ENVI

ENVI Tutorial: Introduction to Hyperspectral Data

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Overview of This Tutorial

This tutorial is designed to introduce you to imaging spectrometry, hyperspectral images, and selected spectral processing basics using ENVI. You will use Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to learn how to spatially and spectrally browse imaging spectrometer data. You will start with 1995 AVIRIS radiance data for Cuprite, Nevada, USA, provided by NASA Jet Propulsion Laboratory (JPL), and compare the results of several reflectance calibration procedures.

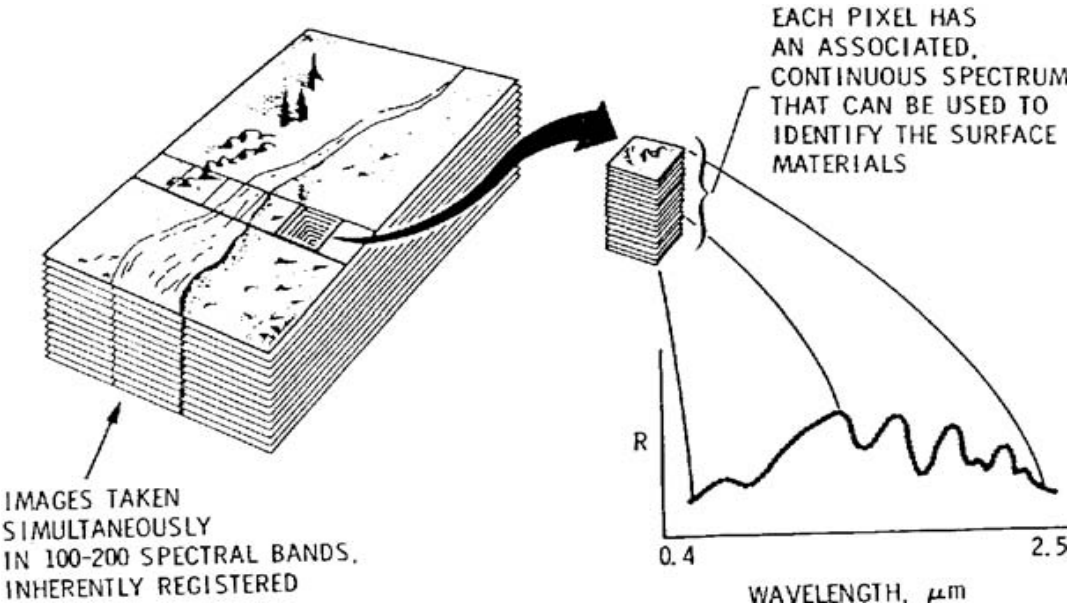
Files Used in This Tutorial

ENVI Resource DVD: `envidata\c95avsub`

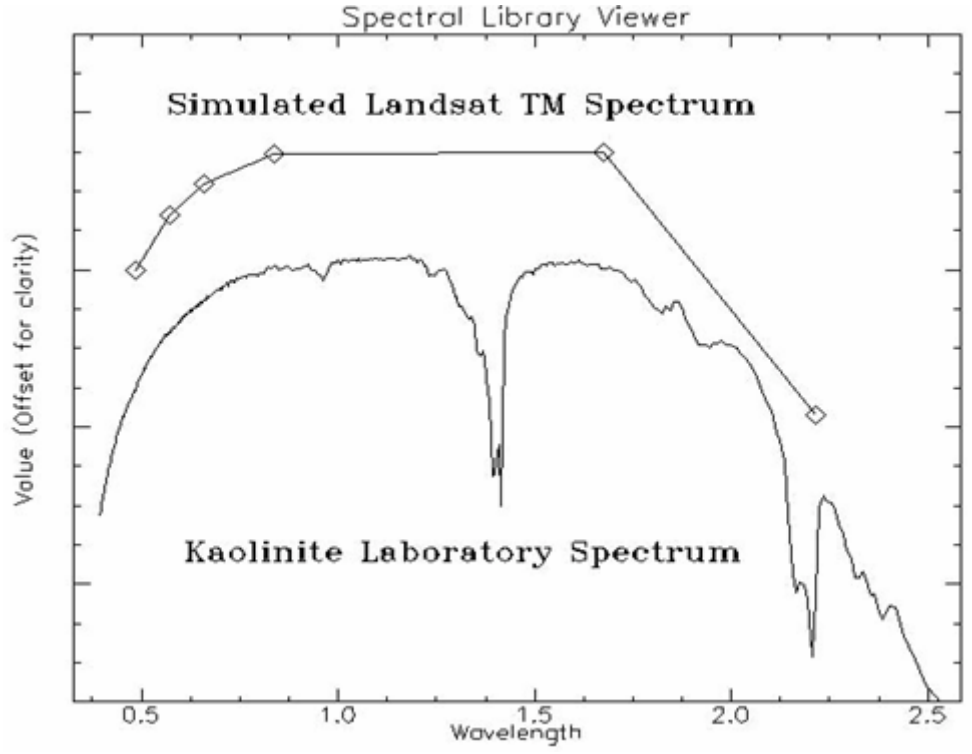
File	Description
Required Files	
`cup95_rd.int (.hdr)`	AVIRIS radiance data (400 samples, 350 lines, 50 bands)
`cup95_at.int (.hdr)`	AVIRIS atmospherically corrected reflectance data (50 bands)
`cup95cal.sli (.hdr)`	Spectral library of calibrations for selected minerals (integer)
`jpl1.sli (.hdr)`	JPL spectral library in ENVI format
`usgs_min.sli (.hdr)`	USGS spectral library in ENVI format
Optional Files	
`cup95_ff.int (.hdr)`	Flat-Field-calibrated apparent reflectance integer data (50 bands)
`cup95_ia.int (.hdr)`	Internal average relative reflectance (IARR) integer data
`cup95_el.int (.hdr)`	Empirical line-calibrated apparent reflectance integer data

