LunarReconnaissanceOrbiter: (LROC/ LOLA)

Audience
Grades 5-12

Time Recommended
30-45MinutesPerActivity(Lessoncontains5activities)

AAAS STANDARDS

- 1B/1:Scientificinvestigationsusuallyinvolvethecollectionofrelevantevidence,theuseoflogicalreasoning,andtheapplicationofimaginationindevisinghypothesesandexplanationstomakesenseofthecollected evidence.
- 3A/M2:Technology is essential to science for such purposesasaccesstoouterspaceandotherremote locations,samplecollectionandtreatment,measurement, datacollectionandstorage,computation,andcommunication of information

NSES STANDARDS

ContentStandardA(5-8):Abilitiesnecessarytodoscientific inquiry:

c. Useappropriatetoolstogather,analyzeandinterpret data.

d. Developdescriptionsandexplanationsusing evidence.

e. Thinkcriticallyandlogicallytomakerelationships between evidence and explanations.

ContentStandardD(5-8):EarthandSpaceScience-Earth's History:

a. TheEarthprocesseweseetoday,includingerosion,movementoflithosphericplates,andchanges inatmosphericcomposition,aresimilartothose thatoccurredinthepast.Earth'shistoryisalso influencedbyoccasionalcatastrophes,suchasthe impact of an asteroid or comet.

Content Standard E (5-8): Science and Technology:

b. Technology is essential to science, because it providesinstrumentsandtechniquesthatenable observationsofobjectsandphenomenathat areotherwiseunobservableduetofactorssuch asquantity,distance,location,size,andspeed. Technologyalsoprovidestoolsforinvestigations, inquiry, and analysis.

MATERIALS

- Copiesofthestudentactivities(oneforeachgroupof 2-3 students)
- Science journals/ notebooks used in class (used throughout each activity)
- Colored pencils
- Pencil/ pens
- Metric rulers
- Scrap paper
- Calculators
- Magnifying glasses (optional)

Mapping The Surface of the Moon

Learning Objectives:

- Able to correctly identify, observe, record, illustrate and label important geologic features on the Moon.
- Able to describe and explain the types of geologic features found on the Moon, how they formed, and how those features compare with like features on Earth.
- Able to accurately measure and calculate scale and distance relationships for specific geologic features on the Moon relative to a feature, or between and among features.
- Able to successfully reconstruct, record and explain the geologic history of specific areas on the lunar surface through identification of geologic features and identification of relationships evident among features, using the basic principles of geology and evidence found in the data; especially those related to the principles of superposition and cross-cutting.
- Able to identify and explain the technological advances evidenced when comparing Apollo era images to modern LRO (LROC and LOLA) images.
- Describe how students have come to understand, and be able to explain to others, common misconceptions about the Moon i.e. motions in space relative to Earth and the Sun, the myth of 'the dark side of the Moon', and that yes, the Moon rotates and revolves in synchronous motion with Earth.

Preparation:

1. Read and review the background content for all sections you plan to teach and have fun conducting the mapping activities embedded in the teacher background content section and in the student lesson activities before you work with your students!

2. Check the materials list provided to be sure your students will have everything needed to conduct the activities.

3. Conduct a pre-assessment piece to check for prior knowledge and misconceptions. A sample pre-assessment piece is located in the assessment section.

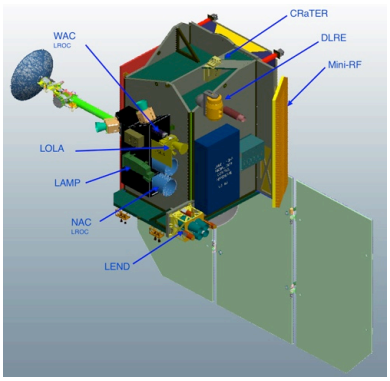
4. Assign groups of 2-3 students. Be sure each group member has a task/ role. One student could be the note-taker, another student the reader, and a third the illustrator. All students would need to complete their science journal work as they progress through the activities you choose to teach.

5. Before delivering the content the students will need, begin a KWL to find out what students already know, what they want to know and to guide them away from misconceptions. Of course, the "L" is done at the end of the activities (what they learned).

6. Video references will appear in activities. A General video on LRO South Pole First Light Data: http://www.youtube.com/watch?v=SN2kdavy-wA&feature=results_main&playnext=1&list=PL20FB3CA56CF49779

Background Information:

Welcome to the Mapping the Surface of the Moon activities module for the Lunar Reconnaissance Orbiter mission (LRO). Mapping the surface features of the Moon is a lot like working on the history of the surface of Earth— if Earth had no weather, climate, or living things. In fact, we live on a planet that has factors that allow much of the life on Earth to flourish; air, water, sunlight, nutrients, soil, global magnetic field, an atmosphere and more. Earth experiences weather day to day. Accumulated over time, weather creates climates. The Moon however, has no life sustaining system of air, atmosphere, global magnetic field or weather and climate. Thus, due to the lack of weathering, the Moon looks essentially the same as it did thousands, if not billions of years ago. With the exception of impact craters and features created by such impacts, the Moon displays its complete geologic story for humans to explore.



Instruments onboard LRO.

The Moon is Earth's only natural satellite and our closest neighbor in the solar system. A mystery for thousands of years, myths and legends from centuries past abound attempting to explain the origin, power and importance of this celestial body. However, we knew little science about the Moon before the Apollo program in the 1960's. Even with six manned trips to the Moon, and dozens of unmanned missions, we still have a lot to learn.

The activities in this lunar mapping module address many of the concepts related to landforms and geologic features that students learn about in science and social studies classes. Much like Earth, the Moon has many of the same geologic features, except for those produced by weather and glaciers.

So, with this in mind, Mapping the Lunar Surface activities will look at impact craters, maria, volcanoes and tectonic features such as rilles, wrinkle ridges and fractures in the crust. With the latest technology, NASA's lunar missions have advanced imaging instruments that provide incredibly clear details of the lunar surface features.

The Lunar Reconnaissance Orbiter (LRO) is a NASA orbiting science lab going around the Moon from an altitude of 50 km (30 miles). Instruments onboard LRO include the Lunar Reconnaissance Orbiter Camera (LROC) and the Lunar Orbiter Laser Altimeter (LOLA). LROC carries two narrow-angle cameras (NAC) and one wide-angle camera (WAC). The images are high resolution and are very clear because at 50 km above the surface (remember that is the height of the spacecraft's orbit above the Moon) we can identify objects as small as a half meter (19 inches).

Alternatively, LOLA uses a laser beam, split into five beams, to produce topographical data of the Moon accurately (discussed more thoroughly later). The two instruments, LROC and LOLA, provide us with a wealth of scientific data that help us to know where we need to send spacecraft or humans to safely land on the Moon. Understandings about the composition and geologic history of the Moon also helps us to better understand Earth, its history, and its future.

The purpose of the Mapping the Surface of the Moon activity guide is to provide an exciting planetary space activity for teaching and learning about geologic features found on the surface of orbiting bodies in space, including Earth. Better yet, we will be using images created from data collected with scientific instruments orbiting the Moon on the Lunar Reconnaissance Orbiter (LRO). This is a unique opportunity to observe geologic features using images created with high quality instruments, and is just one of many significant ways educators can bring current scientific exploration into the classroom.

From impact craters, to faults, to volcanoes, the background content for teachers is embedded with questions that are connected with student activities to both enhance teacher content knowledge and provide hands-on engagement for students in current science missions.

The Lunar Features content is delivered into eight sections (listed below). Each section is supported with images of the Moon created from data collected by instruments aboard the LRO (LROC and LOLA images) with occasional images from the Apollo program and other lunar missions. Each section includes a stand-alone activity for students (and you!) and does not require other activities in the guide to support successful completion. The topics included are:

- A Look at the Full Moon
- Impact Craters
- Volcanoes
- Volcanoes and the Moon
- Rilles
- Wrinkle Ridges
- Determining the Surface History
- The Lunar Orbiter Laser Altimeter

Procedure:

See each individual activity (in worksheets section) for procedure.

worksheet

STUDENT ACTIVITY 1

What Do We See When We Look at the Moon?

You are now a lunar scientist! Your task is to observe images of the Moon and identify surface features. The features on the Moon help us to understand the geologic history of the Moon. Knowing the history and formation of the Moon will actually help us understand more about the history of Earth.

When we look at the Moon on a clear night, we can see dark and light areas. The light areas are called lunar highlands. They are made up of a light colored rock called anorthosite. The dark areas are called mare (Mahr-ay; plural is maria; MAH-ree-uh). The word mare comes from a Latin word for sea. Early observers of the Moon thought the mare were bodies of water. That was before sophisticated telescopes were invented. We now know that these dark areas are cooled lava flows of a dark rock called basalt.

It is not easy to see smaller features on the surface of the Moon without binoculars or a telescope. When we look at the Moon with a telescope, we see thousands of depressions on the surface. Most, but not all of these depressions, are impact craters. They are called impact craters because interplanetary bodies in the solar system have impacted the surface, creating the craters. Interplanetary bodies include meteoroids, asteroids, and comets. In addition, many impact craters, when viewed from above, appear to look like hills instead of craters. This is an optical illusion in which they appear to pop out of the surface rather than sink into the surface.

Some of the craters are tiny, while others are huge. The largest known impact crater on the Moon is the South Pole-Aitken Basin. It is 2,500 kilometers (1,550 miles) in diameter. That is about the same distance we would need to travel from New York City to Denver, Colorado! The smallest craters on the Moon include tiny depressions on the surface of the rocks collected by astronauts during the Apollo program. It is also important to point out that not all depressions on the Moon are impact craters.

Let's identify mare and lunar highlands, find craters, and do a little math!

Directions: Carefully draw or trace this image in your journal. Be sure to color the dark and light areas.

1. Label the mare and lunar highland areas.
2. This image is the 'near side' of the Moon. It is called that because this is the side of the Moon we always see from Earth. If you had to estimate how much of the Moon is made up of maria, and how much is made up of lunar highlands, what would be your guess? How would you figure that out? Be sure to write your answers in your science journal and use the resources in the assessment section.

Figure 1. The Moon.

A. Can you tell where the maria are in this image? Can you tell where the lunar highlands are? Use your journal to draw the image and label the areas you think are mare and the areas you believe are lunar highlands.

B. Before we take a look at the far side of the Moon, let's talk about the motion of Earth and Moon. There is really no 'dark side' of the Moon. As the Moon orbits Earth, it rotates in a synchronous orbit. This means that it rotates at the same rate that it revolves around Earth. You can model these motions with a classmate and see how it works. Ask a friend to be the Sun and have him/ her stand in one place off to the side of the room. Ask another friend to be the Moon. Ask him/her to move around you in a

counterclockwise direction. At the same time, your friend MUST keep facing you, Earth. In the diagram below, the little cones represent a person standing on the same spot on the Moon for about 28 days. It takes about 28 days for the Moon to complete a full orbit Earth. The arrows represent sunlight. The diagram is not to scale in size or distance.

