Saltville Archeological Site: data from AVIRIS sensor taken 10 August 1999

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Background: AVIRIS flew over the Saltville, VA historic area on 10 August 1999 (Figure 1). Saltville was the Confederacy's sole source of salt during the Civil War, and thus became a strategic area in the conflict. Historical records indicate that the saltworks were quite extensive, though this does not seem to be the case today.

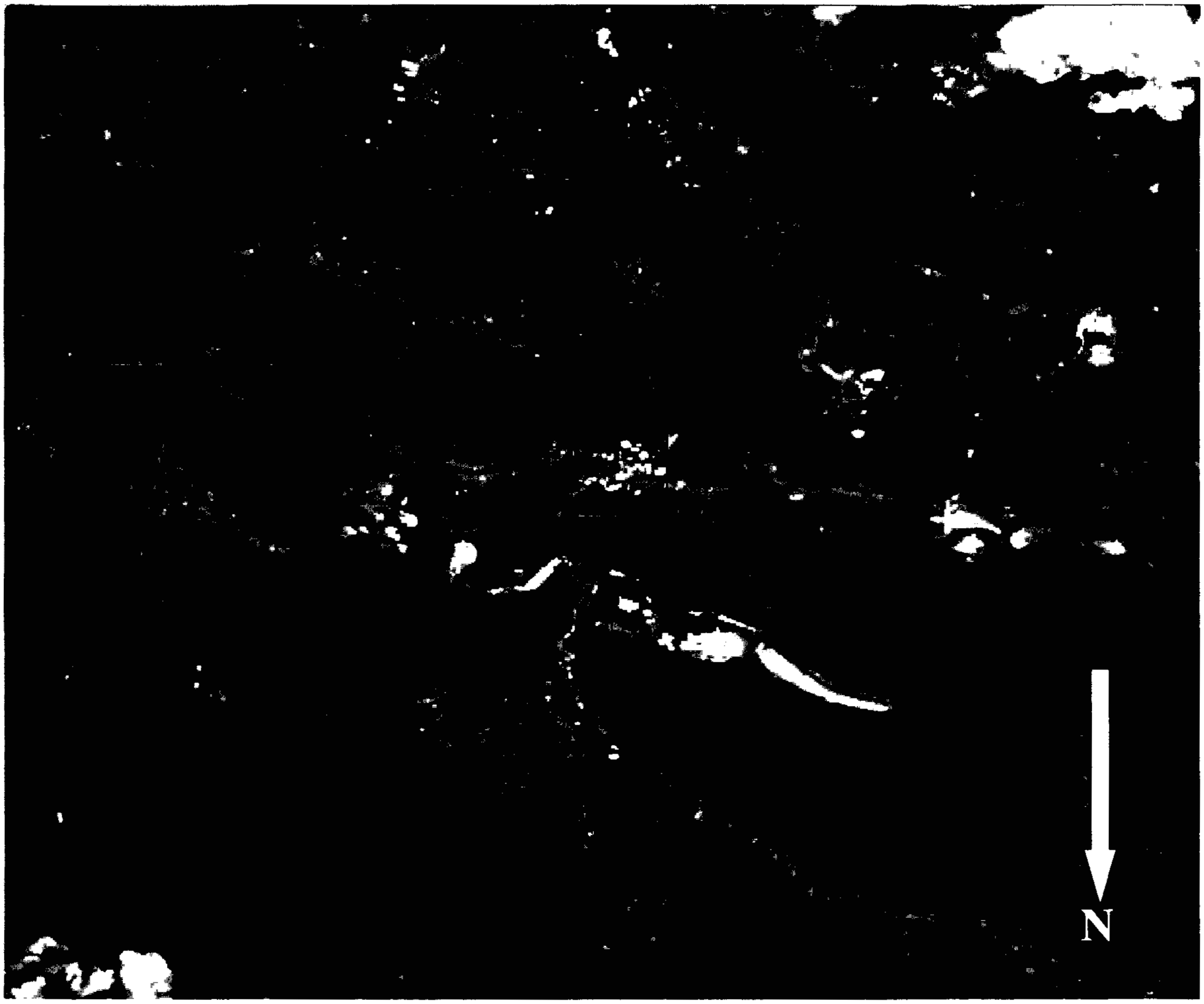

Figure 1: True-color AVIRIS image of historic region of Saltville, VA, taken by AVIRIS sensor. Red box indicates location of current city.

Archeologists are interested in finding the historical extent of the old saltworks. Rock salt (halite) does not have a distinctive spectrum (Figure 2), and in any case, the old saltworks are not obviously exposed on the surface, which is overgrown with vegetation. The purpose of this project is to see if the salt in the soil may be stressing vegetation covering the historical site, allowing the extent of the old saltworks to be determined in a secondary fashion.