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, as the following figure shows.



Compare this to broadband multispectral scanners such as Landsat Thematic Mapper (TM), which only has six spectral bands and spectral resolution on the order of 100 nm or greater. The high spectral resolution from an imaging spectrometer allows you to identify materials, whereas broadband sensors only allow you to discriminate between materials.



Introduction to Basic ENVI Spectral Processing

In this part of the tutorial, you will learn about ENVI features that are useful for spectral processing of imaging spectrometer data.

Before attempting to start the program, ensure that ENVI is properly installed as described in the Installation Guide that shipped with your software.

1. From the ENVI main menu bar, select **File** → **Open Image File**.

2. Navigate to the `envidata\c95avsub` directory, and select `cup95_rd.int`. Click **Open**. The Available Bands List appears with a list of 50 bands (1.99-2.48 μm) of JPL-calibrated AVIRIS radiance for the Cuprite Mining District, Nevada, USA.

Display a Grayscale Image

1. In the Available Bands List, double-click **Band 193**. A gray scale image of Band 193 is loaded into an ENVI display group.

2. In the Image window, move the Zoom box to a desired location. The Zoom window automatically updates.

3. Use the Zoom controls to change the Zoom factor. Clicking in the Zoom window centers the selected pixel.

Display a Color Image

1. In the Available Bands List, select the **RGB Color** radio button.

2. Click sequentially on **Band 183**, **Band 193**, and **Band 207** (2.10, 2.20, and 2.35 μm, respectively).

3. Click **Display #1** and select **New Display**. A new display group appears.

4. Click **Load RGB**. The color image is loaded into the display group.

Link Two Display Groups

Linking display groups allows you to query two or more images simultaneously. If you move the Zoom or Image box, change the zoom factor, or resize the display group window in one image, the other linked display groups reflect your changes.

1. From any Display group menu bar, select **Tools** → **Link** → **Link Displays**. The Link Displays dialog appears.

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

3. Move the Zoom box in Display #1 to a new location. The Zoom window in Display #2 updates to correspond with Display #1.

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

4. Click in either Image window to cause the second linked image (the overlay) to appear in the first image (the base).

5. You can quickly compare the images by repeatedly clicking in the Image window, which causes the overlay area to flicker.

6. Change the size of the overlay by clicking the middle mouse button in a display group and dragging the corner of the overlay to the desired location.

7. After experimenting with linking and dynamic overlays, select **Tools** → **Link** → **Unlink Display** from a Display group menu bar.

Extract Spectral Profiles

ENVI's Z Profile tool provides integrated spectral analysis. You can extract spectra from any multispectral dataset including MSS, TM, and higher spectral dimension data such as GEOSCAN (24 bands), GERIS (63 bands), and AVIRIS (224 bands). With a Z Profile, the spectrum for the current cursor location appears in a plot window. A vertical line on the plot marks the wavelength position of the currently displayed band. If a color composite image is displayed, three colored lines appear, one for each displayed band in the band's respective color (red, green, or blue).

1. From the Display #2 menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. A Spectral Profile plot window appears.

2. Click in the Image or Zoom window to move the cursor position. The spectrum is extracted and plotted for the new point. The spectrum is based on radiance (not reflectance) data in this case.

3. From the Spectral Profile menu bar, select **Options** → **Collect Spectra**.

4. You will collect spectra in another plot window, so open a new plot window by selecting **Options** → **New Window: Blank** from the Spectral Profile menu bar. An ENVI Plot Window appears that will contain saved image spectra.