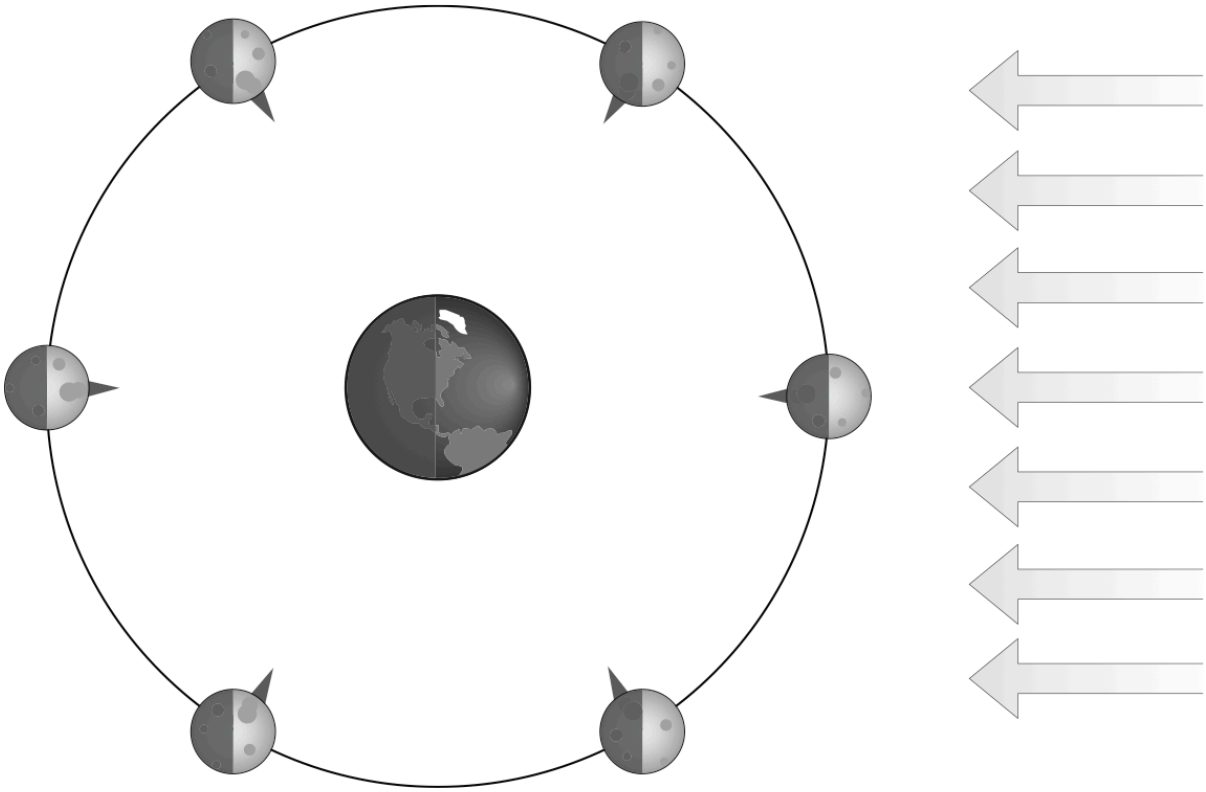


Image credit: SUNY New Paltz/NASA GSFC/Rosemary Millham

Now, illustrate or trace the diagram in your journal and shade the unlit side of the Moon. Next, answer the following questions in your journal:

1. What does the drawing tell you about the Moon's far side?
2. Does the far side ever see sunlight? Explain how you have come to know this.
3. Does the way the Moon orbits Earth allow us to see the far side? Explain how you know this.
4. Can you truthfully call the far side the 'dark side'? Explain why or why not.

Now take look at an image of the far side of the Moon (on the next page) and compare it to what we see on the near side.

Directions: In your journal, carefully draw or trace the far side of the Moon shown on the next page. Be sure to keep the light and dark areas separate. It will be important later! Be sure to use the resources in Appendix B.

1. Label the mare and lunar highland areas
2. When finished, compare the near side drawing you created with the far side drawing.

worksheet

3. Answer the following questions and statements in your journal:

   a. Describe the similarities and differences.
   b. What are the most noticeable similarities?
   c. What are the most noticeable differences?
   d. What makes these features more noticeable to you?
   e. Why do you think they look so different?

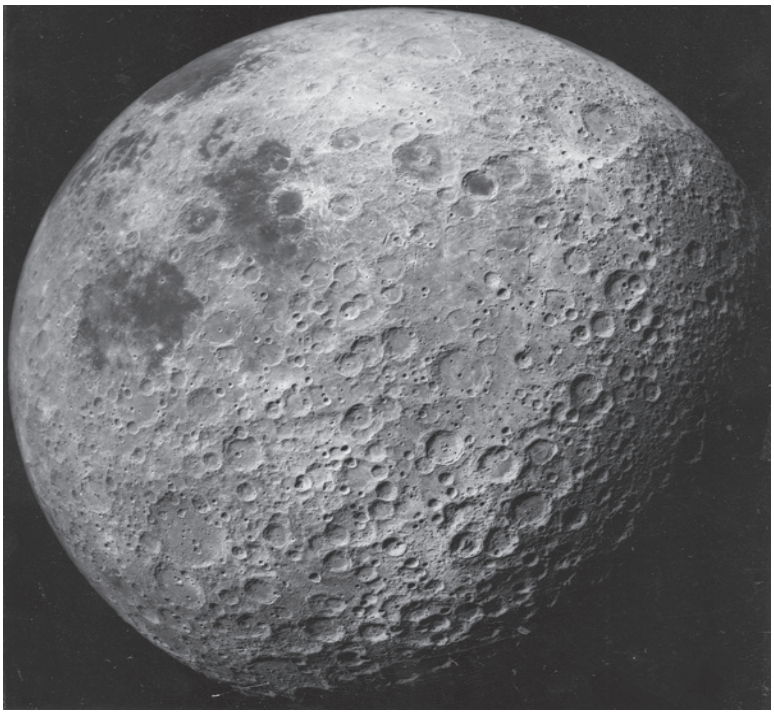
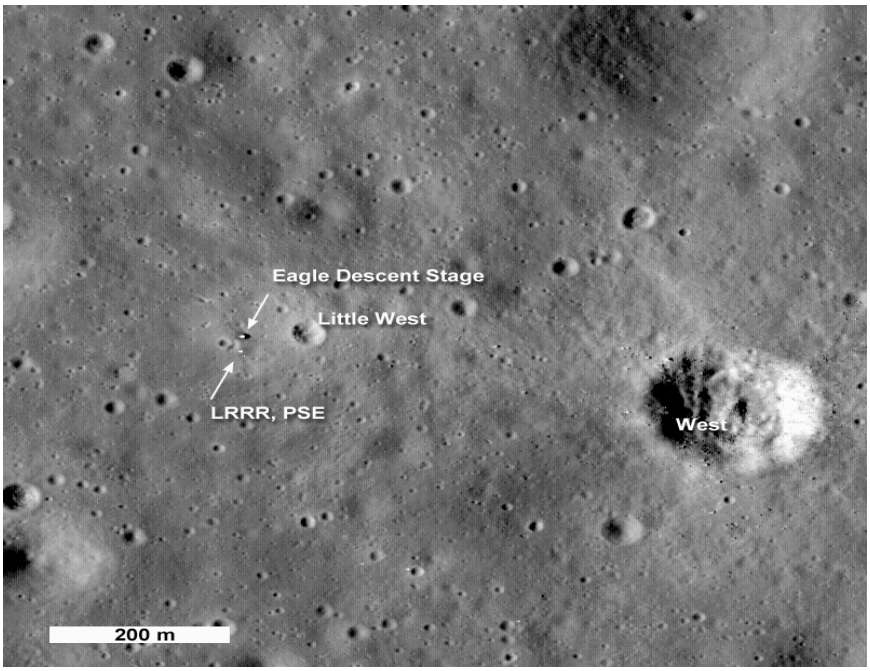


Figure 2. This far side image was taken by Apollo 16 astronauts. (Apollo 16, AS16-3021):

4. Now that you have both sides of the Moon drawn and labeled, did your estimate for the percentage of maria on the Moon change? If so, how did it change? Explain in detail. Remember to use your journal.
5. If you were an astronaut going to the Moon, where would you go if you wanted to be as safe as possible— the Near side, or the Far side? Explain your answer and describe what you mean by safe.
6. Do you have any questions to ask at this time?



C. Scientists also count the number of craters on the surface of the Moon. Craters help them figure out the history of the Moon and Earth. Scientists also try to find out how big craters are and know how to measure them in meters and kilometers. Now let's count and measure impact craters! Use the image of West Crater to the left.

Figure 3. This image of the Apollo 11 landing site was taken with a camera aboard the Lunar Reconnaissance Orbiter (LRO). The spacecraft has been orbiting the Moon and collecting data since July of 2009. The orbiter has many instruments on board. The camera that created this image is called LROC, which is short for Lunar Reconnaissance Orbiter Camera.

worksheet

Directions: Study the image of the West crater area on the next page and read the questions. Use your journal to record your answers and any questions you may have at this time. Be sure to use the resources in the supplemental materials section.

The previous image of the Apollo 11 landing site here also has a scale bar in meters to help you find the sizes of, and distances between, features. NOTE: 1 km = 1000 m.

1. How many impact craters can you find in the image below?
2. The scale bar represents 200 meters. What is the diameter of West Crater in meters?
3. What is the diameter of Little West Crater in meters?
4. Remember, 1 km = 1000 m. Use this information to answer the following:
   a. What is the width of the image in kilometers? (That means from side to side).
   b. What is the length of the image in kilometers? (That means from top to bottom).
   c. 'Eagle' is the name of the Apollo 11 landing craft on the Moon. What is the distance between the Apollo 11 landing site and the center of West Crater in kilometers?
5. Look at the image carefully. What obstacles did Astronauts Neil Armstrong and Buzz Aldrin have to avoid when finding a spot to land the Eagle?
6. Can you see some areas that look like they might be impact carters, but are too dim for you to really decide? Explain your answer.

Resources:

VIDEO: Here is a video resource that demonstrates how an impactor forms a crater. Simulated Meteor impact in slow motion: http://www.youtube.com/watch?v=XzIw0c_MjTc

VIDEO: Here is a video demonstrating how LRO determines a safe landing place on the Moon: http://www.youtube.com/watch?v=dySd8l6rSEI

Impact Craters

Impact craters and volcanoes look much the same on the Moon as they do on Earth. Therefore, Scientists can use features on the surface of the Earth as a comparison for the Moon. During the following activities you will be a mission scientist trying to figure out what has been happening on the surface of the Moon. Geologic features on the Moon are easy to identify if you know what you are looking for. The following is a description of some of the most common geologic features on the Moon. Becoming familiar with these features will assist you in completing the activities that follow.

Impact craters on the Moon, Mars or any other planetary body, are formed when interplanetary bodies such as meteoroids, asteroids and comets slam into planetary surfaces displacing rock and pounding rocks into dust and regolith. Regolith is similar to soil except that it does not contain any organic matter; hence, it cannot be called soil. The impacting bodies strike the Moon at a wide range of impact speeds with 20 kilometers per second being the typical speed. Such a high-speed impact usually produces a crater that is 10 to 20 times larger in diameter than the impacting body. The bowl-shaped depression created by an impacting body is generically called an impact crater. Impact craters on the Moon vary in size from tiny micrometeorite crater sizes to 2,092 km (1300 miles) in diameter. The crater may have several parts, or features, although not all of these features are visible in all craters. Some craters are simple, small craters that appear to be circular depressions, and others are larger with features that are more complex. Material displaced by the impact blows upward and outward and falls back to the surface. This material is called ejecta. Other features that may form include breccias, fractures, impact melt, central peaks, and a ring of blocky mountains caused by compression and rebound of the crater floor materials.

Figure 4: The LROC image of the crater shown has features that you can identify. Also, can you tell from what direction the Sun is shining on this area? How can you tell?

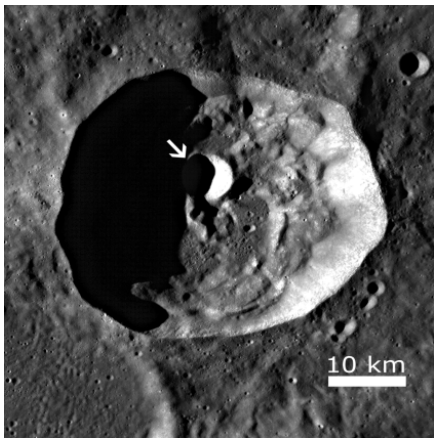


Figure 4. Credit NASA GSFC/ASU.

Figure 5. Credit NASA GSFC/ASU.

Much of the material ejected from the crater during impact is deposited in the area surrounding the crater. Close to the crater, the ejecta usually forms a thick continuous layer of debris. At larger distances the ejecta may occur as discontinuous clumps of material. Some material ejected upon impact is large enough to create a new crater when it falls back down to the surface! These new craters are termed secondary craters and frequently occur as a chain of craters that point back to the original crater.

Figure 5: A string of secondary craters are clearly visible in this LROC image taken from the Lunar Reconnaissance Orbiter.

