

# CORRELATING AVIRIS IMAGERY TO FIELD SAMPLING AND SPECTROMETER MEASUREMENTS FOR INORGANIC SOIL CARBON

Michael L. Whiting and Susan L. Ustin\*

## 1. INTRODUCTION

The AG2020 USDA and NASA program sponsors the advancement of remote sensing and other spatial technologies to enhance precision farming and sustainability. This affiliated study in the San Joaquin Valley (<http://www.ag2020.net>) is through the leadership of the National Cotton Council and the cooperating farm manager. Both contribute funding support and in-kind services. The majority of support is from the 23+ investigators who volunteer time and their own research funding for this collaborative effort. The list of cooperating organizations includes: NASA-JPL through AVIRIS and other imagery contributions; USDA – Agricultural Research Service, at Shafter Research Field Station, studying the use of hyperspectral imaging for the detection of plant stress and disease through their own airborne multispectral scanner and contracting of additional hyperspectral imagery and analysis from Opto-Knowledge Systems, Inc. (OKSI). The University of California Cooperative Extension, and UC Department of Agriculture and Natural Resources, and Kings County Farm Advisor have contributed staff in nutrient status and ground measurements. The University of California, Davis facility in the Departments of Agronomy and Range Science, and Land, Air and Water Resources are studying soil and plant nutrient through remote sensing, and amendment and fertilizer trials. Many investigators have joint studies among these organizations, including Center for Spatial Technology and Remote Sensing (CSTARS), joining in remote sensing of soil quality and plant stress. This report is a brief description of one field study, soil surface spectra and sampling conducted in July 2000. The status of lab and image data, and initial findings in the relationships between soil chemical analysis and spectra for the study site, are also discussed.

Of the several measures of soil quality, salinity/alkalinity is of particular importance to sustaining semi-arid and arid agriculture. Farmers worldwide face declining productivity where there is a lack of adequate drainage in both irrigated and non-irrigated lands. Without proper drainage management, soils accumulate salts near the surface due to parent materials abundant in salt and/or imported with irrigation water. Salinity is due to high contents of carbonate, and some chloride salts,  $\text{CaCO}_3$ ,  $\text{MgCO}_3$  and  $\text{NaCl}$ , and will raise the soil pH to less than 8.5. Salinity creates moisture and nutrient uptake difficulties for less tolerant crops. Sodicity, proper term for alkalinity, is due to the soil solution containing greater than a 13:1 ratio of sodium to calcium and magnesium contents. This is generally from sodium chloride, and can raise the pH far beyond pH 9. These soils are toxic to nearly all crops. The mixture of saline and sodic soils varies spatially and temporally due to subsurface hydrology, generally appearing on the surface as spotty and random.

At high pH's the cation retention sites on the clay particles are overwhelmed by calcium and sodium cations.  $\text{Ca}^{++}$  and  $\text{Na}^+$  replace magnesium, potassium, and important micronutrients, which are then lost through leaching. In a very basic environment,  $\text{H}^+$  is limited to that extruded from the plant roots. In sodium dominated soil-water solutions, farmers apply lime, gypsum or dolomite as amendments to overcome deficiency in calcium and magnesium and replace the  $\text{Na}^+$  on the clay exchange site. Applications of elemental sulfur or sulfuric acid are far more efficient and less expensive in reducing the pH, but do not contribute the necessary cations Ca and Mg. Overtime, sulfate amendments, even the fertilizer ammonium sulfate ( $\text{NH}_4\text{SO}_4$ ), will help acidify the soil.

Growers have preserved and improved the soil productivity through adjusting cropping practices, such as salt tolerant crops, installing drainage systems, additional irrigation applications, and reclamation amendments. Just as precision farming techniques have increased the efficiency and economic return in the application of fertilizers

---

\* Center for Spatial Technologies and Remote Sensing (CSTARS), Department of Land, Air and Water Resources, University of California, Davis, California 95616 ([mwhiting@ucdavis.edu](mailto:mwhiting@ucdavis.edu))

and pesticides, there is potential to increase the efficiency of amendments and additional irrigation applications. A one percent  $\text{CaCO}_3$  content in the soil is equivalent to approximately 40 tons of most agricultural grade calcium amendments, or \$1800/acre of gypsum. Remotely sensed image maps that identify salt types and contents in the soil surfaces are essential to developing precision farming practices. The image derived map of salt contents is one of the layers in the precision farming prescription used by the tractor computer to meter acid or sulfur, and placement of lime and gypsum amendments.

