122 60 2,3nm 4.6nm 9,2nm	SWIR none 2x 4x 254 127 63 5,8nm 11,6nm 23,2nm
Swath acquisition, option 1	See data acquisition option 1 below.	
# spatial pixels FOV IFOV Swath width	VNIR 320 24 degrees 0,075 degrees 0,43 x altitude	SWIR 320 24 degrees 0,075 degrees 0,43 x altitude
Swath acquisition, option 2	See data acquisition option 2 below.	
# spatial pixels FOV IFOV Swath width	VNIR 1024 37,7 degrees 0,037 degrees 0,68 x altitude	SWIR 320 24 degrees 0,075 degrees 0,43 x altitude
Camera SNR	VNIR CCD 12 bits 450:1 (peak)	SWIR MCT 14 bits 800:1 (peak)
Integration time	Settable, independent of frame rate	
Image rate	Up to 100 images/s	
Shutter	Electromechanical shutter for dark background registration in both channels, user controllable by software.	
FODIS	In VNIR channel	

Figure 48. Operator and ProSpecTIR in Cessna 206. Sensor system is mounted in vibration isolation to the floor of the aircraft, but is not in a pitch, yaw and roll stabilized mount.

Figure 49. Dual ProSpecTIR test image acquired on 7-7-2006 showing "Buddingtonite Bump" area of Cuprite Nevada. This test image was geometrically adjusted using 47 control points and rubber sheeting the data to a DEQ with a 3.7 RMS error.

A flat field correction was applied using an area in adjacent Stonewall Plays. This area was geographically referenced to an area that has been used by other investigators for similar spectral adjustments.

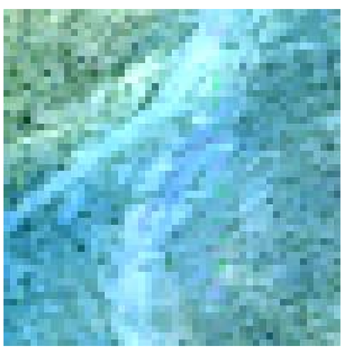


Figure 50. Zoom Image showing Buddingtonite spectral training area in light blue

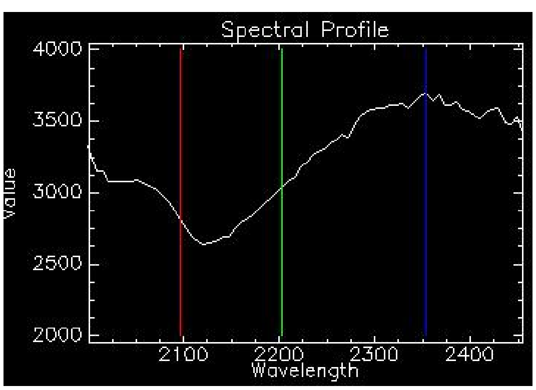


Figure 51. Spectral Plot from Prospectir image data of deepest blue area, coinciding with Buddingtonite spectra

The first two files on this list were collected using the ProSpecTIR Dual imager. This imager collects data in [400, 2450] nm at 5-nm spacing. The sequence of processing steps were:

(1) Convert raw data (directly from the collection) into radiance using a calibrated radiance sphere as a standard, together with a dark-current sample recorded at flight time for each flightline;

(2) Using the information gathered at flight time, determine the geographic location of each pixel in the image, placing that in the GLT files;

(3) Convert radiance to pseudoreflectance, wherein it is assumed that the pixels on Stonewall Playa are spectrally flat, so that if we divide every pixel in the image by an average of the pixels over Stonewall Playa, here 5,000 in number, we obtain a "pseudoreflectance" that is proportional to true reflectance as would be measured on the ground with a spectrometer. This is a standard procedure for benchmark comparisons between this imagery and that obtained using other sensors such as in the ENVI™ dataset based on AVIRIS95 data;

(4) Apply image polishing with mitigation of the major water features. Shown is the option we prefer, in which the water bands are set to zero, however, the user can opt not to set these to zero in this fashion. For flights this low, it is possible to see valid data through the water bands in dry-air conditions, and so this setting of spectral values to zero might not be applicable or even preferred.

The next two files are the result of attempting to discover spectral endmembers using an enhanced version of the "spectral hourglass" method of ENVI™. This is a spectral library which can be opened in the Spectral Library Viewer from ENVI™.

The GLT files can be used to get fairly accurate geocoordinates of each pixel. The data have not had *orthorectification* applied, an option most users will not require for the most accurate possible location of ground coordinates down to the size of the pixel, but which is computer-time intensive. Use of the data and GLT file in ENVI™ allows precise geographic coordinates to be associated with each pixel. The geocorrected data can be displayed by opening **0707-1156_ffSG.dat** and **0707-1156a_rad_GLT.dat** from ENVI™ and then selecting **Map → Georeference from Input Geometry → Georeference from GLT**. The following endmembers drawn from the spectral library described above are recognized as being very similar to laboratory spectra measured with an ASD spectrometer.

Below, only endmembers are shown in the SWIR, but signatures for the iron minerals are also accessible using this technology, and are generally better determined in the visible and near infrared portion of the spectrum (400 – 900 nm). Note that, unlike the JPL AVIRIS imager, the hyperspectral benchmark, the data here give useable information beyond 2400 nm.

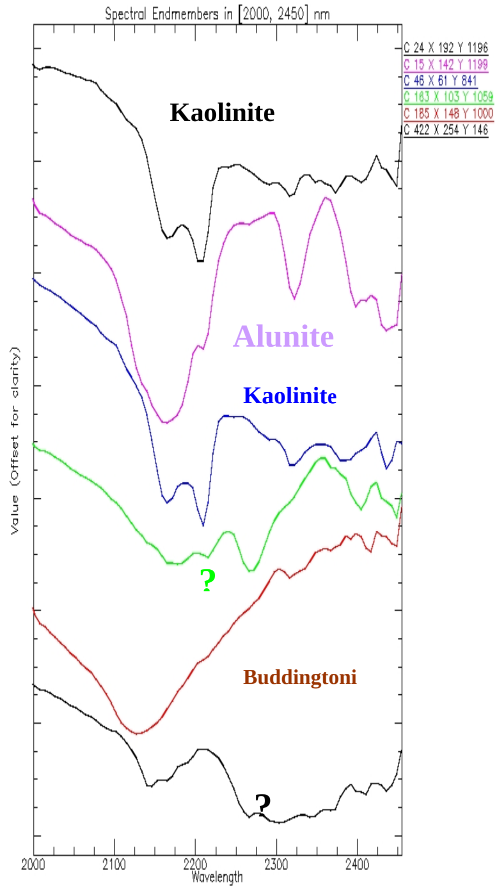
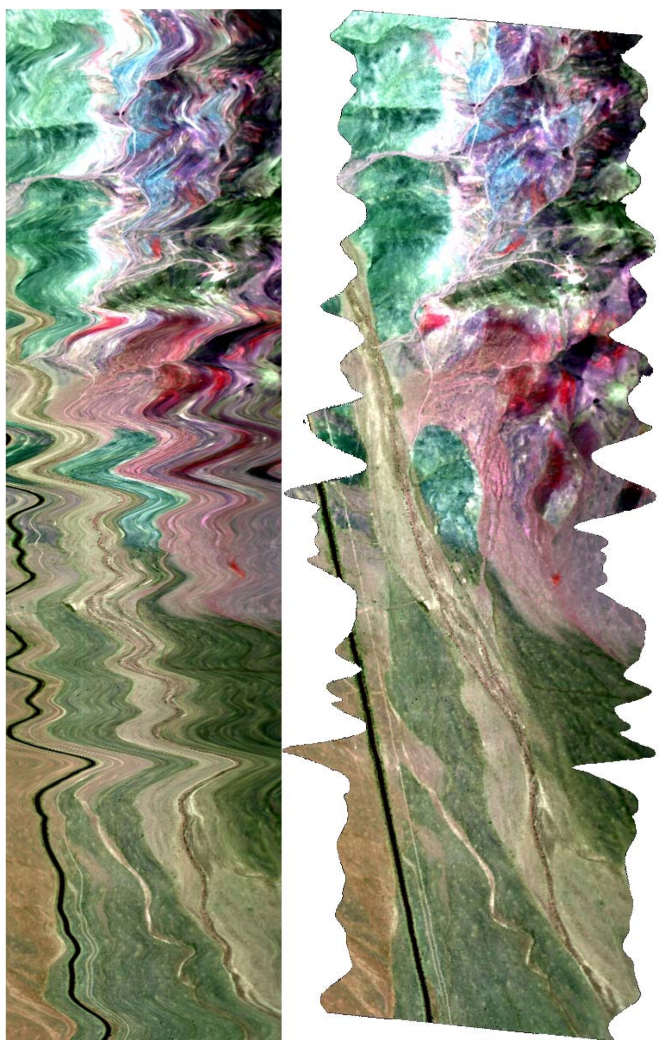


Figure 52. Spectral Endmembers: Kaolinite, Alunite and Buddingtonite.

This image shows how the georectification takes place. Using the known position of the plane and its orientation, it is possible, using a DEM, to locate each ground pixel geographically. The original image (upside down because it was flown south to north) is shown on the left. On the right is the geocorrected image. Note on this latter image that U.S. Highway 95, down and left, plots as a straight line as on a map of the region. The heavy waviness of the original image is caused by motion of the plane during the data collection flightline. The trueness of the road gives immediate confirmation that the geographic coordinates so determined are reasonably accurate. On either image, note how the strong signal-to-noise ratio allows very clear determination of regions with differing spectral signatures, as shown by the variety of sharply-distinctive colors. These 3-color images have {red, green, blue} as wavelengths {2095, 2203, 2352} nm. Note that the geocorrection requires that DEMs be available. This is true throughout the U.S., but in extremely steep terrain large location errors can result on this as on any imagery.



(a) (b)

Figure 53. (a) geometrically uncorrected and (b) corrected ProSpecTIR data.

The goal of this section was to collect, co-register and analyze all of the available hyperspectral datasets acquired over Cuprite, NV between 1995 and 2006. Overall the plan was devised as following:

- Collate all of the available radiance and reflectance data (and ancillary sets) available in the ABLE laboratory: Dual ProSpecTIR, HyperSpectir (HST), HyMap, Low and High altitude AVIRIS and Hyperion.

- Find the cross-correlating subset area in all of the sets gathered in the geospatial database (i.e. Buddingtonite Bump). Every cube should cover the same identical area, regardless of resolution.

- Determine the radiometric, spectral and spatial parameters of the subset area.

- Analyze each subset cube separately using the same parameters, and streamlined hourglass processing, logging every step and determining the statistics of the endmembers obtained.

- Compare the overall quality and quantity of endmebers obtained within the narrowly defined subset area with regards to spatial, spectral and radiometric resolution.

Available Datasets

Sensor	Range	Resolution	Acquisition	Affiliation and Link
Hyperion	400-2500nm 220 bands	30 m	June 2001	NASA
AVIRIS High Altitude	400-2500nm 224 bands	20m	July 12, 2002	NASA JPL
HyMAP	450-2500nm 126 bands	5m	Sept. 11, 1999	HyVista Corp.
AVIRIS Low Altitude	400-2500nm 224 bands	4m	July 30, 2002	NASA JPL
HST-1	450-2450nm 227 bands	2.2m	June 30, 2002	SpecTIR Corp.
HST-3	450-2450nm 230 bands	2.0m	April 27, 2004	SpecTIR Corp.
ProSpecTIR	400-2500nm 356 bands	1.0m and 2.5m	July 7, 2006	SpecTIR LLC.

Table 2 – Available datasets over Cuprite, NV

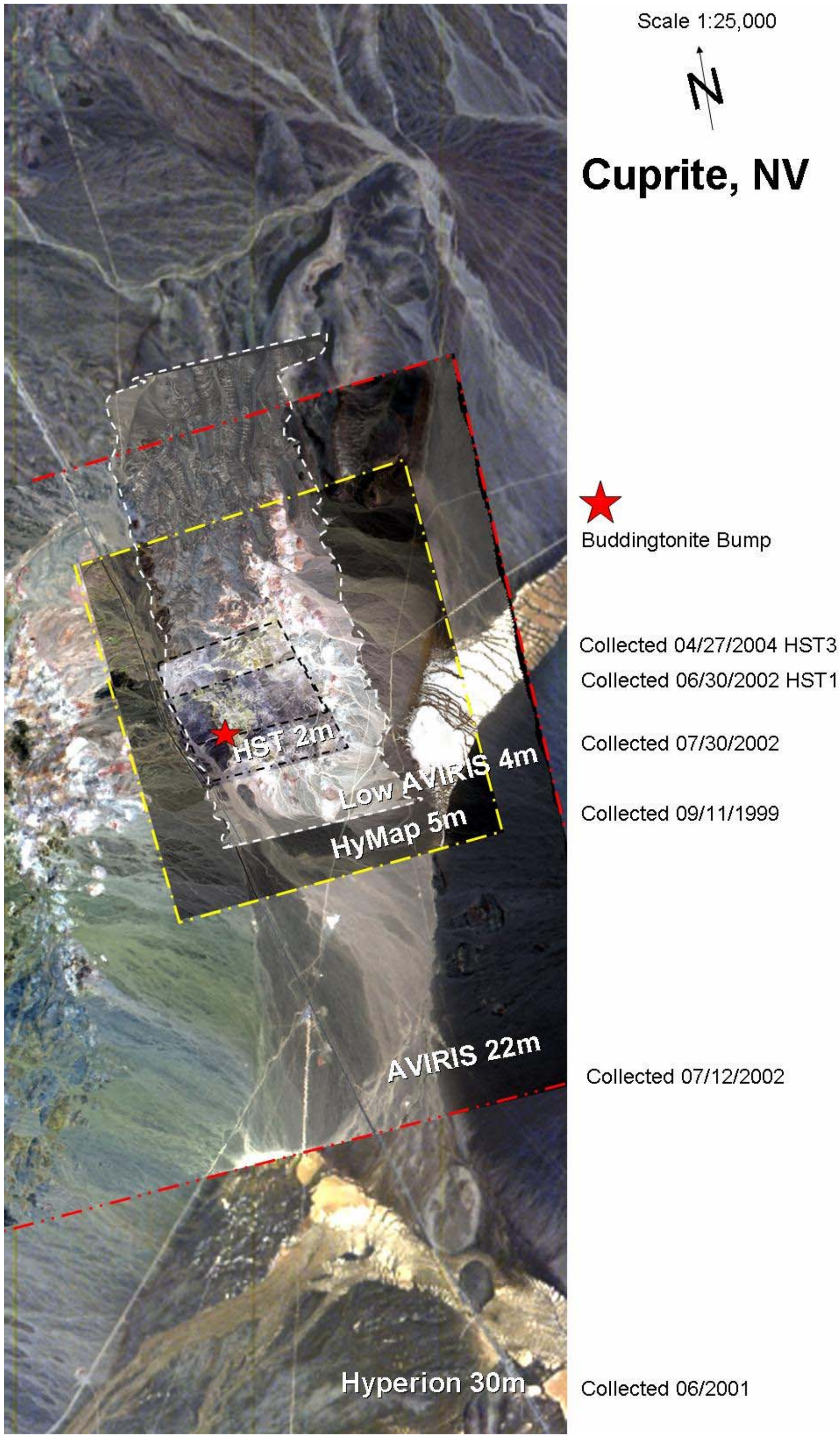


Figure 54. Graphic representation of the available sensor coverage over Cuprite.

Target Area

The Cuprite-Ralston area was chosen because it has been extensively studied and well mapped (Abrams et al, 1977, Clark et al, 1993, Swayze et al, 1998). Cuprite lies in southwest Nevada, along Highway 95, about 40 miles south of Tonopah and 10 miles south of the Goldfield Mining District. The area is named after one of the ghost town sites (Cuprite, Ralston, Lida). This is an arid to desert environment with low scrubby grass, sage and rabbit brush sparsely covering the terrain. The Stonewall Playa (a dry silt / salt flat) lies to the south and east and is used as a reflectance calibration site. Cuprite is a hydrothermal alteration system that has been emplaced in volcanic host rocks. Although there is no known mineralization at Cuprite, the hydrothermal alteration mineral suite is extensive and exhibits excellent zoning, which can easily be detected with airborne sensors. The eastern side of the district contains a distinctive "Bulls Eye" pattern of silica, surrounded by alunite, surrounded by kaolinite. Cuprite has been used as a benchmark site for calibrating many new hyperspectral sensors (Swayze et al, 1998).

Buddingtonite is an NH4-feldspar, once thought to be fairly rare, but with the advent of mineral spectroscopy discovered to be fairly ubiquitous in the volcanic-hosted hydrothermal systems. The area of unusually high Buddingtonite concentration located in the eastern portion of Cuprite hydrothermal system is known as the “Buddingtonite Bump (Figure 55).” The area is rhomboidal-shaped about 150m long and 70m wide (Figure 3), exhibiting fairly-high albedo and in the field manifested as white, porcelain-like rock with powdery-like precipitate. Buddingtonite mineral exhibits fairly distinct absorption spectrum and is chosen in this study to represent the named area of interest for the radiance/reflectance cross-comparison of different hyperspectral systems.

Figure 55. Buddingtonite Bump sampled with field spectroscopy (Courtesy: SII).

Radiance Comparison

Most sensor data are already developed to customer in a radiance-at-sensor format. The user is often not provided with the calibration files and/or steps used in conversion of raw DN instrument data to radiance. Usually, the raw data are subjected to dark current removal (a procedure that scrubs the instrument noise data), bad pixel mapping (pushbroom sensor CCDs occasionally experience voltage fluctuations manifesting as striping in the data) and application of proper gains and offsets to adjust the raw DN values to lab or on-board calibration parameters. The exact parameters of radiance conversion are unknown in this case, so the radiance values were cross-compared on “as-is” basis.

The available radiance data were re-scaled to same X and Y axes and compared over 30 x 30m average (presumed relatively uniform radiance) region-of-interest area. The region of interest-selected is the Buddingtonite Bump area (Figure 56).

Figure 56. Buddingtonite Bump observed with (from the left): Hyperion (30m), AVIRIS (20m), Hymap (5m), Low Altitude AVIRIS (4m), and HyperSpecTIR (2m).

All of the pixels in the target region-of-interest area were averaged for each dataset, and data-sets re-scaled to same axis values (wavelength ranges and FWHM ranges) for easier cross comparison and basic statistical comparison.

Overall, Hyperion has the lowest radiance reading and the feature is shifted. I ascribe that to low SNR and shifted calibration file - this is the 2001 evaluation dataset. HyMap also has shifted feature, but the shift is ascribed to the 16nm bandpass. Low and High altitude AVIRIS are nearly identical and match well with Buddingtonite feature. HST-1 has somewhat shallower feature, but this is ascribed to the higher number of pixels averaged which, unexpectedly works against the clarity of the feature. When only the center-area pixel readings are compared, the resulting signature is very similar to AVIRIS, albeit noisier. This portion of the final report was supported by Dr. Amer Smailbegovic of Teraelement, LLC, a former Ph. D. student from the Arthur Brant Laboratory of Exploration Geophysics, who provides contract support to ABLE.

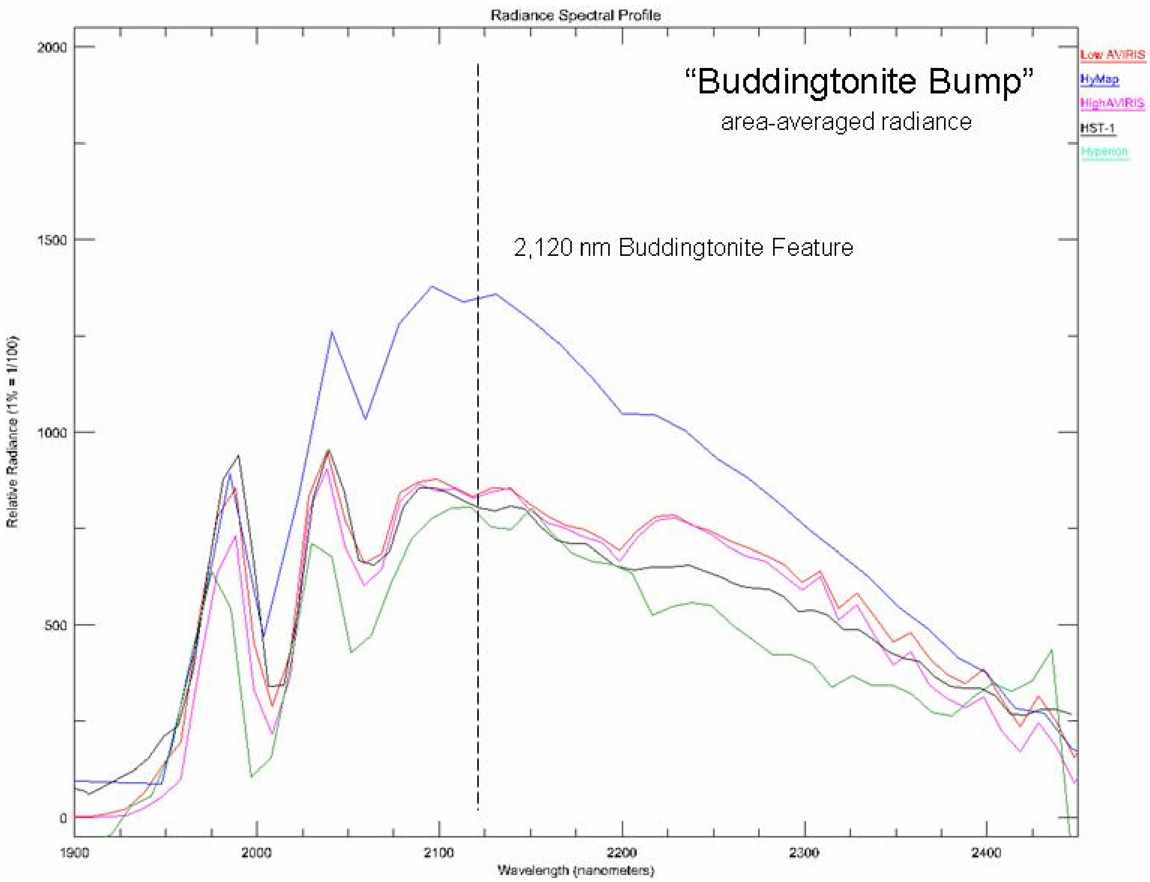


Figure 57. SWIR portion of radiance comparison with 2,120nm Buddingtonite absorption feature marked. The spectrum shows Hyperion, Hymap, AVIRIS and HST-1 data.

The majority of the analyzed datasets have fairly similar radiance values, which suggests that the process of obtaining reflectance should focus on a method which can be easily applied for all without having to resort to various atmospheric models, multipliers, converters and assumptions. A secondary assessment of radiance features shows fairly flat radiance profile (SWIR) over the central portion of the Stonewall playa. Considering that ALL of the datasets have a portion of an image (or flightline) that extends across the uniform region of Stonewall playa it was decided that flat-field-derived reflectance would be the best method for reflectance cross-comparison.

Flat-field Reflectance

The "Flat Field Calibration" technique is generally used to normalize images to an area of known "flat" reflectance or radiance (Goetz and Srivastava, 1985; Roberts *et al.* , 1986). The method requires an input region consisting of a large, spectrally flat, spectrally uniform area in the radiance hyperspectral data, usually defined as a Region of Interest (ROI). The radiance spectrum from this area is assumed to be composed of primarily atmospheric effects and the average, standard solar spectrum. The average input radiance spectrum from the ROI is used as the reference spectrum, which is then divided into the spectrum at each pixel of the image. The result is apparent reflectance data that can be compared with laboratory spectra.

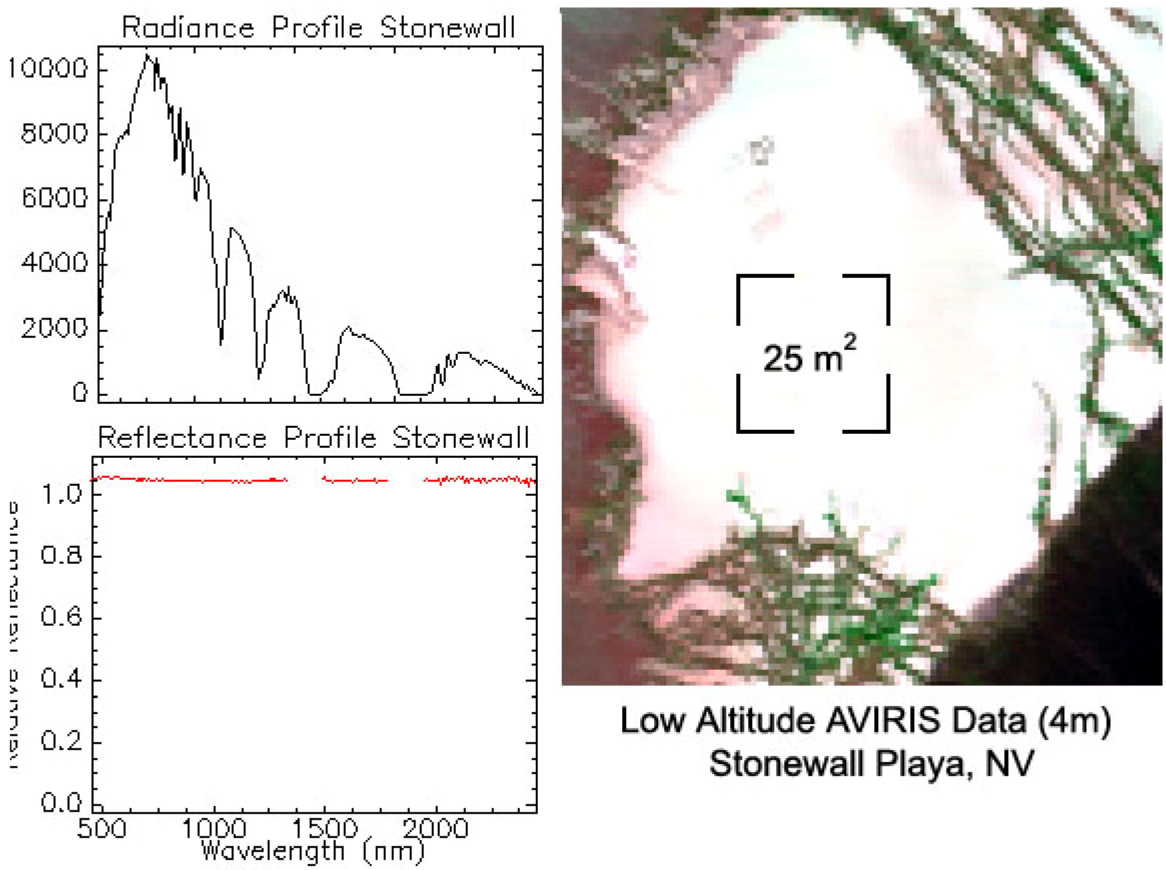


Figure 58. Stonewall Playa derived flat-field reflectance. The same region (in different data-sets) was used to derive the reflectances for Hyperion, AVIRIS, HyMap, HST and ProSpecTIR.

