

Visible/near infrared (VNIR) theory & spectroscopy
Week #5: September 27, 2023

I. General Information

- the first *graded* lab is next week (Oct. 4th)
- remember to check when your lab group meets (*it changed from the pre-lab*)
- similar to the pre-lab, I will post a lab document online that will guide you through the exercise
 - The TA will also go over this at the start of the lab next week
 - she will also be creating a lab writing guide, which I will post at the bottom of the main class page
 - if, after the lab, you feel confused – please work with Poushalee and arrange more time with her
 - *this will help you a lot for later labs and completing your first lab written report!*

II. This Week: What is spectroscopy??

- spectroscopy = science and analysis of the EM spectra of materials
 - the type of spectroscopy is a function of the wavelength region under study
 - examples: gamma ray spectroscopy, TIR spectroscopy, etc.
 - recall that the analysis of a spectrum tells you something about the surface material
 - *we've talked about some of this already*
- techniques (**review**):
 - the type of analysis, results in the type of spectrum
 1. reflection/scattering
 - common technique (especially in VNIR spectroscopy)
 - detector measures reflected component of the source energy
 - produces a reflection peak
 2. absorption/emission
 - common technique in SWIR and TIR spectroscopy
 - detector measures emitted component from the sample
 - produces an emission trough
 3. transmission
 - common technique for chemistry or atmospheric remote sensing
 - liquids, gasses, suspended fine-grain particulates
 - detector measures transmitted component of the source energy through the sample
 - produces an absorption trough commonly preceded by a peak
 - *we won't examine this in the class*

III. Energy/Matter Interaction

- Electronic Processes: occur in the 0.3 - 1.5 micron region
 - here, we are interested in reflection (other energy/matter interaction terms are ignored)
 - reflection dominates in the VNIR region (primary source is the sun)
 - reflectance = measure of how much incident EM energy (E_{inc}) is reflected (E_{ref}) from the surface, giving us the simplest definition of:

$$R(\lambda) = E_{ref} / E_{inc}$$

- for an absolutely perfect reflector, $R = 1.0$ (100%)
- if no energy is reflected, $R = 0.0$ (0%)
- three factors control the amount of reflectance:
 - i. physical properties of the material (n & k)
 - ii. particle size
 - iii. wavelength (λ)
- **physical properties of the material (n & k)**
 - if you took a Mineralogy or Chemistry class where you did microscope work you may recall *Snell's Law*:

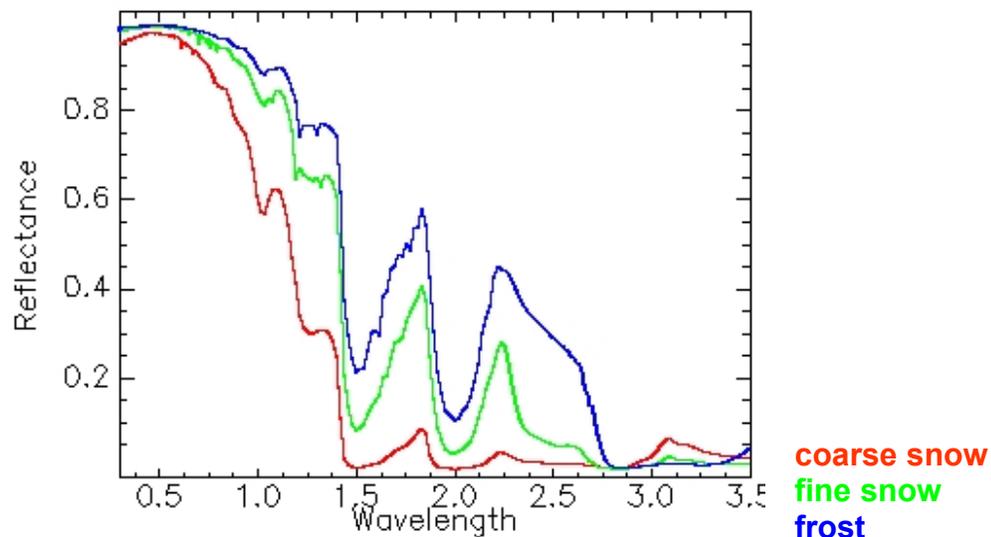
$$R(\lambda) = [(n - 1)^2] / [(n + 1)^2]$$

