Remote Sensing 4113
Lab 10: Lunar Classification
April 11, 2018

Part I Introduction

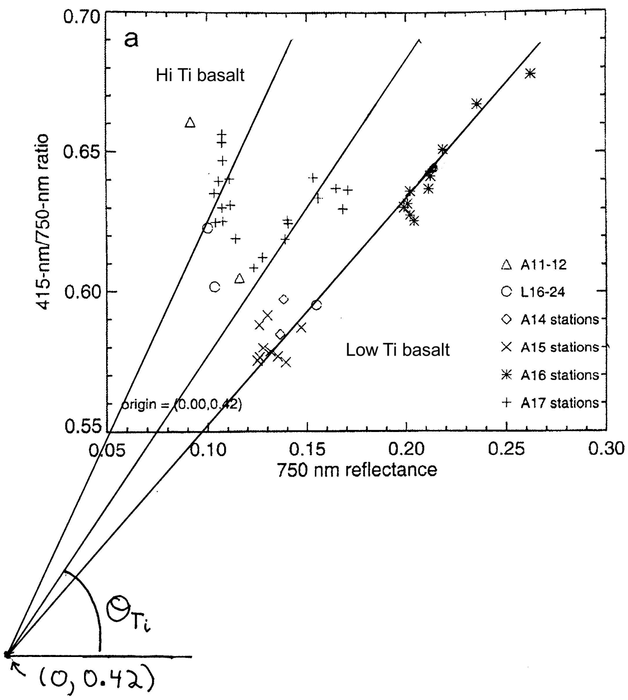
In this lab we'll explore the use of sophisticated band math to estimate composition, and we'll also explore the use of a decision tree classification scheme. We'll be using data from the UV-Visible sensor on the Clementine mission which orbited the moon in the 1990's. The band math will be used to estimate the Ti abundance in the mare basalts. Once that is done the decision tree will be used to classify the lunar surface into three types: highlands, low-titanium mare basalts, and high-titanium mare basalts.

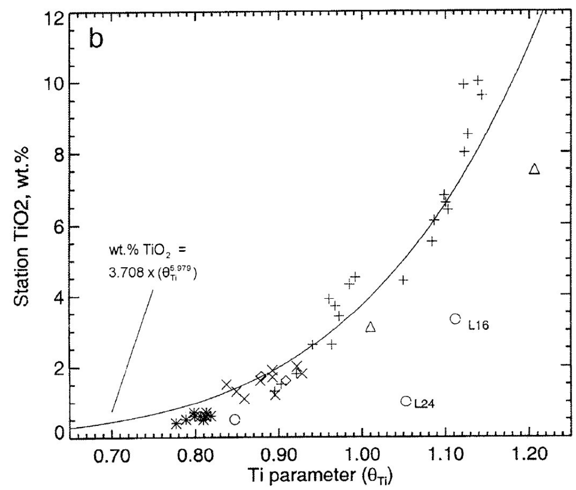
The lab instructions consist of three parts: 1) an introduction/background section, 2) a set of specific instructions regarding data to analyze and results to obtain, and 3) an more general explanation of the ENVI instructions needed to carry out the work in section 2. As usual, copy the **`lab_10`** data files from the class website and unzip them to a temporary directory within **`c:\tmp`** on your local machine. Save any files you want to keep on your **`Home Drive`**.

The moon's surface is contains two very different types of terrain, the "highlands", and "maria". The highlands are the anorthosite crust which floated to the top of the original global magma ocean when the moon formed approximately 4.5 billion years ago. Anorthosite has relatively high albedo. The maria (the singular is mare) are basalts which erupted from the interior between approximately 3.0 to 3.5 billion years ago. They have a range of compositions, with different iron (Fe) and titanium (Ti) compositions. Increased Ti has the most obvious effect on the spectra. The common mineral it occurs in (ilmenite) is dark, so it lowers the albedo of the maria. However a more reliable test is that it is dark at all wavelengths, while Fe and some other variable components tend to be not just dark, but "red" -- with relatively high albedo in the red and low albedo in the blue. Therefore the Ti rich mare appear <u>dark but blue</u> (relative to the Ti poor regions). The amount of Ti can be estimated by comparing the brightness in the 0.415μm and 0.750μm bands, and using a mathematical transformation described below, similar in principle to that described in class to estimate Fe abundance.