A region in Stonewall Playa about 25 square meters in size was used as a flat-field region of interest. All of the datasets have portions of flightline over Stonewall Playa, so it was possible to derive a comparable reflectance dataset. The reflectance is fairly well matched in SWIR, although in VNIR an artifact related to playa's high albedo is noted. Because most of the mineral identification was conducted in SWIR range, a pseudo-increase in VNIR was considered not relevant. In some of the datasets (notably high-altitude AVIRIS), the playa was wetter than the surrounding areas in overcompensation of H2O water-vapor regions near 960nm and 1120nm in drier regions of the scene (Figure 58).

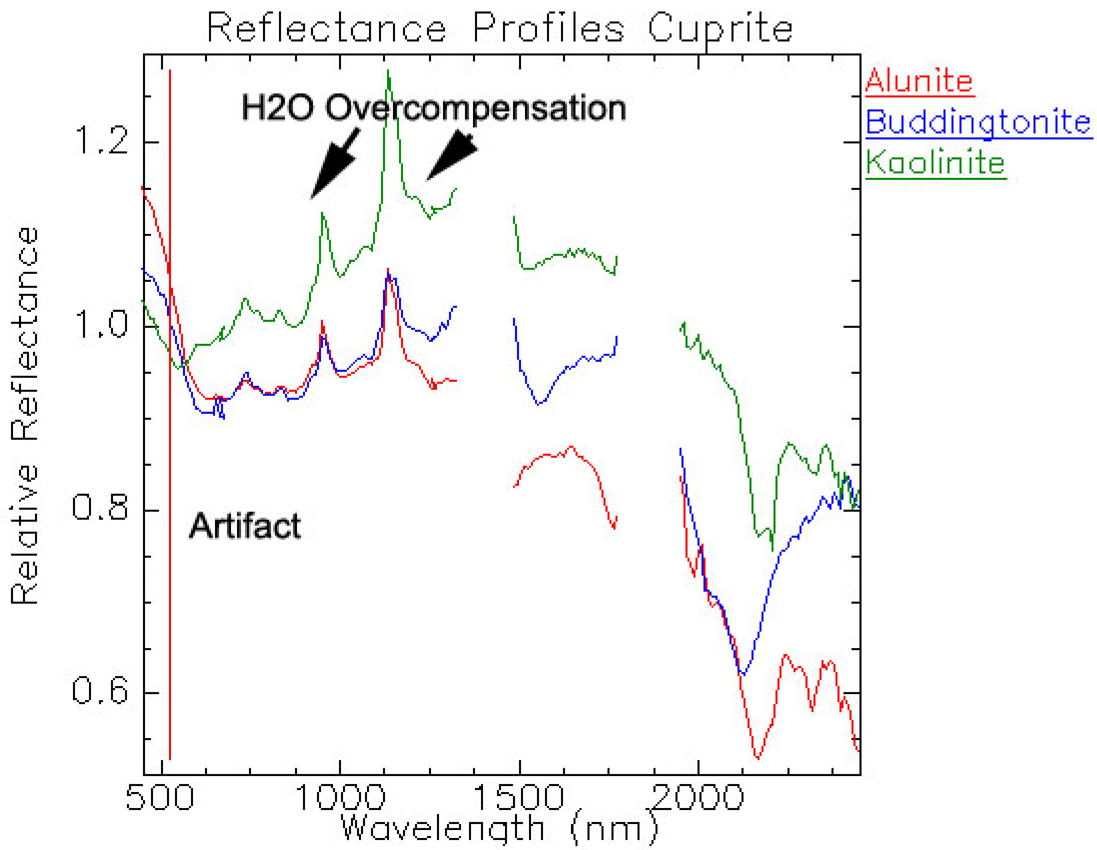


Figure 59. High altitude AVIRIS flat-field spectra over the most prominent regions (Alunite, Buddingtonite and Kaolinite Hills). Note that whereas the SWIR region used for mineral identification is well preserved, flat-field reflectance spectrum has artifacts occurring in UV/VIS region and water-vapor regions.

Analysis

A standardized image processing method was utilized to identify the spectral target endmembers associated with a subset-region area of interest (Buddingtonite Bump). The processing method utilized in the data analysis is a modification of the standard hourglass (Boardman, 1999) processing method that begins with a re-scaling of the radiance-at-sensor data and ends with endmember selection and statistical analysis. The procedure include the Minimum Noise Fraction (MNF) transformation (Green et al., 1988; Boardman, 1993), spatial data reduction using the Pixel Purity Index (PPI) (Boardman, 1993), an n-Dimensional Visualize to determine image endmembers (Boardman, 1993), identification of endmembers using their reflectance spectra (Kruse et al., 1993) and Mixture-Tuned-Matched Filtering (MTMF) to validate the endmember classes (Boardman, 1998). The image processing software package ENVI (Environment for Visualizing Images), Version 4.2, was used in the processing of image information. A Minimum Noise Fraction (MNF) transformation was used to produce spectral bands free of instrumental and/or atmospheric noise. A Pixel Purity Index (PPI) routine utilizing 10,000 iterations and 1.0 – 6.0 mrad threshold was used to select all of the pixels in the image that are above the noise floor and appear to contain unique spectra that can be further used to determine spectral “endmembers” for a given dataset. The term “endmember,” is used to denote a spectrum that is unique, representative, and characteristic of a dominant surficial material (e.g. vegetation, water, mineral or mixture of minerals) in a dataset.

The cut-off for MNF bands was set at “2” from the generated Eigen-values. MNF had to be adjusted for ProSpecTIR and Hyperion, eliminating first 10 input bands (to eliminate the occurrences of NaN values – the input bands fall outside of MNF’s ability to handle them). The results entering n-dimensional visualizer were thresholded above the 10% of maximum “hit” value in the PPI routine (e.g. Maximum value = 100, ROI threshold = 10). The multi-dimensional (n-dimensional scatter plot) analysis of endmembers resulted in the selection of several characteristic (unique) endmember-minerals in the scenes. The endmember-types were used to further classify (and refine) the spectral information from the data using the Mixture Tuned Matched Filtering (MTMF) algorithm. The algorithm produces an “abundance” image map for each selected endmember-type and an associated "infeasibility" image to prevent detecting "false positives" (Boardman, 1998). The abundance image can be plotted against the infeasibility image in a 2D scatter plot to reveal the threshold for the best-match endmember classes (those with the highest likelihood and the lowest infeasibility). The points above the threshold are assigned to a particular Region of Interest (ROI). All of the spectral information in the ROI is averaged to produce a mean spectral value; the spectral representative of an “endmember-class.” The endmember-class ROIs were assigned colors and overlain on grayscale images, producing thematic displays of relative endmember-class distribution in the scene.

Instrument	MNF Bands	mrad	Thresh	Pure	MTMF	Endm’r Cls.
Hyperion	8	6	1	10	3	5
AVIRIS HI	21	1	6	233	15	6
HyMap	17	1	10	399	22	7
AVIRIS LO	22	0.8	10	791	40	12
HST-1	16	0.9	9	890	27	9
HST-3	20	1	8	666	31	11
ProSpecTIR	27	0.75	10	588	52	9

Table 3. Hourglass process output values (number of MNF bands, Eigen vector angle, PPI selection threshold, total number of pure pixels, MTMF number of pixels and final endmember classes).

Endmembers

Hyperion

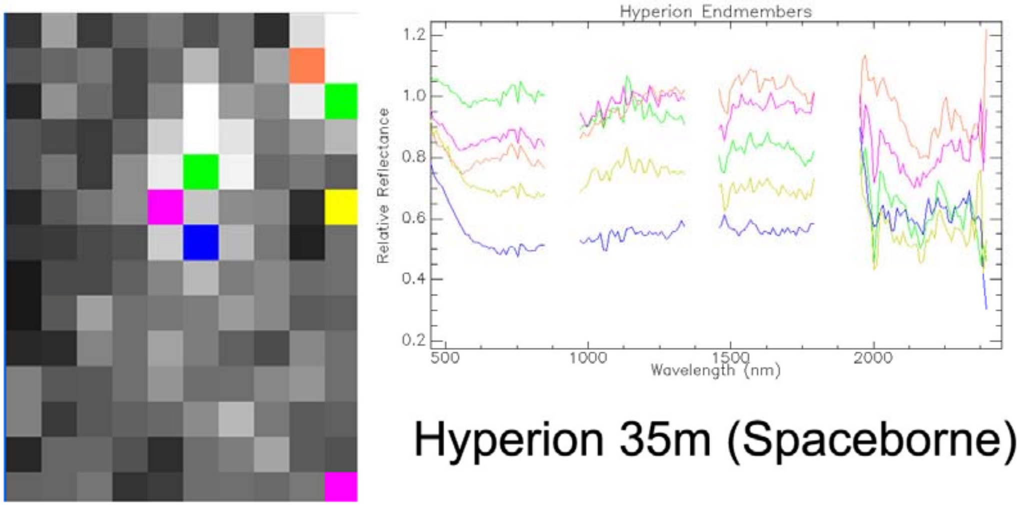


Figure 60. Hyperion endmembers: the data is fairly coarse and noisy. However, it is possible to differentiate 5 endmembers: alunite (orange), buddingtonite (magenta and green) and possible clay minerals (blue, yellow).

AVIRIS High

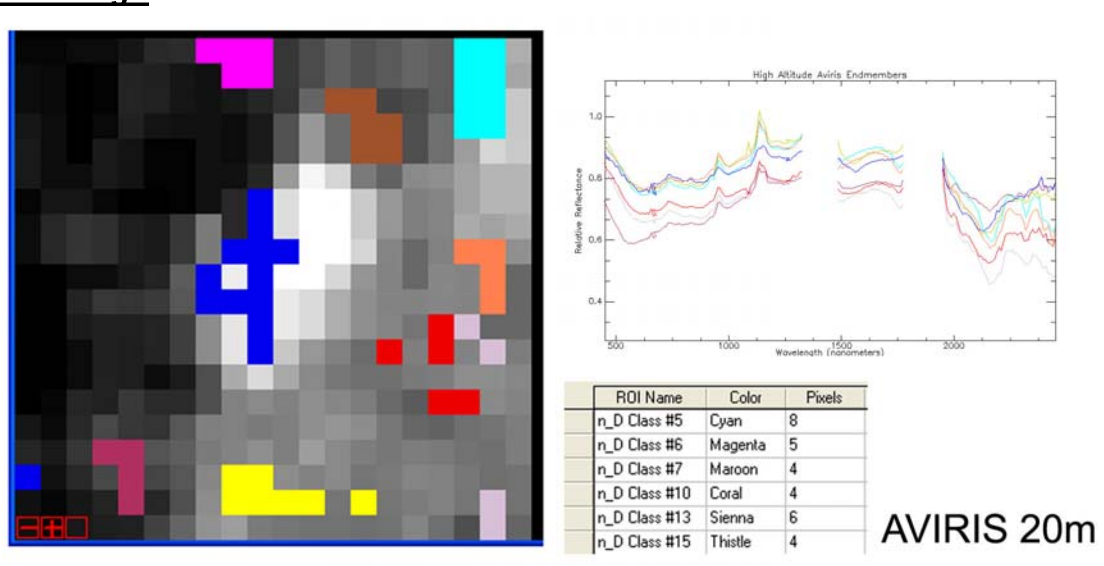
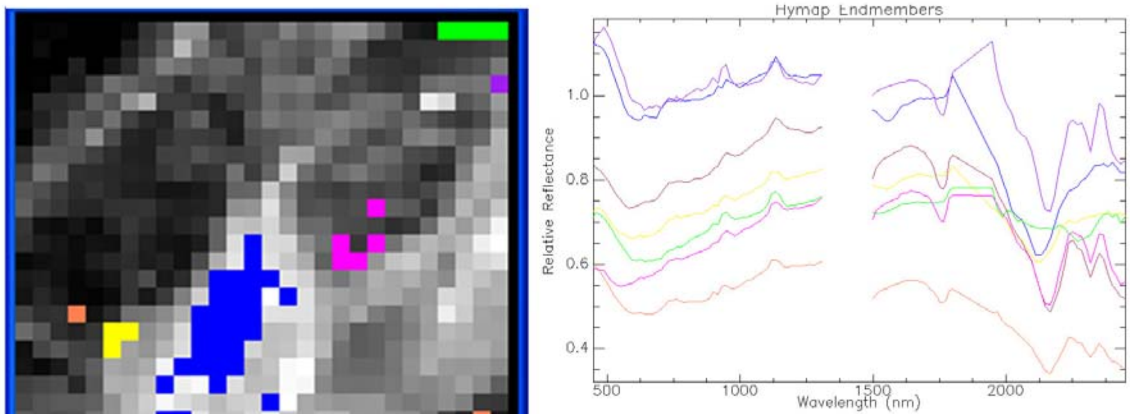


Figure 61. – High altitude AVIRIS endmembers. It is possible to differentiate several different endmembers: buddingtonite (blue), alunite (red, coral and orchid) and clay minerals (cyan, coral, yellow).

HyMap

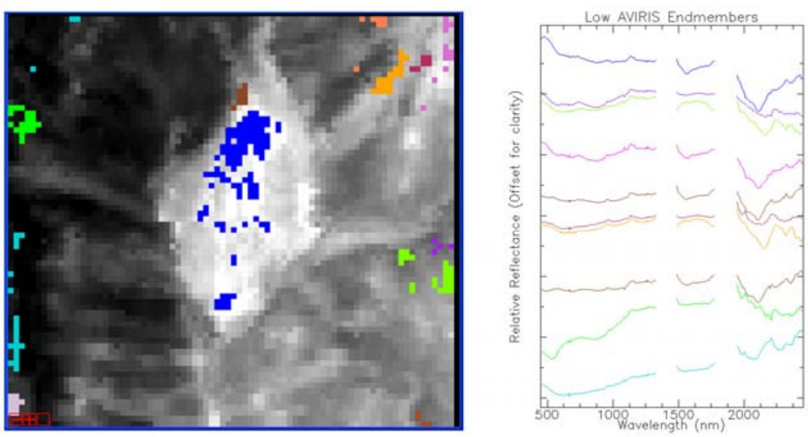


	ROI Name	Color	Pixels
*	n_D Class #2	Green	6
	n_D Class #3	Blue	32
	n_D Class #4	Yellow	4
	n_D Class #6	Magenta	5
	n_D Class #7	Maroon	3
	n_D Class #9	Purple	4
	n_D Class #10	Coral	6

HyMap 5m

Figure 62. Improved spatial resolution of HyMap gives better spatial control on the endmembers and points to some others not seen previously: buddingtonite (blue), alunite (magenta, purple and coral) and possible jarosite (green).

AVIRIS Low



	ROI Name	Color	Pixels
*	n_D Class #2	Green	19
	n_D Class #3	Blue	106
	n_D Class #6	Magenta	9
	n_D Class #7	Maroon	6
	n_D Class #9	Purple	4
	n_D Class #10	Coral	7
	n_D Class #12	Orchid	12
	n_D Class #13	Sienna	5
	n_D Class #14	Chartreuse	22
	n_D Class #15	Thistle	9
	n_D Class #29	Cyan2	22
	n_D Class #40	Orange1	19
	n_D Class #46	Sienna3	8

AVIRIS (low) 3.5m

Figure 63. Low altitude AVIRIS data shows additional endmembers in greater detail: buddingtonite (blue and magenta), alunite (orange), kaolinite (green), goethite (cyan), jarosite (orchid).

HyperSpecTIR

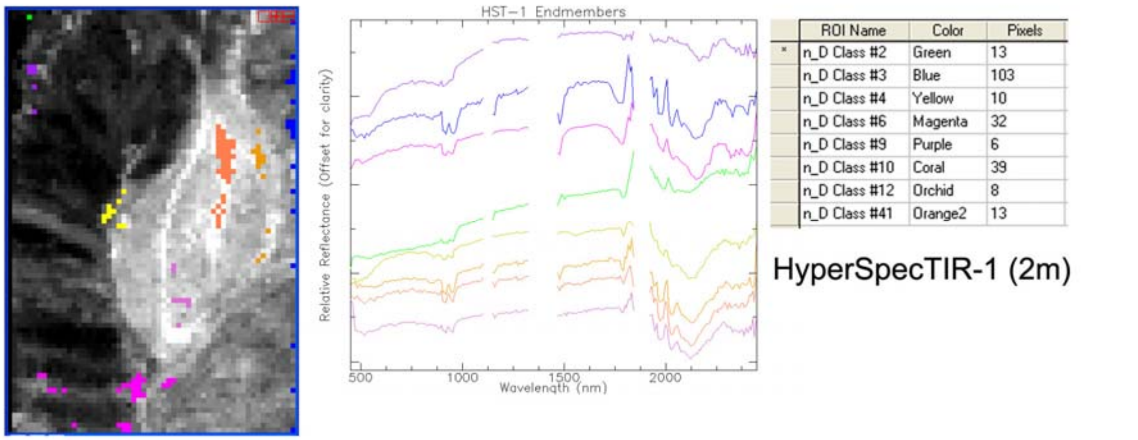


Figure 64. High resolution HST data shows several different buddingtonite endmembers within the Buddingtonite Bump. It also shows some alunite (blue and magenta) and dickite (purple) on the periphery.

ProSpecTIR

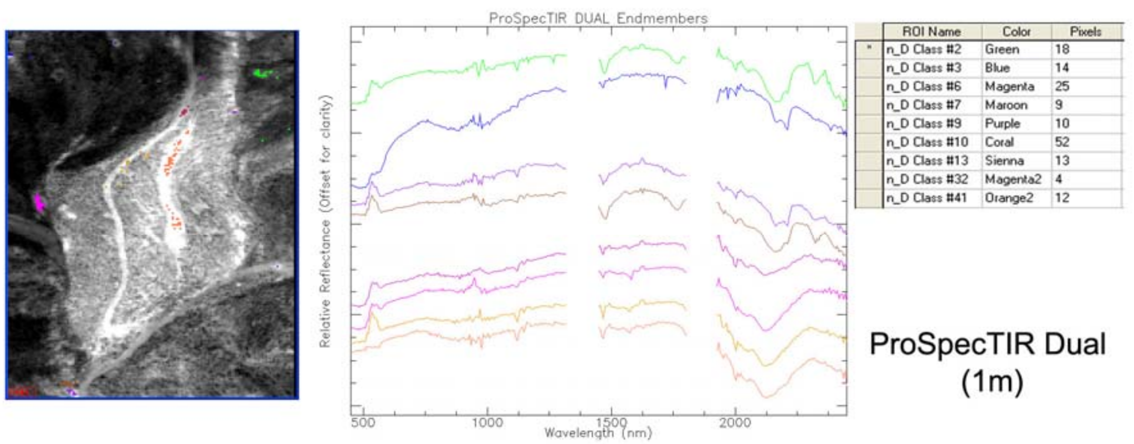


Figure 65. Shows (un-georectified) ProSpecTIR image over Buddingtonite Bump outlining several buddingtonite endmembers (coral, orange, magenta, purple), alunite (maroon and green), dickite (purple), kaolinite (blue).

Spectral Comparison

The best-match (USGS Spectral Library) buddingtonite endmembers for each of the sensor system were averaged to produce a "sensor-average buddingtonite spectrum," which were then graphically and statistically cross compared.

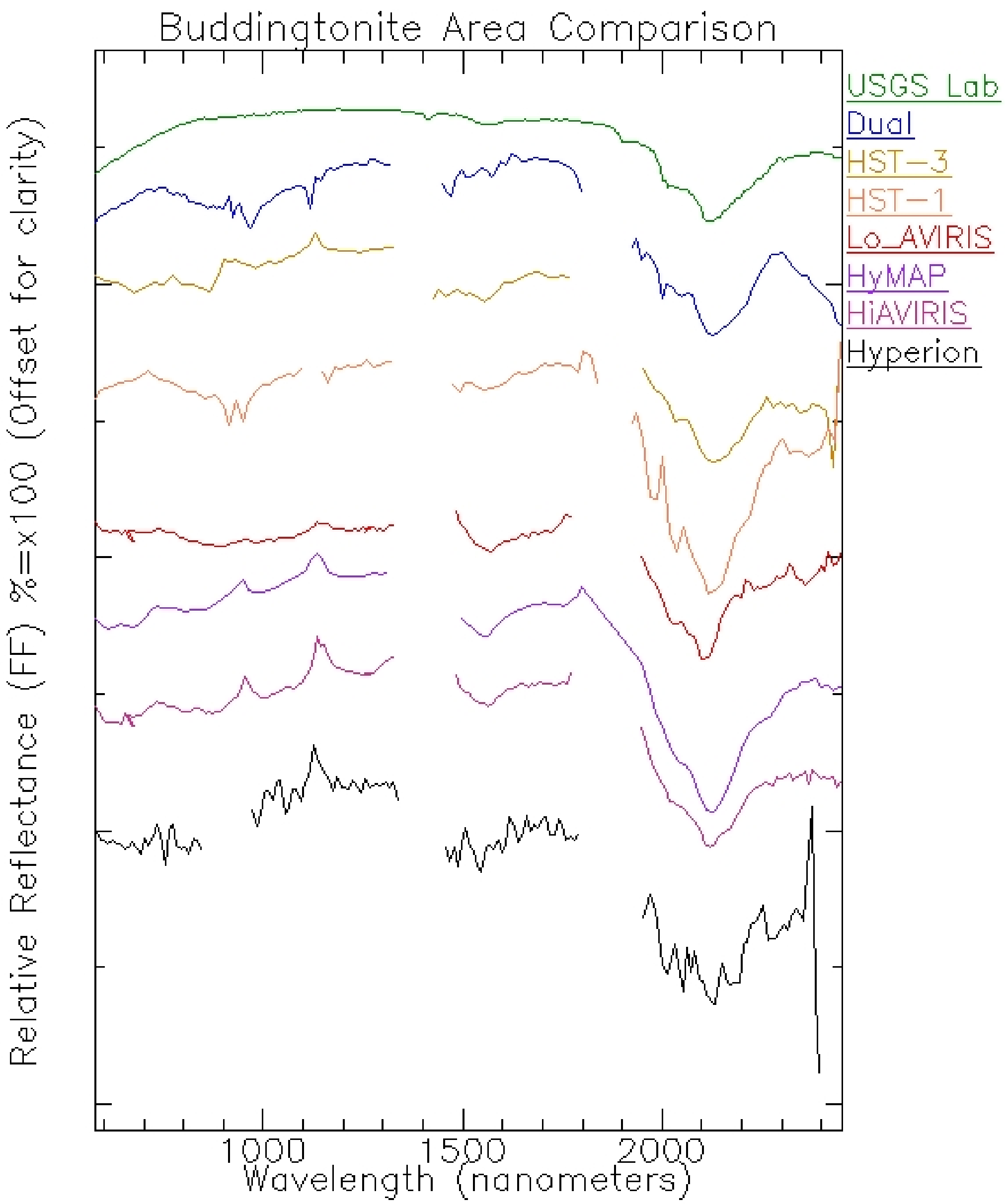


Figure 66. – Sensor-average buddingtonite endmembers compared to USGS spectral library buddingtonite sample.

The sensor-average spectra were statistically compared with the laboratory data to show the approximate curve-match, whereas the curve-statistics are not going to be the best method for judging the performance of a sensor. It shows that almost all of the analyzed system are fairly close-matching with the laboratory reference data. The image spectra are noisier and sampled at wider intervals than the lab spectrum, but a visual and statistical match of about 30% is generally considered to be good.

Figure 66, (above) shows that Hyperion data are fairly noisy, but some residual identification elements exist, which allow buddingtonite identification. Overall match with the library spectrum is only 11.52%. AVIRIS high altitude data is fairly smooth and matches well with the library entry, but relatively large spatial sampling also introduces some uncertainties resulting in a 43.08% match. Finer spatial resolution and wider sampling interval (16nm) of HyMap produces a smoother, better match with the library spectrum at 49.51 %. Low altitude AVIRIS produces another good match with the library at 57.65 %/ HST-1 is somewhat noisier (due to older focal plane), so the match is about 37.15%. HST-3 with a newer scientific-grade focal plane has a very good match of about 54.52% ProSpecTIR is another good match with a laboratory spectrum at 57.05%.

