Module 3: Spectra as an Analysis Tool for Lunar Exploration

In this module, students will demonstrate the advantage of using spectroscopic data and will make connections between familiar features on the Earth and what they are observing on the Moon. We strongly recommend that you conduct the introductory activities on comparative geologic processes from Module 2 and the ALTA activities from Module 1 before the "Remote Analysis of the Moon" activity.

Activity 3-1: Observing the Moon in Different Light (30 minutes)

Students observe images of the Moon at various wavelengths, and deduce that the various types of light are sunlight reflected from the surface of the Moon. Students observe that some features are more readily seen at certain wavelengths. Students discuss the limitations of our current data from the Moon, and the research by the Moon Mineralogy Mapper instrument.

Activity 3-2: Moon Mineral Exploration (90 minutes)

Students break up into teams of "Orbiters" and "Earth scientists" to gather reflectance data from "Moon rocks" and Earth rocks respectively. Students compare the reflectance spectra from their Moon samples to the spectra from known Earth rocks to identify the rock types on the Moon.

Activity 3-1: Observing the Moon in a Different Light

Overview

In this 60-minute activity, students observe images of the Moon at various wavelengths. Students deduce that the various types of light are sunlight reflected from the surface of the Moon. Students observe that some features are more readily seen at certain wavelengths. Students discuss the limitations of our current data from the Moon, and the Chandrayaan-1/Moon Mineralogy Mapper instrument.

Learning Objectives

The student will:

- identify light from the Sun as the source of moonlight
- contrast the Moon's appearance at different wavelengths of light
- compare ongoing missions examining the Moon's surface with past missions

Key Concepts

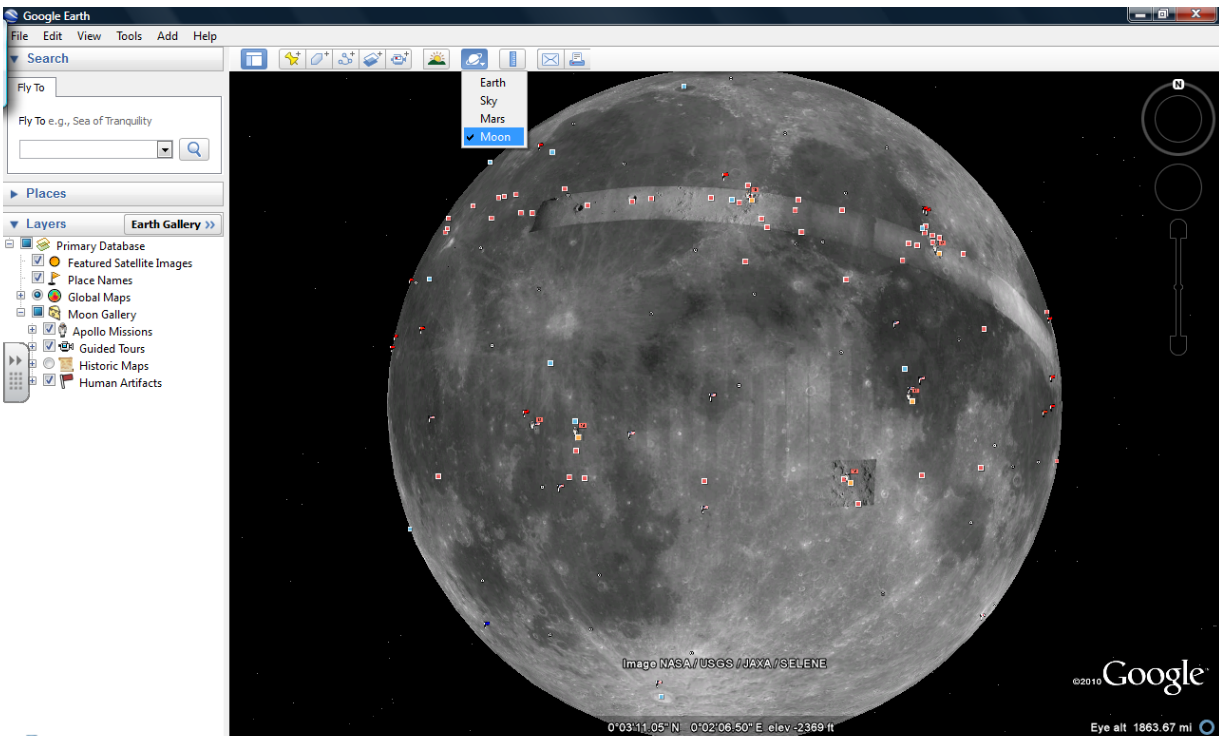
- The Moon can be viewed in many different wavelengths of light, because sunlight is reflected off of its surface, and sunlight includes all of these wavelengths.
- The Moon's surface is not uniform; there are various features visible at different wavelengths of light.
- Spectra for the different rocks on the Moon's surface can be used to identify the rocks and mineral resources on the Moon.
- The Clementine mission gathered spectroscopic data on the Moon, with limited resolution, at limited wavelengths.
- Ongoing missions, including the Chandrayaan-1/M^3, will gather more detailed data about the Moon using spectrometers.

Materials

- Images or Interactive Whiteboard Lesson for this lesson
- 1 overhead transparency per student
- Overhead transparency markers (per student, if available, or per group)
- Copies of Infrared Waves (page 9) and Visible Waves (page 11) from NASA's Tour of the Electromagnetic Spectrum WebBook (http://missionscience.nasa.gov/ems/TourOfEMS_Booklet_Web.pdf) per group
- 1 copy of the Visible Photo of the Moon for half of the class
- 1 copy of the Mid-Infrared Photo of the Moon for half of the class. Note: The copies do not need to be in color; black and white are acceptable.
- Demonstration copies of XRay and Radio Photos of the Moon
- Video projector and computer

Preparation

1. Bookmark the Mission: Science – Tour of the EMS: Introduction, http://missionscience.nasa.gov/nasascience/ems_full_video.html
2. Bookmark the Mission: Science – Tour of the EMS: Infrared Waves, http://missionscience.nasa.gov/ems/emsVideo_04infraredwaves.html
3. Set up the video projector and computer
4. Download Google Earth (which includes the Google Moon application). See image below for how to activate this application in Google Earth.



The Activity

1. Begin by telling your students that NASA is planning future human missions to the Moon and that NASA needs to know more about the different types of rocks and minerals on the Moon. We will eventually use this information to answer questions about the Moon's composition, how its surface has been altered, and where resources might be located, possibly to support future human missions.
2. Invite your students to share how we could learn more about the Moon, using what they have learned about light and spectra.

Part I: Making Observations

1. Present the Visible Photo of the Moon and the Mid-Infrared Photo of the Moon on the screen. Ask students to make observations of each.
   - **What feature can you identify on each picture? How are these images the same? Different?** [Accept all answers.]

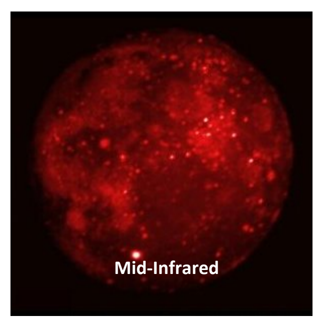
1. Using the interactive white board, if available, ask a volunteer to come and trace one key feature that they observe. Tell students that they will continue this process in their groups of two. Review your expectations for group work. Model with your students how they will use the transparency and marker to trace features shown on each image.
2. Distribute black and white copies of the Visible Photo of the Moon (taken by a ground-based telescope) to every other student and the Mid-Infrared Photo of the Moon (taken during an eclipse) to the remaining students. Next distribute overhead transparencies and a marker to all of the students.
3. Ask them all to trace the most important features onto the overhead transparency with a marker.

Analysis

1. Direct students to overlay their transparencies to examine the features. While viewing the transparencies, discuss in pairs or as a class which features are more prominent.
    a. **Do these images of the moon share any similarities? If so, what are they?** [Many of the shapes of these features are nearly the same; such as the "C" shaped feature (which is dark on the visible image and bright on the mid-infrared one).]
    b. **What are the differences among these two images? Why do these differences exist?** [The visible Moon shows the large dark regions; the infrared Moon shows light areas. Also, many of the features appear to be the same but they do not line up exactly. The moon rotates among its axis, so these images were not captured at the same time.]

