Lab 5 Band Ratios and Principal Components
Utilizes Textbook's Remote Sensing Digital Database: Chapter 3 data.

The objective of this lab is to use Information Extraction tools (see Chapter 9 Digital Image Processing for discussion) to process multispectral Landsat data in *Reflectance***.** The tasks we will complete with this lab are done with tools in the **ENVI Toolbox**.

Three digital files are to be uploaded to the instructor and eight questions are to be answered on the last pages of this handout.

IMPORTANT NOTE: ENVI does not retain display enhancements for images when you use ***Save As***. These include rotating, zooming, contrast, brightness, sharpening, stretching, Portals, or viewing multiple layers. Use the ***Export View To > Image File*** to retain display enhancements and original scale (choose Zoom Factor 1.0000).

We will use Landsat 8 bands of Thermopolis that have been converted from radiance to reflectance to ensure our band ratios are accurate. Reflectance data are also required for spectral libraries that we will work with in a later lab. The data set is located in the "Remote Sensing Digital Database \ Ch_3_Landsat" folder.

1) *Start up ENVI*

Open the subfolder "Plates_7and27_Thermopolis". Open the subfolder "Landsat8_Reflectance_6bnds_VNIR-SWIR".

Select "OLI_Thermopolis_Sep2015_reflectance_bnds2-7_ENVI" > *Open*

> *Zoom to Extents*

If you have your ENVI Display preferences set at "No Stretch", the 12-bit bands will appear white with some of the Wind River in yellow and green?!

Click-on the Histogram Stretch tool 

With "No Stretch", the histogram low and high vertical DN bars are set to "0" and "255" (8-bit) while the data are 12-bit.
Click-on the contrast stretch drop-down menu and *select* "Linear 1%"
Analyze the stretched histograms in the Histogram Stretch tool.

Open the Data Manager. *Move* the slider all the way to the right so you can see the wavelengths of the six Landsat 8 bands. The USGS attaches the center wavelength of each band to the file name (excellent!) when they convert Landsat from radiance to reflectance. The USGS also ensures the bands are correctly labelled: OLI 2 – 7.

2) <u>Band Ratios</u>**:** Band ratios (or ratio images) are prepared by (digitally) dividing the DN

in one band by the corresponding DN in another band for each pixel in an image. In a ratio image, the darkest pixels represent the smallest ratio values and the lightest pixels represent the largest ratio values. The darkest signatures are areas where the band in the denominator (7 in the 5/7 ratio image) has a greater reflectivity (higher DN value) than the band in the numerator. The brightest signatures show pixels where the numerator is larger than the denominator. Bands should be corrected to reflectance prior to band ratioing.

Look at Figures 9-25 A and C along with textbook discussion in Chapter 9.

<u>OLI Band Ratio 4/2 (red/blue):</u>

Spectra of weathered iron-bearing (ferrous) minerals have strong reflectance in the visible red region of the electromagnetic spectrum (TM band 3 or OLI band 4) wavelengths at ~0.63 to 0.69 *u*m). Because red-colored material, or Iron-bearing minerals, have a weak reflectance in the visible blue portion of the spectrum (TM band 1 or OLI band 2) at ~0.45 to 0.52 *u*m) a ratio image of TM bands 3/1 or OLI bands 4/2 could indicate iron- stained areas. Areas with iron-staining will be bright.

<u>OLI Band Ratio 6/7 (SWIR1/SWIR2)</u>

Landsat TM band 7 (OLI band 7) is preferentially absorbed by the hydroxyl-bearing clay minerals as compared with TM band 5 (OLI band 6); therefore, a ratio image of TM bands 5/7 (OLI bands 6/7) could show anomalously high concentrations of these clay minerals as bright areas.

ENVI Toolbox > Band Algebra > Band Ratios

Select Band 4 first. ENVI automatically places Band 4 in the Numerator.
Select Band 2 next. ENVI places Band 2 in the Denominator.
Click “Enter Pair” > *OK*
The “Band Ratios Parameters” window pops up.
Enter an Output Filename: “Landsat iron ratio_ENVI”
Accept “Floating Point” as the output data type (each pixel DN will have a decimal place).

The iron ratio grayscale image needs to stretched.

