Table of Contents

Overview of Seeing the Moon Educator's Guide

While working through the activities and modules in *Seeing the Moon: Using Light to Investigate the Moon*, students will become more familiar with the electromagnetic spectrum and its uses as a diagnostic tool. Through the enclosed hands-on and inquiry-based activities students collect real data using a spectrometer, examine and compare rock samples, learn about the Earth-Moon system, and map features to uncover the history of the Moon.

Key Content Outcomes

Students will be able to:

- Compare the characteristics of light of different frequencies to white light
- Describe features of a plotted spectrum as wavelength versus brightness
- Demonstrate how spectra can be used to identify and map minerals and rocks
- Describe why the spectra taken by the Moon Mineralogy Mapper / Chandrayaan-1 instrument will obtain more information about the Moon than any observations to date

Key Inquiry Outcomes

Students will be able to:

- Develop descriptions, explanations, predictions, and models using evidence
- Use appropriate tools and techniques to gather, analyze, and interpret data
- Communicate scientific procedures, results, and observations
- Recognize and analyze alternative explanations and predictions
- Express the role of technology in science & exploration

The activities are divided into two primary "modules," with each module containing several steps that include open and guided inquiry investigations, demonstrations, hands-on activities, presentations, and a discussion to synthesize and assess the students' understanding. Also featured is a set of interactive whiteboard activities which showcase many of the images found within the lessons, as well as videos, and other web content.

Multi-Media Support

SMART Notebook Lessons: http://m3.cofc.edu/educators.html

- Access supplemental interactive whiteboard lessons (available in SMART Notebook but available for import in other whiteboard software like Promethian). All student sheets, directions, additional videos, etc. are all at your fingertips!

Moon Mineralogy Mapper Education: http://m3.cofc.edu/educators.html

- A suite of hands-on inquiry based activities engage middle-school students in understanding and interpreting reflectance spectra from Earth and Moon rocks. These activities are part of a suite of educational resources that investigate the geologic history of our Moon, the Chandrayaan-1 Mission, spectrometry, and future lunar exploration.

Moon Posters: http://www.lpi.usra.edu/education/moon_poster.shtml

- A series of three posters explores what C and how Cwe know about our Moon's formation and evolution, and how its history affects lunar resources. The front of the posters provide content depth for students, while back panels provide educators with information, activities, stories about the Moon, resources, and introductions to lunar scientists.

The Electromagnetic Spectrum: http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

- Imagine the Universe investigates the spectrum and offers lesson plans for exploring emission spectra from supernovas for grades 9-12.

Cool Cosmos: http://coolcosmos.ipac.caltech.edu/

- What does a cat look like in the infrared? Tour Yellowstone in the infrared and learn more about this portion of the electromagnetic spectrum through discussion, activities, images, and games at this rich site.

Northwestern University Reflectance Spectroscopy Lab: http://ser.sese.asu.edu/SPECTRA/

- Explore reflectance spectroscopy and perform online analysis of lunar and Martian rocks in this undergraduate laboratory exercise.

Active Astronomy: http://www.sofia.usra.edu/Edu/materials/activeAstronomy/activeAstronomy.html

- Infrared activities (geared for 7th grade through high school)

ALTA II Reflectance Spectrometer: http://www.vernier.com/labequipment/altaspectrometer.html

- The ALTA is a rugged, simple classroom instrument designed to help students in grades 5 to undergraduate learn about light, color, and spectroscopy. Using the spectrometer, students can collect spectral data on the proportions of colored light (including infrared) that reflect from real-world objects. Lesson plans are included.

Rock Around the World: http://ratw.asu.edu/

- Send a rock for spectral analysis! Scientists studying Mars are collecting spectra from Earth rocks so that they can compare the spectral data collected by Martian spacecraft.

Mars Student Imaging Project: http://msip.asu.edu/index.html

- Students in grades 5-12 analyze THEMIS visible spectrum camera aboard NASA's Mars Odyssey spacecraft.

Missions to the Moon

The Moon Mineralogy Mapper (**http://moonmineralogymapper.jpl.nasa.gov/**) is one of NASA's instruments aboard the Indian Space Research Organization's Chandrayaan spacecraft (http://www.chandrayaan-1.com/index.htm). It will map the entire lunar surface, and reveal the minerals of which it is made. Extensive educator content and classroom resources are available on the education pages.

NASA's Lunar Reconnaissance Orbiter mission (**http://lunar.gsfc.nasa.gov/**) will return detailed information about the surface of the Moon and the lunar environment. Explore the Outreach pages for links to more activities and resources.

The Japan Aerospace Exploration Agency's SELENE mission (**http://www.jaxa.jp/projects/sat/selene/index_e.html**) will gather gravity, magnetic, and compositional data from the Moon to help scientists better understand how the Moon formed and has changed through time and to support future exploration.

European Space Agency's SMART-1 spacecraft (**http://www.esa.int/SPECIALS/SMART-1/index.html**) orbited the Moon for three years, collecting spectra to characterize the composition of the lunar surface and provide chemical data that would help scientists understand how our Moon formed.

The Clementine Mission (**http://nssdc.gsfc.nasa.gov/planetary/clementine.html**) was a joint venture between the Department of Defense and NASA to test instruments in long-term space environment and to acquire a global multispectral map of the Moon's surface.

NASA's Lunar Prospector (**http://lunar.arc.nasa.gov/**) spacecraft orbited the Moon, acquiring a global map of lunar resources, gravity, and magnetic fields. The education section offers a teachers guide, lesson plans and a multitude of other resources.

NASA's Galileo Mission (**http://galileo.jpl.nasa.gov/gallery/earthmoon.cfm**) made two passes by the Moon, providing the first multispectral images

This Educator Guide is the result and compilation of hard work by many dedicated lunar scientists and educators. Activities contained herein have been vetted through numerous educator workshops across the country over a five year period. Although primarily designed for grade levels 6-9, many of these activities are also appropriate for upper and lower levels.

Original activities on spectroscopy are combined herein with relevant activities from the NASA's *Active Astronomy Educator's Guide,* and *Exploring the Moon -- A Teacher's Guide with Activities* (NASA EG-1997-10-116-HQ). This educator guide uses traditional U.S. units of measure (e.g., inch, foot, mile). Metric units are provided as comparisons where appropriate. The information provided in this document is accurate as of the original publication date.

Authors: Christine Shupla (Lunar and Planetary Institute), Dr. Cassandra Runyon (College of Charleston), Dr. Stephanie Shipp (Lunar and Planetary Institute), and Dr. Allan Treiman (Lunar and Planetary Institute), Elizabeth Joyner (College of Charleston), Cyndi Hall (College of Charleston), Heather Meyer (College of Charleston), and Starr Jordan (College of Charleston) all contributed to this collection of activities.

Special thanks to the many teachers who worked with us over the last five years to test and tweak these activities. In particular, the following educators provided critical feedback:

- Barbara Brown, Texas
- Alicia Goodrick, Texas
- Daryl Grantham, Texas
- Ashley Mosher, Texas

Layout and Design: Elizabeth Joyner, Cynthia Hall, Cassandra Runyon
Edited by: Cassandra Runyon , Cynthia Hall and Elizabeth Joyner

National Science Education Standards (NSES) Concepts Correlated to *Seeing the Moon* Activities		1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3	3-1	3-2	4-1
K-4th												
Science as Inquiry	Abilities necessary to do scientific inquiry	x	x	x	x	x	x	x	x	x	x	x
	Understandings about scientific inquiry	x	x	x	x	x	x	x	x	x	x	x
Physical Science	Properties of objects and materials	x	x				x	x	x			
	Light, heat, electricity, and magnetism	x	x	x	x	x				x	x	
Earth Science	Properties of earth materials			x						x	x	
	Objects in the sky									x		
Science and Technology	Understandings about science and technology									x		
	Science as a human endeavor									x	x	
5th-8th Grade												
Science as Inquiry	Abilities necessary to do scientific inquiry	x	x	x	x	x	x	x	x	x	x	x
	Understandings about scientific inquiry	x	x	x	x	x	x	x	x	x	x	x
Physical Science	Properties and changes of properties in matter	x	x	x								
Science and Technology	Transfer of energy		x		x	x						
	Science as a human endeavor	x	x	x	x	x	x	x	x	x	x	x
9th- 12th Grade												
Science as Inquiry	Identify questions and concepts that guide scientific investigations.	x	x	x	x	x				x	x	x
	Design and conduct scientific investigations.										x	
	Use technology and mathematics to improve investigations and communications.				x	x				x	x	
	Formulate and revise scientific explanations and models using logic and evidence.									x	x	x
Physical Science	Develop understanding of structure and properties of matter.	x	x	x	x							
	Develop understanding of interactions of energy and matter.			x	x	x				x	x	
	Develop understanding of energy in the earth system.			x	x	x	x	x	x	x	x	x
Earth and Space Science	Develop understanding of the origin and evolution of the earth system.						x	x	x			x
	Identify a problem or design an opportunity.										x	x
Science in Personal and Social Perspectives	Develop understanding of science and technology in local, national, and global challenges.										x	
	Develop understanding of science as a human endeavor.					x				x	x	x

Assessing Current Preconceptions & Misconceptions

- What do your students know and understand about white light and the frequencies of light?
- What do they know and understand about the Moon and current robotic space missions?

You may wish to spend some time during the activities or before beginning the activities discovering your students' current preconceptions of the topics to be presented. Education research has shown that many students have confused and naive concepts of light and color, and that their misconceptions may interfere with their learning. If you are able to address your students' misconceptions, you are much more likely to meet your learning objectives and the students will be more likely to retain their new understanding.

Common misconceptions about light

Research shows that students in middle school through college have misconceptions regarding light and the electromagnetic spectrum. These misconceptions include:

- An object is seen whenever light shines on it, with no recognition that light must move from the object to the observer's eye.[1]
- We see by the act of looking (visual ray idea), and not by light being reflected to our eyes.[1,2]
- Light is reflected away from shiny surfaces, but light is not reflected from other surfaces.[1]
- Different forms of light include "natural," "electric," "ultraviolet," and "radioactive."[3]
- When light passes through a prism or a filter, color is added to the light.[4]
- Color is a property of an object, not affected by the illuminating light.[5]

There are also misconceptions regarding NASA's exploration of the Solar System. Some students may believe that humans have never been to the Moon7, while others may believe that astronauts have visited many of the planets in the Solar System. Students may not be aware of past or ongoing scientific robotic missions to our Moon and other planets.

To determine your students' current understanding of light, conduct at least one of the following activities, if not both.

[1]Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 10-32). Milton Keynes, UK: Open University Press. Fetherstonhaugh and Treagust (1992)

[2]Watts, D.M. 1985. Students' conceptions of light-a case study. *Physics Education* 20: 183-187

[3]Zylbersztajn, A. and Watts, D.m. (1982) *Throwing Some Light on Colour* Mimeograph, University of Surrey

[4]Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London and New York: RoutledgeFalmer.

[5]Anderson, C. and Smith E. (1986) Children's Conceptions of Light and Color: Understanding the Role of Unseen Rays. Research Series No. 166.

1.1 Writing Preassessment: The Story of a Bit of Light

In this 20-minute activity, students complete a story about light. The teacher will then examine their stories for key concepts and misconceptions regarding how we see and the role of light in seeing, using the rubric provided.

Outcomes

The teacher will be able to use the results of this activity to better understand his or her student's misconceptions of sight, as well as document student growth in conceptual understanding through the writing rubric provided.

Key Concepts

- Light travels or moves until it is reflected or absorbed by an object.
- Light can be reflected, or "bounce" off of any object (not just mirrors).
- In order for a person to see something, light must be reflected off of that object and into his or her eye(s).

Materials for each student:

- One copy of the *Story of the Little Bit of Light*
- Pen or pencil
- Colored pencils

Assessment Activity

1. **Hand out copies of the Story of the Little Bit of Light to your students.** Let them know that this science writing activity is for you and that their work will not receive a grade—this is not a test.
2. **Let the students know they have 15 minutes to write the rest of the story.** Their assignment is to write what happens to the light. What does it do? Where does it go so that the student in the photo can see the book or map? Remind the students that this is a science writing exercise; you would like a scientific story about the light, not a fictional story.
3. **At the end of 15 minutes, collect the students' work.** Outside of class, examine the stories for indications that the students understand that light keeps moving (instead of stopping), that the light reflects or hits objects, and that it does travel to the child's eyes in order for him or her to see. Use the rubric provided to assess student scores. Make note of common misconceptions and preconceptions.
4. **Keep your students' misconceptions in mind while conducting the activities in this guide and address them throughout the activities.** If there is substantial confusion as to how we see, consider additional discussion and activities about sight and seeing before conducting the activities in the modules.
5. **Re-apply this assessment after the students further explore light, the electromagnetic spectrum, and how we (humans) see, to assess if there has been an increase in their understanding of these concepts.**

STUDENT
Pre/Post Assessment

Student Name: ______________________
Date:___________ Class Period:_________

Writing Preassessment: *The Story of a Bit of Light*

Instructions: Pick one of the images and complete the following story about light. Your story should include how or why the student in the photo can see the object.

I am a little bit of light. I was formed by the sun . I moved through space and the Earth's atmosphere and then I … ____

____

____

____

____

____

____

____

____

____

____

____

____

____

EDUCATOR

Writing Preassessment: The Story of a Bit of Light

Rubric for “A Little Bit of Light Story”

	Light travels in straight lines from a source.	**Light travels outward in all directions from a source.**	**After light bounces off an object, it travels in a straight line in a new direction.**
Beginning	Does not explain that light travels	Is unable to explain that light travels outwards in straight lines in all directions	Is unable to explain that light bounces or travels in straight lines
Developing	Is able to demonstrate that light travels from a light source but does not under-stand that it travels in a straight line	Is able to demonstrate that light travels outward from a light source but does not describe that it travels in all directions.	Is able to demonstrate that light bounces off objects, just not in straight lines in new di-rections
Proficient	Describes how light travels in straight lines from a light source	Describes how light travels outward in all directions from a light source	Describes how reflected light travels; bouncing off an object in a straight line in a new di-rection
Advanced	Understands at a proficient level and shows interest in investigating the path of light in everyday situations	Understands at a proficient level and applies understanding to control how light travels from a source.	Understands at a proficient level and applies understand-ing to real-world scenarios. (For example, such as light bouncing off a glass)

STUDENT

Pre/Post Assessment

Student Name: ____________________

Date:__________ Class Period:________

1. **Which phrase best describes electromagnetic radiation?**
   A. Visible light
   B. Gamma rays
   C. Reflection
   D. Waves of energy

2. **Which is NOT part of the electromagnetic spectrum?**
   A. Radio waves
   B. Microwaves
   C. Water waves
   D. X-rays

3. **Which phrase best describes the most powerful EM radiation?**
   A. Longer wavelength
   B. Shorter wavelength
   C. X-ray
   D. Radio wave

4. **The best definition of refraction is ____.**
   A. passing through a boundary
   B. bouncing off a boundary
   C. changing speed at a boundary
   D. changing direction when crossing a boundary

5. **Which of the following rocks are NOT found on the Moon:**
   A. Dunite
   B. Basalt
   C. Anorthosite
   D. Limestone

6. **Which color of visible light has the shortest wave-length?**
   A. yellow
   B. green
   C. blue
   D. violet

7. **Which of the following places waves from longest to shortest:**
   A. Gamma ray, x-ray, ultraviolet, visible, infrared, microwave, radio
   B. Visible, radio, microwave, infrared, ultraviolet, x-ray, gamma ray
   C. Gamma ray, x-ray, ultraviolet, infrared, microwave, radio, visible
   D. Radio, microwave, infrared, visible, ultraviolet, x-ray, gamma ray.

8. **Spectroscopy is:**
   A. The study of objects based on the spectrum of color they emit or absorb
   B. An important investigative tool in astronomy
   C. Used to analyze the properties of distant objects
   D. Tells scientists the age of relative objects

9. **Infrared spectroscopy is useful to obtain information about:**
   A. Waves of radiation smaller than visible rays
   B. Waves of radiation associated with heat
   C. Waves of radiation associated with using radios
   D. Waves of radiation associated with using nuclear power

10. **Colored filters ______.**
   A. Absorb some of the colors of light and only allow a few of the colors to pass through
   B. Allow you to see all colors but turn everything the color of the filter
   C. Allow you to see all colors but turn everything a secondary color on the color wheel
   D. Do not change the light

Module 1: Introduction to Light and Spectra

In this first activity module, students will be introduced to the visible and infrared portions of the electromagnetic spectrum, take a spectral measurement using the ALTA hand-held reflectance spectrometer, and receive an introduction to the Moon Mineralogy Mapper / Chandrayaan-1 Mission.

Activity 1-1. Experimenting with Color Filters (45 minutes)

Students begin their exploration of the properties of light. They observe different colors of construction paper using colored filters as eyeshades and discuss their findings. Based on their observations, students make and test predictions of the appearance of other colors through the colored filters.

Activity 1-2. Making Observations of Spectra (60 minutes)

This activity introduces the concept of a spectrum, including both visible light and wavelengths that are not visible to human eyes. Students observe a light spectrum, created using a diffraction grating and an overhead projector. Students experiment with observations of the spectrum, using their color eyeshades and construction paper, and a solar-cell and sound amplifier to detect near-infrared light through sonification.

Activity 1-3. Fingerprints of Light (20 minutes)

This introductory activity introduces students to the useful tools of observation and comparison as a means of classifying and potentially identifying similar features/objects. Students will compare collected fingerprints, classify and describe them as analogous to looking at spectra.

Activity 1-4. Introduction to the ALTA Spectrometers (60 minutes)

Using the ALTA reflectance spectrometer, students take readings of different colored objects at different wavelengths, and graph a reflectance spectrum for those objects. Students compare their reflectance spectra graphs and observe that different objects have different spectra.

Activity 1-5. Spectrometers in Action (30 minutes)

Students collect reflectance spectra and discover that objects that appear similar can have different spectra. Students discuss the advantages of a high-resolution spectrum to identify objects, and learn about the Moon Mineralogy Mapper / Chandrayaan-1 mission.

Activity 1-1: Experimenting with Color Filters

Overview

In this 45-minute exploration, students begin their exploration of the properties of light. They observe different colors of construction paper using colored filters as filter strips and discuss their findings. Based on their observations, students make and test predictions of the appearance of other colors through the colored filters.

Learning Outcomes

The student will:

- interpret the relationship between an object's appearance or color and the light reflected off of that object.
- compare reflection and absorption of light by an object.
- describe the role of predictions and testing in the process of science.

Key Concepts

- An object's appearance or color depends on the light reflected off the object that reaches our eyes.
- Objects absorb some colors of light and reflect other colors of light.
- Scientific investigation includes making observations and making and testing predictions.

Materials

For each student:

- Two different 2" x 6" strips of color sheets (color filters)
  (Gels may be purchased from a variety of locations, including http://stagelightingstore.com/, http://www.stagespot.com, and http://www.premier-lighting.com. Gels come in 20x24" sheets; each will produce 40 sets of filter strips. Recommended Roscolux colors include: red #27, blue #74, green # 90, orange #23, and blue-green #95. Prepared paddles of colored gels can be purchased at http://store.rainbowsymphonystore.com.)

-Or-

One color paddle with multiple color filters (from Oriental Trading Company, etc. or a *cheaper and more accessible option is to purchase plastic, transparent, colored report covers and cut them in strips and place in a zip lock bag.)*

For each group of 4 to 5 students:

- Sheets of colored construction paper: red, dark blue, yellow, green, orange, and two additional colors. ***Alternative:*** Consider using M&M's or Skittles.
- Observation Sheet

Preparation

Cut the color filters into 5 by 15 centimeter (2 by 6 inch) strips, with two different colors for each of your students. Note: Each sheet will make 40 strips.

The Activity

Guided Inquiry

Hypothesis

1. Give each student two different color filter strips. Alternative: hand out one set of color paddles.
2. Invite students to hold the color strip in front of their eyes. Ask your students to predict how the different colors of paper will look behind the colored filter. Students should record their predictions.
3. Model with your students how to record their predictions on their Observation Sheet 1.
4. Remind the students never to look directly at the Sun with their filter strips; even dark filter strips will not protect their eyes. Also keep in mind, some students may have partial or complete color-blindness. Depending on the severity of the condition, some of the color-related activities may be difficult for them.