Upon impact, the material below the surface of the new impact crater is significantly disrupted by the shock of the impact event. Near the surface of the Moon is a layer of breccia, a type of rock composed of coarse, angular fragments of broken-up, older rocks.

Figure 6: This figure shows idealized cross-sections of smaller simple craters (left, top) and of larger, more complex craters (left, bottom). Simple craters have bowl-shaped depressions with rim diameters of less than about 15 kilometers. Craters with diameters larger than 15 kilometers have more complex forms, including relatively flat, shallow floors, central peaks and slump blocks and terraces on the inner wall of the crater rim. In lunar craters with diameters between about 20 and 175 kilometers, the central peak is typically a single peak or small group of peaks. Lunar craters with diameters larger than about 175 kilometers can have complex, ring-shaped uplifts. When impact features exceed 300 kilometers in diameter, they are called impact basins rather than craters. More than 40 such basins have been identified on the Moon.

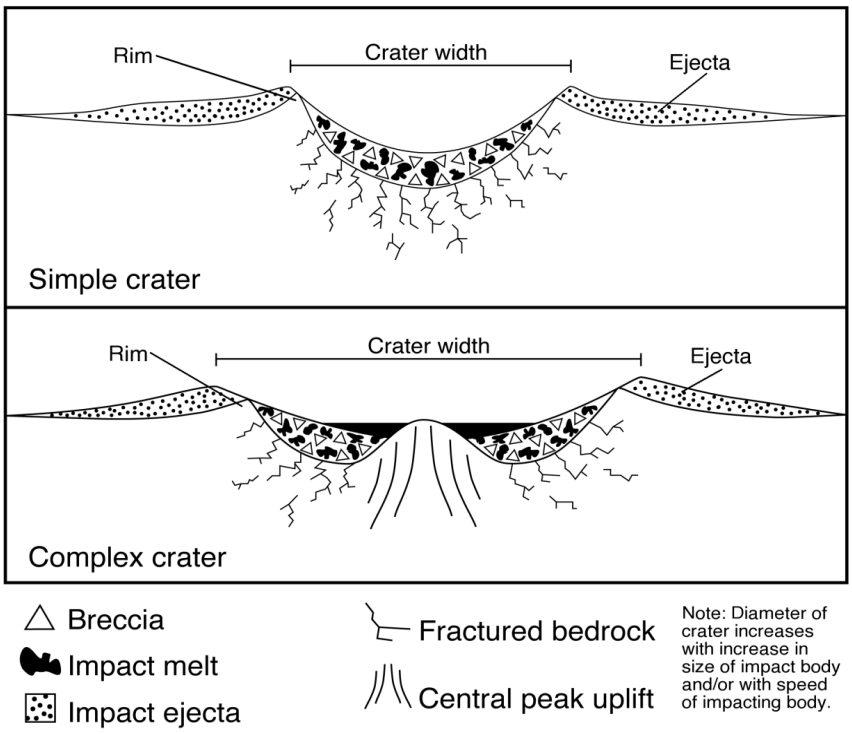


Figure 6. Credit: Lunar Planetary Institute crater(s) graphic modified by Rosemary Millham, 2010.

Rocks at deeper depths within the Moon usually remain in place (called bedrock) but are highly fractured by the impact. The amount of fracturing decreases as the depth below the surface increases. The energy of the impact typically (but not always) causes some material to melt. In small craters, impact melt can occur as small blobs of material within the breccia layer. In larger craters, the impact melt can occur as small to large sheets of material.

Figure 7: Examples of lunar craters from left to right illustrate simple, intermediate (Bullialdus Crater with central peak), and complex craters. LRO LROC images.

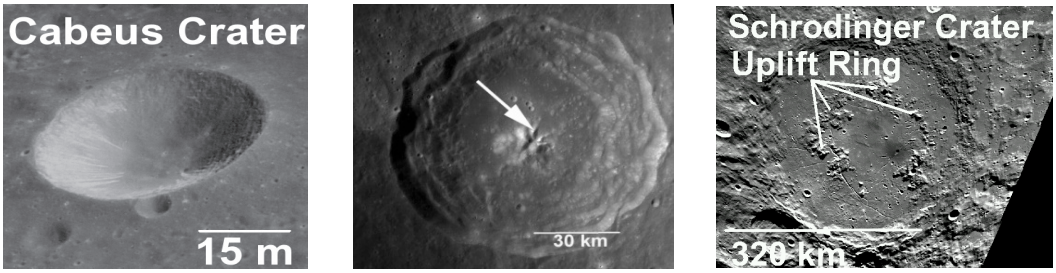


Figure 7. Credit: NASA GSFC/ASU.

Now, let us look at images of real craters on the Moon and apply what we now know, one feature at a time. The image below is of the craters Gauss and Hahn, both being complex craters. Craters similar to these are found on the Moon, Earth and Mars. So, you might ask why we do not see all of these craters on the surface of the Earth. On Earth, we experience weathering/erosion, earthquakes and volcanic activities caused by movement of crustal plates in a process known as plate tectonics. All of these processes help to reshape the surface of the planet through time. Additionally, Earth has a significant atmosphere where most small meteoroids (they are meteoroids in space; meteors as they burn in the atmosphere and meteorites if they land on Earth) burn up before they can impact the Earth. Meteoroids burn due to friction caused by the meteor moving through matter (air and other particles in this case) in the atmosphere where they usually burn up long before they reach the surface of the Earth. Mars has an atmosphere as well, but it is thinner than Earth's and many meteors do not burn up completely before they strike the surface of Mars. The Moon has no true atmosphere and meteoroids strike the surface unchanged before impact.

Figure 8: This LROC image shows a portion the large Gauss crater to the upper right with several noticeable craters on the crater floor. The partial image of the Hahn crater to the lower left has noticeable central uplift peak and an impact crater on its rim. Some impact craters are enormous while others are so tiny they are hardly noticeable even for the astronauts walking on the Moon during the Apollo program.

Looking at craters can be fun when deciding what kind of features can be seen, especially when they are complex craters. Observe and note the craters on and in Gauss and Hahn craters in figure 5. We can clearly see the depressions, or craters, and the raised area around the edge of the craters called the rim. The rim is comprised of displaced rocks and regolith that were thrown upward and outward by the violence of the impact that created the craters. The walls of the crater slope downward to the floor of the crater and often appear to be flat. If the impact is violent enough to melt the rock that becomes the floor of the crater, a central peak will often form due to the compression of solid rock and subsequent rebound of rock from a significant depth inside the Moon. You can see an example of a central peak for yourself by adding drops of water to a glass of water. As each drop hits the surface of the water, a crater will form, complete with a central uplift peak.

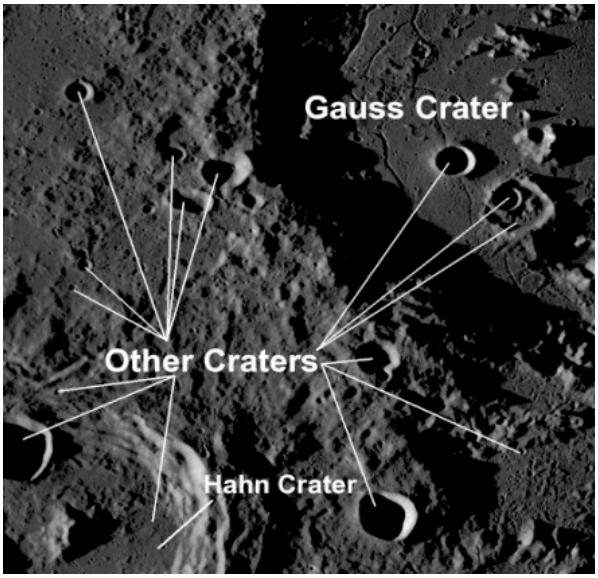
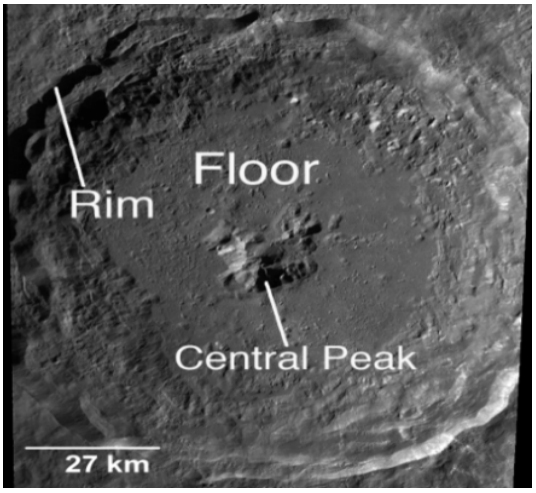
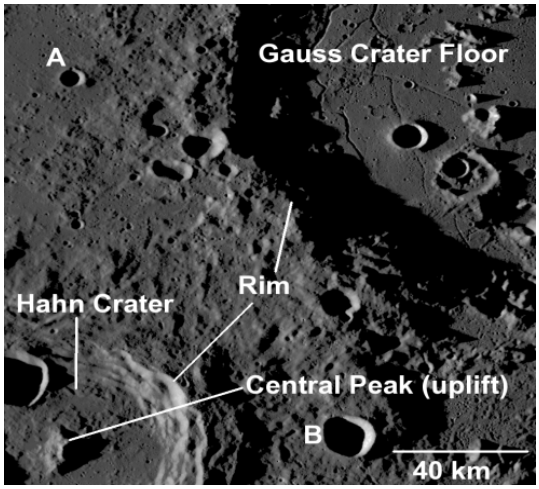


Figure 8. Credit NASA GSFC/ASU.

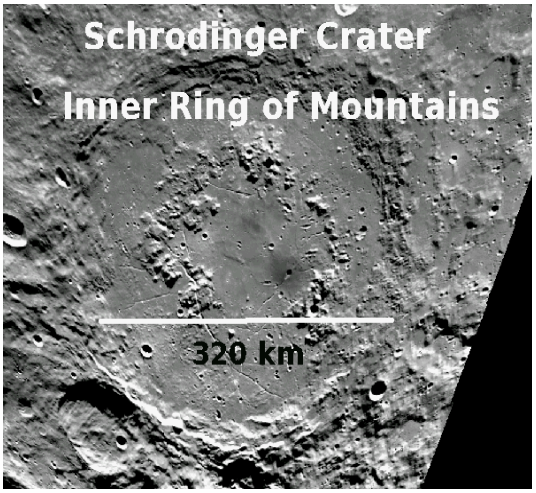


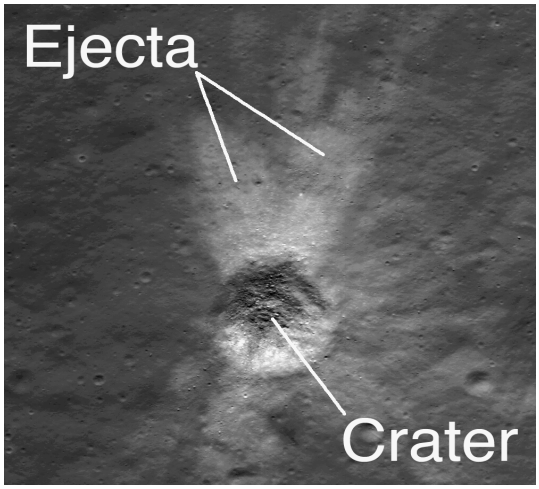


Figures 9 and 10. Credit NASA GSFC/ASU.

Figures 9 and 10: LROC WAC image (on left) of Tycho crater. This image clearly shows the circular depression, central peak, and rim of the large crater, Tycho. In the figure to the right, the LROC Wide Angle Camera (WAC) images that created this mosaic image were acquired on July 8, 2009. On the bottom left is Hahn crater with its terraced walls that form as material slumps down the sides, and central peak that rebounds from depth during the impact process. Can you determine the approximate diameter of the Hahn crater with the limited information provided? How about the diameters of craters labeled A and B?

If the impact is large enough, an inner ring of blocky mountains will also form on the floor of the crater (below, left). Some of the material in the crater can be thrown high into the air and land outside the crater in an irregular blanket called ejecta (below, right).





Figures 11 and 12. Credit NASA GSFC/ASU.