ENVI Toolbox > Band Algebra > Band Ratios

Select Band 6 first. ENVI automatically places Band 6 in the Numerator.
Select Band 7 next. ENVI places Band 7 in the Denominator.
Click “Enter Pair” > *OK*
The “Band Ratios Parameters” window pops up.
Enter an Output Filename: “Landsat clay ratio_ENVI”
Accept “Floating Point” as the output data type (each pixel DN will have a decimal place).

The clay ratio grayscale image needs to stretched.

3) Let's open up four Views. *Views > 2 X 2 Views*

Slide the iron ratio image into View 2.
Slide the clay ratio image into View 3.
Turn off the iron and clay ratio images in View 1.

Zoom to Extent and *Optimized Linear* stretch for the View 1 (natural color), View 2 and View 3.

Views > Link Views > GeoLink *active > Link All > OK*
Pan around *Zoom in & out*
In the Cursor Value window,
select "Link Views" and "Display Information for All Views"

Question 1: Activate View 2 with the iron ratio image. Put your cursor on the brightest pixel you see in the Chainman Shale (Red Rose Anticline (see textbook Figure 3-11H if you don't remember where that is). (Show only two decimal places for the DN below).

A. What is the Data value (DN) for the bright pixel on the iron ratio image:

B. What is the Data value (DN) for the same pixel on the clay ratio image:

Question 2: Put your cursor on the brightest pixel you see in the clay ratio image in a Wind River agricultural field (see textbook Figure 3-11H if you don't remember where the river is). (Show only two decimal places for the DN below).

A. What is the Data value (DN) for the bright pixel on the clay ratio image:

B. What is the Data value (DN) for the same pixel on the iron ratio image:

4) You are planning field work and only want to visit sites in the field with the highest potential iron content and potential clay content. To make a useful map we can interactively determine which pixels we want to be pure white and which we want to be pure black. The pure white pixels have the highest potential iron and clay content in the Thermopolis field area. In the Layer Manager, highlight View 2 with the iron ratio image.

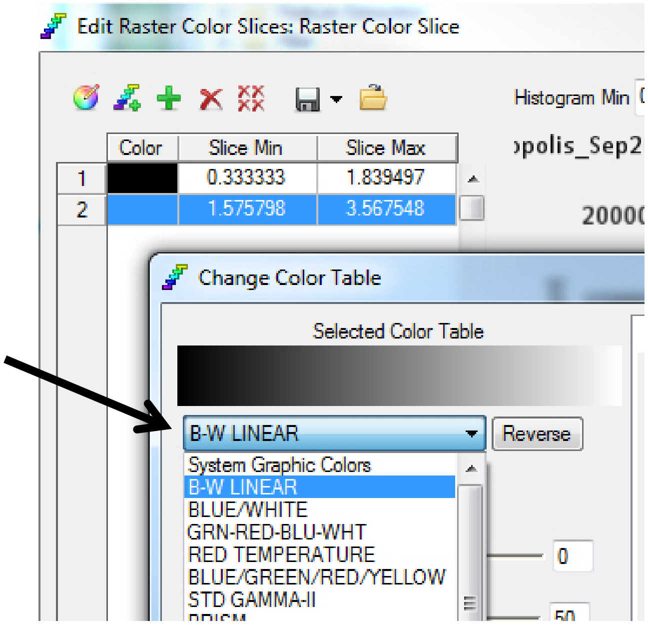
ENVI Toolbox > Classification > Raster Color Slices
The "Data Selection" window pops-up
Select your "Landsat_iron_ratio_ENVI" image first > *OK*

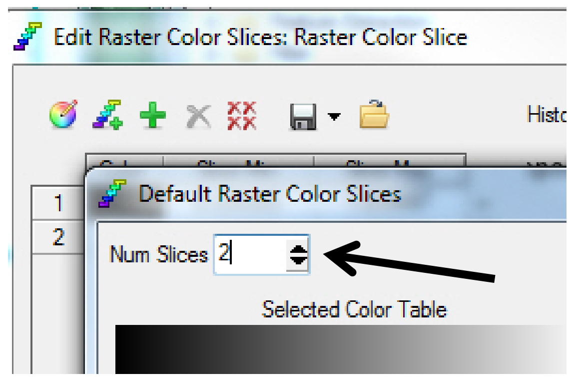
The "Edit Raster Color Slices: Raster Color Slice" window pops-up
(The default density slice has 16 levels and a rainbow color scheme)

Change the color scheme and the number of slices.

