

ENVI Tutorials



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Tutorial 12: Introduction to Hyperspectral Data and Analysis

The following topics are covered in this tutorial:

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Overview of This Tutorial

This tutorial is designed to introduce you to the concepts of *Imaging Spectrometry*, *hyperspectral images*, and selected spectral processing basics using ENVI. For this exercise, we will use Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to familiarize you with spatial and spectral browsing of imaging spectrometer data. We will start with 1995 AVIRIS radiance data for Cuprite, Nevada, USA, provided by Jet Propulsion Laboratory (JPL) and then compare the results of several reflectance calibration procedures.

Files Used in This Tutorial

CD-ROM: ENVI Tutorial and Data CD	No.	2
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Path: envidata/c95avsub

File	Description
Required Files	
cup95_rd.int	Cuprite AVIRIS radiance data. 400 samples x 350 lines x 50 bands (Integer).
cup95_rd.hdr	ENVI Header for above
cup95_at.int	Cuprite ATREM-calibrated apparent reflectance data. 50 bands (Integer).
cup95_at.hdr	ENVI Header for above
cup95cal.sli	Spectral Library of calibration results for selected minerals (Integer).
cup95cal.hdr	ENVI Header for above
jpl1sli.dat	Spectral Library in ENVI format.
jpl1sli.hdr	ENVI Header for above
usgs_sli.dat	USGS Spectral Library in ENVI format
usgs_sli.hdr	ENVI Header for above

File	Description
Optional Files	
cup95_ff.int	Cuprite Flat-Field-calibrated apparent reflectance data. 50 bands (Integer).
cup95_ff.hdr	ENVI Header for above
cup95_ia.int	Cuprite Internal Average Relative Reflectance (IARR) data. 50 bands (Integer).
cup95_ia.hdr	ENVI Header for above
cup95_el.int	Cuprite Empirical Line calibrated apparent reflectance data. 50 bands (Integer).
cup95_el.hdr	ENVI Header for above

Note

Optional files listed may also be used if more detailed calibration comparisons are desired. All image data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. A value of 1000 therefore represents apparent reflectance of 1.0.

Background: Imaging Spectrometry

Imaging spectrometers or "hyperspectral sensors" are remote sensing instruments that combine the spatial presentation of an imaging sensor with the analytical capabilities of a spectrometer. They may have up to several hundred narrow spectral bands with spectral resolution on the order of 10 nm or narrower (Goetz *et al.*, 1985). Imaging Spectrometers produce a complete spectrum for every pixel of the image (Figure 12-1).



Figure 12-1: The imaging spectrometer concept; hundreds of spectral images, thousands to millions of individual spectra (from Vane, 1985).

Compare this to broad-band multispectral scanners such as Landsat Thematic Mapper (TM), which only has 6 spectral bands and spectral resolution on the order of 100 nm or greater (Figure 12-2). The end result of the high spectral resolution of imaging spectrometers is that we can identify materials, where with broad-band sensors we could previously only discriminate between materials.



Figure 12-2: Comparison of a simulated Landsat TM spectrum to the corresponding laboratory spectrum.

Introduction to Basic ENVI Spectral Processing

This portion of the tutorial is designed to familiarize you with ENVI features that are useful for spectral processing of imaging spectrometer data.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in Unix, enter envi at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

- 1. Select **File** → **Open Image File** and navigate to the c95avsub subdirectory of the *ENVI Tutorial and Data CD No.* 2.
- 2. Choose cup95_rd.int as the input file name.

The file contains 50 bands (1.99 - 2.48 μ m) of JPL-calibrated AVIRIS radiance for the Cuprite Mining District, Nevada, USA.

The Available Bands List dialog will appear, listing the 50 spectral band names.

Display a Gray Scale Image

- 1. Use the scroll bar on the right side of the **Available Bands List** dialog to scroll through the list until Band 193 (2.2008 μ m) is displayed.
- 2. Click on the **Gray Scale** radio button, then select Band 193 and click on the **Load Band** button at the bottom of the dialog.

The Main Image window containing the selected band will appear.

3. Position the red box outlining the Zoom window by clicking the left mouse button at the desired location in the Main Image window.

The Zoom window will be automatically updated.

4. Change the zoom factor by clicking the left mouse button in + graphic located in the lower left hand corner of the zoom window to zoom up or on the - button to zoom down.

- Clicking the left mouse button in the Zoom window centers the selected pixel.
- The Zoom window can also be changed by dragging the red outlining box within the Main Image window by using the left mouse button.

Display a Color Image

- 1. Load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
- Click sequentially on Band 183, Band 193, and Band 207 (2.10, 2.20, and 2.35 μm).
- 3. Select **New Display** from the **Display** pull-down button at the bottom of the dialog to start a new display.
- 4. Click **Load RGB** at the bottom of the dialog.

The color image will be loaded into the new (second) image display.

Link Two Displays

Images can be linked to allow simultaneous, identical user action on multiple images. Once linked, moving the zoom box, the scroll box, changing the zoom factor, or resizing any of the image windows causes the same actions to occur in the linked windows.

1. Place the cursor in the Display #1 Main Image window and select **Tools** \rightarrow Link \rightarrow Link Displays.

The Link Displays dialog will appear (Figure 12-3).

2. Use the defaults and click **OK** to enable the link.

🗐 Link	Displays X
Displa	y #1 Yes Link xoff yoff 1
Display	y #2 Yes Link xoff 1 yoff 1
Link Si	ze / Position Display #2
Dynam	ic Overlay On 👫 Opacity (0-100%) 🛛 🖨
ОК	Cancel

Figure 12-3: The Link Displays dialog.

3. Position the Zoom window for Display #1 by clicking the left mouse button in the red Zoom Window outlining box in the #1 Main Image Display and dragging it to a new location.

Note how the Display #2 Zoom window updates to correspond with the first display.

Multiple Dynamic Overlays are available when two or more images are linked, allowing real-time overlay and flicker of multiple gray scale or color images. Dynamic overlays are activated automatically when two or more windows are first linked.

- 4. Click the left mouse button in either of the linked images to cause the second linked image (the overlay) to appear in the first image (the base).
- 5. You can make a quick visual comparison of the images by repeatedly clicking and releasing the left mouse button, which causes the overlay area to flicker.
- 6. Change the size of the overlay by pressing the middle mouse button and dragging the corner of the overlay to the desired location.
- 7. After trying the different possibilities, turn off dynamic linking in the displayed color image by selecting **Tools** \rightarrow **Link** \rightarrow **Unlink Display**.