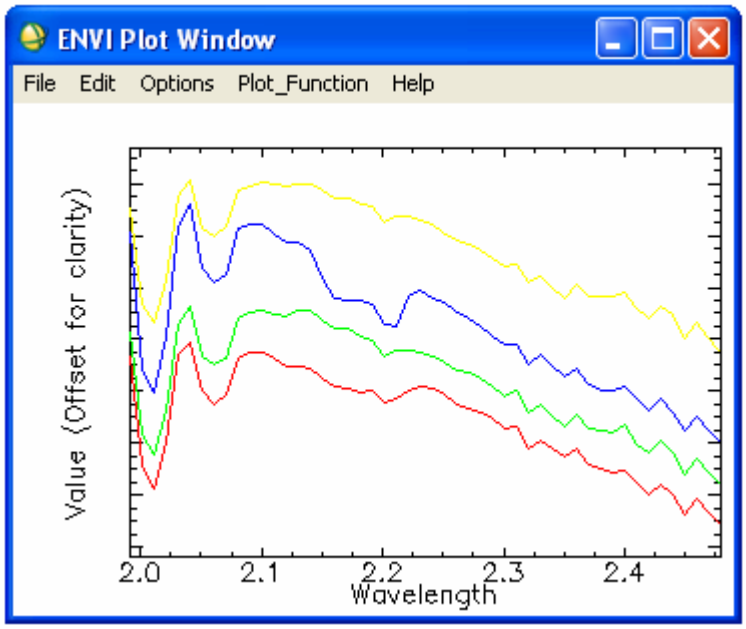
5. Right-click in the Spectral Profile and select **Plot Key** to display the spectrum name to the right of the plot.

6. Select a new spectrum from the image by moving the current pixel location in the Image or Zoom window. The spectrum is added to the Spectral Profile.

7. Click and drag a spectrum name from the Spectral Profile to the ENVI Plot Window, and release the mouse button.

8. Repeat Steps 4-5 a few times to build a collection of spectra in the ENVI Plot Window.

9. From the ENVI Plot Window menu bar, select **Options** → **Stack Plots**. The spectra are vertically offset to assist in interpretation. Your plot should look similar to the figure at right.



10. To change the color and line style of the different spectra, select **Edit** → **Data Parameters** from the ENVI Plot Window menu bar. A Data Parameters dialog appears, listing each spectrum by name and location.

11. In the Data Parameters dialog, select a spectrum and change its properties as desired.

12. When finished, click **Cancel** to close the Data Parameters dialog.

13. Select **File** → **Cancel** from the Spectral Profile and ENVI Plot Window menu bars.

Animate the Data

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

1. From the Display #1 menu bar, select **Tools** → **Animation** to create a movie using the AVIRIS data. The Animation Input Parameters dialog appears. This dialog lists all of the bands provided in the Available Bands List.

2. All bands are selected by default. Click once on the filename (**`cup95_rd.int`**) to deselect all of the bands.

3. Click band **197**, click **<Shift>**, and click band **216** to select a subset of 20 bands for animation.

4. In the **Window Size** field, enter **320** x **280** to reduce the size of the image to be animated, thus increasing the speed of the animation.

5. Click **OK** to start the animation loading process. A status bar appears as each image is processed. When all of the bands are loaded, the Animation Controls dialog appears and the animation begins. Selected bands are displayed sequentially. Use the Animation Controls dialog to specify the animation parameters. Vary the animation speed from 1 to 100 by entering a **Speed** value.

6. Use the control buttons (which look like CD player buttons) to run the animation forward and reverse and to pause specific bands. When paused, click and drag the slider to manually select the band to display.

7. From the Animation Controls dialog menu bar, click **File** → **Cancel** to end the animation.

8. Close the two display groups.

Working with Cuprite Radiance Data

1. In the Available Bands List, select the **RGB Color** radio button.

2. Under `cup95_rd.int`, select bands **183**, **193**, and **207** in sequential order. Click **Load RGB**. The color composite is loaded into a new display group.

Extract Radiance Spectra

1. From the Display group menu bar, select **Tools** → **Pixel Locator**. A Pixel Locator dialog appears.

2. Enter **590** in the **Sample** field and **570** in the **Line** field to center the Zoom window over Stonewall Playa. Click **Apply**.

3. Extract the radiance spectrum for this location by selecting **Tools** → **Profiles** → **Z Profile (Spectrum)** from the Display group menu bar. A Spectral Profile plot window appears.

