Integrated Multispectral and Hyperspectral Mineral Mapping, Los Menucos, Rio Negro, Argentina, Part II: EO-1 Hyperion/AVIRIS Comparisons and Landsat TM/ASTER Extensions

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1. 0 Introduction

The Los Menucos gold district was discovered in 1998 by Arminex, S.A. using regional exploration methods employing Landsat Thematic Mapper (TM) satellite imagery and field investigation (Franco et al., 2000; Gemuts and Perry, 2000; Perry and Gemuts, 2000). This district has the largest significant concentration of advanced argillic, altered Permian ignimbrite and rhyolite assemblages in Argentina. Alteration is related to the intrusion of Triassic-age (?) rhyolite dome complexes below thick Permian-age felsic volcanic rocks. Associated with dome fields are large areas of phreatic breccias and hematite-rich altered oxidized zones. Alteration is characterized by vuggy silica, quartz stockwork, kaolin, and alunite. The region has potential for low-sulfidation style gold mineralization. The Los Menucos region was submitted and selected as a NASA E0-1 collection site during 2000 to evaluate other earth observation sensors, including hyperspectral (airborne AVIRIS and satellite EO-1 Hyperion) as well as multispectral data sets (Landsat 7 Enhanced Thematic Mapper and ASTER imagery). The results of the TM reconnaissance and AVIRIS analysis are presented in a companion paper (Kruse et al., 2002a). The Hyperion, ETM and ASTER results are presented here.

2.0 Landsat TM Reconnaissance and AVIRIS Verification

Over 100 sites were predicted as alteration anomalies resulting from digital enhancement of Landsat TM imagery analyzed by Perry Remote Sensing LLC (PRS). These results were used to drive field exploration, and in less than one year, a field crew of six geologists systematically visited and sampled all of these anomalies. Eighty percent of the areas visited exhibited epithermal-style alteration, and five percent were mineralized. The exploration effort led Arminex to assemble 80,000 hectares near the village of Los Menucos and established the area as the first gold district in Rio Negro province. Early in 2000, Rio Tinto Mining & Exploration (RTZ) took an option on the Arminex property and agreed to continue drilling and testing at key prospect areas.

Since the district was initially identified by field testing Landsat, and hosts an array of alteration minerals, the location was also submitted and selected as a NASA E0-1 site to evaluate the EO-1 Hyperion sensor as well as multispectral data sets (Landsat 7 Enhanced Thematic Mapper and ASTER imagery). Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were flown by NASA/Jet Propulsion Laboratory (JPL) in support of Hyperion during February 2001.

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AVIRIS is a 224-channel imaging spectrometer with approximately 10 nm spectral resolution covering the 0.4 – 2.- μm spectral range. Six overlapping flightlines at 3.5m spatial resolution were analyzed and used to identify and map common alteration minerals at the Los Menucos site (Kruse et al., 2002b) These detailed mineral maps were compiled as "ground-truth" for the Hyperion analysis and were used along with the Landsat TM and field reconnaissance conducted during April 2001 to validate the Hyperion data.

3.0 EO-1 Hyperion

Hyperion, launched in November 2000, is a new satellite hyperspectral sensor covering the 0.4- to 2.5-μm spectral range with 242 spectral bands at approximately 10-nm spectral resolution and 30-m spatial resolution from a 705km orbit. A typical dataset covers an approximately 7.5-km-wide swath 165 km long. Hyperion data for the Los Menucos, Argentina, site were first acquired on 25 February 2001, close to the 14-15 February AVIRIS acquisition date. Unfortunately, the Hyperion data were predominantly cloudy, however, several RTZ prospects were mostly clear on the 25 February date. Additional datasets were acquired on 30 April (mostly cloudy), 16 May (cloudy), 1 June (mostly cloudy), 17 June (clear – but low signal-to-noise), 3 July (cloudy), and 19 July (cloudy).