Making Observations

1. Organize the students into groups of four to five, making sure that each group has all of the different colored strips.
2. Give each group a sheet of red, dark blue, yellow, orange, and green construction paper.
3. Next, have your students observe the different sheets of construction paper through their filter strips, describing what they look like, i.e., does the paper look brighter or darker? Students should record their observations on their group's Observation Sheet 1. While comments may vary, in general the blue filter strips will make red construction paper look dark grey and will make the blue construction paper appear brighter than the other papers. The red filter strips will do the opposite.
4. Ask the students to remove their color filter strips and discuss their recorded observations. They should look for patterns, and write down their thoughts. Encourage the students to test their predictions. Did their predictions match their observations? Ask each group to devise an explanation for their observations.

Making Conclusions

1. Ask your students to devise their own experiment using the color filters, record their observations, and arrive at conclusions.
2. Invite each student to share their research findings with the class.
3. Be prepared for the possibility that your students may be unaware that they are color-blind. They may be disturbed by this discovery. Alternately, if the student is comfortable with discussing their vision, it may be a useful point of discussion and observation.
4. To make the activity accessible for students who are color-blind, you might use textured or patterned surfaces in addition to the colors.

Opportunities to Explore

Invite the students to observe clothes and objects in the room, and to share what they see. Students may comment that objects appear darker or brighter, or appear to be a different color. As they discuss their observations, ask them to look for patterns. Your students may notice that light colored objects still appear bright through most filters, but darker colored objects only appear bright through some filters. For instance, dark red objects will be much brighter through a red filter than through a blue filter.

Class Discussion

As a class, invite the students to share their groups' predictions, outcomes, and any explanations they have devised.

Possible Discussion Questions

1. **What do the students think of the various explanations from the groups? Are there any that they think may be mistaken, If so, why? Are there ways to test any of them?**
   [Let the students critically examine each group's hypotheses. You may want to point out that important aspects of "doing science" include arriving at results, sharing those results, evaluating each others work, and proposing alternative ideas.]
2. **What do the students think the point of the activity was?**
   [Answers may vary greatly, but could include observing colors, testing how color filters affect objects' appearances, and studying how filters absorb colors of light.]
3. **Which aspects of science did your students do today?**
   [Answers could include making observations, making predictions, testing predictions, and forming hypotheses.]
4. **We need light in order to see. How does light help us observe something?**
   [In order for us to see something, light is reflected off that object and into our eyes.]
5. **How does light allow us to see an object's color?**
   [The object absorbs some wavelengths or colors of light, and reflects other wavelengths or colors of light. The wavelengths that are reflected give the object its "color."]
6. **What did the color filter strips do to the light before it reached our eyes?**
   [The filter strips absorbed some of the colors of light, and allowed other colors to pass through. The filter strips did not add color.]
7. **If red filter strips allowed red and orange light through, what would dark blue paper look like through red filter strips? Why do red filter strips make yellow and white paper look red?**
   [Almost all of the light reflected off of the blue paper was absorbed by the red filter, making the blue paper appear black. Yellow and white papers reflect many colors; red filters absorb most of these colors but allow the red light to pass through, making those sheets of paper appear red.]

Note: Animals found in various environments on Earth benefit from the color filtration, absorption and reflection of light. For example, animals and plants living in aquatic environments have adapted so that their coloration is minimized to keep predators away. This explains why many living things in the deep ocean are a bright red color. Encourage students to test this themselves.

1-1 Observation Sheet STUDENT

Team Members: **Date:**

Observation Sheet: Experimenting with Colored Filters

Team prediction

Fill in the color of the paper and the filter, and circle how bright *you predict* the paper will look:

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

If the paper is _____________, *then it will look* **very bright/bright/dark/very dark** through a ___________ filter.

Data Collection

Fill in the color of the paper and the filter, and circle how bright the paper looks:

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

_________ paper looks **very bright** **bright** **dark** **very dark** through a __________ filter.

Team discussion

1. Did your observations match your predictions? Why/why not?
2. Are there any patterns to what you see?
3. Why do the different colored papers look different through colored filters?
4. What environments and settings found naturally does light absorption and refraction through color filters play an important role?

Activity 1-2: Making Observations of Spectra

Overview

This 60-minute activity introduces the concept of a line spectra and how scientists use this as a tool for analysis and exploration. Students discover that visible light is comprised of different colors through building a spectroscope of common household materials. As an extension, students experiment with observations of the spectrum, using their color filters, construction paper and a solar-cell and sound amplifier to detect near-infrared light through sonification. [Modified from activities in *NASA's Active Astronomy Educator's Guide*, *NASA: Cool Cosmos; Build Your Own Spectrometer*, and *NASA LAUNCHPAD: Analyzing Spectra* (NASA-EG-2010-07-011-LaR)]

Learning Outcomes

The student will:

- Design a spectroscope to identify basic properties of visible light
- Identify elements based on spectral properties
- Explain how wavelengths are used in scientific investigations

Key Concepts

- White light is made of many different colors, or wavelengths of light.
- When white light is divided into its different wavelengths, we call it a spectrum.
- Each color of light has a corresponding wavelength.
- There are wavelengths of light that are not visible to the human eye.
- Scientific investigation includes making observations, making and testing predictions, and sharing and skeptically examining explanations.

Materials for Observing Spectra

Demonstration

- White, blue, and red light source
- Prism
- Whiteboard, Posterboard, or white banner paper
- Tape

For each student

- Spectrum Observation Notes

For the class: *Per Group of 3*

- color filters or color paddles used in Activity 1-1
- Spectroscope Instructions
- fluorescent light source
- Incandescent light source (flashlight)
- CD or DVD
- 1 cereal Box (any size)
- scissors
- tape
- ruler
- colored pencils
- aluminum Foil
- protractor triangle or 60° angle template

Materials for Extension (Optional)

Receiver Circuit

- Solar cell
- Amplifier/Speaker
- Audio cable with 1/8 inch mini-plug on one end
- 2 jumper cables with alligator clips on both ends
- 9 volt battery for amplifier/speaker
- Small Phillip's-head screwdriver to open amplifier/speaker
- Small handheld fan

For the audio detector, the mini Audio Amplifier is available at suppliers such as Radio Shack (277-1008), as are alligator clip cables; the photocell is available from suppliers such as Solar World (#3-300).

Infrared Camera

- Infrared camera*
- BNC to VGA adaptor (male to male)
- DC power adaptor
- Video projector
- Remote control for TV, DVD, or similar electronic device

**For the infrared camera, a mini lipstick camera is available from suppliers such as LDP LLC (XNiteCamBtBW) and the rest of the materials are available at many A/V and electronics stores.*

Preparation—Demonstration

1. Close the blinds and turn off most of the lights making the classroom fairly dark.
2. Tape the white banner paper or posterboard to the front of the room, unless you use a whiteboard.
3. Load the NASA Launchpad: Neon Lights—Spectroscopy in Action (**http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms=neon&category=0000**)

The Activity

Addressing Prior Knowledge

1. Write ROY G BIV on the board. Ask the students what they know about what this means. (This stands for the colors of the rainbow in order – red, orange, yellow, green, blue, indigo, violet.)
2. Direct students to draw in their notebooks how a rainbow is produced. (Light is being refracted by small water droplets in the atmosphere.)
3. Tell students that you can create a rainbow without water and the sun's light in the classroom.
    - Turn the lights off and shine a white light through a prism. Be sure the light exiting the prism shines on a screen or board.
    - Ask the students to share what they observe. (Students will observe that the light exits at a different angle than it entered.)

- Lead students to understand that the light is being refracted by the prism as it travels through the prism and white light is composed of all of the colors of the rainbow and that each color represents a specific wavelength of light. As the white light passes through a prism, the different wavelengths of light are refracted at different angles so the individual colors can be observed.)

4. Ask students to predict what will happen if a blue light is used instead of a white light. Shine a blue light through a prism and ask the students to compare their predictions to their observations. (Students should observe that the blue light exits at a different angle than the white light.)
5. Ask students to predict what will happen when red light is used. Shine a red light through a prism and ask the students to discuss what they observe.
6. Pick a student to use markers to draw on the poster sheets where the red light begins and ends. Ask other students to do the same for the other colors of light.

Questions to consider with your students

- Are the marks in the "right" place? If not, why not?
- Do all of your students see colors exactly the same way?

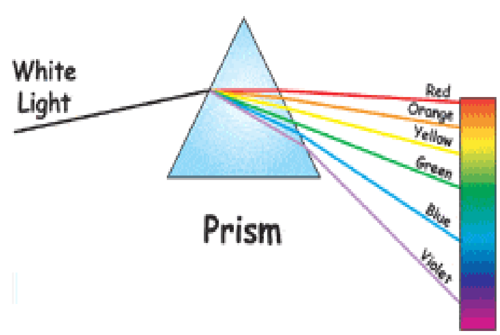
  [Individuals see variations in colors differently, so students may have differing opinions on where the tape should be.]

Alternatives for Accessibility

Note: Some students may have partial or complete color-blindness. Depending on the severity of the condition, some of the color-related activities may be difficult for them. If you have a student or students who is/are color-blind, pair them up with other students who are not and ensure that the group discussion includes good descriptions of the width and relationship of the various color zones within the spectrum. Any diagrams or sketches may include patterns or textures rather than colors to represent the changes in color.

Be prepared for the possibility that your students may be unaware that they are color-blind. They may be disturbed by this discovery. Alternately, if the student is comfortable with discussing their vision, it may also be a useful point of discussion and observation.

7. Keeping the prism and the light source location constant, shine each colored light through the prism and on to a white board or white poster paper. Mark the position of the red light on the board.
8. Next, distribute materials, including Spectrum Observation Notes and allow students to collect observations of incandescent light (if available) and fluorescent. Review the terms and your expectations prior. Review the sheet before allowing students to proceed.



Hypothesis

1. Next, distribute the color paddles or filters used in the 1-1. Demonstrate how to use these with their partner to make observations.
2. Ask the students to predict what they will see when they look at the spectrum with their color eyeshades, and share those predictions with a partner.

   "If I look at ______________ color with my spectroscope,
   the ___________________ colors will shine through."

Make Observations

1. Invite the students to observe the spectrum through their color filters and describe which colors they can see and which colors have disappeared. Remind the students never to look directly at the Sun with their eyeshades; even dark eyeshades will not protect their eyes.
2. Ask students what they see?

   [Red and orange light will be easily seen through the red eyeshades, but green and blue light will not. Blue will be easily seen through the blue eyeshades, but yellow and orange will not.]

Sharing Explanations

As a class, invite the students to discuss their conclusions.

[Students may suggest that their filters block some colors of light, but allowing other colors of light through to be seen. Other students may guess that the filters have added color to the lights.]

Recognize and Analyze Alternative Explanations

Invite the other students to add any points that may support or refute the ideas.
[For instance, if the filters were adding color, then a red filter should turn the entire spectrum of light red, rather than simply making some of the spectrum disappear.]

Class Discussion

Spend time after all of the observations to analyze and synthesize the students' thoughts and understanding.

1. **What do the students think the point of the activity was?**

   [Answers may vary greatly, but should include the terms "light" and "spectrum".]

2. **Which aspects of science did the students do today?**

   [Answers could include using technology, making observations, making predictions, testing predictions, and forming hypotheses.]

Class Discussion [continued]

1. **What is a spectrum? How did your class create one?**
   [A spectrum is white light spread out into its component colors. The class created a spectrum using an overhead projector as the source of white light, and a diffraction grating to spread the light out into different colors.]
2. **What did the filters do to the spectrum of light?**
   [The filters absorbed some of the colors of light and only allowed a few of the colors to pass through. Introduce the term “absorption” if the students haven’t used it.]
3. **Are there parts of the spectrum that humans can’t see? Which parts of the spectrum can our eyes detect?**
   [We can see the visible light, red, orange, yellow, green, blue, and violet. We cannot see infrared light, and other types of radiation. Invite the students to name other types of radiation, such as x-rays, UV or ultraviolet light, radio waves, and gamma rays.]
4. **If your class had an ultraviolet camera, where should the students point it to look for ultraviolet light in our spectrum?** [We would look past the blue end of the spectrum.]
5. **In what way could looking at objects in different colors or frequencies give us useful information?**
6. **Ask students to think of examples of different invisible colors or wavelengths of light, that we use to look at objects?**
   [Examples include having x-rays to check for broken bones, or using ultraviolet light at a crime scene to check for clues. Some students may have seen pictures of stars, planets, or galaxies in x -rays, infra-red, or other wavelengths.]

Extension

Set Up the Video Camera (optional)

Infrared Camera - If you plan to use an infrared camera, turn it on by plugging it into a DC power adaptor, and plug the power adaptor into the wall. Attach the BNC-VGA adaptor to the camera's video cable, then plug it into the *input for video* on your video projector.

1. Turn on the video projector (facing a different direction from the projected spectrum) and point the infrared camera at the spectrum. Observe the video to make sure it works. NOTE: you will not see the infrared part of the spectrum until you cover the camera with colored filters.

Prepare the Audio Photocell Detector

1. The first important but often forgotten step: install a 9V battery in the audio amplifier.
2. Plug the 1/8-inch mini plug into the "input" of the audio amplifier. Clip a jumper cable to one of the leads on the photocell, and clip the other end of the jumper cable to one of the leads of the audio cable. Use the second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.

Infrared Camera Experiment (Optional)

1. Inform the students that there are cameras that can "see", or detect infrared light.
   a. Turn on the video projector with the infrared camera attached, and point the camera at different objects in the room, allowing the students to see its view.
   b. Describe the camera as a visible and infrared camera sensitive to low light levels, and ask the students what that means.

2. Point the infrared camera at the projected spectrum on the wall and tell the students that the camera is overloaded by the amount of light.

Hypotheses / Questions

a. **What will the camera see through a blue filter?** [It will show light where the blue part of the spectrum is, and some red light, and infrared light.]

b. **What will the camera see through a deep red filter?**
[It will show only red and infrared light.]

c. **What will the camera see through a blue and red filter together?**
[It will show a little of the deep red light, and infrared light.]

1. Using a remote control for a TV, VCR, DVD, etc., observe what happens on the infrared camera when you push buttons on the remote control.
   - **What does the camera show about the remote controller?**
     [When in use, the controller emits light (infrared) that the camera can detect.]
   - **Why would a TV remote controller emit infrared light?**
     [So it won't interfere with your viewing pleasure.]

Photocell Detector/ Audio Receiver Circuit Experiment (Optional)

1. Share with the students that you are going to use an instrument to examine the light.
   a. Show the students the photocell detector/ audio receiver and switch it on.
   b. Demonstrate that the amplifier/speaker emits a noise when the photocell is placed in front of a light, such as the projector light, and that the noise is louder when the light is interrupted by a small fan (the instrument is sensitive to changes in light levels).
   c. Then slowly pass the photocell in front of the spectrum that is being projected on the wall, holding the fan in front of the photocell.

2. Ask students the following questions:
   a. **Which colors or frequencies of light can the photocell detect**?
   b. **Are there any visible colors that it cannot detect?**
      [It does not detect the purple light as well as the other colors.]
   c. **How does the detector respond when it is moved from yellow to orange to red and beyond**?

See The Active Astronomy curriculum, developed for the SOFIA mission, that includes additional activities on the spectrum and on transforming energy from one form to another.
http://www.sofia.usra.edu/Edu/materials/activeAstronomy/activeAstronomy.html

Activity 1-2: Making Observations of Spectra

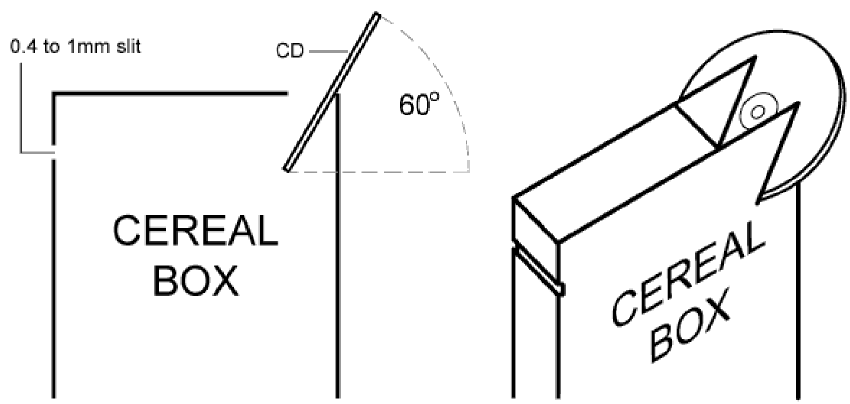
Make-your-own spectroscope Instructions

Modified from NASA: Cool Cosmos; Build Your Own Spectrometer)

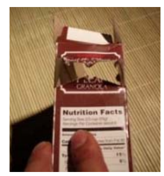
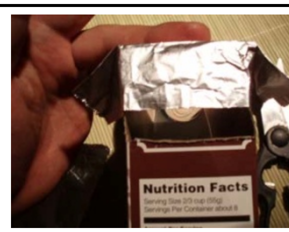
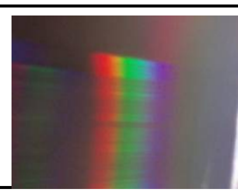
1. You will need the following materials:

- Fluorescent light source
- Incandescent light source
- CD or DVD
- 1 Cereal Box (any size)
- Scissors
- Tape
- Ruler
- Colored pencils
- Aluminum Foil
- Protractor triangle or 60° angle template

This is a schematic of the model:

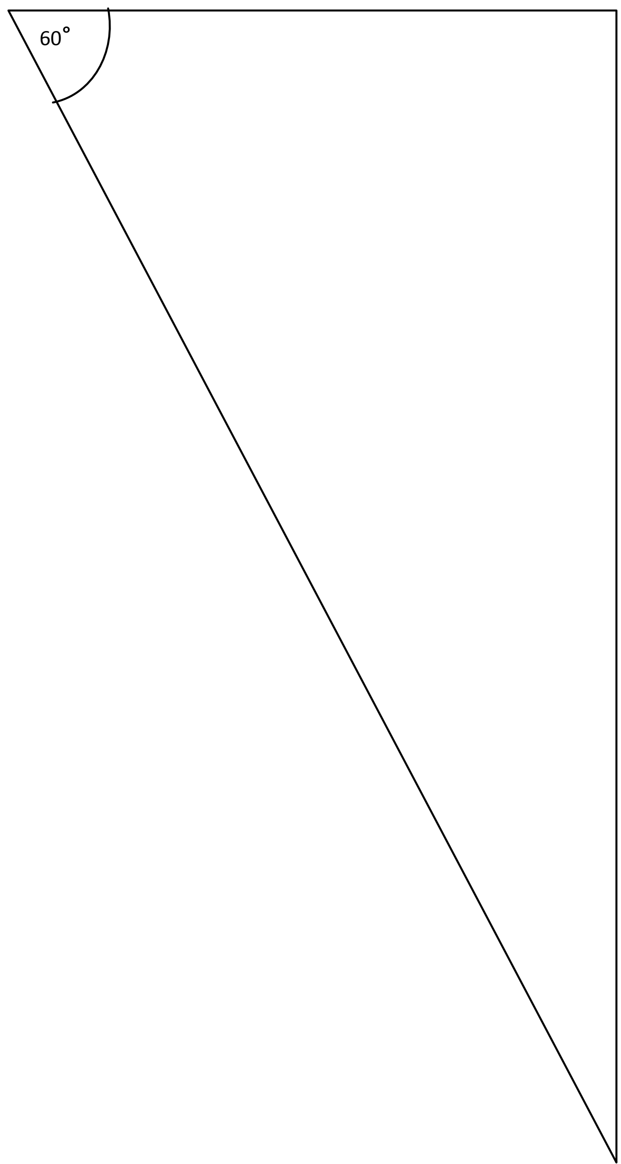


2. On the top of the box, measure in 1.5 inches and make a mark.	
3. Using the 90 degree edge of the tri-angle...draw a guideline across the width of the box.	 
4. Cut along the guideline, then unfold the flaps you just made. Cut off the flaps.	 

5. Place the short edge of the triangle along the top edge of the box and draw a 3 inch line towards the center of the box: Using those lines as guides...cut two 3" slits on both sides of the cereal box as shown.	 
6. Flip the box over and do the same thing on the other side.	
7. Slide the CD into the slits as shown.	
8. Now you're going to cut a rectangle out on the opposite long side of the box as shown. The rectangle should be the width of the box and one inch high. The top of the rectangle should be about half an inch from the top of the box. To cut it, first poke a hole towards the top of the box with a pen. Then, cut a rectangle using the hole as a starting point.	  
9. Take enough aluminum foil to cover the hole and fold it in half. place the creased side towards the middle of the hole and tape it in place.	
10. Take a second piece of foil and cover the bottom half of the hole. You want to leave a gap between the two pieces of foil. This gap should be between .4 and 1mm. Too wide and the spectra gets blurry. Too narrow then not enough light gets in.	
11. Tape the top of the box closed.	
12. Point the slit at a bright light bulb, and look into the square hole. You should see something like the picture. Explore light by looking at other light sources.	