In the laboratory, full range spectrometry techniques have demonstrated the ability to accurately estimate many of the soil parameters, such as salinity, texture, organic matter and associated components (Ben-Dor and Banin, 1994; Condit, 1972; Csillag et al., 1993; Stoner and Baumgardner, 1981; Stoner et al., 1980). A few important studies have transferred these techniques of soil characteristic identification to airborne and satellite images (Metternicht and Zinck, 1996; Palacios-Orueta and Ustin, 1996).

Important work related to carbonate identification was reported by Ben-Dor and Banin in the last decade (1995; 1990; 1994). The carbonate region of the spectrum is 2230 – 2270nm and 2310 – 2330nm for calcite (Ben-Dor et al., 1999). Nearby, the attached hydroxyl groups (–OH) and cations provide the identifying features to clay content measured near 2200nm. Sulfates, such as gypsum (hydrated calcium sulfate), with absorption at 2250nm

(Clark, 1999) are another common group of soil compounds near the carbonate spectral features. While their work is based on laboratory analysis of near pure mineral samples, Ben-Dor and Banin (1990) developed the near infrared analysis (NIRA), a regression of the wet lab chemistry of the soil samples compared to the first derivative of both the 2230 – 2270 and 2310 – 2330 nm spectra curves. They achieved a standard error of prediction within 15%, dried soil. When the samples were super heated to 650° C to evolve the bound water, the standard error of prediction improved.

The promise of precision farming techniques can be negated by the high costs of field mapping. Identifying the type of salt and the areal extent is routinely mapped by field sampling using transects and grids, based on aerial photos of crop conditions. Due to the

