MULTIPLE APPLICATIONS FOR AIRBORNE HYPERSPECTRAL SENSORS*

James M. Ellis, Hattie H. Davis, and Michael B. Quinn
HJW GeoSpatial, Inc.,
Oakland, California, U.S.A.

ABSTRACT

Airborne hyperspectral systems that span the visible near-infrared to short wave-infrared (VNIR-SWIR) wavelength range acquire a rich data cube that can be used for many applications. A VNIR-SWIR data cube can be effectively used for evaluating environmental, facility, and geologic conditions. The distribution and vigor of vegetation; characteristics of soils (including the surface distribution of clays, iron, and other minerals); water conditions, and stratigraphy can be derived from the data cube. Integration of enhanced images with DEM's improves mapping for natural hazards and structural geology. The dataset can be effectively classified for land use and to support change detection. Recently we completed a new VNIR-SWIR spectral library for detecting oil-impacted surfaces (including onshore oil seeps). A cooperative R&D effort coordinated by The Geosat Committee, Inc. and sponsored by progressive petroleum companies enabled the library to be built. With this library, VNIR-SWIR hyperspectral technology can be more effectively applied to detect oil-impacted soils and surfaces within industrial sites and brownfields. The most significant issue facing broader use of the technology and integration of images and derived products with GIS is the cartographic error associated with line-scanner technology. Acquiring VNIR-SWIR hyperspectral datacubes reduces the risk for management because the data can be effectively used to achieve several different business objectives.

1.0 INTRODUCTION

As airborne hyperspectral imagery become more common and more sophisticated, diverse uses of the rich data cubes are being developed. We have been successfully processing and interpreting VNIR-SWIR data cubes acquired in different parts of the U.S.A. and in different countries. The clients have specific needs that can be addressed by the hyperspectral imagery. This paper provides examples of some of these diverse interests and focuses on environmental applications. Petroleum and mineral exploration applications are not addressed in this paper (see Ellis and others, 2000, 2001, submitted).

The surveys were acquired with 5-meter ground sampling distance (gsd). Each flight strip covered an area about 2.5 km across. The hyperspectral sensor acquired VNIR-SWIR wavelengths across 128 bands. The sensors discussed in this paper were built by Integrated Spectronics and are deployed by HyVista (HyMap sensor) and Earth Search Sciences, Inc. (Probe-1 sensor).

We used ENVI software for the analysis (see Kruse, 1999). The flight strips are difficult to integrate into a GIS and digitally mosaic due to inherent distortions associated with line-scanner technology. We have found that line-scanner sensors are excellent for detection, but are not satisfactory for generating maps that are acceptable to our clients. Orthophotographs are recommended as the base for the GIS. Portions of the flight strips can be digitally warped to the orthophotographs over key areas of interest. Patience and skill is required to accurately locate individual hyperspectral pixels on basemaps and orthophotographs and to correlate GPS ground control points with individual hyperspectral pixels.

2.0 MULTIPLE APPLICATIONS

*Presented at the Fifth International Conference on Airborne Remote Sensing, San Francisco, California, 12-14 September 2001.

2.1 VEGETATION STRESS

Blue shift of the red edge and chlorophyll absorption depth are two ways to evaluate vegetation vigor/stress with hyperspectral imagery. Maps are developed of vegetation vigor/stress to better evaluate the impact of industrial facilities, monitoring remediation, or prioritizing field operations. More sophisticated analyses may attempt to map the degree of vigor/stress within spectrally-defined plant communities. Figure 1 is an example of using chlorophyll absorption to evaluate the impact of a facility on vegetation - in this case there is no discernable impact.

2.2. PLANT COMMUNITIES

Spectrally defining plant communities can be difficult (see Ustin and others, 1998) and is dependent upon several factors including canopy closure, spectral uniqueness of the vegetation, degree of mixing, abundance, and growth cycle. We have had success mapping invasive species when their canopy is expansive enough to cover the underlying soil. Figure 2 shows a spectral signature developed by both field and airborne sensors for ice plant growing along the coast of southern California. Extensive spectral libraries have been developed for many vegetation types, but our experience indicates it is more reliable to develop a library based on local training sites.