Extract Spectral Profiles

ENVI's Z-profile capabilities provide integrated spectral analysis. You can extract spectra from any multispectral data set including MSS, TM, and higher spectral dimension data such as GEOSCAN (24 bands), GERIS (63 bands), and AVIRIS (224

bands). From the displayed color image, you can select **Tools** \rightarrow **Profiles** \rightarrow **Z Profile** (**Spectrum**) in the Main Image window menu bar to start a spectral profile.

Current Spectrum

The spectrum for the current cursor location will be plotted in a plot window. A vertical line on the plot is used to mark the wavelength position of the currently displayed band. If a color composite image is displayed, three colored lines will appear, one for each displayed band in the band's respective color (red, green, or blue).

- 1. Select Tools \rightarrow Profiles \rightarrow Z Profile (Spectrum) in the Main Image window menu bar to start a spectral profile.
- 2. Move the cursor position in the Main Image or Zoom window.

The spectrum will be extracted and plotted for the new location.

3. Browse the spectral profile by clicking and holding the left mouse button in the Main Image window and dragging the box across the image.

The spectrum will be updated as the Zoom window box moves. Note that the spectra you are viewing are radiance—not reflectance—spectra, as you are currently working with Cuprite radiance data.

4. Save spectra for comparison using the File \rightarrow Save Plot As option from the menu bar at the top of the plot window.

Collect Spectra

1. Select **Options** \rightarrow **Collect Spectra** in the **Spectral Profile** window to accumulate spectra in this plot (Figure 12-4).

Optionally, to collect spectra in another plot window, open a new plot window and save image spectra from the **Spectral Profile** window.

- 2. Select **Options** \rightarrow **New Window: Blank** from the plot menu to open a new plot window to contain saved image spectra.
- 3. Click the right mouse button in the previous plot to display the spectrum name to the right of the plot window.
- 4. Click and hold the left mouse button on the first character of the spectrum name, drag the name to the new plot window, and release the mouse button.
- 5. Select a new spectrum from the image by moving the current pixel location in either the Main Image or Zoom window and repeat the drag-and-drop process to build a collection of spectra in the new plot window.

 Once you have several plots in the plot window, select Options → Stack Data in new plot window. The spectra will be offset vertically to allow interpretation.





7. To change the color and line style of the different spectra, select $Edit \rightarrow Data$ **Parameters** in the new plot window.

Each spectrum is listed by name/location in the **Data Parameters** dialog.

- 8. Select a line and change its properties as desired.
- 9. When completed, click **Cancel** to close the dialog.
- 10. Select **File** \rightarrow **Cancel** to close the plots after completing this section.

Animate the Data

You can animate gray scale images to make the spatial occurrence of spectral differences more obvious.

1. In the Main Image window of the previous gray scale image (Display #1), select **Tools** → **Animation** to create a movie using the Cuprite AVIRIS data.

The **Animation Input Parameters** dialog will appear (Figure 12-5). This dialog lists all the bands provided in the **Available Bands List.**

🗃 Animation Input Parameters 🛛 🔀
Animation Input Bands
Band 208 (2.3501) Band 209 (2.3600) Band 210 (2.3700) Band 211 (2.3799) Band 212 (2.3898) Band 213 (2.3997) Band 214 (2.4096) Band 215 (2.4196) Band 216 (2.4295)
Band 217 (2.4394)
Spatial Subset Full Scene
Window Size 300 x 262
 Nearest Neighbor Resampling: Pixel Aggregate
OK Cancel

Figure 12-5: The Animation Input Parameters dialog.

- 2. Choose a subset of the full set of bands for animation. Click and drag to select a desired range of bands, or use Control-Click to select specific bands. For the purposes of this exercise, select bands 197 216 (20 bands).
- 3. Change the **Window Size** field to 200 x 175 to reduce the size of the image to be animated (and thus increase the speed of the animation).
- 4. Click **OK** to start the animation loading process.

The **Animation Window** and the **Animation Controls** dialog will appear. The selected bands are loaded individually into the **Animation Window**. A status bar appears as each image is processed. You can cancel the animation in progress at any time by clicking **Cancel** in the status window.

Once all of the selected images have been loaded, the animation will start automatically. Selected bands are displayed sequentially.

The **Animation Controls** dialog (Figure 12-6) are used to specify the animation characteristics. The animation speed is varied from 1 to 100 using the spin box labeled **Speed**.



Figure 12-6: The Animation Controls dialog.

- 5. Use the control buttons (which look like CD player buttons) to run the animation forward and reverse and to pause a specific bands. When paused, click and drag the slider to manually select the band to display.
- 6. Choose the **File** \rightarrow **Cancel** to end the animation.

Working with Cuprite Radiance Data

Continue this exercise using the images displayed in the first section.

- If you have quit ENVI and IDL, restart ENVI and select File → Open Image File.
- 2. Navigate to the c95avsub subdirectory of the envidata directory on the *ENVI Tutorial and Data CD No. 2.* Choose cup95_rd.int as the input file name.

Load AVIRIS Radiance Data

- 1. If you don't already have this image displayed, load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
- 2. Click sequentially on Band 183, Band 193, and Band 207 and then **Load RGB** at the bottom of the dialog.

The color image will be loaded into the current image display.

Extract Radiance Spectra

You can extract selected image radiance spectra for specific targets in the AVIRIS radiance data with the following steps:

- 1. From the Main Image window menu bar, select **Tools** \rightarrow **Pixel Locator**.
- 2. Position the Zoom window over Stonewall Playa, centered around the pixel at sample 590 and line 570 by entering these pixel coordinates in the Pixel Locator and clicking **Apply**.
- 3. Extract the radiance spectrum for this location by selecting the **Tools** \rightarrow **Profiles** \rightarrow **Z-Profile** (**Spectrum**) option.
- Select Options → Collect Spectra to extract radiance spectra for the following locations and load into the same plot window for comparison (Figure 12-7).