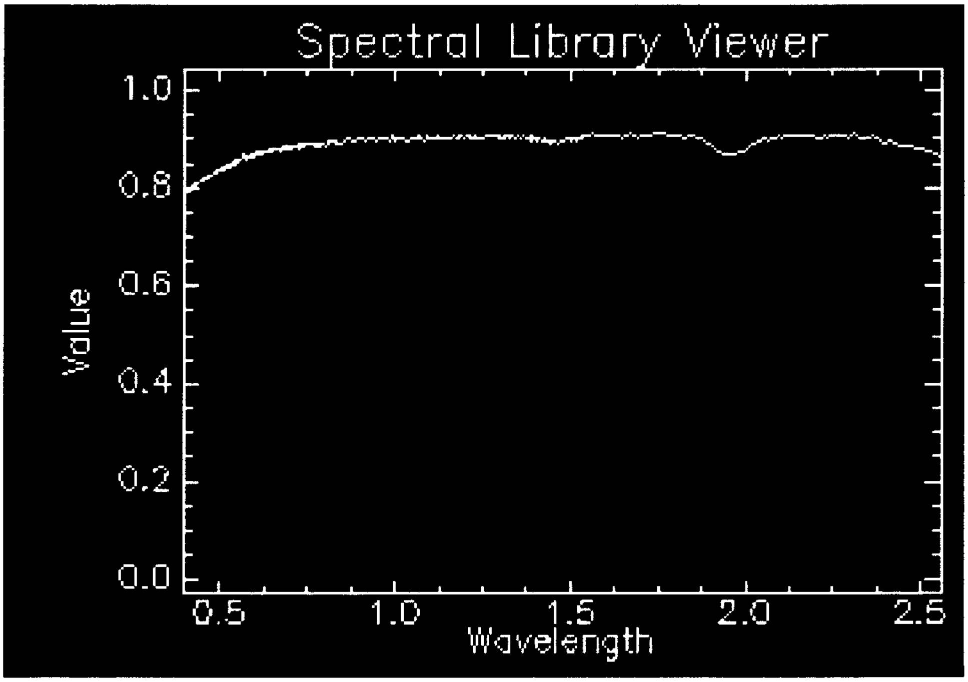

Figure 2: Halite (salt) spectrum, courtesy USGS spectral library. Notice lack of strong spectral features.

Method: Vegetation stressed by contaminants in the soil (or other factors) can be identified spectrally. Stressed vegetation may be found by looking for a red edge shift toward the blue:

> The long-wavelength side of the chlorophyll absorption (~0.68 to ~0.73 micron) forms one of the most extreme slopes found in spectra of naturally occurring common materials, plant or mineral ... The absorption is usually very intense, ranging from a reflectance low of less than 5% (near 0.68 micron) to a near infrared reflectance maximum of ~50% or more at ~0.73 micron). The properties of reflectance spectra (e.g. Clark and Roush, 1984) indicate such an absorption band is "saturated." In such a case, the absorption band minimum will not change much with increased or decreased absorption, but the wings of the absorption will change. When the chlorophyll absorption in the plant decreases, the overall width of the absorption band decreases. The short wavelength side of the chlorophyll absorption is not observed in reflectance as is the long wavelength side because of other absorptions in the ultraviolet (UV). The result of this combination appears as a shift to shorter wavelengths as the chlorophyll absorption decreases. This has popularly become known as the "red-edge shift" or the "blue shift of the red edge" and can be caused by natural senescence, water deprivation, or toxic materials (e.g. Collins et al., 1983; Rock et al., 1986).
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> The ratio of two spectra, one shifted in wavelength, the other not, and each with steep slopes as seen at the "red edge," will produce a spurious feature when there is only a small shift between the two. If the blue shifted spectrum is divided by an unshifted spectrum, a peak will be observed in the ratio. For a spectrum of green vegetation ... a 1 nm shift will produce a residual feature of about 6%. The AVIRIS data have a signal to noise of several hundred in this spectral region, so red-edge shifts of less than 0.1 nm are possible to detect.
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> **from: Initial Vegetation Species and Senescence/Stress Indicator Mapping in the San Luis Valley, Colorado Using Imaging Spectrometer Data** http://speclab.cr.usgs.gov/PAPERS.veg1/vegispc2.html
> Roger N. Clark, Trude V.V. King, Cathy Ager, and Gregg A. Swayze, U. S. Geological Survey

Figure 3 illustrates this "red edge shift" effect for the case of sorghum grown in contaminated soil, with AVIRIS channels overlaid for comparison.

