Lab 10 Hyperspectral

Utilizes Textbook's Remote Sensing Digital Database: Chapter 9 data.

The objectives of this lab are to become familiar with hyperspectral data, learn about spectral libraries and different methods for processing hyperspectral data. The tasks we will complete with this lab are done with tools in the **ENVI Toolbox**.

Two hyperspectral datacubes are available to be analyzed. The first datacube has VNIR data and is analyzed for vegetation. The second datacube has SWIR data and is processed for minerals. Different image processing tools are utilized with each datacube. Lab time may be a limiting factor for both datacubes to be processed and analyzed in one session.

Therefore, this lab exercise is clearly separated into two sections – with the first section utilizing the hyperspectral VNIR datacube (pages 2 – 8) and the second section analyzing the hyperspectral SWIR datacube (pages 9 – 25).

The VNIR vegetation section has two digital uploads to be uploaded to the instructor and six questions to be answered on the last pages of this handout (page 26). The SWIR geologic section has one digital file to be uploaded to the instructor and eleven questions to be answered on the last pages of this handout (pages 27 and 28).

The VNIR vegetation section includes the following image-processing tasks:

- Normal and continuum removed spectral profiles.
- Using the chlorophyll absorption feature to document vegetation vigor.
- Editing spectral profiles for presentation.
- Building a 3D cube.
- Minimum Noise Transform (MNF).
- Unsupervised classification of select MNF bands.

The SWIR geologic section includes the following image-processing tasks:

- Using the USGS Spectral Library converted to the 50-band SWIR dataset.
- Comparing spectral profiles at select pixels with published mineral maps.
- Using the Spectral Library Viewer and adding/deleting files.
- Using ENVI's "Spectral Hourglass Wizard".
  - Data dimensionality determination,
  - Pixel Purity Index (PPI),
  - n-Dimensional Visualization,
  - Spectral Analyst tool.
  - Spectral Angle Mapper (SAM) classification.
  - SAM Rule images.

Hyperspectral VNIR Datacube for Vegetation Analysis

The first datacube was acquired over semi-arid terrain of the High Plains in central Colorado. This datacube contains 128 bands of reflected VNIR wavelengths. The data is courtesy of Galileo Group, Inc. A white paper by Galileo is included in the folder containing the datacube – it is highly recommended that you review this 22-page overview of commercial hyperspectral capabilities and case histories.

The datacube is in the Chapter 9 folder of the Remote Sensing Digital Database. The subfolder "AISA_VNIR_Hyperspectral" contains the datacube, a USGS topographic map, and metadata.

1) *Start-up* ENVI > drive to the "Ch_9_Image_Processing \ AISA_VNIR_Hyperspectral" folder > *Select* "AISA_Semiarid_Hyperspectral_VNIR_ENVI" and "ESRI USGS TOPO Basemap_GIS.tif > *Open*

We use the ENVI version of the datacube because it displays the center wavelength of each band. The GeoTIFF version does not and you have to refer to the folder named "Table of AISA VNIR bands and wavelengths".

The datacube automatically opens as a color IR image
(Band 90 - Band 65 – Band 38 or NIR-Red-Green as R-G-B)

Drag the topo map beneath the color IR image in the View.
Zoom in so the color IR image fills your View.

Open the "Data Manager" to see the list of 128 bands with their wavelength.

2) Highlight (select) the hyperspectral file in the Layer Manager >
Display > *Profiles* > *Spectral*
With your cursor (the "Select" arrow is highlighted), *Click-on* bright red pixels and note how the spectral signature of pixels remains relatively constant.

The units of the horizontal axis are nanometers. The Data Value on the vertical axis is a measure of brightness or reflectance.

Click-on the Options drop-down menu and *select* "RGB Bars" to see where the 3 bands displayed in the ENVI View are located in the VNIR spectrum.

Click-on the small black triangle in the white band on the right side of the "Spectral Profile" menu to display properties of the plot.
Scroll down the "General" and "Curve" menus.
You can change the symbology, name, and range of wavelengths displayed with these menus.

With your cursor, *click on* the spectral profile line to see the exact wavelength and brightness (Data Value) for that part of the profile

3) Review Figure 9-37A and B and the text in the textbook's Chapter 9.

Click your cursor on a brightest red pixel (most vigorous vegetation) in the scene. This spectral profile is unique to vegetation.

Question 1: What is the name of the unique sharp increase in brightness (Data Value) between 680 and 745 nanometers?

Question 2: Why is the reflected brightness highest in the 520 – 600 nm range compared to the 400 – 520 nm and the 600 - 680 nm ranges?

There is another way to view spectral profiles named "Continuum Removed". This type of profile is generated by the algorithm fitting a "convex hull" arc over the top of the spectrum. The continuum removed spectral profile is very useful for evaluating absorption features (depth, shape, and width).

Click-on the "Y: Data Value" drop-down menu at the bottom of the Spectrum Profile window. *Choose* "Continuum Removed"
The shape of the spectral profile changes to highlight absorption features.

Question 3: What causes the unique absorption feature for healthy vegetation that is between ~600 and 680 nm? (Hint: think about what is causing the higher reflectance values at shorter and longer wavelengths).

The name of the deep absorption feature unique to vegetation that is revealed with the "continuum removed" tool is the "*chlorophyll absorption feature*".

Click-on the "Options" drop-down and select "Vegetation Index (NDVI)"

Question 4: A. What is the calculated NDVI value for your brightest (most vigorous) pixel?

B. What is the calculated NDVI value for the gray terrain (in the color IR image gray may represent dormant, dry grasses and other ground vegetation)?

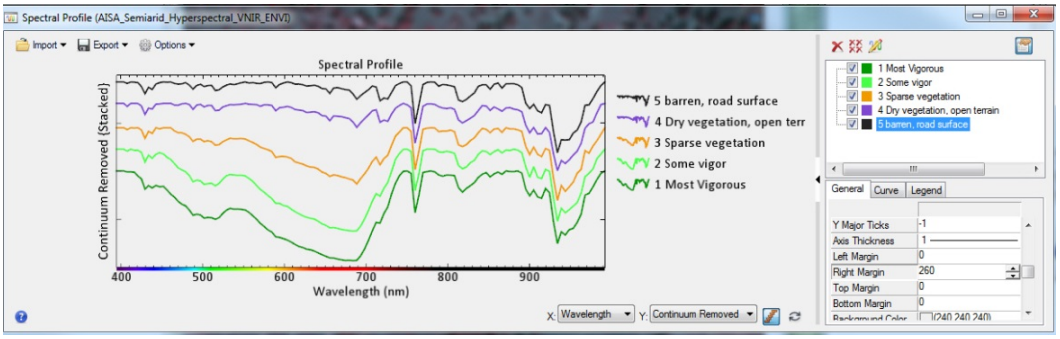
C. How did the program calculate NDVI?

4) Let's move our cursor around the image clicking on five pixels that represent a trend from most vigorous vegetation (bright red), to less vigorous vegetation, to the gray terrain (dry vegetation?) to barren ground on the road (white pixels). Place your cursor on a bright red pixel to start this task - the deep chlorophyll absorption feature is redisplayed in the "Spectral Profile" window.

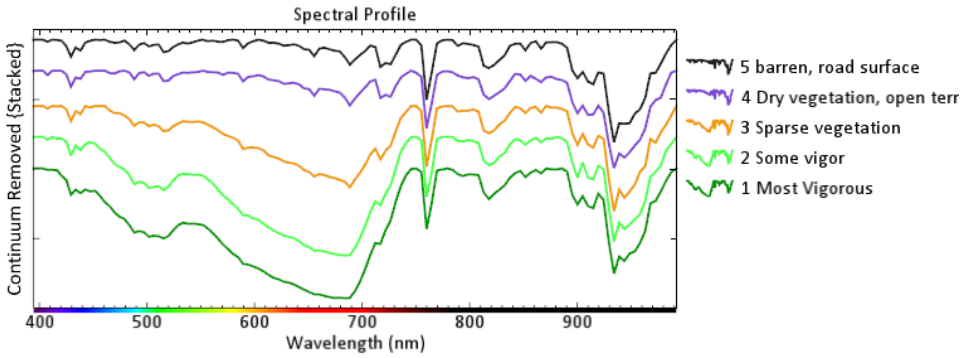
We will stack these five spectral profiles in one window so we can compare the signatures. *Click-on* the icon at the bottom of the Spectal Profile window that looks like a staircase  This stacking feature is only active when the icon is highlighted.