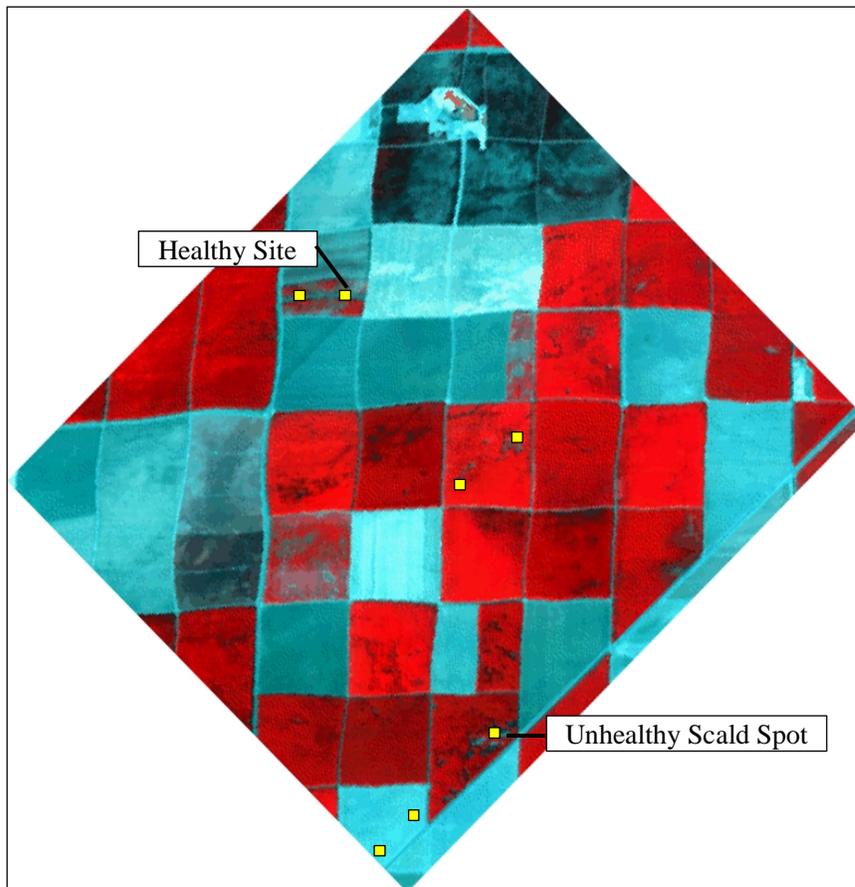


Figure 1. Pseudo-CIR from AVIRIS, 8/28/99

mapping and chemical analysis expense, reclamation recommendations are generally field-wide. Remote sensing of the salt type and content through hyperspectral imagery is a promising alternative. The challenge is to un-mix the varying salt concentrations spatially.

## 2. STUDY SITE

The AG2020 site in Kings County, California, is on the northwest edge of the Tulare Lake basin, at the southern end of the San Joaquin Valley. These highly fertile, clayey soils have naturally accumulated salts, over the millenniums, in the bottomland and on the rim of this ancient closed basin. In most areas, high value crops of garlic, beans, tomatoes, and cotton, made farming economical. As prices and production decline, the producers are forced to reclaim the poor producing areas within their fields. Conventional farming is practiced, after summer and fall harvests, they plow under the residues leaving little residue on the surface at fall planting time. This is a benefit for this study in reducing the cellulose on soil surface for summer and fall images.

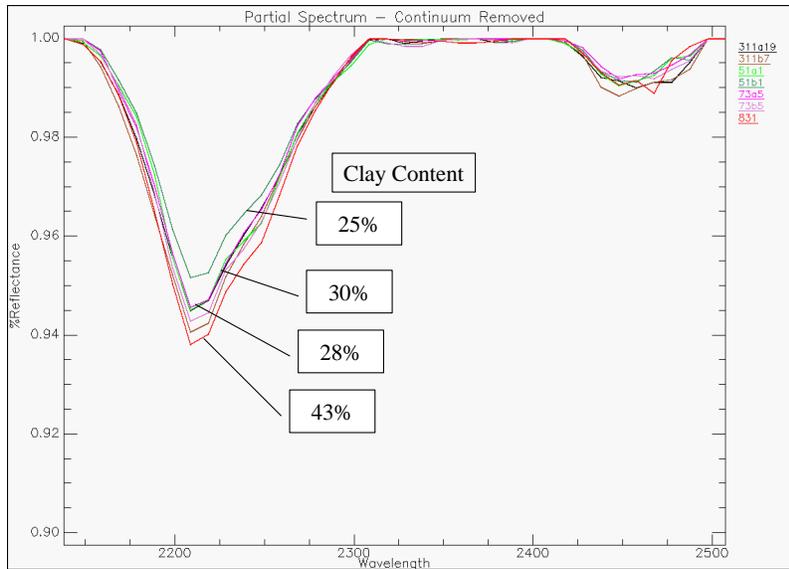


Figure 2. Representative samples of varying clay contents compared to adsorption depths, after continuum removal process.

was used to select areas of non-/slightly saline and highly saline soils. The sample sites are within large areas, and with ample saline surface characteristics. The pseudo-CIR image was sufficient to find the positions in the fields. GPS coordinates were used to geo-positions during sampling.

Seven sites were selected. At each site, nine sample points were taken, in a 3 by 3 grid, approximately 10-m apart. The sampling proceeded in a north to south direction through the points. Approximately 500-g of the first 3-cm of tilled soil surface was collected at each point. The soil surface was a mix of loose material from less than 1-mm up to clods 6-cm in size. Crop residues were removed by hand. Standing to the north of each point, three spectral measurements were taken approximately 1-m apart in the SE, S, and SW directions. Soil spectra were collected with an Analytical Spectral Devices, Inc. full range (FR) field spectrometer. The optical cable tip was held approximately 2-m from the surface using an extension pole, gathering a 1.2-m radius ground view area in nadir. The field spectra measurements are not presented in this paper.