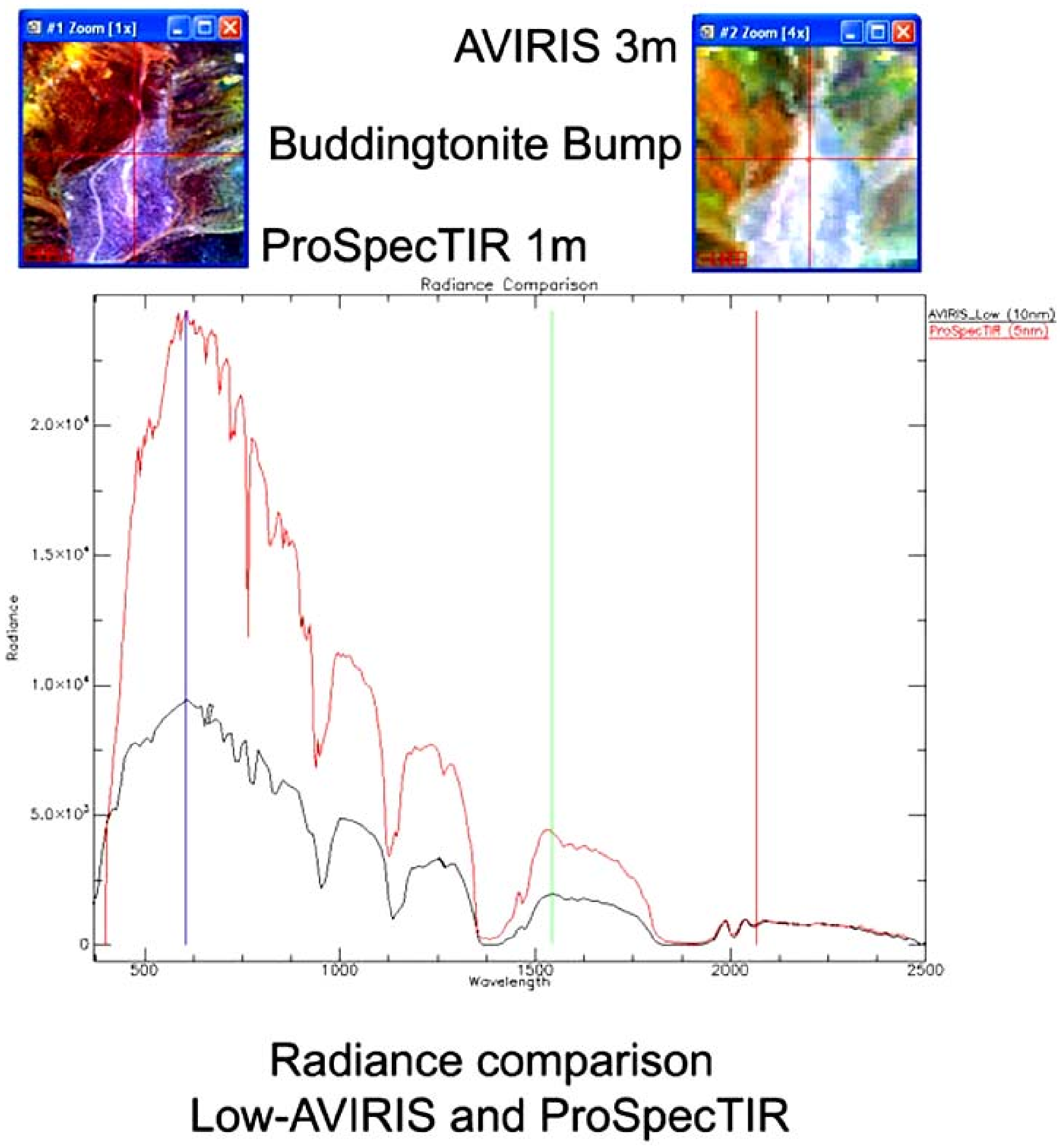
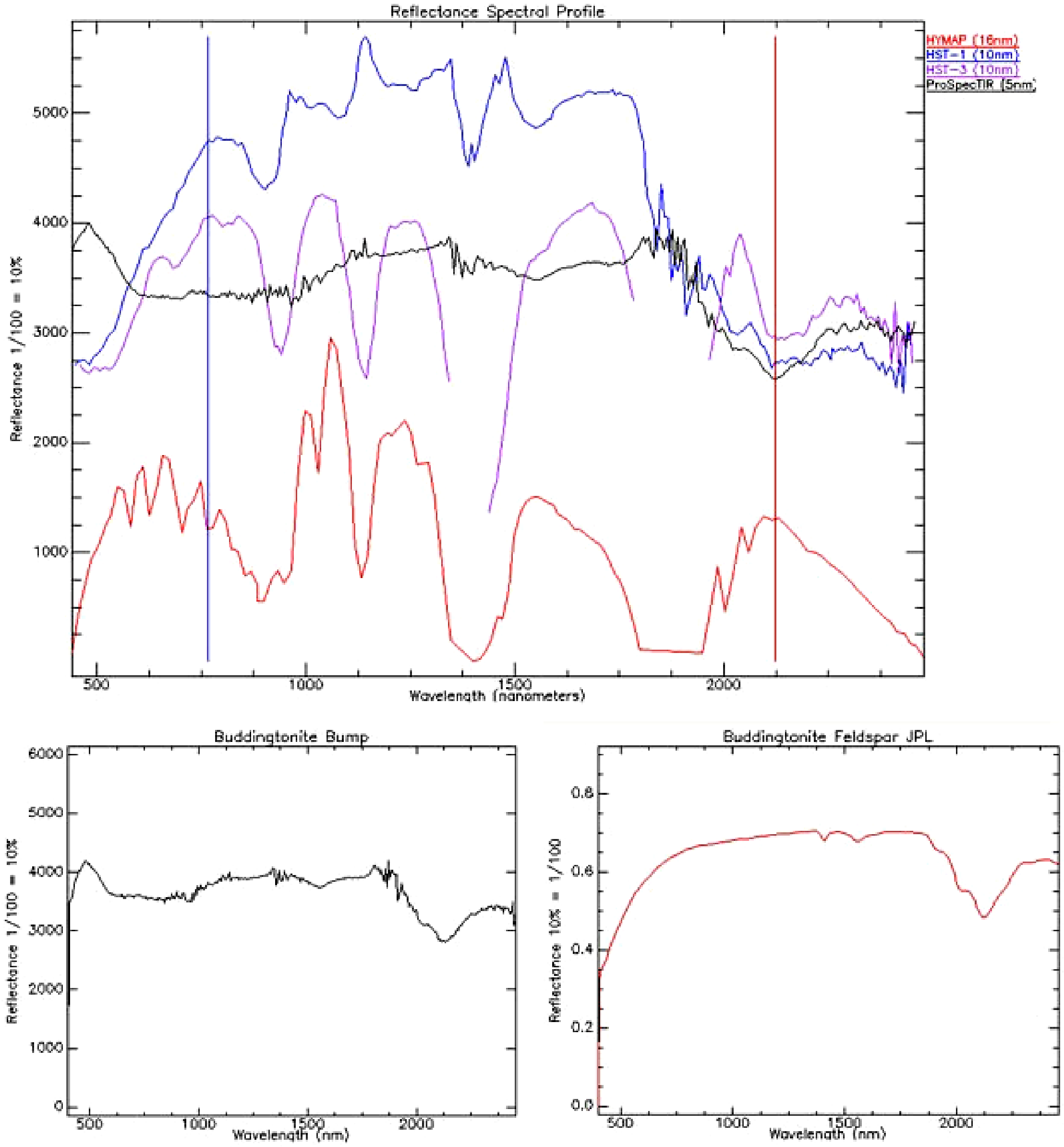


Figure 67. Comparison of radiance measured by Low-Altitude AVIRIS (black) and radiance measured by ProSpecTIR (red).

MODTRAN-derived Reflectance Comparison*



Comparison of ProSpecTIR averaged Buddingtonite endmember (black) and JPL lab spectra for Buddingtonite (red)

Figure 68

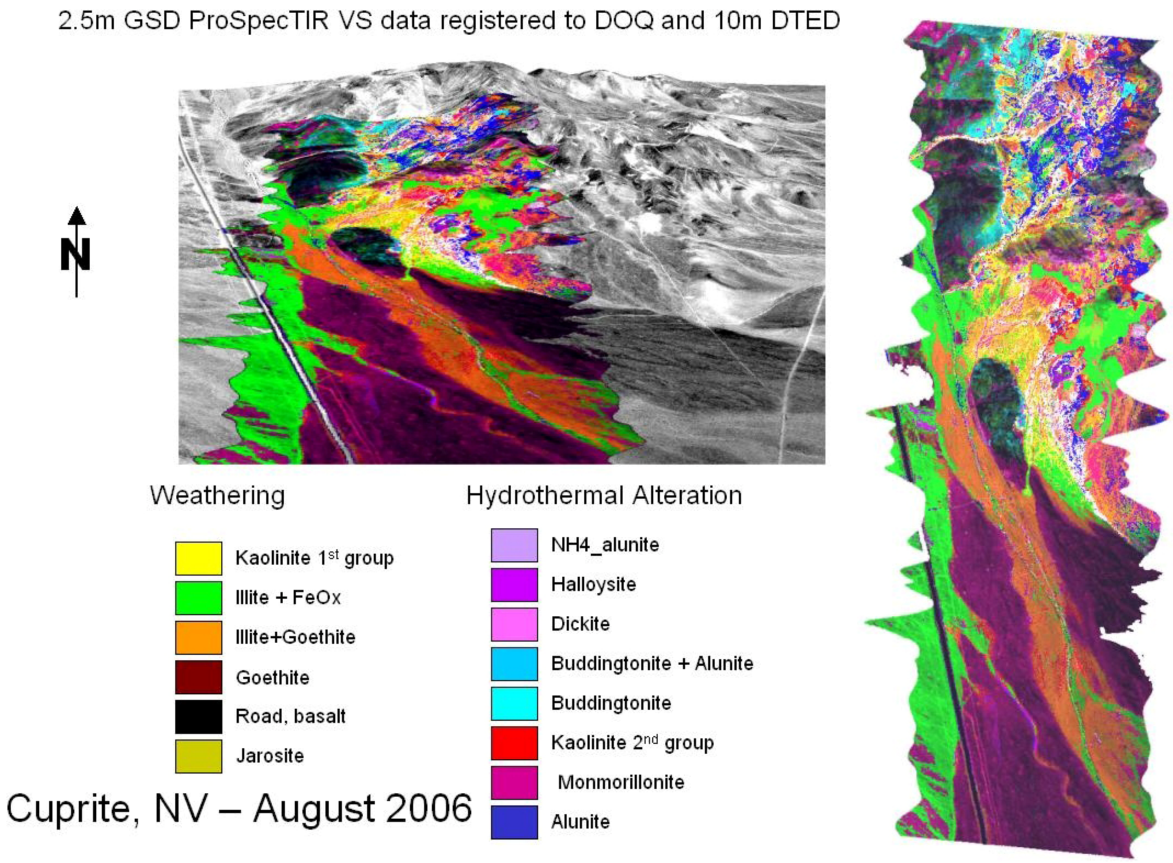


Figure 69. Perspective 3D view of Buddingtonite Bump area. 30 km strip.

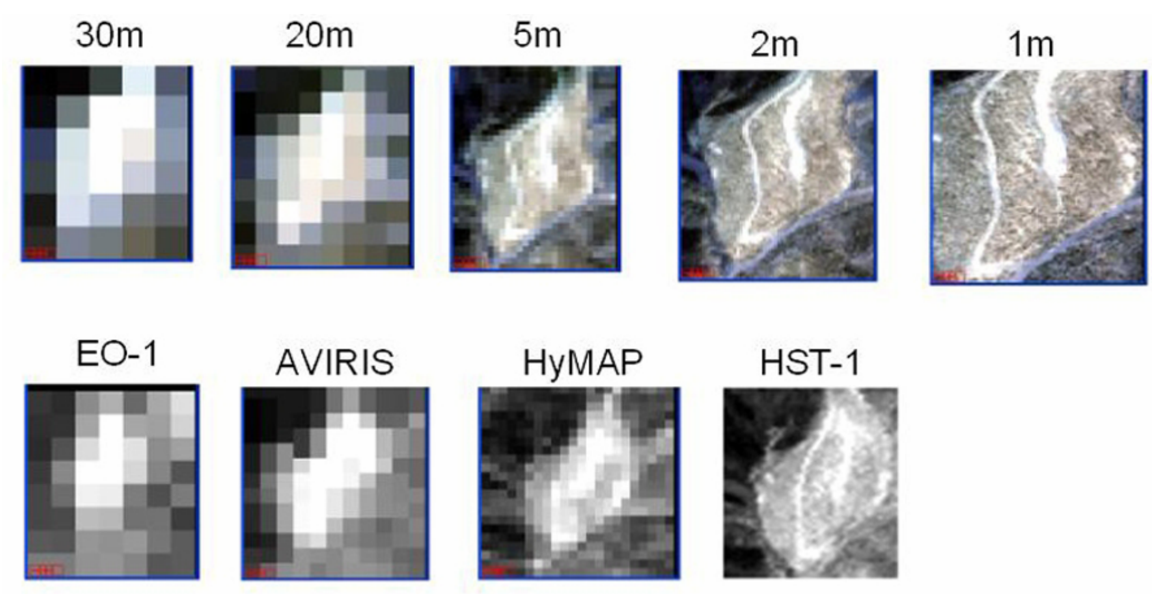


Figure 70. Resampled ProSpecTIR images over Buddingtonite Bumb, Cuprite (top) compared to actual pixel sizes for various hyperspectral sensors.

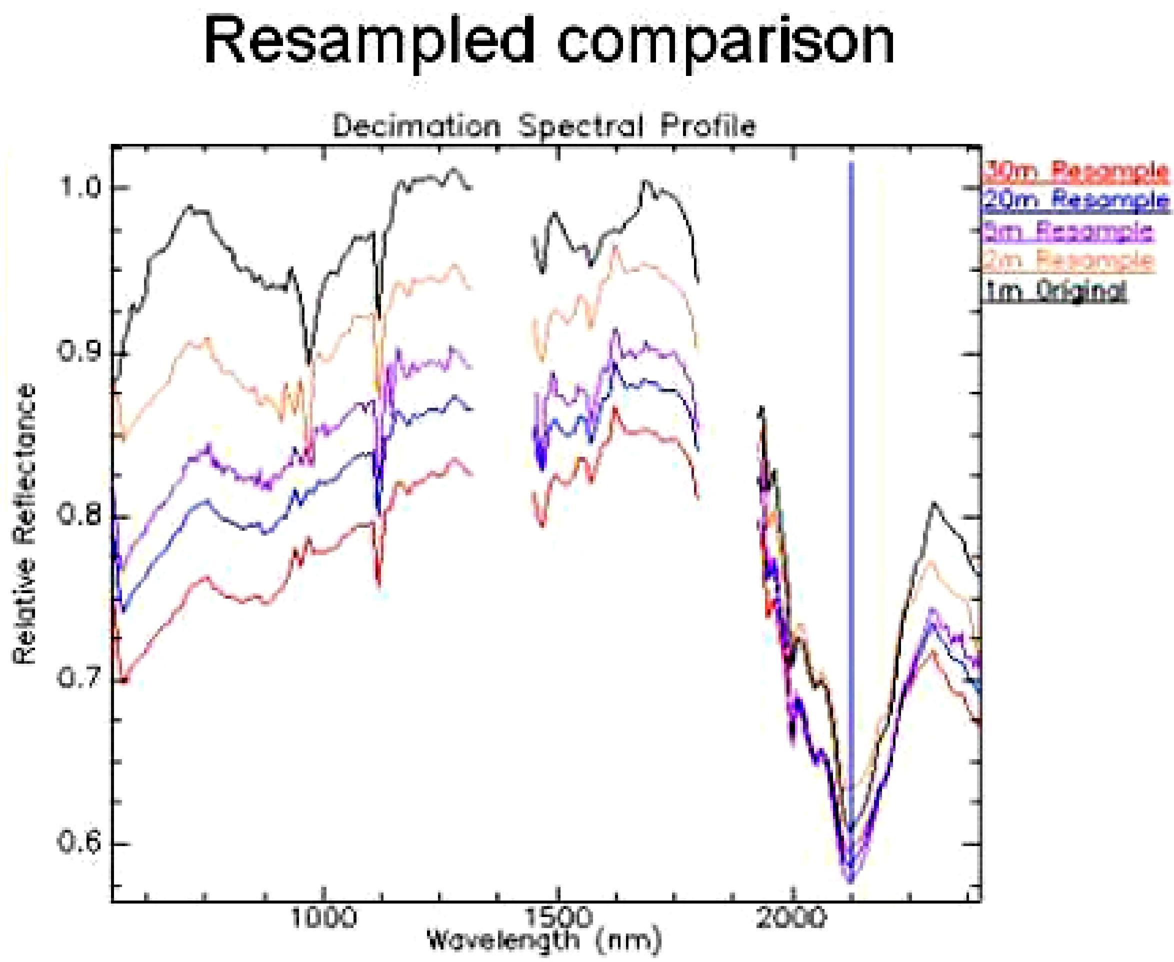


Figure 71. Spectra derived from resampling the spatial resolution of ProSpecTIR

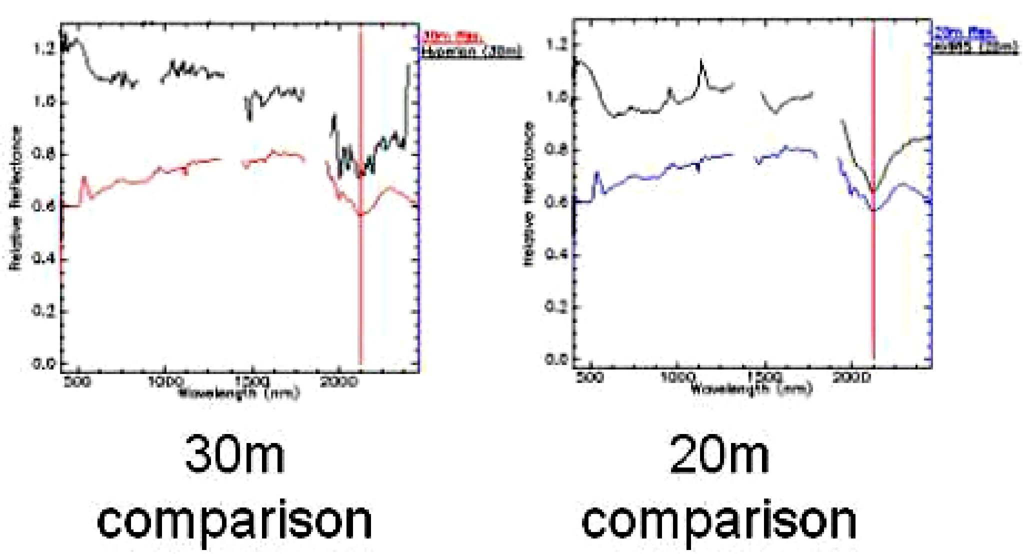


Figure 72. Hyperion and AVIRIS compared to ProSpecTIR at 20 and 30m.

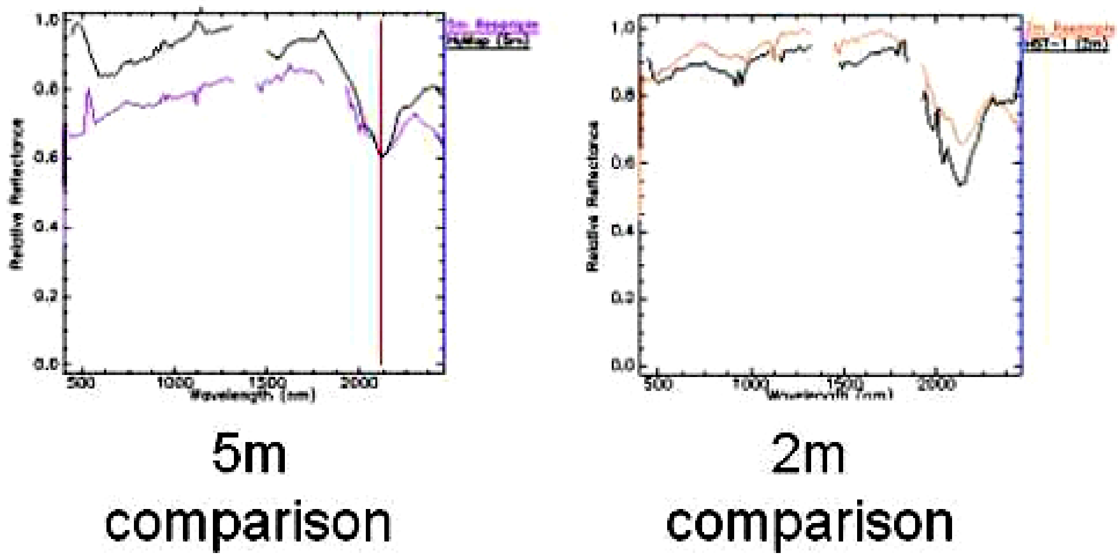


Figure 73. Comparison of HyMap and HST-1 to ProSpecTIR.

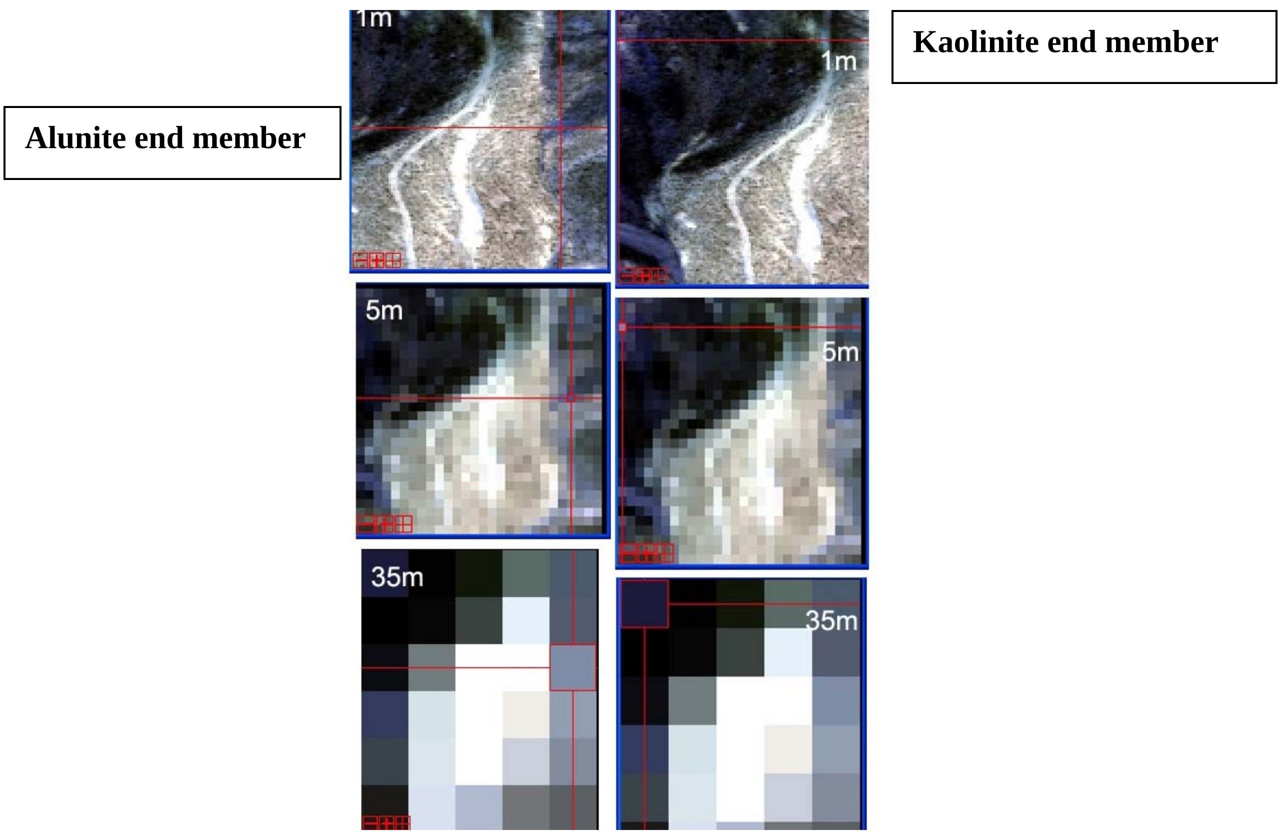
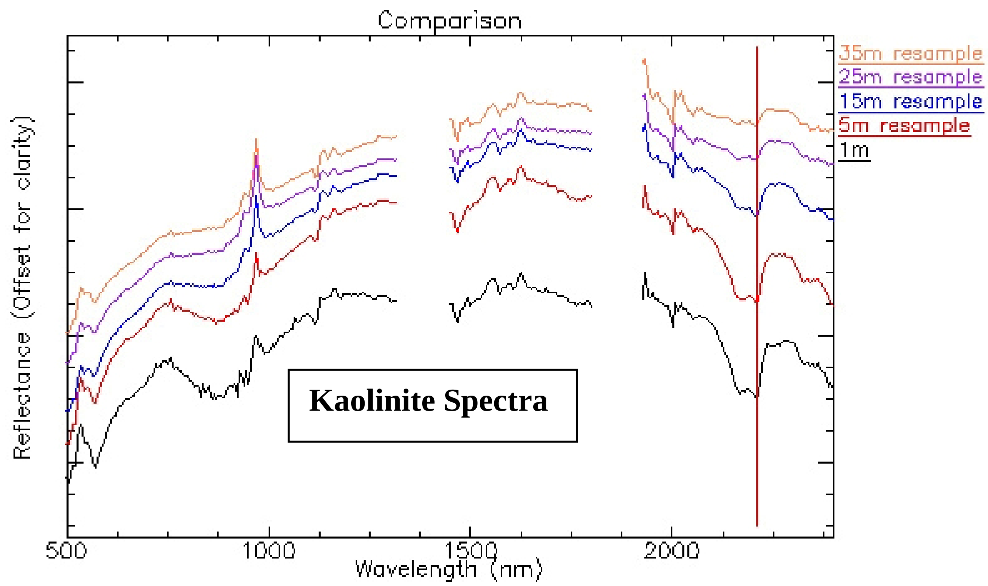


Figure 74. Location of pixels for spectral analysis at different spatial resolutions.