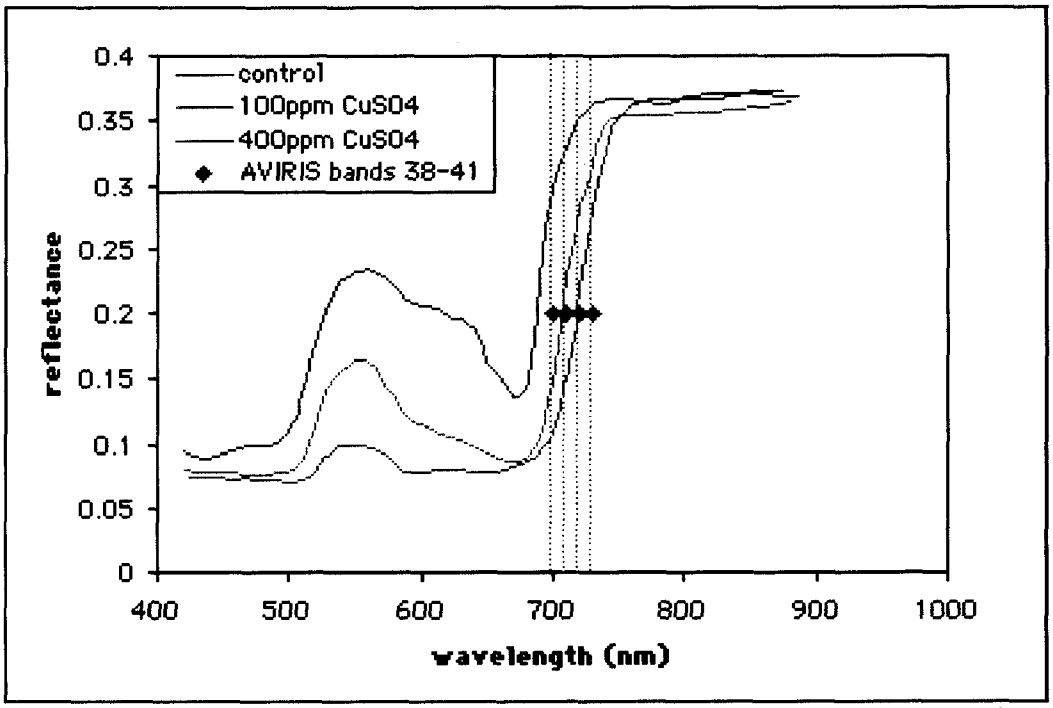

Figure 3: spectrum of sorghum grown in $CuSO_4$-contaminated soil. Note shift in red edge with increasing contamination. Figure reproduced from Chang and Collins, 1983. Centers of AVIRIS bands 38-41 illustrate utility of hyperspectral data in detecting the spectral shift.

The movement of the "red edge" is diagnostic of stress, but does not indicate the type of stress that the plants may be experiencing. Conversly, unstressed vegetation tends to have a common "red edge", irrespective of species. Figure 4 shows fir and grass spectra, illustrating the relatively invariant location of the "red edge" under normal condtions:

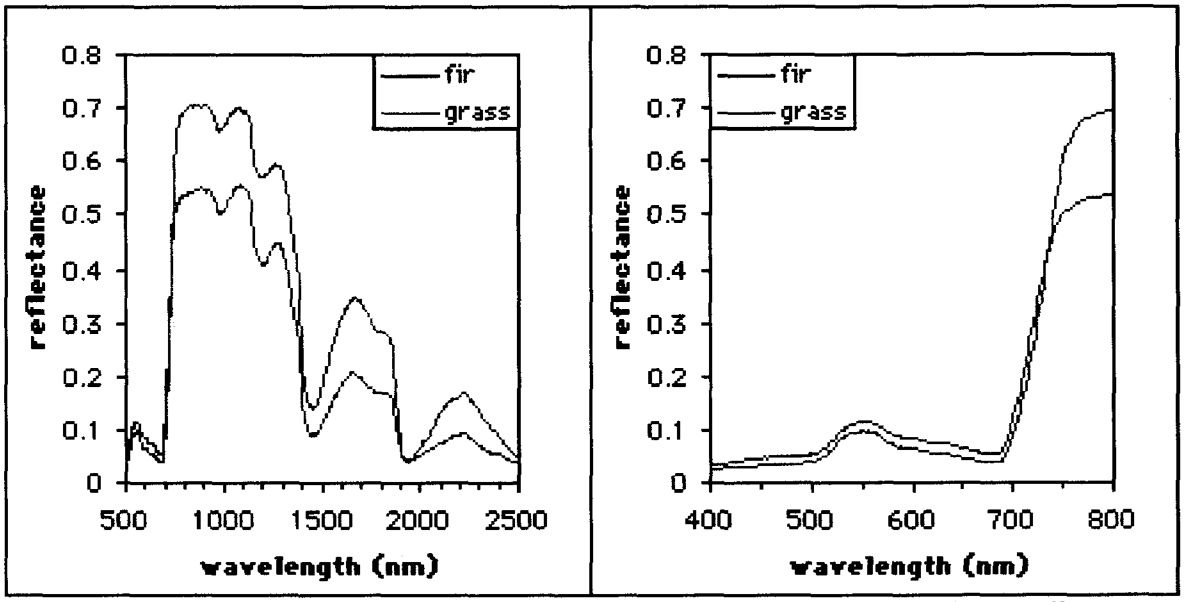

Figure 4: vegetation spectra, showing common sharp "red edge" due to chlorophyll. Courtesy USGS spectral library.