In the upper left corner of the window is the
"Change Color Table…" icon and next to it the
"New Default Color Slices…" icon.

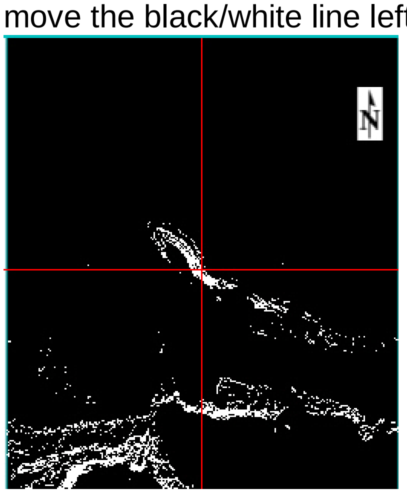
In the Change Color Table window *Select* “B-W Linear”
In the “New Default Color Slices” window *Change* 16 to 2

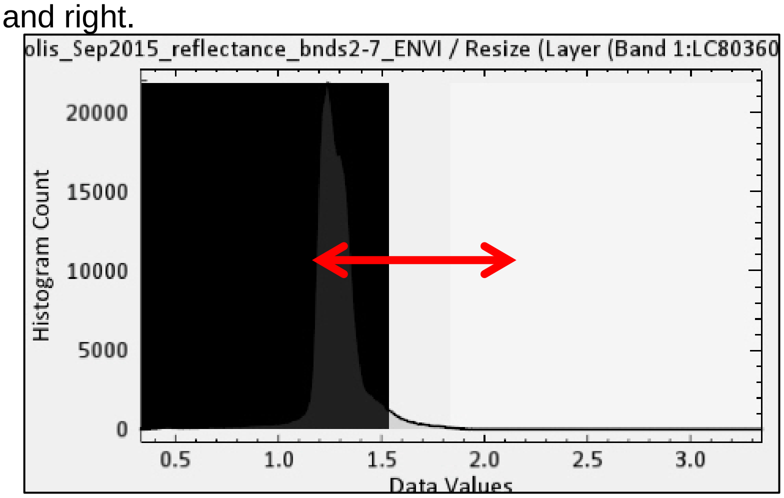




In the “Edit Raster Color Slices: Raster Color Slice” window, move the vertical line separating the black and white patterns on the histogram while looking at the grayscale ratio image. Choose a black-white dividing DN that shows only the most promising sites on the band ratio image for you to find iron-stained rocks at the surface – that may indicate hydrothermal alteration and mineralization! To reduce your field area (saving time and money), density-slice your iratio image so only a few areas have white pixels.

You can also *change* the “Slice Min” value in the table to the left of the histogram to move the black/white line left and right.





Let’s save your Black-White prospecting image for your GIS.

Ensure that the “Raster Color Slice” is checked and highlighted in your Layer Manager (the black and white slices for the iron ratio image are in a subfolder)

File > *Export Selected File to TIFF* > *name* the image
"Your Name_Iron_Sites_GIS"
Check the "Display result" so you can see if the output identical to your black-white iron image in View 2. Upload to the instructor.

5) You are now an agricultural soil scientist and want to find sites in the Thermopolis area that have the highest potential for clay to support your proposed grape vineyard. In the Layer Manager, *highlight* View 3 with the clay ratio image. Repeat the process you did for the black-white iron image under Step 3).

Name your GIS output image "YourName_Clay_Sites_GIS". Upload to the instructor.

6) <u>Normalized Difference Vegetation Index (NDVI)</u>
(see textbook Figures 9-27, 9-37)

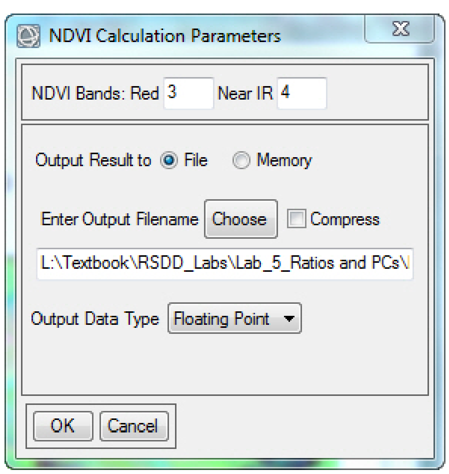
The difference in reflectance values between NIR and red wavelengths is used to map vegetation greenness (also termed vigor and stress). Healthy plants reflect NIR light but absorb red light (cholorphyll). Scientists like to have a number describe a situation – an "index".