- where (n) is the index of refraction
- this equation is simplified from (the more complete) Fresnel Equation:

$$R(\lambda) = \frac{[(n_{(\lambda,\alpha)} - 1)^2 + n_{(\lambda,\alpha)}^2 k_{(\lambda,\alpha)}^2]}{[(n_{(\lambda,\alpha)} + 1)^2 + n_{(\lambda,\alpha)}^2 k_{(\lambda,\alpha)}^2]}$$

- where (α) is incidence angle of the reflected energy, and (k) is the absorption coefficient
- as (k) approaches zero the equation reduces to Snell's Law
 - *this occurs mostly in the VNIR region and at perpendicular ($\alpha = 0$) incident angles (like looking through a microscope)*
- absorption coefficient (k) & index of refraction (n)
 - both vary with wavelength
 - both combine to control how much reflectance (R) comes from a surface and at what wavelengths (λ)
 - *results in a reflectance spectrum*
- two components of reflectance
 - volume component: $r^v(\lambda)$
 - energy is scattered through the mineral grains in the spectral regions of **low** $k(\lambda)$

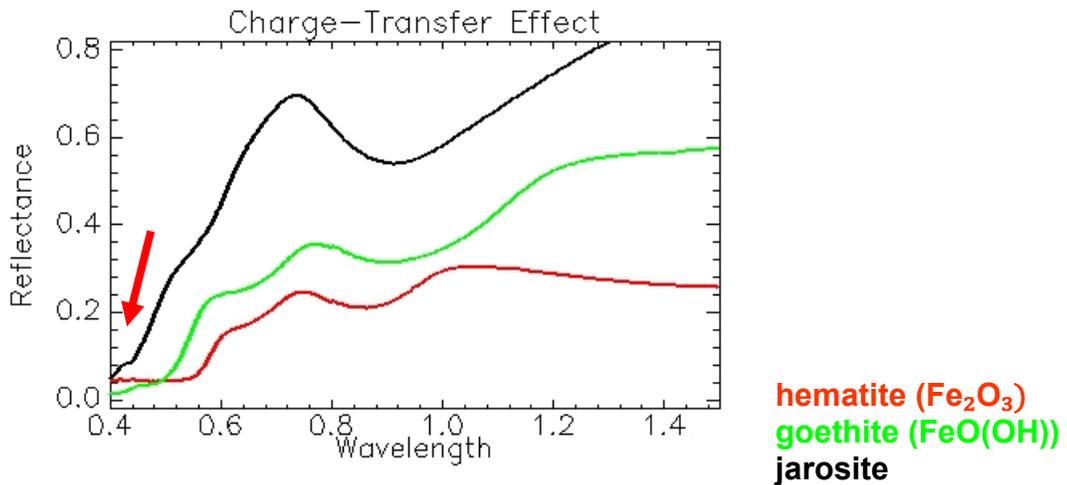
- specular component: $r^s(\lambda)$
 - energy reflects off the mineral grains in the spectral regions of **high** $k(\lambda)$
- another way to measure reflectance is: $R(\lambda) = r^v(\lambda) + r^s(\lambda)$
- **particle size**
 - change in particle size has the net effect of increasing (or decreasing) the volume transmitted component depending on the $k(\lambda)$
 - where $k(\lambda)$ is low-moderate, $r^v(\lambda)$ will *increase* as particle size *decreases*
- example: quartz grains (shown in class)
- another example: snow
 - brighter than most materials on the surface of the Earth in the VNIR but not in the longer SWIR regions
 - reflectance drops from $\sim 97\%$ in the VIS to $< 3\%$ at 3 microns
 - a direct function of the n & k of water/ice
 - brightness also varies with snow particle size
 - finer particle sizes are brighter
 - darkens with age (particle size increases)