## 3. METHODS AND RESULTS

### 3.1 Soil Chemistry, Mineralogy and Laboratory Spectra

Presented here is a preliminary review of the soil spectra, chemistry and mineralogy in this study. The Division of Natural Resources and Agriculture laboratory, UC Davis, laboratory conducted the chemical analyses on the 63 soil samples. The laboratory spectra was collected using a LabSphere diffusion sphere attachment to a Cary 5 laboratory spectrophotometer (Varian Inc.), at the Center for Spatial Technology and Remote Sensing, UC Davis (CSTARS). The soil samples were prepared by lightly grinding in a mortar and pestle, then removing remaining

On August 28, 1999, high altitude, and on July 19, 2000, low altitude AVIRIS flights covered the main project area, a block of 13 km<sup>2</sup> (approximately 3 miles square) containing 23 quarter section fields. In the high altitude image (figure 1) exposed soils appear after the harvest of wheat, garlic, garbanzo beans and within the young pistachio orchard. The strong infrared reflectance (red) in the image are from the cotton fields. Cooperating agronomists and other production scientists are also using this flight for vegetation vigor studies (Greenberg et al., 2001).

For the low-altitude overflight, sample sites were selected within the available bare soil fields. Plant vigor expressed in the pseudo-CIR image from the August 28, 1999 high-altitude AVIRIS flight (figure 1)

plant materials with 2-mm sieve. Samples were put in small petri dishes loosely, and graded flat across the top with a spatula without packing. ENVI (Research Systems, Inc.) software was used for image and endmember spectral analysis.

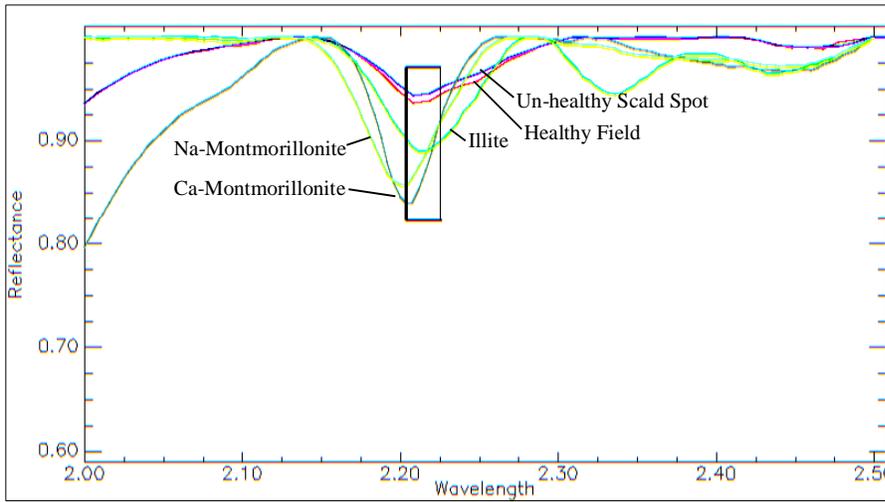


Figure 3. Laboratory spectra, continuum removed, of mixed mineralogy and soils.

In figure 2, the absorption depth in the clay bands, near 2200-nm, of laboratory spectra are closely related to the amount of clay found in hydrometer analysis for a subset of samples from the project.