Processing: The first step in processing AVIRIS data is to convert raw radiance data (Figure 5) to reflectance, so that image spectra can be compared to spectral libraries and to each other without interference from atmospheric effects. Radiance data can be converted to reflectance data (Figure 6) using estimates of atmospheric parameters with the atmospheric modeling program MODTRAN. Explanation of "stressed" and "unstressed" vegetation follows in Analysis section.

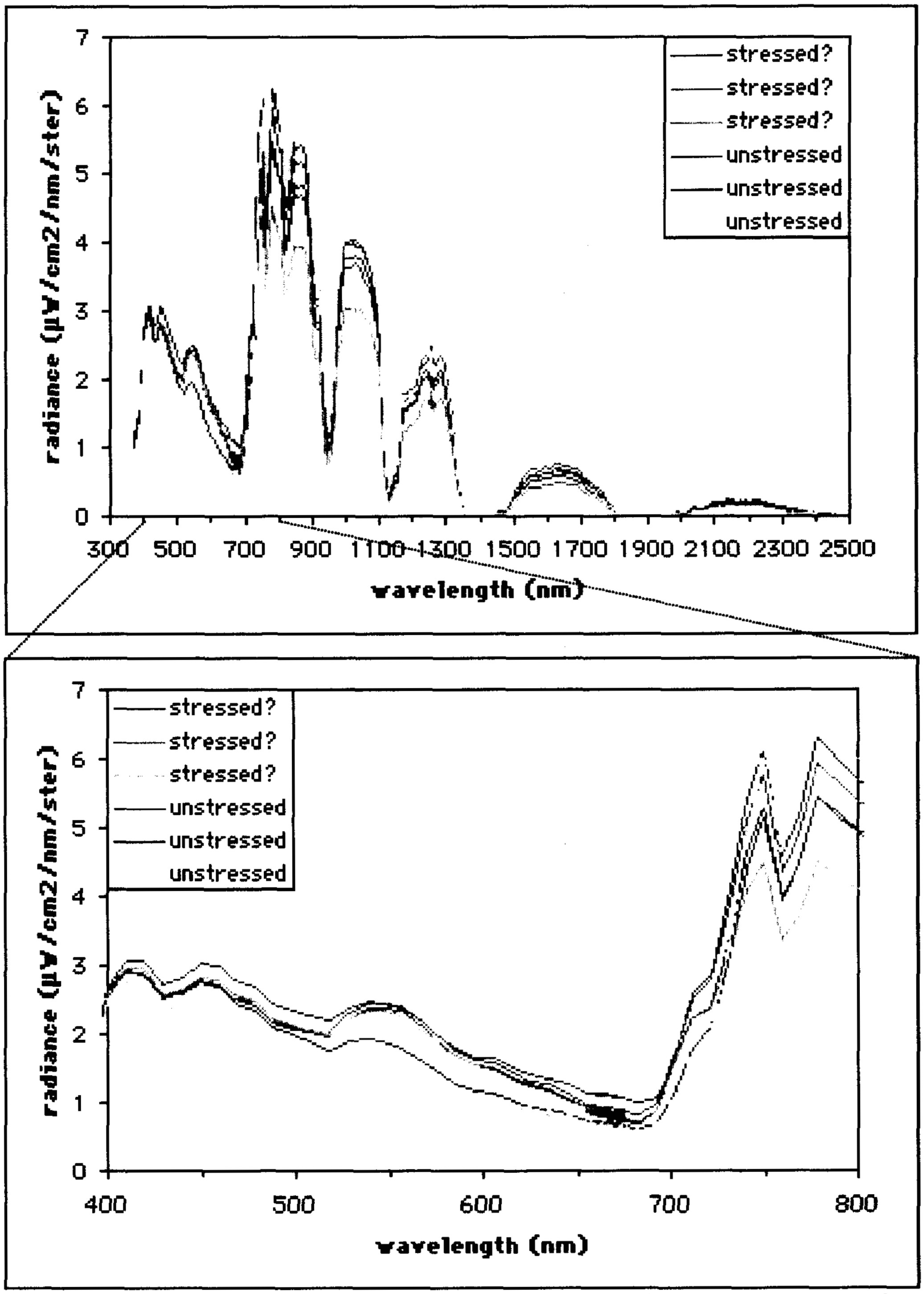

Figure 5: spectral samples of various vegetation areas in Saltville radiance image. Identification of "stressed" and "unstressed" vegetation is explained in following Analysis section.