Location Name	Sample (with offset)	Line (with offset)
Stonewall Playa	590	570
Varnished Tuff	435	555
Silica Cap	494	514
Opalite Zone with Alunite	531	541
Strongly Argillized Zone with Kaolinite	502	589
Buddingtonite Zone	448	505
Calcite	260	613

5. Use the **Pixel Locator** dialog to obtain the spectra for the other locations.

- 6. Select **Options** \rightarrow **Stack Data** to be able to separately view each spectrum and right-click in the plot display to show the legend for the spectra.
- Change the colors of the individual plots if necessary by selecting Edit → Data Parameters and making the appropriate changes in the subsequent dialog.



Figure 12-7: AVIRIS Radiance Spectra.

Compare the Radiance Spectra

Note how similar the radiance spectra appear. The overall shape of the spectra is caused by the typical combined solar/atmospheric response. Note small absorption features (minima) near 2.2 micrometers that may be attributable to surface mineralogy.

Load Spectral Library Reflectance Spectra

Now compare apparent reflectance spectra from the image to selected library reflectance spectra.

- 1. Select Spectral \rightarrow Spectral Libraries \rightarrow Spectral Library Viewer from the ENVI main menu.
- 2. When the **Spectral Library Input File** dialog appears, click **Open Spec Lib** and select jpl1.sli from the spec_lib/jpl_lib subdirectory.
- 3. Click **OK**. The jpl1.sli file will appear in the **Select Input File** field of the dialog.

4. Click on the file name and click **OK** to open the **Spectral Library Viewer** dialog (Figure 12-8).

Spectral Library Viewer	- 🗆 ×
File Options	
Library: jpl1.sli	
ACTINOLITE IN-4A ALBITE TS-6A ALMANDINE GARNET NS-4A ALUNITE SO-4A AMBLYGONITE P-3A ANALCIME TS-18A ANATASE SYNTHETIC O-12A ANDESINE TS-4A ANDESINE SO-10A ANDEHTE SO-10A ANORTHITE SO-10A ANORTHITE SO-10A ANTHOPHYLLITE IN-8A ANTHOPHYLLITE IN-8A ANTLERITE SO-11A APATITE P-1A APATITE P-1A ARSENOPYRITE SO-5A ATACAMITE H-4A ALGITE IN-15A AZURITE CO-3A BERYL CS-2A	

Figure 12-8: The Spectral Library Viewer dialog.

- 5. Plot the following spectra in the **Spectral Library Viewer** window by clicking on the appropriate mineral name in the list of spectra:
 - ALUNITE SO-4A
 - BUDDINGTONITE FELDS TS-11A
 - CALCITE C-3D
 - KAOLINITE WELL ORDERED PS-1A
 - If desired, change the X-Axis scale by choosing **Plot Parameters** from the **Edit** menu and entering the values 2.0 and 2.5 for the range.

This allows direct visual comparison of radiance (Figure 12-7) and reflectance (Figure 12-9), though the Y-axes will not have the same scale.

6. Click **Cancel** to close the **Plot Parameters** dialog.



Figure 12-9: Library Spectra.

Compare Image and Library Spectra

When visually comparing and contrasting the corresponding AVIRIS radiance spectra with the laboratory measurements for alunite, buddingtonite, calcite, and kaolinite, you should notice how difficult it is to visually identify the minerals by comparing features in the radiance spectra to absorption features shown in the laboratory spectra. You should also notice the effect of the superimposed convexupward solar-atmospheric signature in the AVIRIS radiance data on visual identification.

Close the Windows

When you are finished with this section, close all of the plot windows by choosing **Windows** \rightarrow **Close All Plot Windows** from the ENVI main menu.

Compare Radiance and ATREM

In this portion of the tutorial you will extract selected image radiance spectra and compare them to ATREM apparent reflectance spectra for specific targets in the AVIRIS radiance data.

Background: ATREM Calibration

The ATmospheric REMoval Program (ATREM) is a radiative transfer model-based technique for deriving scaled surface reflectance from AVIRIS data without *a priori* knowledge of surface characteristics (Gao and Goetz, 1990, CSES, 1992). It utilizes the 0.94 and 1.1 micrometer water vapor bands to calculate water vapor on a pixelby-pixel basis from the AVIRIS data, the solar irradiance curve above the atmosphere, and transmittance spectra for each of the atmospheric gases CO2, O_3 , N_2O , CO, CH₄, and O_2 . At the time this tutorial was released, ATREM was unavailable for distribution. Additional information is available at http://cires.colorado.edu/cses/atrem.html (Center for the Study of Earth from Space, University of Colorado). The ATREM-calibrated data used for this tutorial were reduced to apparent reflectance using ATREM 1.3.1.

Note

ATREM is not included as part of ENVI. The other calibration methods examined in this tutorial and described here are implemented within ENVI.

Continue or Restart ENVI

Continue this exercise using the images displayed in the first section.

- 1. If you have quit ENVI and IDL, restart ENVI and select **File** \rightarrow **Open Image File** and navigate to the c95avsub subdirectory of the envidata directory on the *ENVI Tutorial and Data CD No. 2*.
- 2. Choose cup95_rd.int as the input file name.

Load Radiance Data and Start the Z-Profiler

- 1. If it is not already loaded, load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
- 2. Click sequentially on Band 183, Band 193, and Band 207.
- 3. Click Load RGB at the bottom of the dialog.

The color image will be loaded into the current image display.

- 4. Extract the radiance spectrum by selecting Tools \rightarrow Profiles \rightarrow Z Profile (Spectrum) from the Main Image window menu bar.
- 5. Move the Z-Profile window to the bottom of the screen for easy access.

Load ATREM Apparent Reflectance Data and Start the Z Profiler

Now open a second AVIRIS data set.

 Select File → Open Image File and choose cup95_at.int as the second input file name.

This is 50 bands (1.99 - 2.48 μ m) of AVIRIS data calibrated to apparent reflectance using the atmospheric model ATREM to process the AVIRIS radiance data. The 50 band names will be added to the **Available Bands List** dialog.

- 2. Use the scroll bar on the right side of the **Available Bands List** dialog to scroll through the list until Band 193 of cup95_at.int is listed.
- 3. Click on the Gray Scale radio button and select band 193.
- 4. Select **New Display** from the **Display** pull-down button at the bottom of the dialog, and then **Load Band** to start a second ENVI image display and load the selected band.
- 5. Extract the radiance spectrum by selecting Tools \rightarrow Profiles \rightarrow Z Profile (Spectrum) in the second Main Image window.
- 6. Move the Z-Profile window to the bottom of the screen next to the Z-Profile from the radiance data for easy comparison.

