ENVI Tutorial:
Selected Hyperspectral Mapping Methods

RSI

ITT Industries

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Overview of This Tutorial

This tutorial describes advanced concepts and procedures for analyzing imaging spectrometer data or hyperspectral images. You will use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data from Cuprite, Nevada, USA, to investigate the unique properties of hyperspectral data and how spectral information can be used to identify mineralogy. You will evaluate EFFORT "polished" spectra and Atmosphere REMoval (ATREM)-calibrated data, and review the Spectral Angle Mapper (SAM) classification method. You will compare apparent reflectance spectra (and images) to continuum-removed spectra (and images), and you will evaluate Spectral Feature Fitting (SFF) results. Finally, you will learn how to use Multi Range SFF to define specific wavelength ranges for analyzing mineral spectral signatures.

Files Used in This Tutorial
CD-ROM: Tutorial Data CD #2
Path: `envidata/c95avsub`

The following files are required for this tutorial. All image data files have been converted to integer format by multiplying the reflectance values by 1000 to conserve disk space. A value of 1000 represents an apparent reflectance value of 1.0.

File	Description
cup95_at.int (.hdr)	Cuprite ATREM-calibrated apparent reflectance data. 50 bands (integer)
cup95eff.int (.hdr)	Cuprite EFFORT-corrected, ATREM-calibrated apparent reflectance data. 50 bands (integer)
jpl1.sli (.hdr)	JPL spectral library in ENVI format
usgs_min.sli (.hdr)	USGS spectral library in ENVI format
cup95_av.roi	Saved region of interest (ROI) locations
cupsamem.asc	Optional file of ROI mean spectra
cupsam1.img (.hdr)	SAM classification image using ROI image spectra endmembers
cuprul1.img (.hdr)	SAM rule image using ROI image spectra endmembers
cupsam2.img (.hdr)	SAM classification image using spectral library endmembers
cuprul2.img (.hdr)	SAM rule images using spectral library endmembers
cup95_cr.dat (.hdr)	Continuum-removed data (floating-point)
cup95sff.dat (.hdr)	SFF results
cup95sfr.dat (.hdr)	SFF Band Math results

Remove Residual Calibration Errors

Empirical Flat Field Optimized Reflectance Transformation (EFFORT) is a correction method used to remove residual "saw-tooth" instrument (or calibration-introduced) noise and atmospheric effects from ATREM-calibrated AVIRIS data. It is a custom correction designed to improve the overall quality of spectra, and it provides the best reflectance spectra available from AVIRIS data. EFFORT is a relatively automated improvement over the Flat-Field calibration method (Boardman and Huntington, 1996).

The EFFORT correction method selects AVIRIS spectra that match a low-order polynomial estimate in a least-squares sense as representative, featureless spectra. These spectra are averaged and a mild gain factor is determined to remove systematic, coherent noise present in every spectrum, including small residual atmospheric effects near the 2.0 μm range attributable to CO_2.

You normally run EFFORT by selecting Spectral → Effort Polishing from the ENVI main menu bar, but you will not run EFFORT during this exercise. Instead, you will use AVIRIS data already corrected with EFFORT.
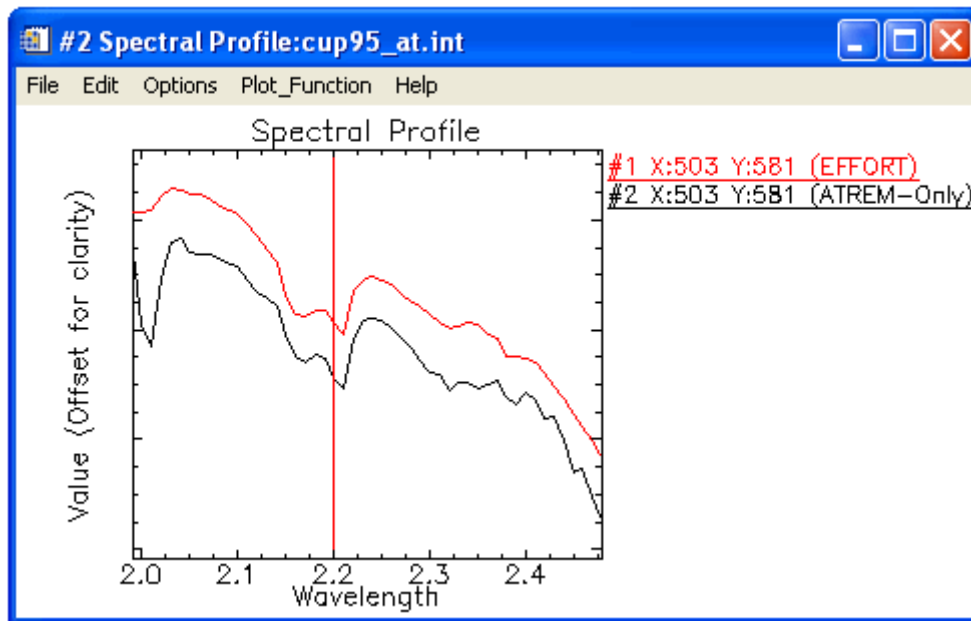
Load EFFORT-Corrected Data

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

2. Navigate to `envidata/c95avsub` and select `cup95eff.int`. Click **Open**. This file contains EFFORT-corrected, ATREM-calibrated, AVIRIS apparent reflectance data.

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

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

5. From the ENVI main menu bar, select **File → Open Image File**. Select `cup95_at.int` and click **Open**. This file contains the original ATREM-calibrated, AVIRIS apparent reflectance data (with no EFFORT correction).

6. In the Available Bands List, select **Band 193** (2.20 μm), click **Gray Scale**, and click **Load Band**.

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

8. Compare the two spectral profiles.

Compare EFFORT and ATREM Spectra

1. From the Display #1 menu bar, select **Tools → Link → Link Displays**. A Link Displays dialog appears.

2. Click **OK** to accept the default values.

3. From the Display #1 menu bar, select **Tools → Link → Dynamic Overlay Off** to enable normal mouse interaction. Both spectral profiles show the spectrum for the current pixel.

4. Move the Zoom box in an Image window and compare the corresponding ATREM and EFFORT spectra. Note where the major differences occur.

5. From the Display #1 menu bar, select **Tools → Pixel Locator**, and position the cursor at location (503,581).

6. Right-click in the Spectral Profile #1 plot window and select **Plot Key** to display the plot legend.

7. Drag and drop the EFFORT spectrum into the Spectral Profile #2 plot window, by clicking the spectrum name from the Spectral Profile #1 plot window and dragging it into Spectral Profile #2.

8. Right-click in the Spectral Profile #1 plot window and select **Plot Key** to display the plot legend.

9. From the Spectral Profile #2 menu bar, select **Edit → Data Parameters**. A Data Parameters dialog appears.

10. Change the color of the EFFORT spectrum by selecting **#1 X:205 Y:581** in the list and clicking the **Color** box to the desired color.

11. In the **Name** field, add the text **(EFFORT)** to the end of the name. Similarly, add the text **ATREM-Only** to the name of the ATREM spectrum.

12. Set the **Right Margin** field to **15** so you can view the full legend.

13. Click **Apply**, followed by **Cancel**.

14. Stack the spectra by selecting **Options → Stack Plots** from the Spectral Profile #2 menu bar. The plot should look similar to the following:

15. Compare the EFFORT-corrected spectrum to the ATREM-only spectrum. The two are very similar, but small coherent noise perturbations have been removed from the EFFORT spectrum. You should also see the correction of residual CO_2 at 2.01 µm.

16. Right-click the first character of the EFFORT spectrum name in the Spectral Profile #2 plot window to delete the imported spectrum.

17. Use the Pixel Locator to move the cursor to location (542,533). The corresponding EFFORT spectrum appears in Spectral Profile #1.

18. Drag and drop this spectrum into the Spectral Profile #2 plot window. Compare the two spectra. What are the major differences?

19. When you are finished, close all plot windows and Display #2. Keep `cup95eff.int` open for the next exercise.

Spectral Angle Mapper Classification

Next, you will use image and laboratory spectra to classify the AVIRIS data using the Spectral Angle Mapper (SAM) algorithm. You will collect endmembers for SAM but will not actually run the algorithm. You will examine previously calculated classification results to answer specific questions about the strengths and weaknesses of the SAM classification.

SAM is an automated method for comparing image spectra to individual spectra or to a spectral library (Boardman, unpublished data; CSES, 1992; Kruse et al., 1993a). SAM assumes that the data have been reduced to apparent reflectance (true reflectance multiplied by some unknown gain factor, controlled by topography and shadows). The algorithm determines the similarity between two spectra by calculating the *spectral angle* between them, treating them as vectors in *n*-D space, where *n* is the number of bands.