2.3 SURFACE WATER CONDITIONS

Material at the surface of water bodies can be successfully detected. A common application is to determine the amount of chlorophyll-bearing biomass in industrial ponds (Figure 3). Significant differences in the amount of chlorophyll present at the surface may assist facility managers with prioritizing their field sampling program and prioritizing remediation.

2.4 LAND USE CLASSIFICATION

The contiguous bands of a hyperspectral data cube enable detailed classifications of materials at the surface to be developed. However, for some applications only a generalized land use/land cover classification is needed (wetlands, forests, shrubs, grass, open space, roads & buildings) that is comparable with satellite and/or airborne multispectral mapping. Figure 4 shows an area surrounding a tank farm that has been classified into basic land use categories using bands equivalent to Landsat TM 3, 4, and 5. More detailed land cover mapping was developed using the entire spectral range for oil-impacted soils in the vicinity of the tank farm (Figure 4).

2.5 OIL-IMPACTED SURFACES

Brownfields, refineries, tank farms, pipeline corridors, oil fields, and other industrial sites can have surface deposits of hydrocarbon-based materials. Sophisticated VNIR-SWIR hyperspectral sensors are ideal for detecting soils and surfaces that have been impacted by oil-based materials. The state of asphalt on roads can be evaluated using a VNIR-SWIR sensor (Figure 5).

2.6 SOILS

VNIR-SWIR sensors are exceptional tools for mapping variations in the surface composition of soils when vegetation cover and the surface organic soil layer are minimal (see Ben-Dor and others, 1999). Different iron oxides (hematite, goethite, jasperite), clay minerals (kaolinite, montmorillonite, illite, chlorite, etc.), calcite, dolomite, and other minerals can be mapped. This mapping can be very diagnostic of subtle changes in lithology and stratigraphy. Figure 6 compares a dolomite and calcite signature with the bitumen absorption feature in the SWIR portion of the spectrum. The sensor requires narrow band widths and excellent signal to noise characteristics for differentiating soils containing these minerals.

3.0 ACKNOWLEDGMENTS

The Geosat Committee's HGS98 and HGS2000 projects provided the initial support and feedback that enabled cost-effective evaluation of different applications for VNIR-SWIR hyperspectral data cubes. The foundation for much of the fieldwork was coordinated and carried out by Patrick Caldwell of Pacific Estuaries. Dr. Joseph Zamudio of ESSI was instrumental in developing spectral libraries and field measuring procedures.

4.0 REFERENCES

Ben-Dor, E. J. Irons, G. Epema, "Soil Reflectance," In *Remote Sensing for the Earth Sciences*, 3 ed., vol. 3., edited by A.N. Rencz., p. 111-188, 1999.

Ellis, J.M., H.H. Davis, and J. Zamudio, submitted, "Exploring for Onshore Oil Seeps with Hyperspectral Imaging" *Oil and Gas Journal,* 10 p.

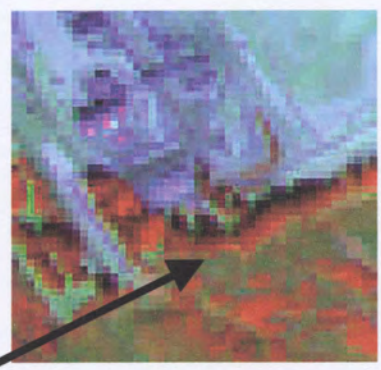
Ellis, J.M. and M.B. Quinn, "Crude Findings - GPS Surveying to Support Hyperspectral Detection Efforts" *Point of Beginning*, p. 28-32 , April 2001 (see www.pobonline.com - April 2001 archives)

Ellis, J. M., H. H. Davis, and M. B. Quinn, "Airborne Hyperspectral Imagery for the Petroleum Industry" In *Proceedings of the Fourteenth International Conference on Applied Geologic Remote Sensing*, Las Vegas, Nevada, p. 89-96 , 6-8 November 2000.

HJW, unpublished, "Hyperspectral Group Shoot 1998 Report," *The Geosat Committee, Inc.,* 50 p., 1999 (see www.geosatcom.com)

Kruse, F.A, "Visible and Infrared: Sensors and Case Studies," In *Remote Sensing for the Earth Sciences*, 3 ed., vol. 3., edited by A.N. Rencz., p. 567 – 612, 1999.