You have to press the Shift key on your keyboard when you *click on* the image to *collect* a spectral signature in order for the spectra to *stack* in the profile window. Have the Properties window (right side of the Spectral Profile window open so you can delete spectra you don't like.

You can edit the names of the 5 spectra, change the line thickness, and add a legend to the side so that this change in a spectral signature as vegetation cover becomes less vigorous or is reduced for a report. An Example is below with the Properties menu open so that you can see where some changes were made.



You can Export the spectral profiles and the legend to several different graphic formats (see .png graphic below). This makes the spectral work you have done more accessible to others who don't have or want to do image processing.



For this lab, it is an option to customize your 5 spectral profiles so you can learn about the symbology tools in ENVI. Use the "Curve" tab to customize your legend. Use the "General" tab to add the legend to the Export, change line thickness, etc. The symbology work takes some time…but is worth it if you are going to present your results to others.

Export > *Image* > *Name* the plot "YourName_5_Spectral_Profiles" as a .png.

Upload your png graphic to the instructor.

Question 5: Discuss in 2 or 3 sentences what happens to VNIR spectral profiles when you move from vigorous vegetation to no vegetation (barren terrain).

5) Let's visualize the data cube.

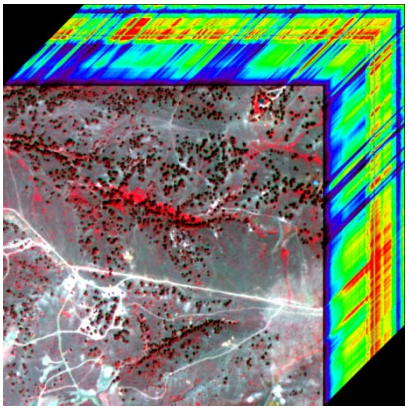
ENVI Toolbox > *Spectral* > *Build 3D Cube*
Select the 128 band datacube > *OK*

For the front of the datacube, let's generate a color IR image using the same bands as were automatically displayed in the View by ENVI (these three bands are designated in the metadata for automatic display). *Select* the following 3 input bands:

R = Band 90
G = Band 65
B = Band 38 > *OK* > the ""3D Cube Parameters" window pops-up

Accept defaults (rainbow color scheme and spectral scale)
Name the visualization "Colorado_3D_cube"

The processing may take 1-2 minutes.
The 3D cube is an ENVI .img file with .hdr header.
This format is *not* useful for a report graphic.
Let's *save* our 3D cube as a full resolution, .tif.



Uncheck the topo map.
Zoom in to the datacube so it fills your view.
File > *Export View To* > *Image File*
Ensure "Output Extent" is *Current"*
Leave "Zoom Factor" as 1.000
Change Output Format to "TIFF"
Uncheck "Display result"
Name the 3D cube "YourName_3D_Datacube" > *OK*
Upload your excellent graphic to the instructor.

6) To help understand the richness of the hyperspectral data, we can compress the 128 bands with an algorithm named “Minimum Noise Transform” (MNF) which is similar to Principal Components. *Open* **Help** and *search* for “MNF” to learn more – a lot more about MNF. **MNF Rotation** transforms determine the inherent dimensionality of image data, segregate noise in the data, and reduce the computational requirements for subsequent processing (Boardman and Kruse, 1994).

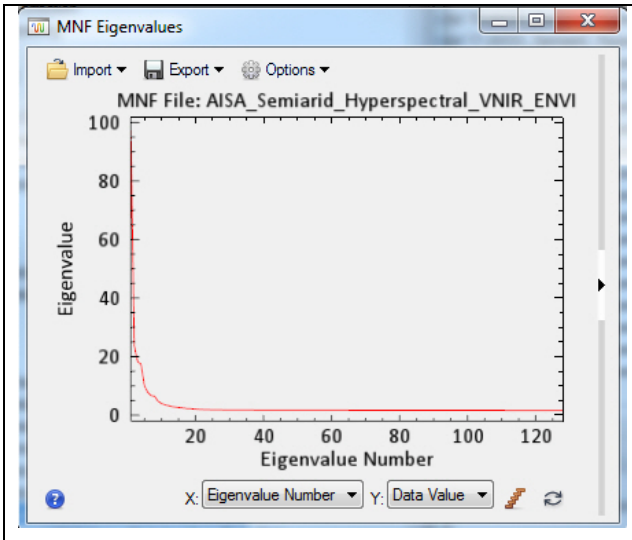
We will run the MNF program, select those grayscale MNF bands that contain the vast majority of variance and little noise, and then perform an unsupervised classification on the selected MNF Bands to determine if this enhancement improves our understanding, pattern recognition, and mapping of vegetation, soils, and clearings .

ENVI Toolbox > Transform > MNF Rotation > Forward MNF Estimate Noise Statistics
Select the AISA 128 band hyperspectral data *> Open*
Accept defaults on the MNF Transform Input File > OK

The “Forward MNF Transform Parameters” window pops-up
Output Noise Stats Filename: “VNIR_MNF_noise_”
Output MNF Stats Filename: VNIR_MNF_stats”
Output Filename: “VNIR_MNF_128bands” *> OK*

The computation of MNF bands will take some time – be patient.

When done, the 128 MNF bands appear in the Data Manager and a color composite of MNF Band 3 – 2 - 1 as R – G –B is displayed in the View.



The MNF Eigenvalues plot

Note the rapid drop-off in Eigenvalue.

This plot indicates that most of the original information in the data cube (variance) is now contained within the first 10 to 15? MNF bands.

We will use the Band Animation tool to examine the MNF bands and create color composites to determine how many MNF bands we will use going forward.

The MNF Eigenvalues plot also appears (VERY similar to the PC plot)

7) Determine the number of MNF bands for further processing. *Zoom-in* so the image fills your view.

If the MNF image in the View is *black*, click "Linear 1%"
Right-click on "VNIR_MNF_128bands" file in Layer Manager
> *Band Animation*
You may have to *stop* Band Animation and *stretch* the MNF file in the Layer Manager with "Linear 1%"
Keep *moving* the slider back to 1 after you start to see too much noise
Set timer for 1 second

MNF Band 1 has noise and all bands >10 to 15 have excessive noise?

Close the Band Animation tool > Use the Data Manager to generate color composites from MNF Band 2 to MNF Band 10. Evaluate quality.

We will create a new MNF Band dataset with bands 2-10
File > *Save As* > *Save As (ENVI, NITF…)* "Data Selection" menu pops-up
"VNIR_MNF_128 bands" should be highlighted.
> *Click* "Spectral Subset" > *Select* bands 2 – 10 > *OK* > *OK*
Name the output file "VNIR_MNF_9bands" in ENVI format > *OK*

8) The 9-band MNF dataset appears in the Data Manager. You may have to load a color MNF 4-3-2 as R-G-B using the Data Manager to have the "VNIR_MNF_9bands.dat" file appear in the Layer Manager.

9) We'll run an unsupervised classification on the 9-band MNF file to determine if new information is seen compared to the color IR and other band combinations.

ENVI Toolbox > Classification > Unsupervised Classification > IsoData Classification

Choose the "VNIR_MNF_9bands.dat file" > *OK*

The ISODATA Parameters window pops-up.
Change the Max number of classes to 15
Change Maximum Iterations to 15
Change Threshold % (0-100) to 3.00
Accept other defaults *Press* "Help" to learn what these parameters mean.

Output Filename : "VNIR_9-MNF_iso_15cla" > *OK*

10) If not already done, change to 2 vertical Views. Have the unsupervised classification in one view and the color IR image in the second view. Link the Views.

Question 6: A. Do you think there is new information and patterns in the classification map about vegetation, soils, barren ground, etc. that made our MNF and isoDATA effort worthwhile?

B. Do you see shadows in the classification map? If so, what class number represents many shadows?

C. What class number represents the most vigorous vegetation?

Close all files in the Data Manager. Return to one blank View.

Hyperspectral SWIR Datacube for Geologic Mineral Mapping

The second hyperspectral datacube is in the Chapter 9 folder of the "Remote Sensing Digital Database" in the "Ch_9_Image_Processing \ Dig_Img_1-2_Hyp-Multi_Cuprite-NV" subfolder. Digital Image 1-2 shows the Cuprite, Nevada area of interest.