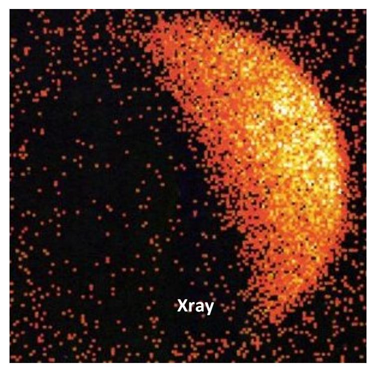
Further Research

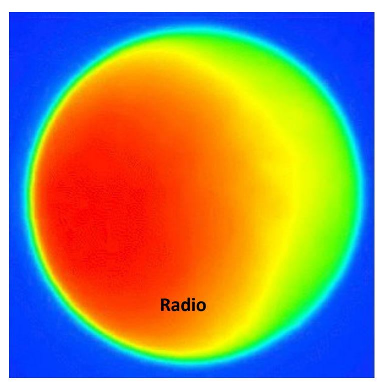
1. Tell students that they will now make inferences of their observations of the Moon using these images. However, they will need to research background information on the "tools" (or images) used to make these inferences.
2. Show students the video segments from the "Tour of the EMS: Introduction" and "Tour of the EMS: Infrared Waves" (through to 1:40 seconds).(http://missionscience.nasa.gov/nasascience/ems_full_video.html and http://missionscience.nasa.gov/ems/emsVideo_04infraredwaves.html)
3. Distribute pages 9 and 11 to student groups to use to answer their questions.
    a. **What is the difference between these two images, as related to the electromagnetic spectrum? What causes these differences**?
    b. **What kind of additional information is provided by these images?** [Visible waves show different rock types, or high and low places, etc., while mid-infrared waves indicate areas that are hot versus cold.]
    c. **What inferences can you make, from these different kinds of information, about the moon?** [Perhaps some areas or rock types retain heat from the impact which created them. Some students may infer that new rock is being formed, such as by tectonic activity found on Earth. Confirm with students that no tectonic activity is occurring on the Moon.]
    d. **What other data would you like to have in order to have a better picture about what the Moon is made of?** [Lunar rocks, images taken from other parts of the EMS, etc.]



Part 2. Digging Deeper

1. Ask the class about past missions to study the Moon. Students may mention the Apollo astronauts, who collected 842 pounds (382 kilograms) of rock samples from six geographically-close locations on the nearside of the Moon.
2. Show Google Moon and the landing sites, then hold a class discussion about the missions and the resulting collections of rock samples.
   - **Why haven't we visited more of the Moon's surface?** [There many be many opinions: missions are limited by funding, time, technology, distance]
   - **How much do we understand about the Moon from the Apollo rock collection?** [Rocks were only collected from 6 locations on the Moon; we have an incomplete picture and there may be many other types of rocks on the Moon.]
   - **If we collected samples from the same areas, or relative distances apart on the Earth, would we know much about the Earth? Do we have enough samples to know all about the geologic history of the Moon?** [No! We would not have been able to sample the ocean floor, the Rocky Mountains, the Himalayas, the Alps and so much more! We need to know much, much more about the Moon!]
   - **Why are the Moon rocks important in understanding the spectra we get from the Moon?** [Having Moon rocks on Earth gives us a basis of comparison for other spectra we may gather from a distance.]
3. Share that the Moon has been remotely explored at many different wavelengths. Show the image of the Rontgen Satellite (ROSAT) X-ray photo of the Moon and the Very Large Array (VLA) radio photo of the Moon. (Let them know that the red regions have the brightest radio waves and the blue regions have the faintest radio emission.)
   - **What do they observe?** [One side of the Moon is "brighter" than the other.]
   - **Why is only part of the Moon showing X-rays? Why is the radio emission strongest on the left part of the Moon?** [The X-rays and radio waves were coming from the Sun, which was shining on the right side of the Moon for the X-ray picture and the left side for the radio picture.]





4. Let the students know that scientists have studied the Moon using ground-based telescopes, satellites, and several spacecraft. Show the image of the Spectroscopic Map from the Clementine Mission (a spacecraft that orbited the Moon) to the class. Unlike the photos at one specific range of wavelengths, this map is made from different photos of the Moon at different wavelengths, stacked together, like the students did with the overhead transparencies. This map is of many different wavelengths, and gives scientists a fingerprint for particular minerals, like iron.
   - **How is this picture different from the other photos they've examined?**
     [There are multiple colors used here for each image; they have more data.]

- **Are the colors used, for the image, the "real" colors of the Moon?** [No, the colors are coded for particular 'fingerprints' of brightness of reflected light.]
- **Why are there different colors?** [The different colors represent regions that were bright at different wavelengths of light, so different colors tell us that those parts of the Moon are made of different minerals.]
- **Which parts of the Moon have lots of iron? Which parts of the Moon are low in iron? If we only had the photo of the Moon in visible light, would we know that the Moon contains iron?** [No, we can only determine it by looking at specific wavelengths.]

5. Describe recent and current missions: the Indian Space Research Organization's Chandrayaan-1 mission, NASA's Lunar Reconnaissance Orbiter (LRO), the Japan Aerospace Exploration Agency's Kaguya, and the Gravity Recovery and Interior Laboratory (GRAIL). All of these missions have spectrometers aboard. Questions you might expect during discussion include:

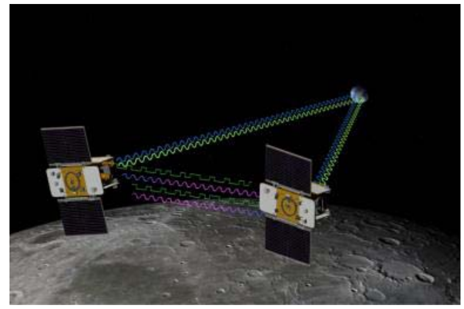


Image courtesy of NASA—Artist rendition of GRAIL twin spacecraft

- **If we already have this information, why are we collecting more?** [As we've observed, different wavelengths reveal different features. We need data at a higher resolution to see more specific features, and with many more wavelengths to determine what specific minerals or rocks are there. These missions will also gather data to help us better understand the lunar environment, such as radiation and temperatures.]
- **What might the new instruments tell scientists?** [Spectrometers will help scientists identify the types of rocks and minerals that are on the surface, where they are, and the amounts.]

Class Discussion

Time for your students to synthesize some of this information.

1. **What do the students think the point of this activity was?** [Answers could include "learning about missions to the Moon," "observing the Moon in different types of light," or may even include "learning about the spectrum" or "learning about light."]
2. **Which aspects of science did your students do today?** [Answers could include examining data and making observations.]
3. **Why might scientists want to observe the Moon using different wavelengths of light?** [Different wavelengths of light will make it easier to spot certain features, and if enough wavelengths are used, scientists can get a spectrum of the Moon's surface.]
4. **How will the upcoming missions help us to understand what the Moon is like?** [These missions will take photos at many different wavelengths. Scientists will put together a spectrum for detailed features on the Moon to learn about the types of rocks and minerals on the Moon.]

Extensions

Cool Cosmos has created a wide variety of educational products that explain the infrared as well as the multi-wavelength universe. Further information about the Moon at different wavelengths is available at: **http://coolcosmos.ipac.caltech.edu//cosmic_classroom/multiwavelength_astronomy/multiwavelength_museum/moon.html**.