Consider a reference spectrum and an unknown spectrum from two-band data. The two different materials are represented in a 2D scatter plot by a point for each given illumination, or as a line (vector) for all possible illuminations.
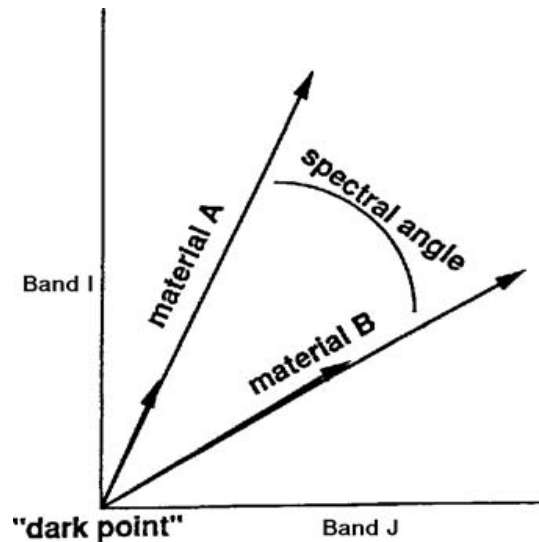
Because SAM uses only the *direction* of the spectra, not the length, SAM is insensitive to the unknown gain factor. All possible illuminations are treated equally. Poorly illuminated pixels fall closer to the origin of the scatter plot. The *color* of a material is defined by the direction of its unit vector. The angle between the vectors is the same, regardless of the length. The length of the vector relates only to how fully the pixel is illuminated. The SAM algorithm generalizes this geometric interpretation to *n*-D space. SAM determines the similarity of an unknown spectrum t to a reference spectrum r, by applying the following equation (CSES, 1992):

$$\alpha = \cos^{-1}\left(\frac{\vec{t} \bullet \vec{r}}{\|\vec{t}\| \bullet \|\vec{r}\|} \right)$$

which also can be written as:

$$\alpha = \cos^{-1}\left(\frac{\sum\limits_{i=1}^{nb} t_i r_i}{\left(\sum\limits_{i=1}^{nb} t_i^2\right)^{1/2} \left(\sum\limits_{i=1}^{nb} r_i^2\right)^{1/2}} \right)$$

where *nb* equals the number of bands in the image.

For each reference spectrum chosen in the analysis of a hyperspectral image, the spectral angle α (in radians) is determined for every image spectrum (pixel). This value is assigned to the corresponding pixel in the output SAM image, one output image for each reference spectrum. The derived spectral angle maps form a new data cube with the number of bands equal to the number of reference spectra used in the mapping. Gray-level thresholding is typically used to empirically determine areas that most closely match the reference spectrum while retaining spatial coherence.

The SAM algorithm implemented in ENVI takes as input a number of *training classes*, or reference spectra from ASCII files, ROIs, or spectral libraries. It calculates the angular distance between each spectrum in the image and the reference spectra or *endmembers* in *n*-dimensions. The result is a classification image showing the best SAM match at each pixel and a *rule* image for each endmember showing the actual angular distance in radians between each spectrum in the image and the reference spectrum. Darker pixels in the rule images represent smaller spectral angles—spectra that are more similar to the reference spectrum. The rule images can be used for subsequent classifications using different thresholds to decide which pixels are included in the SAM classification image.

Select Image Endmembers

1. In the Available Bands List, under `cup95eff.int`, select **Band 193** (2.20 μm), click Gray Scale, and click **Load Band**.

2. From the ENVI main menu bar, select **Classification → Supervised → Spectral Angle Mapper** to start collecting endmembers. A file selection dialog appears. Select `cup95eff.int` as the input file and click **OK**. An Endmember Collection:SAM dialog appears.

3. From the Endmember Collection:SAM dialog menu bar, select **Import → from ASCII file**. A file selection dialog appears.

4. Select `cup95_em.asc` and click **Open**. An Input ASCII File dialog appears.

5. Hold down the **<Ctrl>** key and deselect **Mean:Dark/black**, **Mean:Bright/playa**, **Mean:Silica? (Dark)**, and **Mean:Alunite (2.18)** in the Select Y Axis Columns list.

6. Click **OK** to load the remaining endmember spectra into the Endmember Collection:SAM dialog.

7. Click **Select All**, followed by **Plot**. An Endmember Collection Spectra plot window appears.

8. From the Endmember Spectra menu bar, select **Options → Stack Plots** to offset the spectra.

9. Right-click in the plot window and select **Plot Key** to display the legend. The result is shown in the following figure:
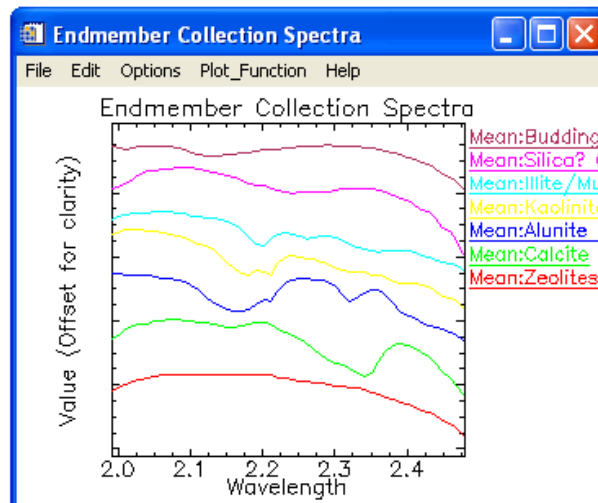
10. Normally, you would click Apply in the Endmember Collection:SAM dialog to start the classification, but because classification can take some time, preprocessed results are provided for this exercise.

- If you have time, click **Apply** in the Endmember Collection:SAM dialog, enter output file names in the Spectral Angle Mapper Parameters dialog, and click **OK**.

- Or, in the Endmember Collection:SAM dialog, click **Cancel** and continue with the following exercise.

Execute SAM

Open a SAM Classification Image

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

2. Select cupsam1.img. The classification image has one band with coded values for each class. Click **Open**.

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

4. In the Available Bands List, select **Sam** under cupsam1.img and click **Load Band**. The classes are automatically color-coded as follows:

Mineral	Color
Zeolites	White
Calcite	Green
Alunite	Yellow
Kaolinite	Red
Illite/Muscovite	Dark green
Silica	Blue
Buddingtonite	Maroon

The number of pixels displayed as a specific class is a function of the threshold used to generate the classification. Just because a given pixel is classified as a specific mineral does not mean it is actually that mineral. SAM is a similarity measure, not an identifier.

Open EFFORT-Corrected Data

5. In the Available Bands List, click **Display #2** and select **New Display**.

6. Click **RGB Color**, then select **Band 183**, **Band 193**, and **Band 207** under cup95eff.int. Click **Load RGB**.

7. From the Display #3 menu bar, select **Tools → Profiles → Z Profile (Spectrum)**.

8. Compare the SAM classification results with the distributions shown in the color composite.

Open SAM Rule Image

9. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

10. Select cuprul1.img and click **Open**. This rule image has one band for each classified endmember, with the pixel values representing the spectral angle in radians. Lower spectral angles (darker pixels) represent better spectral matches to the endmember spectrum.

11. In the Available Bands List, click **Gray Scale**. Click **Display #3 → New Display**.

12. In the Available Bands List, select **Rule (Mean:Zeolites)** under `cuprul1.img` and click **Load Band**.

13. Evaluate the image with respect to the color composite and the SAM classification image, as well as the ROI means and individual spectra in the Spectral Profile plot window.

14. From the Display #4 menu bar, select **Tools → Color Mapping → ENVI Color Tables**.

15. Use the **Stretch Bottom** and **Stretch Top** sliders to adjust the SAM rule thresholds to highlight those pixels with the greatest similarity to the selected endmember.

16. Pull the **Stretch Bottom** slider all the way to the right and the **Stretch Top** slider all the way to the left to highlight the most similar pixels in white.

17. Move the **Stretch Bottom** slider gradually to the left to reduce the number of highlighted pixels and show only the best SAM matches in white. You can use a rule image color composite or image animation if desired to compare individual rule images.

18. Repeat the process with each SAM rule image. When finished, select **File → Cancel** from the ENVI Color Tables dialog menu bar.

19. From the ENVI main menu bar, select **Window → Close All Display Windows**.

Select Spectral Library Endmembers

In this exercise, you will select endmembers again, but you will not actually perform the SAM classification. Previously saved SAM results will be used for comparisons. If you have time, you can perform your own SAM classification using spectral library endmembers.

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

2. Click **Open → Spectral Library**. A file selection dialog appears.

3. Navigate to `envidata/spec_lib/jpl_lib` and select `jpl1.sli`. Click **Open**.

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

5. Select **ALUNITE SO-4A**. A Spectral Library Plots window appears.

6. Right-click in the Spectral Library Plots window and select **Plot Key** to view the spectral library name.

7. In the Spectral Library Viewer dialog, select the following spectra to plot them in the same Spectral Library Plots window.

> **BUDDINGTONITE FELDS TS-11A**
> **CALCITE C-3D**
> **CHABAZITE TS-15A** (a zeolite mineral)
> **ILLITE PS-11A**
> **KAOLINITE WELL ORDERED PS-1A**

8. Start the SAM endmember selection process by selecting **Classification → Supervised → Spectral Angle Mapper** from the ENVI main menu bar. You can also access this function from the ENVI Spectral menu. A Classification Input File dialog appears.

9. Click **Open → New File**, navigate to `envidata/c95avsub` and select `cup95eff.int`. Click **Open**.

10. In the Classification Input File dialog, select `cup95eff.int` and click **OK**. An Endmember Collection: SAM dialog appears.

11. From the Endmember Collection: SAM dialog menu bar, select **Import → from Spectral Library file**. A Spectral Input Library File dialog appears.