File > *Open* drive to the "Dig_Img_1-2_Hyp-Multi_Cuprite-NV" folder, and open the "AVIRIS SWIR 50 bands" subfolder. We will be working with only SWIR data.
Select "cuprite_AVIRIS95_atm_50-SWIR_ENVI_" > *Open*

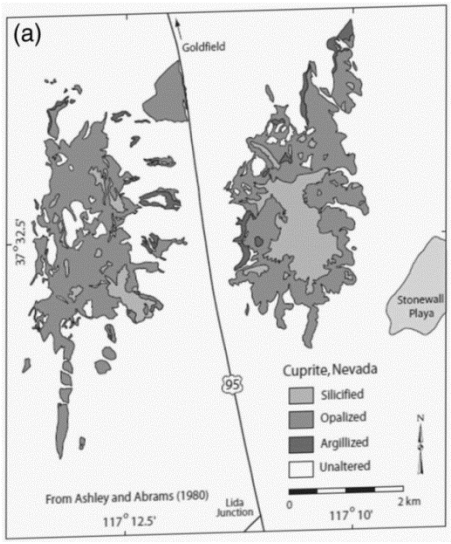
Apply a Linear 1% stretch

Open the Data Manager. *Select* Bands 214 – 193 – 173 as R-G-B > *Load Data*

File > *Open* return to the "Dig_Img_1-2_Hyp-Multi_Cuprite-NV" folder and open the "Cuprite_Geology_Maps" folder. We will load two geology maps.

*Select "*Field_Alteration_Zones_Ashley-Abrams_GIS.tif" and
"USGS Hyperspectral Map_GIS_JARS_9_1_0960044.tif"

1) Cuprite is in the mining district of Nevada, located about 200 km northwest of Las Vegas. Hydrothermal alteration is extensive at Cuprite. There are three mapped zones (silicified, opalized, and argillized) that include mineral assemblages (see below). The silicified zone contains abundant quartz, chalcedony, minor alunite, kaolinite and post-alteration calcite. Opalized rocks (opalite) contain opal with variable amounts of kaolinite and alunite, and minor calcite. Argillized areas are typically within or adjacent to opalized zones and contain primary quartz, unaltered sanadine, opal, montmorillonite and kaolinite. (*Kruse, Baugh, and Perry, 2015, Validation of DigitalGlobe Worldview-3 Earth Imaging satellite shortwave infrared bands for mineral mapping: Journal of Applied Remote Sensing, SPIE, v. 9, p. 096044-1 to 096044-17*).



Ashley and Abrams, 1980, USGS Open File Report 80-367.

Kruse, Baugh, and Perry (2015) also provide the USGS hyperspectral mineral map and legend (available in the Remote Sensing Digital database as "USGS Hyperspectral Map_GIS_JARS_9_1_096044.tif" and "Hyperspectral Legend" (see below).

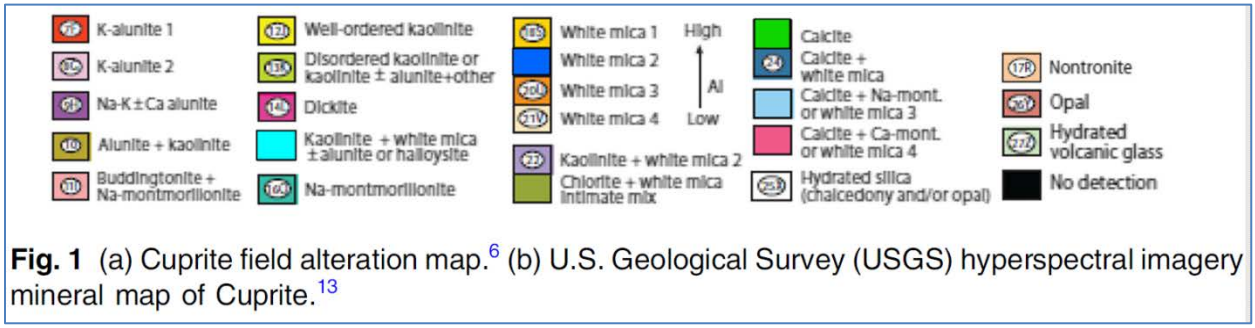


Fig. 1 (a) Cuprite field alteration map.[6] (b) U.S. Geological Survey (USGS) hyperspectral imagery mineral map of Cuprite.[13]

To see this legend picture on your screen, *drive* to the "**Lab_11_Data**" or the "Cuprite_Geology_Maps" folder and *open* "Hyperspectral_Legend.tif". You can see and enlarge this legend on your computer screen with any computer picture viewer program while mapping in ENVI.

Next we'll be comparing the geology maps, legend, and AVIRIS SWIR color image.

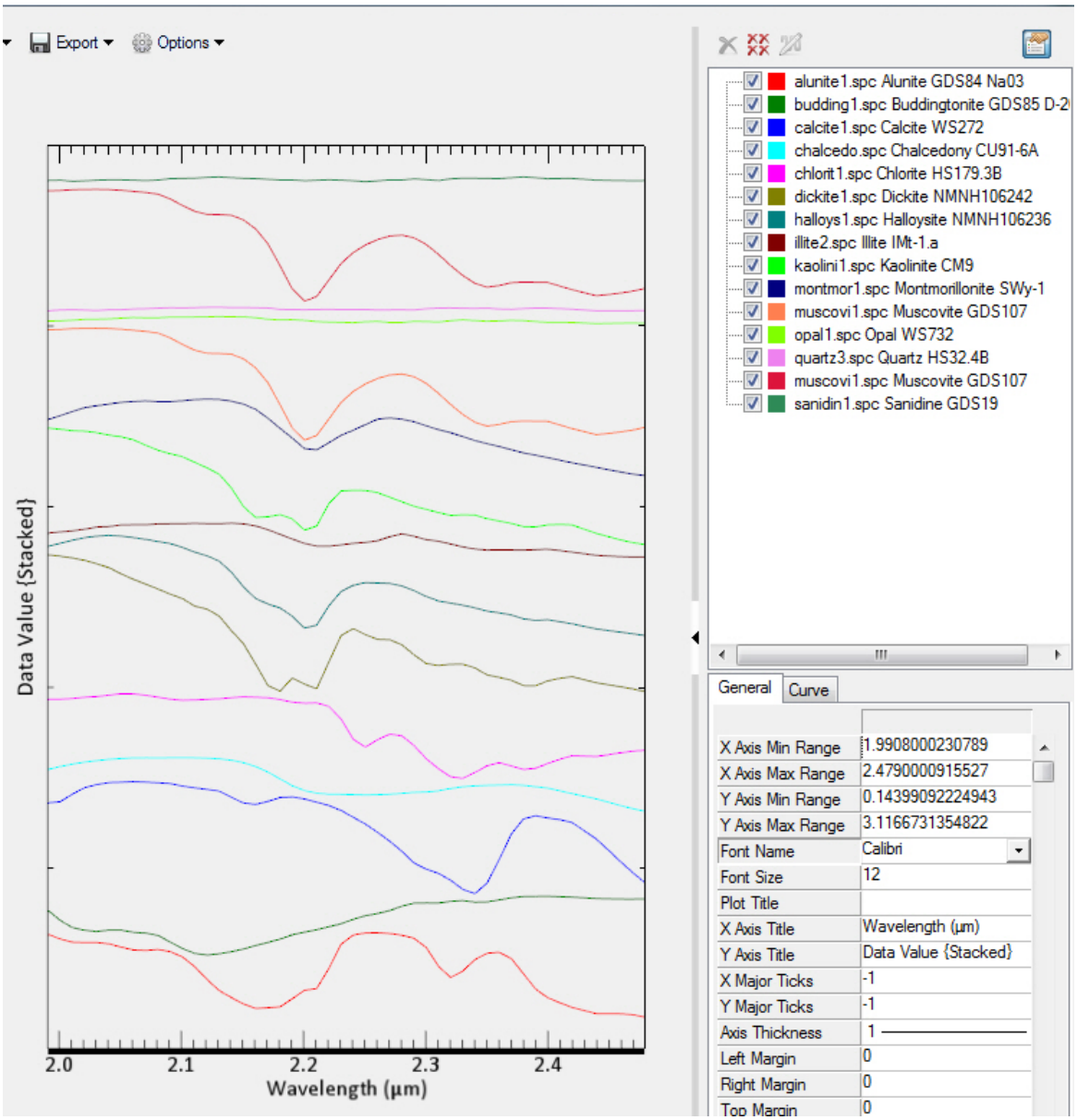
2) To expedite this lab, I used the USGS Mineral Spectral Library (available from the USGS; in ENVI available as "usgs_min.sli") that was developed with detailed VNIR-SWIR signatures of minerals in a laboratory setting, and I converted this library to a spectral library that fits the airborne AVIRIS 50-band SWIR data. Then I extracted 14 minerals that were mapped by the USGS at Cuprite (see legend above) and created a new spectral library for this lab's AVIRIS 50-band SWIR data.