NDVI is an index that is normalized so the value varies between -1 and +1>
NDVI = (NIR – red) / (NIR + red)
NDVI = (OLI 5 – OLI 4) / (OLI 5 + OLI 4)
= (145 – 35) / (145 + 35) = 110 / 180 = +0.61 (healthy vegetation!)

Highlight View 4 (so the NDVI image is displayed in this empty view)

6a) *ENVI Toolbox* > *Spectral* > *Vegetation* > *NDVI*
Select the six-band Landsat dataset as the *Input File*

The "NDVI Calculation Parameters" window pops-up.



The selection of NDVI Bands is correct – the 3rd band in the dataset is red and the 4th band is Near IR.
Name "Landsat_NDVI_ENVI"
Leave as "Floating Point" so range of DNs in the NDVI pixels should range between -1.0 and 1.0 (pixels with noise or error could be outside this range) *> OK*

6b) Zoom to Extents > Contrast stretch with "Linear 1%"

Link View 4 with the NDVI image to the other 3 Views
Views > *Link Views* *click-on* New Link *or Link All*

Turn off the density slices in Views 2 and 3. Enhance all the grayscale ratio images with "Linear 1%" *Pan* around and *zoom in & out* of the linked Views

Question 3: A. Why do you think the clay ratio image in View 3 is so similar to the NDVI image (vegetation greenness or vigor) image in View 4?

B. Roam around the linked Views. What type of feature has pixels on the clay ratio image that are bright but dark on the NDVI image?
(hint: look also at the color image in view 1 – change the bands to OLI 7-5-2 as R-G-B. Look at the iron band ratio image also).

6c) Use the *Cursor Value* tool and *click* around the NDVI grayscale image.

Question 4: A. What range of NDVI values do you find on your NDVI image?

B. Did you find any negative values?

6d) *Right-click* on the NDVI image in the Layer Manager > *Quick Stats*
Select Plot drop-down menu > "Histogram Band 1"

Question 5: A. What range of DN values (Min and Max) do you find in the metadata for the NDVI image?

B. Is the range of DNs in the image's metadata different than what you found clicking around the image with the Cursor Value tool? YES NO

C. Approximately how many pixels have values greater than +1.0?

D. Approximately how many pixels have values less than -1.0?

E. How many pixels are in this image? (Remember Metadata?)

F. What is your opinion about those pixels in the metadata with DNs outside of the NDVI -1 to 1 range?

It is very important to use your brain and eyes - look at the image, metadata, and statistics - to help you understand the quality and technical issues with your imagery to ensure that what you are doing makes sense – and that the maps you generate are useful. We'll see the impact of blindly using all the DNs that are in the NDVI image in the final NDVI exercise below.

6e) Let's color-code the NDVI to highlight those pixels with vigorous vegetation
ENVI Tool Box > Classification > Raster Color Slices
Select the grayscale NDVI image *> OK*

The ENVI density slice program uses the DN range documented in the metadata.

The "Edit Raster Color Slices: Raster Color Slice" tool pops-up. Evaluate it!

Question 6: A. What density slice colors appear on your NDVI image in View 4?

B. Is this NDVI image what you want for a final, color-coded product?

We must modify the min and max DN values that we allow to be used by the density slice tool to reflect what we visually see in the image. The remote sensing analyst has to make a <u>decision</u> about what is most valid and what is noise and needs to be ignored. This decision should be documented in your color-coded NDVI GIS image's metadata.

Along the top right portion of the "Edit Raster Color Slices…" window are DN values for "Histogram Min" and "Max" automatically placed by ENVI based on the unedited NDVI input image.