Activity 1-2: Making Observations of Spectra

60° Template



Activity 1-2: Making Observations of Spectra

STUDENT

Spectrum Observation Notes

Student Name:___________________

SAFETY: DO NOT LOOK DIRECTLY AT THE SUN.

Point your spectrometer to a white wall in sunshine or at some clouds instead.

Building Background:

1. Point the spectroscope towards a fluorescent light source. Observe and record your observations:

2. Point the spectroscope towards an incandescent light source. Observe and record your observations:

3. What differences did you observe between the spectra from a fluorescent light versus an incandescent light?

4. Why do you think that the different lights had different spectra?

Making Predictions:

Use your colored filters to make observations with your spectroscope.

5. Predict your findings with an hypothesis statement:

a. "If I look at ______________ color with my spectroscope, the ______________ colors will shine through."

b. "If I look at ______________ color with my spectroscope, the ______________ colors will shine through."

c. "If I look at ______________ color with my spectroscope, the ______________ colors will shine through."

d. "If I look at ______________ color with my spectroscope, the ______________ colors will shine through."

Activity 1-2: Making Observations of Spectra

STUDENT

Student Name:________________________________

Spectrum Observation Notes

Collecting Data:

Make your observations and record your results. Do not change your original hypotheses.

Color Filter	Colors Visible	Colors Not Visible

Making Conclusions:

1. **What is a spectrum? How did your class create one?**

2. **How did the filters affect the spectrum of light you observed?**

3. **Are there parts of the spectrum that humans can't see? Which parts of the spectrum can our eyes detect?**

4. **In what way could looking at objects in different colors or frequencies give us useful information?**

Activity 1-3: Fingerprints of Rocks

Overview

In this 20-minute activity, students will discover the unique properties of fingerprints and how this property relates to the spectral signature of rocks. In this lesson, students develop familiarity with tools used in the scientific process: comparison, observation, description and communication. This introductory activity provides the background to prepare students for spectral analyses as a means of identifying rocks and minerals by their key properties.

Learning Outcomes

The student will:

- Observe similarities and differences in fingerprints.
- Describe their observations.
- Classify their observations and results.

Key Concepts

- Characteristics found in fingerprints may be similar, and classified by their patterns.
- Fingerprints can be used to identify a person using comparative analyses.
- All matter, such as rocks and minerals, possess observable and measureable properties, but no two are identical, similar to fingerprints.

Materials (For each group of 3 to 5 students)

- Ink pad
- Baby wipes or access to a sink and soap
- Copy of Student Fingerprint Data Sheet
- Index Card (per person)
- Ruler

The Activity

1. **Pose the following questions to your students, "How are we "unique" from one another? Which of these properties can be measured or quantified? What tools does the government use to identify and track people of interest?"** Begin a discussion on ways to identify people. Responses may include appearance, name, photo identification, signatures, and fingerprints.
2. **Show the class a picture of a fingerprint. Ask students to make observations (qualitative and quantitative) of these prints. Also, ask about the ways fingerprints are used? What other technologies are used, like fingerprints, to give information?** (DNA sequences, barcodes, etc.)
3. **Tell the class that they will model the process of collecting fingerprints. Divide the class into groups of three to five people per group, and give each group a fingerprint worksheet, an ink pad, and a means of cleaning their hands.** Instruct the students to take each other's fingerprints (one fingerprint per student) on the handout using the ink pads. Ask the students to press firmly to get a clear print.

Observing

Lead each group into a discussion comparing their fingerprints.

1. What do you observe about the fingerprints you just collected? List qualitative and quantitative observations.
2. What are some similarities in the fingerprints? What are some differences?

Classifying

Invite the students to identify at least two characteristics of the fingerprints, and to classify the fingerprints into categories based on those characteristics.

1. Students classify characteristics and record their data on the student handout.

Sharing Explanations

Invite the students to share their reasoning.

1. Students should describe general fingerprint patterns such as whorl, arch, and loops.

Identifying and Recording

Have students create a Finger Print Card on an index card of their prints or use the Finger Print Data Sheet. Students should use opposing sides of the card for each hand. Under their prints, they should quantitatively and qualitatively describe their fingerprints in paragraph form and in data tables. Students should also label their prints. [DO NOT have them write their names on the card!]

1. Students classify characteristics and record their data on the student handout.

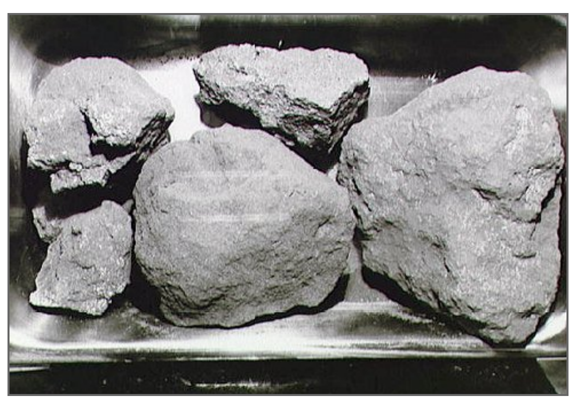
Class Discussion

Lead a large group discussion comparing the finding of the characteristics and categories of fingerprints. Use the discussion as a lead-in to how rocks have their own "fingerprints".

1. View the images of rocks. What do you observe? How may we tell one from the other?
2. Discuss that many of the rocks on the surface of the Moon may look similar, but they contain different minerals or amounts of minerals. Engage students in a brainstorm about how we can observe the Moon rocks if we cannot take a trip to get samples.

How might we identify the minerals that make up lunar rocks from a distance (or remotely)?

Tell students that each mineral reflects very specific amounts of the different wavelengths of electromagnetic radiation, so each mineral has a characteristic spectrum of reflected light- giving it a spectral "fingerprint".



Moon rocks. Image: Courtesy NASA

Extension

Math Connections

1. Collect student predictions as a large group as to how many fingerprints have arches, loops, or whorls. Ask students to explain their predictions.
   a. Why do you think there will be more whorls than arches? Explain your reasoning.

2. Create a prediction chart on the board. Create a graph of predictions for each category: bar or pie. Fractions and/or percentages can be included if students have a strong background with fractions and percentages.

Record student data collected by the groups:

- How many fingerprints arch?
- How many fingerprints have loops?
- How many whorls?

3. Compare the two graphs. Lead a discussion on the results.
   a. What do you observe?
   b. What conclusions can you make from the data? Explain your reasoning.

Activity 1-3: Fingerprint of Rocks

STUDENT

Student Fingerprint Data Sheet

1. **In the boxes below, carefully collect a clean fingerprint from the same finger (e.g., index finger or thumb) from each of your team members.** DO NOT write your name by your print!

2. **Observe the different fingerprints and answer the following questions**:
   a. What are some similarities in the prints? What are some differences in the prints?
   b. Classify the fingerprints into categories based on the characteristics and explain your reasoning:

3. Collect and analyze data:
   a. To the right, create a data table using the main features you identified and number of times those features were found in all of the prints above.

Fingerprint Features	#

   b. What was the most common feature?

   c. What was the least common feature?

   d. How might rocks have their own "fingerprints"?

Activity 1-4: Introduction to the ALTA Reflectance Spectrometer

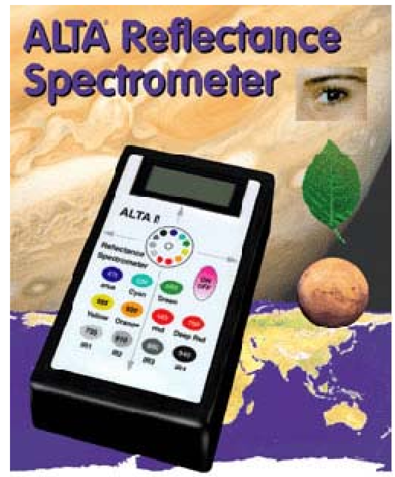
Overview

In this 60-minute activity, students use the ALTA handheld reflectance spectrometer to take readings of different colored objects at different wavelengths, and create a graph of a reflectance spectrum for those objects. Students compare their reflectance spectra graphs and observe that different objects have different spectra, or "fingerprints".

Learning Outcomes

The student will:

- record measurements of the amount of light reflecting from a surface using an ALTA reflectance spectrometer
- construct a graph from the reflectance spectrum data
- compare reflectance spectra
- predict that different objects have their own unique spectra



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

Key Concepts

- The ALTA Reflectance Spectrometer can be used to measure the amount of light that is reflected off of an object at 11 specific wavelengths.
- The data can be used to construct a graph of the reflectance spectrum for an object.
- Each object has its own unique reflectance spectrum, like a fingerprint.
- Scientific investigation often includes the use of technology to gather, analyze, and interpret data.

Materials

- 1 ELMO or document camera (recommended but not necessary)

For each group of three to four students:

- Bag of various and familiar materials for the students to analyze, such as colored construction paper, a variety of fabrics, foam sheets, magazines, etc. Ensure that a variety of materials colors with different hues and lusters with flat surfaces are available.
- 2 sheets of white paper such as copier paper
- 1 Calculator
- 1 copy of Tips on Using the ALTA
- 2 copies of the Reflectance Datasheet
- 2 copies of the Spectrum Graph
- *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. South Carolina 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/*

Preparation

1. Plan to break your class into groups of three to four students each, with one ALTA spectrometer per group.
2. Check each ALTA reflectance spectrometer to make sure that it has a working battery and that numbers appear on the digital display when turned on. NOTE: You may have to hold down the On/Off button for a second or two to turn the unit On or Off.

The Activity

1. Divide the class up into groups of three to four each.
2. Review with your class, the "Fingerprints of Rocks" activity and the similarities and differences observed in their different fingerprints. Have them discuss it briefly within their groups.
3. Explain that materials also have a type of 'fingerprint'; therefore each material has a characteristic "reflectance spectrum." Scientists can use this information from a distance, such as from orbit around a planet, to identify substances, such as minerals.
4. Introduce students to an ALTA spectrometer, and let the students know that they will use these instruments to gather the reflectance spectra of different objects.
    - The ALTA spectrometer emits energy and measures how much of that energy is reflected back (in mV). Using a mathematical formula, we can identify what the percent <u>reflectance</u> is. S<u>even bands in the visible</u> portion of the spectrum and <u>two bands in the infrared</u> portion of the spectrum are measured by the ALTA spectrometer. Show students that the back of the instrument has a round hole where light passes, with buttons in the front that go with each of the bands (and light emitting diodes, or LED, bulbs).
5. Model for students how to activate the ALTA spectrometer using an ELMO or document camera. Show students the main features of the spectrometer. Some of the spectrometers may turn themselves off immediately; the students will need to toggle with the on/off button until it stays on. If there is no reading on the digital display, the spectrometer is off. You may have to check the battery.
    - **What do the students see on the back of the spectrometer?**

      [There is a circle of 11 little lights LED's (light-emitting diodes) with another similar-looking object in the middle.]
    - **What do the students see on the front of the spectrometer?**
      [There are 11 buttons, in addition to the On/Off button, each with a different color and a different numberCthat color's wavelength.]
6. Distribute the spectrometers after reviewing classroom expectations. Direct the students to turn the instrument on and experiment with pushing the different buttons on the front, and observing the LED's on the back. If they are having difficulty pushing the buttons hard enough or holding down the buttons, recommend that they use a pencil eraser to push the buttons. (Caution: Please make sure that you do not touch any of the bulbs because it could affect the measurements and damage the instrument. Please handle the instruments with care because they are very fragile.)
    - **What do the students see when they push the "blue" button after turning it on?**

      [The blue led on the back lights up and remains lit while you hold the button down.]

- **What happens when they push one of the "IR" buttons on the front?**

  [One of the infrared LED's on the back "lights up" but at a wavelength our eyes cannot see.]

7. Ask the students to observe the numbers on the front.
   - **What do the numbers do when the students hold the bottom of the ALTA over a desk or book? What happens when students hold it up in the air?**
     [The numbers change and increase with increased brightness, until they overload the detector at which point the ALTA gives a "1".]
   - **What do the numbers do when the students cover up the back?**
     [They go down.]

8. Direct students to place the ALTA flat onto a colorful surface (such as a book, a coat, etc.) and push two or three of the buttons (one at a time) and observe the numbers. Ask them to place the ALTA onto a white piece of paper and repeat the same buttons, comparing the numbers.
   - **How were the numbers different?**
     [The numbers should be much higher for the white piece of paper.]
   - **What could the reflectance spectrometer be measuring?**
     [Answers may include "color" or "brightness" or "light;" a better answer is the amount of light that is reflecting off of an object.]
   - **Which part of the ALTA could be taking the measurements?**
     [The object in the center of the LED's on the back is a detector, measuring the amount of light that is entering it.]

9. Share with the students that the light detector measures the amount of light it receives, and displays that amount as a number on the front of the ALTA, measured as voltage.
   - **Why are the numbers higher when the ALTA is held up in the air?**
     [Light from the room is entering the detector. This may include fluorescent lights, sun light and reflected light]
   - **Why are the numbers so low when the ALTA is completely covered up?**
     [No light is getting into the detector. "Dark Voltage" is the number that each ALTA reads when it is receiving absolutely no light or the reading given when the instrument is placed over a material, without a button being pressed. It's the random energy entering into the sensor. This value will have to be subtracted from future values.]
   - **Do the ALTAs have the same numbers for the "Dark Voltage"?**
     [Each ALTA detector will be slightly different, producing different numbers.]
   - **Why do different colored light bulbs turn on when you press the buttons on the front?**
     [The different colors can emit specific wavelengths of light, a unique number value, which will reflect off of a surface and into the detector, so that we can measure how well an object reflects that particular wavelength of light. The values of energy that is being reflected back at the sensor are measured in millivolts (mV).]
   - **Why are the numbers higher for a white sheet of paper than a dark object?**
     [More light is bouncing off of the white paper and into the detector. Light colors reflect, dark colors absorb.]

- **Why do we have to have a “white paper reading”?**

  [Measuring percentages requires that we know how much energy would be reflected at 100% reflectance. Therefore, we use a small stack of plain white paper so it reflects almost all of the energy back to the instrument and gives us a reference value.]

10. Invite the groups to collect spectra for different objects.
    a. To do this, they will collect readings of different wavelengths of light reflecting off of two objects, and then graph the data.
    b. Give each student a blank copy of the Tips on Using the ALTA, two Reflectance Datasheets, a calculator, and two Spectrum Graphs and ask them to write their names and a description of their material.

11. Model with your students how to calibrate the instrument and document your standard on the datasheet.
    a. Discuss the word “calibration” (to adjust an instrument against a standard to ensure precision) and the need to perform this standardization test.
    b. One way to measure how much light of each wavelength is being reflected is to measure the percentage (%) of light reflected, by comparing the light reflected from an object to the light reflected from a bright standard material, such as white paper.
    c. Direct the students, working in groups, to place their ALTA face-down on two stacked sheets of blank white paper and press the different wavelengths (colors) one at a time. All of the students in each group should record the numbers for each of the 11 wavelengths on their Reflectance Datasheets in the “white paper” column. Note: if the readings are changing (dropping) rapidly, direct the students to record the first high number.

12. Students should also record the “Dark Voltage” (the number displayed when none of the buttons are being pushed and the ALTA’s detector is completely covered).

Gathering Data

1. Next, the groups should place the ALTA directly onto the materials they are analyzing, and push the different wavelengths (colors) one at a time, and record the number for each of the 11 frequencies on their Reflectance Datasheet. Students in the groups can share roles: the group data recorder, the ALTA user, the recorder, and the calculator.
2. Using the calculators, have the groups follow the instructions on their Reflectance Datasheet to determine the percentage (%) of reflectance for the different materials at each of the 11 frequencies. They should record these values to two decimal places.

Analysis

1. The students should fill out their Spectrum Graphs with the final numbers from their Reflectance Datasheet.
2. Discuss graphing as a class and model one example of a spectrum graph if the students have limited graphing experiences.

- **Where is the x-axis for the graphs? What does it indicate?**
  [The horizontal x-axis indicates different frequencies of light.]
- **Where is the y-axis for the graphs? What does it indicate?**
  [The vertical y-axis indicates the percentage of light reflected off of their object.]
- **Do the students' graphs have any peaks or high points? If so, at what wavelengths? What does that tell them about the objects?**
  [Objects reflect more of the light at those wavelengths; red objects will reflect more red and orange light, for instance.]
- **Do the students' graphs have any 'valleys' or low points? If so, what does that tell them about the objects?**
  [The objects absorb most of the light at those wavelengths.]
- **Are there any strange graphs with unusual numbers (close to 0 or higher than 1)? What are possible sources of error?**
  [Buttons may not have been held down during the readings, too much light might enter the ALTA, the battery may be running low, the calculations may have been incorrect.]

Sharing Conclusions

Invite each group (one at a time) to present their results, then as a class discuss the similarities and differences in their spectra.

- **Do any materials have identical spectra or does each have a different spectrum?**
  [Although some of the spectra may be similar, different materials should have different spectra. However, with only 11 data points, the ALTA cannot always show these differences.]

Class Discussion

Invite the students to reflect on the activity and analyze their results.

- **What do the students think the point of this activity was?**
  [Answers could include taking data and learning to use the ALTA, or may even include learning about the spectrum and learning about light.]
- **Which aspects of science did your students do today?**
  [Answers could include using technology, collecting data, putting those data into a readable format of a graph, making predictions and testing predictions.]
- **How did each student's spectrum compare to the others in his or her group? How did the different groups' spectra compare to each other?**
  [Different objects have different spectral "fingerprints;" each object had a unique spectral graph.]
- **What does the ALTA record? How might this be useful?**
  [The ALTA measures the amount of light that is reflected off of an object, for different wavelengths of light. Scientists could use the reflectance spectrum to identify a mysterious substance.]
- **How is the ALTA similar to the human eye?**
  [Both the human eye and the ALTA can measure the amount of light we see, at different wavelengths or colors of light.]

- **In what ways can the ALTA detect more than we can?**
  [It can detect four different infrared wavelengths.]
- **How might the ALTA be improved to collect more data about the spectrum of an object?**
  [More wavelengths could be could be added.]
- **How might spectrometers on spacecraft help us learn about other planets?**
  [It is much easier to fly an instrument like a spectrometer past a planet than landing on that planet. Spectrometers can take reflectance spectra of those planets to help us identify their makeup.]

Activity 1-4: Introduction to the ALTA Reflectance Spectrometer

Student Name:_______________

Team Members: ____________________ ____________________

____________________ ____________________

Material Description: ______________________________

Dark Voltage Constant: ______________

Color	Wavelength in Nano-meters	White Paper Reading	Dark Voltage Constant	White Paper Reading - Dark Voltage (A)		Sample Reading	Dark Voltage Constant	Sample - Dark Voltage (B)		Sample / White Paper	(B ÷ A) x 100 or *([Sample - Dark Voltage] ÷ [White - Dark V])x 100 = % Reflectance*
Blue	470										
Cyan	525		same				same				
Green	560		same				same				
Yellow	585		same				same				
Orange	600		same				same				
Red	645		same				same				
Deep Red	700		same				same				
Infrared 1	735		same				same				
Infrared 2	810		same				same				
Infrared 3	880		same				same				
Infrared 4	940		same				same				

Activity 1-5: Spectrometers in Action

Overview

In this 30-minute activity, students collect reflectance spectra and discover that objects which appear similar can have different spectra or "fingerprints". Students discuss the advantages of a high-resolution spectrum to identify objects, and learn about the Moon Mineralogy Mapper / Chandrayaan-1 mission.

Learning Outcomes

The student will:

- collect data and graph the spectra of two different substances that look alike, using the ALTA spectrometer.
- compare the different spectra.
- infer the potential uses of reflectance data.

Key Concepts

- Each object has a unique reflectance spectrum.
- Data from a reflectance spectrum can be used by scientists to identify objects remotely.
- The Moon Mineralogy Mapper will be used remotely by scientists to analyze rocks on the surface of the Moon.
- Scientific investigation includes observations, gathering, analyzing, and interpreting data, and using technology to gather data.

Materials

For classroom:

- ELMO or document camera, not required
- Student Behavior Checklist
- Collaborative Group Rubric

For each group of three-four students:

- 1 copy of the Reflectance Data Sheet, from Activity 1-4: Introduction to the ALTA Reflectance Spectrometer
- 1 copy of the Spectrum Graph
- 1/3 sheet of white construction paper
- 1/3 sheet of black construction paper [Note: do not use black cardstock; it may not work for this experiment.]
- 1 black marker
- 1 ALTA reflectance spectrometer
- 1 calculator
- Scissors
- Zip-seal bag
- Ruler

Materials list is continued on next page.

z

For each student:

- To hold all students equally accountable in their collaborative groups, it is recommended that each child receive a duplexed copy of the Reflectance Data Sheet and the Spectrum Graph to be turned in for a grade.