Link Images and Compare Spectra

- Link the two AVIRIS images together by selecting Tools → Link → Link Displays from the first Main Image window and clicking OK in the subsequent Link Displays dialog.
- Now turn the dynamic overlay off in the first Main Image window by selecting Tools → Link → Dynamic Overlay Off.
- 3. Once the images are linked and the overlay is turned off, positioning the current pixel in one image (either by clicking the left mouse button in the image, dragging the Zoom window box using the left mouse button, or by using the Pixel Locator) will also position the cursor in the second image.

The Z profiles for both images will change to show the radiance and apparent reflectance spectra at the current location.

4. Position the zoom window over Stonewall Playa, centered around the pixel at sample 590 and line 570 (use the **Pixel Locator** dialog found in the **Tools** menu of the Main Image window).

Visually compare both radiance and apparent reflectance spectrum for this location using the two Z-Profiles. If you wish, save the radiance spectrum in one new plot window and the reflectance spectrum in a second new plot window.

Location Name	Sample (with offset)	Line (with offset)
Stonewall Playa	590	570
Varnished Tuff	435	555
Silica Cap	494	514
Opalite Zone with Alunite	531	541
Strongly Argillized Zone with Kaolinite	502	589
Buddingtonite Zone	448	505
Calcite	260	613

5. Now extract radiance and apparent reflectance spectra for the following locations and visually compare.

Note

An alternate method for getting linked spectral profiles simultaneously from two or more images is to select **Tools** \rightarrow **Profiles** \rightarrow **Additional Z Profile** and choose additional datasets for extraction of profiles.

6. Select **Options** \rightarrow **Stack Data** to offset data vertically for comparison.

 Load the corresponding spectral library spectra into the apparent reflectance plot window for direct comparison of image apparent reflectance spectra (Figure 12-10) with laboratory spectra.



Figure 12-10: ATREM Apparent Reflectance Spectra.

Close the Windows

When you are finished with this section, you can close all of the plot windows by choosing **Windows** \rightarrow **Close All Plot Windows**. Then you can close all of the image displays by choosing **Windows** \rightarrow **Close all Displays**.

Compare Atmospheric Corrections

Background: Atmospheric Correction

This section of the tutorial compares several image apparent reflectance spectra. You will use a spectral library of apparent reflectance spectra generated using ENVI's Flat Field Correction, Internal Average Relative Reflectance (IARR) Correction, and Empirical Line Correction functions to compare the characteristics of the various calibration methodologies. The calibration techniques used are briefly described below.

Flat Field Correction

The Flat Field Correction technique is used to normalize images to an area of known "flat" reflectance (Goetz and Srivastava, 1985; Roberts *et al.*, 1986). The method requires that you locate a large, spectrally flat, spectrally uniform area in the AVIRIS data, usually defined as a Region of Interest (ROI). The radiance spectrum from this area is assumed to be composed of primarily atmospheric effects and the solar spectrum. The average AVIRIS radiance spectrum from the ROI is used as the reference spectrum, which is then divided into the spectrum at each pixel of the image. The result is apparent reflectance data that can be compared with laboratory spectra.

Internal Average Relative Reflectance (IARR)

The IARR calibration technique is used to normalize images to a scene average spectrum. This is particularly effective for reducing imaging spectrometer data to relative reflectance in an area where no ground measurements exist and little is known about the scene (Kruse *et al.*, 1985; Kruse, 1988). It works best for arid areas with no vegetation. The IARR calibration is performed by calculating an average spectrum for the entire AVIRIS scene and using this as the reference spectrum. Apparent reflectance is calculated for each pixel of the image by dividing the reference spectrum into the spectrum for each pixel.

Empirical Line Calibration

The Empirical Line correction technique is used to force image data to match selected field reflectance spectra (Roberts *et al.*, 1985; Conel *et al.*, 1987; Kruse *et al.*, 1990). This method requires ground measurements and/or knowledge. Two or more ground targets are identified and reflectance is measured in the field. Usually the targets consist of at least one light and one dark area. The same two targets are identified in the AVIRIS images and average spectra are extracted for Regions of

Interest. A linear regression is calculated between the field reflectance spectra and the image radiance spectra to determine a linear transform from radiance to reflectance for each band of the AVIRIS data set. Gains and offsets calculated in the regression are applied to the radiance spectra for each pixel to produce apparent reflectance on a pixel-by-pixel basis.

Continue or Restart ENVI and Select Spectral Library of Calibration Results Spectra

1. If you have quit ENVI and IDL, restart ENVI and select **Spectral** → **Spectral** Libraries → Spectral Library Viewer.

The **Spectral Library Input File** dialog will appear to allow selection of a spectral library.

- 2. Click **Open File** at the bottom center of the dialog to start a standard file selection dialog.
- 3. Navigate to the c95avsub subdirectory of the envidata directory on the *ENVI Tutorial and Data CD No.* 2, and select the file cup95cal.sli.

This is the spectral library containing the results from the various calibration methods.

4. In the **Spectral Library Input File** dialog, select the open library file name and click **OK**.

The **Spectral Library Viewer** will appear with a list of the available spectra (Figure 12-11).

Select Atmospherically Corrected Spectra from Spectral Library

1. Select the ATREM, Flat Field, IARR, and Empirical Line corrected spectra for the mineral Alunite.

The spectra are plotted in a **Spectral Library Viewer** plot (Figure 12-12). Visually compare the various calibrations and note and compare their characteristics.

2. Attempt to explain some of the differences in terms of the correction methodology used (see the above brief descriptions of the various methods).

3. When finished, select **Options** → **Clear Plots** in the menu bar at the top of the **Spectral Library Viewer** to clear the spectra.