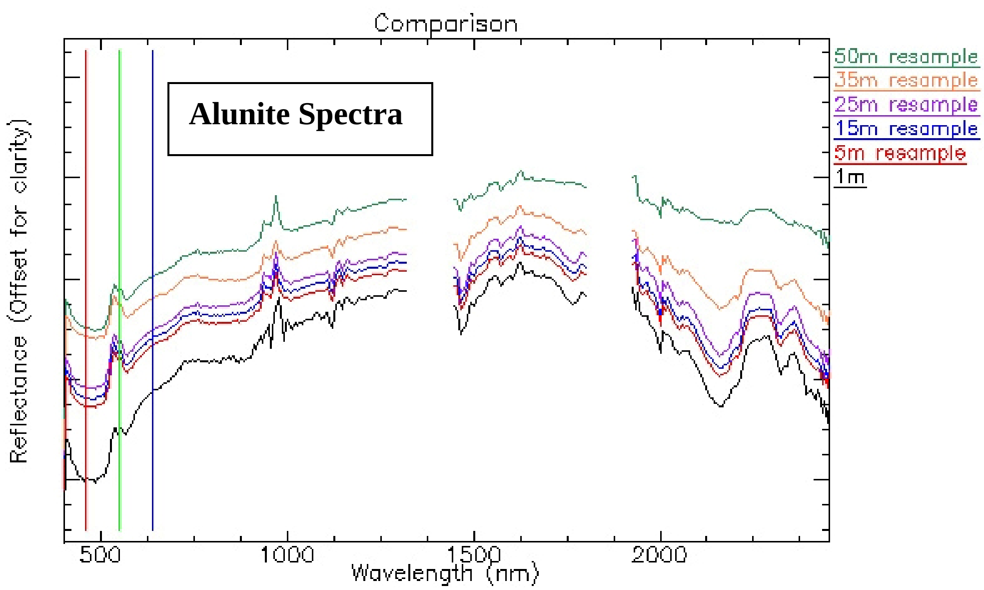


Figure 75. Spectra from areas dominated by alunite and kaolinite end members at different spatial resolutions

CHAPTER 8

Acquisition of Hyperspectral SpecTIR –VS Image Data over NPTEC

During the third quarter of 2006 we had to re-fly the NPTEC collects because of the sensor problems encountered on the earlier overflights.

1. SpecTIR Corporation agreed to re-fly the NPTEC with their Vis-SWIR (VS) hyperspectral system called ProSpecTIR and to acquire hyperspectral data at four different flight heights and thus spatial resolutions of 0.5, 1, 2 and 3 meters. This hyperspectral data was acquired on July 30, 2006 and is under analysis.

2. SpecTIR Corporation acquired ProSpecTIR hyperspectral data over the SEBASS flight lines in Virginia City.

3. SpecTIR Corporation acquired ProSpecTIR hyperspectral data over Cuprite.

4. Dr. Herb Fry visited UNR on July 27-28, 2006 and met with the ABLE staff including; Dr. Taranik, Dr. Wendy Calvin, Ph. D. Candidate Zan Alsett, Professor Tim Minor of the Desert Research Institute, Dr. William Pepppin of SpecTIR, Dr. Amer Smailbegovic of Teraelement, LLC., and Mr. Mark Landers CEO and President of SpecTir Corporation. During this visit, ABLE gave Dr. Fry unclassified SEBASS data sets over Virginia City, Nevada, and several research papers related to exploitation of SEBASS and multiband thermal data of Steamboat Springs, Nevada. Dr. Fry demonstrated his Hyperspectral Image Processing (HIP) software and spectral librarie, using ABLE's SEBASS image data over Virginia City. Dr. Fry agreed to return to UNR, bring some members of his staff and assist ABLE staff, and assist ABLE staff in learning how to use HIP software and the associated spectral libraries.

5. ABLE Ph. D. student, Zan Alsett visited the National Security Technologies (NSTEC) Laboratory in Santa Barbara, California and met with Dr. John Di. Benedetto to discuss his deployment to the NPTEC during Tarantula.

6. DRI, a subcontractor to the UNR NA-22 projects, provided Alsett with a high-end computer for ENVI processing and analysis of STL data acquired during Tarantula. Alsett will be performing the following tasks in support of NSTEC's

    a. Loading/Unloading of sensor equipment
    b. Installation of NSTEC/DRI/UNR/Personal computers
    c. Communication between NSTEC acquisition & analysis personnel
    d. Quality-checking of recorded data
    e. Blind and open testing of NPTEC releases
    f. Low-level chemical plume detection
    g. Preliminary characterization of chemical plume absorption features

h. Preliminary correlation of chemical plume abundance / quantitative gas release estimate
i. Daily presentation of previous day's findings
j. Preparing data for transport to NSTEC personnel in Santa Barbara
k. Recording daily log of events, jobs finished/pending, etc.
l. In addition to daily reports, a final document will act as a compilation of activities undertaken and list success/failure. Final tally of data cubes processed and dispensed will be included in this. He also include a list of contacts made while on NTS, for purposes of academic collaboration.

7. STL was able to hire a Ph. D. student, Seth Peterson, from Dr. Dar Roberts' program in the Geography Department at the University of Santa Barbara. This was done through our DRI subcontractor to support ENVI analysis of hyperspectral image data of vegetation at NSTEC, and software programming for analysis of HIRIS data.

8. Dr. Taranik and his graduate student, Zan Alsett, are now learning how to use the HIP software and associated spectral library to process already acquired SEBASS data over Virginia City. This learning process includes applying the Gas Tool Kit (GTK) to various hyperspectral thermal data and comparing the results to the HIP software. In addition, several new spectral libraries are being used for the comparison.

9. Spectir Corporation acquired Dual ProSpecTIR data over the NTS NPTEC at four different spatial resolutions.

10. Zan Alsett took the ABLE Full-Range Spectrometer to the NTS NPTEC in the hope of collecting ground spectral measurements during the Tarantula Exercise.

11. ABLE graduate student, Zan Aslett, participated in the Tarantula Exercise at the NTS NPTEC site from August 7^{th} to August 17^{th}. Upon his return, he was asked to participate in the analysis of Tarantula data at the National Security Technology (NSTEC) facility in Santa Barbara during the following week.

12. Spectir Corporation acquired ProSpecTIR data over the NTS NPTEC site at three different spatial resolutions on July 7, 2006, before the Tarantula exercise:
    a. Flight Line 1 – 3m
    b. Flight Line 2 – 2m
    c. Flight Line 3 – 1m
    d. Flight Line 4 – 1m
    e. No 0.5m data were acquired. Data have been processed to radiance and some additional geometric corrections need to be applied. 1-meter data may have holidays between adjacent flight lines. The clutter field appears to be covered in all overflights.

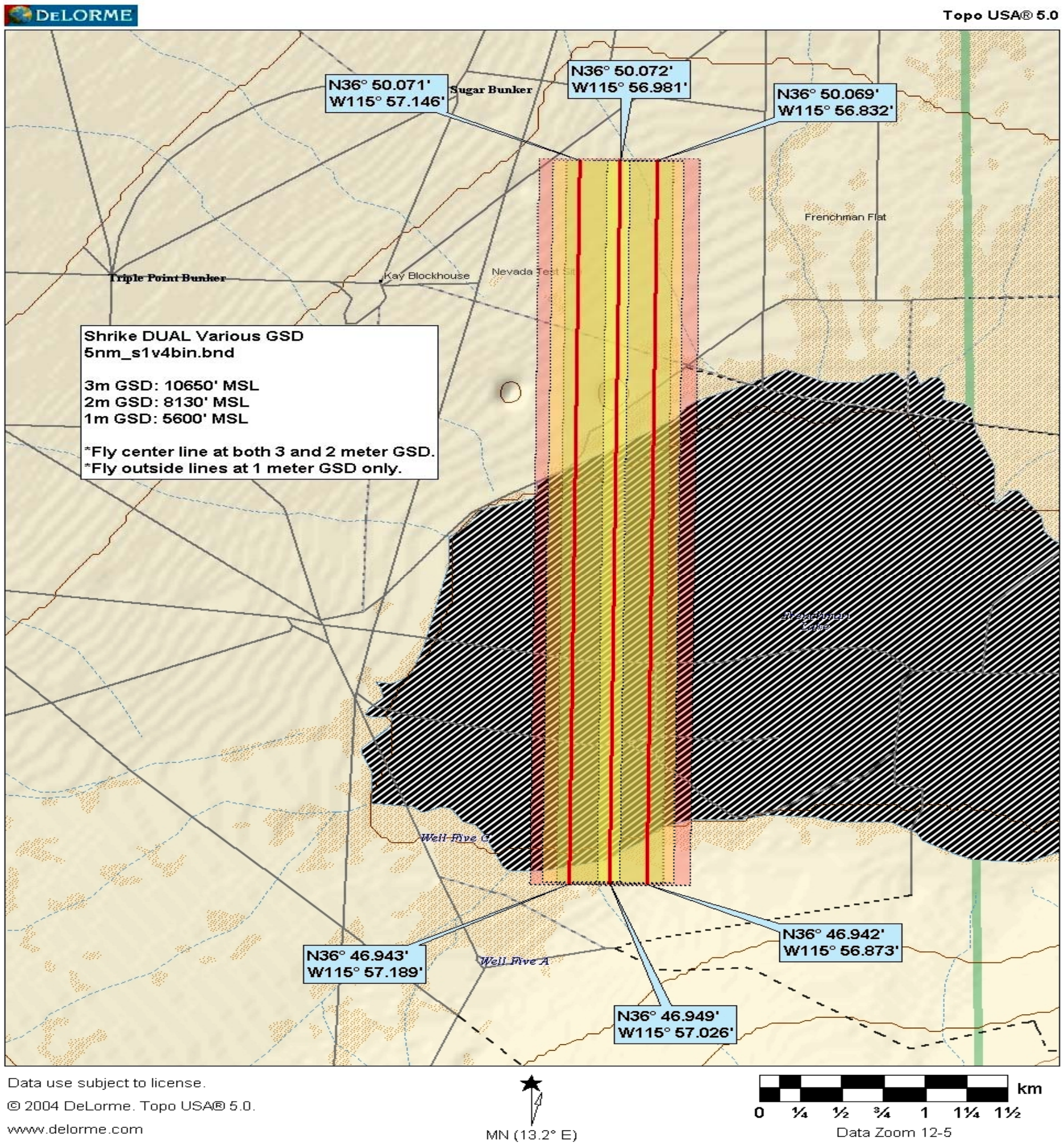


Figure 76. Flight line coverage of July 7, 2006 overflights of NPTEC at 3m, 2m and 1m data.

Figure 77. ProSpecTIR 1m portion of geometrically and radiometrically corrected swath of experimental data over the NPTEC Clutter Field.

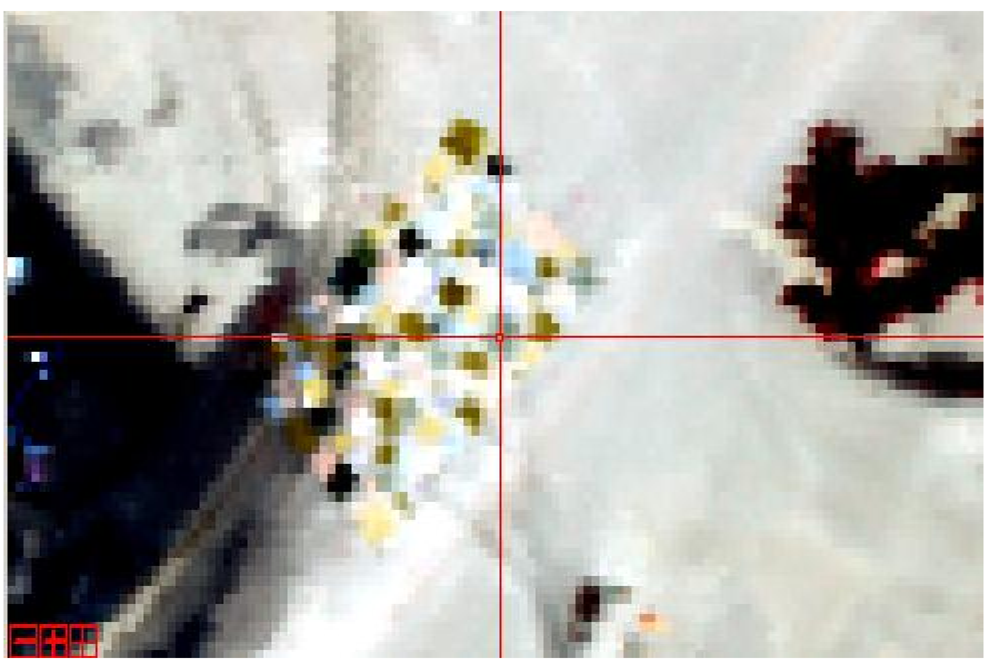


Figure 78. ProSpecTIR 1m subscene over the clutter field.

13. Personnel at the Nellis Remote Sensing Laboratory are providing a mosaic of newly acquired metric camera data for Tarantula. They will also be providing UNR an ASD Full- Range Spectrometer data set acquired over the clutter field and the surrounding playa areas. Zan Alsett was not able to use UNR's ASD during the Tarantula exercise and the post exercise activities because of the post exercise cleanup.

14. We learned that Dr. Foy will be retiring from DOE's LLNL and will be joining the Physics Department of UNR as adjunct faculty. He is an expert in the physics of long-wave infrared spectroscopy. Apparently, he also worked at LANL.

15. The next phases of our research will focus on the following:

    a. Refinement of radiometric correction of ProSpecTIR data over the NPTEC to reflectance.
    b. Comparison of ProSpecTIR spectra to ASD spectra collected by the DOE Remote Sensing Laboratory at Nellis Air Force Base over the Clutter Field.
    c. Mapping of spectral endmembers in and around the NPTEC to document background effects.
    d. Comparison of SpecTIR dual and/or HST-3 data acquired over Cuprite at different spatial resolutions to evaluate the scales, accuracies and formats of spectral information that can be derived, and to better understand the optimal spectral, spatial and radiometric resolutions for analysis of geologic and pedologic backgrounds, against which gases are imaged and analyzed.
    e. Understand how the ATCOR (Atmospheric CORrection program, developed by R. Richter, "Atmospheric/Topographic Correction for Satellite Imagery" (2006), DLR report DLR-IB 565-01/05, Wessling, Germany), is applied to SpecTIR dual data.
    f. Combined analysis of SpecTIR dual, TIR, HST and SEBASS data over Virginia City to assess the scales, accuracies and formats of spectral background information that can be inferred in the 8 to 14 um portion of the spectrum, from the analysis of hyperspectral VISNIR and SWIR image data.
    g. Continue to work with the National Strategic Technologies (NSTEC) laboratory in Santa Barbara on the analysis of broadband temporal signatures data, acquired with HIRIS at 2KHz for several seconds.

    h. Develop a field-deployable PC, with supporting accessories, for analysis of hyperspectral data at the NPTEC site and other DOE sites as appropriate.

CHAPTER 9

Analysis of SpecTIR-VS Image Data over Cuprite and NPTEC

During the fourth quarter of 2006, the project focused on the analysis of hyperspectral data acquired during the previous summer. The analysis work was done by two graduate students and a post doctorate fellow.

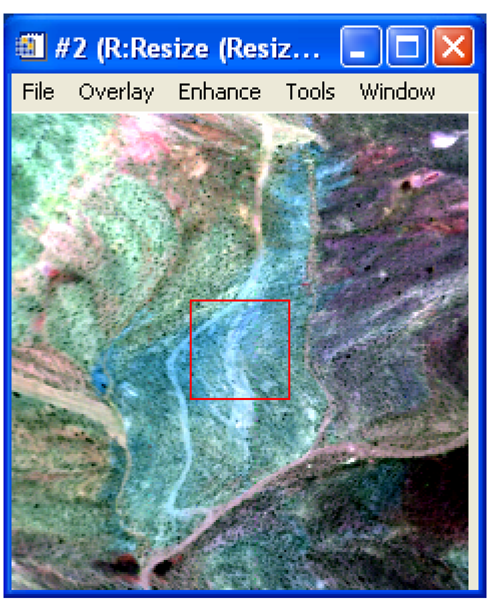
1. SpecTIR Corporation was unable to provide the correct atmospheric corrections to the Specim Dual Spectrometer, data because the ATCOR algorithm for batch processing of the SpecTIR-VS system was not suitable for the SWIR portion of the spectrum.

2. ABLE began an investigation to understand the problems with correction from radiance to reflectance using the Cuprite data for the analysis. Ph. D., graduate student Zan Aslett, worked with M.Sc.graduate student, Laura Huebner, to attempt to duplicate work done by Dr. A. Smailbegovic, using the ENVI hourglass procedure. However, the work could not be duplicated because of SpecTIR pre-processing procedures failed to provide the correct image data metrics.

I. Analysis of Cuprite 1m SpecTIR-VS image data: Laura Huebner, M.Sc. Student Geophysics

Using the DualBuddFlatFieldRef7Jul2006 reflectance file, a MNF transform was done on a spatial sub-set of the data (the area around the buddingtonite bump). The image was cropped to remove data that were affected by roll distortion; however, the remaining image has not been georectified. The spectral bands were also sub-set to remove bands 1-9 and bands 341-356, since these bands were causing difficulties in the MNF transformation process.

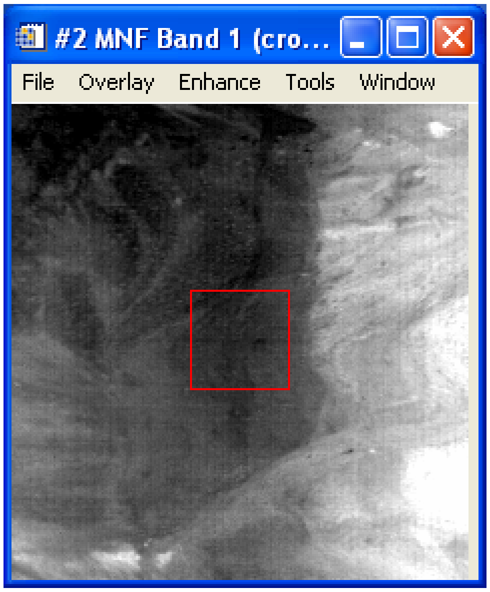
<u>Area used for MNF transformation; RGB (299, 316, 340)</u>

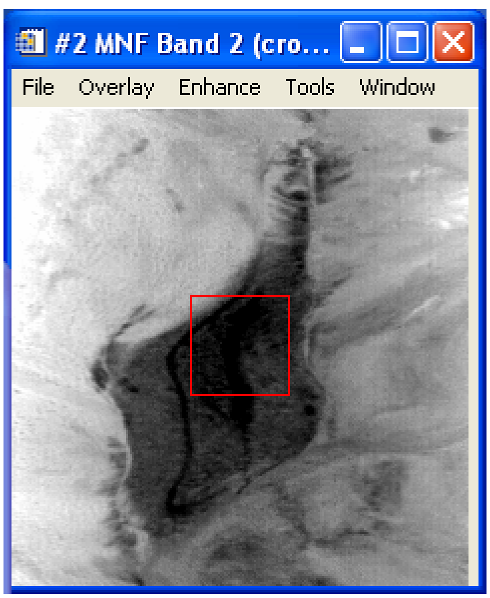


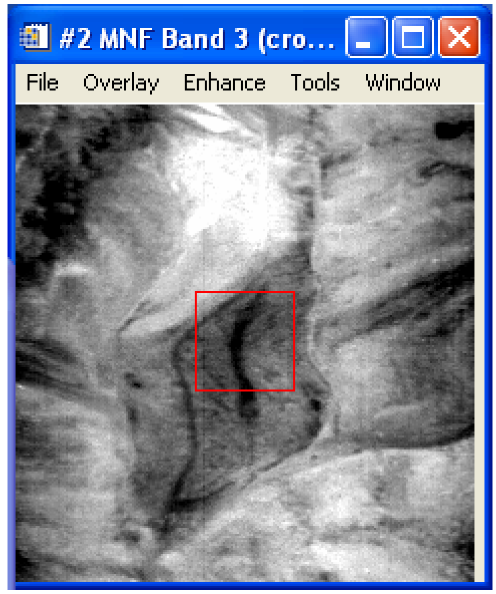
After the MNF transformation, the MNF Bands were spectrally sub-set to remove bands with eigen values less than two. These were then compared to the actual MNF band images. The bands that were visually pixilated from noise were also removed. The MNF bands that were used in further processing steps were bands 1-17.

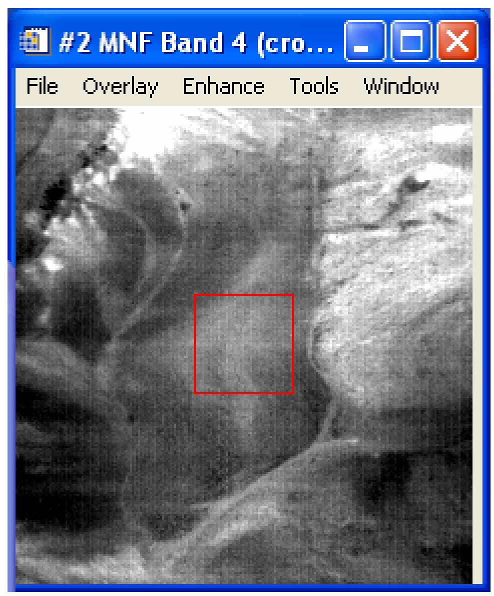
MNF Band examples

Band 1

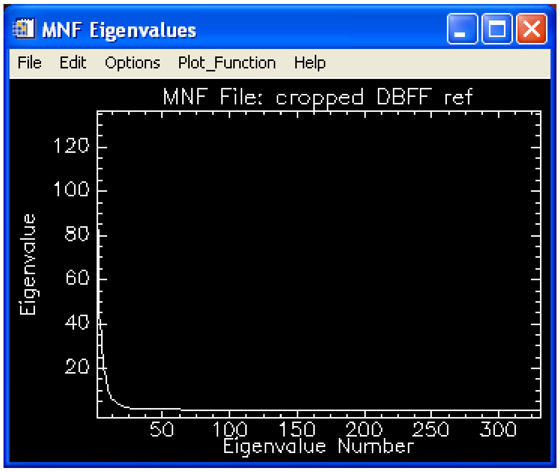






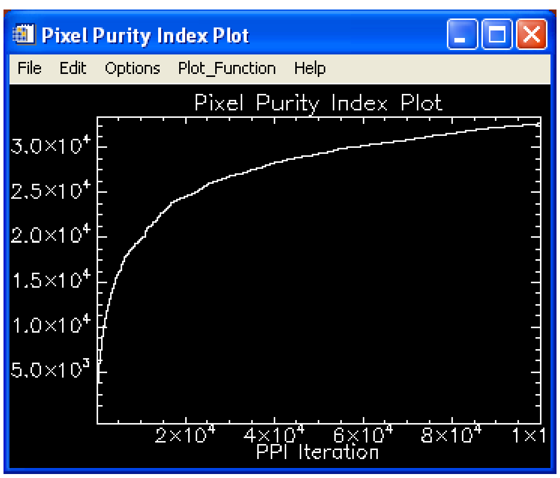


Eigenvalues Plot

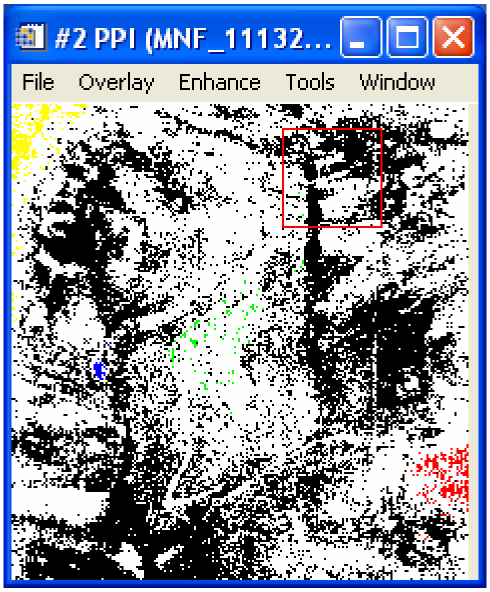


A Pixel purity index was done on MNF bands 1-17. 100,000 iterations were made with a threshold value of 2.5. The amount of pure pixels found, with respect to the amount of pixels in the scene, was at first a concern; however, since the spatial resolution of the survey is 1 m, it makes sense that there would be more spectrally pure pixels than surveys made with a larger spatial resolution.

PPI plot

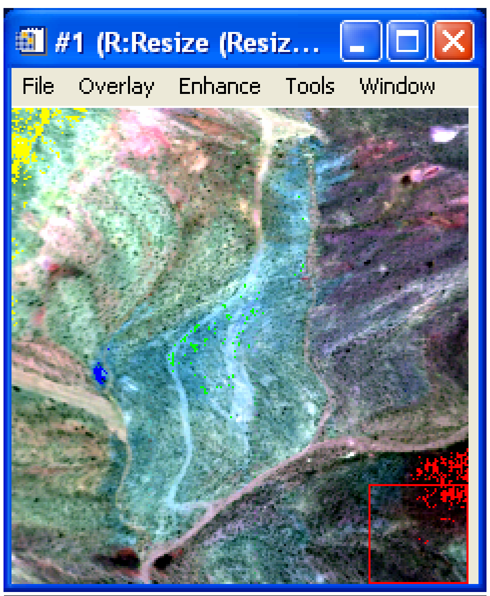


After completion of the PPI, a band threshold region of interest was applied to the PPI image. The minimum for the band threshold ROI was 225, and it contained approximately 2,800 pixels. Using this ROI and n-dimensional visualizer, four separate endmembers were chosen.