Preparation

1. Test your black construction paper ahead of time; look at the infrared reflectance raw numbers. If they are lower than 200, you will need a different type of construction paper. Most types of black construction paper yield numbers higher than 800 for infrared voltages.
2. Cut one small square, about 5 by 5 centimeters (2 by 2 inches), out of black construction paper. Draw a similar-sized square using black marker on white construction paper. Fill it in and cut the square out.
3. Place both squares in zip-seal bag for future use.
4. Ensure each ALTA reflectance spectrometer's batteries are working properly.

Engaging Prior Knowledge

1. Holding up the two black squares you prepared in advance, ask your students to identify the difference between the pieces of paper.
   - **a. Can your students at the back of the room tell the difference? What about the students at the front of the room?**
   - b. **Are there times when scientists would like to examine something that is too far away for them to touch? Can the students name examples?** [Scientists might want to examine moons, planets, and stars to learn more about them.]

The Activity

1. Explain your expectations. Explain to the group that ½ of the class will measure a 5cm x 5cm square on a white piece of paper, color it black, then cut it out. The remainder will measure the same size on a black piece of construction paper and cut it out. (NOTE: If time is an issue, consider doing Steps 3 and 4 in advance.)
2. After you describe your expectations, give each group an ALTA, a Reflectance Worksheet, a Spectrum Graph, and a calculator.
3. Divide your class into groups of three-four students each and distribute the materials to your groups.

Hypothesize

1. Ask the groups to predict what the spectrum of the black squares will look like.
   - a. **Will the spectrum of the construction paper that has been colored black with marker will look similar or different to the black construction paper?** [Accept all answers.]
   - b. **Based on our what we learned from Activity 1-4, did we learn that dark materials have a high or low reflectance value?** [Students may suggest that there will be low numbers—low reflectance—for most wavelengths.]

c. Guide students through creating two hypotheses statements, one for each type of black square. Encourage students to make their own hypothesis, rather than agreeing with others in the class.

"If the paper is ________________________, then the reflectance value will be ________________."

"If the paper is ________________________, then the reflectance value will be ________________."

Gathering Data

1. Direct students to divide the tasks among group members One person will be needed to use the reflectance spectrometer, one to record the data on the datasheet, one to compute the numbers (using the calculator), and one to take the lead on graphing the results. NOTE: We recommend that all students be responsible for submitting their own datasheet and graph. This holds all children accountable.
2. Quickly review how to operate the instrument, collect data, as well as briefly discuss the "dark voltage" and the role of a standard
3. Next, monitor the groups as they collect reflectance data from plain white paper with their ALTA, as in the last activity, to have a standard for comparison. Students should also record the dark voltage for their ALTA.
4. Instruct teams to collect the data for their black squares and fill out their datasheets.
5. For early finishers, have students repeat these steps with the other square in their bag. Have students perform calculations and graph (See Analysis Section below) as homework.

Analysis

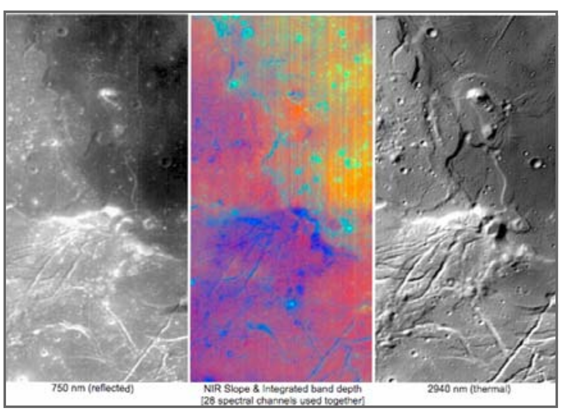
1. As groups complete their data collection, instruct each team to graph the reflectance data for either the black construction paper square or the black-colored white construction paper.
2. Ask the students to decide how to best compare the spectra to see if they are alike or different.

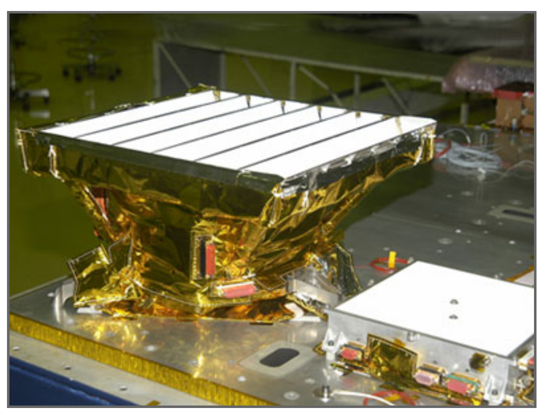
Class Discussion

1. Show the different groups' spectra on the ELMO or document camera. As a class, invite the students to share their results and analyze their conclusions.
   - **Are the spectra similar or different? If there are differences, what can they be attributed to?** [The spectra with black marker are much lower in the infrared range than the black construction paper. The chemicals in the black marker are darker in infrared.]
   - **Can two substances that look alike have different spectra?** [Yes they can, particularly at wavelengths that our eyes can't see. Materials made of different chemicals will absorb different wavelengths of light. Objects with identical chemical makeup have identical spectra.]
   - **What do the students think the point of this activity was?** [Answers could include that objects which look alike to us can still have very different spectral measurements.]

- **Which aspects of science did your students do today?**
  [Answers could include making a discovery, using technology, taking data, making predictions and testing predictions.]
- **We discovered that different materials have different spectra, even when they look alike. How might this be a useful tool on the Moon or Mars?**
  [Scientists can use this to help identify different materials, like rocks, minerals, and resources.]

2. Compare the range of wavelengths visible to humans to the wavelengths taken by the ALTA spectrometer.
    - **What colors do most humans see? How many different shades of color can people see?**
      [People see visible light. The cones in human eyes can detect red, green and blue, but our brains use that information to detect differences between hundreds to thousands of different shades of color.]
    - **In what ways can the ALTA detect more than our own spectrometers—our eyes—can see?**
      [It can measure four different infrared wavelengths.]
    - **In what ways is the ALTA limited? How could it collect more information, and why would those changes be useful?**
      [The ALTA can only give us a spectrum with 11 data points - 11 wavelengths. More wavelengths would give us more details, and make it easier for scientists to identify specific materials.
    - **How might spectrometers on spacecraft help us learn about other planets?**
      [Spectrometers could take reflectance spectra of materials on those planets to help us identify them.]
3. Describe the Moon Mineralogy Mapper (M3), a spectrometer on Chandrayaan-1 that recently orbited the Moon and to collect a detailed set of spectra (with 261 different measured wavelengths, covering all of the visible spectrum and the near-infrared wavelengths) of the Moon's surface. Ask your students how these data will would provide more information about the Moon.
    - **How would a more detailed spectral map help scientists?**
      [It would make it easier to identify the types of rocks and minerals on the Moon.]





TIPS for Using the ALTA Reflectance Spectrometer

1. **You need to HOLD DOWN the buttons to take readings.**
2. **What happens if you place the ALTA down flat and don't turn on any of the lights?**
    - You still have a number. The ALTA's photodetector and electronics do not go to zero. This is the "Dark Voltage" and should be recorded on your datasheet.
3. **You need a large, somewhat flat surface for more accurate readings.** Try not to let outside light into the detector.
4. **Begin with taking the data for two stacked pieces of white paper.**
5. **If the numbers keep changing while you are holding the button, pick the first high number.**
6. **Work in groups of three: one to operate the instrument, one to record the data, and the third to do the calculations.**

Module 2: Analysis of Lunar Features and Their Formation

In this module, students will investigate the Moon's geologic history by modeling the process of regolith formation and explore the roles of impact cratering, volcanic eruptions, and lava layering on the Moon. Additionally, they will continue their exploration of the properties of the Moon and will create their own hypotheses of the Moon's geological history. Finally, the students will assess the role that the Moon Mineralogy Mapper instrument plays in testing scientists' current understanding of the Moon's composition and geologic history.

Activity 2-1: Regolith Formation (30 minutes)

Students model the process of regolith formation and compare the process at work on Earth and on the Moon.

Activity 2-2: Impact Craters (60 minutes)

Students model factors affecting the formation of craters and ejecta on the Moon using everyday materials. They collect data on their observations and make inferences based on these data.

Activity 2-3: Lava Layering (40 minutes)

Students explore the stratigraphy of lava flows produced by multiple eruptions on the Moon. They observe patterns associated with these eruptions and use their observations to make conclusions about these processes occurring throughout the Moon's history.

Activity 2-1: Regolith Formation

Overview

In this activity, students model the process of regolith formation and compare the process at work on Earth versus the Moon.

Learning Objectives

The student will:

- Model the formation of regolith on the Moon
- Model the formation of regolith on Earth

Key Concepts

- Soil and regolith are not the same thing
- Soil is comprised of organic matter and so is non-existent on the moon
- Weathering processes create regolith on Earth
- Meteoric impacts create regolith on the Moon
- Moon's regolith is not disrupted by the most of the processes occurring on Earth due to the Moon's lack of an atmosphere
- Both the Moon and the Earth are at risk of future meteoric impacts

Materials

For each team of two to three students

- toasted white bread or light-colored crackers/cookies
- toasted golden wheat or dark-colored crackers/cookies
- bread
- small pan
- sand paper, nail file, or
- edge of ruler
- ice cube with sand inside
- tray
- fist-size rock

Preparation

1. Review and prepare materials listed on the student sheet.
2. Toast, crackers, or brittle cookies can be used in this activity. Toast is the least expensive but most time consuming choice. In any case, students will need two different colors of materials for procedure C; for example, vanilla and chocolate graham crackers. Invariably, students get hungry at the sight of food, so you may want to reserve some clean materials for consumption or use something other than a rock for the projectile.

Preparation continued on next page.

Preparation continued

3. To prepare bread: use a conventional oven, toaster, or sun-dry method to produce the most crisp and brittle toast. Toast one loaf of white bread and one loaf of golden wheat or rye bread. Note that whole wheat bread does not get brittle enough.
4. For procedure B, fill margarine containers (one for each group) with water and sand, then freeze. The more sand, the better the simulation of a real rock.
5. For procedure C, do not use glass pans. Large plastic tubs are preferred for this procedure. Recyclable aluminum roasting pans or shallow cardboard boxes work as well.

The Activity

1. Divide the students into cooperative groups and distribute materials.
2. Discuss the definition of regolith. Have students guess how regolith is formed on Earth and on the Moon. Ask students for justification.
3. If sand paper or nail files are not available, then students can use the edge of a ruler to illustrate the effects of sandblasting in procedure A. Caution students to use a collection tray in the sink in procedure B to avoid sand-clogged drains. An alternative to using a faucet is to have the students pour a steady stream of water from beakers onto their ice cube rocks to illustrate the effects of falling water.
4. Have students guess individually, then discuss in groups, what the surface of the Moon is like (hard rocks, fine dust, large boulders). Ask students for justification of their answers.
5. Refer to a photograph of an astronaut's bootprint on the surface of the Moon (included below). Give students the opportunity to change or confirm their guesses.
6. Procedure C is best done outside. Drop the rock from waist high. Sometimes the impacting rock causes the pan to bounce so you may want to secure the pan to the ground with tape. Students should stand back as a safety precaution.

Analysis

1. After participating in the activity, have the whole class compare and contrast regolith formation and ask each small group to verify their original guesses.

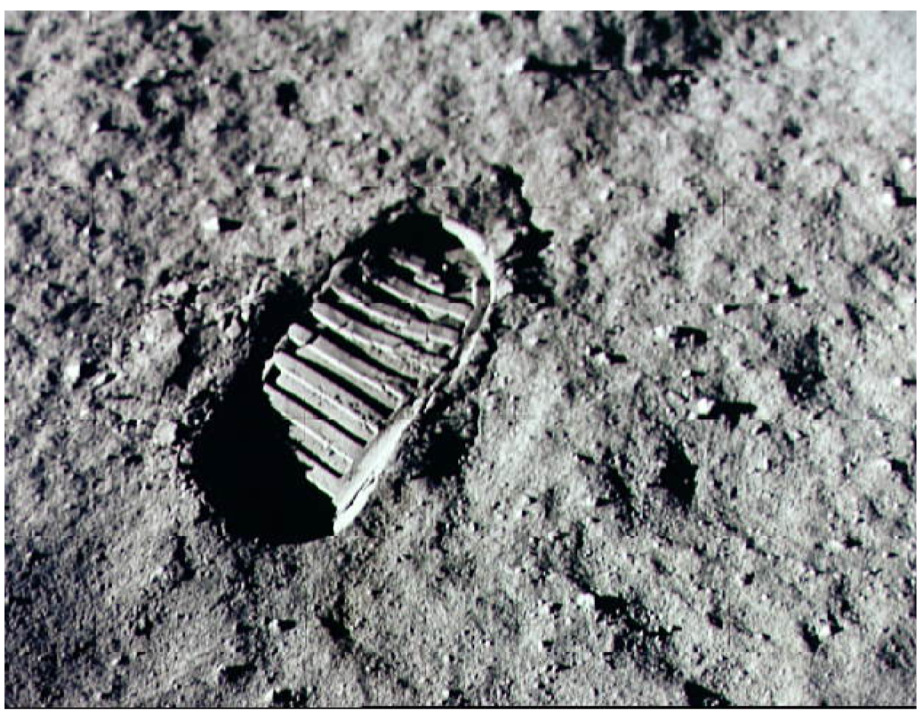


Image courtesy of NASA—Apollo 11 Bootprint

Background

The loose, fragmental material on the Moon's surface is called **regolith**. This regolith, a product of **meteoritic bombardment**, is the debris thrown out of the **impact craters**. The composition and texture of the lunar regolith varies from place to place depending on the **rock** types impacted. Generally, the older the surface, the thicker the regolith. The regolith on young **maria** may be only 2 meters thick; whereas, it is perhaps 20 meters thick in the older lunar **highlands**.

By contrast, regolith on Earth is a product of **weathering**. Weathering encompasses all the processes that cause rocks to fragment, crack, crumble, or decay. These processes can be *physical* (such as freezing water causing rocks to crack), *chemical* (such as decaying of minerals in water or acids), and *biological* (such as plant roots widening cracks in rocks). The rock debris caused by weathering can then be loosened and carried away by **erosional** agents -- *running water* (fast-flowing rivers, rain, ocean waves), *high-speed wind* (by itself or sandblasting), and *ice* (glaciers).

In this activity, procedures A and B challenge the students to determine the effects of wind, sandblasting, and water on regolith formation and deposition on Earth. This is followed by procedure C in which the students simulate regolith formation on the Moon by meteoritic bombardment.

Regolith formation

Procedure A: What effect does wind have on regolith formation?

1. Imagine that the piece of toasted bread is a rock on Earth. Your hand is the wind. The sand paper is wind carrying particles of sand.
2. Predict the effects of rubbing just your hand and then the sand paper across the toasted bread.
3. Now try it. Rub your hand across the **toasted bread;** observe the bread and the pieces which fall from it onto the **pan**.
   Observations:
4. This time rub the **sand paper** across the toasted bread and observe the bread and the pieces which fall from it onto the pan.
   Observations:
5. How was the effect different?
6. How is this activity related to processes on Earth?

Procedure B: What effect does falling or fast flowing water have on regolith formation?

1. How was the effect different?
2. How is this activity related to processes on Earth?
3. Imagine that the **ice cube with sand** is a rock.
   - Place this ice cube on a collection tray beneath the **water faucet**.
   - Adjust the water flow from the faucet so a medium stream hits the ice cube.
   - Observe what happens to the ice cube and the remaining particles.

4. What happened to the rock (ice cube)?

5. Describe the particles which remain.

Procedure C: Regolith Formation on the Moon

1. Do you think regolith on the Moon is formed in the same manner as on Earth? Why or why not?

Now we will investigate the effects of meteoritic bombardment on regolith formation.

2. In a small **pan**, place 2 slices of **toasted white bread** onto 3 slices of **toasted golden wheat bread**. This represents the Moon's crust.
3. Drop a **rock** onto the layers of toasted bread twice.

   Describe the bread slices and the crumbs.

4. Drop the rock 20 times onto the layers of toasted bread.

   Describe the bread slices and the crumbs.

5. Which crumbs can be seen at the surface? Why?

6. How does the thickness of the crumb layers compare after 2 hits and after 20 more hits?

Activity 2-2: Impact Craters

Overview

In this lesson, students will determine the factors affecting the appearance of impact craters and ejecta. Marbles or other spheres such as steel shot, ball bearings, golf, or wooden balls are used as impactors dropped from a series of heights onto a prepared "lunar surface."

Learning Objectives

The student will:

- Determine the factors affecting the formation of impact craters and ejecta

Key Concepts

- The Moon has been bombarded by meteorites in the past
- The meteorites have been various sizes and shapes, and have impacted at different speeds and angles
- The impacts have affected the appearance of the moon

Materials

For each team of two to three students

- Sieve, sifter, or colander
- Balance
- 3 impactors (marbles or other spheres)
- "Data Sheet" for each impactor
- 1 pan
- Meter stick
- Depression
- Lunar surface materials:
  - Flour
  - Cinnamon
  - Cocoa
- Ruler, plastic with middle
- Protractor
- Graph paper

Preparation

1. Review and prepare materials listed on the student sheet.
2. In this activity, marbles or other spheres such as steel shot, ball bearings, golf, or wooden balls are used as impactors dropped from a series of heights onto a prepared "lunar surface."
3. Using impactors of different mass dropped from the same height will allow students to study the relationship of the mass of the impactor to the crater size. Dropping impactors from different heights will allow students to study the relationship of velocity of the impactor to crater size.
4. The following materials work well as a base for the "lunar surface" topped with a dusting of cinnamon, cocoa, or other material in a contrasting color:
   - All purpose flour—reusable in this activity and keeps well in a covered container
   - Corn meal—reusable in this activity but probably not recyclable. Keeps only in freezer in airtight container.

- Baking soda—It can be recycled for use in the lava layer activity or for many other science activities. Reusable in this activity, even if colored, by adding a clean layer of new white baking soda on top. Keeps indefinitely in a covered container. Baking soda mixed (1:1) with table salt also works
- Sand and corn starch—Mixed (1:1), sand must be very dry. Keeps only in freezer in airtight container.
- Cinnamon or cocoa—Sift on top using a sieve, screen, or colander. A contrasting color to the base materials gives striking results.
- Pans should be plastic, aluminum, or cardboard. Do not use glass. They should be at least 7.5 cm deep. Basic 10"x12" aluminum dishpans or plastic tubs work fine, but the larger the better to avoid misses. Also, a larger pan may allow students to drop more marbles before having to resurface the target materials.
- A reproducible student “Data Chart” is included; students will need a separate chart for each impactor used in the activity.

The Activity

1. Begin by looking at craters in photographs of the Moon and asking students their ideas of how craters formed.
2. During this activity, the flour, baking soda, or cinnamon/cocoa may fall onto the floor and the baking soda may even be disbursed into the air. Spread a tarp or dark piece of plastic under the pan(s) to catch ejecta or consider doing the activity outside. Under supervision, students have successfully dropped marbles from second-story balconies. Resurface the pan before a high drop.

3. Since the surface of the moon is not totally smooth, it is acceptable to have a hummocky or uneven surface. You may just shake the pan/tub to “smooth” the surface. The material need not be packed down. Be sure to reapply a fresh dusting of contrast material (cinnamon/cocoa) as needed.. Remind students that better experimental control is achieved with consistent handling of the materials. For instance, cratering results may vary if the material is packed down for some trials and not for others.
4. Allow some practice time for dropping marbles and resurfacing the materials in the pan before actually recording data.
5. Because of the low velocity of the marbles compared with the velocity of real impactors, the experimental impact craters may not have raised rims. Central uplifts and terraced walls will be absent.
6. The higher the drop height, the greater the velocity of the marble, so a larger crater will be made and the ejecta will spread out farther.
7. If the impactor were dropped from 6 meters, then the crater would be larger. The students need to extrapolate the graph out far enough to read the predicted crater diameter.

Analysis

1. Have the students sketch their impacts.
2. Have the students use their data sheets, where they measured crater depth (rim to floor), crater diameter (rim to rim), and drop height to analyze the impacts of drop height and speed to crater size.
3. Have the class compare and contrast their hypotheses on those things that affect the appearance of craters and ejecta.