We'll examine the Clementine images of the moon, apply the mathematical transformation to obtain the percent Ti, then classify the surface based on albedo and Ti abundance. For the purposes of this exercise we'll call surface with albedo greater than 0.15 (at 0.750 μm) "Highlands" and surface with albedo less than that "Maria". We'll call maria with weight % TiO_2 less than 6% "Low Titanium Maria" and those with Ti greater than 6% "High Titanium Maria".

The following section explains the calculation of Ti abundance, which you'll produce in part 2. It is based on Lucey et al. (2000) " Lunar iron and titanium abundance algorithms based on final processing of Clementine ultraviolet-images", J. Geophys. Res. 105: 20,297-20,305. Both of the following figures are taken from there.





For a number of sites, either of Apollo missions or Russian unmanned "Luna" sample return missions, we have samples with measured titanium abundances, and we also have measured reflectances. In the above Plot A we plot the ratio of the 415-nm / 750-nm reflectance, vs. the 750-nm reflectance. The first is a measure of "blueness" – which in general is greater for Ti-rich basalts, but as shown in the plot the amount of "blueness" for a given Ti abundance also depends on the overall albedo or reflectance. The points which fall along the penciled lines have more-or-less constant Ti abundances. The Ti abundance increases with the angle θ_{Ti} as shown in Plot B. We first need to calculate the angle $\theta_{Ti.}$ The lines above are drawn relative to an origin at (0.0, 0.42) so the formula for θ_{Ti} is

$$\theta_{Ti} = \text{Arctan} \left[\quad (R_{0.415\mu m}/R_{0.750\mu m}) - 0.42) \,/\, (R_{0.750\mu m} - 0.0) \right]$$

To convert this θ_{Ti} to a titanium abundance, expressed (following geological convention) as weight percent of TiO_2, we use the following formula which represents the curve fit to the data in Plot B.

$$\%\ \text{Weight } TiO_2 = 3.708 \times (\theta_{Ti})^{5.975}$$

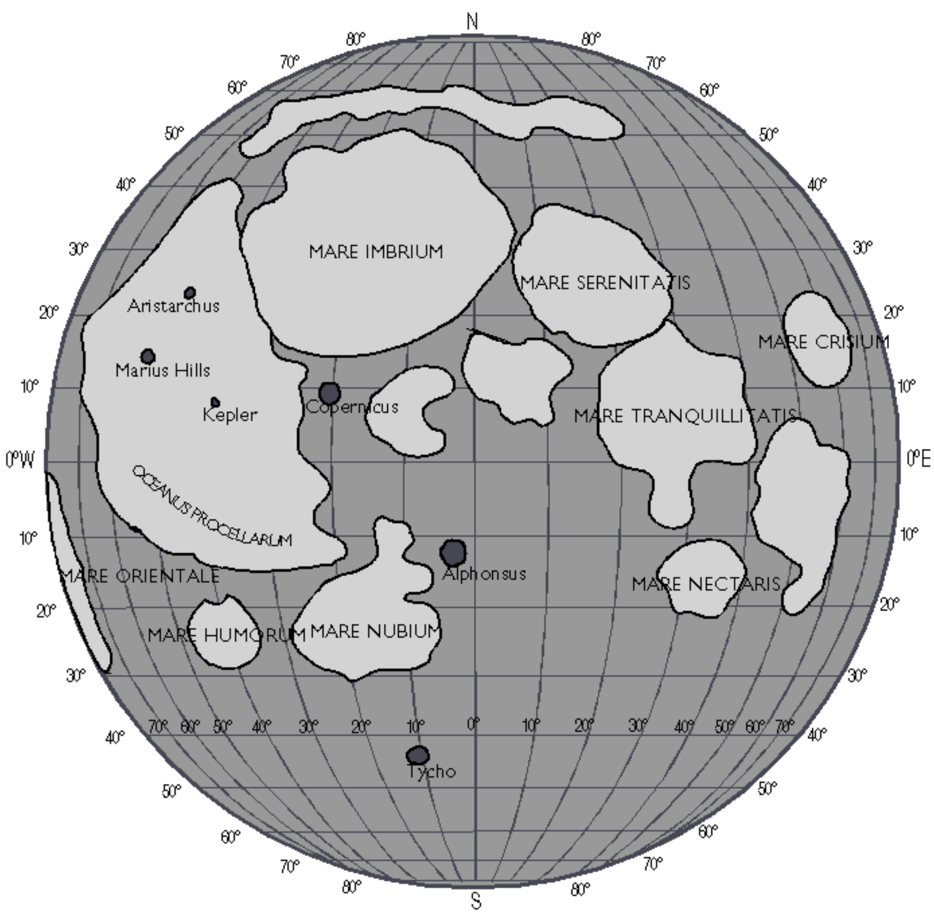
Clementine notes:

The UV-VIS sensor had 5 bands:

Name	Band Center (μm)	Band Width (μm)
Band 1 (A)	0.415	0.040
Band 2 (B)	0.750	0.010
Band 3 (C)	0.900	0.020
Band 4 (D)	0.950	0.030
Band 5 (E)	1.000	0.030

The image file is a mosaic assembled from multiple individual images. In places you can see the boundaries between the images. The images were all obtained at times that were near local noon, so regions along the equator do not show significant shadows. Only variations in albedo are apparent. At higher latitudes some shadows are usually visible.

The following map of the moon's near side can be used for locating major features. The Clementine image shows both sides of the moon, with the near side centered in the image. In recognizing features, Mare Imbrium is a good place to start. The craters Copernicus and Tycho also make good landmarks because they are young, bright, and have large "ray systems" extending out from them.



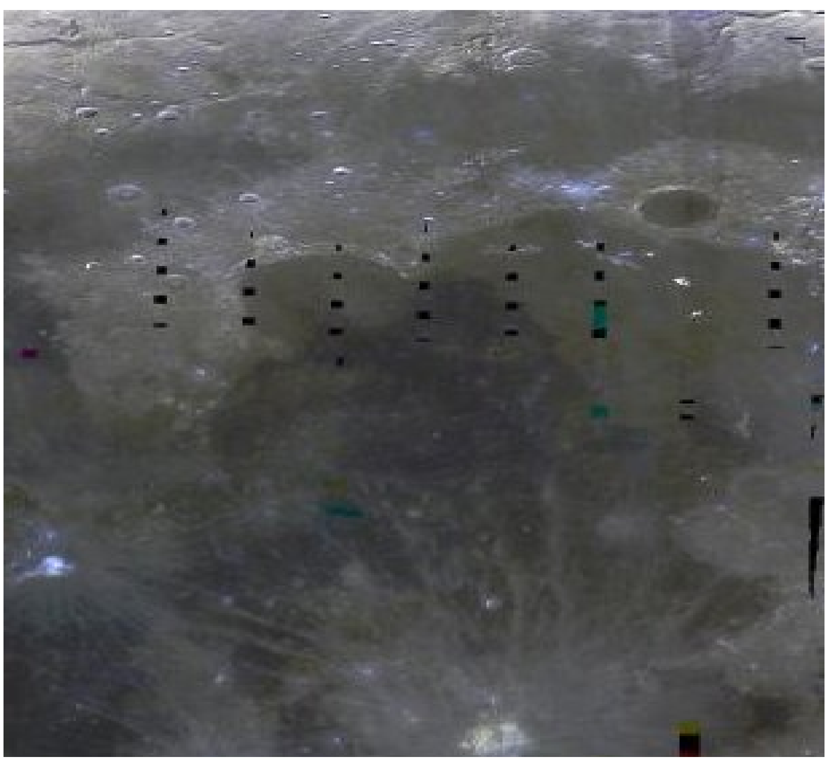
Part II: Specific Lab Instructions

1) Download (from the class website) and unzip the **`lab_10`** data file into your own **`lab_10`** subdirectory within **`C:/temp`**. You should find a **`clementine_uvvis_5km_env`** data file and the corresponding **`clementine_uvvis_5km_env.hdr`** header file.

2) Read the Clementine image into ENVI, and create a **`Display 1`** showing as (R,G,B) bands 5, 2, and 1. Identify on the image the major near-side Mare such as Mare Imbrium, Mare Serenitatis, and Mare Tranquillitatis. Experiment with different image "stretches" to see if you can identify by eye where you expect the maria to be Ti rich or poor. The Ti rich sections should be both darker and more blue (at least compared to the rest of the mare). The automatic stretch routines tend to be confused by the many regions with bad (or empty) pixels. The best results seem to come from positioning the "zoom box outline" in the main image window over an interesting section of mare, then using **`Enhance-> Zoom: Gaussian`** to set the stretch. The following image shows a portion of Mare Imbrium with a good stretch. (Unfortunately the print will probably only show a small fraction of the detail visible on-screen.)