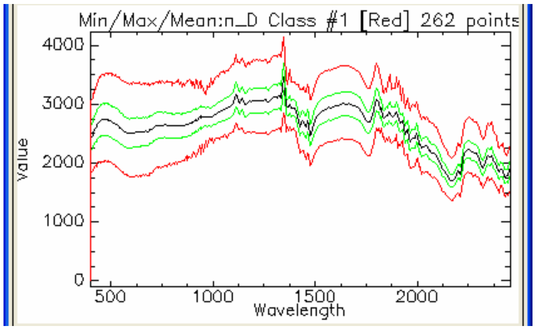


PPI pixel Locations

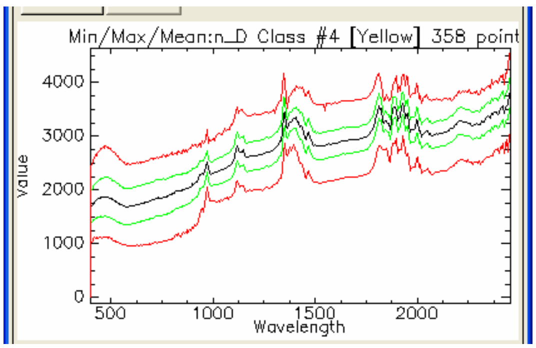
PPI endmembers overlying the cropped reflectance image (299, 316, 340)



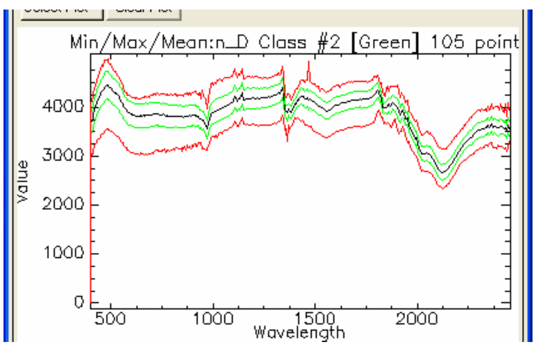
Red class spectra Min/Max/Mean

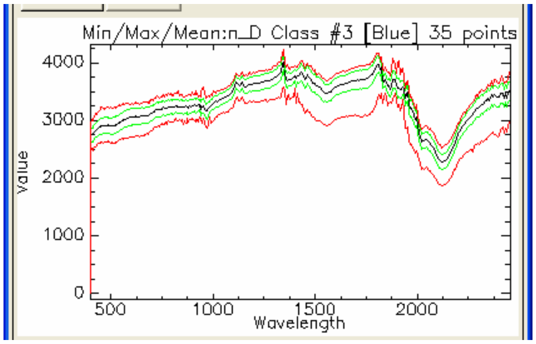


Yellow class spectra Min/Max/Mean



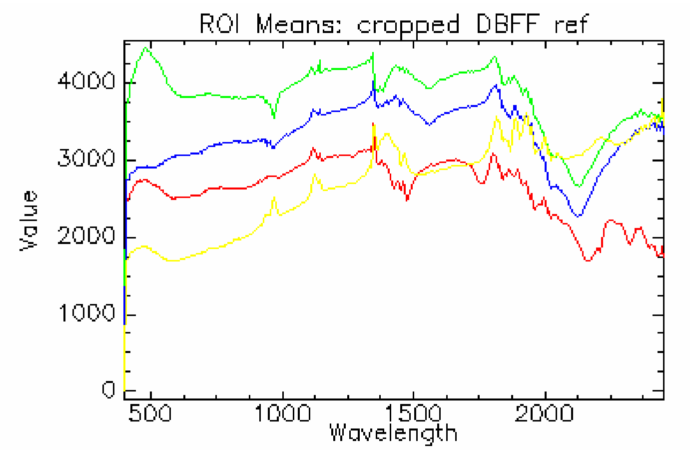
Green class spectra Min/Max/Mean





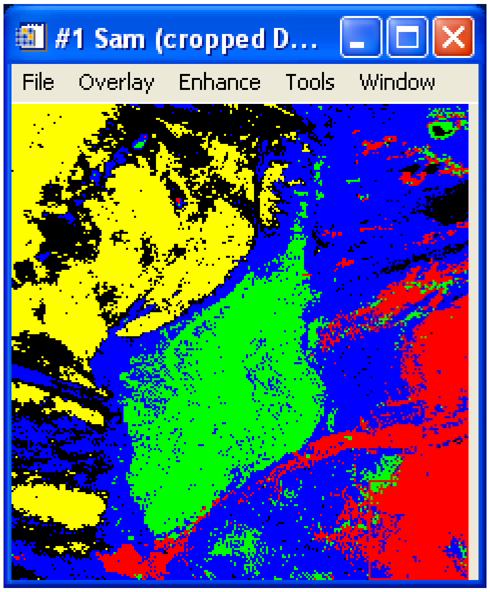
Blue class spectra Min/Max/Mean

All endmembers plotted together (not stacked)



After plotting endmember spectra, Spectral Analyst was run on the spectra using a resampled USGS spectral library. The following results were returned.

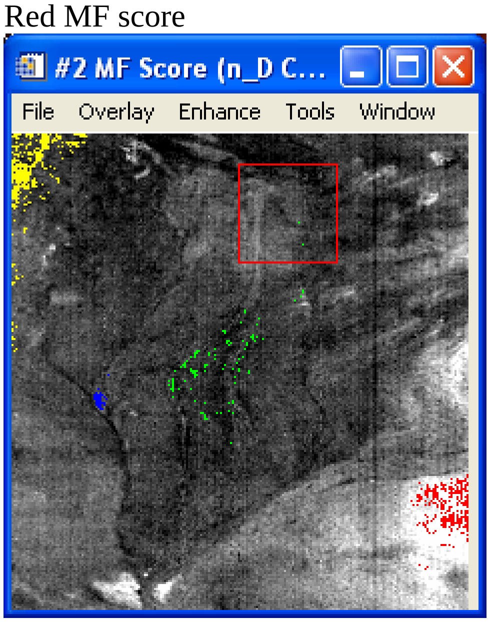
Class Color	Spectral Analyst Result
Red	Alunite/kaolinite
Yellow	Dickite
Green	Alunite/Buddingtonite
Blue	Buddingtonite

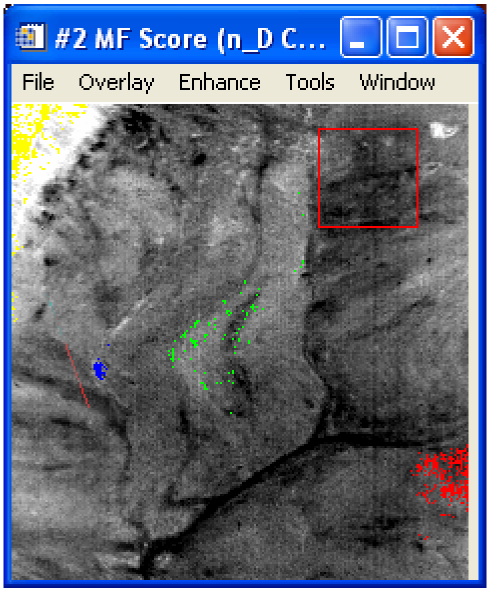


SAM map

MTMF using ROI's

Red MF score

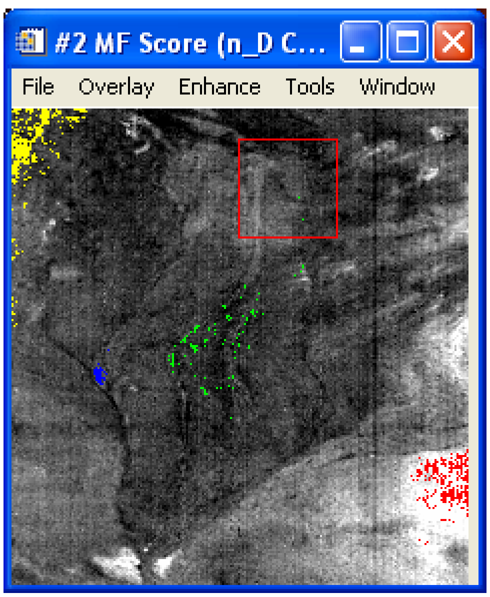


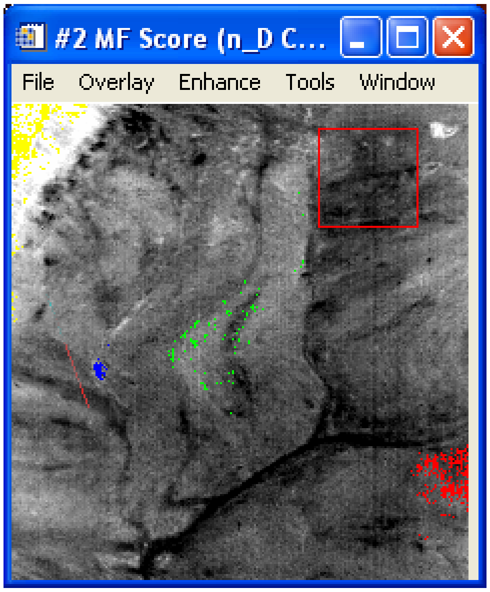


<u>Yellow MF score</u>

<u>MTMF using ROI's</u>

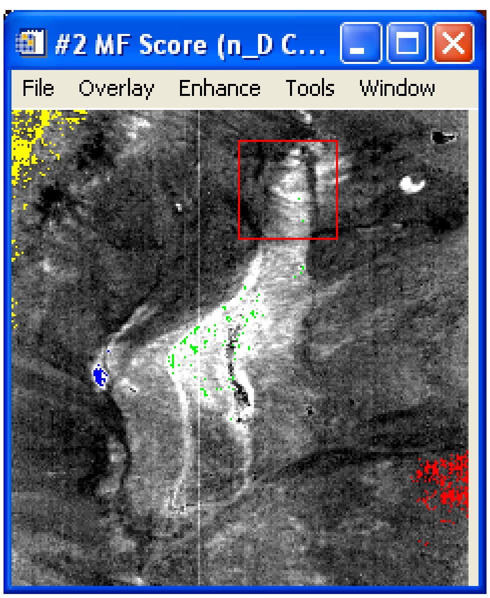
Red MF score

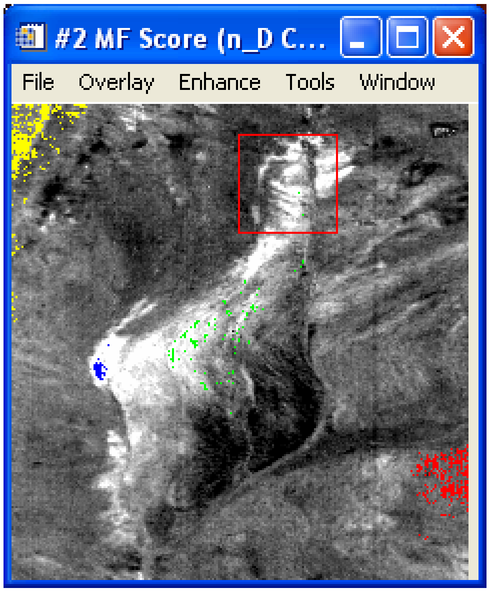




Yellow MF score

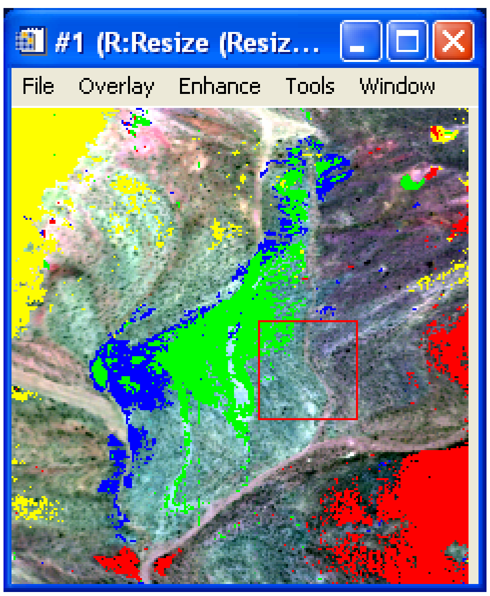
Green MF Score





Blue MF score

Band Threshold ROI's created from the MTMF images over laid on the cropped Dual Budd Flat Field image.



The first problem that arose in the image processing for the Buddingtonite bump area, was the replication of Amer's MNF transform. Each time the MNF transform was run, the bands would come up blank. It was first thought that the reflectance file was actually a radiance file and this was causing the problem; however, the MNF couldn't be performed on the radiance file either. After emailing Amer, he told us that for his MNF transform, he removed the first ten bands, and the last seventeen bands from the reflectance, and then ran the MNF transform. This worked well, and the transform worked, however, good data was lost in the 27 bands that were removed from further processing. After reviewing the reflectance bands, we found that only the first band needed to be removed since this band was blank, and causing the error in the MNF processing. This was the largest problem with the data set, and it took the longest amount of time to resolve.

The second problem with the data was the spiking in the spectra caused by faulty channels during data collection. This made it difficult to pick endmembers, because the spiking was not constant over channels. It also appeared on multiple channels that by removing these channels completely, spectral data would be lost. This made identifying the chosen endmembers difficult, as sometimes the spikes hid important mineral identifiers. This problem was resolved in the second dataset that we received from SpecTIR at the end of November.

The last, minor problem that occurred with this dataset was the PPI processing, which continued to find pure pixels with more and more iterations. This is most likely due to the fine spatial resolution of the survey. The repetition of this processing step with higher threshold values and increasing iterations, in order to find all pure pixels, was time consuming, and stalled processing.

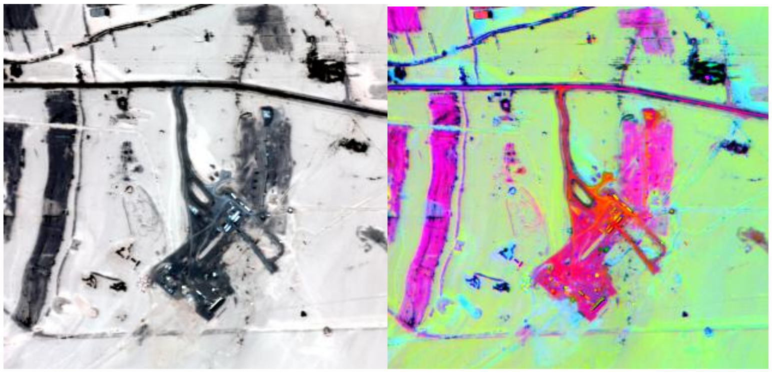
II. Processing of SHRIKE Hyperspectral Data:

Hyperspectral data was acquired over NPTEC in July of 2006 with a new Visible/Near-Infrared and Short-wave Infrared (VNIR/SWIR) sensor, Prospectir. In total, 3 different resolutions of hyperspectral data were collected over NPTEC – 3, 2 and 1 meter. The atmospheric correction algorithms used by Spectir are not robust, and the resulting spectral data does not accurately reflect reality. As a method to bypass this problem, we have proposed using ground-collected spectral libraries supplied by RSL to calibrate the data. The spectral signatures over the clutter field can be used as input to the aerial hyperspectral data, specifically with the Empirical Line formula.

Once the data has been satisfactorily calibrated to reflectance value, the 3 different spatial resolutions will be analyzed individually and then cross-referenced. This will help us identify the spectral resolution limitations imposed by spatial resolution. The boundaries of spatial and spectral resolution are an important aspect of on-going remote sensing research. Our analysis of the clutter field, in particular, will help to define these limitations.

Next, the NPTEC scene and corresponding ground-acquired spectral signatures gives us the opportunity to test new algorithms included with ENVI 4.3, released in October 2006. Specifically, we plan to test and evaluate the “RX Anomaly Detection”, “Linear Band Prediction” and “Support Vector Machine” spectral classification routines.

Lastly, the provided Spectir data was not georeferenced. As such, our current effort includes using the RSL panchromatic imagery as a base map in which to warp the hyperspectral data. This task will be completed by the end of November, 2006.



Above: Hyperspectral image of NPTEC. On left is true-color imager. On right is a principal components image (1,3,8). Additional spectral information can be derived after accurate calibration to reflectance.

CHAPTER 10

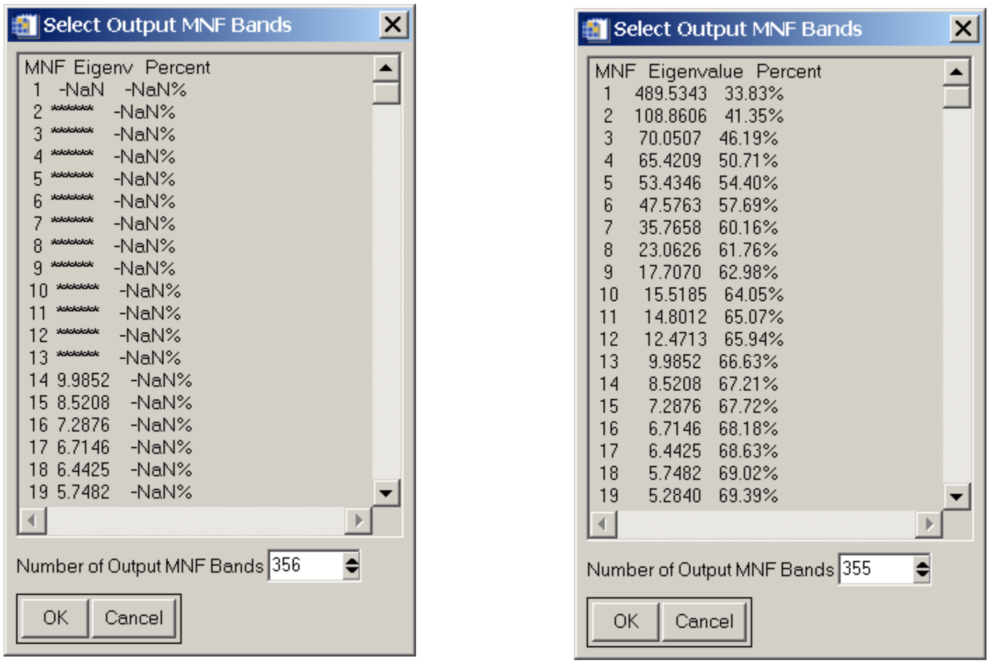
Analysis of SpecTIR-VS Image Data of Background Materials in Cuprite, Nevada

During the first quarter of 2007, another graduate student performed an analysis of SpecTIR-VS data over the Cuprite area of Nevada, because of the problems the project had acquiring acceptable hyperspectral data over the NTS NPTEC site.

Analysis of SpecTIR-VS data over Cuprite, NV – Zan Aslett, Ph. D. student

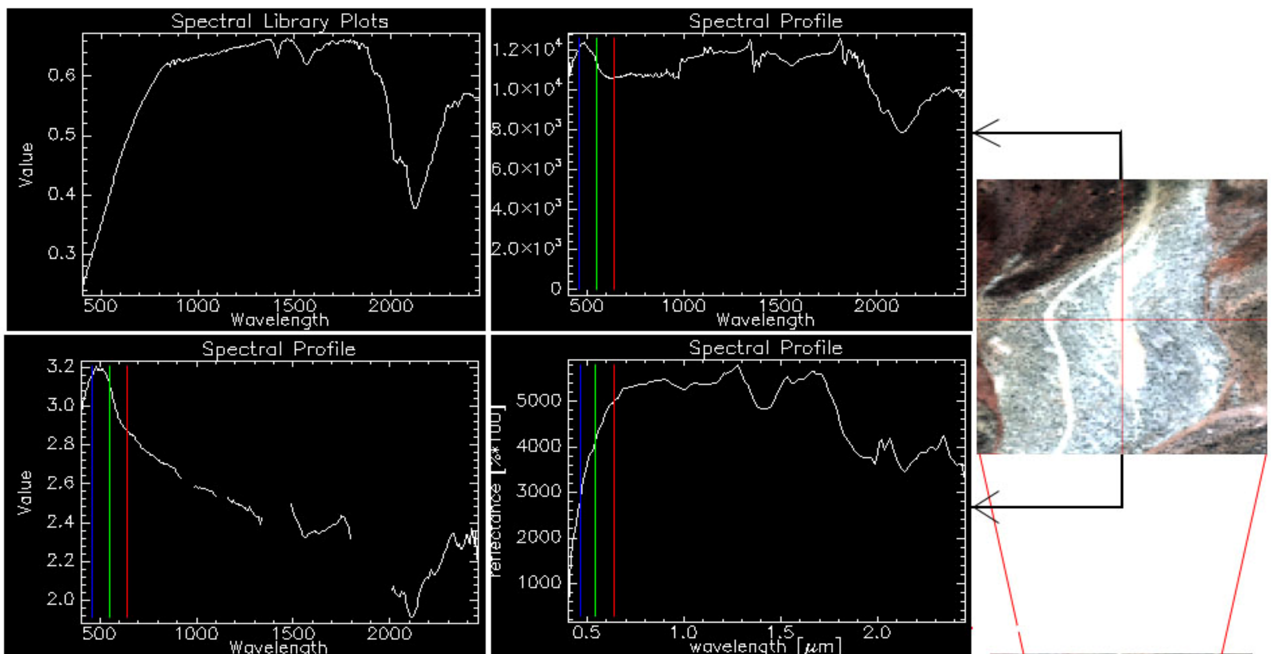
The SpecTIR-VS is a pushbroom Visible, Near-Infrared (VISNIR) and Short-wave Infrared (SWIR) imaging spectrometer operating in the range of 0.4 to 2.5 micrometers. The sensor can collect hyperspectral data at high spectral resolutions of up to 5 nanometers and pixel resolutions of 0.5 to 5 meters. SpecTIR, LLC. operates the sensor and calibrates the subsequently collected data to at-surface reflectance using the Atmospheric Correction (ATCOR) and Haze MODerate spectral resolution atmospheric TRANSmittance algorithm (MODTRAN). Technical problems concerning the integration of the data with ATCOR and MODTRAN have to date resulted in limiting SpecTIR-VS data to reflectance-calibrated spectral resolution of 10 nanometers. The SpecTIR-VS was flown over Cuprite, Nevada for calibration and evaluation purposes in July of 2006. A well-known subset of this area, Buddingtonite Bump, was selected as a study site for the direct comparison of spectral data between several commercial and government hyperspectral sensors. This paper focuses on updated methodology to both produce calibrated data and reduce dimensionality of the data set. The following pages document and summarize the efforts of Arthur Brant Laboratory for Exploration Geophysics (ABLE) graduate student research in late Fall 2006.

In late Summer 2006, A. Smailbegovic compiled a report on the aforementioned topic; however, substantial inconsistencies in data processing methodology and endmember classification were found which prompted reprocessing of the data. Mistakes in methodology include: failing to remove band 1 from subsequent data processing. Band 1 was found to be of a NaN value; when further processing occurred with all bands, statistical errors caused massive error in spectral operations; MNF processing then occurred that did not incorporate bands 1-13, which hold the highest amount of spectral variance, data that is the key to differentiate endmembers. Lastly, although not fully revisited in this brief summary, a key error was made when making comparisons of endmember abundance between various sensors. Direct comparisons were made between an ungeorectified SpecTIR-VS data and georectified AVIRIS, HyMap, Hyperion, and partially georectified HST data. Because all data sets were not spatially registered amongst themselves, no direct tally of abundance of any endmembers could have reliably been made.

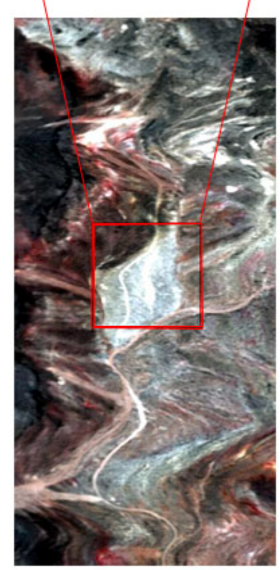


***Above**:* In the left window the MNF eigenvalue plot for bands 1-356. In the right window, the MNF eigenvalue plot for bands 2-356.

SpecTIR-VS data treated with the ATCOR atmospheric correction displayed spectral data in such a manner that the spectral variability within the scene was obviously reduced. In order to assess the accuracy of VS data, either ground collected data or reflectance-processed data from a reliable source such as the Jet Propulsion Laboratory's AVIRIS data should be compared to the data set. The AVIRIS data previously used by Smailbegovic to compare with VS data was corrected using ENVI's FLAASH. While the correction is sufficient for quick reflectance calibrations, substantial error was also introduced. A comparison of VS data to that of JPL-corrected AVIRIS data will occur in the future. A three-tiered correction was implemented by the ABLE laboratory which seems to result in satisfactory spectral data. This involves the use of an MNF transformation, the subsetting of bad MNF bands, an inverse MNF transformation, and



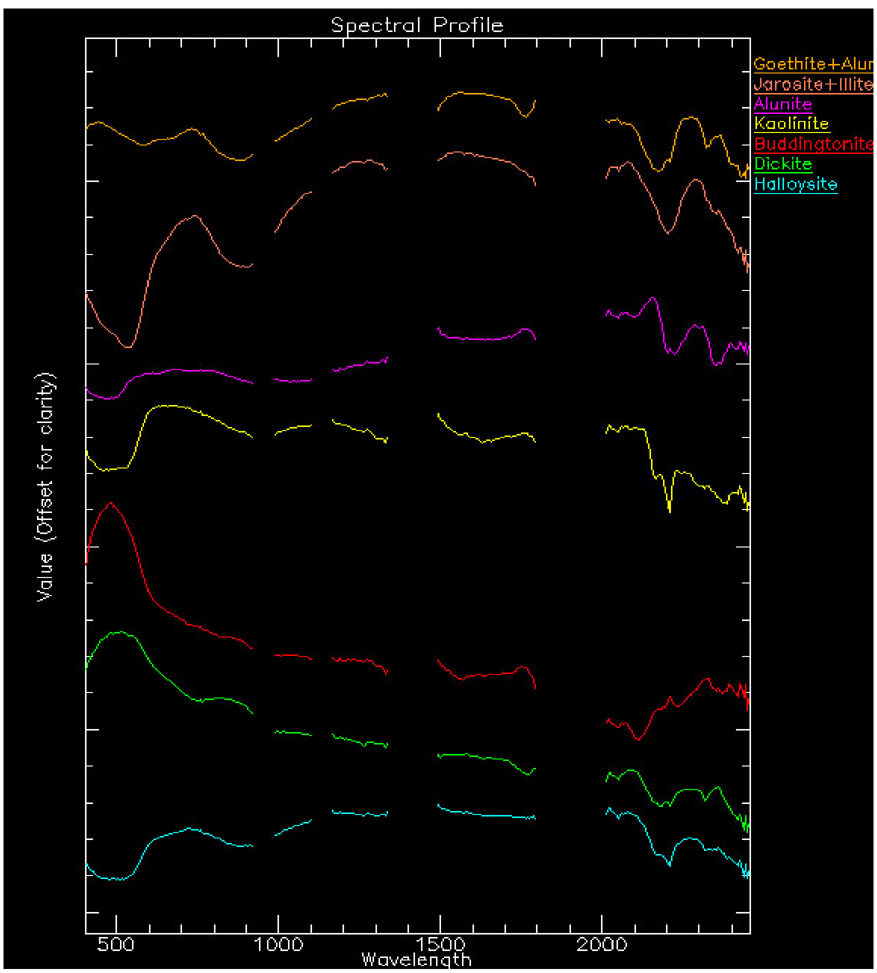
Above Top Left: Buddingtonite Spectra from the USGS Spectral Library. Top Right: Flat Field Corrected Spectra. Bottom Left: IARR Corrected Spectra. Bottom Right: ATCOR Corrected Spectra.