Extensions

1. As a grand finale for your students, demonstrate a more forceful impact using a slingshot.
2. What would happen if you change the angle of impact? How could this be tested? Try it! Do the results support your hypothesis? If the angle of impact is changed, then the rays will be concentrated and longer in the direction of impact. A more horizontal impact angle produces a more skewed crater shape, or oblique crater.
3. To focus attention on the rays produced during an impact, place a paper bulls-eye target with a central hole on top of a large, flour-filled pan. Students drop a marble through the hole to measure ray lengths and orientations.
4. Use plaster of Paris or wet sand instead of dry materials.
5. Videotape the activity.
6. Some scientists think the extinction of the dinosaurs was caused by massive global climate changes because of a meteorite impact on Earth; some disagree. Summarize the exciting work that has been done at Chicxulub on the Yucatan coast of Mexico. (**http://www.jpl.nasa.gov/news/news.php?feature=8**)
7. Some scientists think Earth was hit by an object the size of Mars that caused a large part of Earth to "splash" into space, forming the Moon. Do you agree or disagree? Explain your answer. (**http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question38.html**)

Image courtesy of NASA—Artist's rendering of the Chicxulub crater at the time of impact.

8. Physics students could calculate the velocities of the impactors from various heights. [Answers from heights of 30 cm, 60 cm, 90 cm, and 2 m should, of course, agree with the velocity values shown on the "Impact Craters - Data Chart".]

Background

The circular features so obvious on the Moon's surface are **impact craters** formed when **impactors** smashed into the surface. The explosion and excavation of materials at the impacted site create piles of rock (called **ejecta**) around the circular hole as well as bright streaks of target material (called **rays**) thrown for great distances.

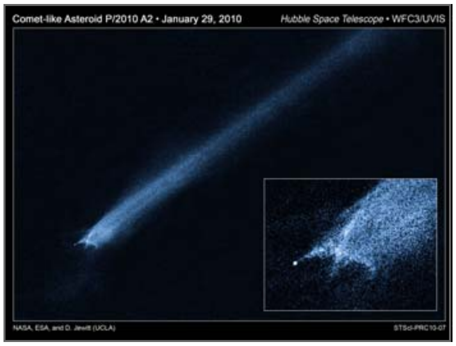


Image courtesy of NASA—Hubble Space Telescope sees suspected asteroid-asteroid collision

Two basic methods forming craters in nature are:

1. Impact of a **projectile** on the surface and
2. Collapse of the top of a **volcano** creating a crater termed *caldera.* By studying all types of craters on Earth, and by creating impact craters in experimental laboratories, geologists concluded that the Moon's craters are impact in origin.

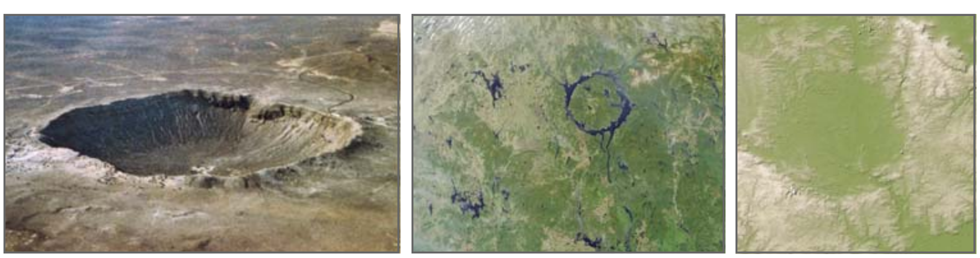
The factors affecting the appearance of impact craters and ejecta are the size and velocity of the impactor, and the geology of the target surface.

Image courtesy of USGS—Crater Lake in Oregon created by the collapse of Mount Mazama Volcano

By recording the number, size, and extent of erosion of craters, **lunar geologists** can determine the ages of different surface units on the Moon and can piece together the geologic history. This technique works because older surfaces are exposed to impacting **meteorites** for a longer period of time than are younger surfaces.

Impact craters are not unique to the Moon. They are found on all the terrestrial planets and on many moons of the outer planets.

On Earth, impact craters are not as easily recognized because of weathering and erosion. Famous impact craters on Earth are Meteor Crater in Arizona, U.S.A.; Manicouagan in Quebec, Canada; Sudbury in Ontario, Canada; Ries Crater in Germany, and Chicxulub on the Yucatan coast in Mexico. Chicxulub is considered by most scientists as the source crater of the catastrophe that led to the extinction of the dinosaurs at the end of the Cretaceous period. An interesting fact about the Chicxulub crater is that you cannot see it. Its circular structure is nearly a kilometer below the surface and was originally identified from magnetic and gravity data.



Images courtesy of NASA Solar System and NASA Earth Observatory—from left to right, respectively, Meteor Crater in Arizona, U.S.A., Manicouagan in Quebec, Canada, and Ries Crater in Germany

Impact Cratering

Procedure

Making an hypothesis

1. After looking at photographs of the Moon, how do you think the craters were formed?

2. What do you think are factors that affect the appearance and size of craters and ejecta?

Preparing a "lunar" test surface

1. Fill a **pan** with **surface material** to a depth of about 2.5 cm. Gently smooth the surface, and then tap the pan to make the materials settle evenly. Do NOT pack it tightly.
2. Sprinkle a fine layer of **cinnamon or cocoa** evenly and completely over the surface. Use a **sieve** or **sifter** for more uniform layering.
3. What does this "lunar" surface look like before testing?

Cratering Process

1. Use the **balance** to measure the mass of each **impactor**. Record the mass on the "**Data Chart**" for this impactor.
2. Drop impactor #1 from a height of 30 cm (~knee height) onto the prepared surface.
3. **Measure** the diameter and depth of the resulting crater.
4. Note the presence of ejecta (rays). Count the rays, measure, and determine the average length of all the rays.
5. Record measurements and any other observations you have about the appearance of the crater on the Data Chart.
6. Repeat steps 2 through 5 for impactor #1, increasing the drop heights to 60 cm (~waist height), 90 cm (~shoulder height), and 2 meters (over the head). Complete the Data Chart for each of these heights. Note that the higher the drop height, the faster the impactor hits the surface.
7. Now repeat steps 1 through 6 for two more impactors. Use a separate Data Chart for each impactor.
8. Compute the average values.

Graphing Your Results

- **Graph #1:** Average crater diameter vs. impactor height or velocity.
- **Graph #2:** Average ejecta (ray) length vs. impactor height or velocity. Note: on the graphs, use different symbols (e.g., dot, triangle, plus, etc.) for different impactors.

Results

STUDENT

1. Is your hypothesis about what affects the formation and size of craters supported by test data? Explain why or why not.

2. What do the data reveal about the relationship between crater size and velocity of impactor?

3. What do the data reveal about the relationship between ejecta (ray) length and velocity of impactor?

4. If the impactor were dropped from 6 meters, would the crater be larger or smaller? How much larger or smaller? (Note: the velocity of the impactor would be 1,084 cm/s.) Explain your answer.

5. Based on the experimental data, describe the appearance of an impact crater.

The size of a crater made during an impact depends not only on the mass and velocity of the impactor, but also on the amount of kinetic energy possessed by the impacting object. Kinetic energy, energy in motion, is described as: KE = 1/2(mv2), where, m = mass and v = velocity. During impact, the kinetic energy of an asteroid is transferred to the target surface, breaking up rock and moving the particles around.

6. How does the kinetic energy of an impacting object relate to crater diameter?

7. Looking at the results in your Data Tables, which is the most important factor controlling the kinetic energy of a projectile, its diameter, its mass, or its velocity?

8. Does this make sense? How do your results compare to the kinetic energy equation?

9. Try plotting crater diameter vs. kinetic energy as Graph #3. The product of mass (in gm) and velocity (in cm/s) squared is a new unit called “erg.”

Impactor #		STUDENT
	Approximate Size	
	Approximate Weight	Student Name: ______________________________ Date: ____________________ Class:______________

		Trial 1	Trial 2	Trial 3	Total	Average
Drop Height = 30 cm Velocity = 242 cm/s	Crater Diameter					
	Crater Depth					
	Average Length of All Rays					
Drop Height = 60 cm Velocity = 343 cm/s	Crater Diameter					
	Crater Depth					
	Average Length of All Rays					
Drop Height = 90 cm Velocity = 420 cm/s	Crater Diameter					
	Crater Depth					
	Average Length of All Rays					
Drop Height = 2 m Velocity = 626 cm/s	Crater Diameter					
	Crater Depth					
	Average Length of All Rays					

Graph Your Results

STUDENT

Activity 3-3: Lava Layering

Overview

The focus of this activity is on the patterns of lava flows produced by multiple eruptions. We use a short cup (or plastic soda cap) to hold the baking soda because we are looking at the flows and not constructing an actual volcano model. Volcanoes, like those with which we are familiar, are not present on the Moon. Three well-known areas on the Moon interpreted as important volcanic complexes are: Aristarchus Plateau, the Marius Hills, and Rumker Hills (both located in Oceanus Procellarum). These areas are characterized by sinuous rilles (interpreted as former lava channels and/or collapsed lava tubes) and numerous domes.

Learning Objectives

- Model the stratigraphy of lava flows produced by multiple eruptions

Key Concepts

- The Moon has experienced volcanic activity with multiple lava flow events
- Meteoric bombardment causes erosion of the regolith which makes interpreting lava flows difficult
- The study of the layering of the rock is called “stratigraphy”
- Younger flows tend to cover older ones and are thus located closer to the surface of the Moon

Materials

For each team of two to three students

- Small paper cups (some cut to 2.5cm in height) or plastic soda caps
- Cafeteria tray or cookie sheet, 1 for each eruption source
- Tape
- Tablespoon
- Baking soda
- Measuring cup
- Vinegar
- Food coloring, 4 colors;
    - for example, red, yellow, blue, green
- Playdough or clay in the same 4 colors as the food coloring
- Plastic knife, string, or dental floss: to slice through the layers
- Student Sheets duplexed

Preparation

- Baking soda-vinegar solutions and playdough are used to model the basaltic lavas.
- Different colors identify different eruption events; this activity calls for 4 colors.
- Students will be asked to observe where the flows traveled and to interpret the resulting stratigraphy.
- Students will be asked to create a map of their lava flows.
- Cover the work area and be prepared for spills!

You may use store-bought play-dough or homemade recipes.

Play Dough (stove-top recipe):

Best texture and lasts for months when refrigerated in an air tight container.

- 2 cups flour
- 1/3 cup oil, scant
- 1 cup salt
- 2 cups cold water
- 4 teaspoons cream of tarter
- food colorings (20 drops more or less)

Make this large batch one color or divide ingredients in half to make 2 colors. You will need 4 colors total. Combine ingredients and cook mixture in a large sauce pan, stirring constantly, until the dough forms a ball. Turn dough out onto a floured surface to cool. Then kneed until smooth and elastic. Cool completely; refrigerate in air tight containers.

Play Dough (no-cooking recipe)"

- 2 cups flour
- 2 Tablespoons oil
- 1 cup salt
- 1 cup cold water
- 6 teaspoons alum or cream of tartar food colorings (as above)

Make this large batch one color or divide ingredients in half to make 2 colors. You will need 4 colors total. Mix ingredients and kneed until smooth and elastic. Store in air tight containers.

In Class

This activity can be done individually or in cooperative teams. Making a vertical cut through the flows reveals, quite dramatically, the stratigraphy of the section.

Background

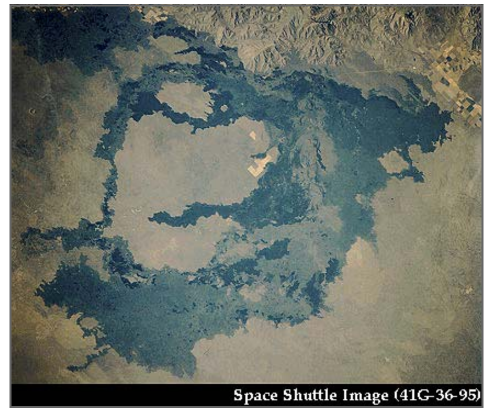


Image courtesy of NASA—Lava field at Craters of the Moon in Idaho; there are over 60 lava flows, a few of which you can discern in the image.

Dark, flat **maria** (layers of **basaltic lava** flows) cover about 16 percent of the Moon's total surface. They are easily seen on a full Moon with the naked eye on clear nights from most backyards. The maria, quite similar to Earth's basalts, generally flowed long distances ultimately flooding low-lying areas such as **impact** basins. Yet, the **eruption sources** for most of the lunar lava flows are difficult to identify. The difficulty in finding source areas results from burial by younger flows and/or erosion from meteoritic bombardment.

Generally, the overall slope of the surface, local topographic relief (small cliffs and depressions), and eruption direction influence the path of lava flows. Detailed maps of the **geology** of the Moon from photographs reveal areas of complicated lava layering. The study of rock layering is called **stratigraphy**.

Image courtesy of NASA—The Galileo spacecraft sent back this image of the moon on its way to the outer solar system. Tycho Impact Basin is the bright crater at the bottom of the image.

On the Moon, older flows become covered by younger flows and/or become more pocked with impact craters. On Earth, older lava flows tend to be more weathered (broken) and may have more vegetation than younger flows. Field geologists use differences in roughness, color, and chemistry to further differentiate between lava flows. They also follow the flow margins, **channels**, and **levees** to try to trace lava flows back to the source area.

The focus of this activity is on the patterns of lava flows produced by multiple eruptions. We use a short cup to hold the baking soda because we are looking at the flows and not at constructing a volcano model. Volcanoes, like those so familiar to us on Earth and Mars, are not present on the Moon. Three well-known areas on the Moon interpreted as important volcanic complexes are: Aristarchus plateau, and the Marius Hills and Rumker Hills (both located in Oceanus Procellarum). These areas are characterized by sinuous rilles (interpreted as former lava channels and/or collapsed lava tubes) and numerous domes.

Lava Layering

Procedure

1. Take one **paper cup/soda cap** and secure it onto the tray. (You may use a small loop of tape on the outside bottom of the cup.) This short cup is your eruption source and the tray is the original land surface.
2. Place one **Tablespoon of baking soda** in this cup.
3. Fill 4 tall paper cups each with **1/8 cup of vinegar**.
4. To each paper cup of vinegar add 3 drops of **food coloring**; make each cup a different color. Set them aside.
5. Set aside small balls of **playdough**, one of each color.
6. You are now ready to create an eruption. Pour red-colored vinegar into your source cup and watch the eruption of "lava."
7. As best you can, use red playdough to cover the areas where red "lava" flowed.
8. Repeat steps 6 and 7 for each color of vinegar and playdough. You may add fresh baking soda to the source cup or spoon out excess vinegar from the source cup as needed.

Results

1. After your four eruptions, can you still see the original land surface (tray)? Where?
2. Describe what you see and include observations of flows covering or overlapping other flows. Sketch in the box on the following page.
3. Where is the oldest flow?
4. Where is the youngest flow?
5. Did the flows always follow the same path? (be specific)
6. What do you think influences the path direction of lava flows?
7. If you had not watched the eruptions, how would you know that there are many different layers of lava? Give at least 2 reasons:

Results continued

Sketch:

8. Which of the reasons listed in answer 7 could be used to identify real lava layers on Earth?

9. What are other ways to distinguish between older and younger layered lava flows on Earth?

10. Which of the reasons listed in answer 9 could be used to identify lava layers on the Moon?

11. What are other ways to distinguish between older and younger layered lava flows on the Moon?

12. Make a vertical cut through an area of overlapping playdough "lava" layers. Draw what you see in the vertical section. Color your sketch and add these labels: **oldest flow, youngest flow**.

Vertical section

through the flows

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

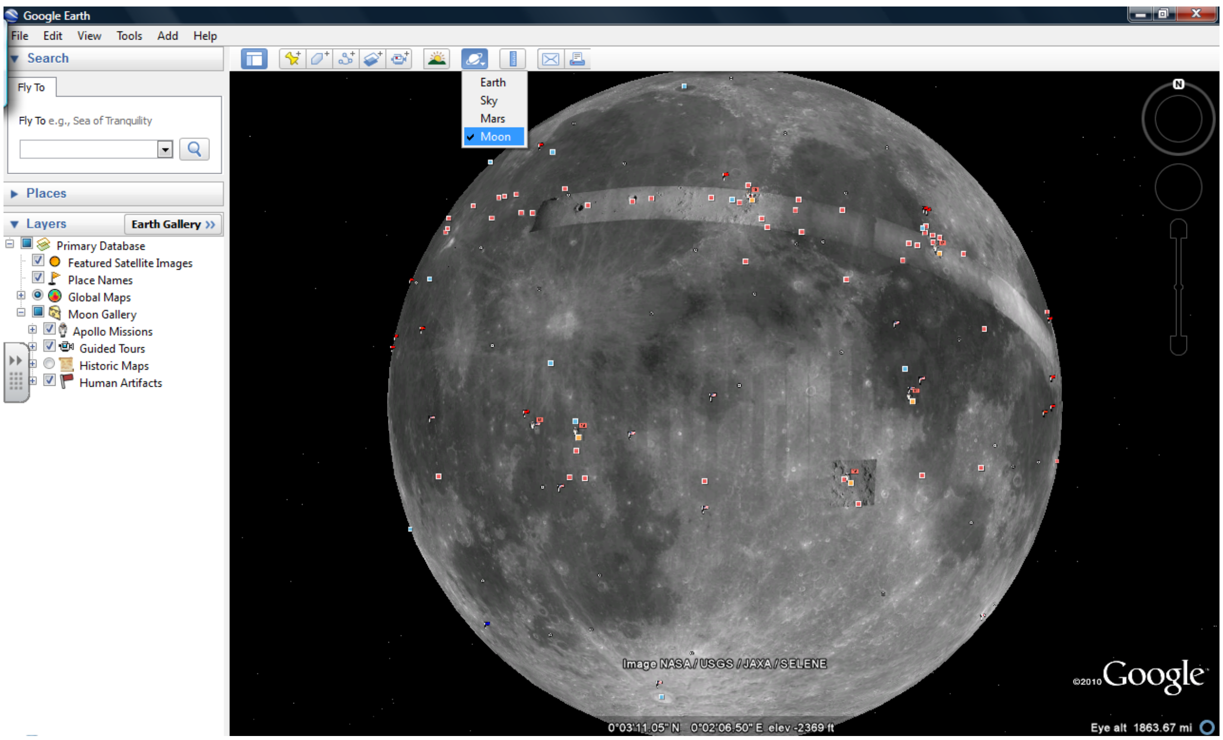
- The Moon can be viewed in many different wavelengths of light, because sunlight is reflected off of its surface, and sunlight includes all of these wavelengths.
- The Moon's surface is not uniform; there are various features visible at different wavelengths of light.
- Spectra for the different rocks 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.]

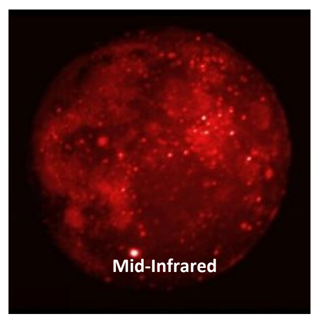
1. Using the interactive white board, if available, ask a volunteer to come and trace one key feature that they observe. Tell students that they will continue this process in their groups of two. Review your expectations for group work. Model with your students how they will use the transparency and 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.