This focused spectral library is named

"USGS_Min_Spec_Cuprite_50band_14minerals.sli"

and is found in the **Lab_11_Data** folder.

The 14-mineral Cuprite library is shown below. The list of minerals on the right is shown as spectral signatures in the reverse sequence on the left. Note the red alunite band is at the bottom of the spectral signatures and at the top of the list on the right. Many unique absorption features that are used to identify minerals occur at different wavelengths.

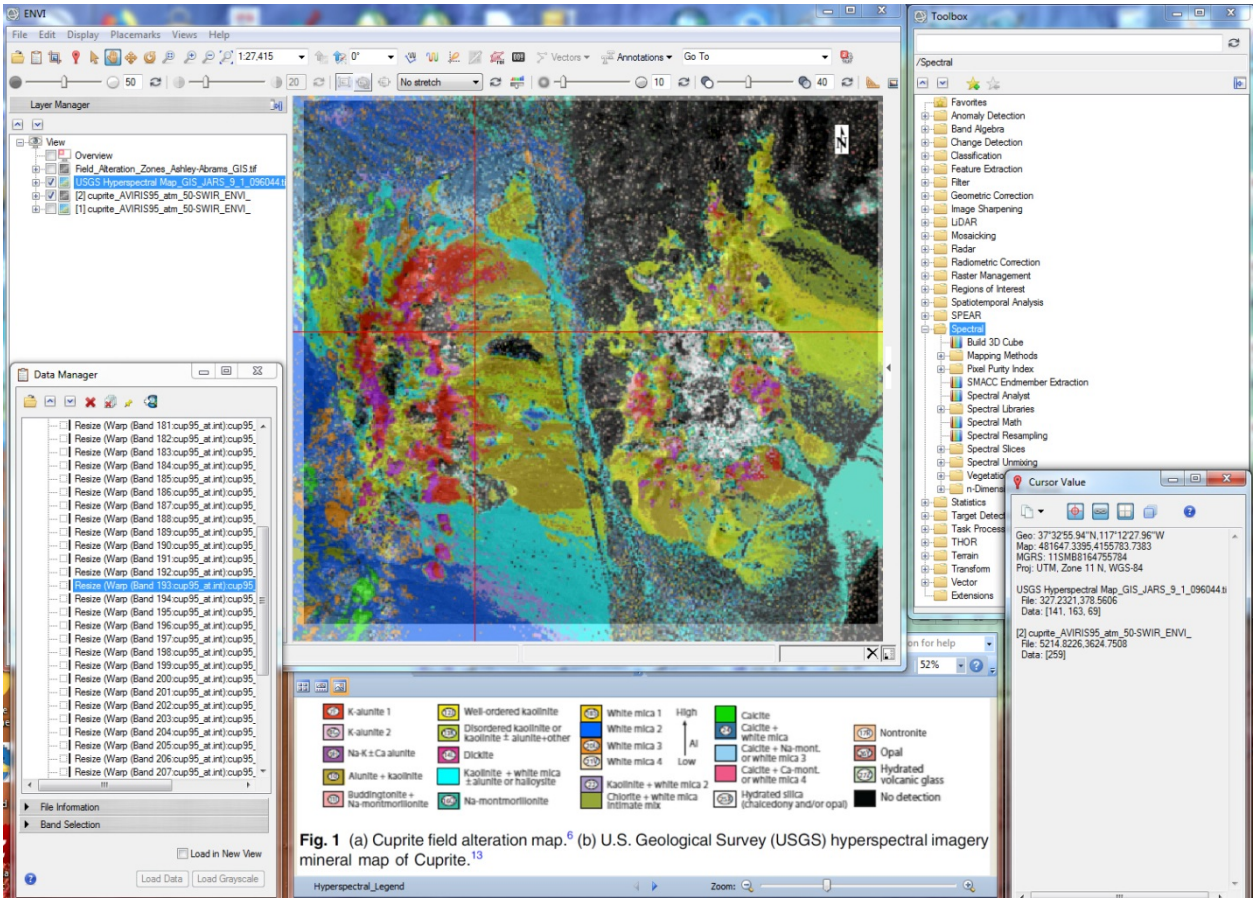


NOTE: My 14-mineral spectral library (above) has significant limitations because I did not account for differences in composition when creating the Cuprite 14 mineral spectral library. Many minerals have more than one entry in the "usgs_min.sli" spectral library because of differences in composition.

Quartz does not have a diagnostic spectral absorption feature in the SWIR wavelengths. Opal, sanadine and chalcedony also lack an absorption feature. They are included in the 14-band spectral library as field work by Ashley and Abrams (1980) confirmed their occurrence at Cuprite.

3) You should have the 50-band SWIR data, the color geologic map and the grayscale map in your ENVI display. Open the USGS color mineral legend (shown above) with a

picture viewer and place it next to the ENVI display so you can more easily correlate colors on the map displayed in ENVI with the legend.



Example of the set-up for one computer screen that includes the ENVI display, Data Manager, Toolbox, and the USGS color legend as a floating picture. The color map is interactively made transparent and opaque with the slider to help pick sites for a spectral profile.

3) Let's compare spectral profiles in our hyperspectral data to spectra in the USGS spectral library.

a) *Zoom-in* so the hyperspectral image fills your View. *Click-on* the grayscale map and *click-off* the color map. Turn the grayscale map *on & off* so you can compare the map patterns to patterns on the hyperspectral image. The "Silicified" pattern can be seen on the image.

b) Notice that the map does <u>not</u> fit the image very well – the image is not orthorectified so distortions due to topography are inherent and both maps were screen-captured from the pdf publication so they also have inherent distortions.

c) *Click-off* the grayscale map and *click-on* the color geologic map. Use the transparency slider to compare the patterns on the color map with the hyperspectral image. Use the Data Manager to load any grayscale band. The color map when partially transparent will be easier to compare with patterns on a grayscale band– it will be more apparent when the map is not aligned with the image.

d) *Set* the transparency for the color map at 40%,
Highlight the 50-band hyperspectral data in the Layer Manager.
Click-on the *Spectral Profile* tool (or use *Display* > *Profiles* > *Spectral*).

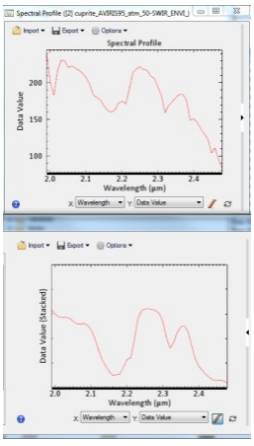
e) The Spectral Profile window pops-up.
Move your cursor to the bright red pattern ("K-alunite 1" mineral) that is mapped on the western hill. "K-alunite" and "alunite1" are the same in this lab exercise.
Move your cursor to different locations in the red, K-alunite outcrop pattern. Notice how consistent the absorption feature is at ~2.17 µm. Place your cursor on the bottom of this absorption feature and see the wavelength value in red numbers at the bottom of the window.

To better interpret absorption feature wavelengths and shapes, *click-on* the "Data Value" drop-down menu below the spectral profile .

Choose "Continuum Removed". Now click around the red pattern and observe the consistency and variation in the ~2.17 µm absorption feature.