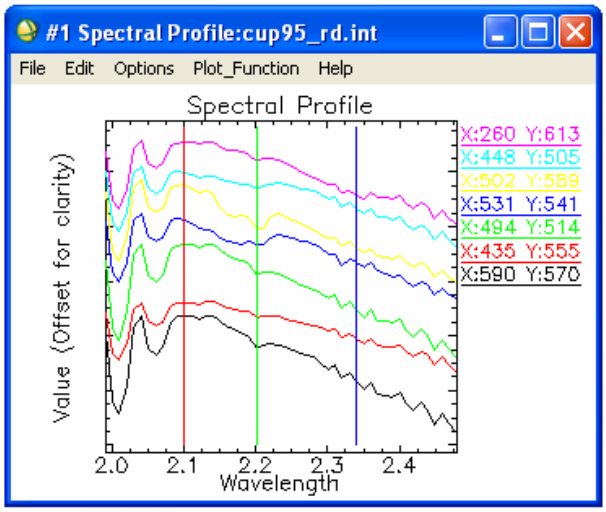
4. From the Spectral Profile menu bar, select **Options** → **Collect Spectra**.

5. Using the following table as a reference, enter **Sample** and **Line** values in the Pixel Locator dialog to extract radiance spectra for different surface features. When you click **Apply** each time, the Zoom box moves to that location and the corresponding spectra are loaded into the Spectral Profile plot window.

Location Name	Sample (with offset)	Line (with offset)
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

6. From the Spectral Profile menu bar, select **Options** → **Stack Plots** to offset each spectrum so you can better compare them.

7. Right-click in the plot window and select **Plot Key** to display the legend for each spectra. Your Spectral Profile should similar to the figure below.



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

8. Close the Pixel Locator dialog, but keep open the Spectral Profile plot for the next exercise.

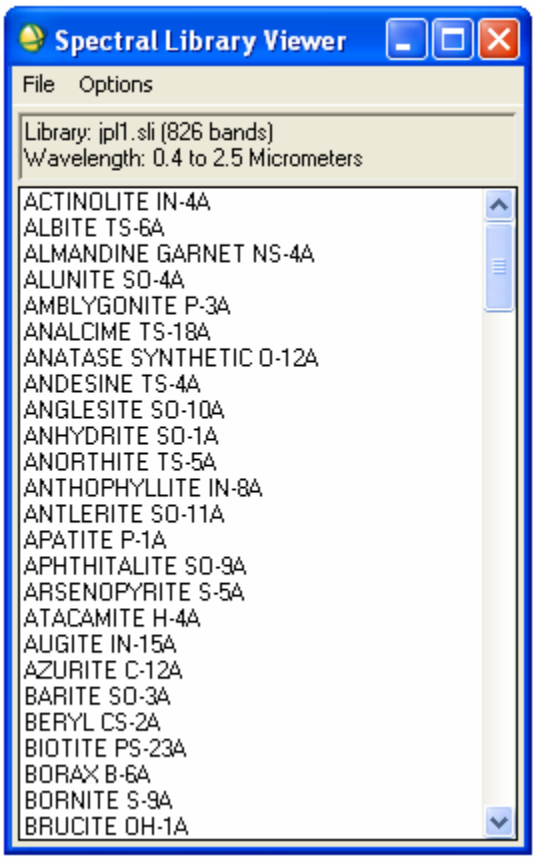
Load Spectral Library Reflectance Spectra

In this series of steps, you will compare apparent reflectance spectra from the image to selected library reflectance spectra.

1. From the ENVI main menu bar, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**. A Spectral Library Input File dialog appears.

2. Click the **Open** drop-down button and select **Spectral Library**. From the ENVI Resource DVD, navigate to `envidata\spec_lib\jpl_lib` and select `jpl1.sli`. Click **Open**.

3. In the Spectral Library Input File dialog, select `jpl1.sli` and click **OK**. A Spectral Library Viewer dialog appears.



4. Select the following spectra in the Spectral Library Viewer, one at a time.

   ALUNITE SO-4A
   BUDDINGTONITE FELDS TS-11A
   CALCITE C-3D
   KAOLINITE WELL ORDERED PS-1A

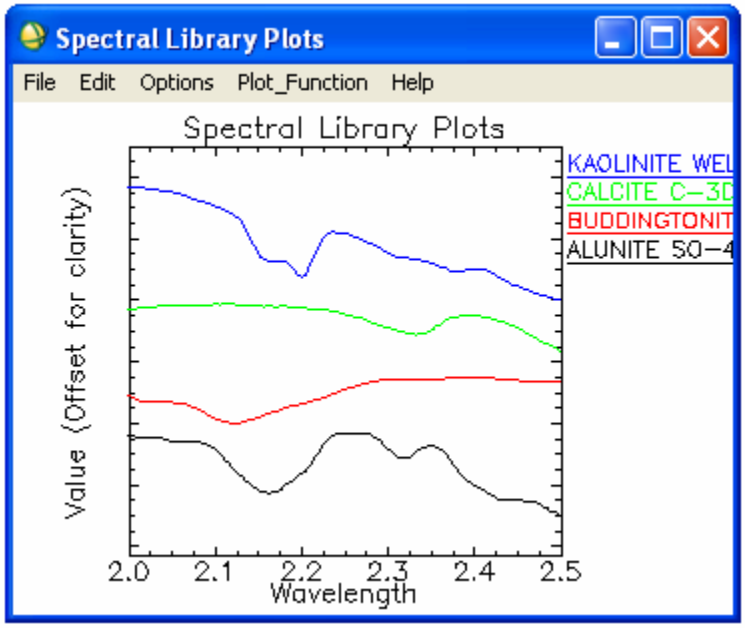
5. When you select ALUNITE SO-4A, a Spectral Library Plots window appears with a spectral profile. As you select the remaining spectra, their profiles are added to the same Spectral Library Plots window.