IV. Electronic Spectral Processes

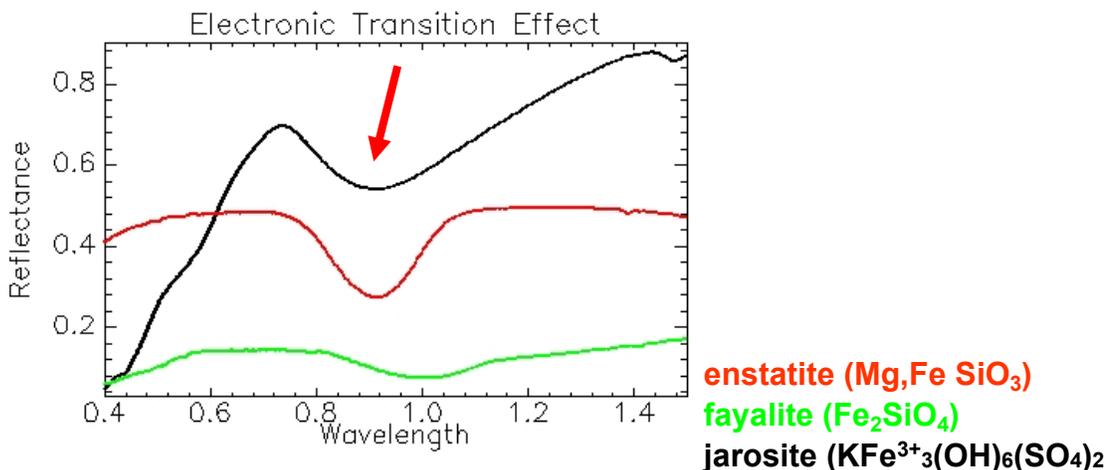
- the VNIR region is dominated by the spectral features arising from electronic transitions
- several types of these processes
 - charge transfer effect:
 - incident photons raise the electron energy state of the mineral, causing the outer electrons to migrate to other ions in the lattice

- results in complete absorption of incident energy from the UV to visible green
- common in iron-bearing materials (Fe-O)
- results in their reddish coloration – *why?*



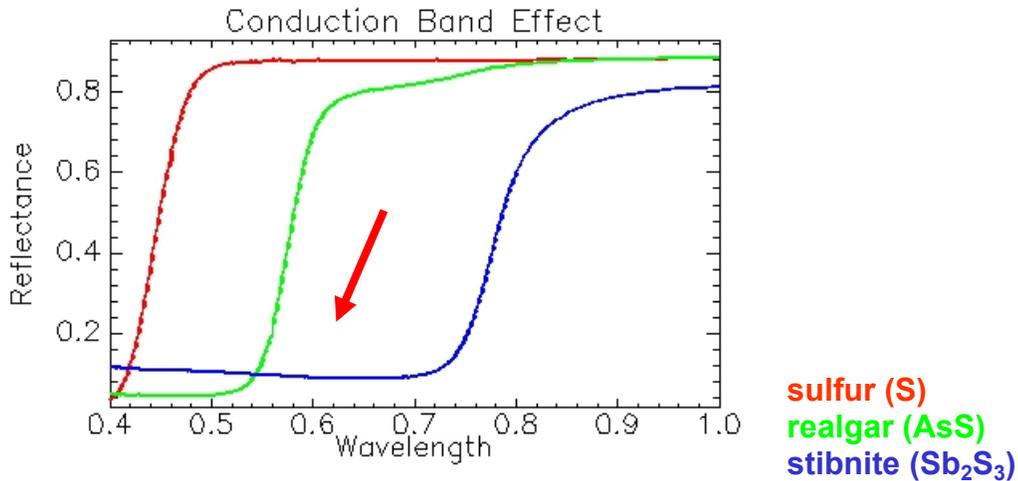
○ electronic transition:

- common in transition metals (Fe^{2+} , Fe^{3+} , Cu^{2+} , etc.)
- complete transfer of the electrons
- produces reflectance minima in the 0.9-1.2 micron region