Keep the Spectral Profile window open – we will *compare* the airborne AVIRIS profile in this window to the USGS spectral library profile of alunite next.

f) We open the 14-mineral spectral library that is in the **Lab_11_Data** folder.
File > *Open* drive to the **Lab_11_Data** folder
Select "USGS_Min_Spec_Cuprite_50band_14minerals.sli" > *Open*



The "Spectral Library Viewer" window pops-up.
The 14-band library is open on the left side of the window.
Select "alunite1…"

Move the library window with the spectral profile under the spectral AVIRIS spectral profile for alunite so the two profiles are aligned. See example to left.

Open the Properties menu (black triangle on the right side) of the Spectral Library Viewer so you can see the mineral that is displayed, and can delete profiles as needed.

Compare the shape and wavelength of the K-alunite1 (red pattern) spectral profile on the geologic map and in the USGS Spectral Library. *Click* around the alunite outcrop on the geologic map with your spectral profile tool.

Alternate profile display between "Continuum Removed" and "Data Value"

Question 7: A. Do you find the absorption feature of alunite is *relatively* consistent between the pixels in the hyperspectral data set and the USGS Spectral Library? YES NO

NOTE: Most pixels are mixtures of minerals – there are very few pixels in a scene characterized by only one mineral – pure pixels are named "end members". So you will see variation in the shape and perhaps in the wavelength of the absorption feature for most pixels in the scene.

g) *Move* and *Click* your cursor on the bright green pattern on the color map (lower left). Your outcrop has to be within the smaller area covered by the AVIRIS image! A new spectral profile from the 50-band SWIR hyperspectral data is displayed. Click around the green pattern – is the spectral profile consistent?

In the "Spectral Library Viewer", find the <u>one</u> mineral in the USGS library that matches the mineral represented by the bright green color on the map.

Select and *delete* the "alunite1…" and other profiles you try out in the properties menu for clarity.

Question 8: A. What mineral is represented by the green color in the USGS color map?

B. What is the wavelength of the absorption feature in both the hyperspectral data and in the spectral library?

h) Kaolinite, Dickite, and Halloysite are clay minerals with similar chemical and physical properties. They are common in hydrothermally altered terrain.

Display these three clay minerals in the Spectral Library Viewer.

Click inside the <u>yellow</u> pattern on the color map (well-ordered Kaolinite).

Question 9: A. Do you find pixels with the deepest absorption feature at ~2.21 µm? YES NO

B. Do you find pixels with the "doublet" absorption feature? (two absorption features next to each other) YES NO

B. What is the wavelength for the deepest absorption feature for dickite and halloysite in the spectral library?

i) *Add* "muscovi1" (muscovite = white mica) to the Spectral Library Viewer.

Click-on many pixels in the blue pattern (White mica 2) on the color geologic map and analyze the spectral profiles.

Click-on many pixels in the orange pattern (White mica 3) on the color geologic map and analyze the spectral profiles.

Question 10: A. What is the wavelength of the absorption feature for "muscovi1" (white mica) in the spectral library?

B. Describe the difference between the shape of the absorption feature of kaolinite and muscovi1 (white mica).

j) Remove all the minerals from the Spectral Library Viewer *except* kaolinite ("kaolini1"). Reload "alunit2" into the viewer. Think about what would happen to the absorption feature between ~ 2.15 and 2.23 µm if you mixed kaolinite and alunite.

Click around the "Alunite + kaolinite" pattern on the color map.

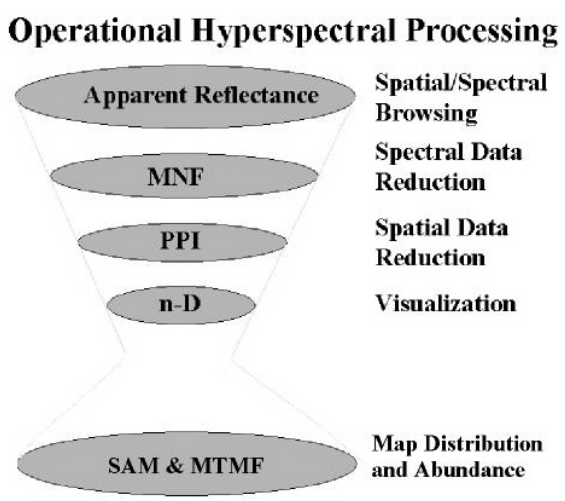
Question 11: A. What often happens to the depth of the first absorption feature in the kaolinite doublet (~2.16 µm) when alunite is mixed in?

NOTE: The spectral profiles of pure pixel end members are used to **unmix** the minerals in mixed pixels…and theoretically estimate what percentage of each mineral is in the mixed pixel. Finding pure pixels (end members) and "Unmixing" are often major goals of hyperspectral processing.

k) *Close* the Spectral Library Viewer and the Spectral Profile windows.

Uncheck all the layers in the Layer Manager except the 50-band hyperspectral data set

A good way to learn about hyperspectral processing is to use ENVI's "Spectral Hourglass Wizard" (created by J. Boardman and F. Kruse). The wizard has extensive explanations for the many processes – and many *warnings* about not letting your processing blindly follow the automated steps and results. Always look at the input and output data. This lab can only touch upon some of the steps – if you are interested in hyperspectral processing work with the wizard on your own.



1. Input/Output File Selection (input data are usually in reflectance)
2. MNF Transformation to reduce spectral dimensions
3. Review of MNF Results
4. Data Dimensionality determination using Spatial Coherence measures
5. Pixel Purity Index (PPI) to reduce spatial dimensions
6. Review of PPI Results
7. n-Dimensional Visualization, including auto-clustering, to select and retrieve individual endmembers
8. The option to manually add User Supplied Endmembers
9. Spectral mapping using Spectral Angle Mapper (SAM) and/or Mixture-Tuned Matched Filtering (MTMF)
10. Investigation of Mapping Results

As you gain experience with hyperspectral data, try ENVI's Toolbox's many tools in the Spectral, SPEAR and THOR Folders.

ENVI Toolbox > Spectral > Spectral Unmixing > Spectral Hourglass Wizard

INTRODUCTION page - *READ* the text for each step!

j) After reading the first page, press > *"Next"*

SELECT INPUT/OUTPUT FILES page

select our 50-band SWIR hyperspectral dataset for input.

Select an output folder for the many files that are produced.

> Next

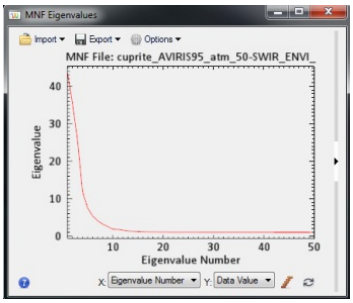
1) FORWARD MNF TRANSFORM page

Accept Defaults input “50” MNF bands

Do not use “Shift Difference Spatial Subset…”

> *Next*

MNF Eigenvalues” plot pops up (see plot to right).



Do you see a flattening of the MNF curve after “10” ?
(10 of the 50 MNF Eigenvalue bands have a value above 1.8538.
The remaining 40 MNF bands have very little data variance – mostly noise).

2) > *Next* <u>VIEW MNF RESULTS</u> page

“Load MNF Result to ENVI Display….”
The wizard may automatically fills the ENVI Classic 3-window display *and* the newer GIS-look display. Look for the list of MNF bands in the Data Manager.

Apply “Linear 1%” stretch if image is black.

“Load Animation of MNF Bands…” If this window does not appear, look in the Windows Taskbar at the bottom of your computer screen to display….
Slow the animation down with Speed “1” More effective to hit the “Pause” symbol and *manually* work your way back and forth through the bands with the black arrows.

Question 12: A. What do you visually see as a reasonable number of MNF bands to use going forward? (relatively clean data, not much noise).

3) > *Next* <u>DETERMINE DATA DIMENSIONALITY</u> page

We see the MNF Eigenvalues plot again – with a black background.

Accept defaults (50) > Calculate Dimensionality

The “Spatial Coherence Threshold” plot shows up. Move the horizontal red line up and down number (use your cursor in the plot or the arrows).
Each Threshold Level specifies the number of bands above the threshold.

Question 13: A. What "Threshold Level" did you decide to use and how many MNF bands does the ENVI program recommend using going forward?

B. Why the difference between what you saw with your eyes and what the computer program specifies as good MNF bands to use going forward?

To achieve lab class consistency, let's type in"20" as the number of MNF bands to retain going forward. Type "20" into the Data Dimensionality window.