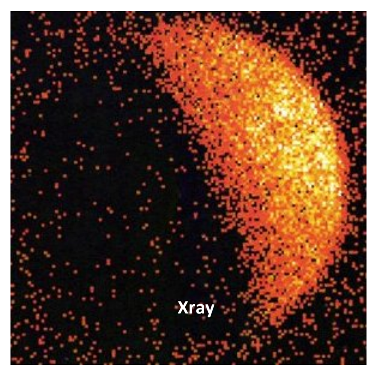


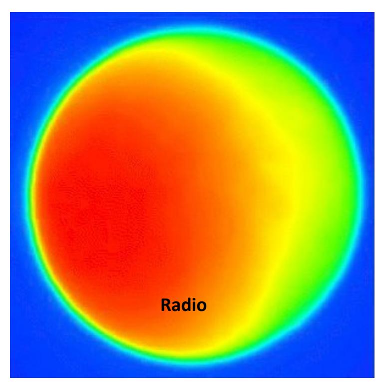
   a. **What is the difference between these two images, as related to the electromagnetic spectrum? What causes these differences**?
   b. **What kind of additional information is provided by these images?** [Visible waves show different rock types, or high and low places, etc., while mid-infrared waves 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:

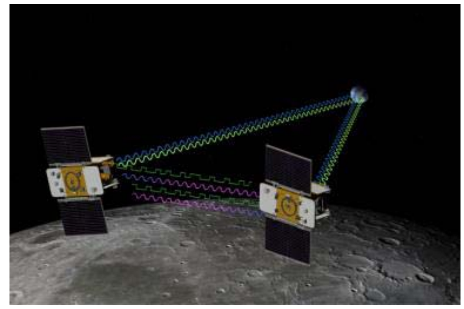


Image courtesy of NASA—Artist rendition of GRAIL twin spacecraft

   - **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

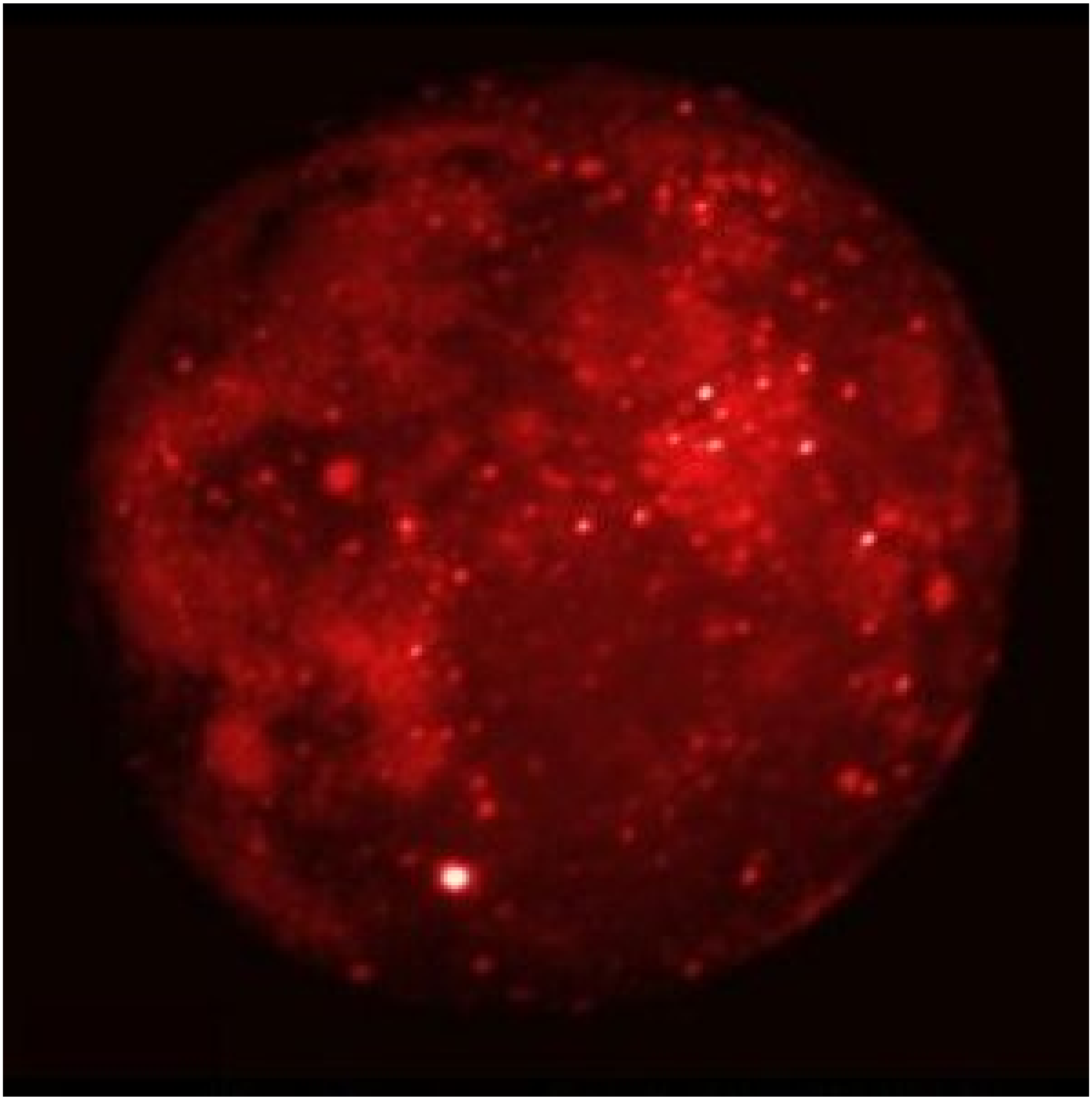


Photo taken from nasaimages.gov

XRay Photo of the Moon

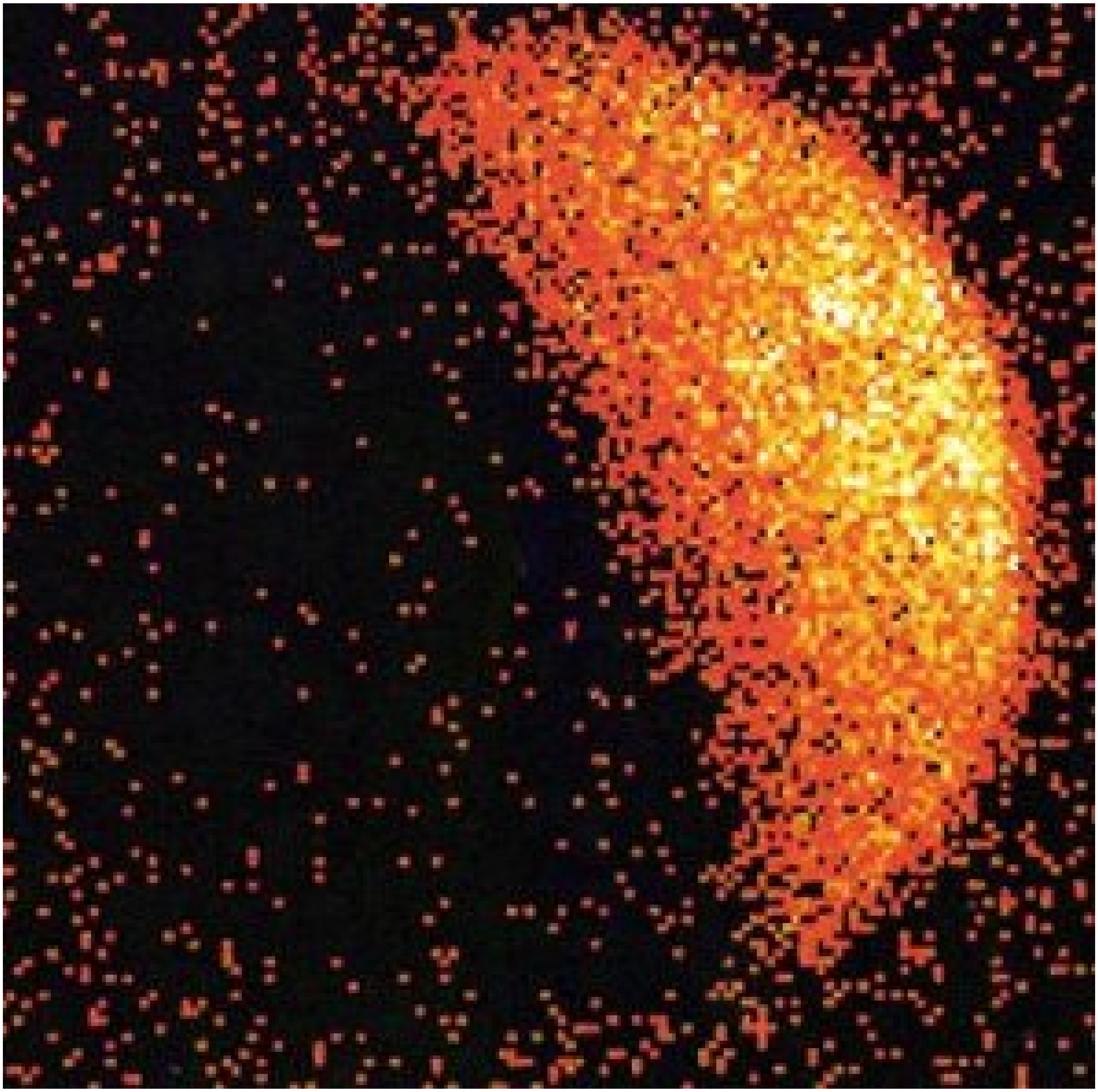


Photo taken from nasaimages.gov

Radio Photo of the Moon

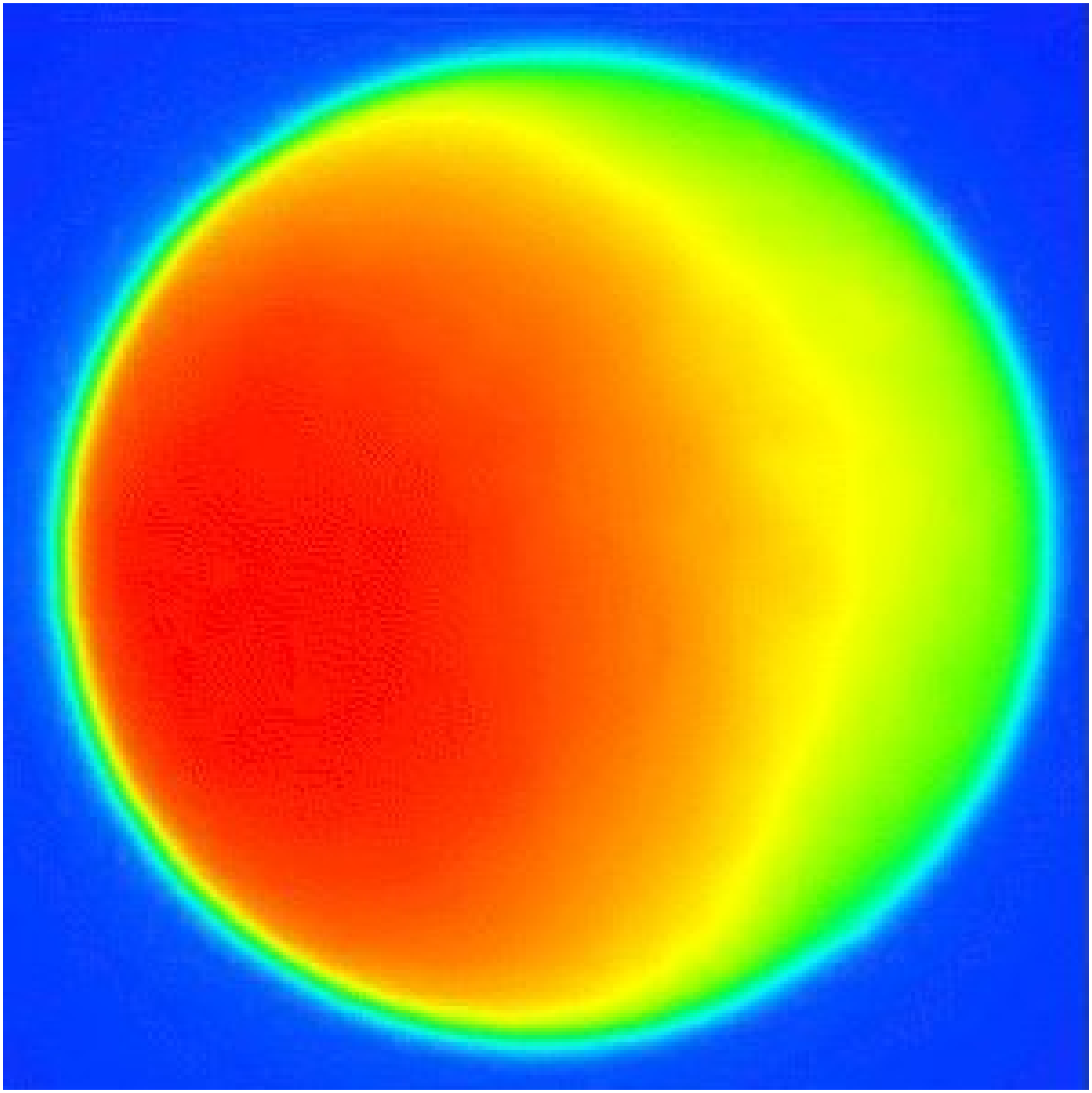


Photo taken from nasaimages.gov

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

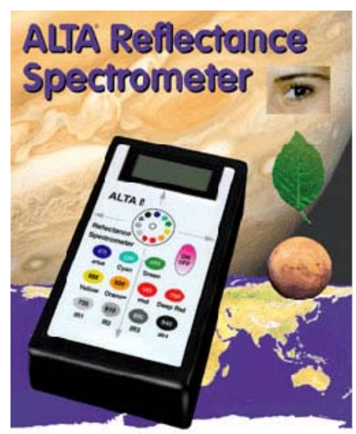
- Rock types have unique reflectance spectra. Rocks can be identified by their reflectance spectrum or "rock fingerprints."
- Scientific investigation includes making observations, gathering, analyzing, and interpreting data, and using technology to gather data.
- Scientists from different teams or different 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

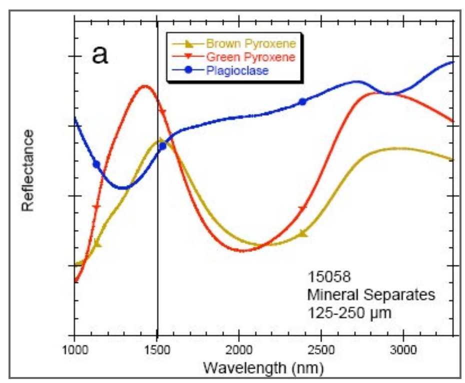
1. Invite the students to share or recall what a reflectance spectrum is-- the amount of light at particular wavelengths that is reflected off of the rocks. Remind your students of the fingerprints they took in the "Fingerprints of Rocks" activity.
    a. **How are fingerprints like reflectance spectra?** [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

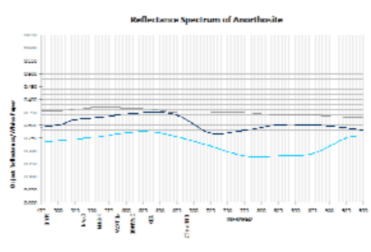
Moon Connection

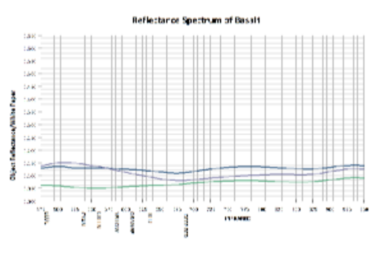
The Moon Mineralogy Mapper (M^3) was a NASA imaging spectrometer that flew on India's first mission to the Moon, Chandrayaan-1. M^3, a state-of-the-art instrument, provided the first mineralogical map of the lunar surface at high spatial and spectral resolution. It generated images of the lunar surfaces 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.

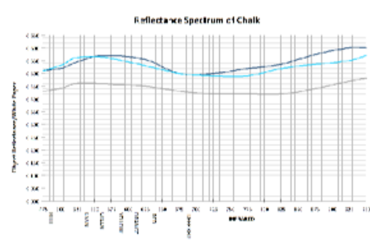
Rock Graphs

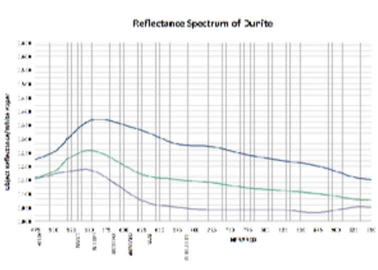
There will be natural variations in each rock sample, and even different sides of the same sample may yield slightly different spectra. Rocks and minerals can be better identified by scientists with more detailed spectra that extend further into the infrared than the ALTA or other reasonably-priced classroom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

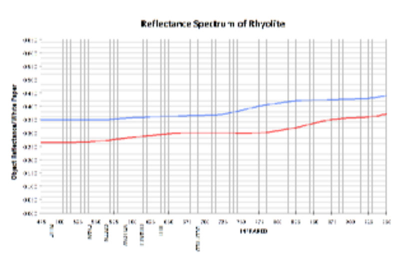
Here are some sample spectra of the rocks used in this activity: These are not “the answers;” it is entirely possible that your students may accurately graph spectra that are very different; it depends on the samples. *Note: Multiple spectra are shown for each rock type, these indicate the slight variations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