Change the Min to -1.0 and the Max to 1.0

Click-on the "New Default Color Slices…" icon in the upper left.
Change "Num Slices" from 16 to 5.
Note "Data Min" is -1.0 and "Data Max" is 1.0 in the lower left. *> OK > OK*

How many colors do you see on your NDVI image in View 4?

There is much research documentation that in terrain such as Thermopolis (semi arid) we have a low probability of finding pixels with NDVI values below -0.2. GIS Resources indicates the following NDVI values can be expected:

1. Barren rocks, sand, or snow show very low NDVI values (-0.1 to 0.1)
2. Shurbs and grasslands or senescing crops (– 0.2 to 0.5)
3. Dense vegetation or tropical rainforest (– 0.6 to 0.9)
4. Deep water (-1)

ENVI's Help indicates vegetation typically ranges between NDVI values of 0.2 and 0.8.

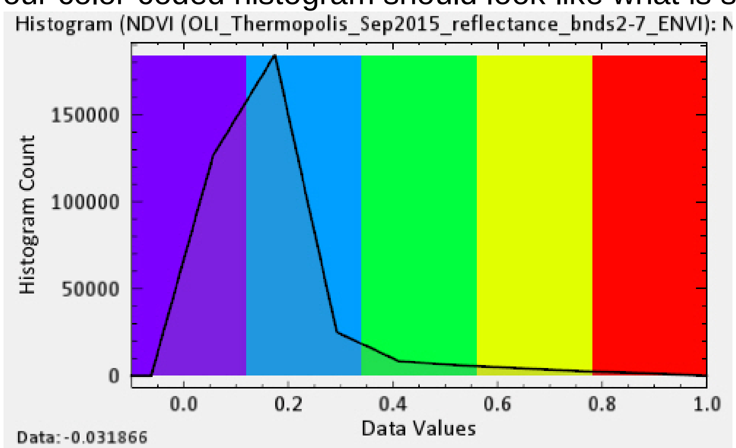
Given the above, let's change our density slice min value to -0.1 since most of us didn't find any DNs more negative than -0.1 while analyzing our NDVI image with the Cursor Value tool earlier.

6f) In the Layer Manager, *Right-click* on the "Slices" folder that contains the 5 colors and their ranges under the "Raster Color Slice" file *> Edit Color Slices…*

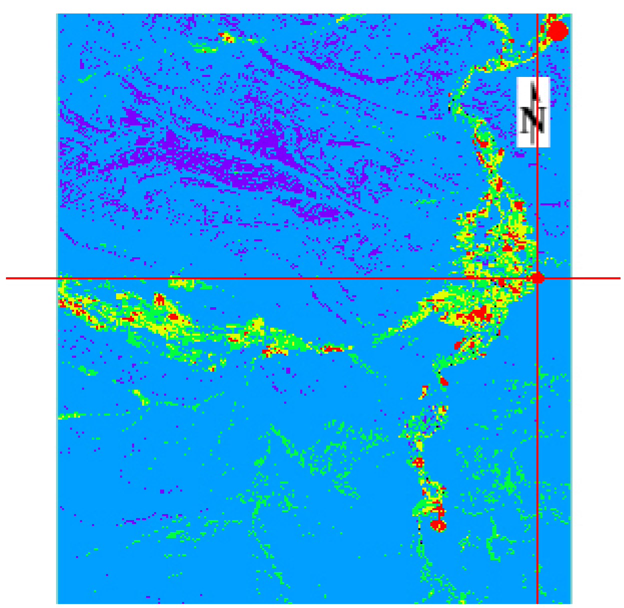
The same menu pops up that we saw in Exercise (6e) above. Update the Min value to -0.1 and the Max value to 1.0. We have to reset the number of slices also.

Click-on the "New Default Color Slices…" icon in the upper left.
Change "Num Slices" from 16 to 5.

Your color-coded histogram should look like what is shown below:



> OK



Your 5-level density slice of the NDVI image should look like this. Agricultural fields that are heavily irrigated are displayed in red. Less vigorous (or more open) fields are displayed in yellow and green. A very useful and new product!

File > Chip View To… > Image > Select “JPEG” in the dropdown window.

Name the color-coded NDVI image “YourName_color-coded_NDVI_jpg”

Upload to the instructor.