Visible Photo of the Moon

Photo taken from nasaimages.gov

Mid-Infrared Photo of the Moon

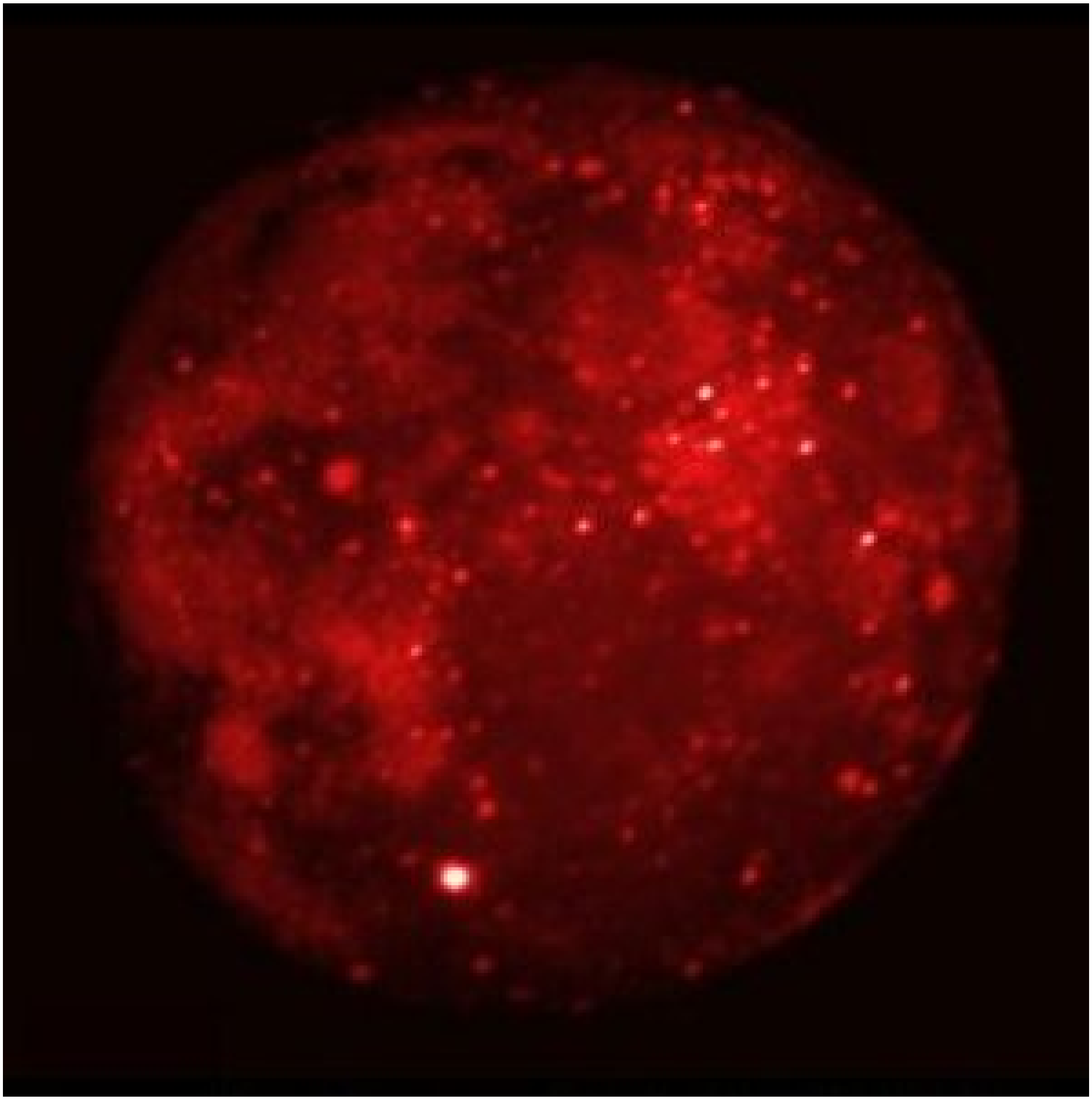


Photo taken from nasaimages.gov

XRay Photo of the Moon

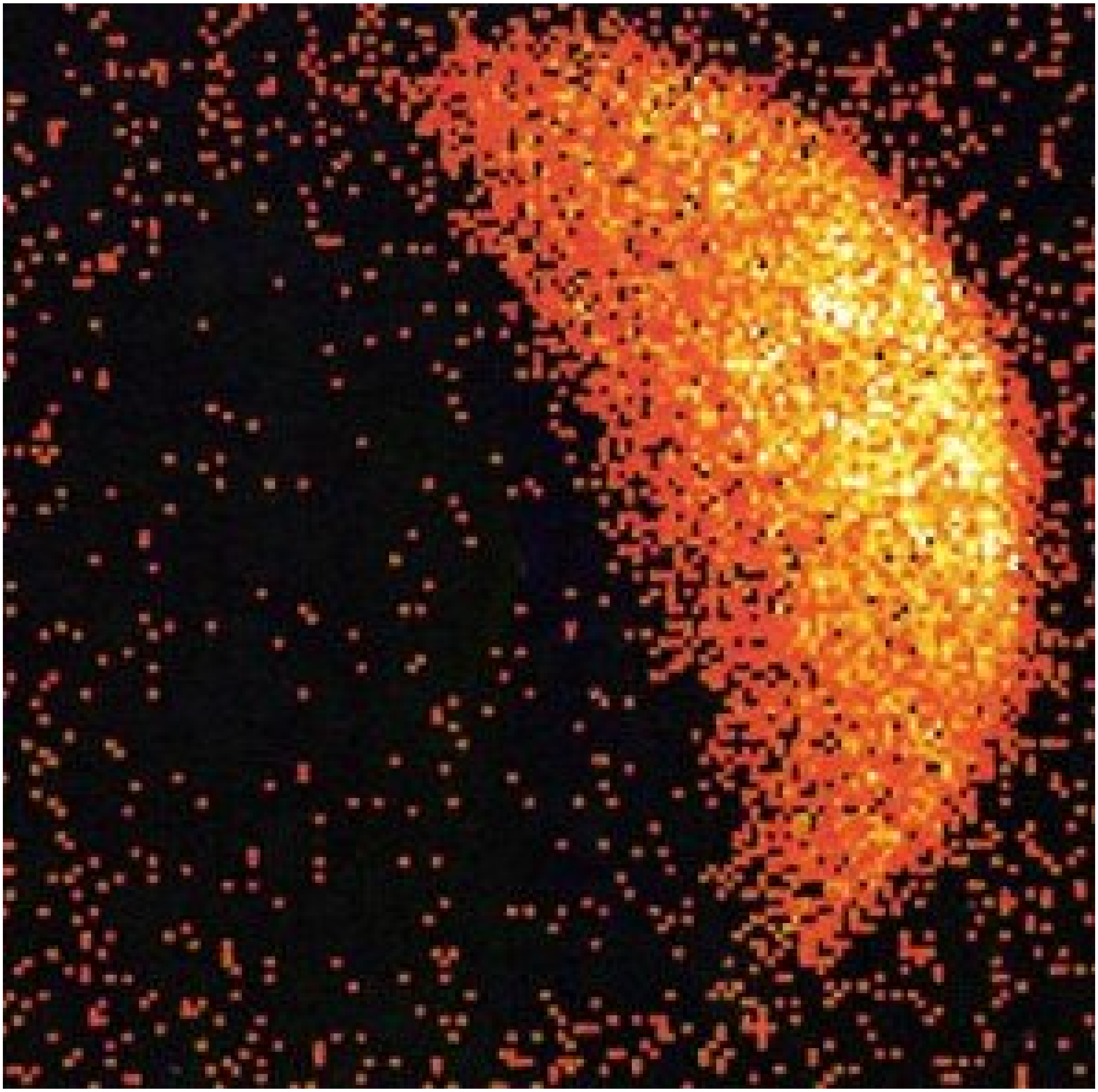


Photo taken from nasaimages.gov

Radio Photo of the Moon

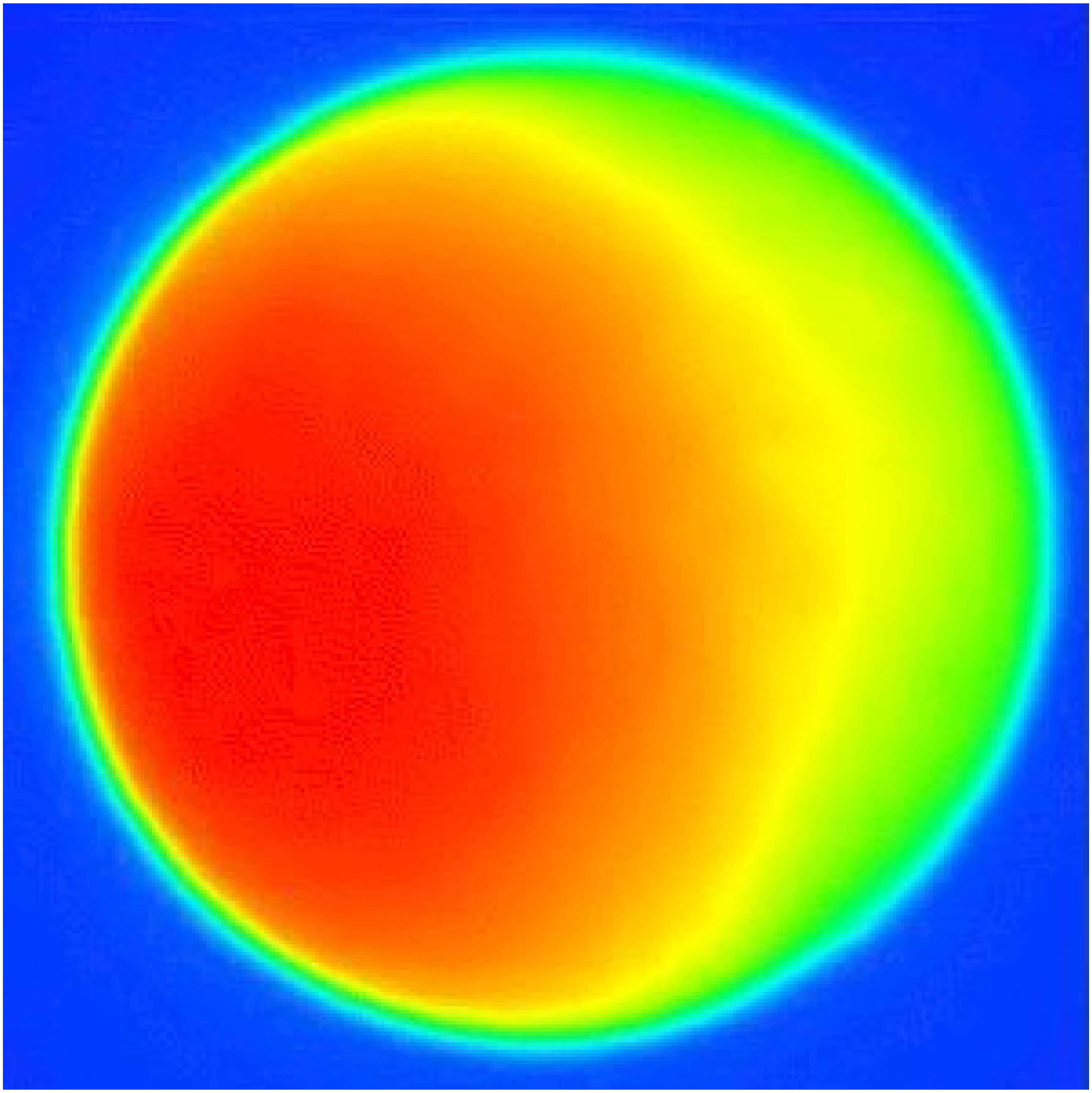


Photo taken from nasaimages.gov

Activity 3-2: Moon Mineral Expedition

Overview

In this 90-minute guided, inquiry-based activity, students break up into teams of "Orbiters" and "Earth scientists" to observe and gather reflectance data from "Moon rocks" and Earth rocks respectively. Students compare the reflectance spectra from their Moon samples to the spectra from known Earth rocks to identify the rock types on the Moon.

Learning Objectives

The student will:

- Describe how a reflectance spectrum can be used to identify an unknown substance
- Describe the characteristics of the reflectance spectra of at least three different rocks
- Infer the value of sharing and comparing scientific data
- Infer the value of communicating scientific findings

Key Concepts

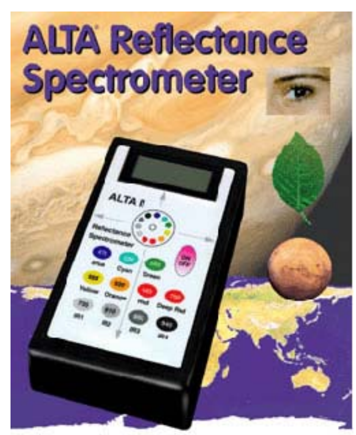
- Rock types have unique reflectance spectra. Rocks can be identified by their reflectance spectrum or "rock fingerprints."
- Scientific investigation includes making observations, gathering, analyzing, and interpreting data, and using technology to gather data.
- Scientists from different teams or different fields may need to share their data and findings to develop new theories or make sense of observations.

Materials

For each team of two to three students

- 1 box or container, large enough to hold 5 or 6 rocks
- Rock specimen of basalt, anorthosite, rhyolite, limestone chalk, and/or dunite at least 5 by 5 centimeters (2 by 2 inches) wide, with a flat surface. Note: rocks will need to be labeled. *See section below for description on how label titles for Orbiters and Earth groups. To label, consider using a dot of White Out on the rock's side with the label written with fine point permanent marker.
- 1 ALTA reflectance spectrometer

  Reflectance spectrometers can be ordered for loan from http://www.lpi.usra.edu/education/products/spectrometer/loan.shtml. Note: 1 9-volt battery per unit will be needed. Southeast Region teachers: Contact Dr. Cassandra Runyon to borrow these. Contact her at runyonc@cofc.edu. Alternatively, spectrometers may be purchased through Vernier Software http://www.vernier.com/.



The ALTA® hand-held Reflectance Spectrometer measures 3.75" × 6.75" and weighs only 9 ounces.

Materials list continued on next page

Materials Continued

- 1 copy of the Rock Information Student Sheets
- 1 copy of the Spectrum Graphs from "Activity 1-5: Spectrometers in Action" for each rock sample.
- 1 copy of the Reflectance Datasheet for each rock sample found in "Activity 1-4: Introduction to Alta Reflectance Spectrometer"

For each group of two to three students (Earth Teams)