6. Right-click in the Spectral Library Plots window and select **Plot Key** to display the legend for each spectra.

7. From the Spectral Library Plots menu bar, select **Edit** → **Plot Parameters**.

8. Enter **Range** values from **2.0** to **2.5**. Click **Apply**, then **Cancel**.

9. From the Spectral Library Plots menu bar, select **Options** → **Stack Plots** to offset each spectrum. Your Spectral Library Plots window should look similar to the following figure.



10. Visually compare the Spectral Profile plot (AVIRIS radiance spectra) with the Spectral Library plot (laboratory measurements of mineral spectra).

11. When you are finished with this section, close all of the plot windows by selecting **Window** → **Close All Plot Windows** from the ENVI main menu bar.

12. Close the Spectral Library Viewer dialog.

13. Keep open the display group for the next exercise.

Compare Radiance and Reflectance Spectra

In this section, you will extract selected image radiance spectra and compare them to apparent reflectance spectra for specific targets in the AVIRIS radiance data.

Load AVIRIS Radiance Data and Start the Z Profile

1. From the Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**.

2. When the Spectral Profile plot window appears, move it to the bottom of your screen for easy access.

Load Apparent Reflectance Data and Start the Z Profile

1. Open a second AVIRIS dataset. From the ENVI main menu bar, select **File** → **Open Image File**. Navigate to `envidata\c95avsub` and select `cup95_at.int`. This file is a 50-band (1.99 - 2.48 µm) subset of AVIRIS data calibrated to apparent reflectance. The 50 bands are added to the Available Bands List.

2. In the Available Bands List, select **Band 193** under `cup95_at.int`, and select the **Gray Scale** radio button.

3. In the Available Bands List, click **Display #1** and select **New Display**.

4. Click **Load Band**.

5. From both Display group menu bars, select **Tools** → **Profiles** → **Z Profile (Spectrum)**.

6. Arrange the two Spectral Profile plot windows side-by-side so you can compare them.

Link Images and Compare Spectra

1. From any Display group menu bar, select **Tools** → **Link** → **Link Displays**. The Link Displays dialog appears.

2. Accept the defaults and click **OK**.

3. From the Display #1 menu bar, select **Tools** → **Link** → **Dynamic Overlay Off**.

4. If you click in the Display #1 Image window, drag the Zoom box, or use the Pixel Locator to change the current pixel location in Display #1, the second image automatically moves the cursor to the same pixel location. The Z Profiles for both images also change to show the radiance and apparent reflectance spectra at the current location.

5. From any Display group menu bar, select **Tools** → **Pixel Locator**. A Pixel Locator dialog appears.

6. Enter **590** in the **Sample** field and **570** in the **Line** field to center the Zoom window over Stonewall Playa. Click **Apply**.

7. Visually compare the radiance and apparent reflectance spectrum for this location using the two Z Profiles.

9. From both of the Spectral Profile menu bars, select **Options** → **Collect Spectra**.

10. Using the following table as a reference, enter **Sample** and **Line** values in the Pixel Locator dialog to extract radiance spectra for different surface features. When you click **Apply** each time, the Zoom box moves to that location and the spectra are loaded into the Spectral Profile plot window.

Location Name	Sample (with offset)	Line (with offset)
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

An alternate method for simultaneously getting linked spectral profiles from two or more images is to select Tools → Profiles → Additional Z Profile from one of the Display group menu bars. Then choose additional datasets to extract spectral profiles from.

11. From both of the Spectral Profile menu bars, select **Options** → **Stack Plots** to vertically offset data for comparison.

12. When you are finished, select **Window** → **Close All Plot Windows** from the ENVI main menu bar.

13. Close both display groups.

14. Keep the Pixel Locator dialog open for the next exercise.

Use the Spectral Analyst to Identify Spectra

ENVI's Spectral Analyst tool uses 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 list of the materials in the input spectral library ranked in order of best-to-worst match. It reports an overall similarity score, along with individual 0.0 to 1.0 scores for each method, with 1.0 equaling a perfect match. The Spectral Analyst does not identify spectra; it only recommends likely candidates for identification.