12. Select `jpl1.sli` and click **OK**. The Input Spectral Library dialog appears.

13. Hold down the **<Ctrl>** key and select the following spectra, then click **OK**:

    ALUNITE SO-4A
    BUDDINGTONITE FELDS TS-11A
    CALCITE C-3D
    CHABAZITE TS-15A (a zeolite mineral)
    ILLITE PS-11A
    KAOLINITE WELL ORDERED PS-1A

    The spectra are listed in the table of the Endmember Collection: SAM dialog.

14. From the Endmember Collection: SAM dialog menu bar, select **Import → from Spectral Library file** again. A Spectral Input Library File dialog appears.

15. Click **Open → Spectral Library**. A file selection dialog appears.

16. Navigate to `envidata/spec_lib/usgs_min` and select `usgs_min.sli`. Click **Open**.

17. In the Spectral Library Input File dialog, select `usgs_min.sli` and click **OK**. A new Input Spectral Library dialog appears.

18. Select **opal2.spc Opal TM8896 (Hyalite)** and click **OK**. The spectrum is added to the table in the Endmember Collection: SAM dialog.

19. In the Endmember Collection: SAM dialog, click **Select All**, followed by **Plot**. An Endmember Collection Spectra plot window appears.

20. From the Endmember Collection Spectra menu bar, select **Options → Stack Plots** to vertically offset the spectra for comparison.

21. Compare these spectra to the image spectra plotted in the previous SAM exercise.

22. Since you will not actually be performing the SAM classification in this exercise, click **Cancel** in the Endmember Collection:SAM dialog to continue the exercise. If you have time, you can generate your own SAM classification by clicking **Apply**.

Review SAM Results

Open a SAM Classification Image

1. Open the pre-calculated SAM classification image generated from spectral library endmembers by selecting **File → Open Image File** from the ENVI main menu bar. A file selection dialog appears.

2. Navigate to `envidata/c95avsub` and select `cupsam2.img`. Click **Open**. This classification image has one band with coded values for each class.

3. In the Available Bands List, select **Gray Scale**.

4. Select **Sam** under `cupsam2.img` and click **Load Band**. The classes are automatically color-coded as follows:

Mineral	Color
Zeolites	White
Calcite	Green
Alunite	Yellow
Kaolinite	Red
Illite/Muscovite	Dark green
Silica	Blue
Buddingtonite	Maroon

The number of pixels displayed as a specific class is a function of the threshold used to generate the classification. Just because a given pixel is classified as a specific mineral does not mean it is actually that mineral. SAM is a similarity measure, not an identifier.

Open EFFORT-Corrected Data

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

6. Click **RGB Color**, then select **Band 183**, **Band 193**, and **Band 207** under `cup95eff.int`. Click **Load RGB**.

7. Compare the classification results with the distributions shown by the color-composite image, the previous classification using image spectra (`cupsam1.img`), and the library spectra. Use image linking for direct comparison if desired.

Open SAM Rule Image

8. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

9. Navigate to `envidata/c95avsub` and select `cuprul2.img`. Click **Open**. Rule images have one band for each endmember classified, with the pixel values representing the spectral angle in radians. Lower spectral angles (darker pixels) represent better spectral matches to the endmember spectrum.

10. In the Available Bands List, select **Gray Scale**. Click **Display #2 → New Display**.

11. In the Available Bands List, select **Rule (ALUNITE SO-4A)** under `cuprul2.img` and click **Load Band**.

12. Evaluate the image using the ENVI Color Tables as you did earlier; and with respect to the color composite, the SAM classification image, the ROI means, and individual spectra extracted using the Z Profile tool. Also, use a rule image color composite or image animation if desired to compare individual rule images.

13. Repeat the process with each SAM rule image. Based upon the results of the two SAM classifications, answer the following questions:

    - What ambiguities exist in the SAM classification based on your images and spectra above?

    - Why are the two classifications so different? What factors could affect how well SAM matches the endmember spectra?

    - How could you determine which thresholds represent a true map of the selected endmembers?

    - Can you see the topographic shading effects in the SAM data? Why or why not?

- Sketch a map of the Cuprite surface mineralogy for all classes on a separate piece of paper. Do some classes co-occur?

- In light of some of the ambiguities in the SAM classification, how could you select better endmembers?

Optional: Generate New SAM Classified Images Using Rule Classifier

If you have some extra time, try generating new classified images based on different thresholds in the rule images.

1. Display the individual bands of one of the two previously calculated rule images (`cuprul1.img` or `cuprul2.img`) and define the threshold for the classification, by selecting **Tools → Cursor Location/Value** from the Display group menu bar and browsing the image. You can also define thresholds by selecting **Tools → Color Mapping → Density Slice** from the Display group menu bar.

2. From the ENVI main menu bar, select **Classification → Post Classification → Rule Classifier**. A Rule Image Classifier dialog appears.

3. Select the same rule image you viewed in Step 1 and click **OK**. A Rule Image Classifier tool dialog appears.

4. Click the Classify by toggle button to select Minimum Value, and enter the previously defined SAM threshold. All of the pixels with values lower than the minimum value will be classified. Lower thresholds result in fewer pixels being classified.

5. Click **Quick Apply** or **Save to File** to begin the processing. The new classification image appears.

6. Compare with previous classifications.

Close Files and Plots

To close all of the files used in this portion of the exercise, select **File → Close All Files** from the Available Bands List menu bar, then click **Yes**. To close all of the spectral plots, select **Window → Close All Plot Windows** from the ENVI main menu bar.

Spectral Feature Fitting and Analysis

Spectral Feature Fitting (SFF) is an absorption-feature-based method for matching image spectra to reference endmembers, similar to methods developed at the U. S. Geological Survey (Clark et al., 1990, 1991, 1992; Clark and Swayze, 1995).

Most methods for analyzing hyperspectral data still do not directly identify specific materials. They only indicate how similar a material is to another known material or how unique it is with respect to other materials. However techniques for direct identification of materials—via extraction of specific spectral features from field and laboratory reflectance spectra—have been in use for many years (Green and Craig, 1985; Kruse et al., 1985; Yamaguchi and Lyon, 1986; Clark et al., 1987). Recently, these techniques have been applied to imaging spectrometer data, primarily for geologic applications (Kruse et al., 1988; Kruse, 1988; Kruse, 1990; Clark et al., 1990, 1991, 1992; Clark and Crowley, 1992; Kruse et al. 1993b, 1993c; Kruse and Lefkoff, 1993, Swayze et al., 1995).

All of these methods require you to reduce data to reflectance and to remove a continuum from the reflectance data prior to analysis. A continuum is a mathematical function used to isolate a particular absorption feature for analysis (Clark and Roush, 1984; Kruse et al, 1985; Green and Craig, 1985). A continuum corresponds to a background signal unrelated to specific absorption features of interest. Spectra are normalized to a common reference using a continuum formed by defining high points of the spectrum (local maxima) and fitting straight line segments between these points. The continuum is removed by dividing it into the original spectrum.
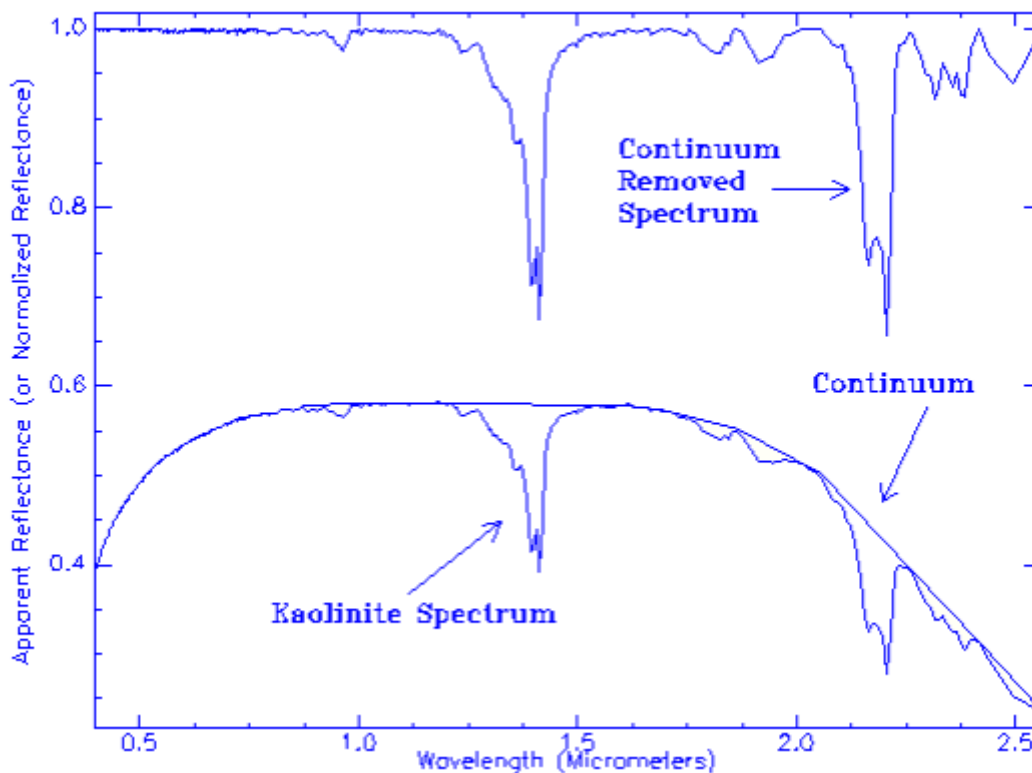
SFF requires you to select reference endmembers from either the image or a spectral library, to remove the continuum from both the reference and unknown spectra, and to scale each reference endmember spectrum to match the unknown spectrum. SFF produces a *scale* image for each endmember selected for analysis by first subtracting the continuum-removed spectra from one endmember (inverting it), and making the continuum zero. SFF determines a single multiplicative scaling factor that makes the reference spectrum match the unknown spectrum. Assuming that a reasonable spectral range has been selected, a large scaling factor is equivalent to a deep spectral feature, while a small scaling factor indicates a weak spectral feature.