Ustin, S, L. Costick, A. P. Orueta, E.W. Sanderson, J. E. Pinzon, L. Jackson, "Hyperspectral imaging for remote sensing of vegetation stress and indicators of habitat condition," http://cstars.ucdavis.edu/proj/ Chevron/ Whitepaper/draftassem/drft0219.htm, 28p, 1998.



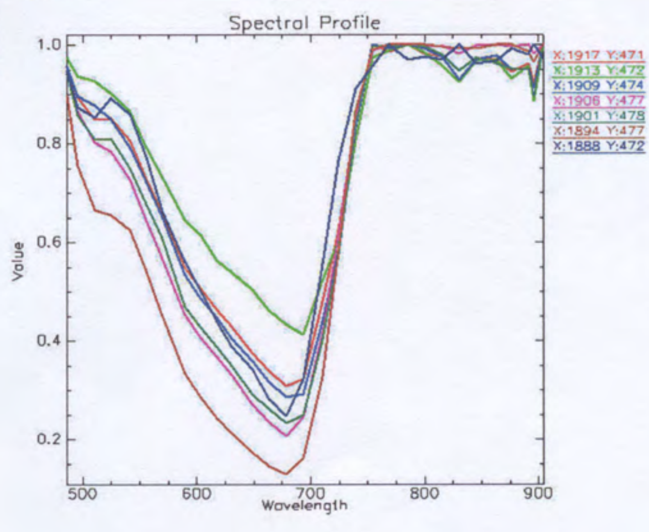


Figure 1. Vegetation "stress" can be evaluated. Here chlorophyll absorption depths ("vigor") of vegetation along perimeter of a pumping facility (see arrow) are determined for individual pixels.