Rock samples: all rocks need to be at least 2 x 2 inches (5 x 5 centimeters) wide and labeled with rock name: basalt, anorthosite, rhyolite, limestone chalk , and/or dunite. See descriptions in back of this section. [Note: it is important for the students to identify the spectrum with the rock type—these are the control samples.]

- 1 basalt rock of same type as one of the Orbiter's basalts
- 1 anorthosite rock of same type as one of the Orbiter's
- 1 olivine-rich rock (for example, dunite or forsterite) of same type as one of the Orbiter's
- 1 rhyolite rock
- 1 chalk limestone rock

[Note: to make the activity go more quickly, teachers can reduce the number of rocks for each team to a random assortment of 3, as long as each rock type is analyzed at least 3 times total by the class' Earth Science teams.]

- 1 copy of the Rock Information Student Sheet
- 1 copy of the spectrum graph for each rock sample, on transparencies if possible
- 1 copy of the Reflectance Datasheet for each rock sample

For each group of two to three students (Orbiter Teams)

Rock samples: all rocks need to be at least 5 by 5 centimeters (2 by 2 inches) wide, with a flat surface. Label each anorthosite as "Rock Type 1," each basalt as "Rock Type 2," and each dunite, as "Rock Type 3."

- 2 basalt rocks
- 2 anorthosite rocks
- 1 olivine-rich rock (for example, dunite or forsterite)

[Note: to make the activity go more quickly, teachers can reduce the number of rocks for each team to a random assortment of 3, as long as each rock type is analyzed at least 3 times total by the class' orbiter teams.]

- 1 copy of the spectrum graph for each rock sample, on transparencies if possible (graph #3, #4, or #5 are recommended; be consistent)
- 1 copy of the Reflectance Datasheet for each rock sample found in "Activity 1-4: Introduction to Alta Reflectance Spectrometer"

All rocks need to be at least 2 x 2 inches wide (hand specimens), with a flat surface; can be purchased at suppliers such as Wards: basalt (item 47 V 1044), anorthosite (item 47 V 0559), dunite / olivine (item 46 V 5834), rhyolite (item 47 V 6904), chalk limestone (47 V 4664).

Preparation

1. Arrange your classroom or two separate rooms so that student groups can work without observing each other. Your class will work in teams of two to three students each: half of the teams will be the "Orbiter" teams, and the other half will be the "Earth Science" teams. The Orbiter teams and Earth Science teams should not be able to see each other's rock samples.
2. Prepare each Earth Science Team box to include an ALTA Spectrometer, copies of the Reflectance Datasheet and Spectrum Graph for each rock, and specifically-labeled rock samples.
3. Prepare each Orbiter Team box to include an ALTA Spectrometer, copies of the Reflectance Datasheet and Spectrum Graph for each rock, and generically-labeled rock samples.
4. Prepare to darken the classroom(s) by closing window blinds. [Note: this will improve results from the ALTA hand-held spectrometers; fluorescent light often introduces errant readings, offsetting the final spectra.]