SFF then calculates a least-squares-fit, band-by-band, between each reference endmember and the unknown spectrum. The total root-mean-square (RMS) error is used to form an RMS error image for each endmember. An optional ratio image of Scale/RMS provides a *fit* image that is a measure of how well the unknown spectrum matches the reference spectrum on a pixel-by-pixel basis.

Open and Load the Continuum-Removed Data

For this exercise, you can use pre-calculated data if you do not want to create your own continuum-removed data. If you want to use pre-calculated data, skip to *Use Pre-Calculated Data* below.

Create Your Own Data

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95eff.int` and click **Open**.

2. From the ENVI main menu bar, select **Spectral → Mapping Methods → Continuum Removal**. A Continuum Removal Input File dialog appears.

3. Select `cup95eff.int`, perform spectral subsetting if desired to limit the spectral range for continuum removal, and click **OK**.

4. Enter an output filename for the continuum-removed data, and click **OK**. This image will have the same number of spectral bands as the input image if you did not perform spectral subsetting.

Use Pre-Calculated Data

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95_cr.dat` and click **Open**. This file contains continuum-removed, floating-point data (0 - 1.0) derived from the AVIRIS EFFORT-calibrated apparent reflectance data.

2. In the Available Bands List, select **Band 193** (2.20 µm), select the **Gray Scale** radio button, and click **Load Band**.

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

4. From the Spectral Profile menu bar, select **Edit → Plot Parameters**. A Plot Parameters dialog appears.

5. Select the **Y-Axis** radio button. Enter **Range** values of **0.5** to **1.0**. Click **Apply**.

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

7. Move the Spectral Profile window to the bottom of the screen for comparison with the EFFORT data.

Open EFFORT-Corrected Data

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95eff.int` and click **Open**. This file contains EFFORT-corrected, ATREM-calibrated, AVIRIS apparent reflectance data. An RGB composite is automatically loaded into a new display group.

2. In the Available Bands List, under `cup95eff.int`, select **Band 193** (2.20 µm), select the **Gray Scale** radio button, and click **Load Band**.

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

4. From the #2 Spectral Profile menu bar, select **Edit → Plot Parameters**. A Plot Parameters dialog appears.

5. Select the **Y-Axis** radio button. Enter **Range** values from **0** to **500**. Click **Apply**.

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

7. Move the #2 Spectral Profile window to the bottom of the screen for comparison with the continuum-removed data.

Compare Continuum-Removed Spectra with EFFORT Spectra

1. From the Display #1 menu bar, select **Tools → Link → Link Displays**. A Link Displays dialog appears. Click **OK** to accept the default values.

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

   - Alternatively, select **Tools → Profiles → Additional Z-Profile** and select the EFFORT data to link a second Z Profile to the spatial location in the continuum-removed image.

   Moving the Zoom box in the continuum-removed image causes the cursor location to be updated in the EFFORT-corrected image. Both spectral profiles show the spectrum for the current pixel. You should see how the continuum-removed spectrum normalizes and enhances spectral features.

3. From the Display #1 menu bar, select **Tools → Pixel Locator**. Enter the pixel location (503,581) and click **Apply**. Compare the continuum-removed spectrum to the EFFORT spectrum.
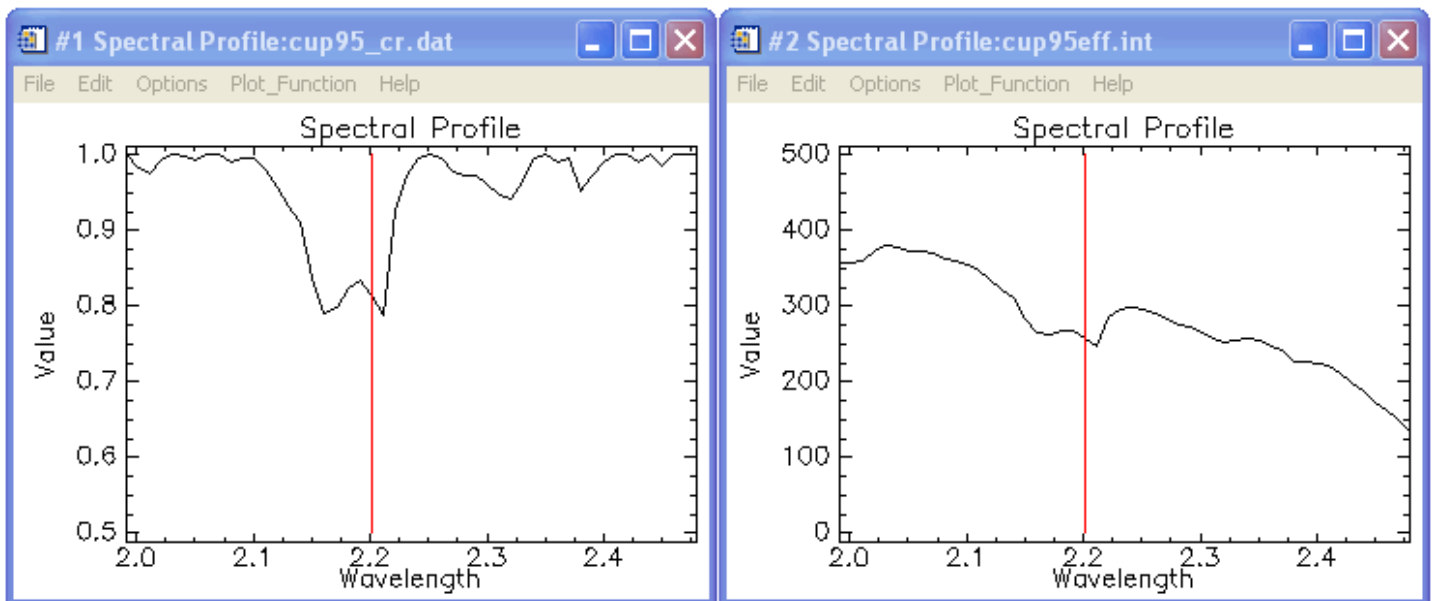
4. Move the cursor location to (542,533) and compare the two images. Note how continuum-removal affects the spectrum.

5. Try selecting some other points in the two images using the Pixel Locator and compare the spectra. What are the major differences? What improvements in visual analysis does the continuum-removal procedure allow?

Compare Continuum-Removed and EFFORT-Corrected Images

1. In the Available Bands List, click **Display #2** and select **New Display**.

2. Click the **RGB Color** radio button. Under `cup95eff.int`, select **Band 183**, **Band 193**, and **Band 207**. Click **Load RGB**.

3. Click inside the Image window that contains the EFFORT-corrected color composite (Display #3) to activate the dynamic overlay.

4. Compare the continuum-removed image for Band 193 (Display #2) to the color composite (Display #3). Note the correspondence between dark areas in the continuum-removed image and red-to-purple areas in the color composite. The dark areas represent absorption bands near 2.2 μm.

5. Move the Zoom box in the Display #2 Image window to some of these dark areas. Compare the corresponding spectral profiles for both the continuum-removed data and the EFFORT-corrected data, and note the image colors.

6. In the Available Bands List, click **Display #3** and select **Display #1**. Under `cup95_cr.dat`, select **Band 207**. Select the **Gray Scale** radio button and click **Load Band**.

7. In the Image window for Display #1 (continuum-removed data), move the Zoom box to the dark areas and examine the spectra. You should see that these areas represent absorption features near 2.34 μm in the continuum-removed and EFFORT spectra.

Close the EFFORT-Corrected Data File

In the Available Bands List, select a band under `cup95eff.int`, then select **File → Close Selected File** from the Available Bands List menu bar. The associated display groups and spectral plots will close.

Open and Load the SFF Scale and RMS Images

For this exercise, you can use pre-calculated data if you do not want to create your own scale and RMS error images. If you want to use pre-calculated data, skip to *Use Pre-Calculated Data* below.

Create Your Own Data
1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95_cr.dat` and click **Open**.

2. From the ENVI main menu bar, select **Spectral → Mapping Methods → Spectral Feature Fitting**. A file selection dialog appears.

3. Select `cup95_cr.dat` file, perform optional spectral subsetting to limit the spectral range for fitting, and click **OK**. An Endmember Collection:Feature Fitting dialog appears.

4. Use this dialog to import image or library spectra to use as endmembers in the SFF and click **Apply**. A Spectral Feature Fitting Parameters dialog appears.

5. In the toggle button field, leave the default value of Output separate Scale and RMS Images. Enter an output filename, and click **OK** to create the scale and RMS error images for each endmember.

Use Pre-Calculated Data
1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95sff.dat` and click **Open**. This file contains the scale and RMS error images derived from SFF using image endmember spectra from the AVIRIS EFFORT-calibrated apparent reflectance data. Library spectra could also have been used, but the image spectra were used to allow direct comparison with other methods that use image spectra.