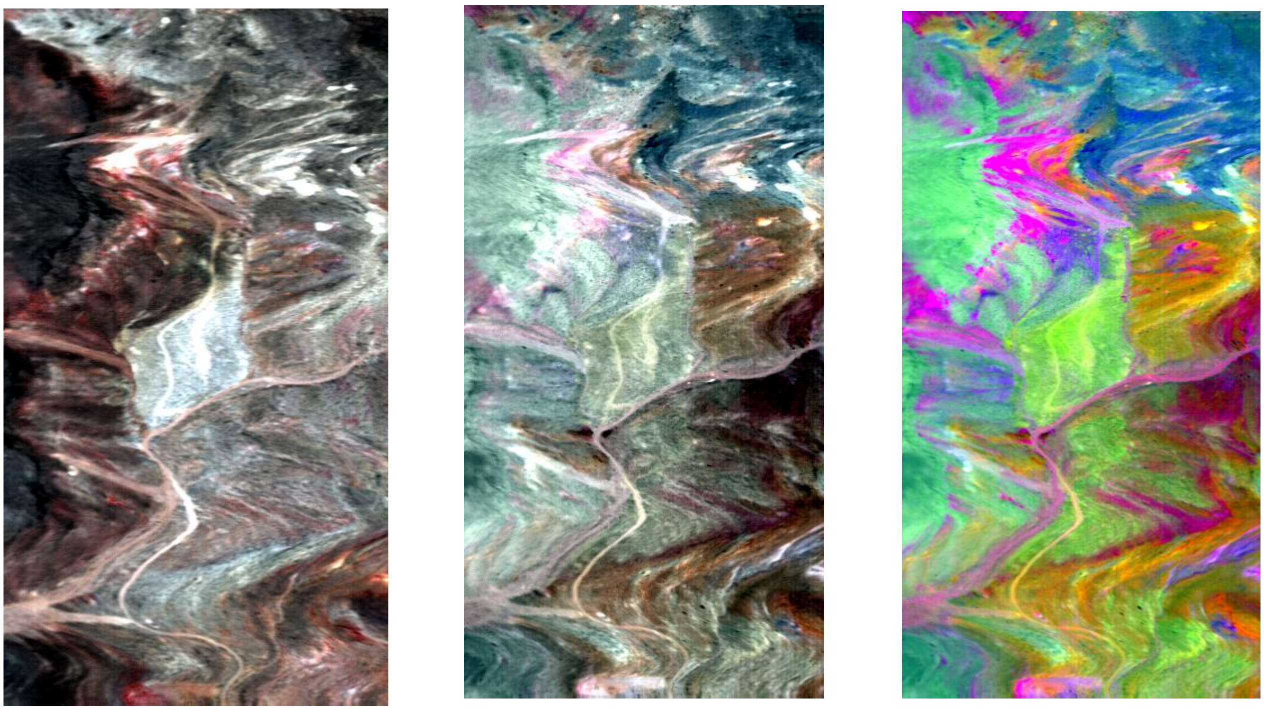
Comparison of the buddingtonite endmember spectra processed via various methods. The IARR-corrected spectra displays the most similarity to USGS library spectra in the SWIR. The Flat field and IARR corrections render the same reflectance feature at 500 nm in the VNIR. The ATCOR correction seems to inhibit the spectral variability in the scene to a greater extent than the other methods presented here. Field measurements will give insight as to which method best represents the best spectral approximation.

then the application of the Internal Average Relative Reflectance (IARR) routine. The calibration techniques used by SpecTIR and Smailbegovic were directly compared to the MNF noise-reduced data input into IARR. Spectral signatures of Buddingtonite Bump were compared to that of United States Geological Survey (USGS) spectral library signatures. The most prominent absorption feature of Buddingtonite is found at 2.12 micrometers. Although pure mineral endmembers are not easily found in the scene, the IARR-calibrated data was found to follow the USGS spectral library endmembers much closer than that of either ATCOR or flat-field calibrations. Absolute accuracy of the respective methods cannot be determined until field measurements are made. These efforts will be made in early Spring or Summer 2007.

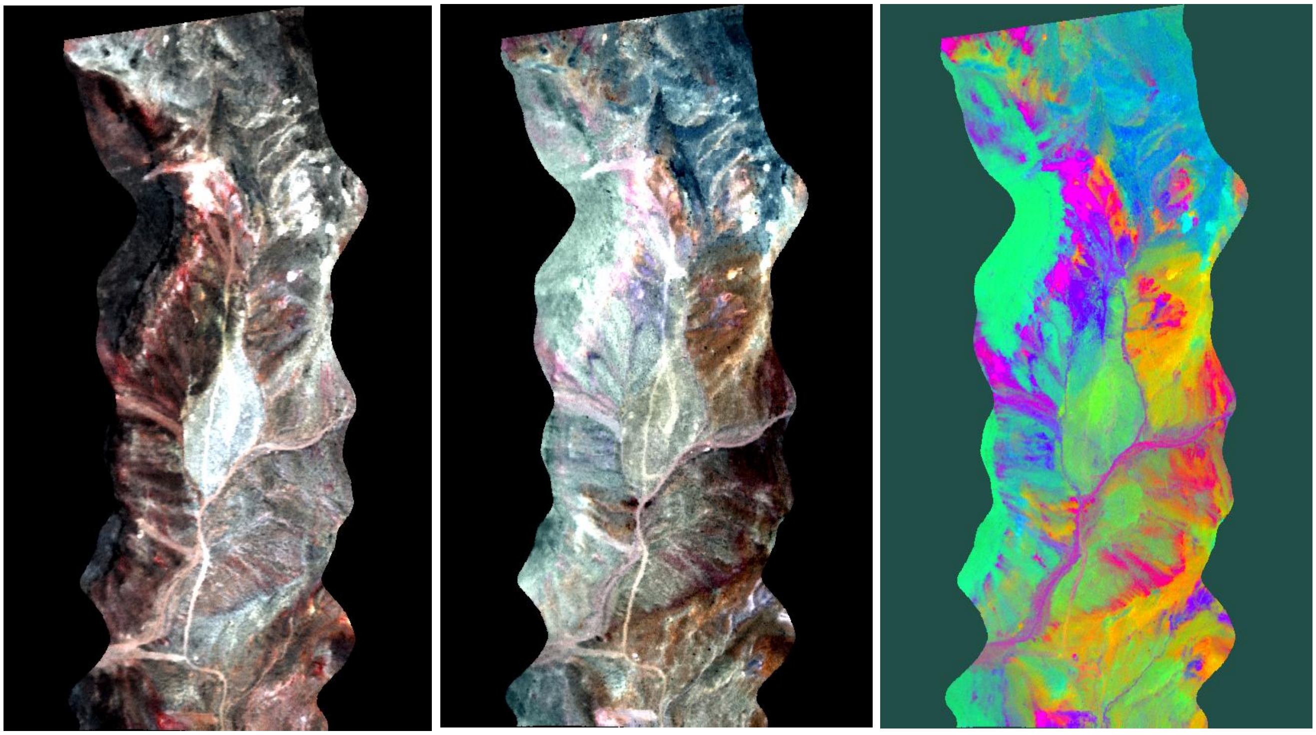
The Sequential Maximum Angle Convex Cone (SMAAC) ENVI routine was applied to the data to derive scene endmembers. In total, 15 endmembers were chosen to represent the mineralogic distribution in the scene. A Spectral Angle Mapper (SAM) routine to eliminate redundant endmembers within a specified spectral angle was run upon the extensive original library.

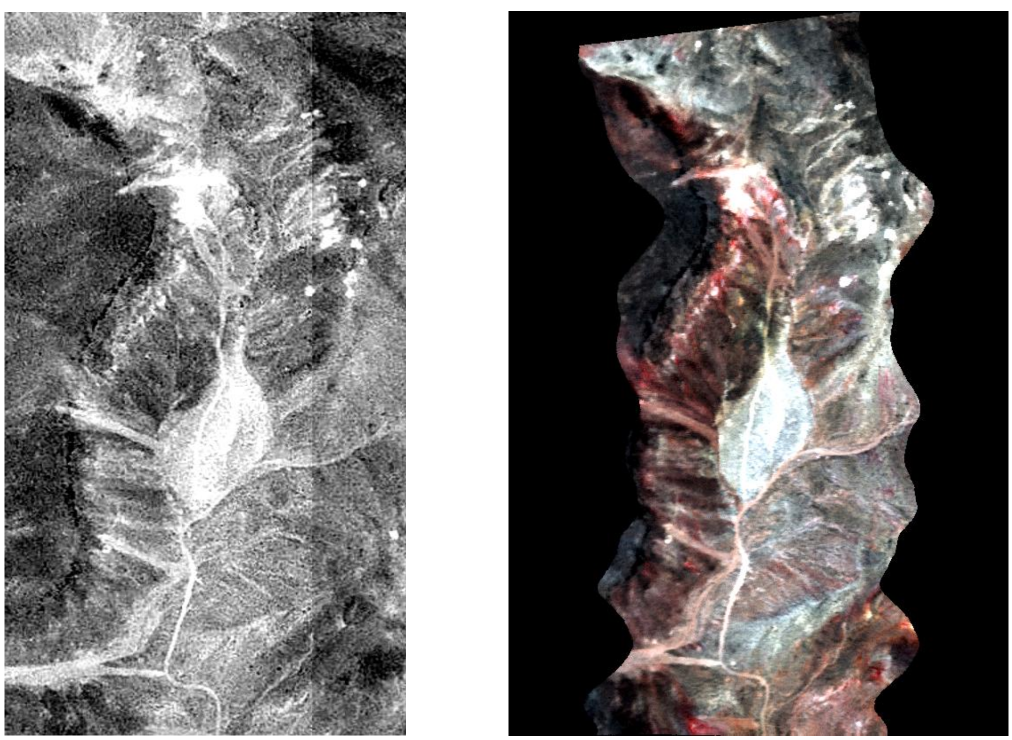


Above: Prominent geological endmembers derived from the IARR data set. The ENVI SMACC routine was used to discover endmembers. Although the slope of the spectra in the VNIR need to be checked with ground measurements, the SWIR features are more pronounced than either those of ATCOR or flat field corrected data sets.
Once spectral endmember derivation was complete, georectification was performed using Geographic Look-Up Table (GLT)s supplied by SpecTIR. Geospatial corrections are necessitated by yaw, pitch and roll movement made by the aircraft during acquisition of imagery data sets.

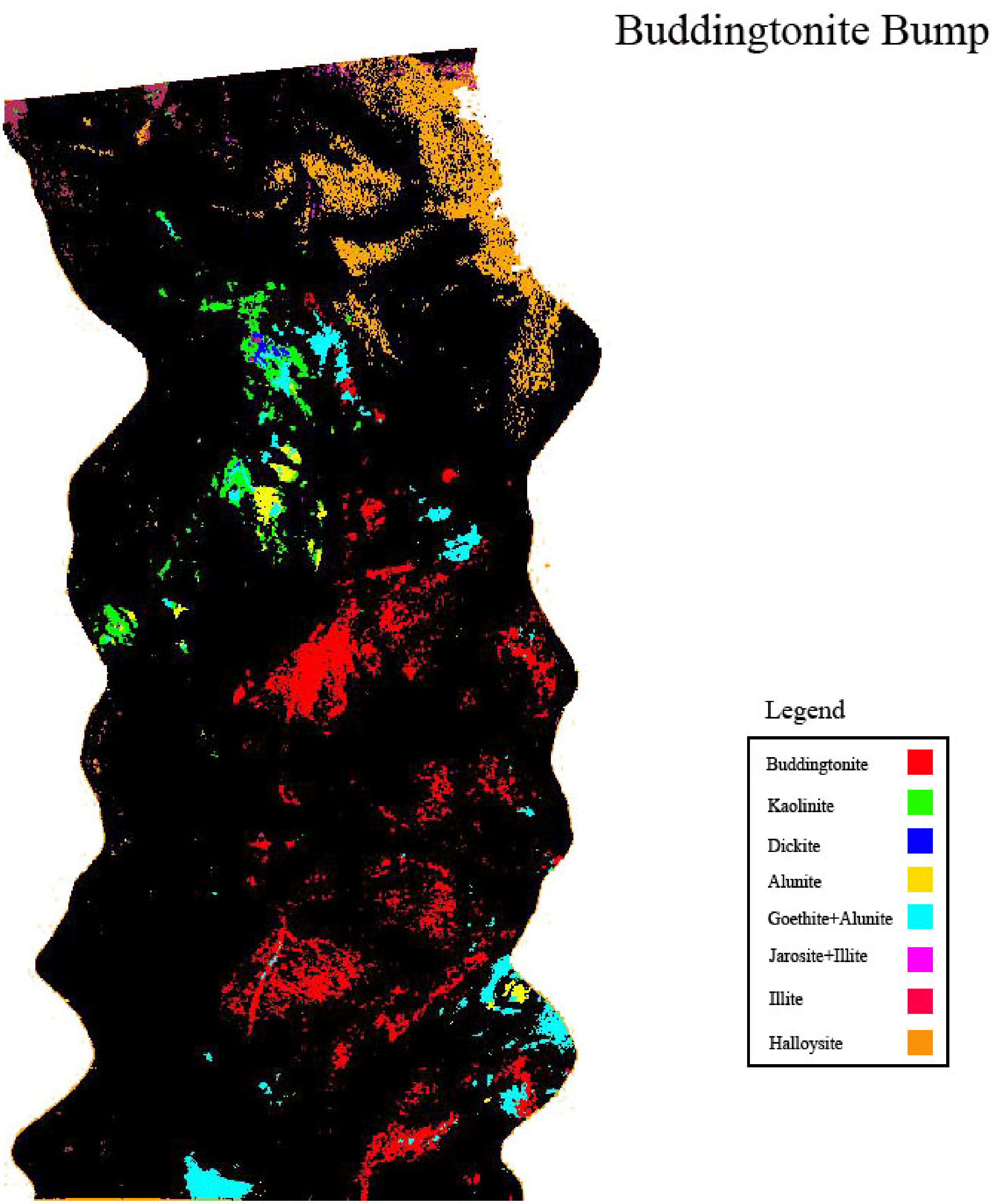


Above: (from the left) True color composite, False color composite R:320 G:316 B:311, DCS R:320, G:316 B: 311. The DCS image on the right shows kaolinite in magenta, buddingtonite in green, and alunite in yellow/orange. ***Below:*** Geo-corrected SpecTIR-VS imagery.





***Above*:** A Digital Orthophoto Quadrangle (DOQ) image is displayed to compare the relative accuracy of the application of a GLT upon the hyperspectral data set.



A comprehensive geologic map was created by using SAM to map the distribution of respective endmembers. SAM was utilized because of the algorithm's ability to mitigate the spectral variability due to topographic change over the scene. Although the defined spectra are fairly easily decipherable when compared to USGS mineral library spectra, ground truthing will have to occur in order to verify the accuracy of the map. A tentative visit to Cuprite, Nevada and specifically, Buddingtonite Bump, has been scheduled for mid-Spring 2007. An Applied Spectral Devices (ASD) field spectrometer will be employed in the field to collect spectral signatures of endmembers identified in the hyperspectral data set and spatially correlated on the ground by the use of a portable Global Positioning System (GPS).

Future work will involve the updating of the spectral data by use of the empirical line formula with input ASD ground data. A new geologic map will be created and compared to the one presented here to determine the accuracy of the MNF/Inverse MNF/IARR atmospheric correction calibration methodology. In addition, a intense study of the comparative mapping abilities of 5 nm VS, 10 nm AVIRIS and 16 nm HyMap data will be undertaken. Although a preliminary study was undertaken by Smailbegovic, the calibration methodology was not based upon field acquired spectra and ground checks. In addition, direct comparison of endmember abundance maps were made between rectified and unrectified imagery, which would inherently skew statistical accuracy. These efforts to improve analysis will hopefully culminate in a professional paper prepared for the proceedings of a major remote sensing conference.

Sidenote: The VS data contains many peculiarities that requires nuanced processing and attention to detail in order to produce believable classifications and reproducible results. These errors affect next-step processes and the final accuracy of classifications. A summary will follow with documentation of specific errors, as they make themselves known.

CHAPTER 11

Atmospheric Corrections to Hyperspectral Reflectance Data

During the second quarter of 2007, the project focused on problems with atmospheric corrections to hyperspectral data.

Over the course of this investigation, the matter of atmospheric corrections to hyperspectral reflectance data have loomed very large. During the past three years attempts to correct SpecTIR's hyperspectral image data, first from their HyperSpecTIR instruments and later from their SpecTIR-VS dual sensor, have proved troublesome. Recently, on another project a different contractor, Terra, based in Vancouver, British Columbia encounter similar difficulties when applying atmospheric corrections to their Specim data. Specim provides the same sensors used by SpecTIR and Terra and it is a Finnish firm that recommends a software atmospheric correction batch processing program ATCOR. ATCOR was developed by a German firm for processing European Space Agency (ESA) broadband satellite data. While ATCOR seems to do a reasonable job in the VIS/NIR it has yet to produce acceptable spectra in the SWIR, either for SpecTIR or for Terra. Other commercial programs, ACORN and FLAASH do not yet work in batch processing mode and are used over specific areas, requiring much analyst interaction for longer flight lines and for larger areas.

An interesting aspect of the Specim-VS dual system used by both Terra and SpecTIR is that 5um bandpasses are possible. However, the ATCOR batch processing program does not work well with 5um bandpasses, only with 10um bandpasses.

The Jet Propulsion Laboratory team under Dr. Rob Green that manages AVIRIS, still uses the latest MODTRAN code compiled from FORTRAN that is tens of years old. MODTRAN comes with a very complete detailed manual that provides examples; however the learning curve is long. Several of the vendors that supply hyperspectral data suggest that it would be very useful to have a study of the various programs for applying atmospheric corrections to hyperspectral image data, especially the SWIR portions of the spectrum. Thus, we do plan to continue our studies in this regard, but perhaps with other research support.

SEBASS data will be acquired under this project over the Beatty, Cuprite, Virginia City, Yerrington Mine, Leviathan Mine areas on July 15, 2007. This data set will be co-registered with SpecTIR-VS and Terra hyperspectral, LiDAR and digital orthophotographic image data to support work with hyperspectral thermal data.

CHAPTER 12

Collection of Hyperspectral Thermal Image Data

During the third quarter of 2007, the project focused on the collection of hyperspectral thermal image data over the Beatty area of Nevada.

I. Introduction – Jim Taranik

During this reporting period, we continued our research to exploit Visible/Near Infrared/Short-Wave Infrared (VIS/NIR/SWIR) data to evaluate the natural geologic and pedologic background against which airborne chemical substances are evaluated. A major thrust of our research involves understanding the spectral attributes that can be measured in the VIS/NIR/SWIR that are unique to that spectral region and how VIS/NIR/SWIR data can be used to infer or predict spectral attributes of background materials in the Long-Wave Infrared (LWIR) region. This report is the last quarterly report because in the final quarter of this project, we are preparing the Final Project Report and this project ends December 31, 2007.

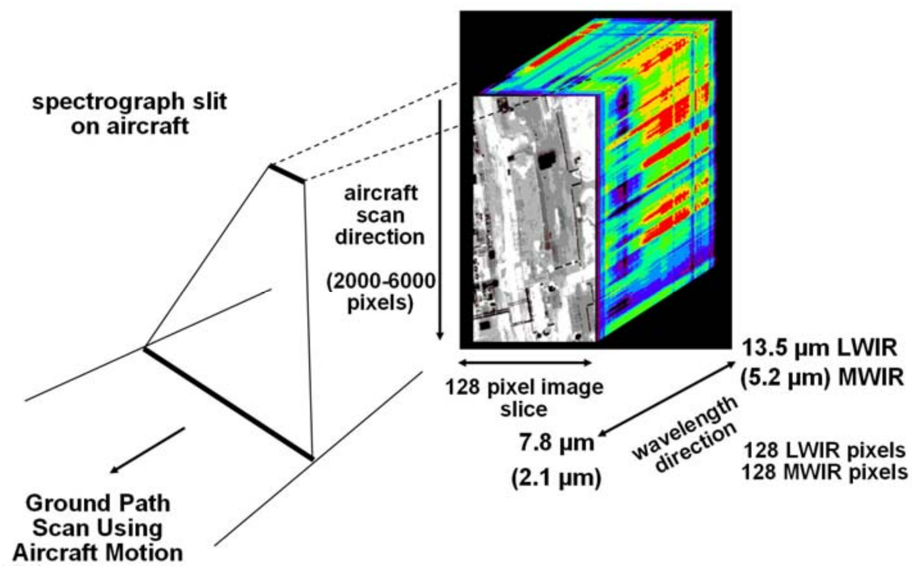
Previous progress reports have summarized the difficulties this project has had in acquiring hyperspectral reflectance data suitable for analysis. In April 2007, under a subcontract to Sierra Nevada Corporation, the Arthur Brant Laboratory of Exploration Geophysics (ABLE) at the University of Nevada (UNR), was able to acquire a high-quality hyperspectral reflectance data set over the Beatty, Nevada area. That data set included hyperspectral reflectance data acquired by two different vendors using the same hyperspectral sensors. One vendor also acquired simultaneous LIDAR and digital orthophoto data and the data sets were registered to approximately 2-meter accuracy.

In July 2007, the Arthur Brant Laboratory for Exploration Geophysics (ABLE) at the University of Nevada (UNR), used its remaining NA-22 FY04 funds to contract with the Aerospace Corporation of Chantilly, Virginia for Spatially Enhanced Broadband Array Spectrograph (SEBASS) thermal hyperspectral sensor over Beatty, Nevada and immediate vicinity. This quarterly report covers the acquisition and preliminary analysis of that data.

The SEBASS sensor is capable of collecting electromagnetic energy in two discrete segments: the mid-wave infrared (MWIR) and long-wave infrared (LWIR). The MWIR segment is collected from 2.1 to 5.2 um while, the LWIR ranges from 7.8 to 13.5 um. Because of the complex dual reflective/emissive nature of the MWIR segment, our research will focus on the emissive LWIR data. Emissivity of common geologic materials has been well studied in the laboratory setting; however, thermal hyperspectral image data sets are relatively rare, and thus limited research has been conducted in this area. ABLE proposes the investigation of thermal infrared SEBASS hyperspectral, data in order to further understand the emissive nature of geologic materials in the Beatty, NV area. This report will outline current efforts to date, in addition to future tasks.

II. Instrumentation

The SEBASS thermal hyperspectral sensor is a pushbroom platform that records two segments of the electromagnetic spectrum, 2.1 to 5.2 um and 7.8 to 13.5 um. The instrument is a liquid helium cooled prism spectrometer which uses two 128 x 128 detector arrays and has a 1-mrad field of view per pixel. The sensor is cooled to 4K to allow for a maximum signal to noise ratio. The aircraft utilized for data collection is a Twin Otter, which is a heavy, stable platform, mitigating X, Y and Z axis deviation from the flight path due to wind or turbulence. SEBASS was first flown in 1995 and has been the focus of a great deal of military and nonproliferation studies. Because of the sensor's importance in these fields, civilian access to the data has been quite limited. The MWIR data set is generally too complex to correct for mixture of emissivity and reflectance. One method to utilize the data is to collect only at night, when reflected energy is not present. However, our collects were acquired during the day to maximize radiance at-sensor, and thus derive the best LWIR emissivity spectra.



Above: The scanning dimensions of the SEBASS pushbroom hyperspectral sensor.