The 25 February Hyperionion data were processed to geologic products using AIG-developed approaches for extraction of mineralogic and geologic information (Boardman and Kruse, 1994; Boardman et al., 1995; Kruse et al., 1996; Kruse et al., 2002c; Kruse, 2002) This hyperspectral analysis methodology includes 1) data pre-processing (pushbroom data destriping), 2) correction of data to apparent reflectance using the ACORN atmospheric correction software (AIG, 2001), 3) linear transformation of the reflectance data to minimize noise and determine data dimensionality, 4) location of the most spectrally pure pixels, 5) extraction and automated identification of endmember spectra, and 6) spatial mapping and abundance estimates for specific image endmembers. A key point of this methodology is the reduction of data in both the spectral and spatial dimensions to locate, characterize, and identify a few key endmember spectra that can be used to explain the rest of the hyperspectral dataset. Once these endmembers are selected, then their location and abundances can be mapped from the original data. These methods derive the maximum information from the hyperspectral data themselves, minimizing the reliance on a priori or outside information.

Several characteristic mineral spectra (silica, kaolinite, muscovite) were extracted from the Los Menucos Hyperion data. Mineral maps were produced and compared to those derived from the AVIRIS data. Comparison of the two datasets shows that Hyperion identifies similar minerals and produces grossly similar mineral mapping results as AVIRIS, however, it doesn't produce the level of detail available from the AVIRIS data. Some minerals are missed, and others are confused (dickite/kaolinite). This is largely the effect of reduced Hyperion signal-to-noise-performance compared to the AVIRIS (~50:1 and less for Hyperion, compared to >500:1 for AVIRIS) (Kruse, 2002). The Hyperion data are most useful for small-scale reconnaissance mapping and are attractive because world-wide acquisitions are possible. In the Los Menucos case, however, the problem was that no cloud-free data were acquired during the southern hemisphere summer – this would have maximized the SNR.

4.0 Extending Mineral Mapping using Landsat ETM+

Multispectral image analyses were also conducted to extend fieldwork to adjacent regions, based on known mineral locations and hyperspectral results. This approach is worth testing because it could vastly aid regional exploration for areas lacking ground truth or hyperspectral coverage. Landsat 7 was launched by NASA in 1999 and carries the Enhanced Thematic Mapper (ETM) sensor, offering 8 spectral bands (3 visible, 1 near IR and 2 shortwave IR bands at 30 meter spatial resolution, plus 1 thermal IR band at 60 meters, and 1 panchromatic band at 15 meters). In evaluating ETM, known mineral locations were outlined as training sites followed by minimum distance (MD) image classification on decorrelated reflectance bands (PCs). Landsat results proved helpful in predicting mineral mixtures and general mineral groups, such as iron oxides (FeOx) and alteration-clay minerals. The broad bandwidth of Landsat 7, however, was not capable of segmenting specific clays, carbonates, or Fe minerals. Nonetheless, Landsat classes were distinct for kaolinite/muscovite and alunite/kaolinite mixtures, as documented at three known mineralized sites inside the project area. In addition, Landsat analysis appeared to spectrally differentiate soil caliche (carbonates) associated with altered alunite locations. Nine exploration targets were identified outside the exploration block for further field investigation based on ETM evaluation.

5.0 ASTER Data Analysis

The ASTER system is on-board the NASA "Terra" satellite, launched late in 1999. ASTER is composed of three Japanese sensors offering a total of 14 spectral bands (3 visible and near IR, 6 shortwave IR, and 5 thermal IR) at spatial resolutions ranging from 15 to 90 meters. ASTER imagery offers better spectral resolution as compared to Landsat ETM, especially in the shortwave IR spectral region. For evaluating ASTER imagery, minerals from Los Menucos spectral libraries (compiled in the field) were selected as endmembers in a Spectral Angle Mapper (SAM) image classification on atmospherically-corrected ASTER bands. Minerals used included alunite, kaolinite, illite, dickite, geothite, hematite, jarosite, and pyrophyllite. ASTER results correlated well with known kaolinite and alunite locations but were less useful in predicting pyropyllite and illite, as well as FeOx minerals (as compared to Landsat ETM). Results suggest that ASTER can be useful in predicting mineral suites, although its bandwidth does not appear capable of differentiating slight spectral differences, such as those needed to identify dickite versus kaolinite or pyrophyllite versus alunite. Nonetheless, ASTER results did coincide with known field locations of alunite and kaolinite inside the project area and also identified twelve areas outside the exploration block.