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

3. Under `cup95sff.dat`, select **Scale (Mean: Kaolinite...)**. Select the **Gray Scale** radio button, and click **Load Band**.

4. In the Available Bands List, click **Display #2** and select **New Display**.

5. Under `cup95sff.dat`, select **Scale (Mean: Alunite 2.16...)**. Select the **Gray Scale** radio button, and click **Load Band**.

6. From one of the Display group menu bars, select **Tools → Link → Link Displays**. A Link Displays dialog appears. Click **OK** to link all three display groups.

7. From one of the Display group menu bars, select **Tools → Cursor Location/Value**. Move the cursor around one of the images, and compare the data values for the two scale images. Although they appear similar as stretched images, their data values are different.

8. Replace the kaolinite scale image with the corresponding RMS error image. In the Available Bands List, click **Display #3** and select **Display #2**. Under `cup95sff.dat`, select **RMS (Mean: Kaolinite...)**. Select the **Gray Scale** radio button, and click **Load Band**.

9. Replace the alunite scale image with the corresponding RMS error image. In the Available Bands List, click **Display #2** and select **Display #3**. Under `cup95sff.dat`, select **RMS (Mean: Alunite...)**. Select the **Gray Scale** radio button, and click **Load Band**.

10. Compare the RMS error images and use the Cursor Location/Value tool to compare their data values. Low RMS values correspond to good spectral matches.

2D Scatter Plots of SFF Results

1. From the Display #2 menu bar, select **Tools → 2D Scatter Plots**. A Scatter Plot Band Choice dialog appears.

2. Under **Choose Band X**, select **Scale (Mean: Kaolinite...)**.

3. Under **Choose Band Y**, select **RMS (Mean: Kaolinite...)**.

4. Click **OK**. A Scatter Plot window appears.

5. Draw a polygon ROI around low RMS values (for all ranges of Scale) in the Scatter Plot window, by clicking and dragging the left mouse button. Right-click to close the polygon and to define the ROI. The pixels corresponding to the ROI are highlighted in the Display #2 Image window (the kaolinite RMS error image).

6. From the Scatter Plot menu bar, select **Options → Change Bands**. The Scatter Plot Band Choice dialog appears.

7. Load other combinations of scale and RMS error data for the various endmembers.

8. From the Scatter Plot menu bar, select **File → Cancel**.

SFF Ratios and Fit Images

For this exercise, you can use pre-calculated data if you do not want to create your own SFF fit images. A fit image represents a scale/RMS ratio for each endmember. If you want to use pre-calculated data, skip to *Use Pre-Calculated Data* below..

Create Your Own Data

1. From the ENVI main menu bar, select **Spectral → Mapping Methods → Spectral Feature Fitting**. A file selection dialog appears.

2. Select `cup95_cr.dat`, perform optional spectral subsetting to limit the spectral range for fitting, and click **OK**. An Endmember Collection:Feature Fitting dialog appears.

3. Use this dialog to import image or library spectra to use as endmembers in the SFF and click **Apply**. A Spectral Feature Fitting Parameters dialog appears.

4. Click the toggle button to select Output combined (Scale/RMS) images. Enter an output filename, and click **OK** to create fit images.

Use Pre-Calculated Data

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears. Select `cup95sfr.dat` and click **Open**.

2. In the Available Bands List, click **Display #3** and select **Display #1**. You will replace the continuum-removed data in Display #1 with a kaolinite fit image.

3. In the Available Bands List, under `cup95sfr.dat`, select **Fit (Mean: Kaolinite...)**. Select the **Gray Scale** radio button, and click **Load Band**. Bright pixels represent the best fit to the reference endmember spectrum of kaolinite.

4. In the Available Bands List, click **Display #1** and select **Display #3**. You will replace the alunite RMS image in Display #3 (from the previous exercise) with the kaolinite scale image.

5. Under `cup95sff.dat`, select **Scale (Mean: Kaolinite...)**. Select the **Gray Scale** radio button, and click **Load Band**. Following is a summary of what each display group should contain at this point:

   - Display #1: Fit (Mean: Kaolinite...)
   - Display #2: RMS (Mean: Kaolinite...)
   - Display #3: Scale (Mean: Kaolinite...)

6. From one of the Display group menu bars, select **Tools → Link → Link Displays**. A Link Displays dialog appears. Click **OK** to link the fit, scale, and RMS images. Note how the scale and RMS images interact to produce the fit result.

7. Create a color-composite image in a new display group, based on fit images for different endmembers. What can you conclude about the effectiveness of SFF for identifying specific endmembers?

8. When you are finished with this exercise, select **File → Close All Files** from the Available Bands List menu bar.

Advanced SFF (Multi Range SFF)

Mineral spectral signatures are usually characterized by a complex set of multiple absorption features. ENVI's Multi Range SFF tool is designed to take advantage of these features by letting you define specific (and multiple) wavelength ranges for SFF comparison.

Select One SFF Range for Dickite and Kaolinite

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

2. Navigate to `envidata/c95avsub` and select `cup95eff.int`. Click **Open**. This file contains EFFORT-corrected, ATREM-calibrated, AVIRIS apparent reflectance data. A color composite image of bands 183, 193, and 207 is automatically loaded into a display group.

3. From the ENVI main menu bar, select **Spectral → Mapping Methods → Multi Range SFF → Use New Ranges**. A file selection dialog appears.

4. Select `cup95eff.int` and click **OK**. A Select Input Spectral Library dialog appears.

5. Click **Open → Spectral Library**. Navigate to `envidata\spec_lib\usgs_min` and select `usgs_min.sli`. Click **Open**.

6. In the Select Input Spectral Library dialog, select `usgs_min.sli` and click **OK**. An Input Spectral Library dialog appears.

7. Choose the mineral spectra to use in the SFF analysis by selecting the mineral name in the dialog. Select **dickite1**.**spc Dickite NMNH106242**, hold down the **<Ctrl>** key, and select **kaolin2**.**spc Kaolinite KGa-1 (wxyl)**. Click **OK**. The Edit Multi-Range SFF Endmember Ranges dialog appears.

Dickite

8. In the Edit Multi-Range SFF Endmember Ranges dialog, the dickite spectrum is highlighted by default. In the plot window, drag the diamond-shaped marker to approximately 2.075 μm (indicated by xpos: 2.0750 above the plot). Right-click and select **Set as Start Range** to mark the starting point of the first continuum segment. Or, enter **2.075** in the **Start Range** field.

9. In the plot window, drag the diamond-shaped marker to approximately 2.235 μm (indicated by xpos: 2.2350 above the plot). Right-click and select **Set as End Range** to mark the ending point of the first continuum segment. Or, enter **2.235** in the **End Range** field.

   You can incrementally adjust the position of the markers, one library spectrum wavelength band position at a time, by clicking the up/down arrows in the Start Range and End Range fields.

   To zoom to a specific range, click and drag the middle mouse button in the plot window to draw a box around the desired spectral range.

   To zoom back out, click the middle mouse button once in the plot window.

   To reset the spectral range, right-click in the zoomed plot and select Previous Range or Reset Range.

10. Click **Add Range** to add the selected spectral range to the Defined Ranges for the dickite1.spc Dickite NMNH106242 spectrum. By default, the fitted continuum is plotted along with the continuum-removed segment in the same plot.

    - Note: If the Add Range button is greyed out, click the up or down arrow once in the End Range field, then set it back to 2.235. The Add Range button should be activated now.

11. Click and drag the middle mouse button inside the plot to draw a zoom box between 2.0 and 2.4 µm.
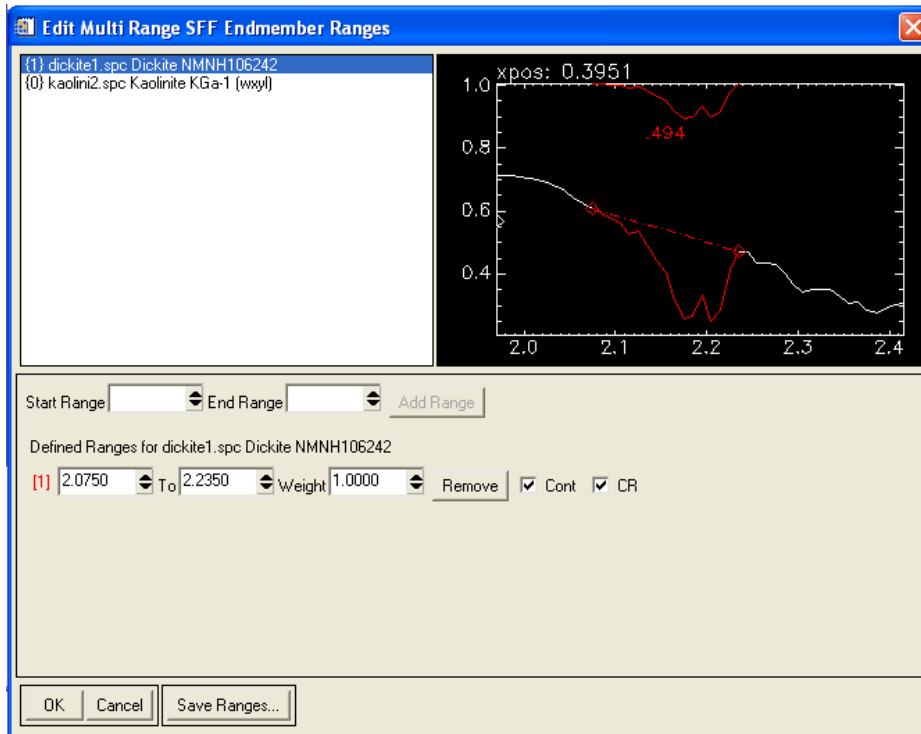

- To remove the continuum plot, click the Cont check box to deselect it.
- To remove the continuum-removed plot, click the CR check box to deselect it.