File Options Library: Cup95cal.sli ▲ Radiance: Playa ▲ Radiance: Varnished Tuff ▲ Radiance: Silica ■ Radiance: Alunite ■ Radiance: Calcite ■ Flat Field: Playa ■ Flat Field: Varnished Tuff ■ Flat Field: Sulica ■ Flat Field: Sulica ■ Flat Field: Sulica ■ Flat Field: Sulica ■ Flat Field: Buddingtonite ■ Flat Field: Buddingtonite ■ Flat Field: Calcite ■ IARR: Playa ■ HARP: Playa ■	Spectral Library Viewer	_ 🗆 ×
Library: Cup95cal.sli Radiance: Playa Radiance: Varnished Tuff Radiance: Silica Radiance: Alunite Radiance: Alunite Radiance: Calcite Flat Field: Playa Flat Field: Varnished Tuff Flat Field: Varnished Tuff Flat Field: Silica Flat Field: Kaolinite Flat Field: Kaolinite Flat Field: Calcite IARB: Playa	File Options	
Radiance: Playa Radiance: Varnished Tuff Radiance: Silica Radiance: Alunite Radiance: Kaolinite Radiance: Buddingtonite Radiance: Calcite Flat Field: Playa Flat Field: Varnished Tuff Flat Field: Silica Flat Field: Alunite Flat Field: Alunite Flat Field: Buddingtonite Flat Field: Buddingtonite Flat Field: Calcite IARR: Playa	Library: Cup95cal.sli	
IARH: Varnished Lutr IARR: Silica IARR: Alunite IARR: Kaolinite IARR: Buddingtonite	Radiance: Playa Radiance: Varnished Tuff Radiance: Silica Radiance: Alunite Radiance: Kaolinite Radiance: Buddingtonite Radiance: Calcite Flat Field: Playa Flat Field: Varnished Tuff Flat Field: Silica Flat Field: Alunite Flat Field: Alunite Flat Field: Calcite IARR: Playa IARR: Varnished Tuff IARR: Silica IARR: Alunite IARR: Alunite IARR: Kaolinite IARR: Buddingtonite IARR: Buddingtonite IARR: Buddingtonite	

Figure 12-11: The Spectral Library Viewer dialog showing spectra from various calibrations.

Compare Corrected Spectra

Repeat the procedure for the minerals kaolinite, buddingtonite, calcite, and silica. What general conclusions can you draw about the quality of the different calibration procedures?

You can also compare the laboratory spectra for these minerals to the AVIRIS spectra by opening the jpll.sli or the usgs_sli.dat spectral libraries, plotting

the corresponding spectra, and dragging and dropping into the **Spectral Library Viewer** plot for direct comparison.





Optional: Browse Corrected Data Files

The corrected data files for all of the different corrections are available for spectral browsing if desired. All files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the data indicate apparent reflectances of 1.0.

File Type	File Name
ATREM	cup95_at.int
Flat Field	cup95_ff.int
IARR	cup95_ia.int
Emp. Line	cup95_el.int

1. Open and load the files listed in the table below if desired.

- 2. Use the Z-profiling and multiple linked images to compare apparent reflectance spectra for specific areas of interest.
- 3. After comparison of all of the correction methods for a variety of minerals, which calibration method(s) best reproduce(s) the laboratory spectra for all minerals? Is there one best calibration method?

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting $File \rightarrow Exit$ (Quit on UNIX) on the ENVI main menu, then click OK to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

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Tutorial 13: Basic Hyperspectral Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial	References	307
Spectral Libraries / Reflectance Spectra 291		

Overview of This Tutorial

This tutorial is designed to introduce you to the concepts of *Spectral Libraries, Region of Interest* (ROI) extraction of spectra, *Directed Color composites*, and to the use of 2-D scatter plots for simple classification. We will use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) apparent reflectance data of Cuprite, Nevada, USA, calibrated using the ATREM atmospheric modeling software. The subsetted data cover the 1.99 to 2.48 µm range in 50 spectral bands approximately 10 nm wide. You will extract ROIs for specific minerals, compare them to library spectra, and design RGB color composites to best display the spectral information. You will also use 2-D scatter plots to locate unique pixels, interrogate the data distribution, and perform simple classification.

Files Used in This Tutorial

CD-ROM: ENVI Tutorial and Data CD No. 2

Path: envidata/c95avsub

File	Description
cup95_at.int	Cuprite ATREM calibrated reflectance data. 50 bands (integer)
cup95_at.hdr	ENVI Header for above
jpl1sli.dat	JPL Spectral Library in ENVI format
jpl1sli.hdr	ENVI Header for above
usgs_min.sli	USGS Spectral Library in ENVI format
usgs_min.hdr	ENVI Header for above
cup95_av.roi	Saved ROI locations.

Note -

The files listed are required to run this exercise. Selected data files have been converted from floating-point to integer format by multiplying by 1000 to conserve disk space. Data values of 1000 represent apparent reflectances of 1.0.

Spectral Libraries / Reflectance Spectra

This portion of the tutorial is designed to familiarize you with Spectral Libraries, browsing and extraction of image reflectance spectra, Region of Interest (ROI) definition in ENVI, and directed design of color composite images for spectral discrimination.

Start ENVI and Load AVIRIS data

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI on UNIX, enter envi at the UNIX command line.
- To open ENVI on Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

- 1. On the ENVI main menu, select File \rightarrow Open Image File and navigate to the envidata/c95avsub directory on the ENVI Tutorial and Data CD No. 2.
- 2. Choose cup95_at.int as the input file name and click **Open**. The **Available Bands List** dialog will appear, listing the 50 spectral band names.

Display a Grayscale Image

- 1. In the Available Bands List dialog, select Band 193 (2.2008 μ m).
- 2. Click the **Gray Scale** radio button and click **Load Band**. An ENVI image display containing the selected band will appear.
- 3. From the Main Image window menu, select **Tools** \rightarrow **Profiles** \rightarrow **Z Profile** (**Spectrum**) to extract an apparent reflectance spectrum.

Browse Image Spectra and Compare to Spectral Library

- 1. Move the Zoom window indicator box around the image while looking at the #1 Spectral Profile window to browse through image apparent reflectance spectra.
- 2. In the Main Image window, drag the box by grabbing and dragging with the left mouse button or click the middle mouse button to center the Zoom Indicator box on the selected pixel.
- 3. Compare apparent reflectance spectra from the image to selected library reflectance spectra.

ENVI includes several spectral libraries. For the purposes of this exercise, you will use the JPL Spectral Library (Groves et al., 1992) and the USGS Spectral Library (Clarke et al., 1993).