The Activity

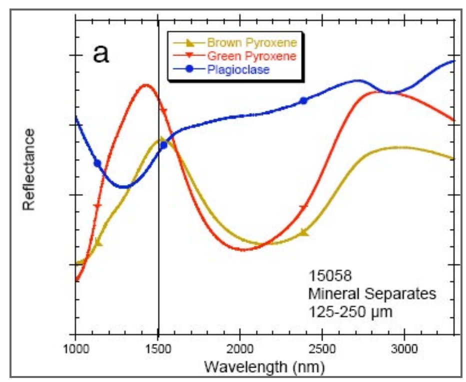
1. Invite the students to share or recall what a reflectance spectrum is-- the amount of light at particular wavelengths that is reflected off of the rocks. Remind your students of the fingerprints they took in the "Fingerprints of Rocks" activity.
    a. **How are fingerprints like reflectance spectra?** [Just as fingerprints can be used to identify people, reflectance spectra can be used to identify materials.]
2. Tell your students that they are going to simulate a mission to identify the rocks on the Moon. They will be separated into teams, with some team members ("Orbiters") gathering reflectance spectroscopic data from Moon rocks, and others ("Earth scientists") gathering spectroscopic data from Earth rocks.
3. After the Orbiter team members and the Earth team members have collected their spectra, they will regroup and compare the spectra. They will not compare the rocks. When spectrometers orbiting the Moon (such as those aboard M^3 and other spacecraft) send data back to scientists, there are no pictures of the rocks; the scientists have only the spectral curves to analyze and interpret.
4. The rocks provided to the "Orbiters" are not real Moon rocks, but are made of the same minerals that have been collected by Apollo missions.
    a. **What will the reflectance spectra tell us?** [Every different type of rock has a different reflectance spectrum. The students will use the spectra to help them identify the rocks on the Moon.]
5. Inform the students that due to the rough and angular nature of the rocks, there will be differences in their reflectance measurements. The overhead lights will be off in order to reduce the amount of outside light entering the spectrometer. Students should not try to fit a pointed part of the rock into the hole—they should only take measurements from flat surfaces. There are samples of each rock type in the box. Students should measure the reflectance value of each.

6. Organize the class into groups of six to eight students. Then designate half of each group as the “Orbiter Team” and half as the “Earth Science Team.” Send each team to their work area. Bring each of the teams their boxes, with rock samples and an ALTA spectrometer. Instruct the Earth Science Teams to take spectra of their Earth rock samples. Instruct the Orbiter Teams to take spectra of their numbered rock samples, representing the rocks observed in different parts of the nearside of the Moon. Working in their teams and sharing duties, students should complete a Spectrum Graph for each rock sample.
    a. **Are there any noticeable patterns? Are any of the spectra high or low? Do any of them have drops or large bumps? Are any of the spectra similar**?

Analysis

1. Ask the individual teams of Earth Scientists and Orbiters to unite back with the other earth science and orbiter teams (leaving their rock samples behind). Each group should compare their spectra and attempt to classify the Orbiters’ rock samples based on the spectra of Earth rocks.
2. Ask the students not to use descriptions of the rocks to try to classify the Moon rocks.
    a. **How do your students describe the spectra?** [Low and flat? Does it rise in the infrared? Does it fall low in the infrared? Does it rise for the blue and then drop?]
    b. **Do any of the groups have spectra that match? Do any of the Earth rock samples have spectra that match the Moon rock spectra**?

Comparing Data



1. Ask the students representing the Earth scientists to meet together and compare their spectra for each of their rock types, laying their transparencies on top of each other to look for patterns.
2. Have the Orbiters do the same. Ask them to identify common characteristics for each of the rock types; if one of the spectra doesn’t match the others, they should focus on those that do match.

Sharing Results

1. Ask the groups to report on their findings and observations to the class, showing their spectra and describing the matches they have found and some of the spectra of Moon rocks that they have not identified.
    a. **What might be some sources of error or difficulties in identification and matching?** [Students may make errors in recording the data, in calculations, or in graphing. Different rocks will vary in reflectance; rocks have natural variations in mineral content. The students may have had difficulty taking a good reading from a rock sample without letting outside light in.]
    b. **Can the students think of ways to reduce their errors?** [They could take more readings, or share their results with each other.]

Communicating Findings

1. Bring all of the students together and ask the Orbiters to show the spectra and characteristics for the different Moon rock types.
2. Invite the Earth scientists to suggest which of the Earth rocks each spectrum resembles.
   a. **Do all of the students agree with all of the identifications or are there any disputes?** [Remind the students that scientists often debate about new findings.]
   b. **What are some ways to settle these debates?** [Scientists look for additional data to confirm or reject their findings.]
3. Hand out copies of the Rock Information Sheet to the students, and ask them to compare its information to their current identifications of the Moon rocks.
   a. **What types of rocks have the students found on the Moon?** [anorthosite, basalt, dunite (rich in olivine)]
   b. **Which rock samples from Earth were not found on the Moon? What might this tell your students?** [Students should not have found limestone - a sedimentary rock - or rhyolite on the Moon. The Moon has no water or wind to form sedimentary rocks like limestone. Its crust is probably not like Earth's continental crust, so it is unlikely to form rhyolite in explosive volcanic eruptions.]

From top to bottom: Basalt, Anorthosite, and Forsterite (olivine-rich) rocks respectively

Class Discussion

1. Invite your students to explore their findings.
   a. **What scientific merit does this activity have? In other words, what is the main idea?** [Answers could include understanding how to gather data and analyze it, how to take and compare reflectance spectra, how to use spectra to identify rocks on the Moon, and how scientists identify rocks on other planets and our Moon.]
   b. **Which aspects of science did your students do today?** [Answers could include making observations, analyzing data, recognizing patterns, devising explanations and evaluating each other's explanations.]
   c. **Why are collaboration between scientists and the sharing of data important for science?** [Collaboration and sharing of data allow scientists to evaluate findings and arrive at more likely conclusions. The scientific process involves testing and retesting of methodology and data. As such, it is essential for peer collaborators to ensure the process that allowed for the given results is repeatable.]
   d. **Do scientists have to account for errors?** [Yes; scientist examine their work for sources of errors.]
   e. **How can taking spectra help us to identify rocks on the Moon and other planets?** [Scientists can compare their spectra to those of known materials.]
   f. **How can scientists take better spectra to better identify rocks on the Moon and eliminate more errors?** [By taking more detailed spectra, with a larger number of wavelengths and at more infrared and ultraviolet wavelengths.]

Background

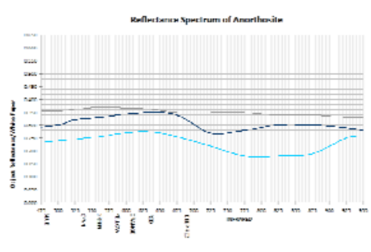
Moon Connection

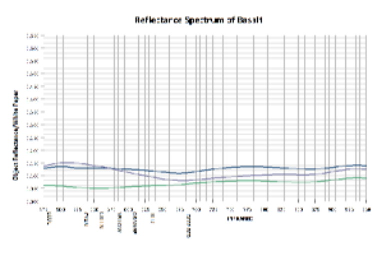
The Moon Mineralogy Mapper (M^3) was a NASA imaging spectrometer that flew on India's first mission to the Moon, Chandrayaan-1. M^3, a state-of-the-art instrument, provided the first mineralogical map of the lunar surface at high spatial and spectral resolution. It generated images of the lunar surfaces in long thin strips and spread the images like a rainbow in push-broom fashion as it recorded the mineralogy of the surface. The instrument provided scientists their first chance to study the Moon's surface at high spatial and spectral resolution (fine detail), making spectroscopic measurements of lunar minerals in the visible and near-infrared regions of the electromagnetic spectrum, while also mapping the range of these materials across the Moon’s surface. Mineralogy is used to characterize the geologic characteristics and evolution of planetary surfaces. M^3 has shown the spatial distribution of lunar mineralogy, and has drawn relationships between visible landforms and their mineral composition. Researchers will apply this information in guiding scientific research about the moon's origin and geologic evolution, as well as the terrestrial planets evolution in the early solar system’s history. Future lunar exploration will also use these data to identify resources, such as water, that may support exploration of the Moon and beyond.