Kaolinite

12. In the Edit Multi-Range SSF Endmember Ranges dialog, switch the mineral to analyze. Select **kaolin2.spc Kaolinite KGa-1 (wxyl)**.

13. Repeat Steps 8-11 to highlight kaolinite features using the same spectral range (2.075 to 2.235 µm).
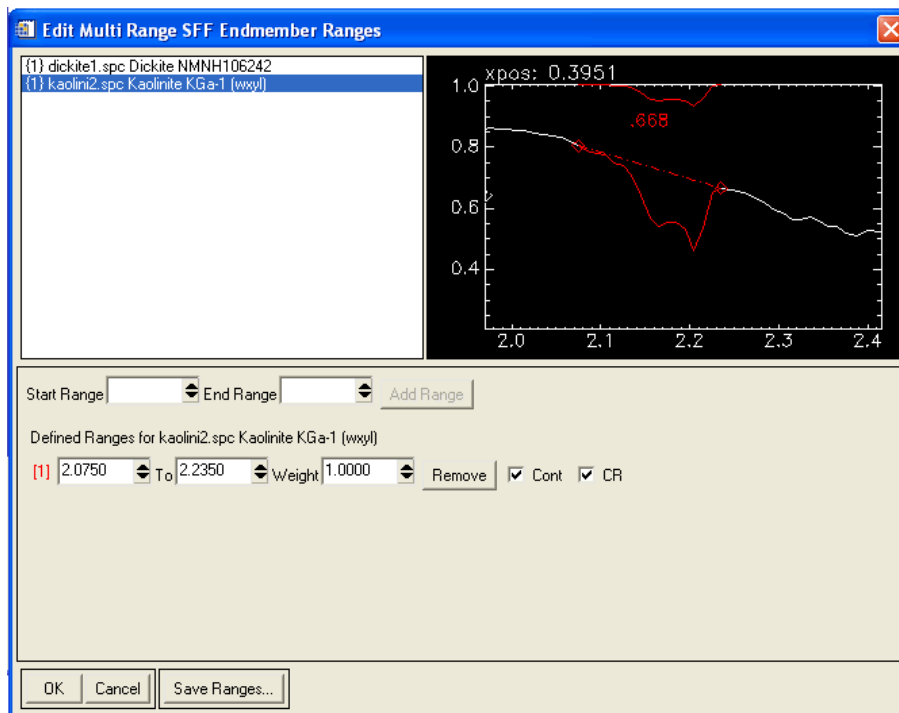
Run Multi Range SFF

14. When finished selecting the wavelength range, click **Save Ranges** at the bottom of the dialog. An Output Multi Range SFF Ranges dialog appears.

15. In the **Enter Output Filename** field, enter `cup95_sff_range1.sff` and click **OK**.

16. In the Multi-Range SFF Endmember Ranges dialog, click **OK** to start the mapping process. A Multi-Range SFF Parameters dialog appears.

17. In the toggle button field, keep the default value of Output separate Scale and RMS Images. Enter an output filename, and click **OK** to create the Scale and RMS error images.

   - Alternatively, click the toggle button to select Output Combined (Scale / RMS) Images, select the output filename, and click OK to create a fit image.

## Analyze SFF Scale and RMS Images Using One Range

The Available Bands List contains the Scale and RMS images derived from the Multi Range SFF using only one spectral range.

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

2. In the Available Bands List, select **Scale (kaolini2**.**spc**…**)**, select the **Gray Scale** radio button, and click **Load Band**.

3. From the Display #2 menu bar, select **Tools → 2D Scatter Plots**. A Scatter Plot Band Choice dialog appears.

4. Under **Choose Band X**, select **Scale (kaolini2**.**spc**…**)** Under **Choose Band Y**, select **RMS (kaolini2**.**spc**…**)**. Click **OK**. A Scatter Plot window appears.

5. Rescale the scatter plot axes by selecting **Options → Set X/Y Axis Ranges** from the Scatter Plot menu bar. A Set Scatter Plot Axis Ranges dialog appears.

6. In the **Xrange** fields, enter **0** to **1.1**.

7. In the **Yrange** fields, enter **0** to **0.1**. Click **OK**.

8. Draw a polygon ROI in the Scatter Plot between Scale values 0.2 and 1.0, and RMS values less than 0.04. Click and drag the left mouse button to define the ROI, and right-click to close the polygon. The pixels corresponding to the ROI are highlighted in the kaolinite scale image (Display #2). Use the following figure as a guideline:
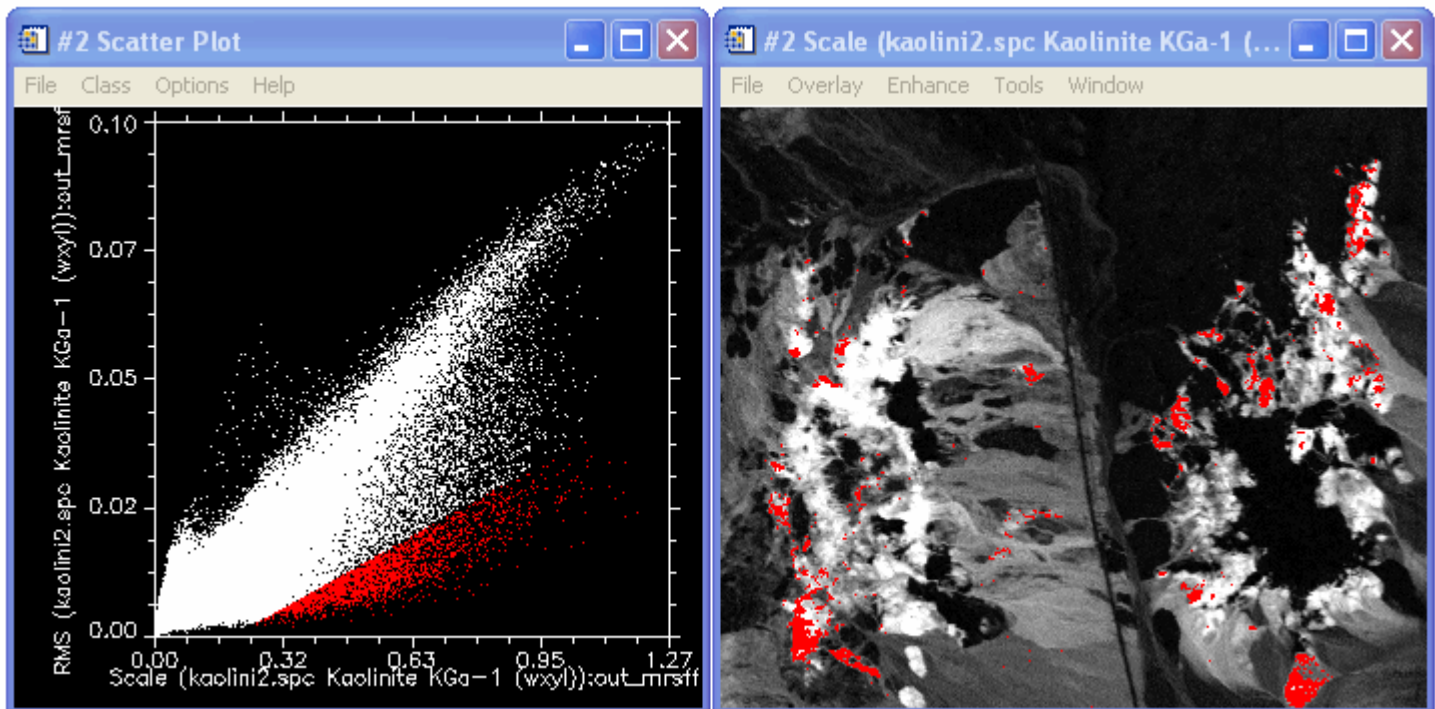
9. From the Scatter Plot menu bar, select **Options → Export Class** to export the highlighted pixels to the ROI Tool.

10. From the Scatter Plot menu bar, select **Options → Change Bands**. A Scatter Plot Band Choice dialog appears.

11. Under **Choose Band X**, select **Scale (dickite1.spc…)** Under **Choose Band Y**, select **RMS (dickite1.spc…)**. Click **OK**. A Scatter Plot window appears.