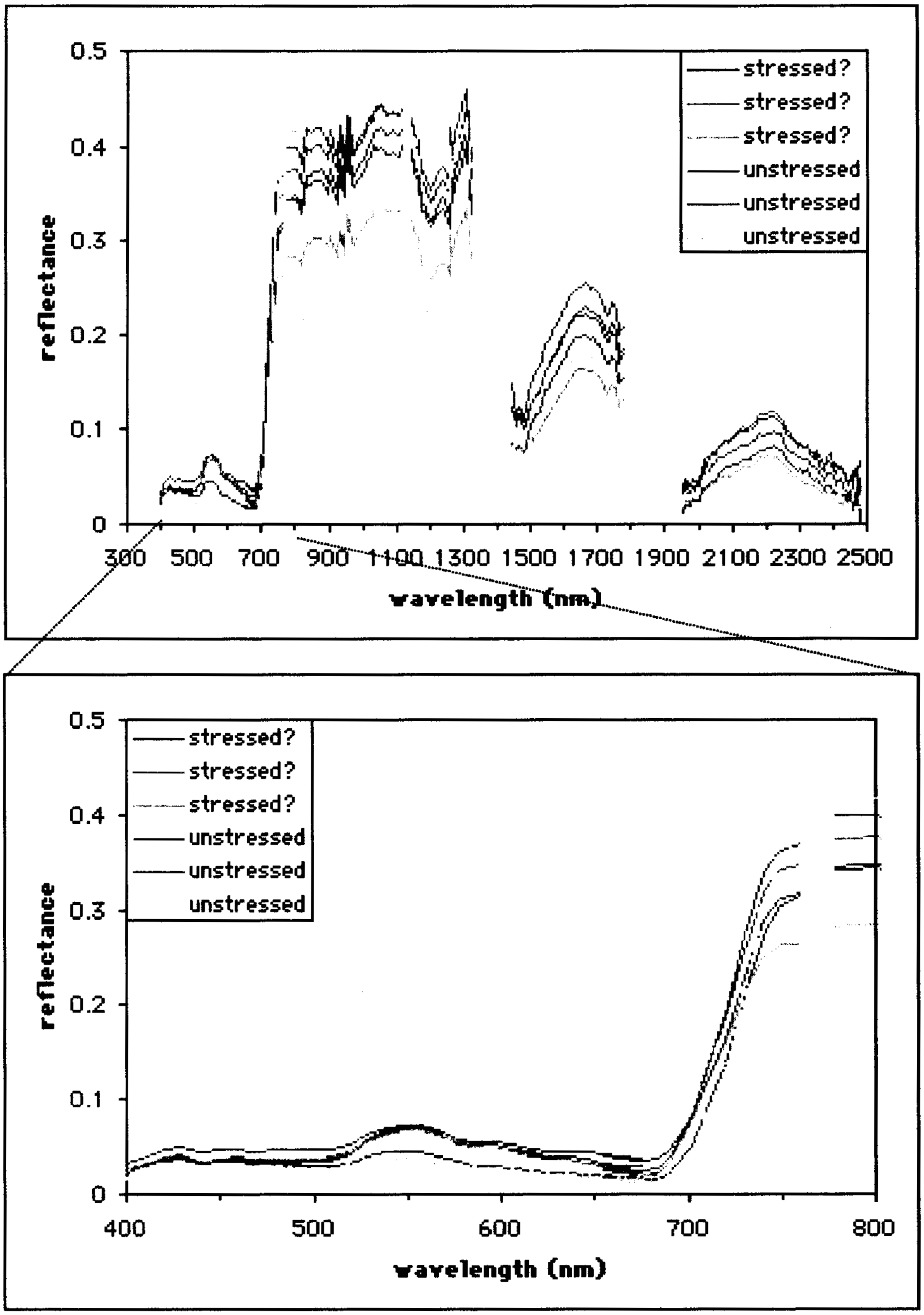

*Figure 6: spectral samples of same vegetated areas in Saltville (**preliminary**) reflectance image - small spectral shift is probably responsible for sharp discontinuities. Regions of strong atmospheric absorption (low signal/noise) have been removed.*

Atmospheric characteriestics are visible in Figure 6 because atmospheric correction has not been optimized for this image. Blank areas are regions of strong atmospheric absorption.

Analysis: Based on the"blue shift" information summarized above, a ratio of band 37 (692.33nm) to band 35 (673.25nm) was constructed, revealing regions of possible vegetation stress. This image is shown in Figure 7. Regions of possible stress are spatially coherent and surrounded by progressively less stressed vegetation, increasing confidence in the result.