Figures 11 and 12: Above, the LROC image of the Schrodinger crater clearly shows the inner ring of mountains formed in many very large impact craters on the Moon. The inner ring looks circular and chunky. To the right, the LROC image displays distinctive asymmetrical ejecta surrounding this 140-meter diameter crater in the lunar highlands. What do you suppose would cause the ejecta to blow outward from the crater asymmetrically instead of in a symmetrical pattern? Credit NASA GSFC/ASU

In addition to all of the features discussed above, crater floors are usually fractured by the stress of impact to the bedrock, and possibly by intrusive magma solidification and contraction. These fractures are visible in some crater images as seen in figure 10.

Figure 13: Can you find the fractures in the Gauss crater to the upper right in this image? Is there an inner ring in this crater? Explain your reasoning. The small crater in the lower left is about 18 km in diameter. The Wide Angle Camera (WAC) images that went into the mosaic image were acquired on July 8, 2009.

Now, let us put most of the features together and see if you can identify all of them. Can you find the following— a circular depression, crater floor, rim, central peak and wall? Is there a noticeable inner ring of mountains? What is the diameter of this crater? Is this a simple or complex crater? What reason(s) can you provide to support your answer?

Figure 14: The unusual shapes of craters at the Flamsteed Constellation region provide information about the thickness of the lunar regolith in this region. Image M111877836LE; scene width is 500 m.

Figure 13. Credit NASA GSFC/ASU.

Figure 14. Credit NASA GSFC/ASU.

worksheet

STUDENT ACTIVITY 2

So, What is an impact crater, really, and how does it happen?

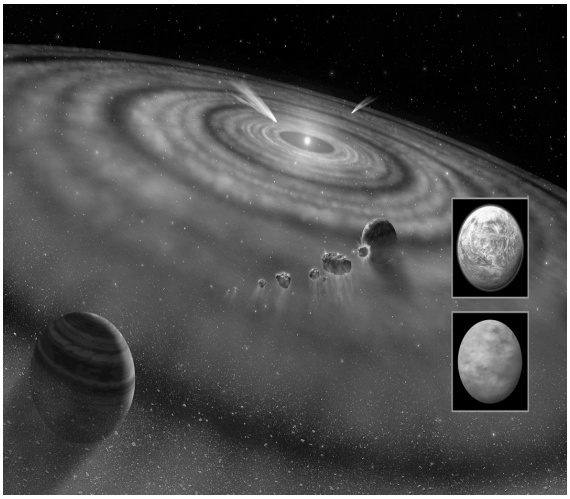


Figure 15. **An artistic illustration of the formation of our early Solar System. Credit: NASA.**

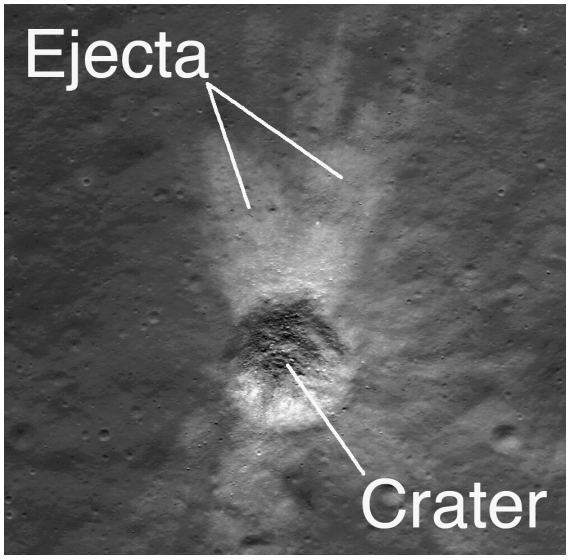


Figure 16. **Impact crater and its associated ejecta.**

Early in the history of our solar system, dust and gases were spinning around in space. Our star was forming in the center of the system. Planets and moons were forming around the star. Some of the dust and gas came together to form the Sun, planets, and moons. Some of the material did not form planets, stars, or moons, and were simply swept aside by the Sun and gas giants. These objects became interplanetary bodies (debris) and include asteroids, comets, and meteoroids. They orbit the Sun just like the planets and moons.

The debris travels in an orbital path around the Sun that often crosses the paths of planets and moons. When this happens, they can impact the surface of a planet or moon, or each other! The debris that strikes a surface is called an impacting body. Upon impact, a depression called an impact crater is formed. When an impacting body hits the surface of the Moon, rocks and regolith (top layer) are usually blown outward from the crater. This is called impact ejecta.

The image to the left is an LROC image of an impact crater and its associated ejecta.

Most of the ejecta falls outside of the crater and is clearly visible around the crater. If the impact is large enough, it can cause melting of the rock and regolith on the crater floor. Regolith is broken down rock, just like soil, but does not have biogenic materials. Without the biogenic stuff, it is not soil.

Some smaller impacting bodies create small, simple craters. Larger impacting bodies can create larger, complex craters. Craters can be very simple, very complex, or anything in between.

To classify craters we study the crater features. Some of the features we study are:

1. The diameter of the crater
2. The amount of impact melts, if any
3. If it has a central peak uplift
4. The extent of fractures in the crater floor
5. If the crater has a ring of blocky mountains circling the central peak uplift.

The blocky ring of mountains is caused by impact compression and rebound (See crater formation diagram).

Simple craters, of course, have a depression, ejecta, fractures, breccia, and maybe some melted rock. Complex craters have everything a simple crater has and more! They usually have central peak uplifts, a ring of blocky mountains circling the central peak uplift and quite a bit more melted rock. After we study a crater we decide if it is simple, complex, or something in between.

A. How do craters form? The size of an impact body, direction/ angle of impacting body, and its speed at the time of impact, has a lot to do with the kind of crater that forms. The following cartoon shows the structure of both simple and complex craters.

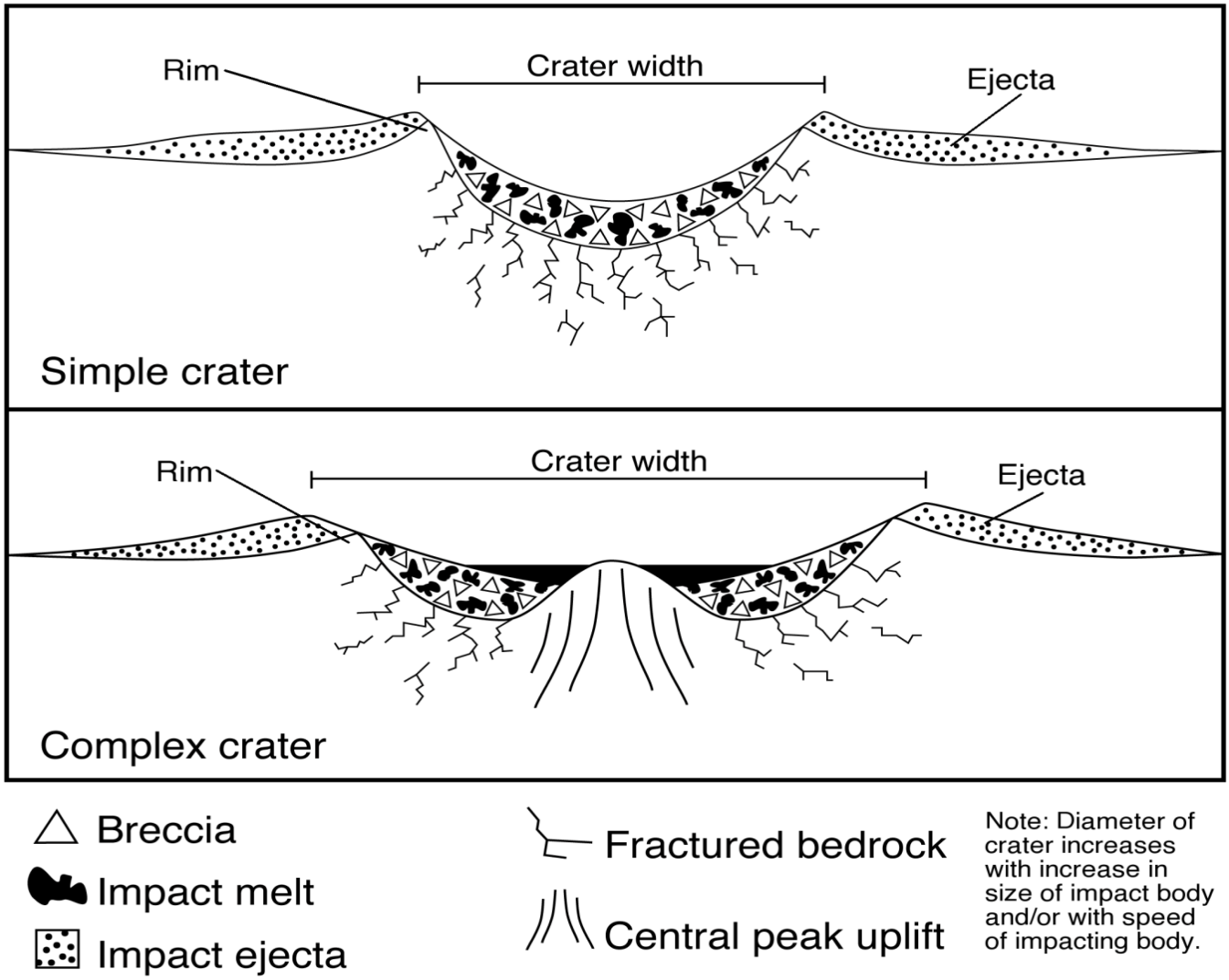


Figure 17. Credit: Lunar Planetary Institute crater(s) graphic modified by Rosemary Millham, 2010.

Directions: From your understanding of the readings in this activity, compare the similarities and differences between the two crater drawings in the cartoon. Describe, trace, or draw and label your thoughts in your journal. Be sure to use the resources in the supplemental materials section.

Now, let's take a better look at what a crater looks like. The images below show craters on Earth and Moon. In the early history of Earth, many interplanetary bodies hit Earth and Moon. We can see thousands of craters on the Moon, but not on Earth. Why can't we find a lot of craters on Earth? Earth is a tectonically active planet with an atmosphere. Earth experiences weather, earthquakes, volcanic activity and other processes that change the surface of Earth every day. The Moon has no true atmosphere or tectonic activity. It has looked the same for millions of years, except for new craters and melted rock flows from impacts.

worksheet

B. Look carefully at the pair of images below. Can you see any differences or similarities in the crater images? How many craters can you find in each image?

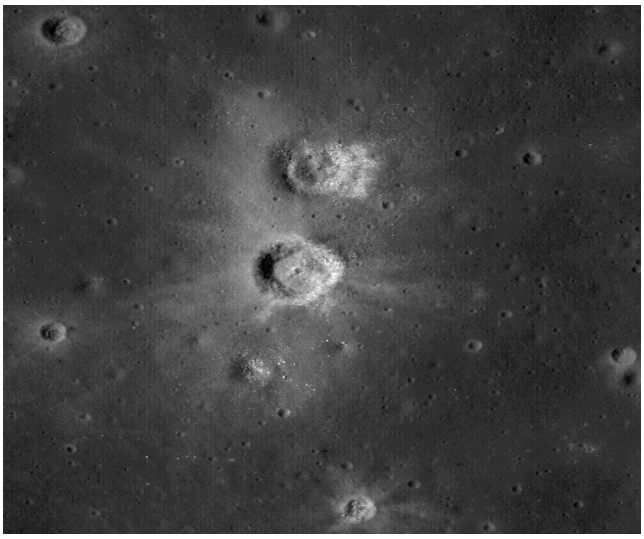


Figure 18.

FIgure 19.

1. What are the similarities?
2. What are the differences?
3. How many craters can you find in Figure 18?
4. How many craters can you find in Figure 19?
5. Which image is an Earth crater image? How do you know this? Explain.

Directions for the images above: Write what you see in your journal using questions 1 through 5 above as your guide. Please note that both images were taken from a birds-eye view. Figure 18 from directly above and Figure 19 at an angle from above.