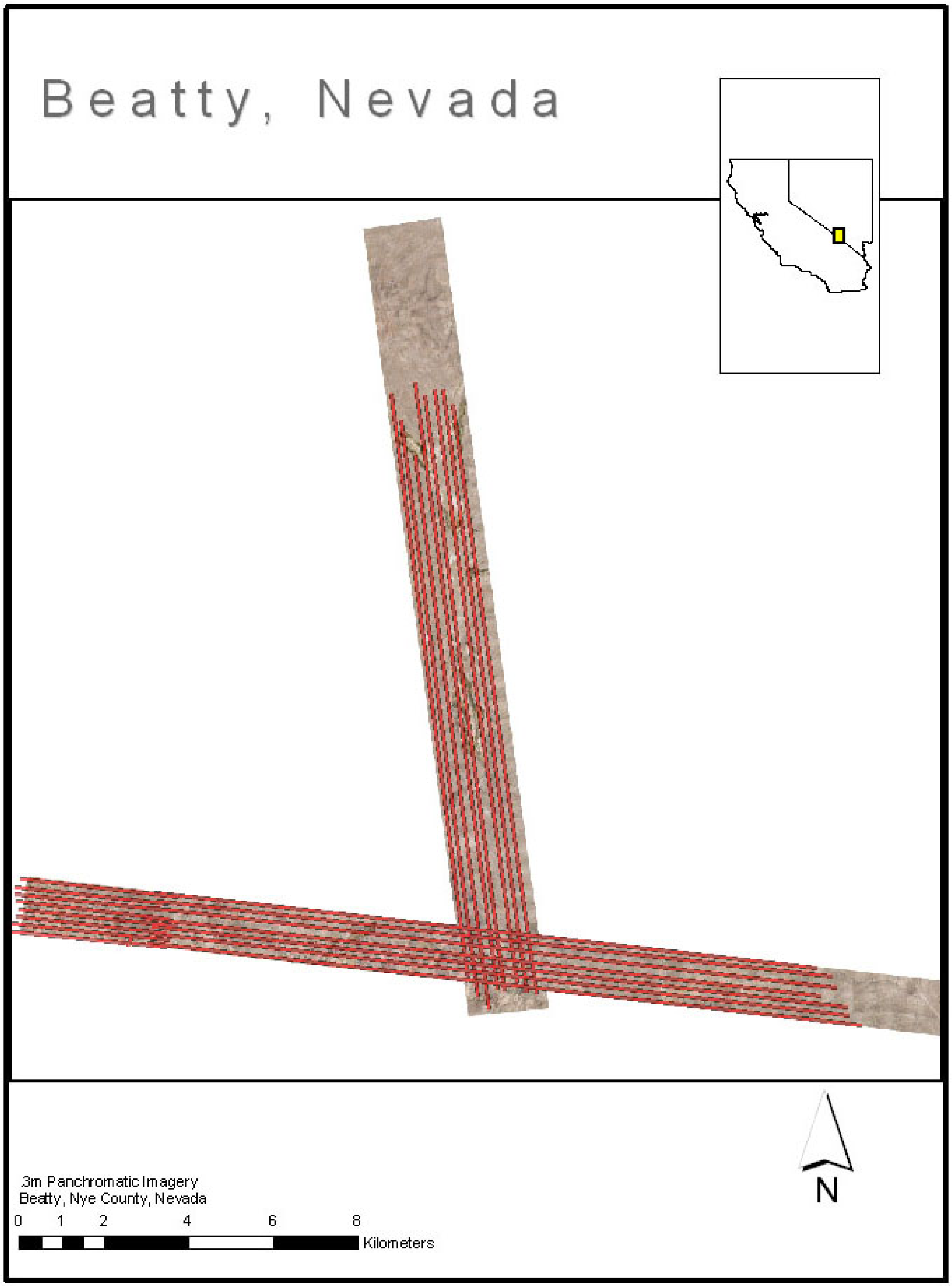
SEBASS is one of very few thermal infrared hyperspectral sensors, in which the collected data is made available to the public. Other sensors feature multispectral thermal infrared bands (MASTER, TIMS, ASTER); however, the spectral resolution of minerals measured at the surface of the earth are not high enough to resolve or differentiate more than broad mineralogical groups, and certainly not able to differentiate endmembers of silicate solid solution series.

Above: The SEBASS instrument installed in a Twin Otter aircraft.

III. Primary SEBASS Data Acquisition – Zan Aslett

The Aerospace Corporation acquired a total of 19 flightlines of hyperspectral data at Beatty, NV in July 16, 2000 over a collection area of approximately 61 square km. The ground spatial distance (GSD) of image data pixels was approximately ~ 3 meters. In addition, two lines were collected at a GSD of 1 meter. The area of study, proposed in 2006, is comprised of two boxes which intersect at a 75 degree angle. The north/south box is 18.8 km long and 1.8 km wide, and the east/west box, which runs 22.5 km long and is 1.2 km wide; due to airspace restrictions near Nevada Test Site boundaries, the total area of collection was reduced to approximately 45 out of 61 square kilometers.

The average elevation is 3308 feet above sea level. The flight acquisition area is located in Nye County, Nevada, which is the largest county in Nevada and third largest in the United States. The town of Beatty, population 1100, is located within the southern portion of the flight box, at the intersection of Highway 95 and California State Highway 374. The region features an arid climate which sees 4.6 inches of annual precipitation. The mean minimum temperature for January is 18 degrees F, and the mean maximum temperature for July is 104 degrees F.



Above: SEBASS flightlines layered upon high resolution panchromatic imagery of the Beatty, Nevada study area.

Vegetation

Vegetation can easily attenuate the thermal infrared energy emitted by underlying rocks. However, the typical species seen in Beatty are sparse and non-leafy. Local vegetation is similar to that of southwestern deserts and ranges. The lower valleys feature mesquite, salt grass, greasewood and rabbit brush. Alluvial fans and low slopes see creosote bush, bur-sage, saltbrush, Mormon tea brush, barrel cactus and yucca growth. Between altitudes of 3800 and 5000 feet, Joshua trees are prevalent, and above 5000 feet pinon pine and juniper appear. Various grasses have developed within a certain distance of a geothermal system running through the study area.

Economy

The local economy is supported primarily by tourism, as the town is the de facto gateway to Death Valley National Park, 7 miles to the west. The second leading provider of income is based on the mining industry.

Geology

The area of study lies within the southwestern region of the Great Basin and the southern end of the Walker Lane belt. Beatty falls within the southern portion of the Goldfield block, one of nine crustal blocks that comprise Walker Lane. The area is also located within the Southwestern Nevada Volcanic field. Tectonic extension in the area began in the mid to late Miocene and resulted in tilting. During the final states of these processes, volcanism surged and resulted in mineralization. Sawyer, et al. studied the feasibility of Caldera-related vs. detachment faulting mineralization events. The research, based upon regional geologic studies of the Nevada Test Site, concluded that the cause of mineralization of mineral deposits in the area was due to detachment faulting.

The regional geology features units ranging from Precambrian to Quaternary. Older Precambrian endmembers include gneissic granite, quartz monzonite and quartz-biotite schist. Younger Precambrian rocks include quartzite, siltstone, micaceous shale or schist, and marble, dolomite and limestone. The Paleozoic unit is comprised of limestone and dolomite. The Mesozoic unit features granodiorite and quartz monzonite instrusions and megabreccias. Tertiary time includes volcanic and tuffaceous clastics, including welded tuffs. Tertiary and Quaternary units both feature alluvial fans. Lastly, recent Quaternary basalt flows and cinder cones are prevalent throughout the area.

The extension of the crust in the study area has resulted in the thinning and the increased heating of the subsurface. Meteoric waters are heated and then rise to the surface. Beatty & vicinity have multiple hot springs, which are an example of this process.

Filename	**Size**	**GSD**
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Above: Table of flight line information for the Beatty, Nevada study area

IV. Secondary SEBASS Data Acquisitions

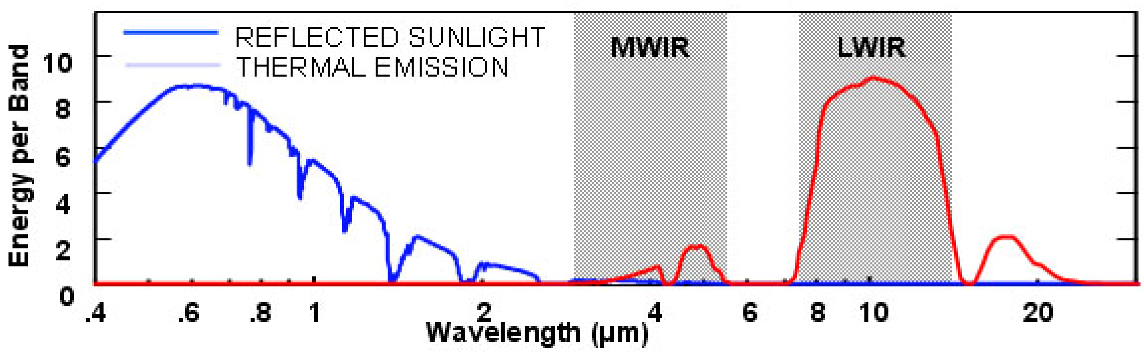
In addition to the Beatty scene, the Aerospace Corporation collected 27 other flight lines in areas across the state of Nevada. A table of the collection areas in given below. A brief description of the areas of study are given for those areas which are presently being investigated by ABLE faculty and graduate students.

Location	**Number of lines**	**Size of data** (radiance)	**GSD**
Cuprite	2	512,000 KB	3m
Goldfield	2	384,000 KB	3m
Hell’s Gate	1	256,000 KB	4m
Tonopah	2	384,000 KB	3m
Humboldt	1	64,000 KB	3m
Leviathan	4	256,000 KB	2m
Scheelite	3	768,000 KB	3m
Yerington	10	2,944,000 KB	3m
Zaca	2	256,000 KB	2m

V. Thermal Analysis

The thermal infrared is a physically unique segment of the electromagnetic spectrum in which to analyze earth materials. This is because of the emissive nature of the energy which is measured, in contrast to that of reflective energy in the visible (VIS), near-infrared (NIR) and short-wave infrared (SWIR) spectrum. Electromagnetic energy is largely generated by the sun, absorbed by certain materials, and consequently emitted (usually at longer wavelengths). This energy is less than that seen in the reflective region, according to Planck's law. If we draw a curve of a blackbody for the temperature of the Earth and that of the Sun, we can see that the energies produced in the thermal infrared are much less than that of shorter (primarily visible) wavelengths.

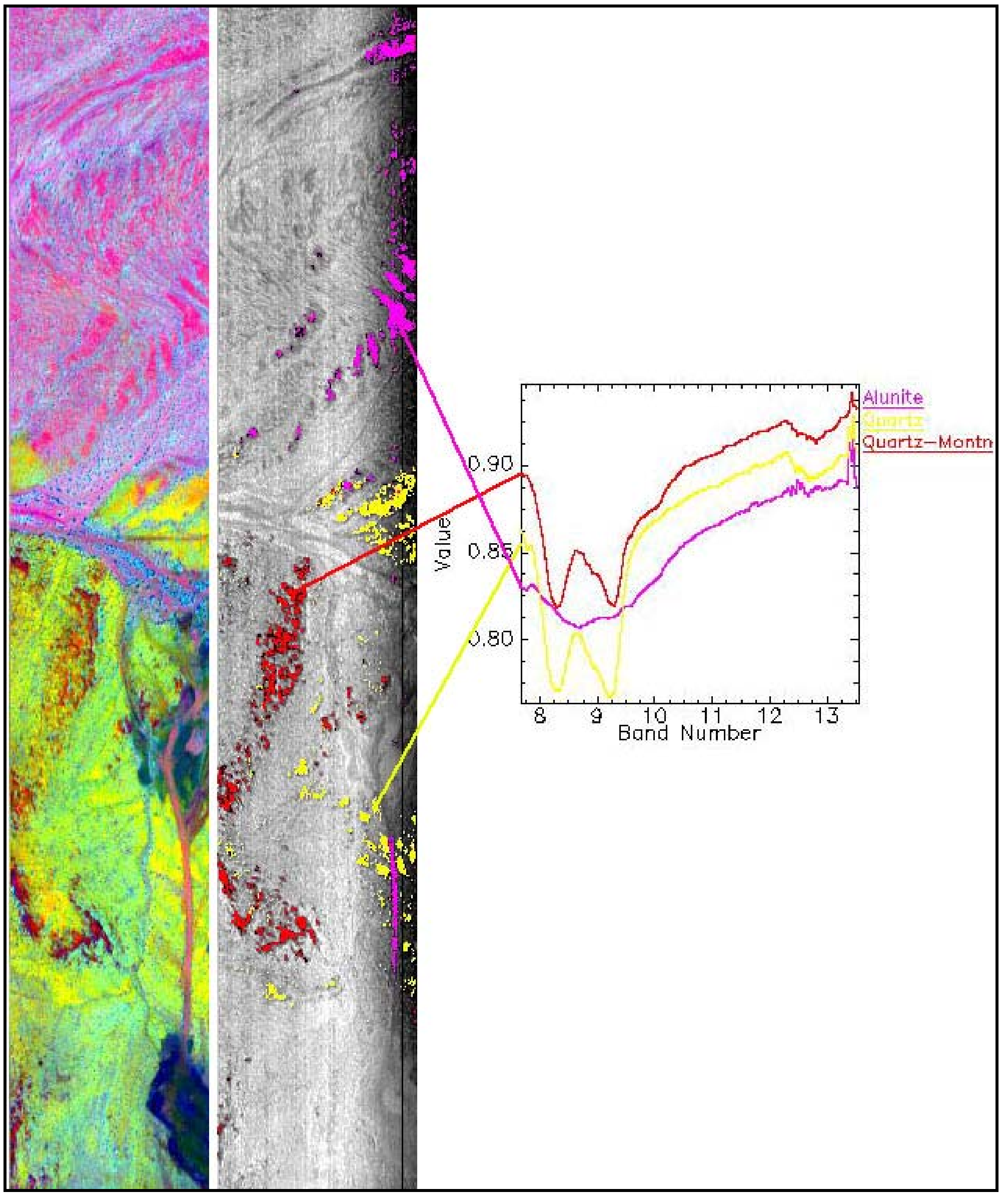
The thermal radiance, measured at-sensor, consists of two components: temperature and emissivity, of which temperature is the major contributor. Using complex temperature/emissivity separation algorithms, we can focus solely on the emissive aspect of image data and begin to take advantage of unique emissivity spectra of a wide variety of graybodies: minerals.



Above: The range of the electromagnetic spectrum measured by SEBASS is 2.1 to 5.2 um in the MWIR and 7.8 to 13.5 um in the LWIR.

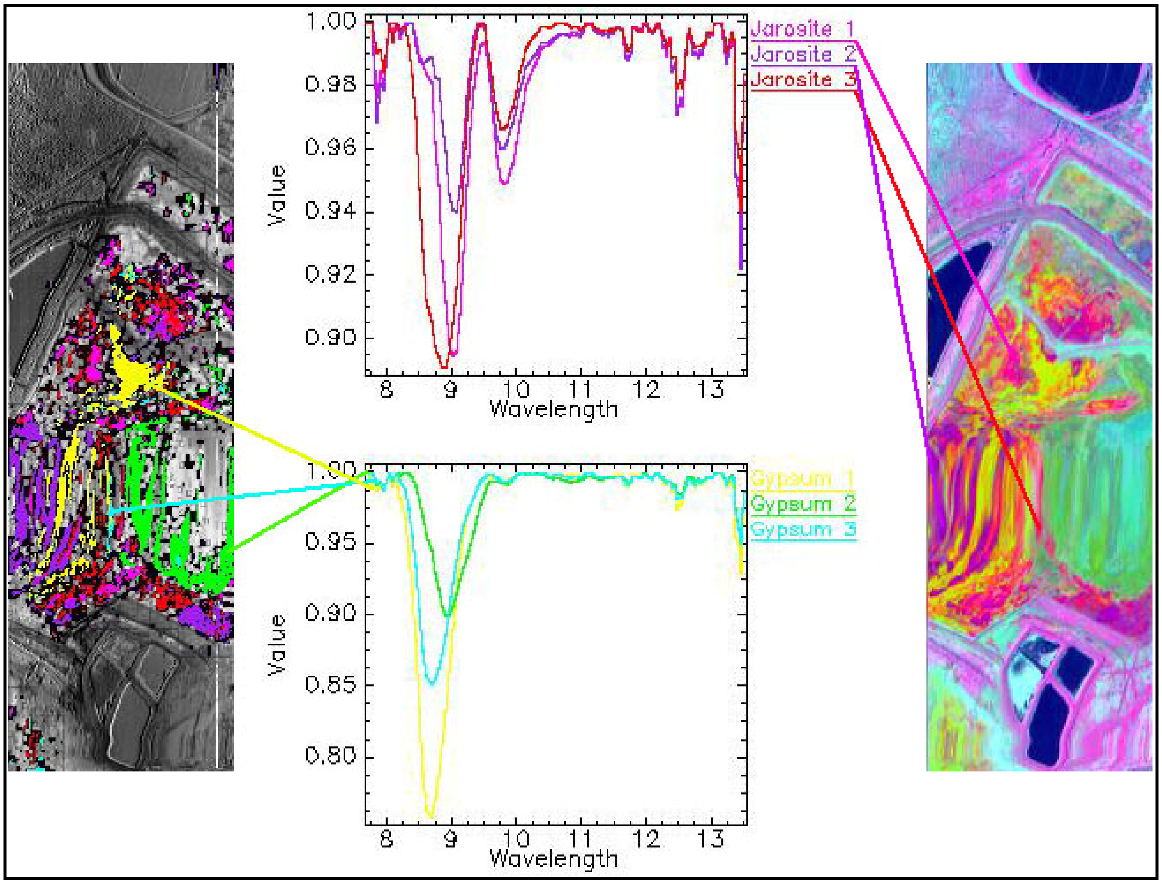
The processing methods used to analyze thermal infrared hyperspectral energy are similar to that of VNIR/SWIR analysis. That is, image data dimensionality is first addressed by using a noise separation process. Commonly, the Minimum Noise Fraction (MNF) function is used to define the threshold of coherent and incoherent (noisy) data. Next, pure pixels are found in the MNF image by using a pure pixel finder algorithm. These pure pixels are then searched for redundancy, and the repeating, or near-similar endmembers are removed. Finally, a spectral library of the scene is composed and used to perform mineral mapping.

We have investigated two separate data sets collected during the Summer 2007 Aerospace collect. Beatty, Nevada is the primary site of investigation for our purposes. Practically speaking, it features a wide range of alteration, volcanic units and rock-forming minerals which result in a diversity of remote sensing research avenues. Our initial analysis of the Beatty area focused on the local hot springs area, located directly adjacent to Highway 95, north of the town of Beatty. A wide range of acid sulfate minerals were mapped at two distinct argillic and advanced argillic alteration centers.



Above: A decorrelation contrast stretch has been applied to the RGB image 67, 36, 25 (11.1, 9.6, 9 um). Mapped endmembers were placed on a single band image. Magenta represents an alunitic endmember, yellow represents weathered quartz and red represents outcrops of quartz containing rock.

The second site of investigation was the Anaconda copper mine in Yerington, Nevada. This site displays a variety of sulfate minerals, which have precipitated upon mine wastes. The use of thermal infrared hyperspectral SEBASS was proposed to map the distribution of gypsum, anhydrite, jarosite, natrojarosite, plumbojarosite and the like. In addition, the study includes spectral characterization of copper sulfates, because they have not been investigated to any great detail in the past.



Above: SEBASS scene over a portion of three sulfuric acid evaporation ponds. A decorrelation constract stretch has been applied to the image on the right (RGB: 10.1, 9.81, 8.86 um).The distribution of gypsum and jarosite are mapped above. Band shifts due to cation substation is our hypothesis for spectral behavior. Laboratory techniques will be used to determine if this is a valid hypothesis.

VI. Training of Graduate Students

During the Fall semester, the ABLE laboratory received two new masters level graduate students, who will be focusing upon remote sensing in their studies. The large amount of data available to analyze has resulted in significant involvement and training opportunities for these students. Todd Morken has a background in computer science and geology. His experience is primarily in computer programming and geographic information systems. The training he is receiving will initially focus on learning the ENVI software package. As his skills with ENVI increase, he will begin to apply them to data from the Beatty site. Matt Weller has a background in physics and geology. He will also become familiar with ENVI this semester, in preparation for a formal remote sensing course conducted by ABLE faculty in the spring semester.

Our research involved some further analysis of the Beatty scene. Because the area of study is located within a geologically diverse area, there are many aspects of mineral mapping which we can capitalize to understand what can be spectrally measured in reflectance and inferred in the LWIR. In particular, we wish to continue the investigation of the aforementioned geothermally active acid sulfate system. Located on Highway 95, the Beatty hot springs area features well-exposed mineralization, including alunite, kaolinite, illite and opalized silica. Next, various rock-forming minerals will be measured across distinct lithologic units.

The second research thrust will be to look into comparing the classification of the same scene using VNIR/SWIR and LWIR data sets. Specific questions include: Do the classified minerals cover the same area? Are there differences in classification accuracy? Are these a function of quantum efficiency? Because we cannot find any peer-reviewed research papers involving this subject, we believe this to be a worthwhile investment of time.

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CHAPTER 13

Development of Training Modules for Analysis of HSI data

During the fourth quarter of 2007 two graduate students, who had not previously been trained in hyperspectral remote sensing or in how to analyze hyperspectral remote sensing image data were asked to learn the Environment for Visualizing Images (ENVI) software by using the tutorials that came with the program. This chapter describes their experiences in learning hyperspectral image processing.

Todd Morkin, M. Sc. Candidate in Geology, ABLE UNR.

Todd Morkin was very knowledgeable with respect to computer technology and software development, but he had no previous knowledge with the use of ENVI for hyperspectral image data analysis. His report below explains some of his learning experiences, aided by the ENVI Tutorials, in processing hyperspectral data.

Introduction:

This report is intended to serve two purposes, first to outline what I have accomplished this semester, and second to serve as an informal guide for others that are new to remote sensing and are interested in learning to use the ENVI software package. I will outline the processes and resources that I used during the semester to learn the ENVI software and also my own personal feedback and recommendations from my experiences this semester. As with any large powerful software package the process took longer than I anticipated and in reality, I have only scratched the surface of ENVI's true capabilities. Anyone looking to conquer ENVI in a weekend or even a couple weeks should reconsider; this is truly a long-term learning experience. I would relate it to a software package many people have heard of, Photoshop, in that I have used Photoshop for over 10 years, but I'd be willing to bet that I probably use less than 1/10 of what the program is truly capable of. I feel ENVI is the same; it's so powerful and has such an extensive feature set that even with years of use, a user probably does not have a true mastery of it. However, it is not a lost cause as most users do not need to master every aspect of the program, only those features that they will need to use. However, even those features require extensive study by the user, in both how to execute them with the software and to learn what is going on in the background in order to understand and obtain the desired results. If one simply presses buttons, the program may perform the intended task, but without at least some understanding of what is happening in the background the user cannot hope to manipulate the data as needed.

Procedures:

As I received a new desktop this semester, my first week or so was spent setting the machine up, having operating, office, and virus software installed, doing required updates, setting system preferences and such. This is a good point to mention that if you want to work with significant data sets with ENVI, it's important to have a powerful computer at your disposal. The amount of data in a hyperspectral dataset is extensive and requires not only a lot of storage space, but a fast processor, graphics card, and extensive memory to process the data. Even with a top end machine, processing a large area of data takes hours and possibly days. Thus, it's important to have as much computer as you can afford, as this reduces the time to process, data and increases the stability which reduces the risk of system failure while running processing jobs. For the purposes of going through tutorials ENVI provides sample data that in most cases makes for fast processing while doing the tutorials. In those cases where processing even the tutorial data may take a long time, ENVI has provided pre-processed results for the user to view after learning the procedure. In addition to a fast computer, having two monitors is a very convenient option if possible. This allows you to have one screen focused on the data, and another screen for the tutorial. It is also a nice option when you start working on data outside of the tutorials, as there are many smaller boxes to set parameters and keep track of data set information, that it's nice to be able to separate those on one screen, and keep the dataset images separate on their own screen.

Once ENVI software was installed on my computer, and I had downloaded the ENVI tutorial data, I logged onto ENVI's website (www.ittvis.com) and went to the online tutorials section. From here you have access to a multitude of tutorials that cover anything from a very basic introduction to the software, to very detailed processing of certain types of data. There are options for classification methods, transform tools, mapping tools, hyperspectral tools, radar and topographic tools, vector tools, and custom programming options. In all, there are probably over fifty tutorials on the site. Some may not be of interest to everyone, as some cover very specific data types or processing options that may not be of interest to every user. In general, I found the tutorials to be well-written and easy to follow. I did not find a lot of errors, and the referenced data files to use were listed correctly and worked as stated in the tutorial information. I spent a day or two just poking around the program on my own, getting used to what menus there were and feeling my way around the user interface. This step could probably be skipped, but I felt it would be good to just look around the program on my own first before tackling the tutorials.

I started with the general quick start guides and introduction tutorials from the website. These are fairly straight forward tutorials that step you through getting the program going, bringing in and displaying data, what the data descriptive windows tell you about your data set. They also cover some simple manipulation of your image such as how to change bands, move between zoom windows, change program focus between windows, and a multitude of other introductory things that just get the user familiar with moving around the program interface. The new user is recommended, at the very least to, complete these tutorials before moving on, as they really teach you the basics of getting up and running on the software. They will not teach you anything specific, or how to manipulate your data or do any processing, but they allow you to get to the point where you can move to the more advanced tutorials without being completely lost. Most of the tutorials could all be completed in less than two hours; however, that is just to step through and do what the tutorial tells you to. In order to gain a true understanding, you have to play with different settings for each step and view the end results. This can take more time than the tutorial itself does, especially if you really want to gain a solid understanding of what each tutorial is trying to teach and how to customize the parameters to get desired results. Taking the time to do this cannot be stressed enough, as you have to have a knowledge of what changing the settings of the program will do to your output if you are to end up with the result you want.

At this point I moved on to the extensive collection of more advanced topic specific tutorials ENVI provides on their website. Even though I will be working with hyperspectral data I decided to do most of the available tutorials. My rationale behind this was that I would gain a more general understanding of the software and its capabilities, and this was indeed the case. In addition it had the added benefit of reinforcing certain topics as they were covered again in the hyperspectral tutorials. It may take more time, but exploring tutorials that are not necessarily on the exact topic of interest, does benefit the user in the long run. The user should be careful not to expend too much time and effort in this area though. Once you start experimenting and exploring the options, you can easily spend as much time or more doing that than the actual tutorial takes. I probably spent more time than I needed to on some tutorials doing exactly that. Thus, it's important to try and balance doing enough extra experimentation to learn what is going on and what effect you can expect with various settings, without spending too much time on any one particular method. I also decided to save the hyperspectral tutorials for last in my case, because I am going to be dealing with hyperspectral data, and I wanted them to be fresh in my mind when I finished the tutorials.

The first general tutorial topic covered is classification methods. In these tutorials ENVI uses Landsat TM datasets to teach different classification methods. There is also a tutorial that deals just with decision tree classification. Most of these tutorials are strait forward and easy to step, however, as mentioned before, changing the parameters and viewing new results teaches the user more than just going through them once. This is especially true of classifications, it's important to be able to adjust parameters to tailor the results to those desired. Having as much experience in this area as possible is important, especially if you are trying to get a model to agree with a ground truth reference map.

The next general topic of tutorials is those covering data fusion using Landsat TM, SPOT, and SAR data sets. Data fusion is a process used to combine multiple images into a single composite image. This is commonly done when one image has greater spatial resolution and you want to impart that resolution upon other lower resolution images of the same scene. For example, Landsat 7 data bands have a resolution of 30 meters; however, they include a panchromatic band that has a resolution of 15 meters. By doing data fusion, you can overlay the 15 meter resolution to the other bands, in essence enhancing their resolution to 15 meters as well. This is another area where experimentation is important to gain an understanding of how different parameters will affect your final image quality.