12. Repeat Steps 5-9 for the dickite images. Before drawing an ROI, select **Class → Items 1:20 → Green** from the Scatter Plot menu bar to change the class color. Use the following figure as a guideline:
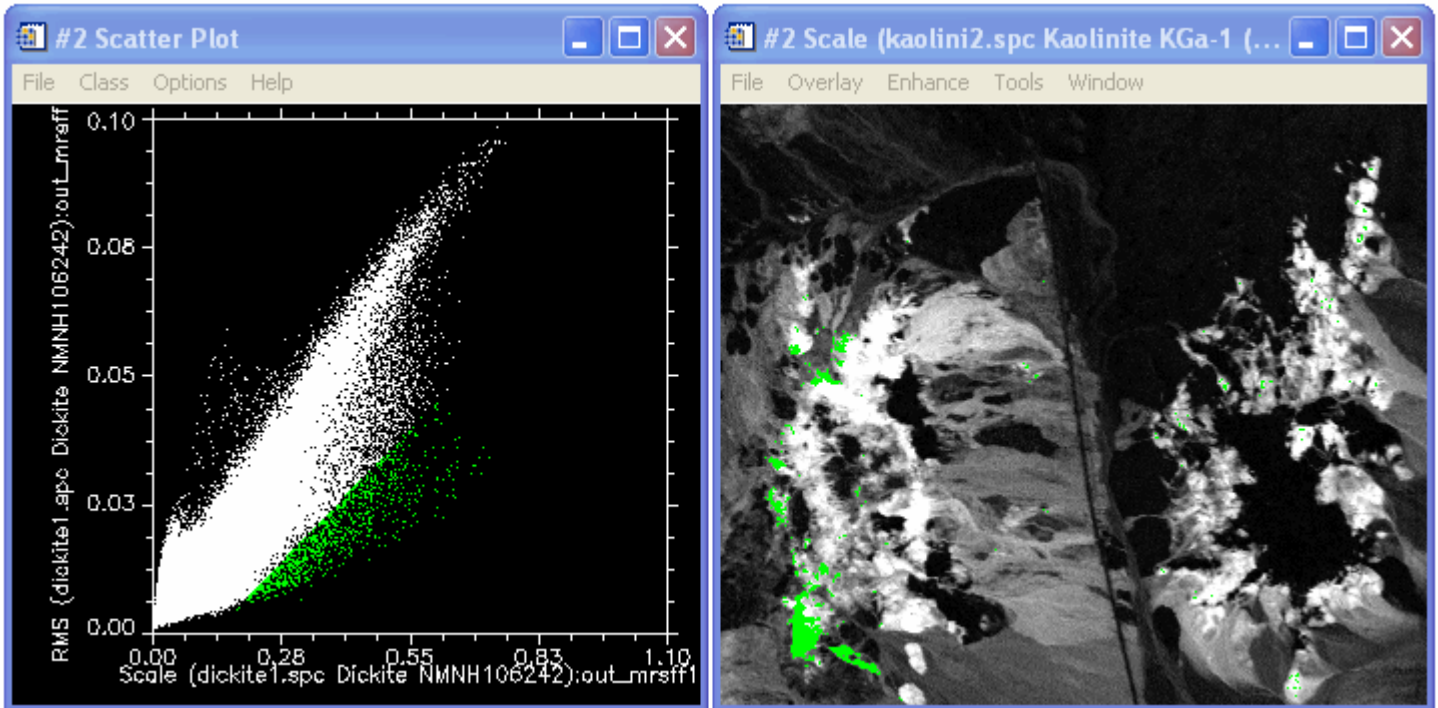
13. Compare the SFF mapping results for the dickite and kaolinite mapping. Note the significant overlap between the two mineral image maps in the left side of the image.

14. From the Display #2 menu bar, select **Tools → Profiles → Additional Z Profile**. A file selection dialog appears.

15. Select `cup95eff.int` and click **OK**. A Spectral Profile window appears.

16. Compare image spectra to spectral library plots of kaolinite and dickite. Note that the spectra show that there are only small occurrences of dickite towards the left side of the image.

17. From the ENVI main menu bar, select **Window → Close All Plot Windows**.

18. Close the two display groups.

Select Two SFF Ranges for Dickite and Kaolinite

Normally, a fitted continuum spanning a complex feature produces good mapping results, but occasionally you may need to further break down the complex feature to better separate the materials. In this exercise, you will select two ranges each with the kaolinite and dickite features.

Normally, fitted continua are constrained to be convex-upward, but for this exercise, the fitted continua dip into the larger kaolinite/dickite absorption feature.

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.

2. Navigate to `envidata/c95avsub` and select `cup95eff.int`. Click **Open**. This file contains EFFORT-corrected, ATREM-calibrated, AVIRIS apparent reflectance data. A color composite image of bands 183, 193, and 207 is automatically loaded into a display group.

3. From the ENVI main menu bar, select **Spectral → Mapping Methods → Multi-Range SFF → Use New Ranges**. A file selection dialog appears.

4. Select `cup95eff.int` and click **OK**. A Select Input Spectral Library dialog appears.

5. Click **Open → Spectral Library**. Navigate to `envidata\spec_lib\usgs_min` and select `usgs_min.sli`. Click **Open**.

6. In the Select Input Spectral Library dialog, select `usgs_min.sli` and click **OK**. An Input Spectral Library dialog appears.

7. Choose the mineral spectra to use in the SFF analysis by selecting the mineral name in the dialog. Select **dickite1.spc Dickite NMNH106242**, hold down the **<Ctrl>** key, and select **kaolin2.spc Kaolinite KGa-1 (wxyl)**. Click **OK**. An Edit Multi-Range SFF Endmember Ranges dialog appears.

Dickite

1. In the Edit Multi-Range SFF Endmember Ranges dialog, the dickite spectrum is highlighted by default. In the plot window, drag the diamond-shaped marker to approximately 2.125 µm (indicated by xpos: 2.1250 above the plot). Right-click and select **Set as Start Range** to mark the starting point of the first continuum segment. Or, enter **2.125** in the **Start Range** field.

2. In the plot window, drag the diamond-shaped marker to approximately 2.195 µm (indicated by xpos: 2.1950 above the plot). Right-click and select **Set as End Range** to mark the ending point of the first continuum segment. Or, enter **2.195** in the **End Range** text box.

3. Click **Add Range** to add the selected spectral range to the Defined Ranges for the dickite1.spc Dickite NMNH106242 spectrum. By default, the fitted continuum is plotted along with the continuum-removed segment in the same plot.

   - Note: If the Add Range button is greyed out, click the up or down arrow once in the End Range field, then set it back to 2.235. The Add Range button should be activated now.

4. Click and drag the middle mouse button inside the plot to draw a zoom box between x-axis values 2.0 and 2.4 µm.

5. Repeat Steps 1-4 for a second feature for dickite, using a spectral range from 2.195 to 2.235 µm.
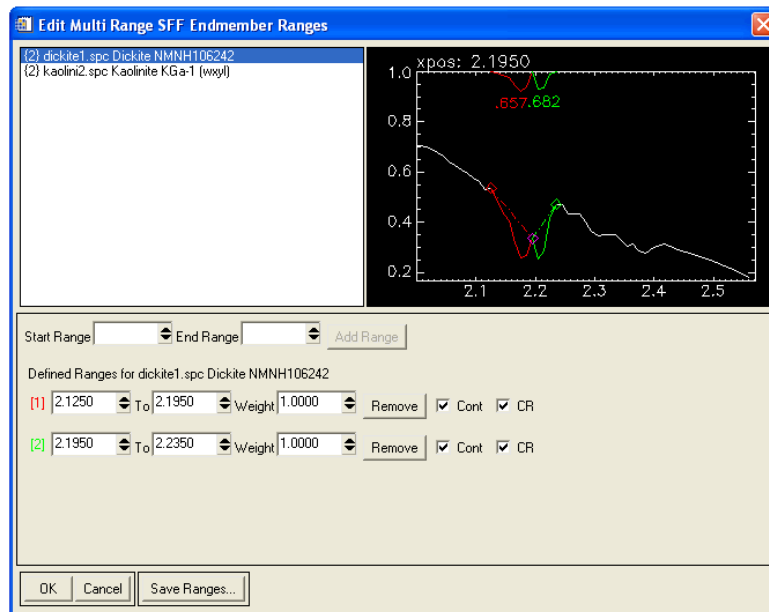
Kaolinite

6. In the Edit Multi-Range SSF Endmember Ranges dialog, switch the mineral being analyzed. **Select kaolin2.spc Kaolinite KGa-1 (wxyl)**.

7. Repeat Steps 1-5 above (under "Dickite"), using the following ranges:

   - 2.135 to 2.175 µm
   - 2.185 to 2.225 µm
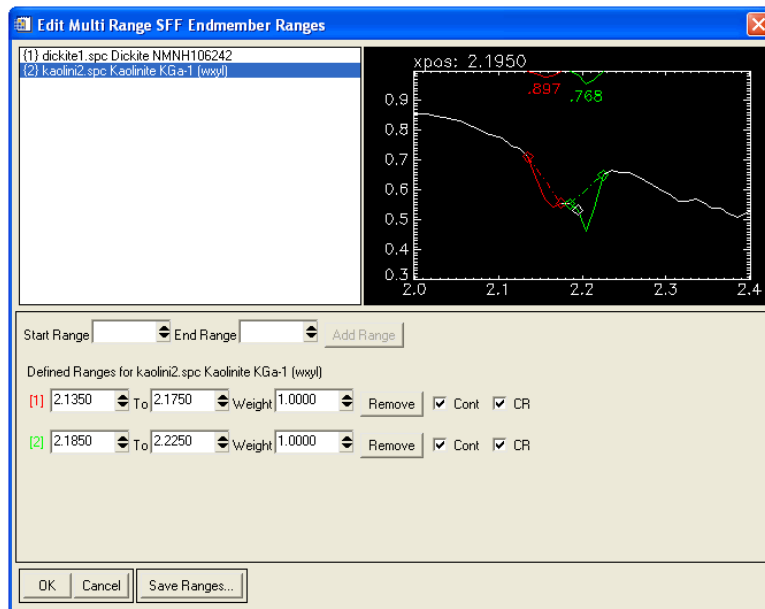
Run Multi Range SFF

8. Click **Save Ranges**. An Output Multi-Range SFF Ranges dialog appears.

9. In the **Enter Output Filename** field, enter `cup95_sff_range2.sff` and click **OK**.

10. In the Multi-Range SFF Endmember Ranges dialog, click **OK** to start the mapping process. The Multi-Range SFF Parameters dialog appears.