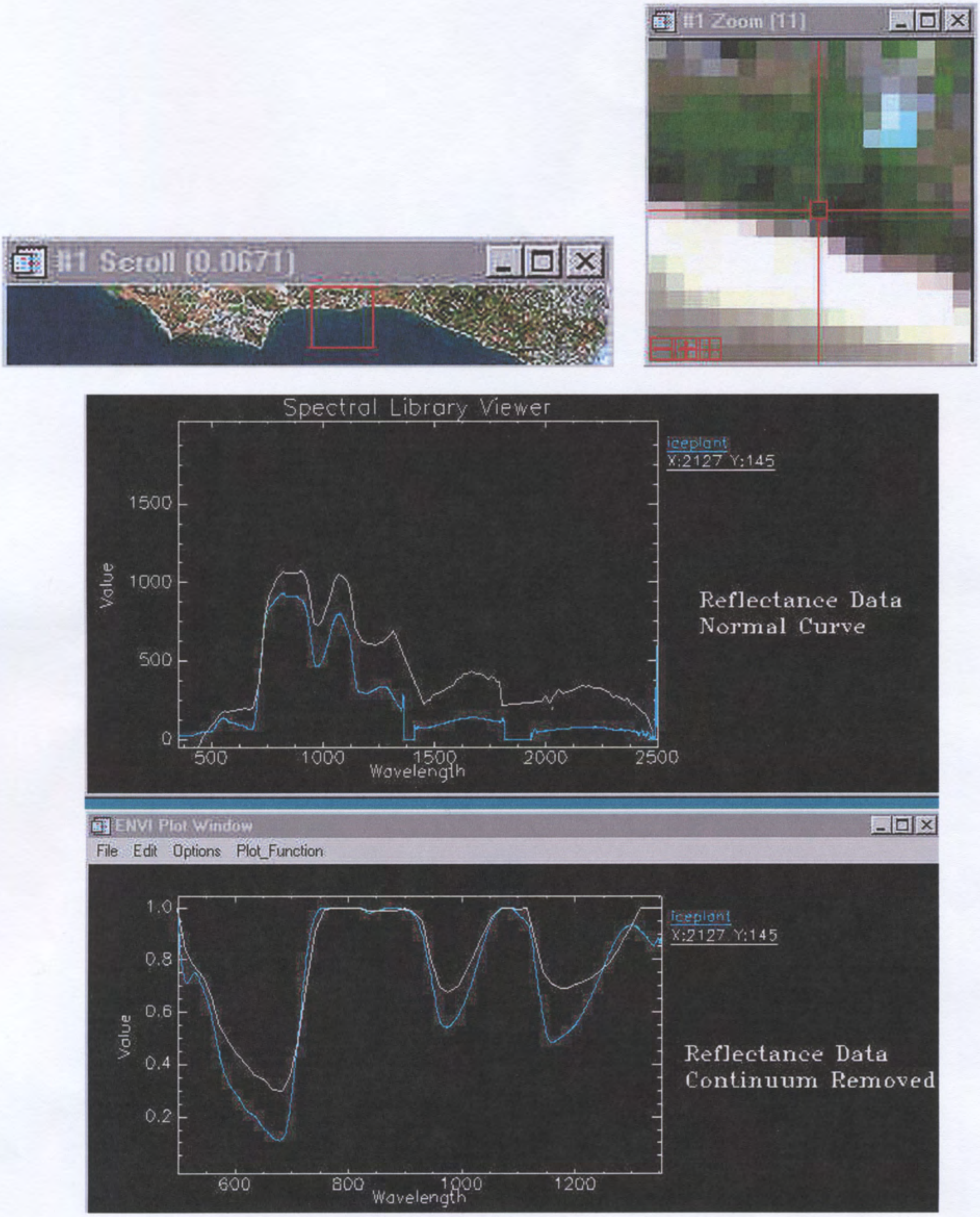


Figure 2. Plant communities can be mapped - here an iceplant spectral signature from airborne sensor (blue) and field spectrometer (white) shows excellent correlation.