7) <u>Principal Components</u>

Highlight Views 2, 3, 4 and for each view *File > Close All Files*
In View 1 > *Change RGB Bands* to OLI 5-3-2 (NIR-Red-Green) as R-G-B
Leave 4 Views – only View 1 has an image.

Principal Components (PCs) are covered in the textbook Chapter 9,
See Figures 9-22, 9-23 A-F, 9-24 and Plate 27. The reflectance image used in this exercise does not cover the exact same area as the textbook Landsat example which is also in radiance. So the PCs developed in this exercise will not look exactly like the ones in the textbook. PCs are specific to the dataset being processed.

Why PCs? When you compare the individual multispectral bands in a dataset there is strong visual similarity. Think back to Lab 3 and the correlation matrix for the Thermopolis Landsat bands. The high correlation means there is much redundancy of information in the multispectral data set. PCs reduce this redundancy by compressing all of the information contained in the original grayscale bands set into a new set of grayscale images named PC1, PC2, PC3, etc. Each successive PC image accounts for a progressively smaller proportion of the variation in the original data set.

Highlight View 2 (this will put the PCs into this empty View)

ENVI Toolbox > Transform > PCA Rotation > Forward PCA Rotation New Statistics and Rotate

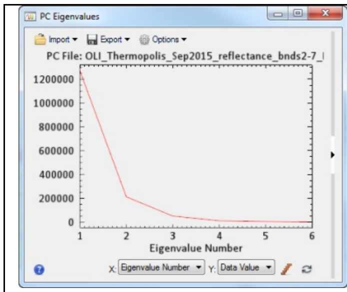
(PCA) means principal component analysis
Use **ENVI Help** to learn more about this analysis and step-by-step details

Select the 6-band Landsat data set > *OK* *Accept* Defaults for subsets & Mask > *OK*

The “Forward PC Parameters” window pops-up.

Name the output Stats file “Landsat_6PC_stats”
Name the output file “Landsat_6PC”
Accept defaults EXCEPT change “floating point” to “byte” > *OK*

The “PC Eigenvalues” window pops-up (see below) and the 6 PCs load into View 2.



Eigenvalue

PC1: 1,270,891
PC2: 212,665
PC3: 51,161
PC4: 11,321
PC5: 5048
PC6: 729

To see the Eigenvalue values (shown on the right above), you choose *Export > ASCII* in the PC Eigenvalues menu. The ASCII file is a simple .txt file that lists the PC Eigenvalues.

NOTE: PC Eigenvalues indicate the proportion of original information (total variance) in the multispectral dataset (all the bands) that each PC contains. To determine the percentage of the total variance within each PC, you sum the Eigenvalues and divide each PC Eigenvalue by the summed total.

Views > Link Views View 1 has 6 Landsat bands, View 2 has 6 PC images.
Look at the Data Manager list of bands and PCs

7a) Next we will examine the grayscale bands and PCs with "Band Animation"
Highlight View 1 > *Right-click* file in Layer Manager > *Band Animation*
Slow the flicker rate to 1 or 2 seconds
Note the high visual correlation between bands
You may have to use "Linear 1%" stretch on the bands

Highlight View 2 > *Right-click* file in Layer Manager > *Band Animation*
Note the low visual correlation between PC images
You may have to use "Linear 1%" stretch on the bands

Both Views should be in Band Animation mode, *Zoom in* to the Red Rose Anticline – band animation should still be working in both Views.

7b) Let's load a grayscale band into View 3 and a grayscale PC into View 4
Highlight View 3 > "Data Manager" > *Select* OLI Band 1 > *Load Grayscale*
OLI Band 1 will display in View 3

Highlight View 4 > "Data Manager" > *Select* PC Band 1 > *Load Grayscale*
PC Band 1 will display in View 4

Views > Link Views > Link All > OK

Zoom in to the Red Rose Anticline. In View 3 use the Data Manager to load another OLI band. Compare a few OLI bands to PC 1.