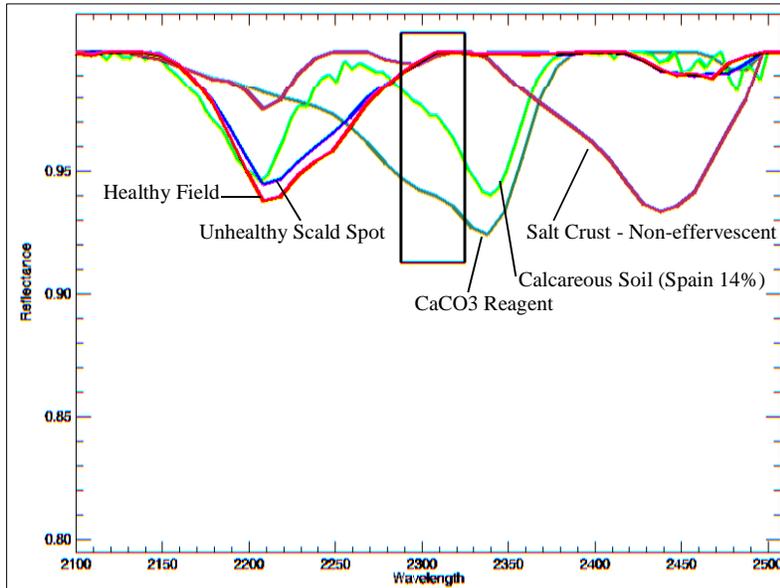


Figure 4. Comparison of soils of varying carbonate contents, continuum removed.

Because the full-range spectrum of sodium chloride is nearly featureless, one thought for quantifying the sodium salt is to use the cation dominance on the clay lattice. This may not be feasible since a variable mix of mineral types will confound the separation of cation dominance on the clay.

In this project, the salinity and sodicity is a function of the sodium chloride contents. Sodium and the other cations will be analyzed in the future. The sulfate contents ranged from 22 to greater than 400 ppm, probably due to

Hydrometer and sieve analyses were conducted for soil texture measurements. The soil texture varied significantly in sand and clay content. Since, soil albedo is sensitive to clay and sand contents (Stoner and Baumgardner, 1981), and to moisture contents (Bowers and Hanks, 1965), the continuum removal technique (Clark and Roush, 1984) was used to remove the albedo in all the laboratory and image spectra shown in the following figures. The sand content varied from 10 to 40% of the texture. The sum

In figure 3, laboratory spectra of the samples from the Unhealthy and Healthy sites are displayed with USGS spectral library samples for Na- and Ca-montmorillonite and illite. Illite is commonly found as a silt and clay size mineral, a mix of dioctahedral and trioctahedral layered silicate minerals (Dixon and Weed, 1989). In a mix with the montmorillonites, illite would shift the clay absorption upwards slightly away from the Na- and Ca-montmorillonite, a 2:1-layered silicate secondary minerals. For the Kings County Soil Survey (USDA, 1978), laboratory analysis describes the soil as a mixed mineralogy of illite and montmorillonite clays. The soils include fine-loamy, mixed (calcareous), thermic Typic Torriorthents, and fine, montmorillonitic, thermic Typic Natrargrids.