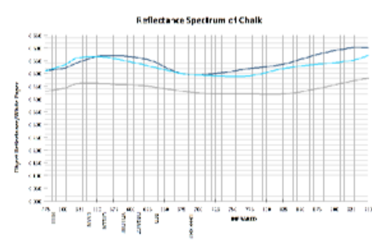
Rock Graphs

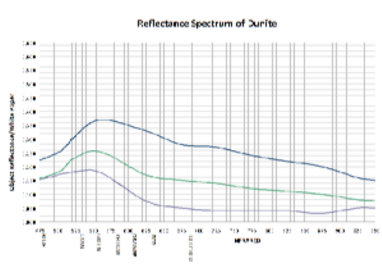
There will be natural variations in each rock sample, and even different sides of the same sample may yield slightly different spectra. Rocks and minerals can be better identified by scientists with more detailed spectra that extend further into the infrared than the ALTA or other reasonably-priced classroom spectrometers can reach.

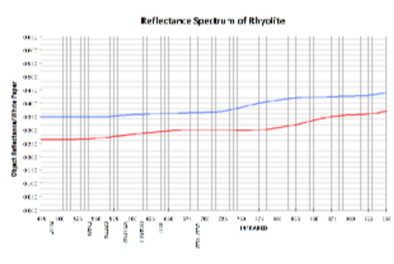
Here are some sample spectra of the rocks used in this activity: These are not “the answers;” it is entirely possible that your students may accurately graph spectra that are very different; it depends on the samples. *Note: Multiple spectra are shown for each rock type, these indicate the slight variations in composition of the rocks.*



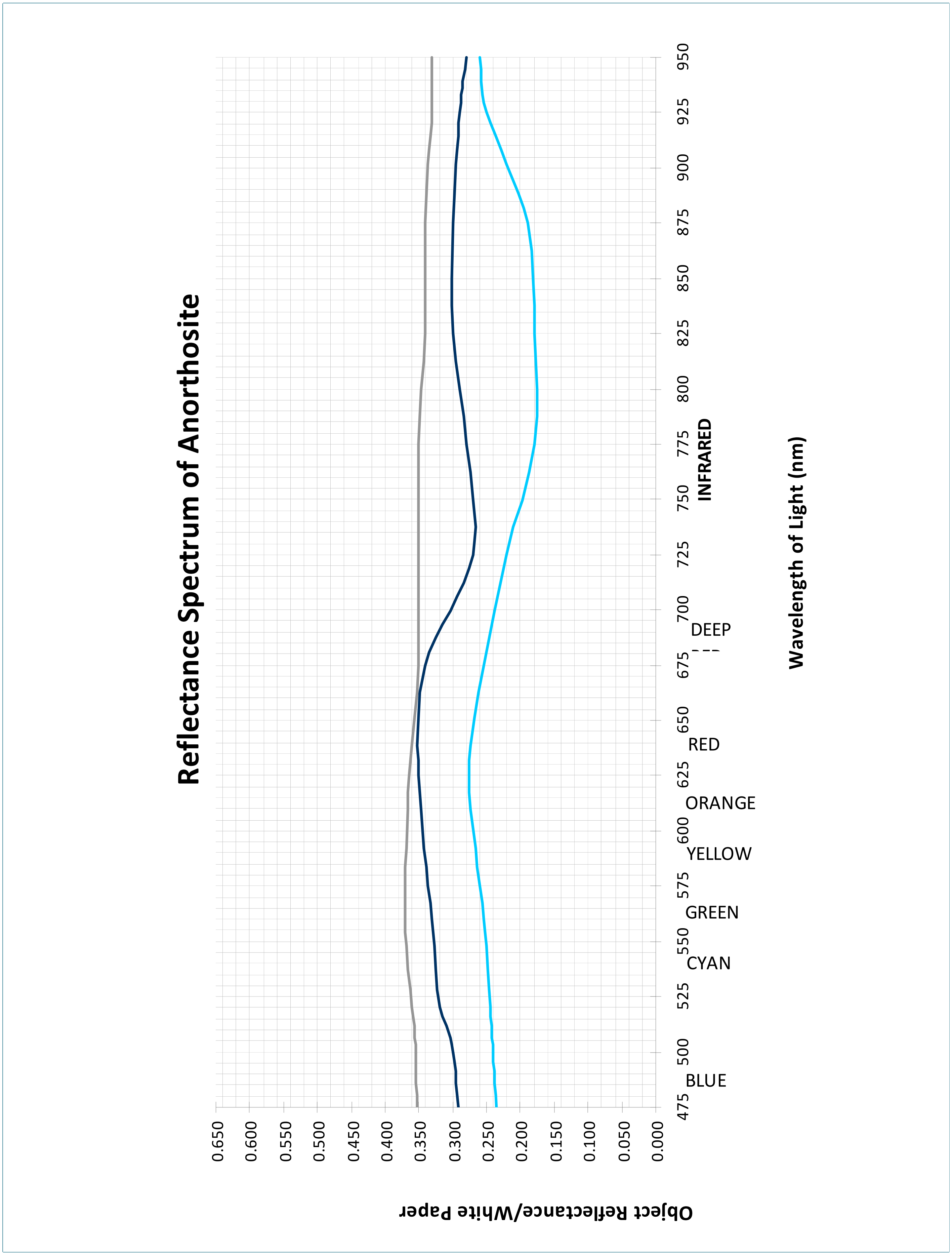








See enlarged versions on subsequent pages.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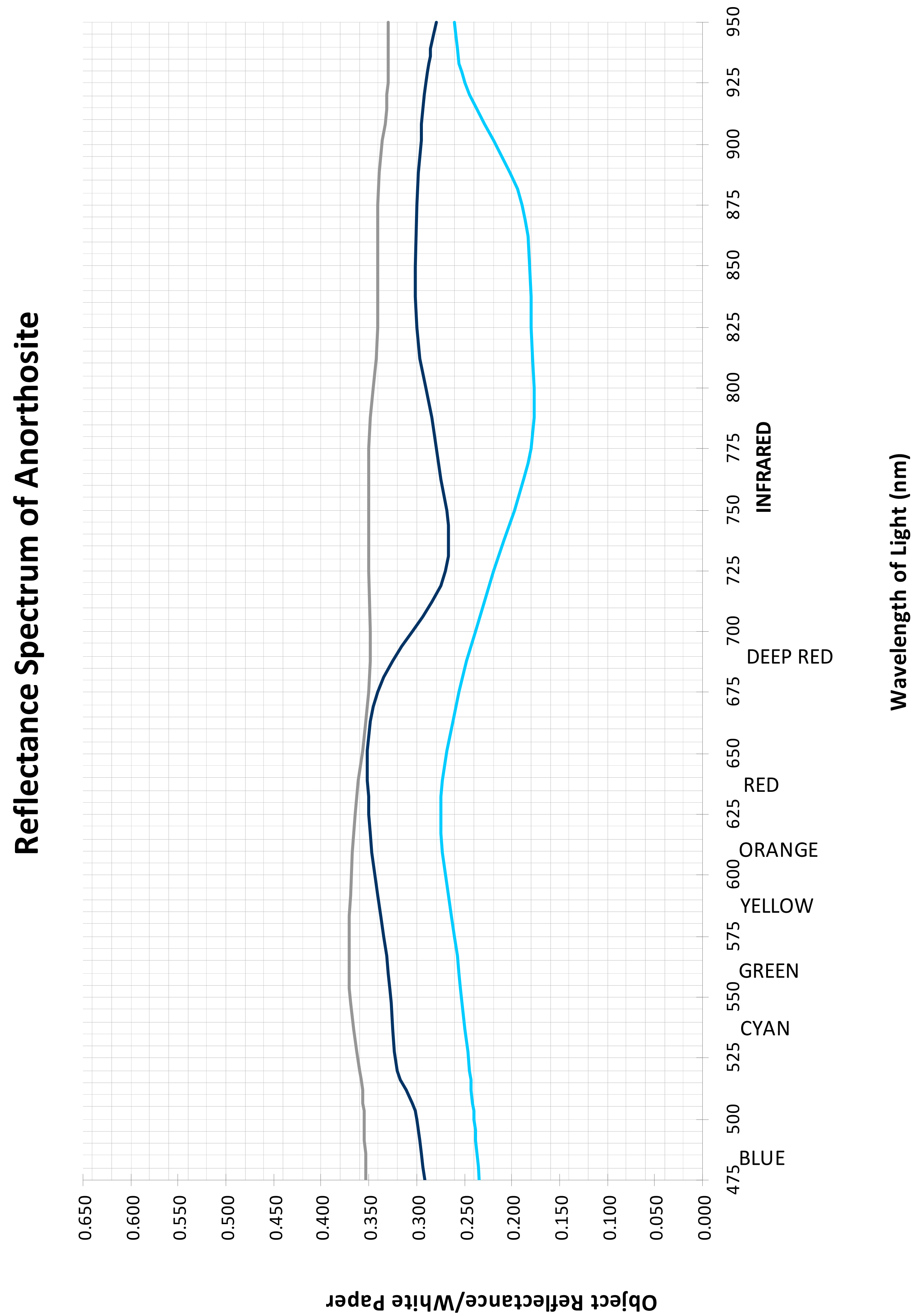
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825
850
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP
INFRARED
Wavelength of Light (nm)