The tutorials after data fusion are a series that deal with mapping. They covered topics such as georeferencing, orthorectifying aerial photos, mosaiking images, and adding map components to scene images. I have had significant GIS experience, so these tutorials went pretty smooth and I was familiar with most of the concepts presented. In general, while ENVI has some powerful tools for georeferencing, those interested purely in such topics are probably better served by a GIS specific software suite. While the results are probably acceptable, many of the map components do not have the professional appearance that you can obtain with a dedicated GIS software package. However, it's a nice option if you already have ENVI and need to produce a map like image from data you are working with. In that case it saves you from having to port your data to a GIS program and add map components there.

After the mapping tutorials, I started to go through the radar and topographic tool tutorials. These tutorials deal with very basic SAR processing and analysis, digital elevation model (DEM) analysis, using the 3D surface view and fly through tools, and working with the DEM extraction wizard. Again while suitable and easy enough to use, I felt the results from a GIS dedicated software suite would be easier and produce better results in most cases. However, considering the fact that both of these software packages can cost thousands of dollars, it may not be practical to own both software suites so it is a nice feature that is provided with ENVI.

The rest of the tutorials cover vector tools, programming, and miscellaneous topics I did not complete every online tutorial. Instead, I tried to pick and choose those that were a more general overview of those topics I thought I may use, or applied specifically to hyperspectral data. I worked with the linear feature extraction, vector overly, ENVI feature extraction, vegetation analysis, atmospherically correcting hyperspectral data, and preparing ASTER data tutorials. Some of these were very in depth and required quite a bit of outside research to attempt to understand what was going on during the tutorial, while others were fairly straight forward.

Additional thoughts and observations:

By the time I finished the tutorials most of the semester was over. I should qualify this with some additional information, because at first glance, one would think that taking that much time to complete the tutorials seems excessive. This would certainly be true if all one did was step through the tutorial and push the buttons in the sequence it told you to. However, I found out very quickly that the tutorials make references to methods and procedures that I had never heard of before. The tutorials are not designed for someone who is new to remote sensing, as I am. They expect you to have comprehensive knowledge of remote sensing topics and processing. As this was not the case for me, I had to spend a lot of time, in fact more time than the tutorials took, doing background research trying to learn terms and methods the tutorials would reference. While I did not need to do this to get through the tutorial, it was essential for me to try and have an understanding of what was going in the processing for later use.

This actually proved to be challenging, because in general, I found two types of information in my research. There was reference information that was too general and of little help in explaining what I did not understand, and then there was information that was too technical on the theoretical mathematical theory behind a method that I simply could not grasp. Finding descriptive information on remote sensing methods, and terms referenced in the tutorials that was not too broad or too technical, proved very challenging. I would say I spent at least as much time getting up to speed on general remote sensing topics, as I did with the tutorials themselves, probably more. Someone who was well-versed in remote sensing and processing methods already, would not have this issue and it would reduce their learning curve significantly and save a great deal of time for them.

In addition, the user that is just learning ENVI and is not competent and comfortable with computers, is going to struggle more so than I did. I have a solid computer programming background, so that certainly assisted me in working through the tutorials and not being intimidated by them. I could easily see where someone new to computers and new to remote sensing, trying to learn to use ENVI for the first time could quickly become frustrated and intimidated by the process. The tutorials themselves are well-written, and I did not find any errors that should hamper the user from completing them. This is impressive, as I've gone through tutorials for other software suites that were poorly written and had extensive errors, so ENVI did a very good job.

After I finished the tutorials and the research that went with them, I was given some actual hyperspectral data from Beatty, NV, I have just started to work on a small sample area from the data in order to get a feel for doing classification and working with actual data. That process is still in its infancy and will continue into next semester.

Matt Weller, M.Sc. Graduate Student in Geophysics

Matt Weller had no background in remote sensing science or with the use of ENVI for processing hyperspectral data. What follows is his experience in learning ENVI over a period of three months.

When I began to work with ENVI, it was without the benefit of any experience with the software package. This is not to say that I was without programming experience. On the contrary, I am familiar with IDL and other computer languages. This familiarity should allow for a great starting point for someone learning the ENVI package. In the following text, I shall outline my thoughts and experiences on learning the software.

The first exposure I had with ENVI was that of the tutorials. I've found that they do a reasonably good job of bringing a user up to speed on the mechanics of the software usage (e.g. z-profile, manipulating windows and images, simple processing procedures, important files, etc…). However, I found that the greatest weakness of these materials is in the explanation. What I mean by this, is that while the tutorials show the steps of the procedure, there is little to no indication of what the program is actually doing and why these steps are important or relevant. In some cases such, as in Tutorial 17: Spectral

Angle Mapper Classification, the tutorial has a reasonable explanation and shows the transparency of the operation. Tutorial 18: Target Finding With SAM and BandMax are simple procedural steps, but little explanation or transparency.

The Help file is not terribly helpful. It shares many of the same problems as the tutorials. Neither of them explain the processes coherently, nor do they give nice, clean examples. Many times when I searched for a specific term in order to understand what the program was doing, or searched for an example on how do a tweak in order to process an image, either a bare bones definition was all I was given, or the information was under a different name. Obviously, this makes learning somewhat difficult. I would say the weakness of both the help file, and tutorial, is a lack of explanation and transparency.

Along the lines of transparency, when running the analysis through either spectral hourglass or via individual component processes (such as MNF transform, PPI, etc…), ENVI does a terrible job letting the user know if there was a failure in one of the processes, other than the out of memory crashes. Oftentimes, the end result was distorted, or otherwise unusable because of these processes outputting bad data. The computer that I was using had some rather unique issues, and the bad data may have been the result of the interplay between ENVI and the neurotic computer.

Personally, I had little trouble navigating ENVI's menus, but some of the redundancies are puzzling (see the following images for examples). I do not see the need in confusing the layout by placing a command or sets of commands in two submenus in the image menu and one in the main menu. This is ludicrous and only serves to confuse the novice.

The only true issue that I have had with the package is that of the actual end member selection, and subsequent determination through known spectra. From what I understand, however, is that this is more experience-based, rather than technical know how. Still, a (again not to sound redundant) much more user friendly, logically ordered and transparent process would greatly simplify this part of the learning curve. Also, some type of sanity check would be logical to include with the spectral mapping. Perhaps if something were added along the lines of a pop up warning, saying that this is statistically improbable with the given data, then it may remove some of the frustration from trying to determine if the end results are indeed valid.

To summarize the key points of this text I need to say, but two words: Transparency and Explanation. I feel that with better organization of the menus and the text, as well as clear succinct explanations and example, followed by an in-depth examination of the methods and processes, then a much less frustrating and more efficient learning experience would result. Similarly, with the inclusion of the sanity check mentioned above of the spectral mapping product, then the ease and comfort of the aforementioned learning experience would result.

Chapter 14

Summary Findings

Linking ABLE Research to DOE National Centers

This project was initially designed to utilize state-of-the-art remote sensing capabilities under development at the University of Nevada, Reno (UNR), and apply them to the information needs of the Department of Energy's non-nuclear proliferation programs (DOE Code NN). In particular, our opportunity to do research for DOE was to exploit hyperspectral remote sensing in support of the chemical and biological programs (DOE Code NA-22). This research opportunity came through a Congressional earmark to NA-22's FY 04 budget to provide research support for the University of Nevada, Reno. This $2 million earmark was requested through Senator Harry Reid's Office to stimulate the development of sensor-related research in materials science and engineering. However, it is our understanding that the earmark to NN-22's budget may have been placed part of NA-22's program office than originally intended.

When UNR was made aware of the $2 million earmark, the Vice President of Research (VPR) had little information on the program, or how it was to be managed. Apparently, the intent of Congress was to get UNR more engaged in DOE research, because so much of DOE's research was directed to the Yucca Mountain Project Office, and that program was moving toward commissioning of the Spent Nuclear Fuel Repository. The UNR VPR corresponded with the NA-22 Office and arranged for its senior managers to visit the University and meet with UNR faculty researchers. Initially, the UNR Office of Research planned to use the $2 million to fund new, junior researchers who had not established their capability to conduct competitive research in the hope of growing the UNR's research capability. However, when the highly competitive researchers in ABLE learned that the NA-22 office had an interest in aerospace remote sensing we asked to be included in the presentations to the DOE managers. Knowing that we were already competitive the UNR Office of Research reluctantly included our presentation as the last of the day. Our presentation on hyperspectral remote sensing turned out to be of great interest to the five DOE NA-22 managers, and they encouraged us submit a proposal. As described in Chapter 1, our proposal was ultimately selected for funding.

ABLE assembled a research group that included the Desert Research Institute, (a Nevada System of Higher Education (NSHE) institution) to do the vegetation studies; SpecTIR Corporation, a local firm that providing the hyperspectral sensors; and Sierra Nevada Corporation, providing the aircraft for the first overflight of NPTEC. One of our aims in establishing this consortium, was to facilitate collaborative investigations and the development of a collaborative center for hyperspectral remote sensing investigations.

After contract negotiations were completed, Dr. Gus Williams mentored our ABLE group to focus our first grant to NA-22 needs. He facilitated our understanding NA-22's mission by connecting our researchers to the research needs of DOE National

Laboratories, including Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Pacific Northwest National Laboratory (PNNL) and the National Special Technologies Laboratory (NSTec). Gus arranged for us to attend the briefings on Shrike at DOE's facilities in Las Vegas. Through collaborations with the scientists at these DOE Laboratories, ABLE scientists learned about the cutting-edge research being conducted in hyperspectral remote sensing. In fact, the serendipity that brought ABLE to connect with NA-22 created new opportunities for both organizations. We then steered our research to support investigations at the Non- Proliferation Test and Evaluation Center (NPTEC). This culminated in learning how to conduct investigations at NPTEC, and one of our graduate students later participated in the Tarantula project, occupied a trailer at the site, and provided image processing needed by NSTec.

Secondly, another major benefit was that researchers at DOE National Laboratories began to write UNR/ABLE researchers into their NA-22 proposals. Currently, we are listed as collaborators with LANL, LLNL, PNNL, and NSTec on their proposals to NA-22. Scientists from these DOE National Laboratories have visited UNR/ABLE, given talks to students and faculty, and shared software with us for the processing of hyperspectral image data.

UNR received a second Congressional earmark from in the NA-22 FY05 budget totaling $3.2 million. ABLE again submitted a proposal, this time to exploit hyperspectral thermal image data for non-proliferation applications. This proposal was submitted with DOE National laboratory collaborators, and was accepted for funding in FY 2005. These two research efforts, funded through Congressional earmarks, enabled ABLE to understand NA-22 research requirements and in 2007, enabled us to submit a competitive, peer-reviewed proposal in response to the NA-22 2008 Broad Area Announcement. This research proposal included a consortium of investigators including:

1. Dr. James V. Taranik, Lead Principal Investigator
2. Dr. Donald Sabol, Lead Investigator for DRI
3. Prof. Tim Minor, Co-Investigator, DRI
4. Dr. Gus Williams, Collaborator from Brigham Young University
5. Dr. John Di Benedetto, Collaborator from NSTec
6. Dr. Herb Fry, Collaborator from Los Alamos National Laboratory
7. Dr. Dean Riley, Collaborator from Aerospace Corporation
8. Dr. Brian Horwitz, Collaborator from Sierra Nevada Corporation

As of this writing, our proposal was listed under funded investigations on the DOE website. Thus, the Congressional earmarks, while stressful to the NA-22 budget, did serve a useful purpose in bringing the ABLE group of investigators into the DOE NA-22 research program.

Hyperspectral Research at NPTEC

During this investigation, we learned how to do research at NPTEC. Our first introduction to doing work at NPTEC, came from the Shrike briefing meeting on January

27, 2005. During this meeting we presented our hyperspectral remote sensing capabilities to the Shrike team and developed important contacts with LLNL, LANL, NSTec and DOE program managers from DOE Headquarters. We learned how to schedule overflights of the NPTEC facility with the help of Dr. Peter Munding and secured the flight clearances for hyperspectral data acquisition. We learned how to submit "Real Estate/Operations Permits" for ground-based spectral measurements. We observed the development of the Shrike Test Plan, and participated in the Shrike planning meeting on March 9, 2005 and presented our plans for data acquisition and analysis in support of Shrike. In 2005 we participated in the development of the Logistics Plan and reviewed the Test Management Summary.

SpecTIR and SNC acquired HyperSpecTIR hyperspectral image data over the NPTEC on April 26, 2005. Because there were no tests scheduled at that time, approval for the overflight was routine. SpecTIR had serious problems with the calibration of the HST data set, and a second data set was acquired on August 31, 2005. We were unable to conduct aerial data acquisitions over the NPTEC during the actual Shrike tests because the experiment plan had been already determined prior to our entry into the program. The August 31, 2005 data set was not useable, because of the high temperatures over the NTS and inadequate cooling of the HST sensor. This acquisition was done in a Cessna 206, flown at relatively low altitude, and heat in the sensor enclosure seriously affected the quality of the SWIR data. On September 29, 2005, SpecTIR had a reflight over the NPTEC, but again calibration of the sensor was problematic and the data was marginal.

Even though the hyperspectral reflectance data over NPTEC were marginal, seasonal differences in the surface cover of the NPTEC site were very evident, notably in the vegetation, soil moisture and impounded water. The immediate area around NPTEC is characterized by a silica-rich playa that is extensively disturbed by vehicles and construction.

UNR/ABLE participated in the Tarantula briefings, in the experiment and we had a graduate student who occupied a trailer at the NPTEC, and provided data and image data processing support for NSTec.

Because the NPTEC site occurs in a playa largely composed of silicates (clays and quartz sand), hyperspectral reflectance data may not provide the optimal sensing tool for evaluation of background variability. We attempted to obtain hyperspectral thermal data over the NPTEC from SEBASS, but found that the image data was classified and restricted in use. Therefore, at the suggestion of our collaborators, we changed the focus of our research away from the NPTEC, to areas having diverse surface cover types and that could be imaged these areas at different times of the year.

Planned Investigations in Diverse Landscapes

Finally, we responded to the DOD NA-22 2008 BAA by proposing to use hyperspectral reflectance data acquired over Beatty at two different times of year, and acquiring SEBASS data over the flight boxes at the same spatial resolutions. Included with this data set were LIDAR coverage and digital Orthophoto data. ABLE, with funding under this contract, also acquired SEBASS data over diverse landscapes, including the Leviathan Mine and Zaca Mine sites in California; Goldfield and Cuprite, Mining District; Hells Gate, Death Valley; Steamboat Springs and Virginia City Mining District; Yerrington Mining District; Humboldt Mining District; Tonopah Mining District; Otman Mining District; using the upgraded SEBASS Aerospace Corporation sensor. This was done in anticipation of our future research program that was proposed under the 2008 BAA. The diversity of landscape cover and topography in these sites and the fact that they are also covered by hyperspectral reflectance data, in addition to hyperspectral thermal data, now prepares our investigators to answer many of the questions being posed, related to the variability of backgrounds against which gas emissions are imaged.

Geometric Correction of Hyperspectral Remote Sensing Data

One of the attractive aspects of the SpecTIR HyperSpecTIR (HST) sensor was that it was focal plane stabilized sensor. Each imaging swath was stabilized for aircraft motion during spectral scanning across track, as described in detail in Chapter 6. HST imaging swaths have a focal plane centered picture element that is mapped to a geodetic reference system using an inertial measurement system (IMS/GPS). With 100 measurements per second, provided by a C-Midgits III system it may be possible to locate the focal plane center picture element to about 8 meters at an imaging spatial resolution of +/- 11 meters. However, in practice with the IMS that was provided for our surveys over NPTEC, we found that it was only possible to locate the central picture elements with an accuracy of + or – 38 meters, using the airborne data alone. The potential exists, however, with an advanced IMS/GPS system to locate hyperspectral data within 5 meters. Once the central pixel is known, a relatively simple algorithm can be used to map all the other pixels into geodetic reference space.

We found that the imaging geometry of the HST enabled us to mosaic swaths manually. We could make even better mosaics using ground control points, with the greatest distortions at the ends of the imaging swaths (the bowtie effects).

SpecTIR has now benched the HST imaging systems, and is now using the Specim Eagle and Hawk systems developed in Finland. The VIS/NIR sensor is co-mounted with SWIR sensor and uses a C-Midgits III IMS/GPS. The entire package was used in a floor- mounted configuration without any motion-compensated aeroflex mount. The imagery acquired in this manner has to be geometrically corrected for aircraft pitch, yaw and roll. Geometric corrections involve the use of resampling algorithms that can smooth out one and two pixel spectral anomalies. Examples of geometrically resampled SpecTIR VS (dual) imagery is shown in Chapters 6 and 8. Our investigation did not review the SpecTIR VS geometric correction programs and their effect on spectral signatures.

Radiometric and Atmospheric Correction of Hyperspectral Data

HyperSpecTIR Sensors: At least one HST imaging mission over NPTEC became marginal, because the instrument was not properly radiometrically calibrated in the laboratory. The HST's utilized calibration lamps, have to be calibrated. Just prior to the mission, the calibration panel failed due to operator error. Substitute lamps were used, but not calibrated. All the spectral measurements from that mission could not be corrected to reflectance, and had considerable artifacts. Calibration of the HST's and correction for atmospheric effects, became a major issue during this project.

SpecTIR Corporation had its origins in Santa Barbara. The HyperSpecTIR technology was developed by Lou Watts, a former Hughes Santa Barbara Research Center (SBRC) optical engineer, and Joe Leveigne, an optical physicist. Lou worked with several optical engineers and physicists in utilizing focal plane stabilization technology developed for guiding smart bombs, and applying that technology to hyperspectral imaging. Three HST's were developed at a cost of approximately $1.5 million each over a period of ten years. Each HST was a unique, experimental instrument and the software to calibrate and process its data was a combination of several different programming languages, and not well documented. New managers joined SpecTIR and moved the corporation to Sparks, Nevada. The developers of the HST's, chose to remain in Santa Barbara, and engineers and scientists unfamiliar with the development of the HST's were hired to do the engineering and calibration of the instruments. HST development was frozen, and two of the three HST's were placed into operational service. However, these were experimental sensors, not ready for routine operational service. In our project, we tested this new technology, because it held such promise for operational hyperspectral data collection in UAV's. Because SpecTIR Corporation had difficulty developing a standard calibration procedure for these sensors, they were ultimately mothballed and SpecTIR moved on to utilize the Specim Eagle and Hawk systems in a dual configuration.

Specim AISA Eagle/Hawk (Dual): This sensor was described in Chapter 7, and when operated by SpecTIR Corporation, has been called the SpecTIR Dual, ProSpecTIR and the SpecTIR – VS sensor variously. Originally, Specim sold the instrument with the expectation that data collected by the system could be batch processed using ATCOR processing software. ATCOR was developed, by a European scientist, for the AISA VNIR sensor called Eagle. However, ATCOR processing software was also assumed to be extendable to the processing of the SWIR data collected by the AISA Hawk. However, after nearly two years of various trials, acceptable batch processing of the Hawk data to reflectance has proved to be challenging for SpecTIR scientists. Part of the problem may lie in the fact that ATCOR was developed in a highly vegetated, low-altitude environment using well-defined knowledge of the effects of water vapor on spectral measurements from 400 nm to 1000 nm. However, in the SWIR, ATCOR does not appear to adequately correct for variations in atmospheric effects. Batch processing of AISA Dual data has proved to be problematic, because of the sparsely vegetated areas in the Great Basin of Nevada, and because of the variable effects of atmospheric gases on spectral measurements. Therefore, while we were able to process small scenes of Specim Dual data over select areas, processing of long flight lines was very difficult. SpecTIR Corporation ultimately developed the empirical line method, which incorporates known spectra from materials in the scene.

Atmospheric Correction: Because of the difficulties in applying atmospheric corrections to hyperspectral reflectance data beginning with this research project, we have been investigating the various atmospheric correction routines that are routinely available. These include the following: FLAASH, ACORN, MODTRAN, ATREM and ATCOR. We have installed these various processing routines in the ABLE laboratory and our graduate students are exploiting and cross-comparing them in preparation for future research.

Atmospheric corrections from radiance measurements to reflectance are necessary to compare aircraft measured spectra to spectral libraries, developed largely from field and laboratory measurements. However, many users are able to work directly in radiance, and convert the laboratory spectra to spectra that might be measured in radiance. This approach will simplify signal processing of hyperspectral data on UAV's. In fact, the ultimate UAV based hyperspectral sensor will be one that scans an area of interest, detects a spectral signature of interest in geographic coordinate space and transmits the coordinates and the spectral, in real time, to decision makers either in the air or on the ground.

Radiometric Resolution: Radiometric resolution is influenced by the signal that can be measured above noise in the focal plane, detector sampling frequency and the quantization of detector response. Our research has found that a minimum signal to noise for of 300:1 is required, while 1:000 to one, or better, is very desirable. Higher signal to noise is limited by detector performance, and becomes more difficult to achieve in the SWIR. For this reason, we found that the signal to noise in Hyperion of 50:1 was unacceptable for identifying spectral patterns in the SWIR. 10 bit to 12 bit quantization was found to be adequate for analysis of most spectra related surface cover types.

Spatial Resolution, Synoptic Imaging and Spectra: Hyperspectral focal planes generally range in size from 256 detectors to 1000 detectors. The instantaneous field of view (IFOV) of these sensors ranges from 0.5 milliradian to 1.0 milliradian. The total field of view at any spatial pixel usually ranges from 20 degrees to 40 degrees. The SpecTIR dual system currently uses 320 spatial pixels in the SWIR and matches the VNIR to this focal plane size. When the aircraft is flown at an altitude above mean terrain that produces 1-meter spatial pixels on the ground, the ground swath is about one third of a kilometer. While one meter spatial resolution image data is useful for detection and identification of one and two spatial pixel anomalies, our research at Virginia City has found that 5 meter spatial resolution is adequate for mapping most variations in geologic and soil types that are important to understanding the effects of background clutter. Recently, SpecTIR Corporation has acquired a 1000 SWIR focal plane array and can now image both the VNIR and SWIR both with 1000 spatial pixels. This new capability, flown with 5 meter spatial resolution, would give a swath width of 5 kilometers, greatly reducing the data acquisition time, the data volume to be acquired and the analysis time for the hyperspectral imagery. Our research conducted through this grant determined that spectra of importance to understanding background variations could be de-convolved through sub-pixel analysis.

Spectral Resolution: In this research, we evaluated a variety of sensing systems that had different spectral resolutions. Our research found that 10 nm spectral resolution allowed most of the spectral features, of importance to measuring variations in the background, to be detected, identified and mapped. The SpecTIR dual sensor has the capability of making spectral measurements at 5 nm and is the only operational hyperspectral sensor capable of measuring at this bandwidth. This increased spectral resolution is useful for measuring shifts in vegetation spectra caused by vegetation stress in the VNIR. However, in the SWIR vegetation spectra are dominated by broad spectral features and most rocks and soils can be adequately discriminated with 10 to 15nm bandpasses. Most of the spectral libraries that are used with hyperspectral reflectance data are organized using 10 nm spectral resolution, and have to be resampled to compare them to 5 nm image data. There is an additional complication for making atmospheric corrections using off the shelf software. However, if 5 nm spectral resolution is desired to resolve narrow band spectral features related to paints, spectral tags, etc., these issues can be dealt with.

Training Students to Analyze Hyperspectral Data: The following graduate students were supported under this grant:

Mr. Blake Morrow, M. Sc. Candidate, Nevada National Guard, Eagle Vision unit.
Ms. Sarah Mahoney, M. Sc. Graduate
Mr. Zan Aslett, Ph. D. Candidate
Ms. Laura Huebner, M. Sc. Candidate
Mr. Todd Morkin, M. Sc. Candidate
Mr. Matt Weller, M. Sc. Candidate
Dr. Amer Smailbegovic, Ph. D. Graduate (Post Doctorate)
Dr. Greg Vaughan, Ph. D. Graduate (Post Doctorate)

Some of these students had considerable expertise in the analysis of hyperspectral image data using the Environment for Visualizing Images (ENVI) software (Aslett, Smailbegovic, and Vaughan). The others had to first learn ENVI, and then apply ENVI to analysis of hyperspectral image data. Huebner and Mahoney had prior courses in remote sensing and were familiar with computer technology. They learned ENVI very quickly with little supervision, using the ENVI tutorials, and were able to do project work within about a month. Morrow, Morkin and Weller had no previous training in remote sensing and had not used ENVI. These students were at the greatest disadvantage in learning the ENVI software by just using the tutorials that came with the ENVI package. The biggest problem appeared to be understanding the nomenclature used in the ENVI tutorials, and understanding the very minimal explanations of how the ENVI algorithms actually process hyperspectral image data.

Importance of NA-22 18-month Program Reviews: Dr. Steven Schubert, of PNNL conducted an 18-month independent program review of our project on September 20, 2006. Dr. Schubert was also joined by Dr. Don Sabol, then from the University of Washington, and Dr. Fred Kruse, who helped develop the ENVI software program. The review identified we needed to expand the manpower available to the project through a Post Doctoral Fellow; needed to expand the spectral range beyond hyperspectral reflectance imaging to hyperspectral thermal imaging; needed to link our efforts to the development of spectral libraries at DOE laboratories (Dr. Sharpe at PNNL); needed to respond to the NA-22 BAA to be released in 2007; needed to leverage other sources of funding that Congressional earmarks to NA-22; needed to expand training of students at NTS and NSTec; needed to connect with New Mexico State group supporting NA-22 and NGA to facilitate clearances for our graduate students and post-doctorate fellows; and finally, to do a better job of linking signatures with observables. We approached this review with trepidation, because NA-22 is unique in reviewing all its research projects. We found the experience to be helpful and it provided perspective with respect to the research directions of interest to NA-22. Subsequently, the PI for this project was a reviewer for a PNNL project related to the analysis of hyperspectral data, and this experience served to introduce us to the spectral laboratory measurement capability, and we established important collaboration opportunities with PNNL researchers.

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* Denotes publications where support from DOE NA-22 is acknowledged. There were no publications of work related to the NTS NPTEC and the experiments conducted there