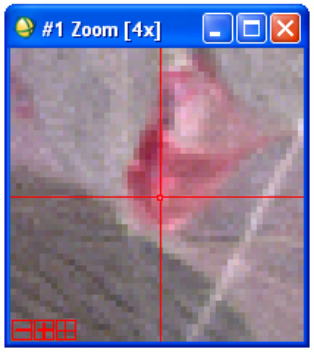
For this exercise, you will match an unknown spectrum in the Cuprite AVIRIS scene that is corrected for apparent reflectance (`cup95_at.int`) with the materials listed in the USGS spectral library.

1. In the Available Bands List, select the **RGB Color** radio button.

2. Under **`cup95_at.int`**, click sequentially on **Band 183**, **Band 193**, and **Band 207** (2.10, 2.20, and 2.35 µm, respectively).

3. Click **Load RGB**. A display group appears with an RGB image of `cup95_at.int`.

4. In the **Sample** field of the Pixel Locator dialog, enter **502**. In the **Line** field, enter **589**. Click **Apply**. The Zoom box centers over a small, pink area with an unknown material.



5. From the Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. A Spectral Profile plot window appears.

6. Right-click in the Spectral Profile and select **Plot Key** to display a legend for the spectrum corresponding to the pixel underlying the cursor in the Zoom box. This represents the unknown spectrum.

7. From the ENVI main menu bar, select **Spectral** → **Spectral Analyst**. A Spectral Analyst Input Spectral Library dialog appears.

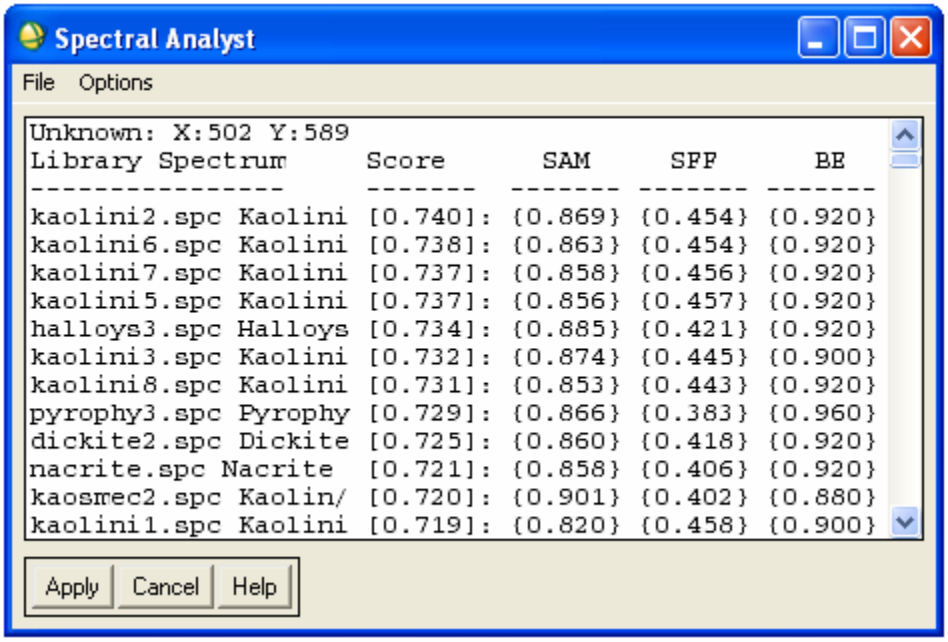
8. Select **Open** → **Spectral Library** at the bottom of the Spectral Analyst Input Spectral Library dialog.

9. Navigate to `envidata\spec_lib\usgs_min` and select `usgs_min.sli`. Click **Open**.

10. In the Spectral Analyst Input Spectral Library dialog, select `usgs_min.sli` and click **OK**. The Edit Identify Methods Weighting dialog appears.

11. You will give equal weight to the Spectral Angle Mapper, Spectral Feature Fitting, and Binary Encoding methods. Enter **0.33** in each of the three **Weight** fields, and click **OK**.

12. In the Spectral Analyst dialog, click **Apply**. The Spectral Analyst scores the unknown spectrum against the spectral library. The Score values range from 0.0 to 1.0, with 1.0 equaling a perfect match.