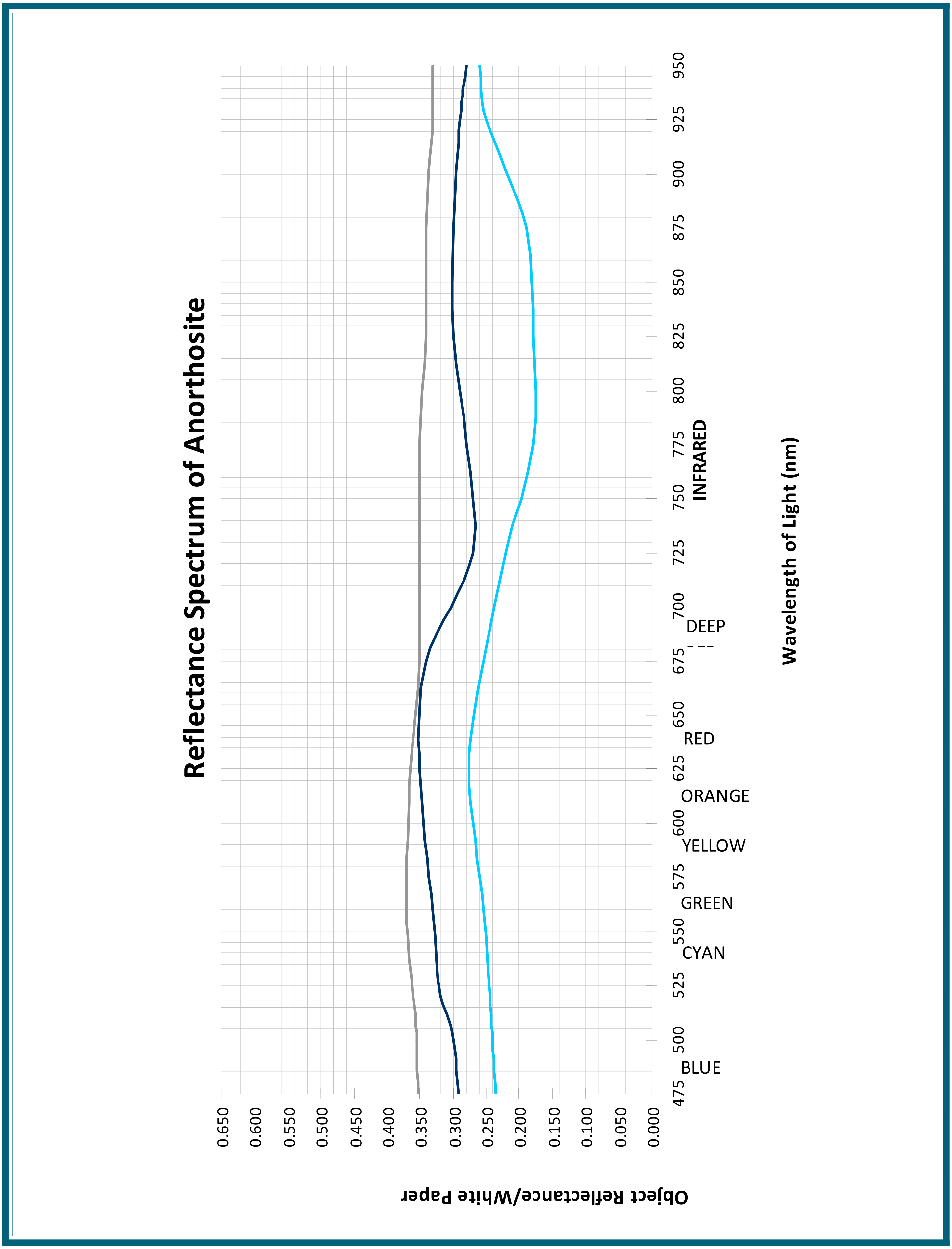




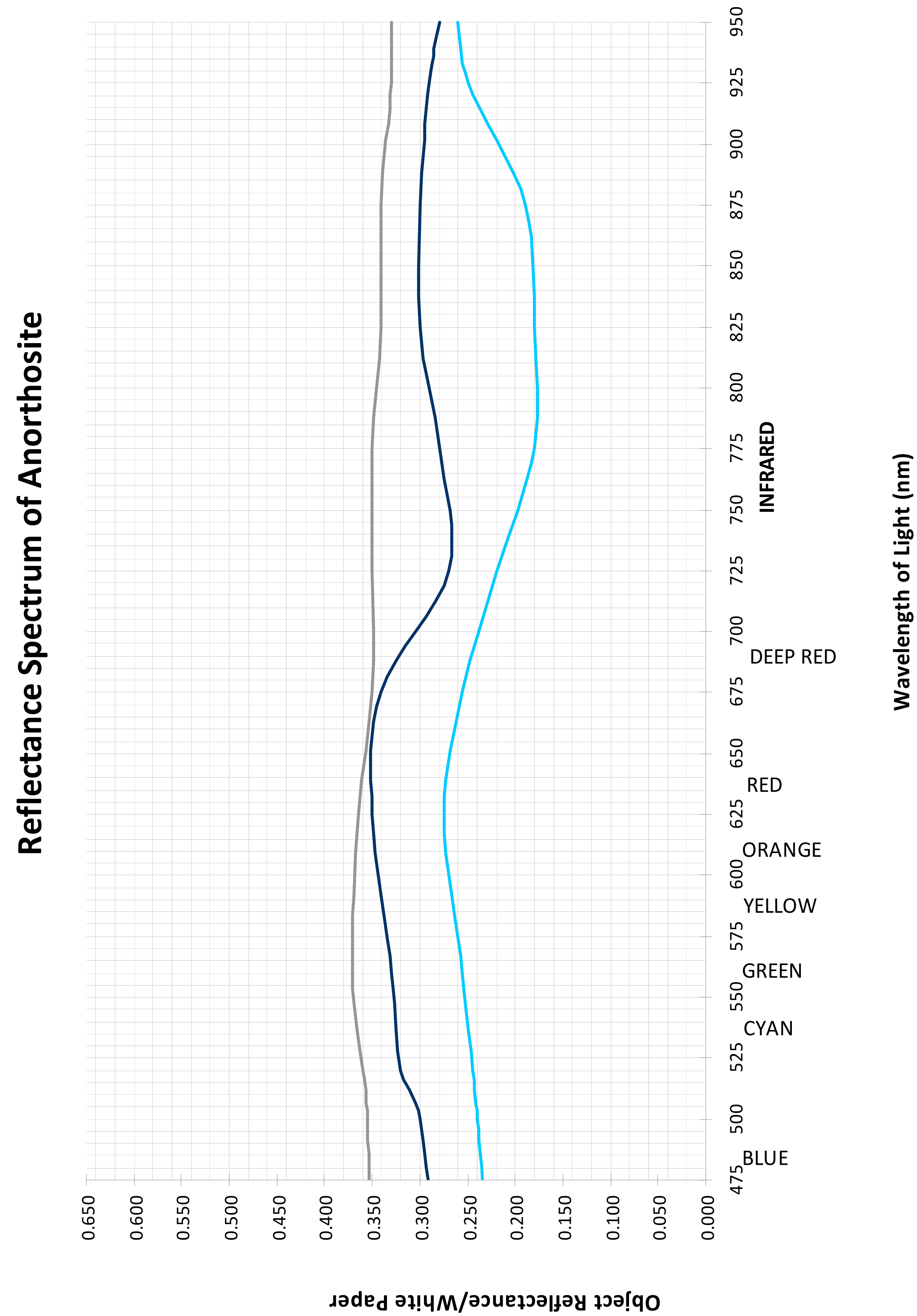


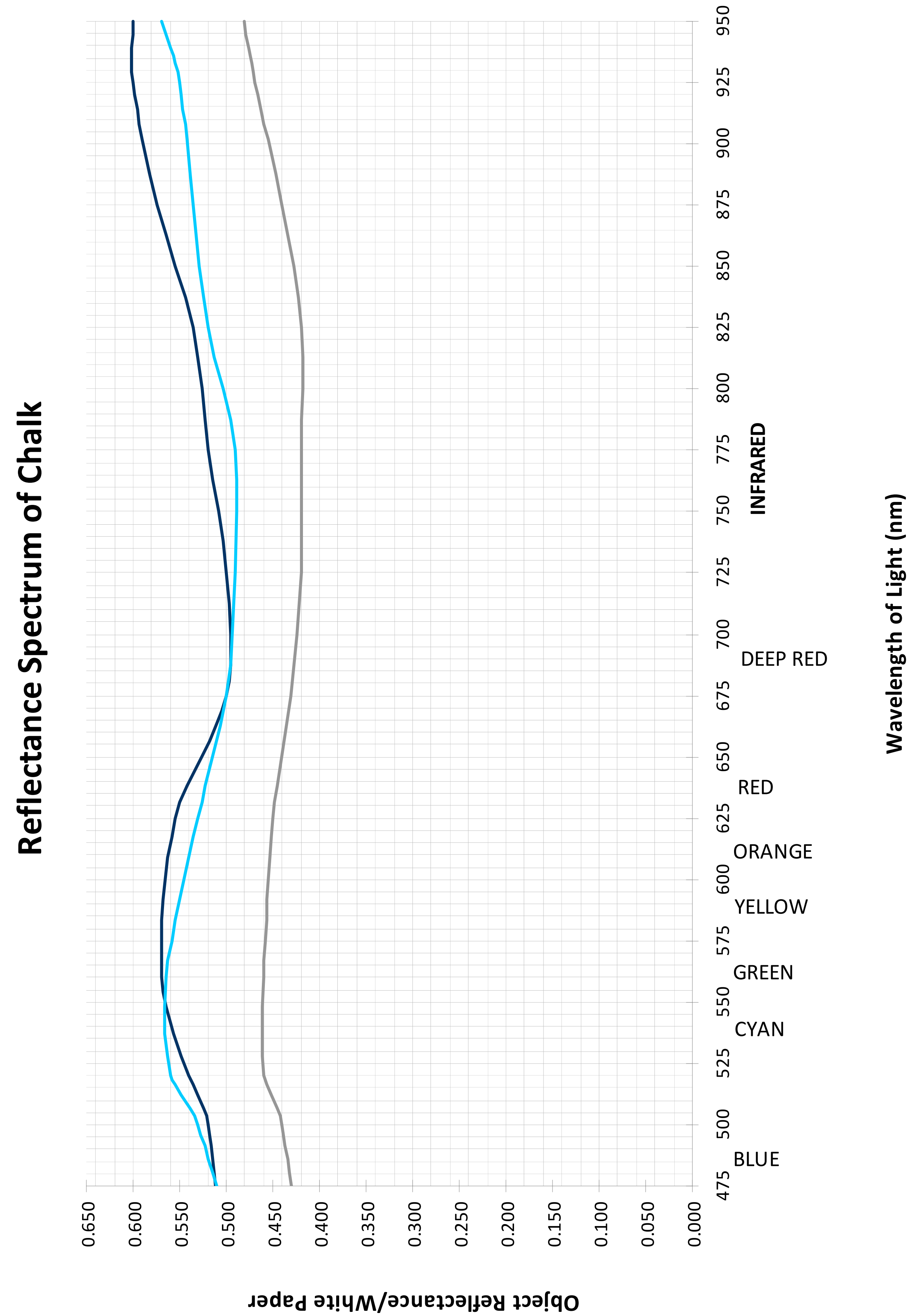


See enlarged versions on subsequent pages.

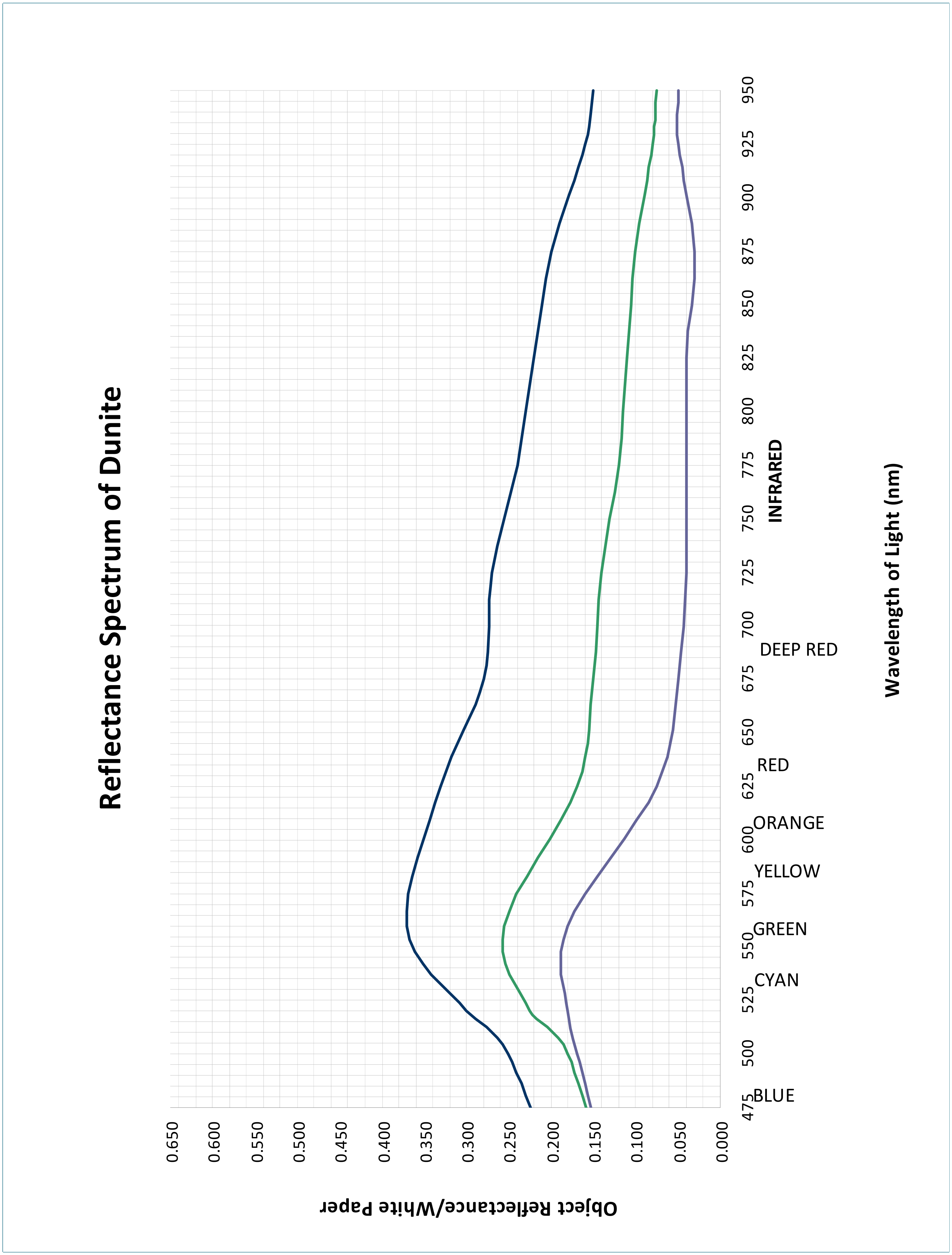


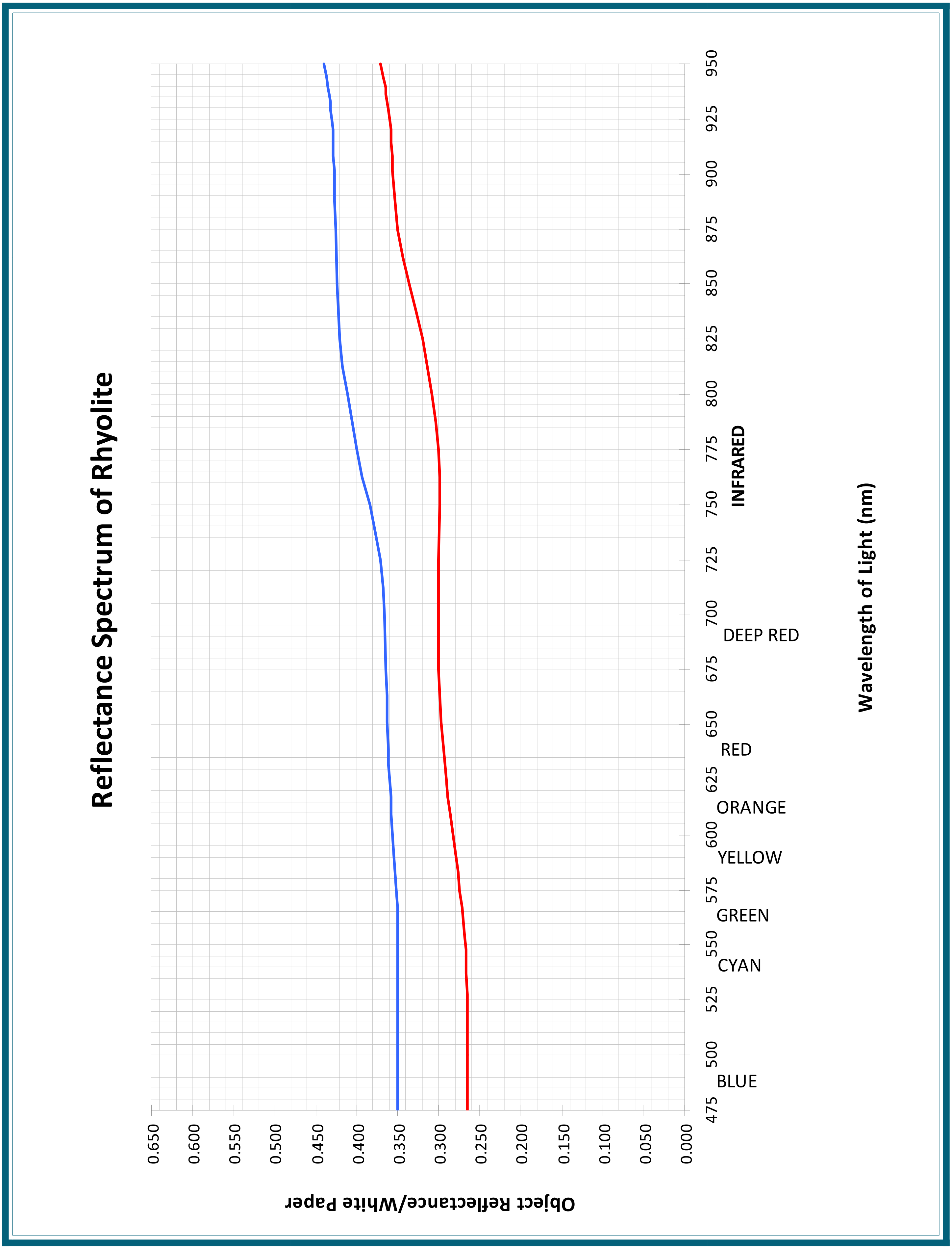
Reflectance Spectrum of Anorthosite
Object Reflectance/White Paper
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
475
500
525
550
575
600
625
650
675
700
725
750
775
800
825
850
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP
INFRARED
Wavelength of Light (nm)


Reflectance Spectrum of Anorthosite
Object Reflectance/White Paper
0.000
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
850
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
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


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
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
Wavelength of Light (nm)


Reflectance Spectrum of Rhyolite
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
850
875
900
925
950
BLUE
CYAN
GREEN
YELLOW
ORANGE
RED
DEEP RED
INFRARED
Wavelength of Light (nm)

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.

Module 4: Finding Treasures of the Moon

In this module, students will continue their exploration of the properties of the Moon and will create their own hypotheses on the Moon's geological history and the role that the Moon Mineralogy Mapper will play in testing scientists' current understanding of the Moon's composition and geologic history.

Activity 4-1: Lunar Treasure Hunt (40 minutes)

Teams compare their maps to topographic maps of the Moon. Students use their spectroscopic data from the Moon and understanding of cratering to create questions and devise some theories for the geologic history of the Moon.

Activity 4-1: Lunar Treasure Hunt

Overview

In this 40-minute activity, teams of students create and compare color-coded mineralogy maps and topographical maps of the Moon. Using spectroscopic data and their understanding of cratering and volcanism from previous Module 3 activities, students create questions and devise theories for the geologic history of the Moon.

Learning Objectives

- Contrast mineralogy maps and topographical maps of the Moon to describe lunar features in terms of their rock types.
- Evaluate the value of spectroscopic data.
- Create and examine hypotheses explaining the geologic history of the Moon.

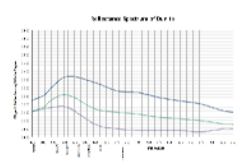
Key Concepts

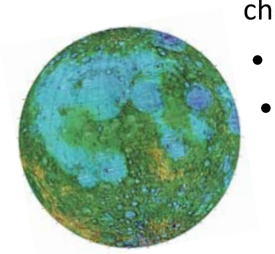
- The Moon has small craters that reflect light well at some wavelengths (visible and mid-infrared) so they appear bright.
- The Moon has large round basins that reflect light poorly at many wavelengths (from ultraviolet through infrared) so they appear dark.
- Craters provide clues to the composition and internal structure of the Moon.
- Our understanding of the Moon is based on the Apollo rock samples and meteorites from the Moon, and our spectroscopic and visual observations of the Moon.
- More detailed data are needed to test our current models of the Moon's rock types, geologic history, and structure.
- Scientific investigation includes observations, gathering, analyzing, and interpreting data, and using technology to gather data.

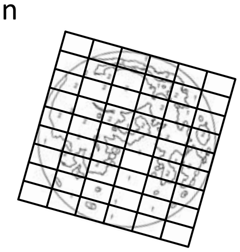
Materials

For each team of 4-5 students:

- Spectral graphs from the Activity 2-2: Moon Mineralogy Expedition—Rock Type #1, Rock Type #2, and Rock Type #3 (anorthosite, basalt, and dunite (olivine))
- One color copy of the Lunar Topographic Map
- One copy of Color Coded Moon Map with regions characterized by numbers
- Colored markers, pencils, or crayons: yellow, grey, and green
- A copy of each of the Activity 2-2: Rock Information sheets







Preparation

- Print out color copies of the Lunar Topographic Map for groups of 4-6 students, or print out posters for the entire class to observe, or prepare to project the image for everyone to see.

Addressing Prior Knowledge

- Begin by asking the class to describe their previous activities related to the Moon, particularly the Moon Mineralogy Expedition, their examination of missions gathering data from the Moon, and the geology activities on cratering and lava layering.
- **What types of rocks have scientists found on the Moon?**
  [anorthosite, basalt, dunite (olivine-rich), and more]
- **Why do we think those are the rocks on the Moon?**
  [We have samples of these rocks gathered by the Apollo astronauts from a few specific locations on the Moon, and we have spectroscopic data for larger areas on the Moon.]
- **Could there be other types of rocks on the Moon? How complete is our knowledge?**
  [There could be other types of rocks; our data is patchy and low-resolution.]
- **What do we need to have a more thorough understanding of the Moon?**
  [We need a more detailed data for the entire surface of the Moon.]