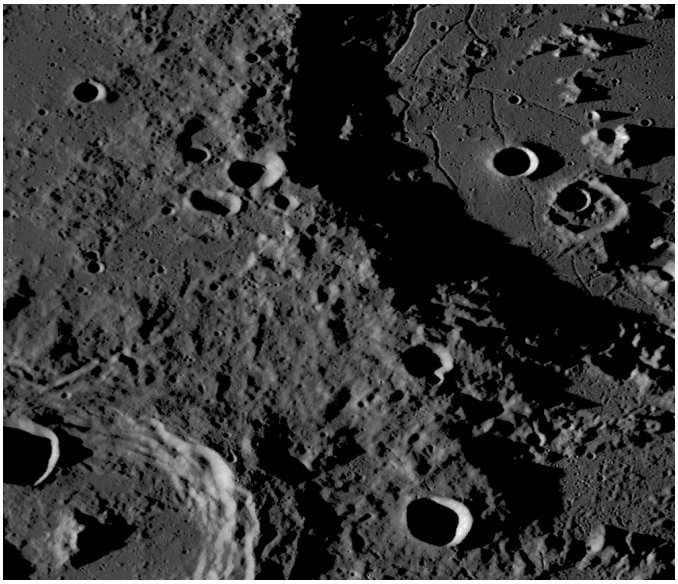


FIgure 20. This image is from the Lunar Reconnaissance Orbiter Camera, LROC.

C. Now, let's see what we know! What do craters really look like? What are the features craters are likely to have?

Directions: In your journal, draw or trace the image in Figure 20 and record what you see using the hints provided below. Write down anything you think you see, and try to explain what it is. Please note the image was taken from above at an angle to the craters. Be sure to use the resources in the supplemental materials section.

Here are some helpful hints to get you started:

1. Do you see any circular shapes?
2. Do you see any shapes that are parts of circles?
3. Do you see any cracks (fractures)?
4. Are there any shapes you cannot identify? What do they look like and where are they located?

5. Can you see any central peaks or inner rings of mountains?
6. Can you identify the crater floors?
7. If the top of the image is north, from what direction is the Sun shining?
8. How do shadows change how you can see features on the surface of the Moon?
9. There are some craters on the Moon that are so deep that parts of the craters are always in shadow. Scientists are very interested in these shadowy areas known as permanently shadowed regions. Can you guess why?

D. How does sunlight change what you see?

Directions: The different angles of the Sun allow scientists to see surface features in different ways. In images A and B below, look at the shadows and light, read the following questions, and answer them in our journals (Be sure to use the resources in the supplemental materials section):

1. From what direction is the Sun shining in Figure 21?
2. What clues provide you with this information?
3. What features are easier to see in Figure 21 as compared to Figure 22?
4. What features are easier to see in Figure 22 as compared to Figure 21?

Look at the images below. Figure 21 is an LROC image of the Apollo 11 landing site near Little West crater on the Moon. The scale bar reads 500 meters. Figure 22 is also an LROC image of the Apollo landing site. The scale bar on this image reads 200 meters. Notice the thin light lines? These are tracks left by the Moon buggy.

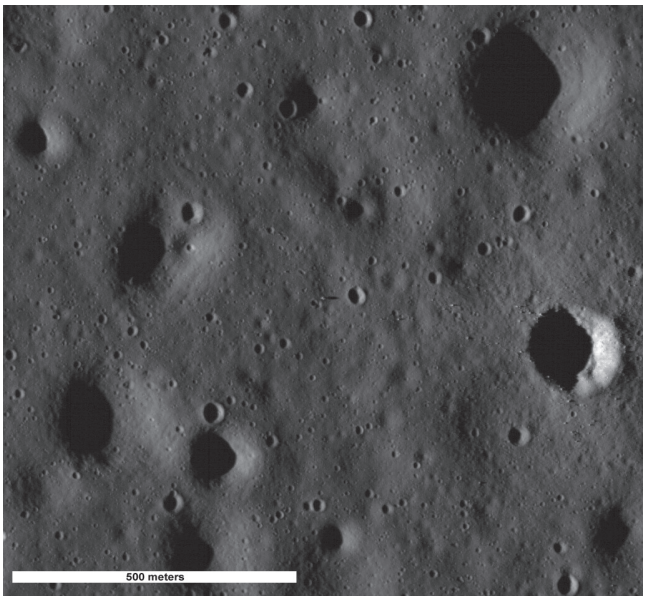


Figure 21.

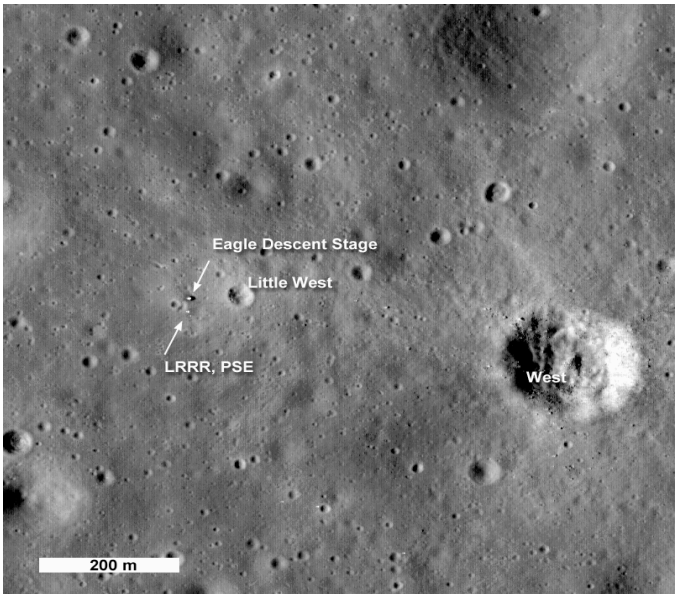


Figure 22.

5. What obstacles do you believe Astronauts Neil Armstrong and Buzz Aldrin had to avoid when landing the Eagle (lunar lander) on the Moon in 1969?
6. In which image are the obstacles more noticeable? Explain your answer.
7. What is the distance between the two largest craters in image A? How did you determine this?
8. What is the distance between Little West crater and West crater in image B? How did you determine this?
9. What is the total distance from W to E in image A? Image B? How did you calculate these answers?

Volcanoes

On the Earth, volcanoes are hills or mountains created from built-up layers of lava (molten rock, or magma, on the surface) ejected from cracks or vents in the planet's crust. Material far below the surface of the Earth can become so hot that rocks melt and form magma. Now, the Earth is composed of layers as seen in Figure 23. The inner core is solid, the outer core is liquid and the mantle with its lower, middle and upper section is a somewhat solid feature. The mantle's uppermost layer is the asthenosphere, an amorphous solid (meaning it is not truly a liquid or a solid) that allows for some extremely slow movement of the crust at the surface of the Earth. Above the asthenosphere is the oceanic and continental crust. The oceanic and continental crusts together with the uppermost mantle make up the lithosphere of the Earth (Figure 23).

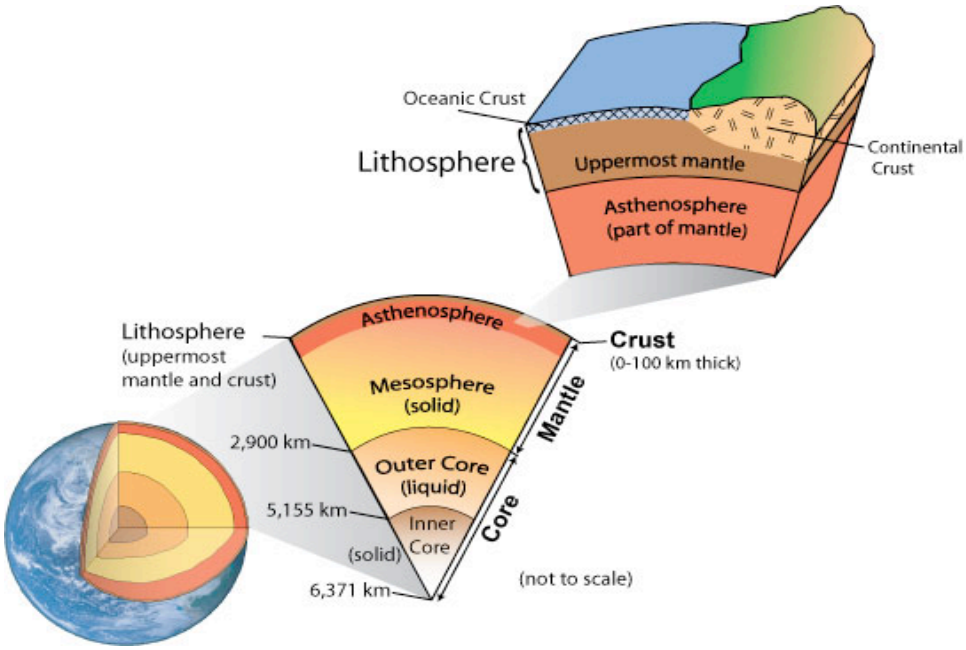


Figure 23. A schematic of the layers of the Earth illustrating the layers and the approximate depth for each layer. Credit: USGS

The lithosphere is made up of many plates that move around on top of the asthenosphere as heat from the center of the Earth migrates upward and convects at the boundary between the upper mantle and lithosphere (Figure 24).

Some of these plates collide (convergent plates) like the India plate as is converges with the Asian continent creating the Himalayan Mountains. Some plates move away from each other (divergent plates) as heat convection reaches the surface and pushes two plates apart. The Atlantic Ocean has been increasing in size for millions of years as the ocean's crustal plates diverge and lava fills in the empty space. Another type of plate movement is the transform fault. The San Andreas Fault in California is the best example of this type of plate boundary where one plate moves laterally relative to another. In all plate movement cases, earthquakes can occur.

Volcanoes, however, occur at convergent and divergent plate margins and in regions known as hot spots. Located in random regions of the mantle are isolated areas of magma not associated with plate boundaries. These hot spots form volcanoes at the surface wherever they happen to be. The Hawaiian Islands are a good example of hot spot volcanic activity. The oldest Hawaiian island is to the northwest, which would indicate the pacific plate has been moving northwestward as the hot spot plume of lava has been creating each island. Yellowstone National Park is another well-known hot spot region known for its volcanic activity and super-heated water eruptions.

Also important to note is that the type of volcano, and the kind of volcano that forms as a result of volcanic activity, is usually dependent upon the composition of the melted rock below the surface, or magma. Continental crust is composed mainly of lighter, less dense silicate minerals, such as feldspars and quartz (SiO2 quartz). Oceanic and mantle materials are darker, denser basaltic rocks higher in iron and magnesium. The higher silica (SiO2 quartz) content in continental crust causes the magma

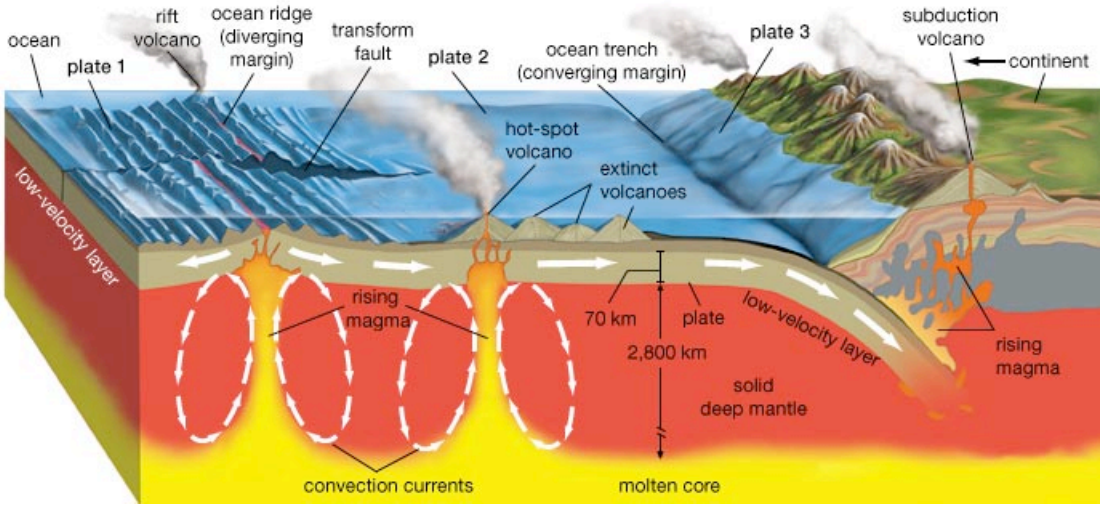


Figure 24. Schematic of convection currents (cells) and plate movement in the Earth's crust. Note the connection between the direction of convection current movement and the movement of the plates relative to one another. Credit: USGS

to be more viscous (resistant to flow) causing volatile gases to be trapped easier than they are in oceanic or mantle magma (see Figure 24). The gases get trapped and, as pressure builds up, the magma may burst through the crust in an explosion of ash, dust, and/or cinders alternating with lava flows. Alternatively, oceanic and mantle rocks are lower in silica and are less viscous allowing the gases to escape less explosively. Hence, lava flows from oceanic crust material produce much calmer basaltic lava flows. So, let us keep these things in mind:

- The composition of the materials that make up a magma are directly related to the type of volcanic eruption and the type of volcano that will be produced as a result
- The amount of silica in magma determines the viscosity of the lava (viscosity is a measure of the materials resistance to movement). The higher the amount of silica (quartz) in the magma, the more viscous, or resistant to flow, the magma becomes
- Highly viscous magmas usually produce violent eruptions of lava, ash, dust and cinders
- Low viscosity magmas usually produce much less explosive lava flows

Most volcanoes have similarities in their features. At the top of the volcano is a roughly circular depression. This volcanic depression is called a crater (not to be confused with an impact crater) if it is small and is the result of cooling lava contracting and sinking. A volcanic depression is a caldera if it is large (greater than one mile (0.6 km) in diameter, and is primarily caused by the collapse of the depression rather than cooling as in volcanic craters (although cooling and contracting is also part of the process).

There are three major types of volcanoes with classifications based on how they erupt and how they form. Remember that volcanic eruptions and formation is dependent upon the composition of the magma. The major volcano types are shield, cinder cone, and composite (stratovolcanoes).

Shield volcanoes are low in silica (SiO2 quartz), usually contain higher amounts of iron and magnesium, and lava flows are generally not explosive (less resistant to movement means lower viscosity). The domes of shield volcanoes are much wider than they are high (shaped like a shield) and have very low-angle slopes (see Figure 25 on next page). They are formed from hot, free-flowing silica-poor basalt in non-explosive lava flows. The largest volcano on Earth is a shield volcano called Mauna Loa. It rises over 9 km (5.4 miles) from its base on the sea floor! The uppermost portion of Mauna Loa is the "Big Island" of Hawaii. The largest volcano in the solar system, Olympus Mons on Mars, is also a shield-like volcano. Olympus Mons is almost 27 km (17 miles) high and its base is almost 700 km (430 miles) across. On Earth, it would cover an area the size of Arizona!

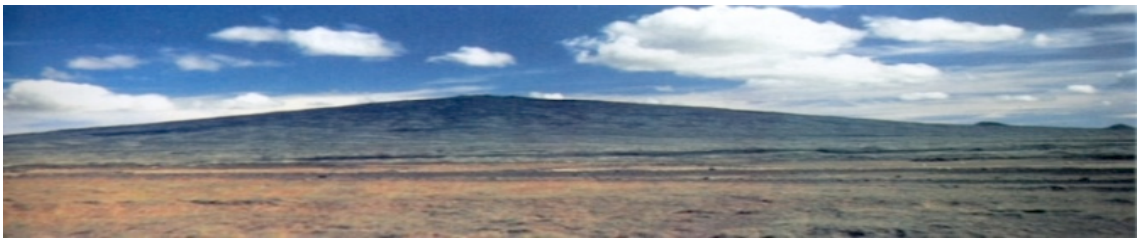


Figure 25. This volcano in Iceland is a classic example of a shield volcano. Low and wide, it is wider than it is tall. Credit: USGS

Cinder cones are the simplest type of volcano. They are built from particles and blobs of congealed lava usually ejected from a single vent (Figure 26). Gas-charged lava is blown violently into the air and breaks into small fragments that solidify and fall as cinders around the vent forming a circular or oval cone (Figure 27). Most cinder cones have a bowl-shaped crater at the summit and rarely rise more than a thousand feet or so above the surrounding land. Cinder cones are numerous in western North America and throughout other volcanic terrains of the world. The most famous cinder cone on Earth appeared in a Mexican farmer's cornfield in Parícutin in1943. The cinder cone erupted for nine years and reached a height of over 400 meters (1300 feet)! Fact or Fiction, it is reported the farmer charged a fee for tourists to watch this awesome site, and made more money in tourism than he ever made farming.

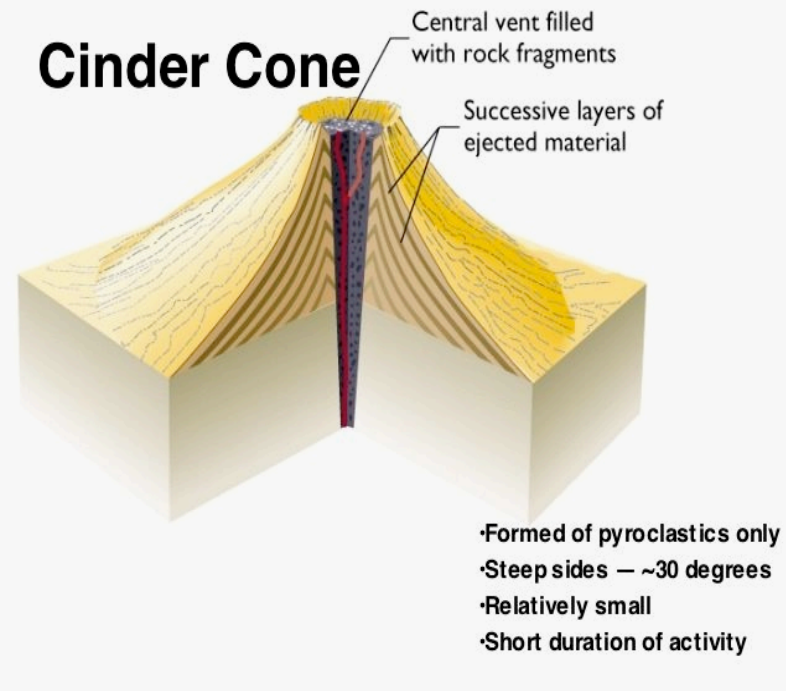


Figure 26. Classic diagram of the cinder cone type of volcano. Credit: Modified image with permission from the Florida State University Geology Department.

Figure 27. This is an image of a real-life cinder cone volcano located at Sunset Crater (that is what it is) in Arizona. Credit: USGS.

Very sluggish lava doesn't flow very far from the vent and gets heaped up into a bulbous "plug", giving a subset type of volcano the name plug dome. Plug domes are usually small, rising not more than a few thousand meters above the surface. Spatter cones, another subset, are of a similar size, but are formed from gas-charged lava fountains that spew lava high into the air.

The most common type of volcano on Earth is the composite, or stratovolcano (Figure 29 on next page). It is actually a blend of the other types of volcanoes in that it has periods of quiet eruptions of free-flowing lava, alternating with violent, explosive silica-rich eruptions with lots of ash and other solid materials. Mount St. Helens in Washington, an example of this type of volcano, erupted violently on May 18, 1980 ejecting ash, dust and lava miles into the atmosphere.

worksheet

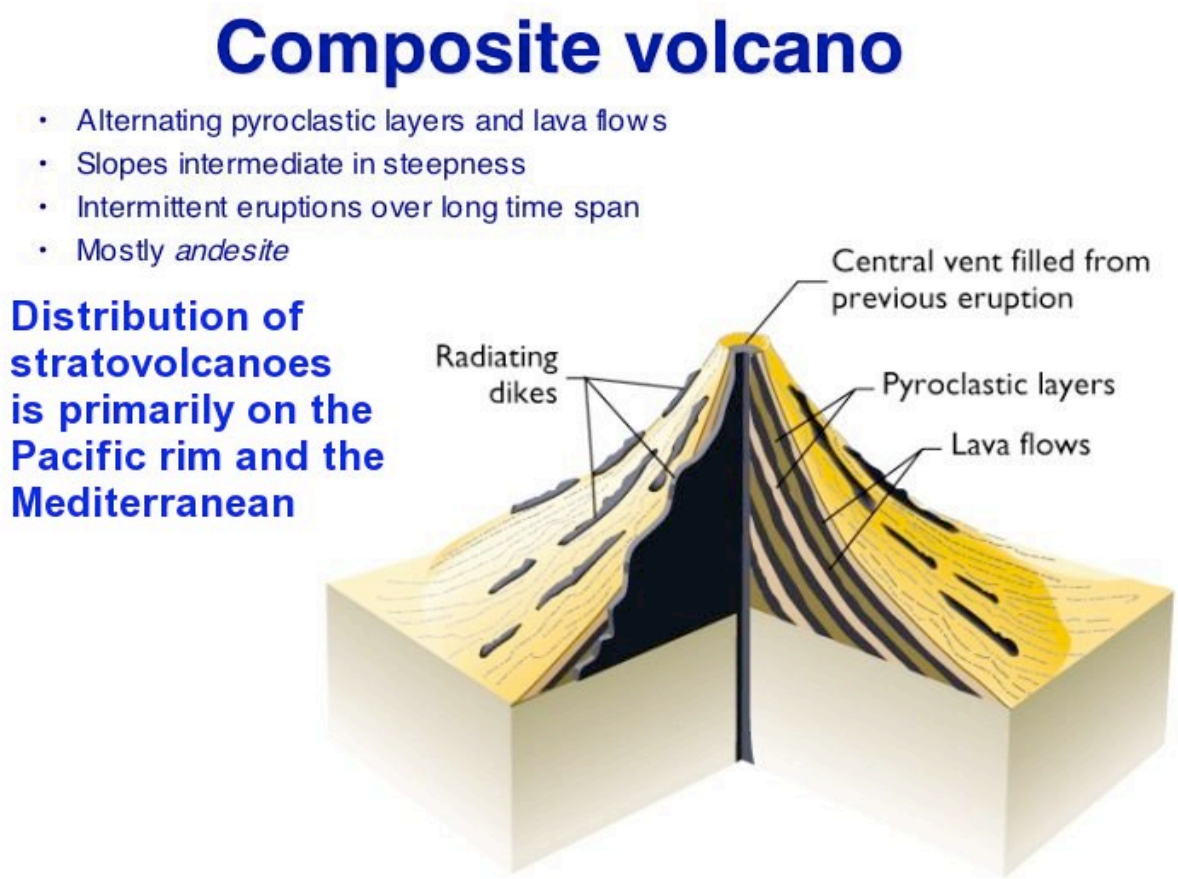


Figure 28. Classic example of the composite or stratovolcano, this diagram illustrates the alternating types of eruptions that identify the volcano type. Alternating eruptions of pyroclastic layers and lava flows composed of highly viscous silica minerals, these volcanoes can explode viciously spewing ash, dust, pyroclastics and lava high into the atmosphere. Ash is significantly important as it is light and can reach the stratosphere where it can remain for extended periods-of-time before dropping into the troposphere to where it can be washed out of the atmosphere with precipitation. Credit: modified image with permission from the Florida State University Geology Department.

Figure 29. Composite volcano Mt. Rainier is the backdrop for the city of Seattle, Washington. A beautiful backdrop for a coastal city, it is part of the chain of volcanoes that includes Mt. St. Helens in the Cascade Range. Credit: USGS.

worksheet

Volcanoes and the Moon

As we know from previous readings, the light colored regions are called the lunar highlands. The highlands are where the oldest lunar rocks are found. These regions contain craters representing the results of thousands of impacts from meteoroids, asteroids, comets and other interplanetary debris since the Moon formed a solid surface. The smooth, dark maria are younger surfaces on the Moon and are composed of solidified basaltic lava. They contain craters, but not as many as found in the lunar highlands. The majority of lava rocks found in the maria and craters of the Moon erupted as typical volcanoes, or lava flowed into impact basin depressions due to collisions with interplanetary debris. Although the Moon does not contain large shield volcanoes as can be found on Earth and Mars, small dome-like features with pits at the peak are probably small lunar volcanoes. As on Earth, there are clusters of dome-shaped and cone-shaped volcanoes across the lunar surface. One such area on the Moon is shown in the LROC image in Figure 30.