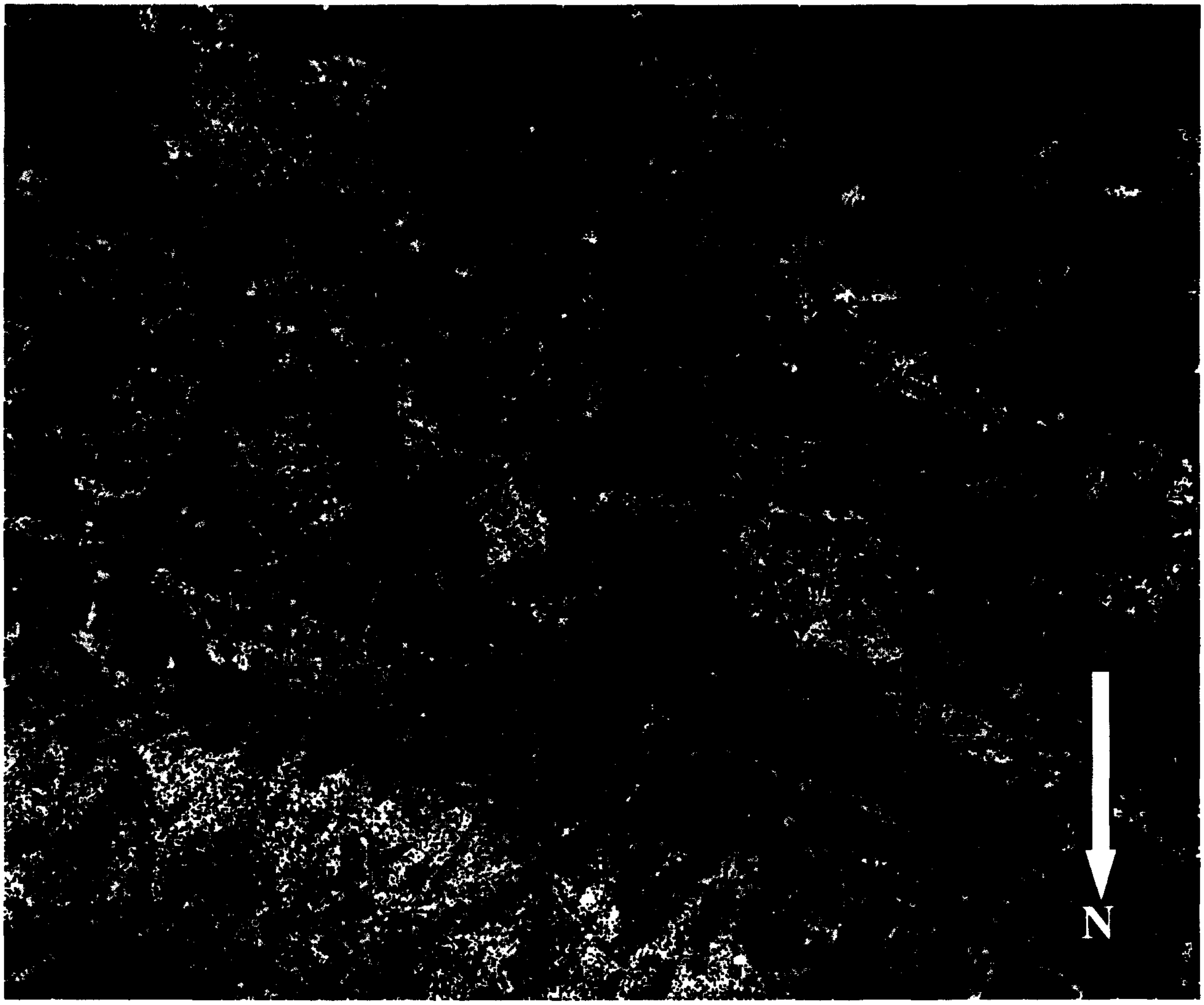

Figure 7: ratio of band 37/35, showing regions of possible plant stress. Sourthern side of ridge is stressed (perhaps the soil is dry due to solar heating?), but the explanation for the stress in other regions is less obvious. Color code for ratio: green, 1.6-1.65; yellow, 1.65-1.75; red>1.75.

Based on this mapping, regions of possible stress were selected for futher analysis, leading to the spectral comparisons shown by Figures 5 and 6. Both figures have 3 spectra selected from "stressed" and 3 from "unstressed" regions. In general, the comparison shows a small red shift associated with possible "stressed" vegetation, but the difference is small and may not be statistically significant.

In order to understand the distribution of possible plant stress, the "hottest" regions from the stress map data were overlaid onto the image of Saltville, to produce a vegetation stress map that could be tied to ground points, and containing additional information regarding the search area suggested by the archeological team. This is shown in Figure 8.