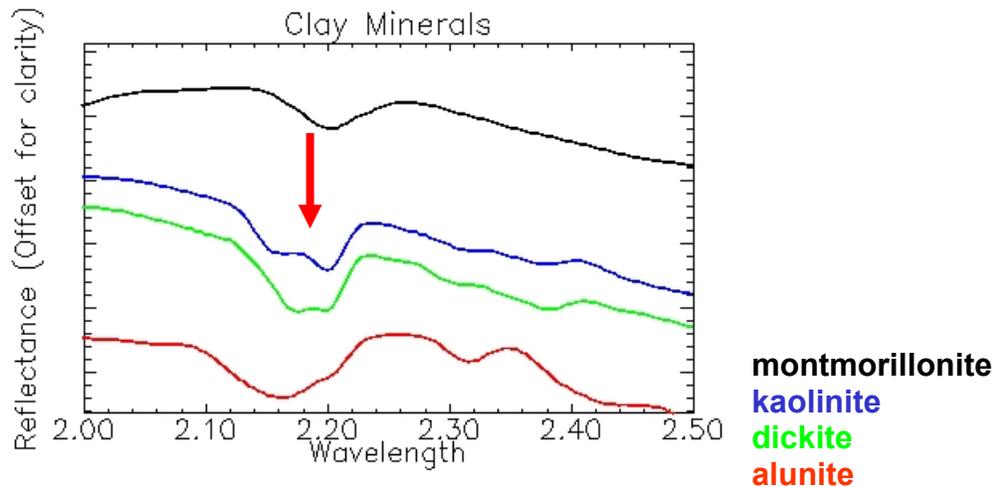
○ conduction band absorption:

- similar to charge transfer only stronger
- produces a prominent and sharp reflectance increase from VIS green to infrared wavelengths
- common in sulfur-bearing minerals



V. Vibrational Processes: 2.0 – 100 microns (SWIR to the TIR)

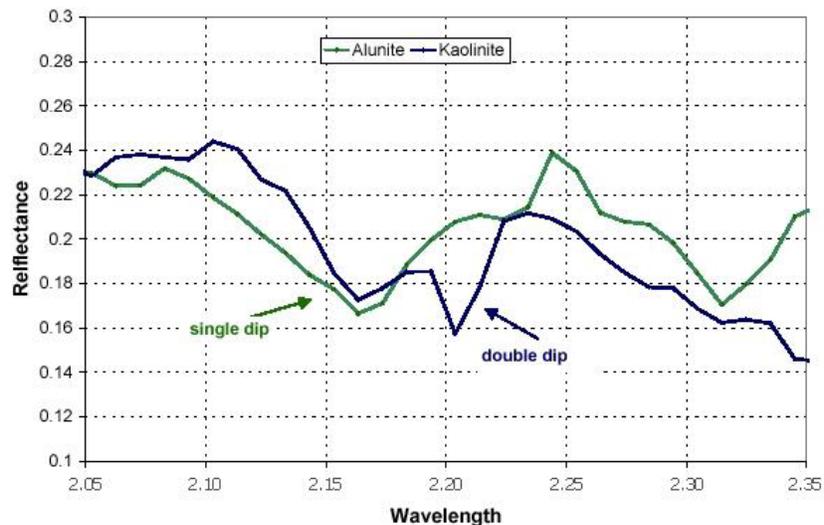
- the short wave infrared (SWIR) and thermal infrared (TIR) region are dominated by the spectral features arising from the bending/stretching of the atomic bonds
 - most-common Earth-forming minerals show strong features
 - *will hear all about this region in the next lecture*
- also produces spectral features in the 2 - 3 micron region in the SWIR
 - caused by combination and overtone vibrations
 - example: water (shown in class)
 - another example: hydroxyl ions (OH⁻)
 - common in clays and other alteration minerals
 - results in a band at 2.1 - 2.4 microns (in combination with heavier atoms: i.e., Al-OH or Mg-OH)



- Landsat TM bands
 - the detection of clay mineralogy in the 2.0 – 2.5 μm region is the primary reason why Landsat TM ended up with a “band 7” in this region

VI. Spectral Image Processing

- Cuprite, NV example
- original work done by: *Roger Clark (USGS)*
 - lies near Tonopah, NV (northwest of Las Vegas, NV) in the southwestern part of the state
 - gold and copper have been mined in the region for more than a century
 - valuable geological study site to evaluate remote sensing for mineral exploration
 - using hyperspectral data sets
 - because of the wide variety of alteration products and other mineralization



- *ENVI demo in class (will go over the following topics):*
 - spectral plotting and spectral libraries
 - spectral feature identification in the 2.0 – 2.5 μm region
 - "continuum removal" in the SWIR region
 - removes broad slope of the spectrum → emphasizes the spectral features
 - spectral feature mapping
 - spectral angle mapper, spectral feature fitting, 3-D image cubes, ...
 - image linking
 - 2-D scatter plots and image correlation
 - ***your notes:***