6.0 Conclusions

The Los Menucos district provides an excellent case history of a complex epithermal gold system initially identified using satellite imagery and further mapped and explored using hyperspectral imaging systems. The district offers a host of argillic and advanced argillic alteration minerals at the surface, including many of which are difficult to visually identify, and therefore is an excellent area to test and gauge spectral sensors. Hyperion provides basic mineralogic information, however, reduced SNR performance with respect to AVIRIS and persistent cloud cover during Hyperion data collection efforts have limited its effectiveness. The combination of detailed AVIRIS mineral mapping with multispectral data produced promising results that may allow extended mapping utilizing multispectral sensors such as Landsat and ASTER.

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8.0 References

AIG, 2001, ACORN User's Guide, Stand Alone Version: *Analytical Imaging and Geophysics LLC*, 64 p.

Boardman, J. W., and Kruse, F. A., 1994, Automated spectral analysis: A geological example using AVIRIS data, northern Grapevine Mountains, Nevada: in *Proceedings, Tenth Thematic Conference, Geologic Remote Sensing*, Environmental Research Institute of Michigan, 9-12 May 1994, San Antonio, Texas, p. I-407 - I-418.

Boardman, J. W., Kruse, F. A., and Green, R. O., 1995, Mapping target signatures via partial unmixing of AVIRIS data: in *Summaries, Fifth JPL Airborne Earth Science Workshop, JPL Publication 95-1*, v. 1, p. 23-26.

Franco, S., Puente, N., Varela, C., Gemuts, I., 2000, Mineralizacion Aurifera en El Distrito Los Menucos, Provincia de Rio Negro, Argentina: *Proceedings, Argentina Mining 2000, Mendoza, Argentina*, August 22 - 25, 2000, p. 112 - 126.

Gemuts, I., and Perry, S., 2000, Los Menucos Au District, Rio Negro Province, Argentina: *Abstract and Presentation, Northwest Mining Association, Spokane, Washington*, December 7 - 10, 2000.

Kruse, F. A., Huntington, J. H., and Green, R. O, 1996, "Results from the 1995 AVIRIS Geology Group Shoot." In *Proceedings, 2nd International Airborne Remote Sensing Conference and Exhibition*, Environmental Research Institute of Michigan, v. I: p. I-211 - I-220.

Kruse F. A., Perry, S. L., and Caballero, A., 2002a, Integrated Multispectral and Hyperspectral Mineral Mapping, Los Menucos, Rio Negro, Argentina, Part I: Landsat TM Reconnaissance and AVIRIS Prospect Mapping: In *Poceedings 11th JPL Airborne Geoscience Workshop, Jet Propulsion Laboratory*, 4-8 March 2002 (This Volume)

Kruse, F. A., Boardman, J. W., and Huntington, J. F., 2002b Comparison of EO-1 Hyperion and Airborne Hyperspectral Remote Sensing Data for Geologic Applications: in *Proceedings, SPIE Aerospace Conference*, 9-16 March 2002, Big Sky, Montana (in press).

Kruse, F. A., Boardman, J. W., and Huntington, J. F., 2002c Comparison of Airborne and Satellite Hyperspectral Data for Geologic Mapping: in *Proceedings, SPIE International Symposium on AeroSense*, 1-5 April 2002, Orlando, FL (in press).

Kruse, F. A., Comparison of AVIRIS and Hyperion for Hyperspectral Mineral Mapping, 2002, In *Proceedings 11th JPL Airborne Geoscience Workshop, Jet Propulsion Laboratory, 4-8 March 2002* (This Volume)

Perry, S., and Gemuts, I., 2000, New High Sulfidation Gold District: Los Menucos, rio Negro Province, Argentina - A Landsat Discovery: *Presented at Fourteenth International Conference, Applied Geologic Remote Sensing, November 6 - 8, 2000, Las Vegas, Nevada*, Veridian ERIM International.