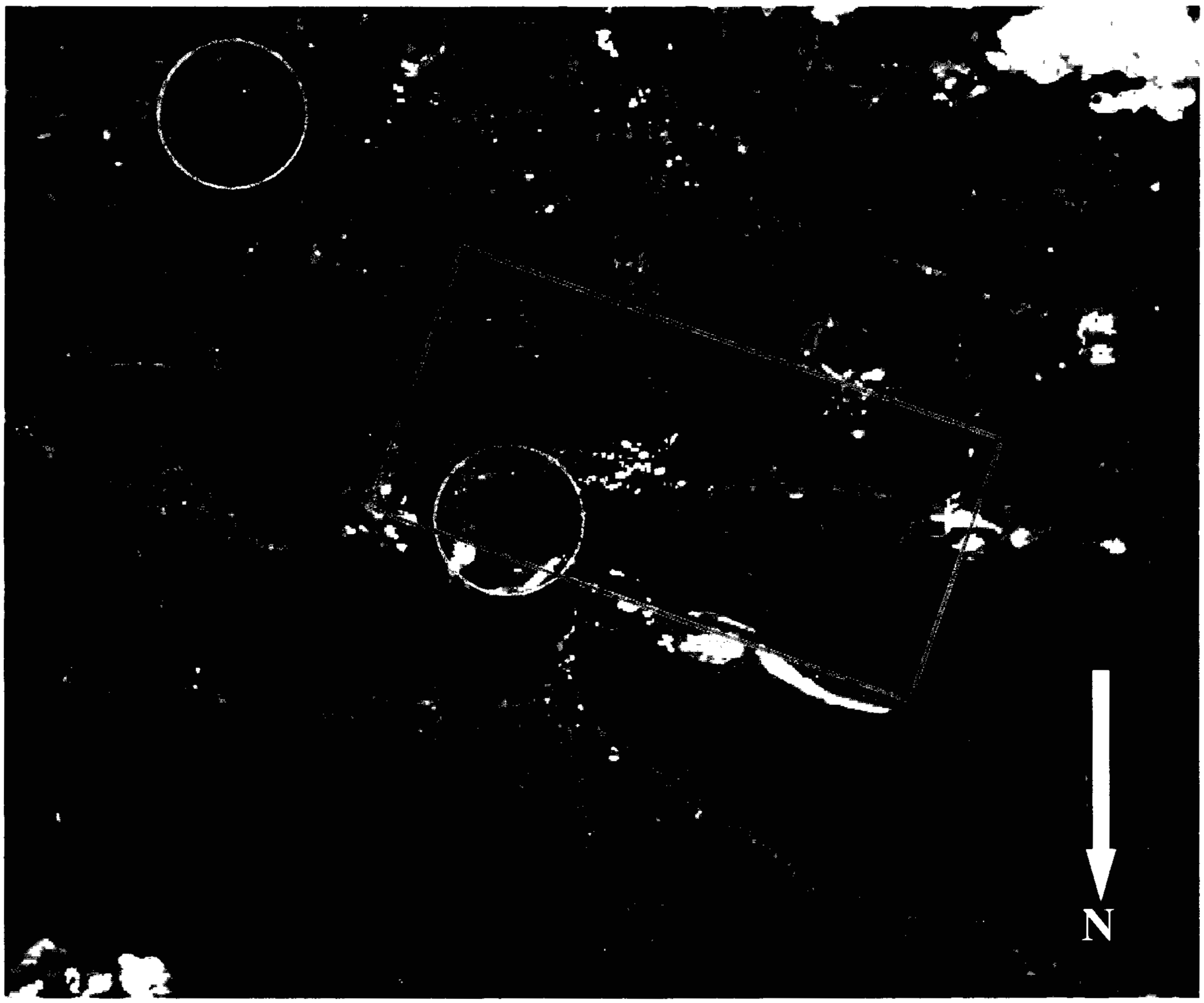

Figure 8: red regionsofpossible vegetation stress from Figure 4 overlaid on true-color image of Saltville. Circled regions have no obvious connection to plant species, terrain, or development. Blue box indicates search region suggested by archeological team.

To check the validity of the band-ratio technique results, the Saltville reflectance data were futher analyzed using the Minimum Noise Fraction (MNF) Transform. The purpose of the transform is to identify spectrally unique regions in the image. Each band in the MNF-transformed image identifies area with common spectral characteristics.

Figure 9 shows one band (band 9) of the transformed image. Note that the regions selected by the band ratio technique (yellow circles) are again common in the MNF image, and that additional regions of interest are indicated (green circles). These areas may merit additional investigation. To ensure that conversion to reflectance had not introduced artifacts which might affect the MNF analysis, the radiance image was also processed. The results were similar, though the regions defined in the MNF were not as distinct, possibly because the radiance data is dominated by atmospheric absorptions.

Figure 10 shows possible stressed vegetation distributions from both the band ratio and MNF transform techniques overlaid on the Saltville image. The match of the distributions increases our confidence in the result.

Figure 9: MNF (minimum noise fraction) transform of Saltville refletance image. Transform picks out spectrally unique regions. Note that same regions of interest are highlighted by both techniques (yellow circles), while the MNF emphasizes addtional regions (green circles).

Further Work: This is a preliminary analysis, and indicates the possibility of stressed vegetation in these areas. A more complete inversion from radiance to reflectance should be completed to fully remove atmospheric features from the Saltville reflectance image. This will make all further analysis less prone to errors due to atmospheric artifacts in the data. Additional work will be necessary to determine if any spectral shifts observed are statistically significant. If the vegetation is stressed, it could be due to any number of factors, such as availability of water, soil type, or presence of contaminants (other than salt) in the environment. Alternatively, the plot may show the edges of existing salt-processing activity. Further work, including ground truth information, will be necessary to determine the meaning of the data analysis provided here.