VII. Band Ratios

- already discussed somewhat in an earlier lecture
- there are well-known/specific ratios developed over the past decades
 - "classic" ratios for Landsat TM bands that highlight mineral identification and vegetation health

- very basic methodology to extract information in multispectral images
- mathematical operation (like a division) of two or more wavelength bands
 - highlight subtle spectral and/or temporal variations
 - typically done after atmospheric correction and conversion to surface units (reflectance, emissivity, temperature)
 - ratios reduce topographic and albedo effects (*may be good or bad*)
- there are well-known/specific ratios developed over the past decades
- “classic” ratios for Landsat bands which highlight mineral identification and vegetation health

1. Normalized Difference Vegetation Index (NDVI):

$$\text{NDVI} = (\text{TM4} - \text{TM3}) / (\text{TM4} + \text{TM3})$$

- for ASTER = $(\text{AST3} - \text{AST2}) / (\text{AST3} + \text{AST2})$
- for OLI = $(\text{OLI5} - \text{OLI4}) / (\text{OLI5} + \text{OLI4})$
- produces values from 0 - 1.0, higher NDVI implies “healthier” vegetation

2. Normalized Difference Moisture Index (NDMI):

$$\text{NDMI} = (\text{TM4} - \text{TM5}) / (\text{TM4} + \text{TM5})$$

- but for OLI = $(\text{OLI5} - \text{OLI6}) / (\text{OLI5} + \text{OLI6})$
- good indicator of “stressed” vegetation
- values from -1.0 to 1.0, higher NDMI implies greater abundance of moisture content

3. OH⁻ bearing rocks (clays, etc.):

$$\text{TM5/TM7} \rightarrow R_{\lambda=1.6} / R_{\lambda=2.2}$$

- for OLI = OLI6/OLI7
- absorption (low reflectance) in TM7 (2.2 microns)
- large values in the ratio: strong OH⁻

4. Fe²⁺ - bearing rocks (basalts, “red-beds”, etc.):

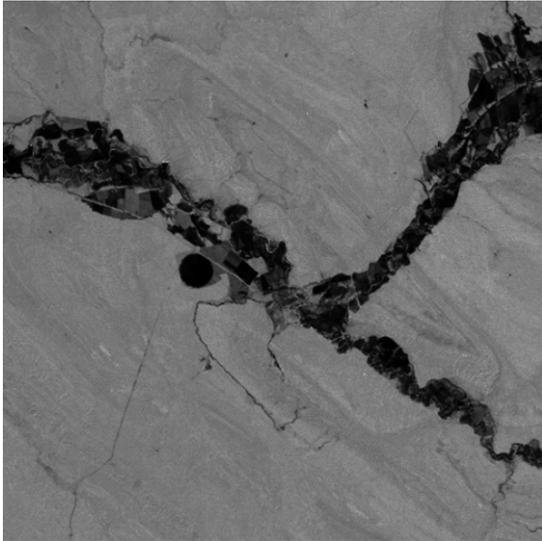
$$(\text{TM5/TM4}) \times (\text{TM3/TM4}) \rightarrow (R_{\lambda=1.6} / R_{\lambda=0.8}) \times (R_{\lambda=0.6} / R_{\lambda=0.8})$$

- for OLI = $(\text{OLI6/OLI5}) \times (\text{OLI4/OLI5})$
- strong curvature between TM3 and TM5
- large values in the ratio: strong Fe²⁺

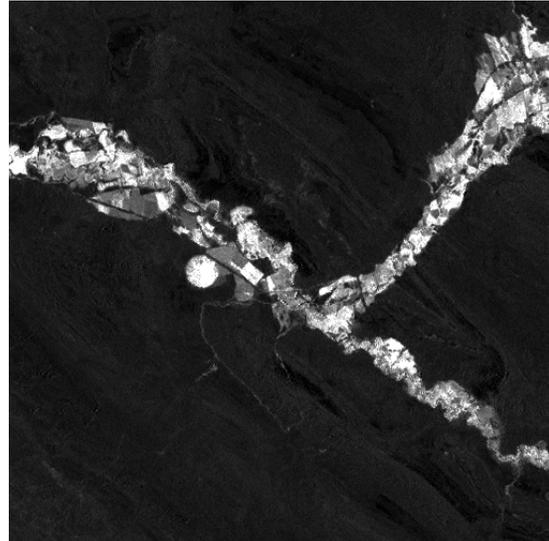
5. “mafics” (or low reflectance materials) ratio:

$$\text{TM1/TM5} \rightarrow R_{\lambda=0.48}/R_{\lambda=1.6}$$

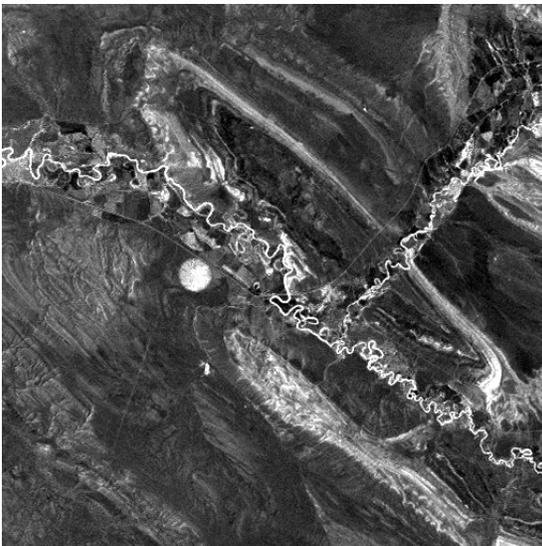
- for OLI: OLI2/OLI6
- highlights the lack of reflectance features in darker objects
- and their low over all albedo
- large values: low reflectance, strong mafic content



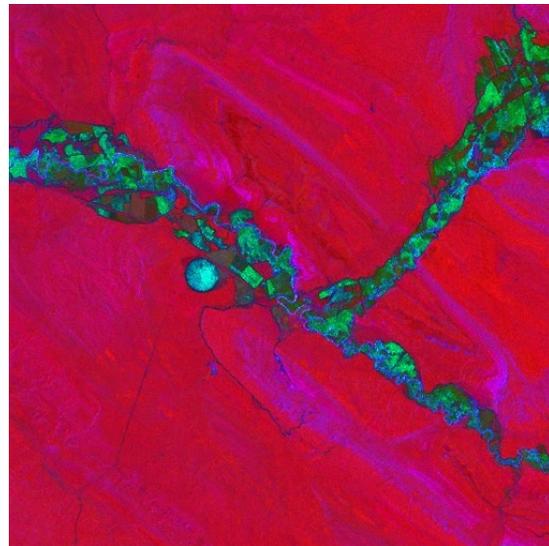
(TM5/TM4) x (TM3/TM4)