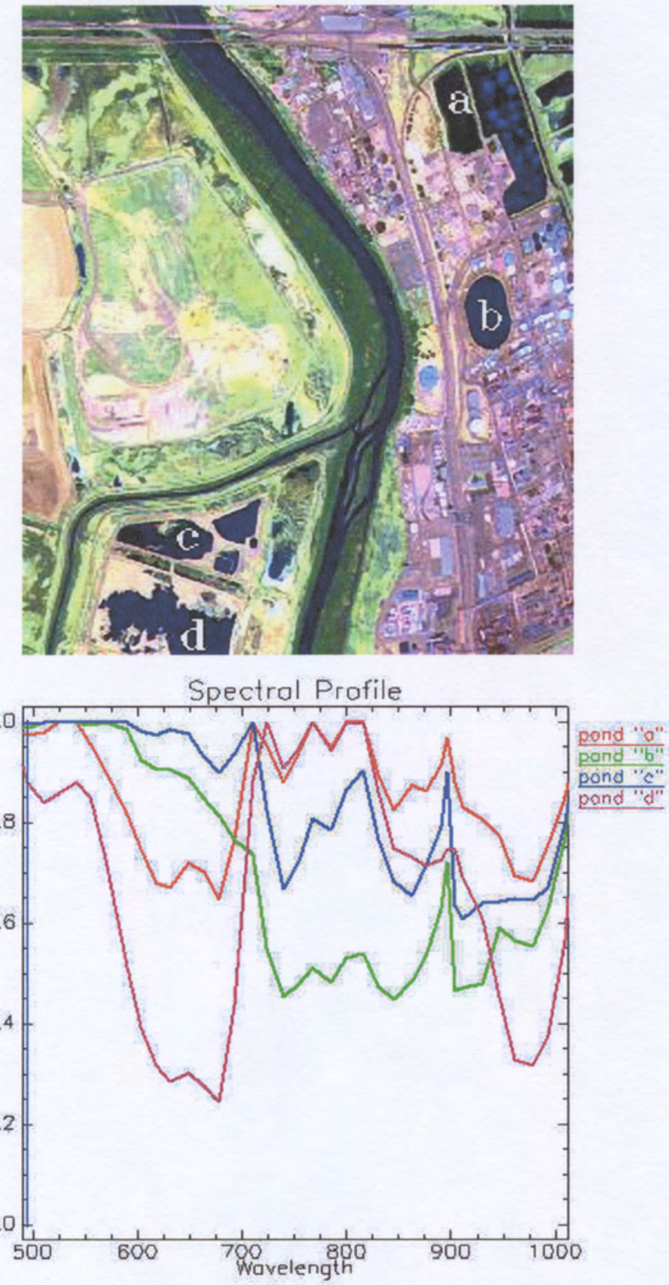


Figure 3. Surface water characteristics can be mapped. Hyperspectral signatures of 4 different settling ponds (a-d) at a northern California location show unique characteristics. The spectral response of pond "a" and "d" are similar and show the 0.67 chlorophyll absorption feature (note depth and width of 550-700 nm curves, above). However, this chlorophyll absorption feature is missing within ponds "b" and "c", perhaps indicating a lack of healthy biomass with chlorophyll.