4) > *Next* DERIVE OR SELECT ENDMEMBERS page

Choose to Derive Endmembers from Image "Yes" > *Next*

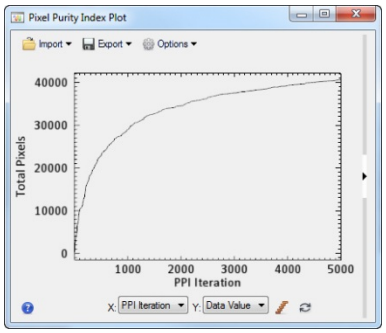
5) PIXEL PURITY INDEX page

Accept the PPI defaults (5,000 iterations, threshold value 2.5, memory use 10.0 Mb. > *Next*

NOTE:
I found 20,000 iterations on a fast workstation provided a curve that flattened more compared to the default 5000 iteration curve.
If you are on a fast computer, try increasing your iterations and maximum memory.

You want to flatten the curve in the upper right.

A PPI image with a grid pops up on the ENVI View.



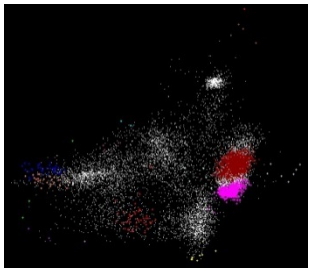
6) EXAMINE PPI RESULTS page *Accept* 10,000 default > *Next*

7) N-DIMENSIONAL VISUALIZER page Read the discussion on this page!

Enlarge the "n-D Visualizer" window > *Start*

Reduce speed to 10. Be amazed by the cloud with end members

These are "pure" pixels color-coded by the ENVI wizard.



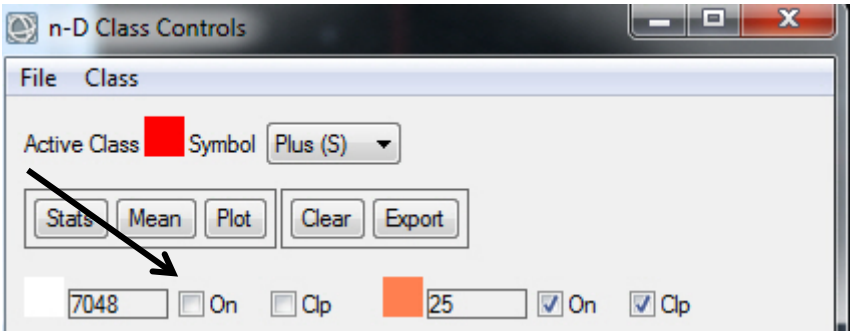
Examine the drop-down menus in the "n-D Controls" window.

Options > Show Axes

Options > Class Controls

The "n-D Class Controls" window pops-up with the 20 color-coded classes

Turn off the White pixels (I have 7048 white pixels). The white pixels are not end members (my understanding…). I see a much clearer picture of the 19 end members! Do you?



There are 20 MNF bands in the "n-D Controls" window (looks like a calendar) They are color-coded in the "n-D Class Controls" window.

Try different 3-band combinations. Turn off the active 3 bands, and then select 3 new bands. After a few combinations, try 18-19-20 > *Start*

Question 14: A. What happens to the cloud when you load MNF bands 18-19-20 into the n-D Visualizer?

B. What does the 3D shape of the 18-19-20 cloud tell you about coherent spectral information and noise in these MNF bands?

8) You can add your own end members by interpreting corners in the cloud or by importing from a Spectral Library. We will import our "alunite1" spectral profile from our 14-band spectral library.

"n-D Controls" > *Options* > *Import Library Spectra* >
"n-D Visualizer Import Spectra" window pops-up >
Import *select* "from Spectral Library File>
"Spectral Library Input File" window pops up
If you don't see our 14-band spectral library in the list, go to the "Open" drop-down menu at the bottom of this window > *choose* "Spectral Library" > drive to **Lab_11_Data** folder with our 14-band library > *Select* > *Open*

In the "Spectral Library Input File" window our 14 band library file displays at the top of the list>

Select "USGS_Min_Spec_Cuprite_50band_14minerals.sli" > *OK*

The “Input Spectral Library” window pops up.

Select “alunite…” accept defaults > *OK*

Two more windows pop-up(!).

The “alunite1…” spectra is highlighted and the profile displayed in the Spectral Library Viewer.

“alunite1…” is also highlighted in the “n-D Visualizer Import Spectra” window > *Apply* and then *the* second small window (“Import Spectra Parameters”) pops-up > *Accept* default color > *OK*

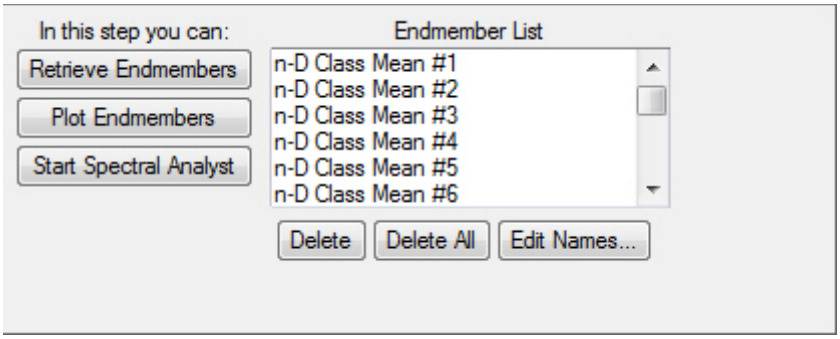
The Alunite1 position in the cloud is displayed and labelled!

Try to determine what if any PPI endmembers correlate spatially with the USGS “alunite1…” spectra. The magenta endmember (553 pixels) and the dark brown endmember (2149 pixels) are often near the USGS spectra as different bands are selected with the n-D Visualizer tool.

6) Let’s delete our Alunite1 point. “n-D Controls” > “Options” > “Delete Library Spectra” window pops-up > select “alunite1*…”* > *OK*

7) In the Wizard’s N-DIMENSIONAL VISUALIZER page
> *click on* “Retrieve Endmembers”
The 19 endmembers populate the Endmember List.

The “Plot Endmembers” and “Start Spectral Analyst” buttons are activated.

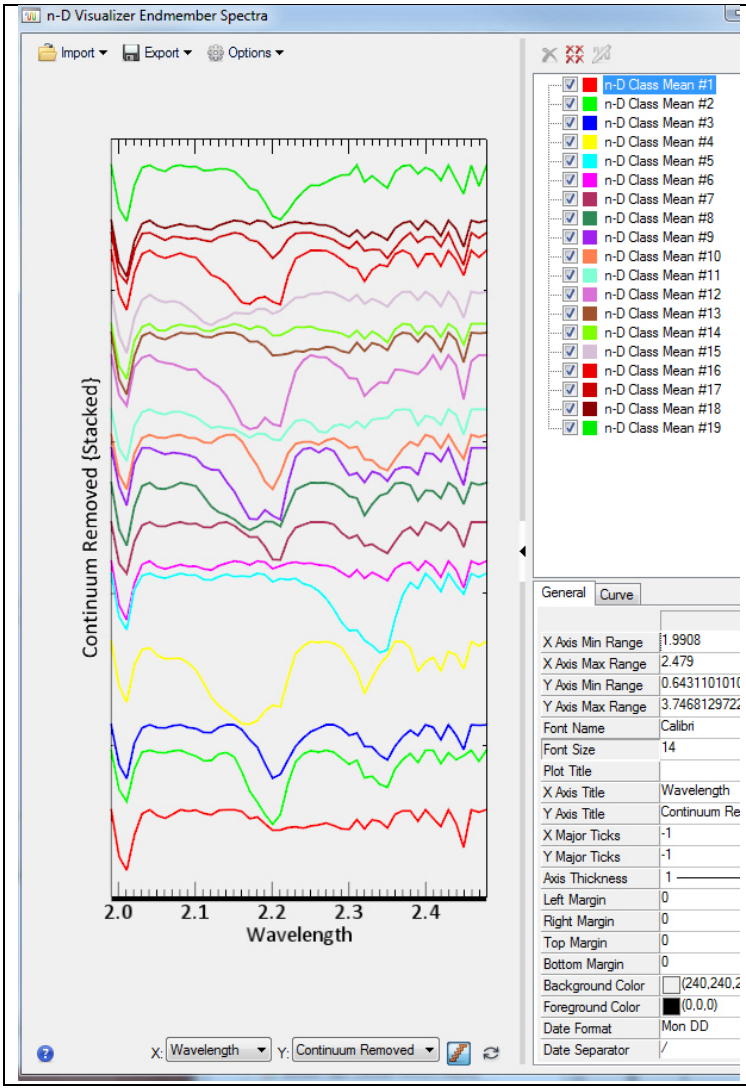


Click-on “Plot Endmembers”

The “n-D Visualizer Endmember Spectra” window pops-up.
(see window below)

Change from “Data Value” to “Continuum Removed”
Click on the “Stack Plots” icon

Read through the text on the right side of the "n-D Visualizer Endmember Spectra" window below. Note how similar these endmember spectra to some of the spectral profiles we found while clicking around the AVIRIS SWIR data set. Muscovite (white mica). Calcite.