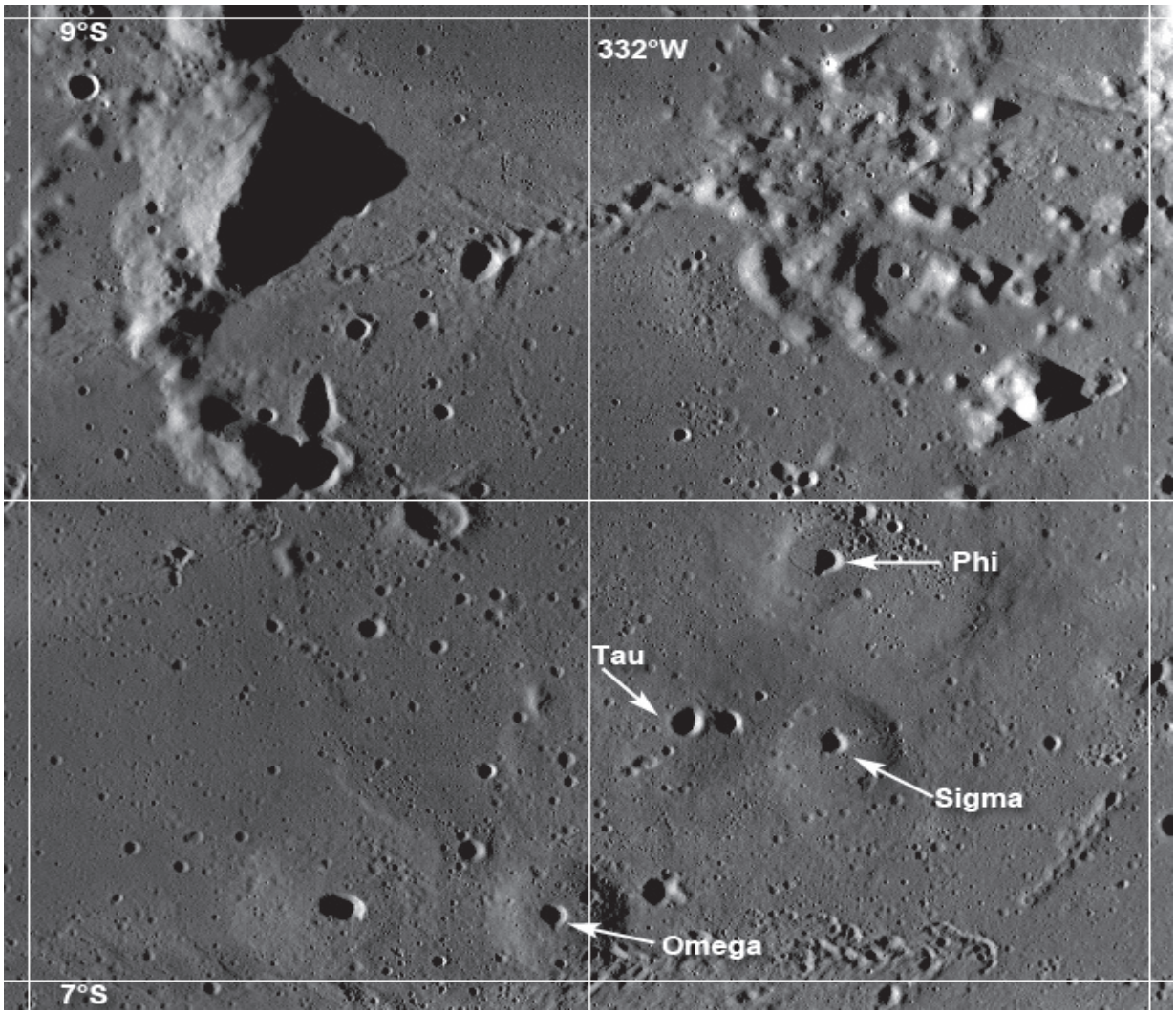


Figure 30. Four main domes in the Hortensius region (Phi, Tau, Sigma, and Omega). The domes display very little relief, making them visible only at low-sun angles, LROC WAC mosaic. Credit NASA/GSFC/ASU.

worksheet

Rilles

A rille is any of the long, narrow depressions in the lunar surface that resemble channels. They may be linear or sinuous (curvy) and can stretch up to several kilometers wide and hundreds of kilometers in length. They often originate and occur down slope from irregular depressions. They are believed to be the result of lava flows and would therefore be lava channels much like a river channel. It is also possible that these channel-like structures could be collapsed lava tubes.

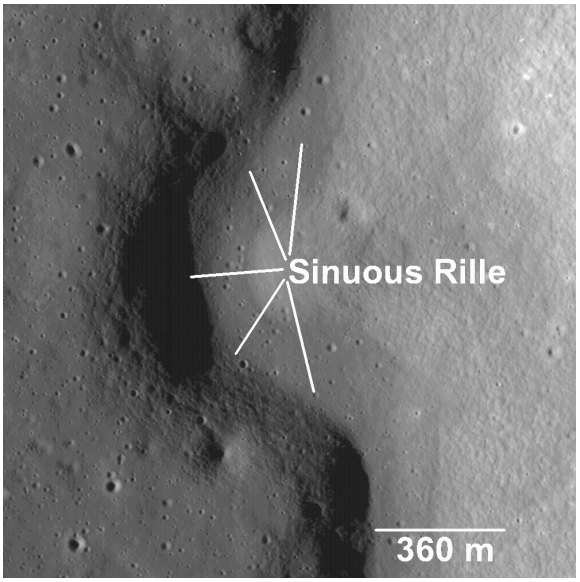


Figure 31 and 32. Rilles in the image at the left are clearly visible in what looks like tire tracks across the crater floor. A close up of a sinuous rille from the LROC image below shows an oxbow bend along the length of a rille. The tight twists and turns of sinuous rilles suggest that a very turbulent lava flow forms this type of rille. North is at the top of the image. Credit NASA GSFC/ASU.

Wrinkle Ridges

Wrinkle ridges are low, sinuous ridges formed by horizontal compression during tectonic activity. They can extend up to several hundred kilometers and are found in nearly all of the lunar maria. Lunar scientists think that there is a genetic relationship between the basalts they deform and the ridges themselves. Basalt is much denser than the anorthositic crust on which the mare basalts are deposited. As the basalt fills in low areas in the crust, the increased weight causes sagging and the mare deposit is compressed, resulting in tectonic deformation in the form of wrinkle ridges.

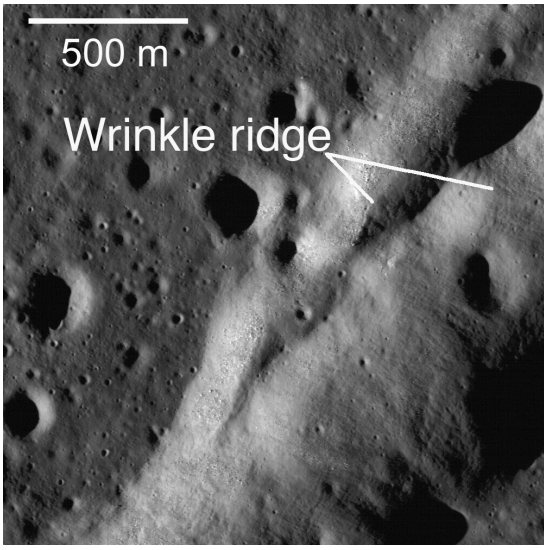


Figure 33. An image of a wrinkle ridge in Mare Imbrium west of the Montes Teneriffe. LROC NAC frame. Credit: NASA GSFC/ASU.

worksheet

STUDENT ACTIVITY 3
Volcanoes on the Moon

A. As we know from our readings, the light colored areas on the Moon are called the lunar highlands. The highlands are where the oldest lunar rocks can be found. The highlands have thousands of impact craters. The smooth, dark maria are younger surfaces on the Moon. They are composed of solidified basaltic lava. They contain craters, but not as many as we see in the lunar highlands. Most of the lava rocks found in the maria and craters of the Moon formed in one of two ways: they erupted as a typical volcano or lava flowed into impact basins after impactors hit the surface.

The images below show where volcanic activity has taken place on the surface. Each type of volcanic activity produces different features. There are many volcanic features on the lunar surface. In fact, the dark lunar mare are huge, fairly level deposits of basalt.

The lunar maria cover about 17% of the Moon's total surface. However, Earth-like volcanoes are rare on the Moon. The Gruithuisen Domes (shown by the black arrows in the Apollo 15 picture to the right) are some of the dome-like volcanic features on the lunar surface. They are made up of lavas that erupted shortly after the mare basalts formed.

Figure 34 was taken during the Apollo 15 mission to the Moon.

The volcanic dome indicated by the arrow on the right is 13 km wide and 1550 m high! The steep sides of the volcanoes suggest that they are cinder cone type volcanoes. Therefore, the magma (lava at the surface) has a fairly high viscosity.

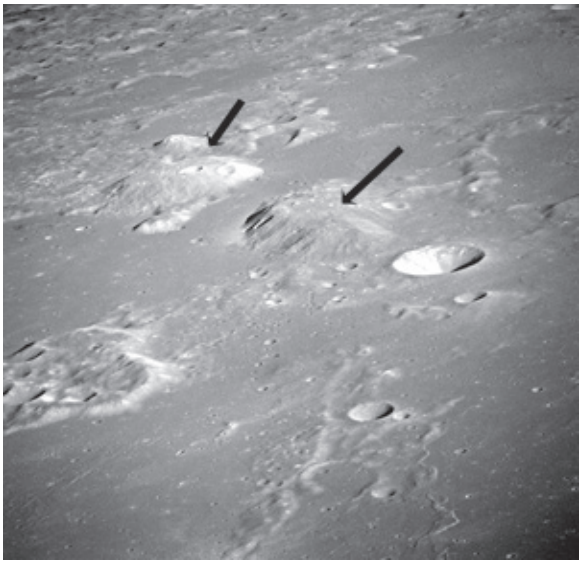


Figure 34. Credit: NASA JSC.

Directions: Draw or trace the image above in your journal and answer the following questions. Be sure to use the resources in the supplemental materials section.

1. Knowing that the volcanic dome located at the arrow on the right is 13 km wide, what is the distance between the two arrows (volcanoes)?

2. The flat areas in the image are maria. What other features can you identify in this image?

B. A **rille** is any of the long, narrow depressions in the lunar surface that resembles a channel. They may be straight lines or curve like a river. They can be several kilometers wide and hundreds of kilometers in length. They often start down slope from impact craters. They are believed to be the result of lava flows. This means that lava channels like a river channel. It is also possible they form as a result of collapsed lava tubes. See the images below for examples of rilles. One is a sinuous rille because it curves and bends. The other image shows fairly straight rilles inside a crater.

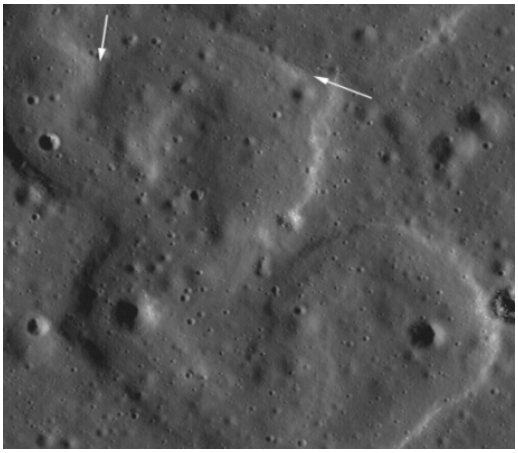


Figure 35.