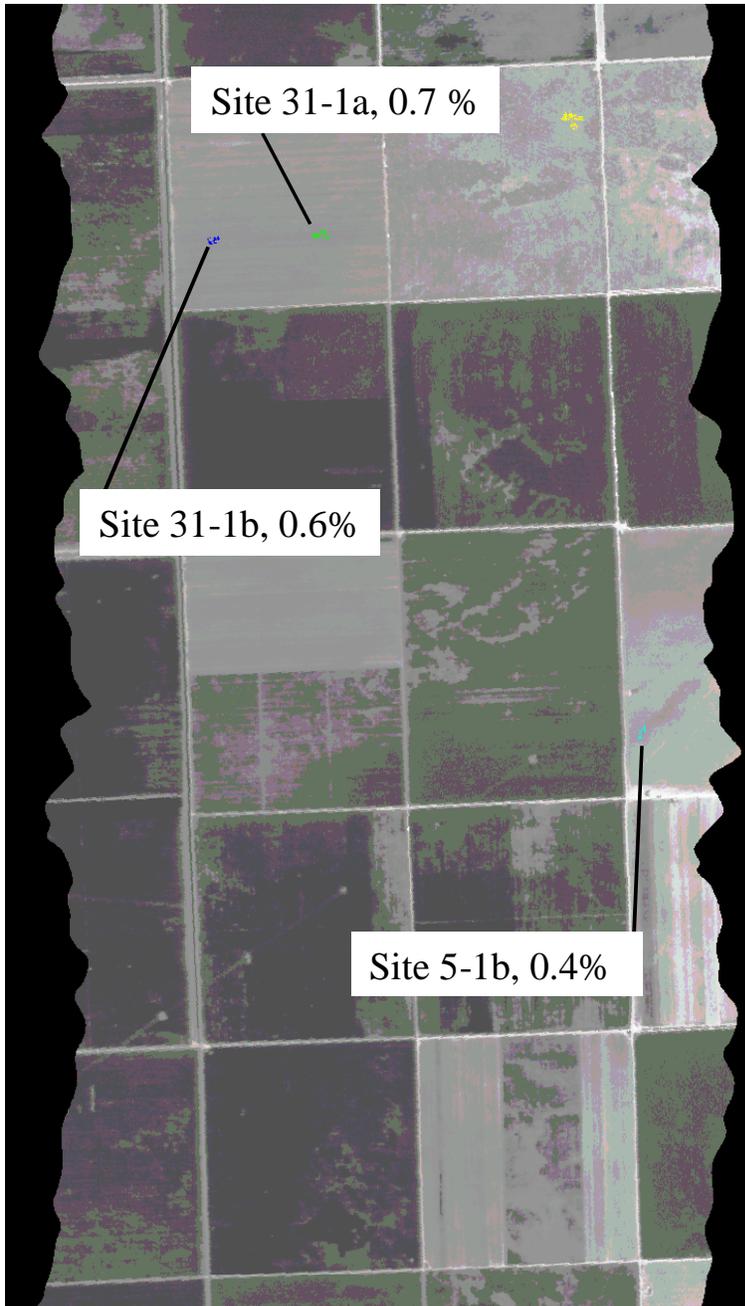


Figure 5. Low-altitude AVIRIS, 8/2000, RGB 2360, 2340, 2320-nm, Gaussian stretch.

removal process (Clark and Roush, 1984) was used to reduce the effect of varying moisture. The Unhealthy soil spectrum from the AVIRIS pixels has a much stronger slope, and deeper absorption within the carbonate range (2350-nm), indicating the greater carbonate content. The absorption features from the Healthy sample are broader, with greater depth in the clay band (2200-nm). Further work is needed to understand the absorption derivative and depth, and the effect of a 10-nm spectral resolution of the AVIRIS instrument.

Pictured in figure 5 is a portion of the project site from July 19, 2000 low altitude AVIRIS image. This RGB is composed of three bands in the carbonate region, 2360, 2340, 2320-nm, respectively. It was enhanced with

application of gypsum. Sulfates, such as gypsum (hydrated calcium sulfate) absorption, at 2250nm (Clark, 1999), are in close proximity to the carbonate absorption bands. This may effect the accuracy of the carbonate spectral measurement. Gypsum is an amendment commonly used by this grower.

For the entire dataset, soil carbonates varied from 0.4 to 1.2 % of the oven dry soil. In terms of salinity, these levels of carbonate are considered very low. A comparison of texture and carbonate contents showed no clear relationship. As many samples with higher carbonate contents had similar textures as those with lower carbonate contents. In figure 4, continuum removal process curves are used to compare: finely ground reagent grade calcium carbonate; a calcareous soil from La Mancha, Spain, (approximately 14% CaCO<sub>3</sub>); an acid non-effervescent salt crust sample of San Joaquin Valley (predominately NaCl); and the Healthy and Unhealthy samples. The strong absorption features in the carbonate range for the calcium carbonate specimen and the Spanish soil demonstrate the spectral separation is possible. The salt crust also shows little absorption difference from the project samples, and the three show little or no adsorption within the carbonate range.