"n-D Visualizer Endmember Spectra" window

"Data Value" changed to "Continuum Removed"

Clicked on "Stack Plots"

What endmembers have unique spectral profiles in the SWIR wavelength range?

Experienced analysts can identify the material (minerals in our example) that is associated with a spectral profile on the left.

"n-D Class Mean #2 (green profile 2nd from the bottom) is very similar to "muscovite" or "white mica".

"n-D Class Mean #5 (cyan profile 5th from the bottom) is very similar to "calcite".

The end member spectra can be exported from this menu as a spectral library using the "Export" dropdown menu! Then you could do an excellent job comparing your endmember spectra to large spectral libraries and more accurately rename the endmembers. You could also delete those endmembers that had spectra that was not in your area (based on field work and knowledge about materials in the scene.

Also you could use the "Start Spectral Analyst" tool that is shown on the "N-Dimensional Visualizer" menu to help identify your endmember spectra.

These are very powerful tools!

The spectral signatures and names of the 19 endmembers are shown on the plot above

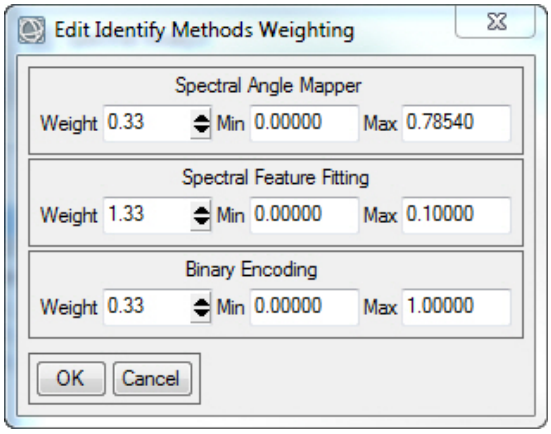
<u>The profiles and list are in reverse order</u>. "n-D-Class Mean #1" is at the bottom of the profile stack…n-D Class Mean#19 is at the top of the profile stack.

8) You should realize that several of these spectral profiles look like spectra in our 14-band Spectral Library. <u>Read the text in the box above.</u>

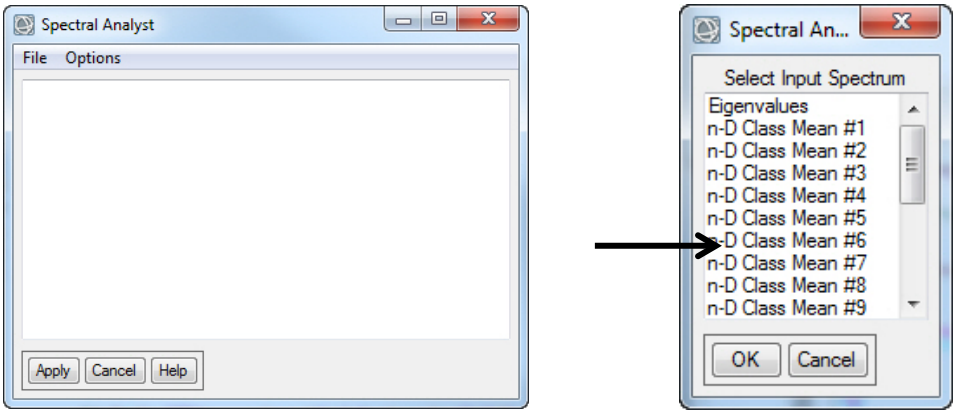
Click-on the “Start Spectral Analyst” button in the Wizard’s N-DIMENSIONAL VISUALIZER page

The “Spectral Analyst Input Spectral Library” window pops-up.
Select our 14-mineral Spectral Library (if it isn’t in the list, go to the drop-down menu at “Open” > Spectral Library > and drive to our library location in the **Lab_11_Data** folder and select > *OK*

The “Edit Identify Methods Weighting” window pops up.
We will use all three methods to evaluate our 19 endmember spectral profiles so enter 0.33 in the three “Weight” windows. > *OK* (see below)

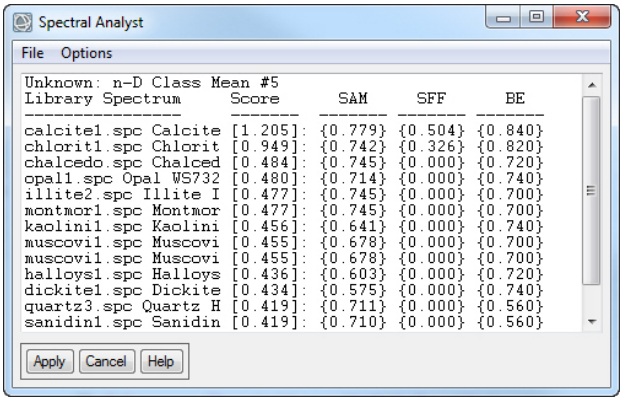


A blank “Spectral Analyst” window pops up (see below at left)
Click Apply and a list with our 19 endmembers pops-up (see below at right)



Select endmember #5 (we think this looks like Calcite) > *OK*

The “Spectral Analyst” window pops back up with a list of potential spectra that match our endmember #5 – ranked by score. (see below)



#1 fit is Calcite!

Click on **Help** at the bottom of the Spectral Analyst menu to understand the limitations and processes involved. Some Help comments below.

NOTE: Use the **Spectral Analyst** to help identify materials based on their spectral characteristics. The Spectral Analyst uses ENVI techniques such as Binary Encoding, Spectral Angle Mapper, and Spectral Feature Fitting to rank the match of an unknown spectrum to the materials in a spectral library.
The output of the Spectral Analyst is a ranked or weighted score for each of the materials in the input spectral library. The highest score indicates the closest match and indicates higher confidence in the spectral similarity. Similar materials may have relatively high scores, but unrelated materials should have low scores.
This function does not identify spectra; it only recommends likely candidates for identification.

Question 15: A. Using the “Spectral Analyst” tool, click on “Apply” and select “n-D Class Mean #9”. What three closely related clay minerals have the highest score?

B. Look at the profile of n-D Class Mean #9. What is the term used to describe the unique spectral absorption feature between 2.17 and 2.21 µm?

C. Using the “Spectral Analyst” tool, click on “Apply” and select “n-D Class Mean #4”. What mineral has the highest score?

9) “Edit Names” in the Endmember List shown in the Wizard’s the Wizard’s N-DIMENSIONAL VISUALIZER page.

Change “n-D Class Mean #5” to “Calcite”
Change “n-D Class Mean #9” to the mineral with the top score.
Change “n-D Class Mean #4” to your answer above.
Your changes will show up on our next map!! *> Next*

10) USER SUPPLIED ENDMEMBERS page. We won't add "User Supplied Endmembers". If you did field work and collected spectra, you could add your spectra her to improve and validate your map. > *Next*

11) MAPPING METHODS page. Carefully **read** this section – excellent review of the different methods!