Question 7: A. Does the PC 1 image look very similar to the OLI bands, especially in areas with topographic relief (ridges, cliffs, valleys, etc.)? YES NO

B. What percentage of the variance in the 6-band Landsat data set is in PC1? (Hint: Use the values in the PC Eigenvalues table above)

C. What percentage of the variance in the 6-band Landsat data set is in PC5? (Hint: Use the values in the PC Eigenvalues table above)

7c) Zoom out so both the Red Rose Anticline and the Wind River agricultural fields are visible in the 4 views.
Highlight View 2 > Use the Data Manager > *Select* PC2 – PC3 – PC4 as R-G-B > *Load Data* > Try different stretches > last stretch "Linear 1%"

Highlight View 3 > Use the Data Manager > *Select* PC4 – PC5 – PC6 as R-G-B > *Load Data* > Try different stretches > last stretch "Linear 1%"

Highlight View 4 > Use the Data Manager > *Select* PC3 – PC4 – PC5 as R-G-B > *Load Data* > Try different stretches > last stretch "Linear 1%"

Pan over the Wind River agricultural fields and note the increased level of information available with PC color images compared with the traditional color IR image in View 1

Question 8: A. Which PC color image in Views 2, 3, and 4 provides the most information for you about the agricultural fields?

B. The PC color image generated from PC4-PC5-PC6 as R-G-B has what percentage of the total variance in the 6-band Landsat dataset?
(Hint: refer to Eigenvalue table above and use your calculator)

NOTE: If we converted our NDVI grayscale image to a <u>Mask,</u> we could mask out the non-vegetated terrain in the Thermopolis scene and generate more detailed and informative PCs over the agricultural and natural vegetated areas. The Mask could be inverted and vegetation eliminated from the PC analysis to extract more unique patterns on the PC images over terrain with geologic outcrops.

Principal Components provide unique and often very subtle but important information about features of interest. PCs should be applied to any multispectral data set to see what spectral patterns may be hidden in the original bands.

The Landsat 8 OLI sensor (VNIR-SWIR) is so noise-free that the PC 5 image is almost noise-free and even the PC 6 image displays unique spectral information. Awesome remote sensing technology!

Lab 5 Band Ratios and Principal Component Name:

Upload the following files to the instructor:

(4) "Your Name_Iron_Sites" geotiff

(5) "Your Name_Clay_Sites" geotiff

(6) "YourName_color-coded_NDVI_jpg" jpg

Question 1: Put your cursor on the brightest pixel in the Chainman Shale (Red Rose Anticline (see textbook Figure 3-11H if you don't remember where that is).

A. What is the Data value (DN) for the bright pixel on the iron ratio image:

B. What is the Data value (DN) for the same pixel on the clay ratio image:

Question 2: Put your cursor on the brightest pixel in a Wind River agricultural field (see textbook Figure 3-11H if you don't remember where the river is).

A. What is the Data value (DN) for the bright pixel on the clay ratio image:

B. What is the Data value (DN) for the same pixel on the iron ratio image:

Question 3: A. Why do you think the clay ratio image in View 3 is so similar to the NDVI image (vegetation greenness or vigor) image in View 4?

B. Roam around the linked What type of feature has pixels on the clay ratio image that are bright but dark on the NDVI image?
(hint: look also at the color image in view 1 – change the bands to OLI 7-5-2 as R-G-B. Look at the iron band ratio image also).

Question 4: A. What range of NDVI values do you find on your NDVI image?

B. Did you find any negative values?

Question 5: A. What range of DN values (Min and Max) do you find in the metadata for the NDVI image?

B. Is the range of DNs in the image's metadata different than what you found clicking around the image with the Cursor Value tool? YES NO

C. What is your opinion about those pixels in the metadata with DNs outside of the NDVI -1 to 1 range?

Question 6: A. What density slice colors appear on your NDVI image in View 4?

B. Is this NDVI image what you want for a final, color-coded product?

Question 7: A. Does the PC 1 image look very similar to the OLI bands, especially in areas with topographic relief (ridges, cliffs, valleys, etc.)? YES NO

B. What percentage of the variance in the 6-band Landsat data set is in PC1?

C. What percentage of the variance in the 6-band Landsat data set is in PC5?

(Hint: Use the values in the PC Eigenvalues table above)

Question 8: A. Which PC color image provides the most information for you about the agricultural fields?

B. The PC color image generated from PC4-PC5-PC6 as R-G-B has what percentage of the total variance in the 6-band Landsat dataset?

(Hint: refer to Eigenvalue table above and use your calculator)