### 3.2 AVIRIS Image Spectra

To evaluate the potential of the near infrared analysis (Ben-Dor and Banin, 1990), spectral samples, figure 6, were extracted from regions of interest in the 1999 high altitude AVIRIS image at sites described as "Health" and "Unhealthy" soil areas (figure 1). The regions of interest represent the extremes in vegetative health; vigorous cotton and saline affected areas denude of vegetation within cotton field. The continuum

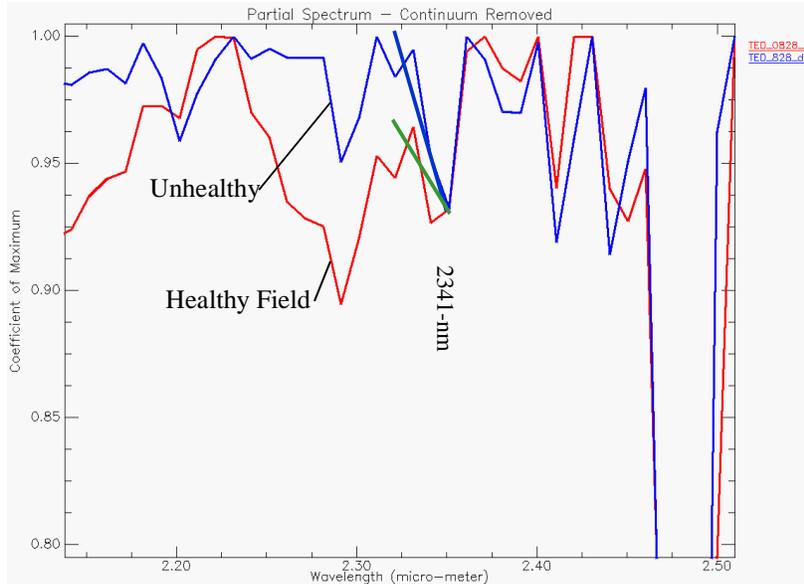


Figure 6. AVIRIS, 1999, spectral plots comparing carbonate bands, in continuum removed.

the potential to separate small concentrations of carbonate. Further work will be conducted to isolate other influences on the spectral differences.

#### 4. CONCLUSION

The evaluation of the high and low altitude AVIRIS imagery, soil chemistry, field and laboratory spectral analysis has just begun. These preliminary results indicate the potential use of AVIRIS images, both high and low altitudes, and other spectrometer measurements for quantifying carbonate in the soil surface. More work is ahead, including analysis of soils having a broad range of carbonate levels to evaluate the robustness of the methods.

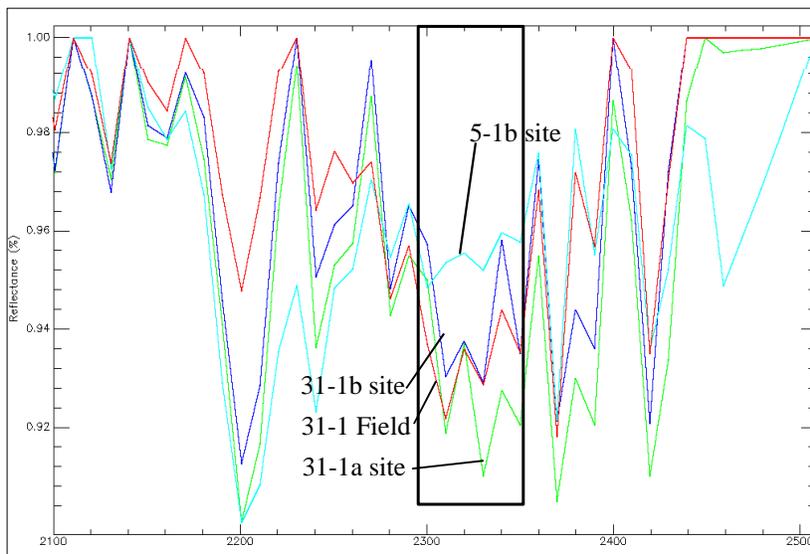


Figure 7. AVIRIS, 2000, low altitude, spectra for areas in figure 5.

a Gaussian stretch. The average carbonate content of the nine samples within the sites of 31-1a and 31-1b vary substantially from the average for the 5-1b site, 0.7, 0.6, and 0.4%, respectively. Though all are very low in carbonates, these regions of interest are spatially very consistent. The regions of interest were allowed to “grow” within 0.5 standard deviation for the 2360nm band (band of the maximum absorption depth) within a distance of 4 pixels. Visually the growth is very small. Average spectra for these expanded regions of interest, with continuum removal, are shown in figure 7. Additionally, the spectra for 31-1a and b samples were averaged for a “31-1 field” spectrum. The grouping of the 31-1 field samples spectra and their separation from the 5-1 field spectra indicate

To understand the affects of variable soil moisture, due to irrigation and precipitation, we need to develop a relationship model of moisture content to spectral adsorption by carbonates and soil mixtures. This will evaluate the effectiveness of continuum removal process for studies such as this. The light absorption in the 2200 – 2400-nm range may not be linearly proportional to the change in hydration of both the clay and carbonate.