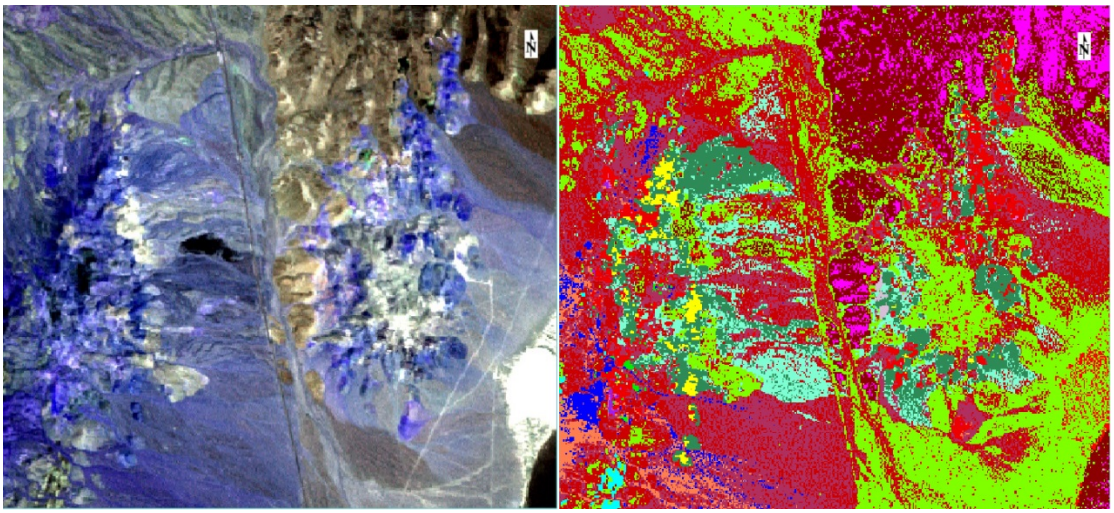
Let's just do *one* method – SAM with the default SAM Maximum Angle of 0.10
(*uncheck* MTMF and Unmixing methods) > *Next*

12) The SAM process is completed and the Wizard page INVESTIGATE SAM RESULTS page pops-up. **Read** this explanation of SAM.

In the Data Manager you will see the SAM 19-class classification map (shown below) and the SAM 19 Rule Images (grayscale).

Turn on your SAM classification map and the USGS Hyperspectral classification map. Turn all other layers *off* in the Layer Manager.

Highlight the SAM map in the Layer Manager. Manually use the transparency slider to fade the SAM map from opaque to transparent. Answer Question 16.



Color composite of SWIR bands SAM map with 19 classes

Question 16: Questions are based on the SAM classification map.
(Hint: Use the "Cursor Value" tool to query the class shown on your map)
A. Is Calcite located in the same place as on the USGS hyperspectral color map? YES NO

B. What is the "nD-Class Mean #3 class on the USGS hyperspectral color map?

C. Right-click on the "Classes" folder under the SAM map in the Layer Manager > *Select* "Statistics for all Classes". In the "Data Selection" window ensure the "cuprite…_sam_class" file is *selected.*

What are the three largest classes?
What are the three smallest classes (don't include "Unclassified")?

D. Does your classification map show spatially coherent classes?
YES NO

13) SAM Rule images are grayscale probability images. Each endmember has a SAM Rule image. The better the fit of the pixel to the endmember's spectral profile, the smaller the "spectral angle" and the blacker the pixels in the Rule image. Use the Cursor Value tool to query light and dark pixels in the Rule images.

In the Data Manager, expand the "cuprite…._sam_rule" file so that the 19 endmembers are displayed.

Select the "Rule (Calcite)" > *Load Grayscale* > *contrast stretch* "Linear 1%"
Calcite is the renamed "n-D Class Mean #5"
Use the Cursor Value tool to query the brightest and darkest pixels.
(you could also use the "Quick Stats" tool to get exact values).

Question 17: A. What is the SAM Rule value for the brightest pixel you find?

B. What is the SAM Rule for the darkest pixel you find?

C. According to the USGS color geologic map, what mineral is located where the Calcite SAM Rule map has the brightest pixels? (meaning spectra in these pixels are very different compared with calcite spectra).

C. Where are the darkest pixels located?

Turn-off all layers in the Layer Manager. *Turn-on* the colorful SAM classification map.
File > *Chip View To* > Geospatial pdf
Leave the metadata blank…bad practice but this lab is too long!
Output Filename: "YourName_SAM_map" *check* "Display Result"
Upload your geospatial pdf to the instructor.

Congratulations for completing this lab! You now have some understanding of the potential for hyperspectral remote sensing to provide unique, very informative, and very detailed maps of material on the Earth's surface.

Lab 11 Hyperspectral Section 1 Name:

Hyperspectral VNIR Datacube for Vegetation Analysis

Upload the following files to the instructor:

"YourName_5_Spectral_Profiles" as a .png

YourName_3D_Datacube" as a .tif

Question 1: What is the name of the unique sharp increase in brightness (Data Value) between 680 and 745 nanometers?

Question 2: Why is the reflected brightness highest in the 520 – 600 nm range compared to the 400 – 520 nm and the 600 - 680 nm ranges?

Question 3: What causes the unique absorption feature for healthy vegetation that is between ~600 and 680 nm? (Hint: think about what is causing the higher reflectance values at shorter and longer wavelengths?)

Question 4: A. What is the calculated NDVI value for your brightest (most vigorous) pixel?

B. What is the calculated NDVI value for the gray terrain (in the color IR image gray may represent dormant, dry grasses and other ground vegetation)?

C. How did the program calculate NDVI?

Question 5: Discuss what happens to VNIR spectral profiles when you move from vigorous vegetation to no vegetation (barren terrain).

Question 6: A. Do you think there is new information and patterns in the classification map about vegetation, soils, barren ground, etc. that made our MNF and isoDATA effort worthwhile? YES NO

B. Do you see shadows in the classification map? If so, what class number represents many shadows?

C. What class number represents the most vigorous vegetation?

Lab 11 Hyperspectral Section 2 Name:

Hyperspectral SWIR Datacube for Geologic Mineral Mapping

Upload the following file to the instructor:

"YourName_SAM_map" as a pdf (at the end of the lab)

Question 7: A. Do you find the absorption feature of alunite is *relatively* consistent between the pixels in the hyperspectral data set and the USGS Spectral Library? YES NO

Question 8: A. What mineral is represented by the green color in the USGS color map?

B. What is the wavelength of the absorption feature in both the hyperspectral data and in the spectral library?

Question 9: A. Do you find pixels with the deepest absorption feature at ~2.21 µm? YES NO

B. Do you find pixels with the "doublet" absorption feature? (two absorption features next to each other) YES NO

B. What is the wavelength for the deepest absorption feature for dickite and halloysite in the spectral library?

Question 10: A. What is the wavelength of the absorption feature for "muscovi1" (white mica) in the spectral library?

B. Describe the difference between the shape of the absorption feature of kaolinite and muscovi1 (white mica).

Question 11: A. What often happens to the depth of the first absorption feature in the kaolinite doublet (~2.16 µm) when alunite is mixed in?

Question 12: A. What do you visually see as a reasonable number of MNF bands to use going forward? (relatively clean data, not much noise).

Question 13: A. What "Threshold Level" did you decide to use and how many MNF bands does the ENVI program recommend using going forward?

Question 14: A. What happens to the cloud when you load MNF bands 18-19-20 into the n-D Visualizer?

B. What does the 3D shape of the 18-19-20 cloud tell you about coherent spectral information and noise in these MNF bands?

Question 15: A. Using the "Spectral Analyst" tool, click on "Apply" and select "n-D Class Mean #9". What three closely related clay minerals have the highest score?

B. Look at the profile of n-D Class Mean #9. What is the term used to describe the unique spectral absorption feature between 2.17 and 2.21 µm?

C. Using the "Spectral Analyst" tool, click on "Apply" and select "n-D Class Mean #4". What mineral has the highest score?

Question 16: Questions are based on the SAM classification map.
(Hint: Use the "Cursor Value" tool to query the class shown on your map)
A. Is Calcite located in the same place as on the USGS hyperspectral color map? YES NO

B. What is the "nD-Class Mean #3 class on the USGS hyperspectral color map?

C. Right-click on the "Classes" folder under the SAM map in the Layer Manager > *Select* "Statistics for all Classes".

What are the three largest classes?

What are the three smallest classes?

D. Does your classification map show spatially coherent classes?
YES NO

Question 17: A. What is the SAM Rule value for the brightest pixel you find?

B. What is the SAM Rule for the darkest pixel you find?

C. According to the USGS color geologic map, what mineral is located where the Calcite SAM Rule map has the brightest pixels? (meaning spectra in these pixels are *very different* compared with calcite spectra).

D. Where are the darkest pixels located?