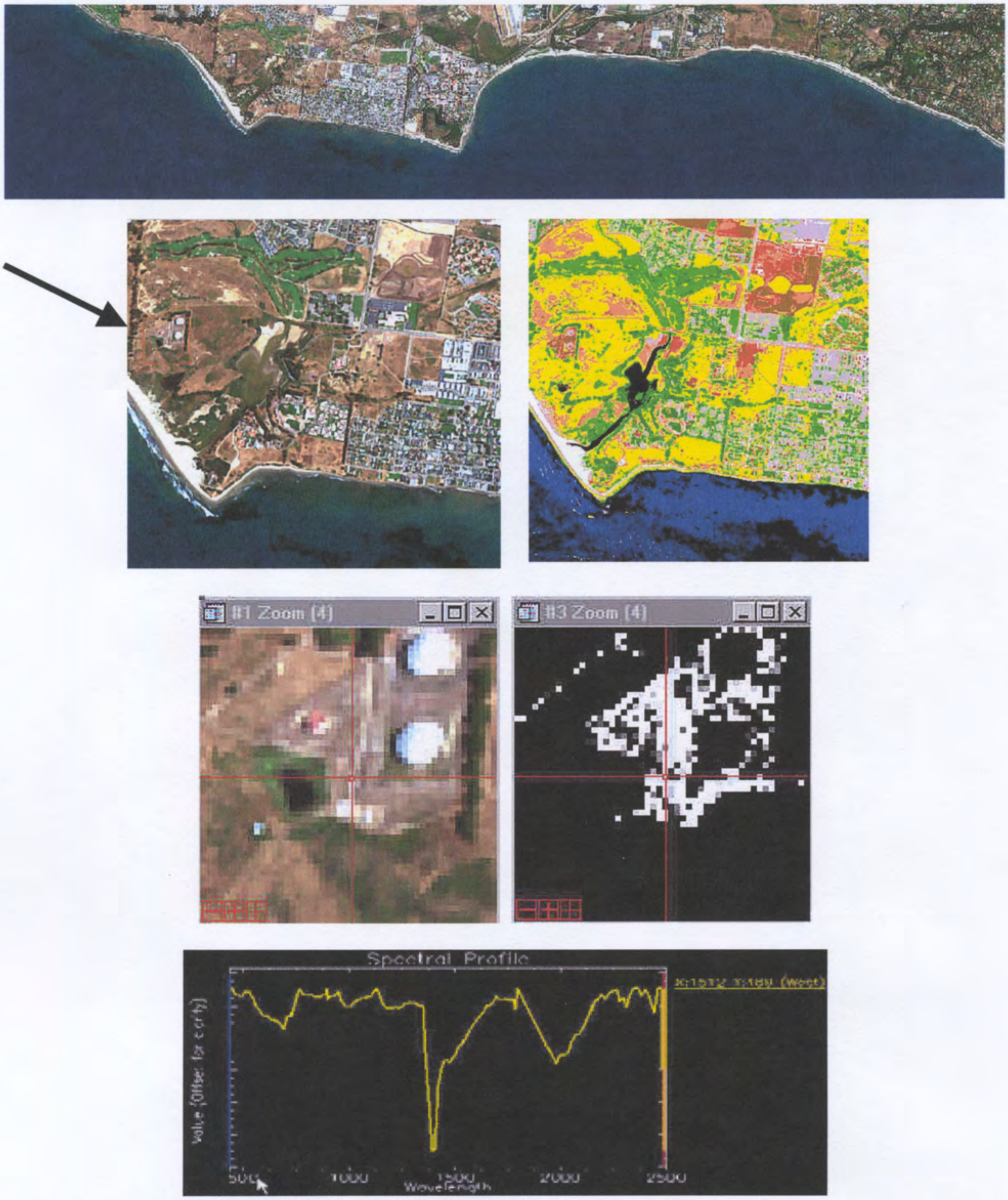


Figure 4. Land use classifications can be derived. Here area surrounding a tank farm (see arrow) is classified. Within the facility, oil-impacted soils can be interpreted from the hyperspectral data cube (see white pixels) based on spectral signature developed elsewhere (bottom figure).

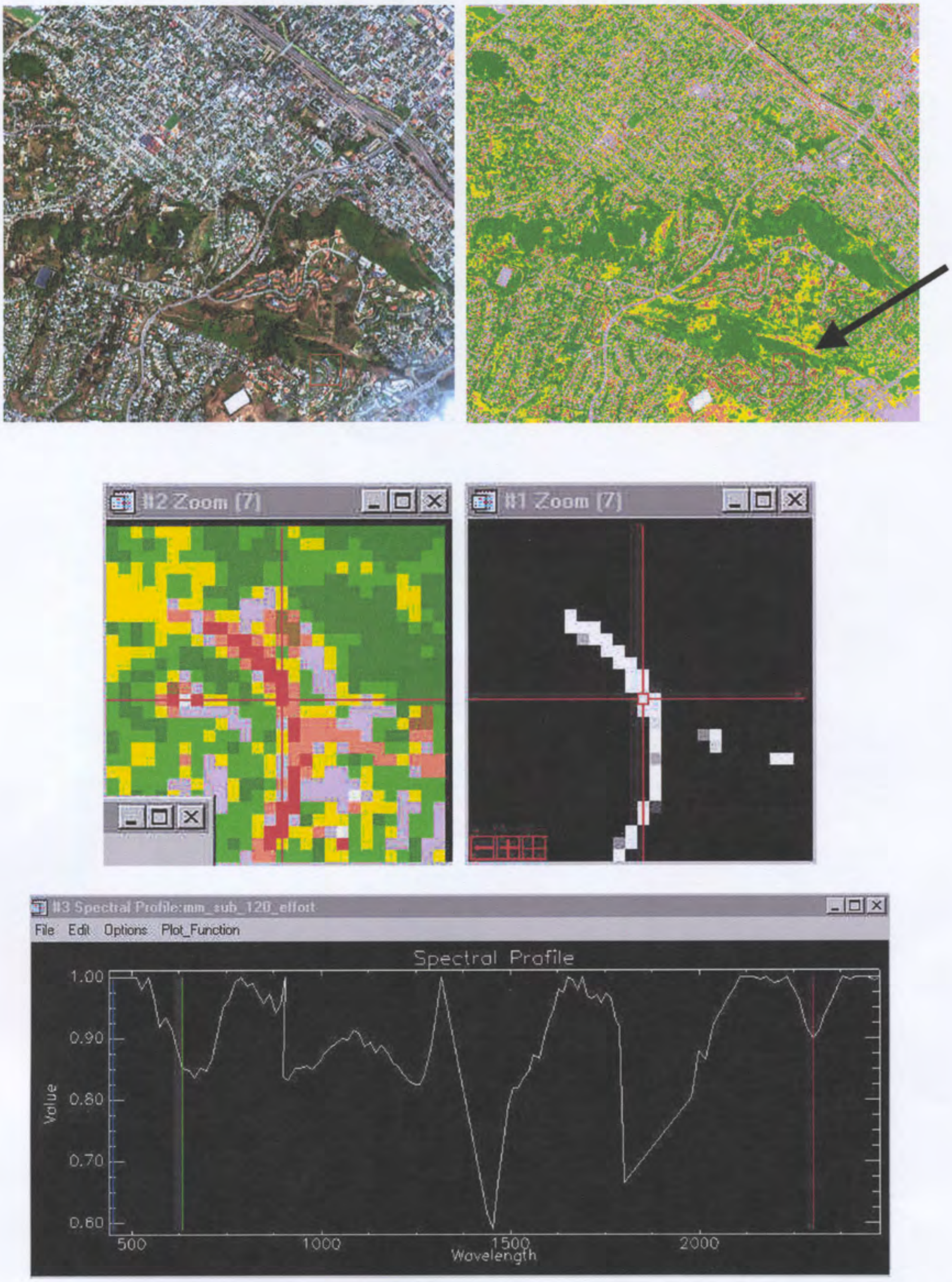


Figure 5. Land use classification of urban landscape with enlargement (see arrow for location) highlighting portion of roads most recently paved with asphalt (white on middle right image. Spectral signature of fresh asphalt taken from pixel at center of crosshair in the enlargement images.