- Select Spectral → Spectral Libraries → Spectral Library Viewer from the ENVI main menu.
- 5. In the **Spectral Library Input File** dialog, click **Open File**, select jpl1.sli from the spec_lib/jpl_lib subdirectory, and click **OK**.
- 6. Click on jpl1.sli in the Select Input File field and click OK.
- 7. In the **Spectral Library Viewer** dialog, select **Options** \rightarrow **Edit** (**x**, **y**) **Scale Factors**, enter a value of 1000 into the **Y Data Multiplier** field to match the image apparent reflectance range (0 1000), and click **OK**.
- 8. Plot the following spectra by selecting the spectra names in the **Spectral** Library Viewer dialog:
 - ALUNITE SO-4A
 - BUDDINGTONITE FELDS TS-11A
 - CALCITE C-3D
 - KAOLINITE WELL ORDERED PS-1A

The following plot is produced:



Figure 13-1: Library Spectra

- Customize the plot by selecting Edit → Plot Parameters from the plot window menu. In the Plot Parameters dialog, do the following:
 - Reduce the **Charsize** to 0.50.
 - Select the X-Axis radio button, and adjust the Range to 1.90 to 2.45.
 - With the **X-Axis** radio button selected, change the **Margin** fields until the X margins are as desired.
 - Select the **Y-Axis** radio button, and change the **Axis Title** to "Reflectance".
 - With the **Y-Axis** radio button selected, change the **Margin** fields until the Y margins are as desired.
 - Click **Apply** then **Cancel**.
- 10. To display a legend of the spectra names, right click in the plot window. Drag the plot window to the desired size to accommodate the spectra names.
- 11. In the plot window, offset the plot data by selecting **Options** \rightarrow **Stack Data**. The plot now looks like the following:



Figure 13-2: Customized Plot Parameters

- 12. Right click in the #1 Spectral Profile window to display a legend of X and Y pixel locations.
- 13. In the #1 Spectral Profile window, select **Options** \rightarrow **New Window: Blank** to open a new plot window. Position the #1 Spectral Profile window and the new plot window so you can see both windows.
- 14. From the Main Image window menu, select Tools → Pixel Locator. We will use the Pixel Locator dialog to locate the exact pixels for the following locations:

Location Name	Sample (with offset)	Line (with offset)	
Stonewall Playa	590	570	
Varnished Tuff	435	555	
Silica Cap	494	514	
Opalite Zone with Alunite	531	541	
Strongly Argillized Zone with Kaolinite	502	589	
Buddington ZOne	448	505	

Location Name	Sample (with offset)	Line (with offset)	
Calcite	260	613	

- 15. In the **Pixel Locator** dialog, enter 590 in the **Sample** field and enter 570 in the **Pixel** field to center the Zoom Indicator on pixel 590, 570 (Stonewall Playa). Click **Apply** to move to that location. The #1 Spectral Profile window updates to show the spectrum for this pixel. The legend should read "X:590 Y:570".
- 16. Right click in the new plot window to display a legend of X and Y pixel locations.
- 17. In the #1 Spectral Profile window, click and hold the left mouse button on the legend item "X:590 Y:570". Drag and drop this spectrum into the new plot window.
- 18. Repeat the previous steps for each site in the above table until the new plot window contains all 7 spectra.
- 19. In the new plot window, select **Options** \rightarrow **Stack Data**. The new plot window should now look like the following:



Figure 13-3: Individual ATREM Image Apparent Reflectance Spectra

20. Visually compare these spectra to the library spectra extracted previously.

Note the similarity of shape and absorption features between the laboratory spectra and the individual image apparent reflectance spectra.

Based on these similarities, we conclude that the image spectra similar to the alunite, buddingtonite, calcite, and kaolinite laboratory spectra represent pixels predominantly of the above minerals.

21. Drag and drop spectra from the Spectral Library Plots window into the #1 Spectral Profile window for direct comparison.

Identify Spectra

Use the Spectral AnalystTM to identify spectra:

ENVI has a spectral matching tool that provides a score with respect to the library spectra. The spectral analyst uses several methods to produce a score between 0 and 1, with 1 equaling a perfect match.

- 1. Select **Spectral** \rightarrow **Spectral Analyst** from the ENVI main menu.
- 2. Click on the **Open Spec Lib** button at the bottom of the **Spectral Analyst Input Spectral Library** dialog.
- 3. Navigate to the usgs_min spectral library directory, select the usgs_min.sli spectral library, and click **Open**.
- 4. The file usgs_min.sli should now appear in the **Spectral Analyst Input Spectral Library** dialog. Select this file and click **OK**.
- 5. In the Edit Identify Methods Weighting dialog, click OK.
- From the Main Image window menu, select Tools → Profiles → Z Profile (Spectrum). Right click in the #1 Spectral Profile window to display the legend of spectra.
- 7. From the Main Image window menu, select **Tools** \rightarrow **Pixel Locator**.
- 8. Enter the pixel 502, 589 in the Pixel Locator dialog and click Apply.
- 9. In the Spectral Analyst dialog, select **Options** \rightarrow **Edit Method Weights**.
- 10. In the **Edit Identify Methods Weighting** dialog, enter 0.33 in each of the **Weight** fields click **OK**. The different matching methods are described in the *ENVI 3.5 User's Guide*.
- 11. In the Spectral Analyst dialog, click Apply. If more than one spectrum is displayed in the #1 Spectral Profile window, a list of spectra will appear. If this

list appears, select the spectrum for pixel 502, 589. The **Spectral Analyst** dialog shows the following:

Unknown: X:502 Y:589					
Library Spectrum	Score	SAM	SFF	BE	
kaolini2.spc Kaolini	[0.740]:	{0.869}	{0.454}	{0.920}	
kaolini6.spc Kaolini	[0.738]:	{0.863}	{0.454}	{0.920}	
kaolini7.spc Kaolini	[0.737]:	{0.858}	{0.456}	{0.920}	
kaolini5.spc Kaolini	[0.737]:	{0.856}	{0.457}	{0.920}	
halloys3.spc Halloys	[0.734]:	{0.885}	{0.421}	{0.920}	
kaolini3.spc Kaolini	[0.732]:	{0.874}	{0.445}	{0.900}	
kaolini8.spc Kaolini	[0.731]:	{0.853}	{0.443}	{0.920}	
pyrophy3.spc Pyrophy	[0.729]:	{0.866}	{0.383}	{0.960}	
dickite2.spc Dickite	[0.725]:	{0.860}	{0.418}	{0.920}	
nacrite.spc Nacrite	[0.721]:	{0.858}	{0.406}	{0.920}	
kaosmec2.spc Kaolin/	[0.720]:	{0.901}	{0.402}	{0.880}	
kaolini1.spc Kaolini	[0.719]:	{0.820}	{0.458}	{0.900}	1

Figure 13-4: The Spectral Analyst dialog, showing a high match to the mineral kaolinite for pixel 502, 589.