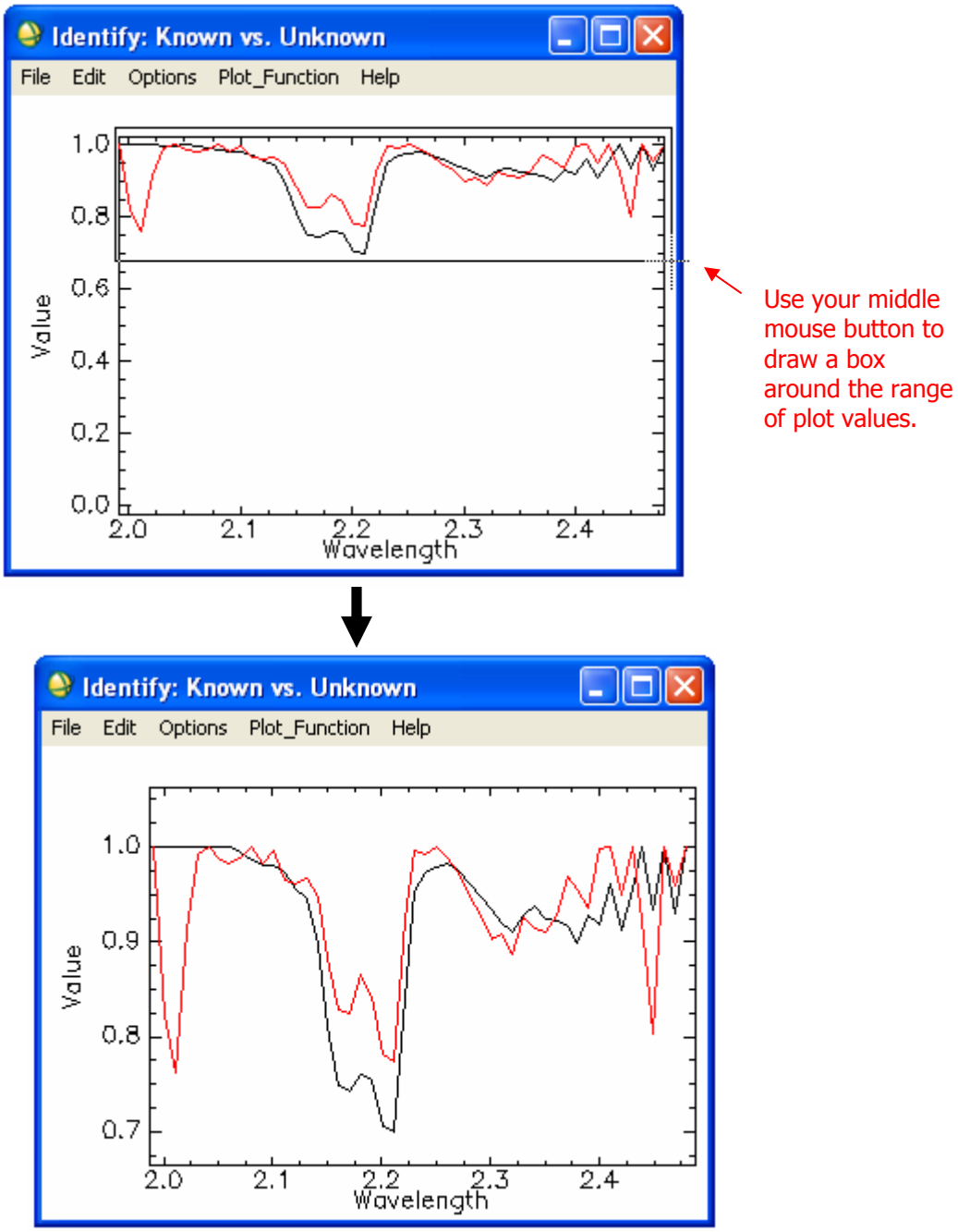
13. Notice how many times the mineral kaolinite appears at the top of the list and its relatively high scores. This would indicate a high likelihood of kaolinite.

14. Double-click the first spectrum name in the list. An Identify: Known vs. Unknown plot window appears with the unknown spectrum plotted in red against the (known) library spectrum.

15. To zoom into the y-axis range of 0.6 to 1.0 µm so you can better discern the two spectra, choose one of the following options:

    From the Identify plot menu bar, select **Edit** → **Plot Parameters**. In the Plot Parameters dialog, click the **Y-Axis** radio button. In the **Range** Field, enter **0.60**. Leave the **To** field as **1.0**. Click **Apply**, then click **Cancel** to close the Plot Parameters dialog.

Click and drag the middle mouse button to draw a box around the full range of x-axis values and a range of y-axis values from 0.6 to 1.0, as shown below:



16. Notice how the shape of the unknown spectrum (red) approximately resembles that of the known spectrum for kaolinite. This comparison, along with the relatively high ranking of kaolinite in the Spectral Analyst table, suggests a high likelihood that the pixel in question contains kaolinite.

17. Close the Identify plot window, then double-click on **pyrophy3.spc** (pyrophyte) in the Spectral Analyst table.

18. Zoom into the y-axis range of 0.6 to 1.0 µm so you can better discern the two spectra.

19. Notice how the shape of the unknown spectrum is significantly different from that of the known pyrophyte spectrum. This visual comparison suggests that the pixel in question likely is not pyrophyte.

20. Continue comparing spectral plots from other minerals in the Spectral Analyst table with that of the unknown spectrum to verify the mineralogy for that location. Pay close attention to the similarity or differences of the spectra in absorption features (where the spectra suddenly decrease in value). Also remember that the library spectra of known minerals were derived a much larger number of samples (and are thus smoother in shape) than the Z Profile spectrum derived from the image.