TM5/TM7



TM1/TM5



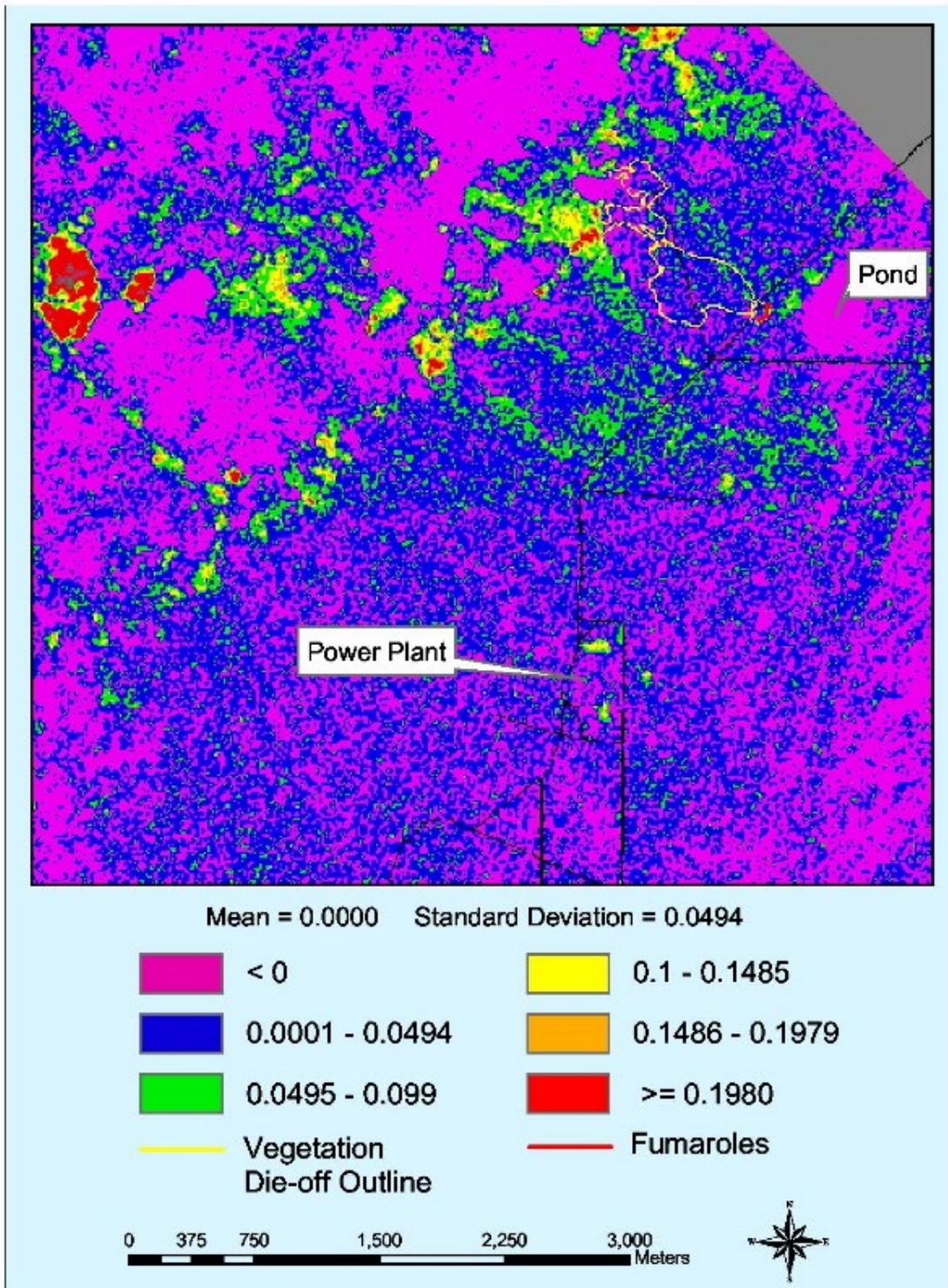
**red: Fe ratio; green: OH ratio;
blue: mafic ratio**

VIII. Example: Spectral Anomalies

- Dixie Valley, NV (1996 – 2002)
- original work by: *Gregory Nash (University of Utah)*
 - main objective

- test the usefulness of remote sensing as a tool for mapping hidden faults and blind geothermal systems
 - develop data processing methodologies that could be used by industry to address exploration needs
- searched for:
 - vegetation anomalies
 - soil mineralogy anomalies
 - thermal anomalies
- anomalies
 - a vegetation spectral anomaly was detected using ground-based spectral data
 - it was spatially associated with a soil-geochemical anomaly
 - both anomalies may have been related to the Buckbrush fault and related mineralization
 - soil geochemical anomaly may be from fluvial processes
 - 1995 AVIRIS airborne hyperspectral data were ordered to facilitate study
 - research focus changes to AVIRIS data analysis and interpretation
 - by 1997 the anomaly had become readily apparent
 - Greasewood trees were dying over a relatively large area
 - pre-anomaly AVIRIS data were tested to determine if early stages of vegetation stress could be detected
- goals
 - determine the number of contributing spectra
 - determine the spectrum of each source
 - determine the relative contribution of each spectrum in each pixel (spectral mixing proportions)
- results
 - used a minimum noise fraction (MNF) transformation technique
 - pixel purity index (PPI) generation (*we'll talk more about these later in the semester*)
 - selection of mineral spectra endmembers from the PPI
 - four mineral endmembers were identified
 - *calcium carbonate, chlorite, kaolinite, muscovite*
- conclusions
 - geothermal system related soil mineralogy anomalies can occur from several sources
 - these anomalies can be mapped using hyperspectral data
 - may be useful in identifying hidden structures and geothermal systems

- field work was needed to provide “ground truth” validation
- able to better determine source of calcium carbonate/kaolinite in the images



calcium carbonate mineral map (Dixie Valley, NV)