Reflectance Spectrum of Anorthosite
Object Reflectance/White Paper
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825
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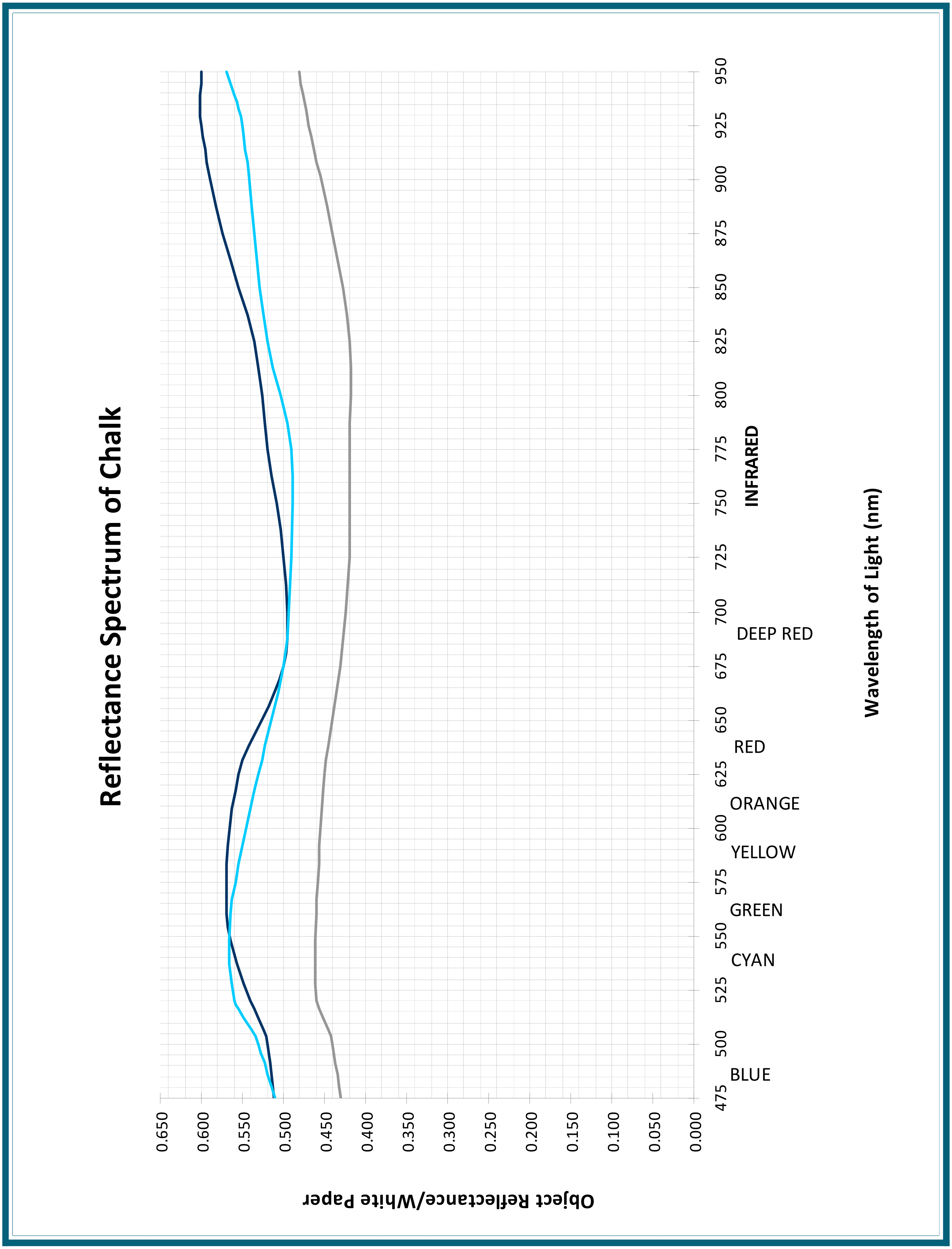
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP RED
INFRARED
Wavelength of Light (nm)



Reflectance Spectrum of Chalk
Object Reflectance/White Paper
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.550
0.600
0.650
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825
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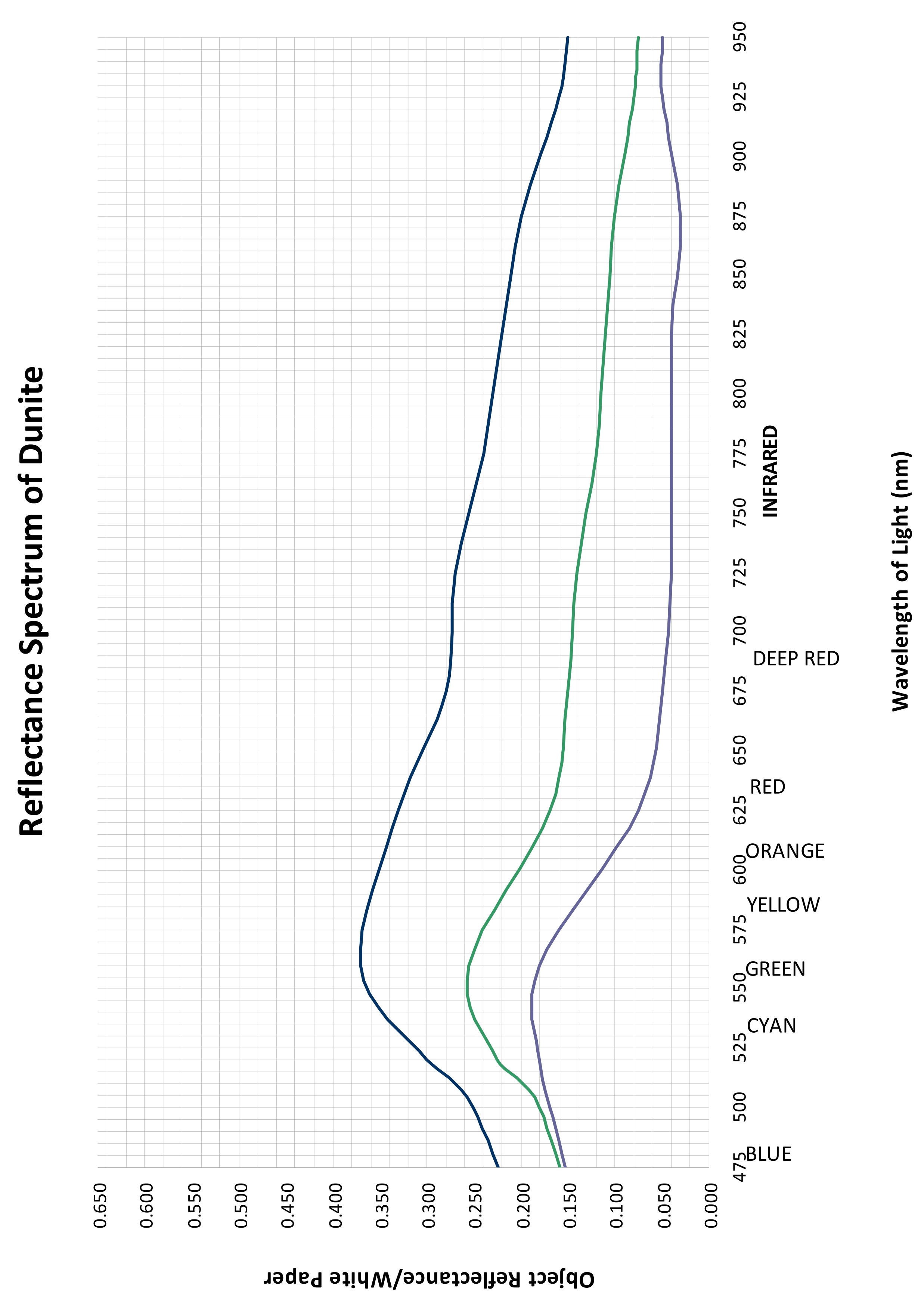
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP RED
INFRARED
Wavelength of Light (nm)