11. Click the toggle button to select Output separate Scale and RMS Images. Enter an output filename and click **OK** to create the scale and RMS error images.

- Or, Click the toggle button to select Output combined (Scale / RMS) Images. Enter an output filename and click **OK** to create a fit image.

## Analyze SFF Scale and RMS Images Using Two Ranges

The Available Bands List contains the scale and RMS images derived from the advanced Multi Range SFF.

1. In the Available Bands List, under the output file you created in Step 11 above, select **Scale (kaolini2.spc…),** select the **Gray Scale** radio button, and click **Load Band**.

2. From the Display group menu bar, select **Tools → 2D Scatter Plots**. A Scatter Plot Band Choice dialog appears.

3. Under **Choose Band X**, select **Scale (kaolini2.spc…)** Under **Choose Band Y**, select **RMS (kaolini2.spc…)**. Click **OK**. A Scatter Plot window appears.

4. Rescale the scatter plot axes by selecting **Options → Set X/Y Axis Ranges** from the Scatter Plot menu bar. A Set Scatter Plot Axis Ranges dialog appears.

5. In the **Xrange** fields, enter **0** to **1.1**.

6. In the **Yrange** fields, enter **0** to **0.1**. Click **OK**.

7. Draw a polygon ROI in the Scatter Plot between Scale values 0.2 and 1.0, and RMS values less than 0.04. Click and drag the left mouse button to define the ROI, and right-click to close the polygon. Use the following figure as a guideline. The pixels corresponding to the ROI are highlighted in the kaolinite scale image.
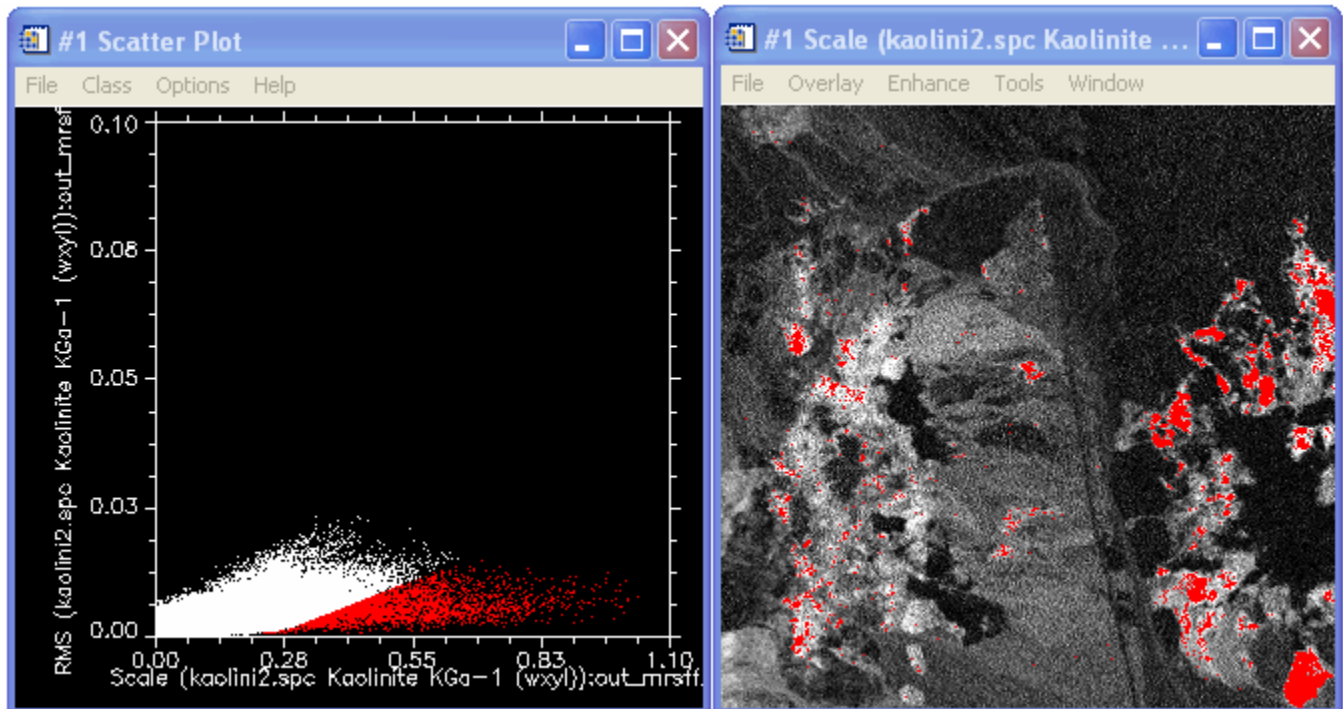
8. From the Scatter Plot menu bar, select **Options → Export Class** to export the highlighted pixels to the ROI Tool.

9. From the Scatter Plot menu bar, select **Options → Change Bands**. A Scatter Plot Band Choice dialog appears.

10. Under **Choose Band X**, select **Scale (dickite1.spc…)** Under **Choose Band Y**, select **RMS (dickite1.spc…)**. Click **OK**. A Scatter Plot window appears.

11. Repeat Steps 5-9 for the dickite images. Before drawing an ROI, select **Class → Items 1:20 → Green** from the Scatter Plot menu bar to change the class color.
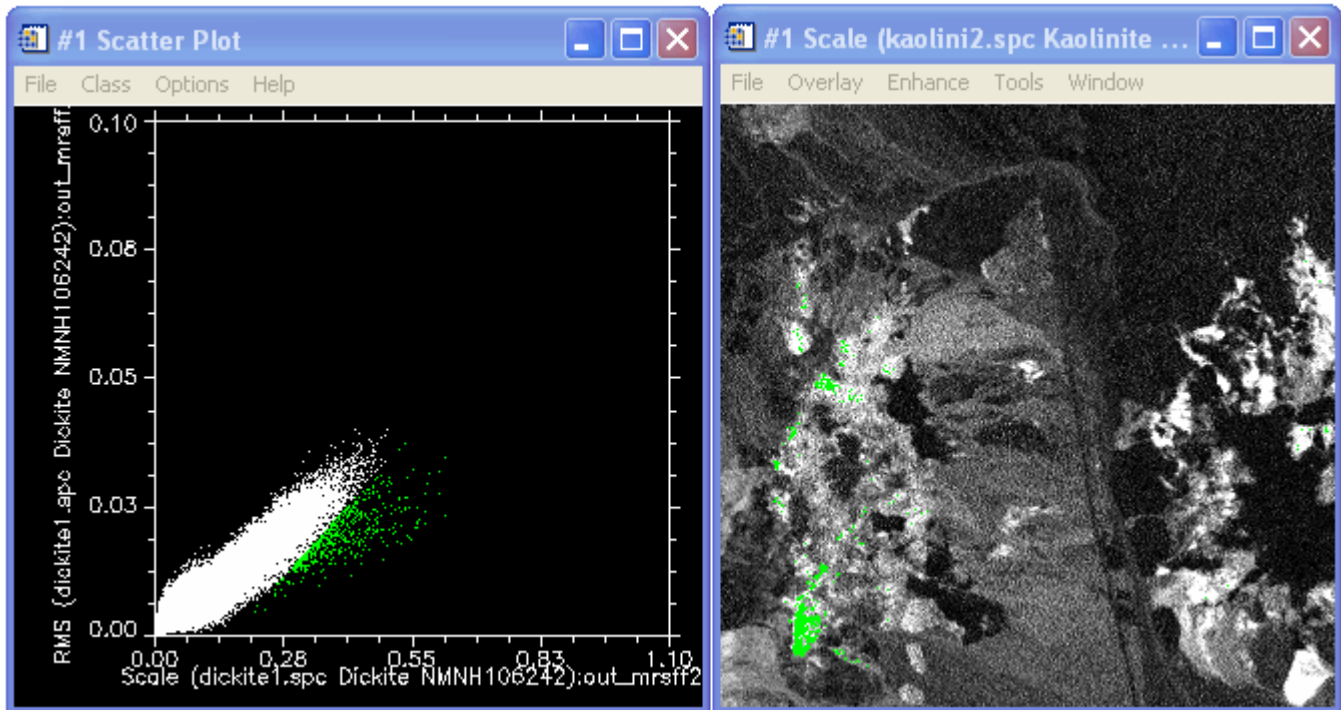
12. Compare the SFF mapping results for dickite and kaolinite. By defining multiple SFF ranges, you should see significantly less confusion between the minerals, and the kaolinite and dickite maps produce distinct spatial distributions.

19. From the Display #2 menu bar, select **Tools → Profiles → Additional Z Profile**. A file selection dialog appears.

20. Select `cup95eff.int` and click **OK**. A Spectral Profile window appears.

21. Compare image spectra to spectral library plots of kaolinite and dickite.

22. When you are finished, select **File → Exit** from the ENVI main menu bar.

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