21. When you are finished with this section, select **Window → Close All Plot Windows** from the ENVI main menu bar, followed by **Window → Close all Display Windows**. Then close the Spectral Analyst dialog.

Compare Atmospheric Corrections

This section of the tutorial compares several image apparent reflectance spectra. You will use a spectral library of apparent reflectance spectra generated from ENVI's Flat Field Correction, IARR Correction, and Empirical Line Correction calibration methods and compare their characteristics.

Flat Field Correction

The Flat Field Correction method normalizes 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 and uniform area in the AVIRIS data, by defining a region of interest (ROI). The radiance spectrum from this area is assumed to contain 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 you can compare with laboratory spectra.

Internal Average Relative Reflectance (IARR)

The IARR calibration method normalizes 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 method forces 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 ROIs. 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 dataset. 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.

Select Spectral Library of Calibration Results Spectra

1. From the ENVI main menu bar, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**. The Spectral Library Input File dialog appears.

2. Click **Open** → **Spectral Library**. Navigate to `envi_data\c95avsub` and select `cup95cal.sli`. Click **Open**. This spectral library contains the results from the various calibration methods.

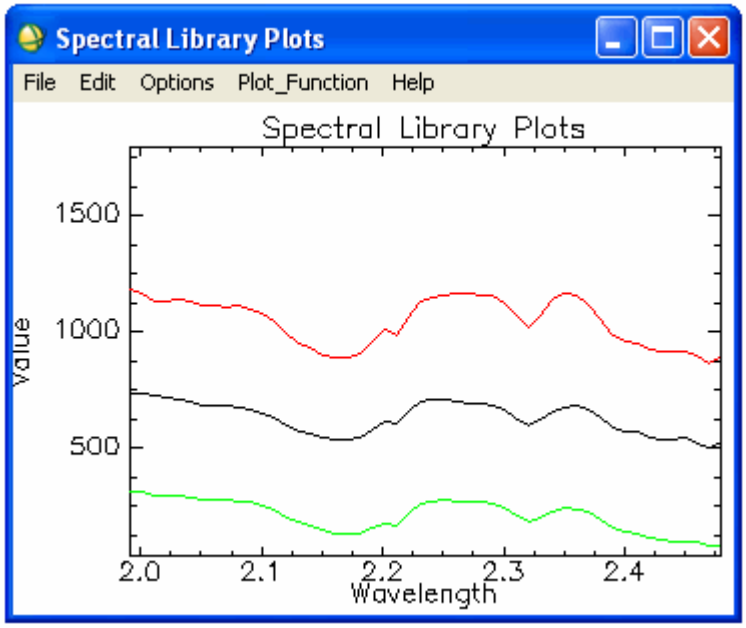
3. In the Spectral Library Input File dialog, select `cup95cal.sli` and click **OK**. A Spectral Library Viewer dialog appears.

Select Atmospherically Corrected Spectra from Spectral Library

1. In the Spectral Library Viewer, select the following:

   Flat Field: Alunite
   IARR: Alunite
   Empirical Line: Alunite

2. A Spectral Library Plot appears with spectral profiles of alunite generated from each calibration method.



3. Visually compare the calibrations and compare their characteristics. What might explain their differences?

4. When finished, select **Options** → **Clear Plots** from the Spectral Library Viewer menu bar.

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

Optional: Browse Corrected Data Files

The corrected data files for all of the different corrections are available for spectral browsing. All files have been converted to integer format by multiplying the reflectance values by 1000 (to conserve disk space). Data values of 1000 indicate an apparent reflectance of 1.0.

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

File Type	File Name
Flat Field	`cup95_ff.int`
IARR	`cup95_ia.int`
Empirical Line	`Cup95_el.int`

2. Use the Z Profile and multiple linked images to compare apparent reflectance spectra for specific areas of interest.

3. After comparing all of the correction methods for a variety of minerals, which calibration methods best reproduce the laboratory spectra for all minerals? Do you find that one calibration method is the best?

References

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Goetz, A. F. H., and V. Srivastava, 1985, Mineralogical mapping in the Cuprite Mining District, Nevada: in Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop, JPL Publication 85-41, Jet Propulsion Laboratory, Pasadena, CA, p. 22-29.

Goetz, A. F. H., G. Vane, J. E. Solomon, and B. N. Rock, 1985, Imaging spectrometry for Earth remote sensing: Science, v. 211, p. 1147-1153.

Kruse, F. A., 1988, Use of Airborne Imaging Spectrometer data to map minerals associated with hydrothermally altered rocks in the northern Grapevine Mountains, Nevada and California: Remote Sensing of Environment, v. 24, no. 1, p. 31-51.

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