Reflectance Spectrum of Dunite
Object Reflectance/White Paper
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
475
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775
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825
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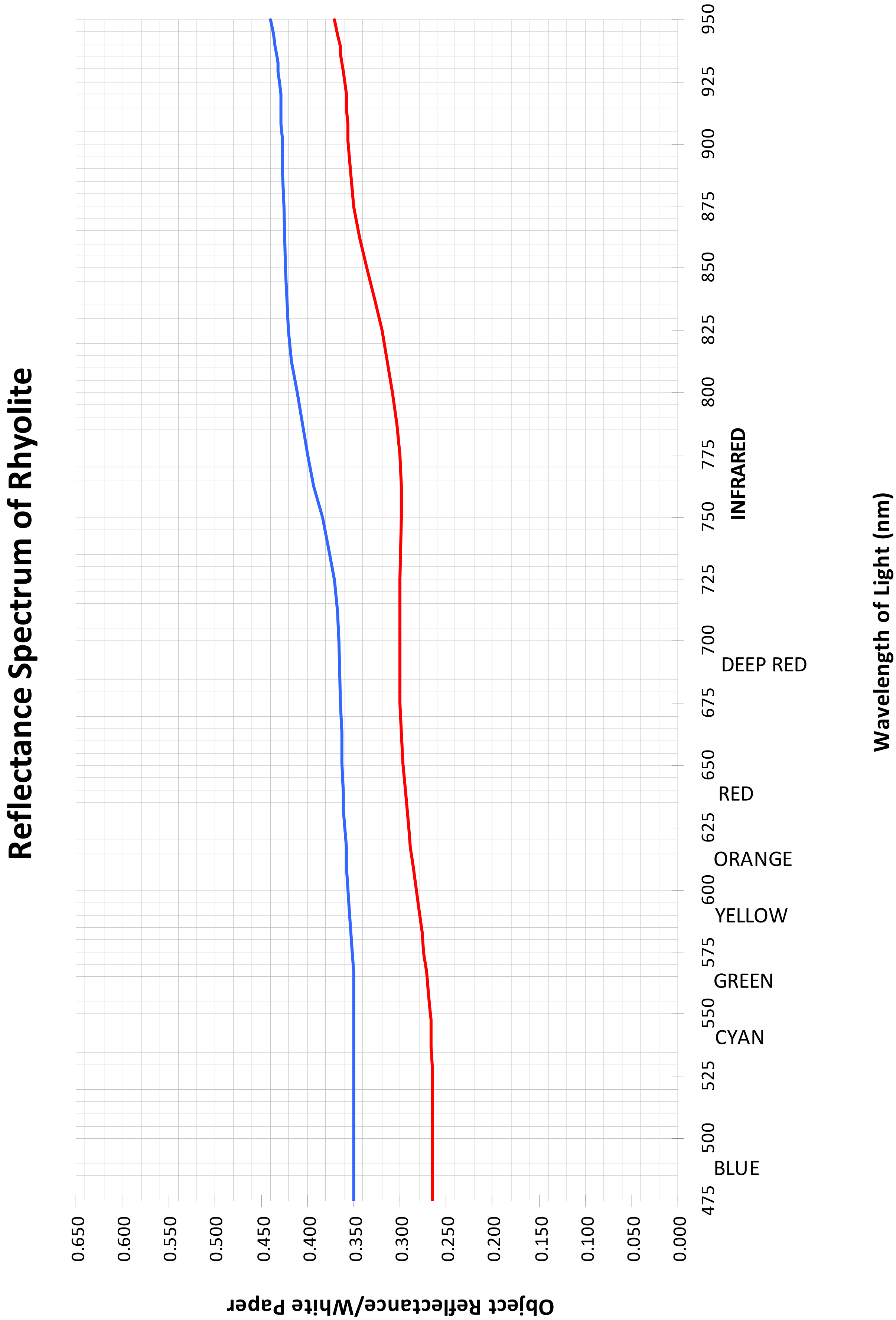
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP RED
INFRARED
Wavelength of Light (nm)


Reflectance Spectrum of Rhyolite
Object Reflectance/White Paper
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.550
0.600
0.650
Wavelength of Light (nm)
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825
850
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP RED
INFRARED

STUDENT

Rock Information Student Sheet

Rock Type: Rhyolite

Description: Rhyolite is a volcanic rock with few or no visible crystals. Rhyolite ranges in color from light grey to pink. It feels lighter than many other volcanic rocks. It may have layers that mimic sedimentary rocks. It has large amounts of the minerals quartz and potassium feldspar; it has varying amounts of plagioclase feldspar.

Locations on Earth: Rhyolite is found in continental crust, near explosive composite volcanos.

Formation: Rhyolite comes from lava formed by melting the Earth's crust, such as melted continental crust or a combination of melted ocean and continental crust. Rhyolite often forms when volcanic ash from an explosive eruption settles in layers.

Reflectance: High reflectance values. Pattern slopes up gently throughout, from blue wavelengths to infrared

Rock Type: Basalt

Description: Basalt is a dark grey volcanic rock with few or no visible crystals. It is heavier than most rocks. It has large amounts of the minerals plagioclase feldspar and pyroxene, and some olivine.

Locations on Earth: Basalt is found on the ocean floor and makes up the ocean crust. It is also found around shield volcanoes like the Hawaiian Islands, and it can form huge, stacked sheets on land, such as the Deccan Traps in India and the Columbia River area of the United States.

Formation: Basalt is formed when magma from the Earth's mantle erupts onto the Earth's surface and cools quickly.

Reflectance: Very low reflectance values. The pattern usually goes higher for green through orange wavelengths, then dips lower for red wavelengths. Infrared numbers remain lower (may slope slightly higher or lower).

Rock Type: Limestone Chalk

Description: Limestone chalk is white sedimentary rock. It is lighter than the average rock on Earth. It has large amounts of calcite, also known as calcium carbonate, which fizzes when an acid, like vinegar, is dropped on it.

Locations on Earth: Chalk is found in rock deposits on land and in water.

Formation: Chalk is formed in deep seas and oceans from the shells or outer coatings of micro-organisms.

Reflectance: High reflectance values. Pattern has a peak around green wavelengths, may slope down; infrared is somewhat flat (sometimes sloping up, sometimes down.)

Rock Information Student Sheet continued

Rock Type: Dunite (rich in forsterite olivine)

Description: Dunite is a rock composed mostly of the mineral olivine, it is olive-green colored. Olivine is common in basalt lava rocks, and makes up most of the Earth's interior (its mantle). Olivine is usually light green but can also be colorless or greenish brown to black. It is heavier than the average rock, because it contains a large proportion of iron and magnesium.

Locations on Earth: Olivine is most commonly found in basalt lava rocks (like in Hawai'i), and in rocks where basalt lava cooled slowly underground.

Formation: Olivine is very abundant in the places where bits of the Earth's mantle have been forced up to the Earth's surface.

Reflectance: Pattern is low for blue wavelengths, slopes higer for green and yellow, flows down for red wavelengths. Slope continues down for infrared usually, unless sample is very dark.

Rock Type: Anorthosite

Description: Anorthosite rock is made mostly of large crystals of the mineral plagioclase. Its color varies from dark grey to white, and can be greenish. Anorthosite can contain small amounts of other minerals, mostly pyroxene and olivine.

Locations on Earth: Anorthosite is found where ancient mountains have been deeply eroded to expose what used to be many kilometers deep in the Earth. In North America, anorthosite is abundant in upstate New York, in Labrador, in southern Ontario, and in a few spots in southern California. Much of the anorthosite has probably been recycled back into Earth's interior due to plate tectonics.

Formation: Anorthosite forms from magma inside the Earth's crust. As it cools, plagioclase, a feldspar rich in silicates making it a very light mineral, rises to the surface, producing anorthosite.

Reflectance: High reflectance values.