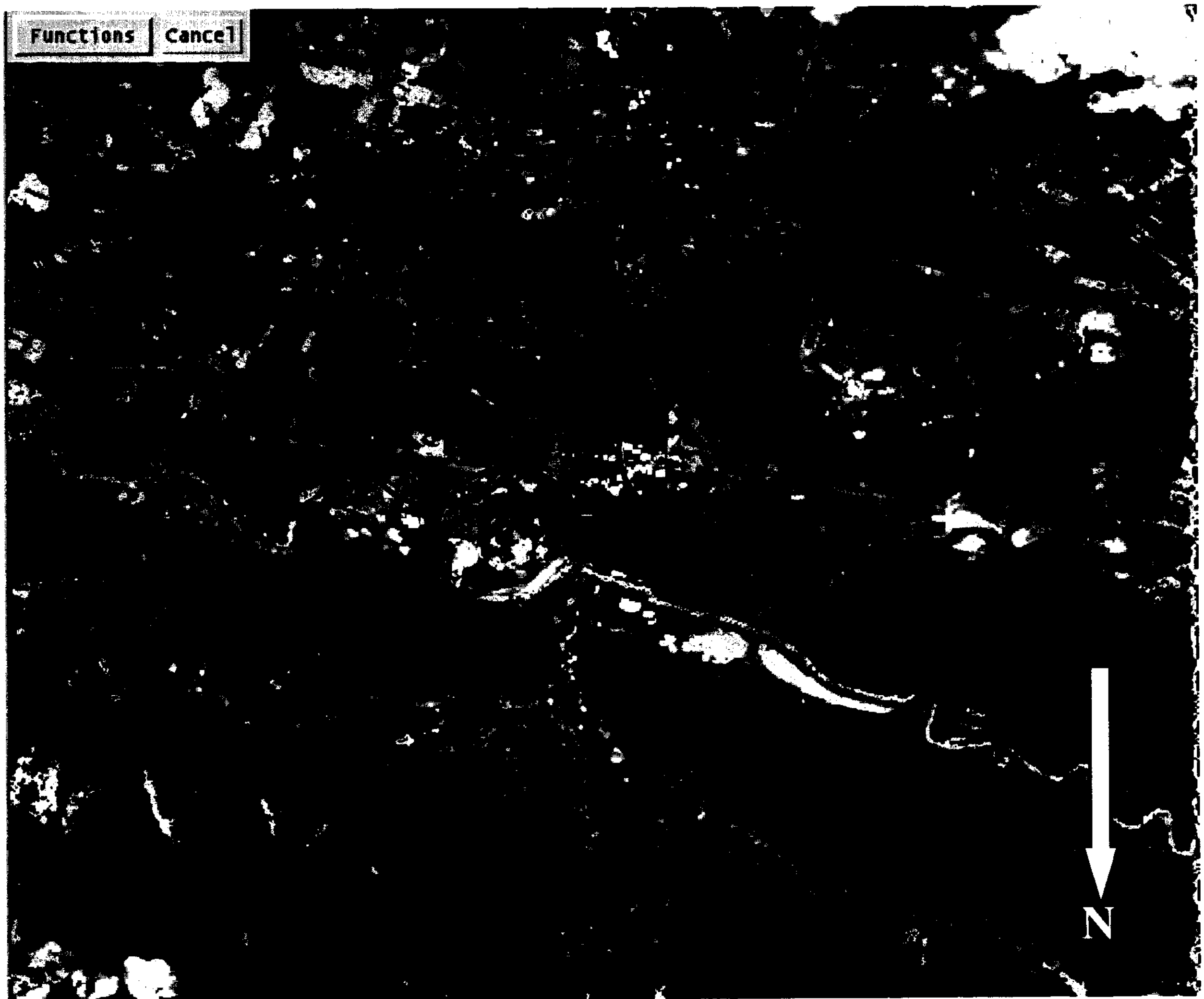

Figure 10: Comparison of band ratio (red) and MNF (yellow) regions of interest. Highlighted regions suggest that areas SW and NE of the city may be promising research areas.

REFERENCES

Chang, S.H. and W.Collins,Confirmation of airborne biogeophysical mineral exploration technique using laboratory methods, Econ. Geol., 78, p. 723, 1983.

Collins, W., S.H. Chang, G. Raines, F. Canney, and R. Ashley, Airborne biogeochemical mapping of hidden mineral deposits: Econ. Geol., 78, p. 737, 1983.

Clark, R.N. and T.L. Roush, Reflectance Spectroscopy: Quantitative Analysis Techniques for Remote Sensing Applications: J. Geophys. Res., 89, p. 6329-6340, 1984.

Rock, B.N., J.E. Vogelmann, D.L. Williams, A.F. Voglemann, T. Hoshizaki, Remote detection of forest damage: Bio. Sci. 36, p. 439, 1986.