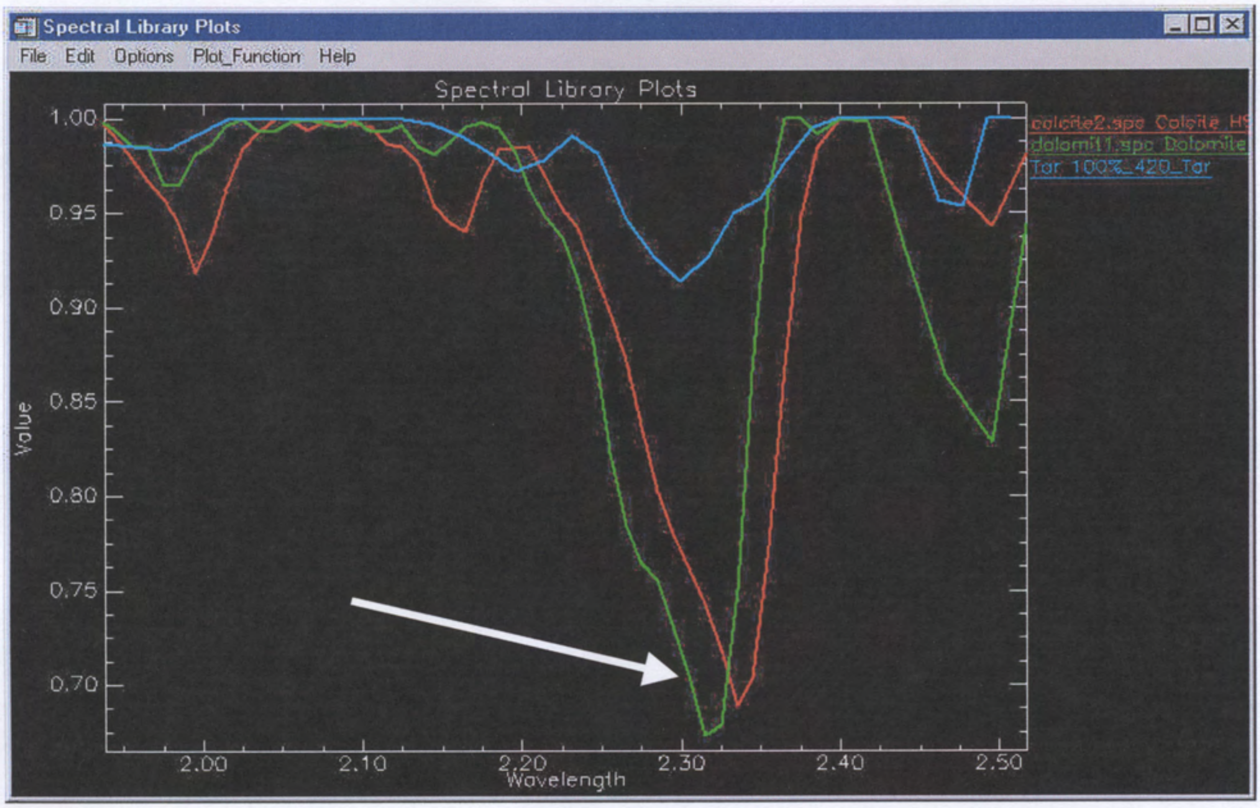


Figure 6. Soils with differing clay, iron oxide, and other minerals at surface can be mapped if vegetation is minimal. Here deep absorption features (see arrow) derived from calcite and dolomite surfaces can be differentiated from each other and from oil-impacted soils that show a relatively shallow bitumen absorption feature