   Once you have a stretch which shows good detail, save a jpg copy of the image for inclusion in your report. (This should be a version of the full moon image – which should be the default image saved.)

   Places that show "interesting" Ti abundances are Mare Tranquillitatis, the inner vs. the outer parts of Mare Serenitatis, and also Mare Imbrium. (See the map for these locations.) Note the patterns you see for comparison with the Ti map we'll obtain later.



3) Using **`Basic Tools -> Band Math`** calculate the θ_{Ti} parameter. Note that you will enter the formula as follows:

```
atan( ((B1/B2)-0.42) / (B2 – 0.0) )
```

You'll need to tell the system that **`B1`** corresponds to Band 1 and **`B2`** corresponds to Band 2.
Save the result to a file **`theta_ti.env`** in your own directory. Examine the resulting image to make sure it does show higher theta values where (based on step 2) you expect to see more titanium. You may want to "link" the two displays together, as described in the computer instructions. When you're done you can close the θ_{Ti} display.

4) Using **`Basic Tools -> Band Math`** convert the above θ_{Ti} parameter into Weight % TiO_2 using the following formula

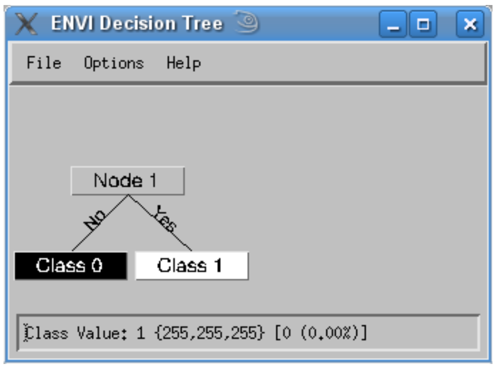
```
3.708 * (B6^5.975)       .
```

You'll need to tell the system that **`B6`** corresponds to the θ_{Ti} "band" you created. Save the result to a file **`ti_abundance.env`**. Display the result and again compare it to your previous images. Once again the automatic stretch routine tends to get confused. **`Enhance->Scroll: Gaussian`** seems to do a better job. Be sure you really do have high Ti values where you expect them. Save a copy of the image as jpg for inclusion in your report. Describe in a few sentences what patterns of Ti abundance you see in Mare Tranquillitatis, Serenitatis, and Imbrium.

5) Use the **`Tools->Cursor Location/Value`** on the Image menu to display pixel values. Find typical values for both the Band 2 (0.750μm) reflectance and the Ti abundance for the following three locations – and put that information in your report.

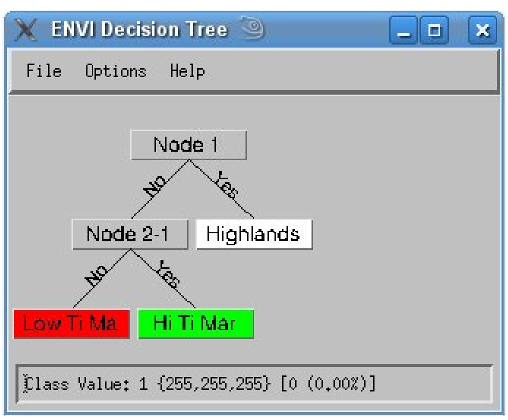
	Typical Albedo	Typical Ti Abundance
Highlands:	____________	__________________
Low Ti Maria	____________	__________________
High Ti Maria	____________	__________________

6) Create a classification image for the lunar maria using **`Classification->Decision Tree->Build New Decision Tree`** from the main ENVI menu. It will open a window like the one below. Click on **`Node 1`** in it and another window will open. Enter the expression **`B2 gt 0.15`**, which will test whether the Band 2 (0.750 μm) reflectance is greater than 0.15, to determine whether a pixel is highland or maria. ENVI will next open up an **`Variables / File Pairings`** window. As in band math you have to tell the system which **`Bnn`** corresponds to which band. Click on **`{b2}`** and another window will open which will let you select the original image's Band 2 (0.750 um) then click **`OK`**. Next click on **`Class 1`** and when ENVI opens a new window, rename this class highlands.