The Activity

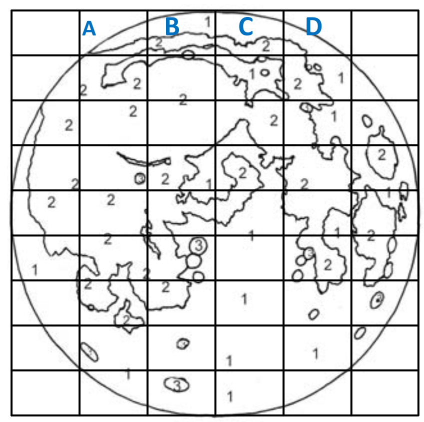
1. Divide your class into groups of 4-6 students and distribute materials to each group (a copy of the Color-Coded Map of the Moon, along with either crayons, pencils, or markers).
2. Tell students that they will use the graphs of the various rocks from their Moon Mineral Expedition to create a map of the composition of the Moon's surface—a mineralogical map of the Moon. Model the process with the students. The numbers on the map indicate where spectra have been taken, matching the rock types the "Orbiters" collected. For instance, wherever a "2" is shown, a spectrum was collected from rock type 2. Using their information from Remote Analysis of the Moon, students should identify the rock types and color in the map.
   - **Is there any pattern to the distribution of rock types? Which cover the greatest area? The least?**
3. After they are finished color-coding their maps, review what they know about the rocks and how they form from Modules 2 and 3. The students may need to revisit the Rock Information Sheet. Ask them to reflect on where the different rock types occur on their mineralogical map of the Moon.
   - **How do basalts form?**
     [Basalts are volcanic rocks that form from molten lava.]
   - **What does the presence of basalt on the Moon tell them?**
     [That the Moon was or is volcanically active.]
   - **Do they see any patterns to where the basalts occur on their map?**
   - **What other ideas or questions do your students have so far, based on this information?**

4. Hand out a copy of the Lunar Topographic Map to each team. Students should identify key features from the Lunar Topography map.
   - **Which parts of the Moon are the highest (the highlands)? Which parts of the Moon are the lowest?**
   - **How would the students describe the lowlands?** [Smooth, dark.]
   - **How would the students describe the highlands?** [Light, rough.]
   - **What makes the highlands rough? What are the circular depressions called? How do they form?** [Remind the students that they experimented with forming craters in the activity.]
   - **Which of the craters are the deepest?**
   - **What are some of the properties of the basins?** [Basins are broad, flat, low features.]
   - **Are some of the basins higher than others?**
   - **Which of the basins have the most craters in them? Which of them have the fewest craters? What does that tell us about the ages of the basins?**
     [The basins with more craters are older; the basins with fewer craters are younger.]
5. Teams compare their mineralogy maps to topographical maps of the Moon, and classify the rocks in the craters, in the basins, and in the highlands.
   - **What types of rock is found in the basins?**
     [basalt]
   - **Are these basins different from each other?**
   - **What types of rocks are sometimes found inside the craters?**
     [anorthosites, dunite (olivine), and others]
   - **Are these craters different from each other?**
   - **What types of rocks are found in the lunar highlands?**
     [mostly anorthosite]
   - **Are these regions different from each other?**
6. Ask your students to think about the Moon, its topography, the types of rocks found in different locations on the Moon, and where those rocks are found on Earth.
   - **Which parts of the Moon are the oldest? Why do they think so?**
     [the highlands are the oldest; they have the most craters]
   - **What types of rocks are found in the oldest parts of the Moon?** [anorthosite]
   - **Which parts of the Moon are the youngest? Why do they think so?**
     [The flat basalt-filled basins are the youngest; they have the fewest craters.]
   - **Where are those rocks found on Earth? How do you think they formed there on the surface of the Moon?** [Scientists believe that cracks in the Moon's crust allowed hot lava from inside to flow out onto the Moon's surface.]
   - **Which parts of the Moon's surface are the deepest?**
     [craters]
   - **What types of rocks are found there?**
     [anorthosites, dunite (olivine), and others]
   - **Where are those rocks found on Earth?**
     [dunite is found in our mantle]

- **How do you think they got to the surface of the Moon?** [Impacts uncovered the layers above these rocks, exposing rocks that may have intruded into the crust of the Moon.]

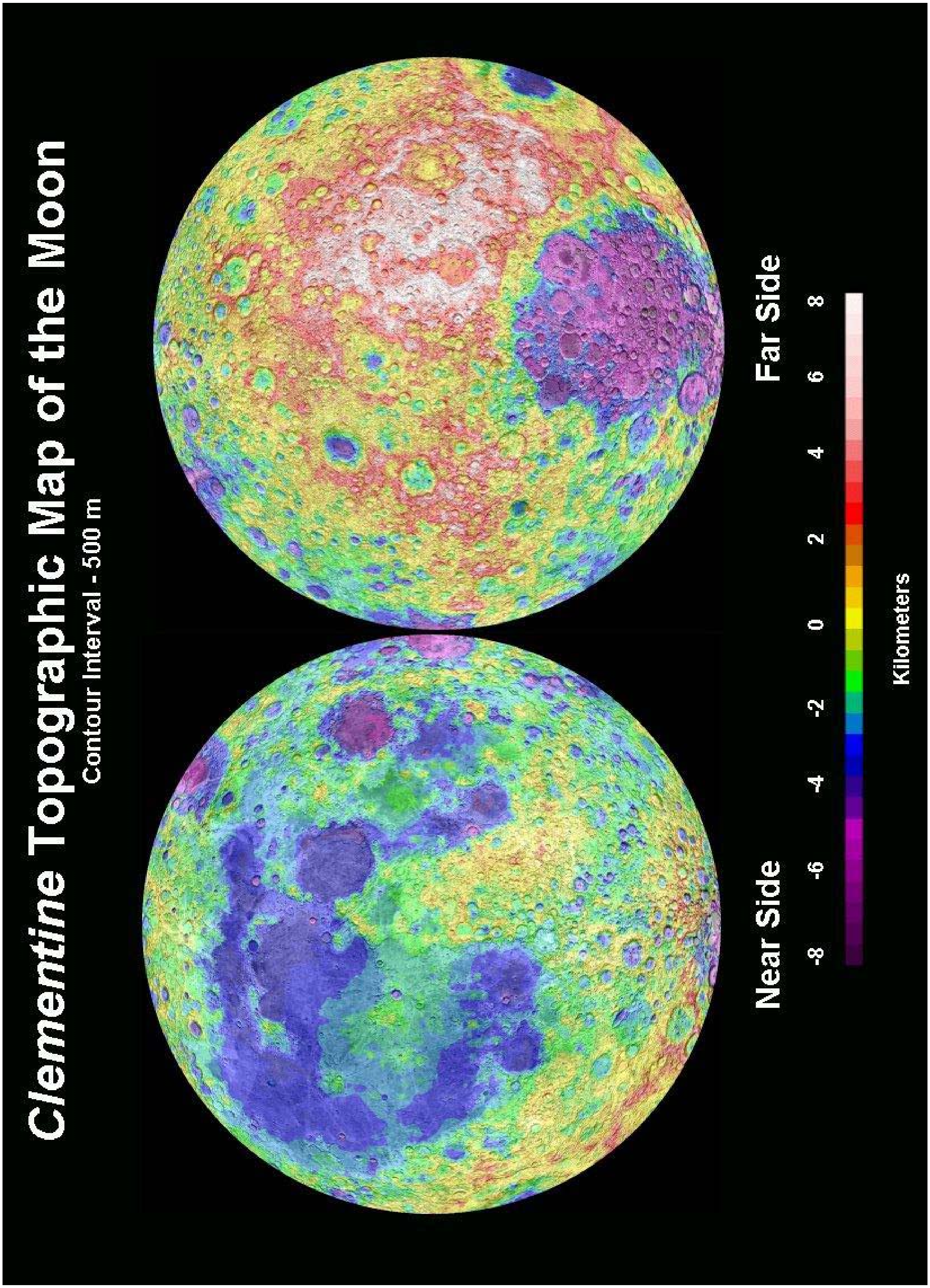
7. Invite the students to reflect on the activity and analyze their understanding of our exploration of the Moon.
   - **What do the students think the point of this activity was?** [Answers could include analyzing data, creating hypotheses, understanding the scientific process, and understanding the formation and evolution of the Moon.]
   - **Which aspects of science did your students do today?** [Answers could include analyzing or comparing data, creating hypotheses and making predictions, sharing conclusions.]
   - **What do your students believe is the value of understanding what our Moon is made of?** [Knowing about resources for future manned exploration of the Moon; compositional information can be used to improve our current models of the Moon's formation and its geologic evolution.]
   - **What do your students believe is the value of understanding the Moon's formation or evolution or structure?** [Scientists can apply what has happened to our Moon to better understand our own Earth and the broader history of the Solar System.]

Extension



To integrate mathematics into this lesson, consider having students estimate the relative abundance of the rock types per square area in the grid. Each square covering the Moon should be given a unique identifier (e.g., labeled A, B, C…XX, as there are 50 squares covering the Moon's surface. Relative abundance can be calculated by Total abundance of Rock Type / Total Abundance of All Rock Types. Students could also analyze the data to build frequency table and histograms, or perform central tendency calculations. Students may collect data into a data table like the one below:

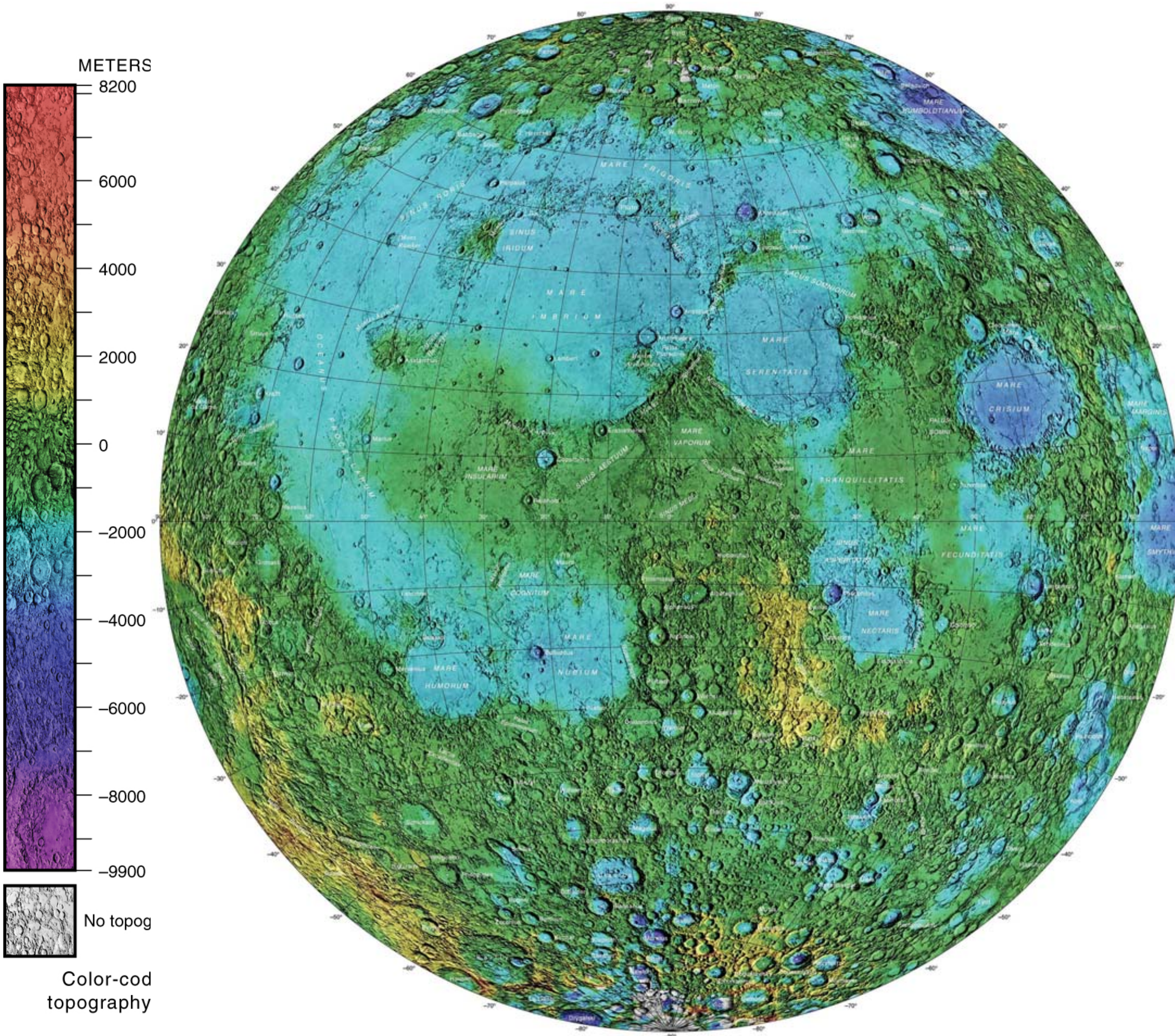
Square ID	**Amount of Rock per Square**			**Total**
	Anorthosite	Basalt	Dunite/Olivine	
A	.55	.45	0	1
B				
C				
D…XX				
Estimated Total				


Clementine Topographic Map of the Moon
Contour Interval - 500 m
Near Side
Far Side
-8 -6 -4 -2 0 2 4 6 8
Kilometers

Color-Coded Topography and Shaded Relief Map of the Lunar Near Side and Far Side Hemispheres

By U.S. Geological Survey

2003



Color-Coded Moon Map

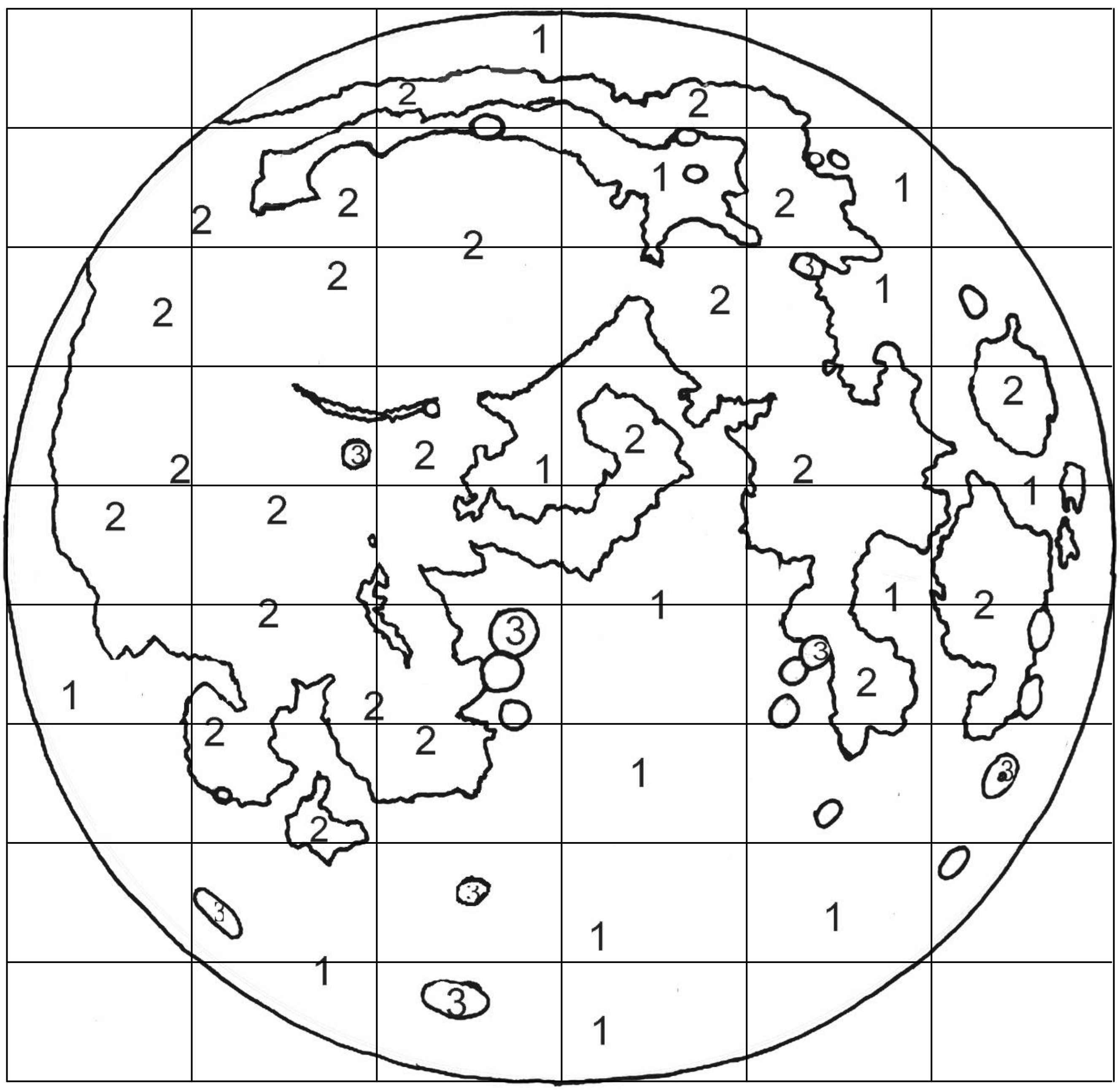
EDUCATOR

Directions

Color the areas with the anorthosite spectrum yellow, color the regions matching the basalt spectrum dark grey, and color the portions matching the olivine spectrum green.

Code:

- 1 is anorthosite
- 2 is basalt
- 3 is olivine



Color-Coded Moon Map

STUDENT

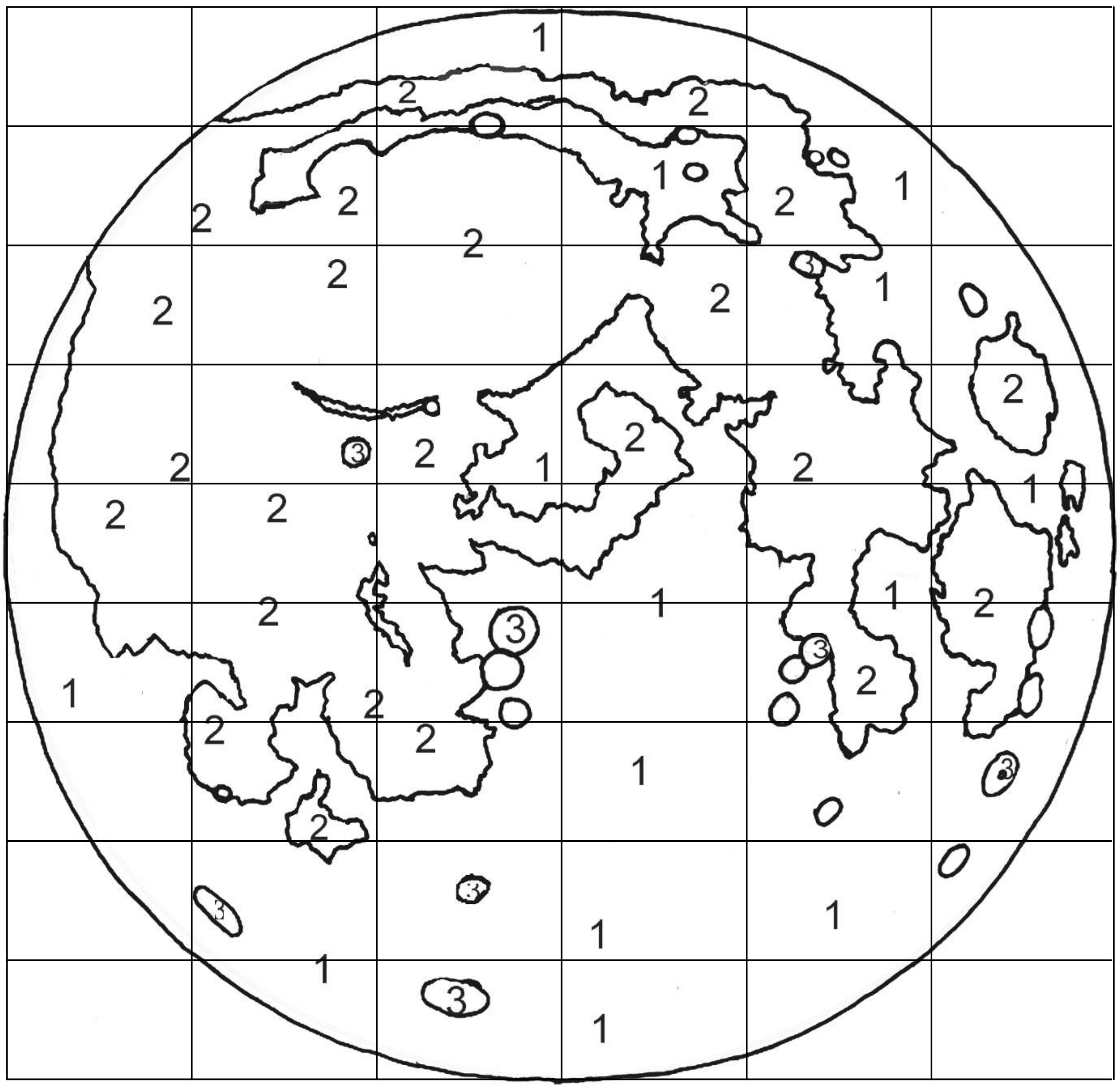
Directions

Color the areas with the anorthosite spectrum yellow, color the regions matching the basalt spectrum dark grey, and color the portions matching the olivine spectrum green.

Code:

1 is ______________________ 2 is ____________________

3 is ______________________



Collaborative Group Evaluation Rubric

Criterion/Points	4	3	2	1/0	Total
Task Participation	Offered leadership in task completion; performed above expectation	Fully prepared; completed all agreed tasks; competent, but not extraordinary	Minimally prepared; superficial knowledge of resources; performed below expectation	Little or no evidence of preparation; did not perform	
Group Communication	Encouraged others to provide ideas; offered solutions; provided positive feedback	Offered solutions and ideas to the group	Offered some ideas but generally went with most of the decisions everyone else offered.	Had little/ nothing to offer	
Attitude	Exceptionally encouraging	Positive; supportive	Disinterested in the task or performance of others	Unhelpful, negative, withdrawn, absent	
Total for all Criteria					

Science Lab Behavior Evaluation

Class: **Period:** **Date:**

Name	Follows Directions 35 points	Completes Task 35 points	Uses Appropriate Voice/Behavior 10 points	Cleans Space 10 points	Total Pts (out of 100)