The Spectral Analyst scores the unknown spectrum against the library. The previous figure shows an identification for pixel 502, 589. Note the high number of kaolinite spectra at the top of the list. This, and the relatively high scores, indicates a high likelihood of kaolinite.

12. Now double click on the first spectrum name in the list. This will plot the unknown and the library spectrum in the same plot for comparison, as shown in the following figure:



Figure 13-5: Comparison plot of the unknown against the best-match library spectrum for kaolinite showing a high degree of match.

- 13. Use the Spectral Analyst and the comparison plots to verify the mineralogy for the image spectra you have extracted. When you have identified several minerals, continue with the next section.
- 14. Optionally, compare spectra from the USGS Spectral Library usgs_min.sli with image spectra and the JPL Spectral library.

Close Windows and Plots

- 1. Close the Spectral Library Viewer and Pixel Locator dialogs.
- 2. Close all of the previous plot windows by selecting Window \rightarrow Close All Plot Windows.

Define Regions of Interest

Regions of Interest (ROIs) are used to extract statistics and average spectra from groups of pixels. You can define as many ROIs as you wish in any displayed image. Select **Overlay** \rightarrow **Region of Interest** from the Main Image window menu to start the ROI Tool.

🗊 #1 ROI Tool	_ 🗆 ×
File ROI_Type Options Help	
Window: 🖲 Image 🔿 Scroll 🔿 Zoom	C Off
Available Regions Of Interest:	
Region #1 [Red] 0 points	
New Begion Edit Erase Delete	1
]
Loto Stats Mean Grow	

Figure 13-6: Region of Interest Tool

Create New Region of Interest

- 1. Click the left mouse button in the image.
- 2. Draw the ROI by clicking the left mouse button at the axes of a polygon, or draw continuously by clicking and dragging the left mouse button.
- 3. Complete the ROI by clicking the right mouse button to close the polygon and the right mouse button a second time to lock-in the ROI.
- 4. Click on the **Stats** button to calculate the statistics and plot a mean spectrum (white), the first standard deviation above and below the mean spectrum (green), and the Min/Max envelope containing all of the spectra in the ROI (red).
- Select File → Cancel in the File Statistics Report dialog, and select File → Cancel in the Avg Spectrum plot.
- 6. Click **Delete** in the **ROI Tool** dialog to delete the selected ROI.

Load Previously Saved Regions of Interest

- 1. From the **ROI Tool** dialog menu, select **File** \rightarrow **Restore ROIs**.
- 2. In the **Enter ROI Filename** dialog, navigate to the envidata/c95avsub directory, select the file cup95_av.roi, and click **Open**. Regions previously defined for known areas of specific minerals will be listed in an ENVI message dialog, and loaded into the **ROI Tool** dialog as shown in the following figure:

🗃 #1 ROI Tool 📃 🛛 🗙
File ROI_Type Options Help
Window: Image C Scroll C Zoom C Off
Available Regions Of Interest:
Region #1 [Red] 0 points
Playa [Hed] 28 points Varnished Tuff (Green) 12 points Silica (Blue) 32 points Alunite (Yellow) 27 points Kaolinite (Lyan) 43 points Buddingtonite (Magenta) 13 points Calcite (Maroon) 15 points
New Region Edit Erase Delete
Goto Stats Mean Grow

Figure 13-7: ROI Tool showing restored regions

- 3. Select the **Off** radio button at the top of the **ROI Tool** dialog to enable pixel positioning within the Main Image display.
- Start a Z-Profile window by selecting Tools → Profiles → Z-Profile (Spectrum) in the Main Image window.
- 5. Move the current pixel position/cursor location into each ROI by clicking the middle mouse button on a pixel in the ROI.
- 6. Click on different pixels in the ROI to move the cursor position and display a new spectral profile in the Spectral Profile window.

Note that the y-axis plot range is automatically rescaled to match the spectral profile for each new ROI. Examine the spectral variability within each ROI.

Extract Mean Spectra from ROIs

1. Select an ROI name in the **ROI Tool** dialog, then click **Stats** to extract statistics and a spectral plot of the selected ROI.

- 2. Examine the spectral variability of each ROI by comparing the mean spectrum (white) with the 1st standard deviation spectra (green above and below the mean) and the envelope spectra (red above and below the mean).
- 3. Repeat for each ROI.
- 4. If you wish, load the corresponding library signatures from the jpl1.sli library into the plot window for direct comparison/identification. Don't forget to use a Y-Scaling Factor of 1000 when loading the library spectra.
- 5. When you have finished, close all of the **File Statistics Report** dialogs and plot windows.
- 6. In the **ROI Tool** dialog, select **Options** → **Mean for All Regions** to plot the average spectrum for each ROI in the same plot window.
- In the plot window, select Options → Stack Data to offset spectra for comparison, as shown in the following figure:



Figure 13-8: ROI Mean ATREM Image Apparent Reflectance Spectra

- 8. Compare the spectral features of each spectrum and note unique characteristics that might allow identification.
- 9. If desired, load the corresponding spectral library signatures from the jpl1.sli library for direct comparison of image apparent reflectance spectra

with laboratory spectra. Don't forget to use a Y Factor of 1000 when loading the library spectra.

10. Optionally, compare spectra from the USGS Spectral Library usgs_min.sli with image spectra and the JPL Spectral library.

Discriminate Mineralogy

Design color images to discriminate mineralogy:

- 1. In the **Available Bands List** dialog, select the **RGB Color** radio button, and click sequentially on Band 183, Band 193, and Band 207.
- 2. Click Load RGB to load the color image into the current image display.
- 3. In the Main Image window, select **Tools** → **Profiles** → **Z-Profile** (**Spectrum**). Note that the positions of the bands used to make the RGB color composite image are marked in the Z-Profile with vertical red, green, and blue lines.
- 4. In the **ROI Tool** dialog, select the **Off** radio button and use the Z profiler accessed through the Main Image window to browse spectra at or near your ROI locations from above.

Note where the selected RGB bands fall with respect to spectral features in the previously displayed mean spectra and how the spectral features affect the color observed in the image.