We now need to add a second-level branch to distinguish between high and low Ti maria. Right click on **`Class 0`** and select **`Add Children`**. A new decision box will appear in place of Class 0. Click on it and enter the expression **`B7 gt 6`**. In the **`Variables / File Pairings`** box assign B7 to TI Abundance. Click on **`Class 2`** and rename it **`Low Ti Maria`**, and click on **`Class 3`** and rename it **`High Ti Maria`**.

You should now have a decision tree which looks like the following.



In its menu click **`Options->Execute`** then in the window which will open specify **`lunar_class.env`** as the name of the file where the results will be saved. The system will classify all the pixels then open up a display showing the result. Link that display to your other (RGB and Ti Abundance) displays and check to see if the classification is reasonable.

In a few sentences describe how well the classification matches what you expected, in particularly in Mare Tranquillitatis, Serenitatis, and Imbrium. How well does it distinguish the high and low titanium basalts? What patterns do you see within the overall mare basins? Finally, either add a graphical classification key overlay (as we did in an earlier lab) or just say in the text of your report which colors correspond to the three terrain types.

Summary: Your report should contain:

1. A copy of the RGB (=Band 5,2,1) image of the moon, showing variations in the color and albedo of the mare lava as well as the overall mare / highland difference.

2. A copy of your Ti Abundance Image, along with a brief description of whether the Ti abundance followed your expectations based on the B1/B2 ratio. You should also include a few sentence description of the Ti abundance patterns seen in Mare Tranquillitatis, Serenitatis, and Imbrium.

3. Your table giving typical albedo and Ti abundances for the three terrain types.

4. Your classification map plus a key or text showing the location of the three terrain types. You should also discuss how well the classification has recognized the patterns in Tranquillitatis, Serenitatis, and Imbrium. In particular, how well does it distinguish the high and low titanium basalts and what patterns do you see within the overall mare basins?

Part III: Computer Procedures

Procedure for Band Math:

From the main ENVI menu select **`Basic Tools->Band Math`**. A Band Math window will appear. Enter the formula you want to use, for example

`B1/B2`

in the middle part of the window then click **`Add to List`**. (Note: You use operands of the form **`Bnn`** where **`nn`** is a one or two digit number, then in a later step tell ENVI which bands are associated with **`Bnn`**.) That formula will appear in the top pane of the window, along with any previous ones you've entered. Select the one you want to use in that top pane, then click **`OK`**.

At this point a **`Variables to Band Pairings`** window will appear. In an upper pane select the Bnn you want to define and in the middle window select which band should correspond to it. Repeat this till all the **`Bnn`** are defined. You may need to use the up-arrow and down-arrow keys in the upper pane to see all the different **`Bnn`**.

For all our tests use the default **`Spatial Subset: Full Scene`** setting, to output the full image.

In the bottom part of the window select whether you want to output the result to memory (for temporary use) or to a file. In most cases we'll want file output. If so, click **`Choose`** and select a file name located in your directory.

When all the above information is completed click **`OK`**, the operation will be performed, and the result will appear in the **`Available Bands`** window.

You can then use the buttons at the bottom of the **`Available Bands`** window to either show it in an existing display, or create a new display for it.

Saving as an Image File Just Part of the Scene

To save a copy of just the main image to the window you can use the procedure in the next paragraph, or as a shortcut, you can press the **`Alt and the Print Screen`** keys to copy the currently active window to the clipboard, then just paste that image into your report. (On the Mac keyboards the equivalent key combination is **`Alt+F14`**.)

When you ask ENVI to save an image (usually in jpg format) it typically saves the full image, as shown in the scroll window. If you want to save just that portion in the main image display window, after selecting
`File->Save Image As->Image File` in the **`Output Display to Image File`** window click **`Spatial Subset`** to override the **`Full Scene`** default. In the **`Select Spatial Subset`** window which will appear, click the **`Image`** button. It will bring up a small image display with the current "main image window" area outlined in a red box. Just click **`OK`** to accept that subscene, or drag the box or its corners to adjust the part of the scene to save.

Comparing two different images

To compare images you can also load your classification results as a `Gray Scale` image on a `New Display` – then use the `Tools->Link->Link Displays` menu of that new display to link it to the original color-infrared image, or to another classification image. Holding down the left mouse button within one image causes the other one to momentarily appear.