Soil samples are still being analyzed for other cations to explain the spectral features in the carbonate and other wavelength regions. The outcome of this analysis will provide a carbonate map to improve to precision applications and the efficiency of lime, gypsum and acid.

## 5. REFERENCES

- Ben-Dor, E. and Banin, A. 1995. "Near infrared analysis (NIRA) as a method to simultaneously evaluate spectral featureless constituents in soils," *Soil Science*, vol. 159, no. 4, pp. 259-270.
- Ben-Dor, E. and Banin, A. 1994. "Visible and near-infrared (0.4-1.1 MU-M) analysis of arid and semiarid soils," *Remote Sensing of Environment*, vol. 48, no. 3, pp. 261-274.
- Ben-Dor, E., and Banin, A. 1990. "Near-infrared reflectance analysis of carbonate concentration in soils," *Applied Spectroscopy*, vol. 44, no. 6, pp. 1064-1069.
- Ben-Dor, E., Irons, J. R., and Epema, G. F. 1999. "Soil Reflectance," *Remote Sensing for the Earth Sciences: Manual of Remote Sensing*, A. N. Rencz, ed., John Wiley & Sons, Inc.
- Bowers, S. A., and Hanks, R. J. 1965. "Reflection of radiant energy from soils." *Soil Science*, vol. 100, pp. 130-138.
- Clark, R. N. 1999. "Spectroscopy of rocks and minerals, and principles of spectroscopy," *Remote Sensing for the Earth Sciences: Manual of Remote Sensing*, A. N. Rencz, ed., John Wiley & Sons, Inc, pgs. 3-58.
- Clark, R. N., and Roush, T. L. 1984. "Reflectance spectroscopy: Quantitative analysis techniques for remote sensing applications," *Journal of Geophysical Research*, vol. 89, no. B7, pp. 6329-6340.
- Condit, H. R. 1972. "The spectral reflectance of American Soils," *Photogrammetric Engineering*, vol. 36, pp. 955-966.
- Csillag, F., Pasztor, L., and Biehl, L. L. 1993. "Spectral band selection for the characterization of salinity status of Soils," *Remote Sensing of Environment*, vol. 43, pp. 231-242.
- Dixon, J. B., and Weed, S. B. 1989. *Minerals in Soil Environments*, Soil Science Society of America, Madison, WI.
- Greenberg, J., Scheer, G., Whiting, M., and Ustin., S. 2001. "Analysis of water and chlorophyll features in cotton agriculture," Tenth JPL Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Workshop, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.
- Metternicht, G. I., and Zinck, J. A. 1996. "Modelling salinity-alkalinity classes for mapping salt-affected topsoils in the semiarid valleys of Cochabamba (Bolivia)," *ITC Journal*, vol. 2, pp. 125-135.
- Palacios-Orueta, A., and Ustin, S. L. 1996. "Multivariate classification of soil spectra," *Remote Sensing of Environment*, vol. 57, no. 2, pp. 108-118.
- Stoner, E. R., and Baumgardner, M. F. 1981. "Characteristic variations in reflectances of surface soils," *Soil Science Society of America Journal*, vol. 45, pp. 1161-1165.
- Stoner, E. R., Baumgardner, M. F., Biehl, L. L., and Robinson, B. F. 1980. "Atlas of soil reflectance properties laboratory for application of Remote Sensing," *Purdue University Research Bulletin* 962.
- USDA, NRCS. 1986. "Soil Survey of Kings County, California," USDA Soil Conservation Service in cooperation with University of California Agricultural Experimental Station, Hanford, CA.