5. Change the plot bars in the spectral profile to the desired bands by clicking and dragging the plot bars with the left mouse button.

Note -

(Note: one way to enhance specific materials is by centering one color bar in an absorption feature and the other two on opposite shoulders of the feature.)

6. Double click the left mouse button within the Z Profile plot window to load the new bands into the display window.

After inspecting a few sites, you should begin to understand how the color composite colors correspond with the spectral signature. For instance, the alunitic regions appear magenta in the RGB composite because the green band is within the alunite absorption feature, giving a low green value, while the red and blue bands are of almost equal reflectance. The combination of red and blue results in a magenta color for pixels containing alunite.

Based on the above results, try these exercises:

- 1. Predict how certain spectra will look, given a particular pixel's color in the RGB image.
- 2. Explain the colors of the training sites, in terms of their spectral features.
- 3. Design and test specific RGB band selections that maximize your ability to map certain minerals, like kaolinite and calcite.

Close Plot Windows and ROI Controls

- 1. Close all open plot windows by selecting Window \rightarrow Close All Plot Windows.
- 2. Close the **ROI Tool** dialog by selecting **File** \rightarrow **Cancel**.

2-D Scatter Plots

Examine 2-D Scatter Plots

- 1. In the Main Image window, select **Tools** \rightarrow **2-D Scatter Plots** to start a 2-D scatter plot for the apparent reflectance image.
- Select band 193 in the Choose Band X list and select band 207 in the Choose Band Y list.
- 3. Click OK.

The following scatter plot is displayed with a plot of the X vs. Y apparent reflectance values:



Figure 13-9: Scatter Plot of bands 193 and 207 (ATREM Apparent Reflectance)

Spectral Libraries / Reflectance Spectra

Density Slice the Scatter Plot

- From the scatter plot menu, select Options → Density On to automatically density-slice the scatter plot. The colors show the frequency of occurrence of specific apparent reflectance combinations for the two bands being scatter plotted. Purple is the lowest frequency, progressing through the colors blue, green, yellow, to red as the highest frequency of occurrence.
- From the scatter plot menu, select Options → Density Off to turn off the color slice.

Scatter Plot Dancing Pixels

- 1. In the Main Image window, click and drag the left mouse button to toggle "Dancing Pixels" in the scatter plot. The red pixels in the scatter plot correspond to those pixels within a 10 x 10 box around the cursor in the Main Image window.
- 2. Try to predict the locations of certain image colors in the scatter plot, then check them. Notice the shape of the red sub-scatter plot of dancing pixels.
- 3. Change the box-cursor size in the scatter plot window by selecting **Options** \rightarrow **Set Patch Size**, and observe the difference.

Image Dancing Pixels

- In the scatter plot window, click and drag the middle mouse button over any portion of the white scatter plot to toggle "Dancing Pixels" in the Main Image window. The red pixels in the image correspond to those pixels within a 10 x 10 box around the cursor in the scatter plot window. Note the spatial distribution and coherency of the selected pixels.
- 2. Change the box-cursor size in the scatter plot window by selecting **Options** \rightarrow **Set Patch Size**, and observe the difference.

Scatter Plots Linked to a Spectral Profile

- From the scatter plot window menu, select Options → Z Profile, select an input file from which to extract the spectral profile, and click OK. This starts a blank ENVI spectral profile linked to the 2-D scatter plot.
- 2. Position the cursor in the 2-D scatter plot and click the right mouse button to extract the spectrum for the corresponding spatial pixel with those scatter plot characteristics.
- 3. Compare spectra from the different parts of the scatter plot and note what sorts of spectra appear at the "points" of the plot versus the center of the plot.

Scatter Plot ROIs

The scatter plot tool can also be used as a quick classifier.

- 1. Click the left mouse button in the scatter plot to select the first point of a Region of Interest (ROI).
- 2. Draw an ROI polygon in the scatter plot by selecting the desired line segments using the left mouse button.
- 3. Click the right mouse button to close the polygon. Image pixels with the twoband characteristics outlined by the polygon will be color-coded red in the Main Image window.
- 4. Choose another color from the *Class* pulldown menu in the scatter plot window.
- 5. Draw another polygon and the corresponding pixels will be highlighted in the selected color on the image.
- 6. To remove a class, select **Options** → **Clear Class**. You can also clear the current class by clicking the middle mouse button outside (below) the plot axes.
- 7. Use the 2-D scatter plot tool to work backwards from the scatter plot to see where certain pixels occur in the image.
- 8. Classes can be converted to ROIs to act as training sets for classification using all of the bands by selecting Options → Export Class or Export All from the scatter plot menu bar. ROIs exported in this fashion will appear in the ROI Tool dialog and be available for subsequent supervised classification. They can also be converted to a classification image by choosing Classification → Create Class Image from ROIs from the ENVI main menu.
- Select Options → Clear All in the scatter plot to clear both scatter plot and image.

Image ROIs

The scatter plot tool also functions as a simple classifier from the image.

- 1. Choose **Options** \rightarrow **Image ROI** in the scatter plot.
- 2. Draw polygons in the Main Image window using the left mouse button to draw lines and the right button to close and lock-in the polygon. They will be mapped to the scatter plot and highlighted in the currently selected color. After the pixels are highlighted on the scatter plot, all of the matching pixels in the image will be inverse-mapped to the Main Image window and highlighted in

the same color, as though you had drawn the scatter plot region yourself. This is the simplest form of 2-band classification, but it is still a powerful tool.

3. Draw a few image regions and note the correspondence between image color and scatter plot characteristics.

Scatter Plots and Spectral Mixing

Can you explain the overall diagonal shape of the scatter plot in terms of spectral mixing? Where do the purest pixels in the image fall on the scatter plot? Are there any secondary "projections" or "points" on the scatter plot?

Choose some other band combinations for scatter-plotting by selecting
 Options → Change Bands in the scatter plot. Try at least one pair of adjacent
 bands and other pairs that are far apart spectrally.

How do the scatter plots change shape with different band combinations? Can you describe the *n*-Dimensional "shape" of the data cloud?

End the ENVI Session

This concludes the tutorial. You can quit your ENVI session by selecting **File** \rightarrow **Exit** (**Quit** on UNIX) from the ENVI main menu, then click **Yes**. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

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ENVI Tutorials