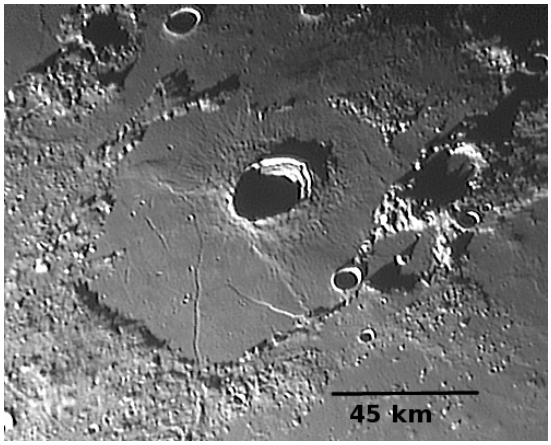


Figure 36.

Directions: In your journal, draw or trace each image above in your journal. Label where the rilles are in each image above and answer the questions below.

1. In Figure 35, can you see any other features other than the rille? If so label them in your journal.
2. After identifying and labeling the rilles in Figure 36, list all of the features you can find and label them on your drawing in your journal.
3. What is the diameter of the largest crater in Figure 36? How do you know this is the largest crater?
4. What is the diameter of the each of the smaller craters in Figure 36?
5. What principle of geology is noticeable inside the larger of the craters i Figure 36?

C. Another feature on the Moon is a wrinkle ridge. Wrinkle ridges are low, curvy (sinuous) ridges formed by horizontal compression during tectonic activity. They can be several hundred kilometers long. They are found in nearly all of the lunar maria.

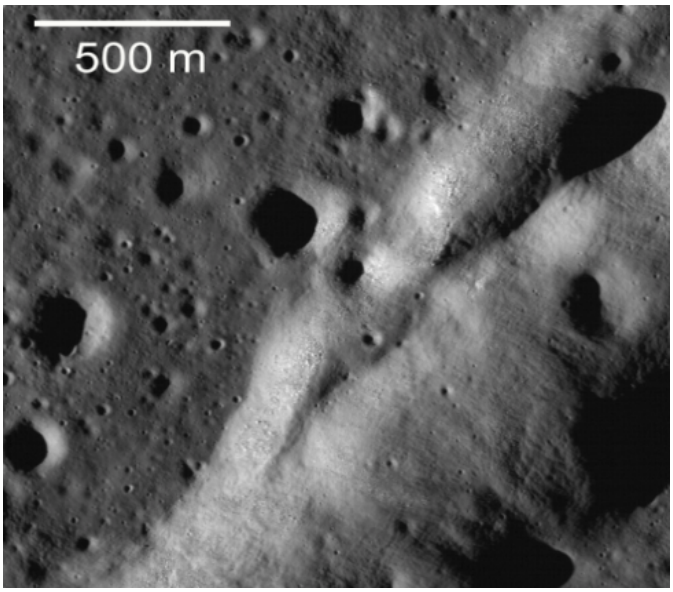


Figure 37. This wrinkle ridge image is found on the Moon. It cuts across the plains of Mare Imbrium. The overall ridge is about 4.5 km wide. Credit: NASA GSFC/ASU.

1. At a scale of 500 m indicated by the white line, how long is the wrinkle ridge in this image?
2. How many craters can you find?
3. Can you describe any features that would support the principle of superposition (see explanation in the next section)? Explain your answer or illustrate and label.

worksheet

Determining the Surface History

Think of the most beautiful and interesting place you have ever seen. Are there mountains, lakes, volcanoes, rivers or rocks there? Do you have any idea how these geologic features were formed? Determining how these and other geologic features formed, and how they influence their surroundings, is the job for geologists. With geologic knowledge gathered from the Earth's surface, geologists can determine what is happening on other planets. Once you have learned to identify geologic features on the Earth, Moon, or other planets, the questions you should ask are, "How were these features formed? Which features were formed first and are therefore older? Which features were formed later and are therefore younger?" The process of answering these questions is called the scientific process and helps geologists determine the surface history of a planet or Moon. In order to make this determination, geologists use three basic rules, or principles, as they unravel the geologic history. Knowing these principles will help you determine the history of the regions of the Moon you will study in the activities that follow.

The Principle of Superposition

The Principle of Superposition describes the order in which geologic units, features, or structures, are placed above or on top of one another. In other words, what came first, second, etc.? Much of the rock material on the Earth's crust is laid down in layers, one on top of the other. The Principle of Superposition states that layers located at the bottom of an undisturbed stack of rocks are older than the layers at the top of the stack. If you think about it, this makes sense. No natural force would have peeled back layers of older rock and then inserted a layer of younger rock in between older rocks. The only place the younger rock could be deposited is on top of the older layers. However, if magma were to seep upward into existing layers of rock (an intrusion) and then spread horizontally through the layers, that intrusion would be younger than the rocks it intruded upon. A common type of igneous intrusion of this type is a sill.

Figure 38. LROC-NAC close-up of clustered craters on the Schrodinger pyroclastic cone. Credit: NASA GSFC/ASU

Figure 38: Above, the LROC-NAC close-up of clustered craters on the Schrodinger pyroclastic cone, one of NASA's former Constellation Program regions of interest. Although they are likely relatively young, the craters in this cluster have a subdued appearance because they formed in loose pyroclastic material. NAC Frame M108313384R, view is 785 m across.

The Principle of Superposition is also applied to geologic features on the Moon. The Principle can be used to determine the order in which the craters were formed as in the image in Figure 38. Older craters can be impacted creating younger craters, and may be filled in by the ejecta from the younger impact craters.

The Principle of Crosscutting Relationships

Another principle geologists will use in determining the surface geologic history of an area is called the Principle of Cross-Cutting Relationships. This principle states that rocks or geologic features such as canyons, sinuous rilles or cracks in rocks may be cut by other rocks or by other geologic features. On Earth, the San Andreas Fault "cuts" through the Earth's crust in California (see image to left, Figure 39) The fault occurred after the continental crust was formed. Therefore, the rocks are the oldest feature, followed by the fault. These kinds of relationships help geologists determine the age of different geologic features on the surface. This process will reveal a lot about the surface history of a region, including the Moon!

Figure 39 (next page): Cracks in the Earth's crust, known as faults, can run for hundreds of kilometers. These faults are frequently the sites of major earthquakes as the tectonic plates shift positions. Pictured is the San Andreas Fault, one of the

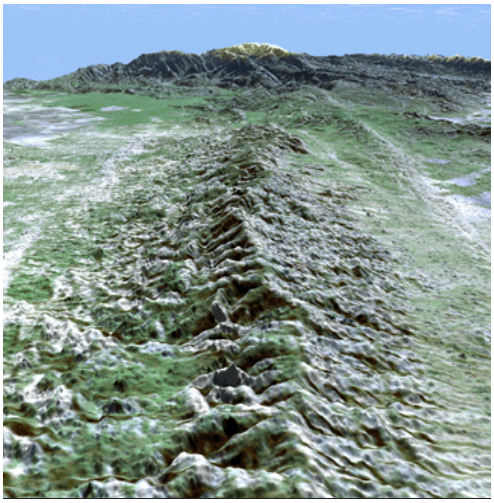


Figure 39. Credit: NASA APOD

longest and most active Transform Faults. USGS scientists estimate that the fault reaches 15 kilometers depth where it meets what is known as the deformation zone. This exaggerated height image was created at the Jet propulsion Lab in Pasadena, CA and combines radar deployed by the space shuttle Endeavor in February of 2000 with a true-color LandSat image. Along the San Andreas Fault, the Pacific Plate is shifting relative to the North American Plate by an average of a few centimeters per year. Los Angeles is on the western side of the plate and San Francisco is on the eastern side and approximately 344 miles apart. At the rate of a few centimeters a year, Los Angeles will have moved far enough northward to be a suburb of San Francisco in a about 25 million years, the Earth's surface will look quite different than it does today.

The Principle of Horizontal Bedding

A well-known principle used by geologists is called the Principle of Horizontal Bedding. It states that rocks formed from sediments deposited by water (such as limestone) or wind, are deposited in nearly horizontal layers. If the layers are no longer horizontal, they must have been shifted, bent, or folded after they were originally deposited. The process of bending, folding or shifting of rocks is usually associated with movements of the lithospheric plates of the Earth during tectonic activity; however, this principle is not usually applicable to the Moon because the Moon does not have rocks that were deposited by water or wind.

worksheet

STUDENT ACTIVITY 4

Studying the Geologic Past

Scientists who study the processes that shape the surface of Earth are called geologists. They have scientific rules, which help them figure out the history of Earth. Some of those rules (principles) include:

- The Principle of Superposition
- The principle of Cross Cutting
- The Principle of Original Horizontality

We will apply two of these principles to features on the lunar surface in the following activities.

Figure 40. This image was created with LROC aboard LRO. Credit: NASA GSFC/ASU.

A. The Principle of Superposition is simple and fun. It is a way of deciding what things happen first, second, and so on. Much like making a peanut butter and jelly sandwich! First, we take a slice of bread, then spread some peanut butter on it, then some jelly, and then put another slice of bread on the top. The oldest layer of the sandwich is the first slice of bread! For lunar features, we look at things that come first, second, third, and so forth also. So, a feature in an undisturbed sequence of features is younger than the one beneath it, and older than the one above it.

Directions: Draw or trace the image above in your journal and label the craters in the order that you think they were formed with numbers or letters. This is one way to date events that happen in a sequence (in order) but does not really give you a date for when it happened. This kind of dating is called relative dating. Now, answer the questions below. Be sure to use the resources in the supplemental materials section.

1. Label the craters in your drawing of the image above. Now, can you identify which craters happened before other craters? In other words, can you recreate the history of when each impact crater was formed?

2. Look at the shadows in the craters. If the top of the image is north, from what direction is sunlight hitting the craters?

worksheet

B. The Principle of Cross Cutting is a lot like Superposition. However, cross cutting looks at how a feature like a fault (crack) or magma (molten rock below the surface) cut into other features (intrusion). For example, faults are younger than the rocks they cut. The features that are not cut by a fault must be younger than the fault. If magma is forced upward through layers of rock (an intrusion), it is younger than the rock it cuts through. See the image on the next page for an example.

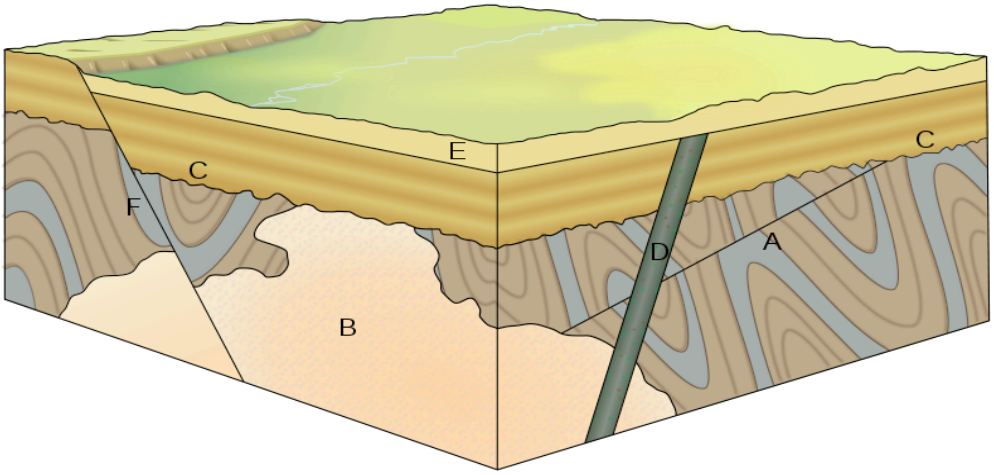


Figure 41. Credit: SUNY New Paltz/NASA GSFC/Rosemary MIllham, 2010.

Directions: Read the descriptions below and answer the questions 1-5 in your journal.

Layers E and C are layers of sediments and sedimentary rocks. Layer D is an intrusion from the magma (B) that was pushed upward from deep in Earth. 'F' and "A" are faults (cracks) in the layers. Be sure to use the supplemental resources.

1. First, illustrate and label the diagram in your journal.
2. Now, what do you think is the youngest part of this image? How do you know this?
3. Is 'C' older or younger than 'F'? Explain how you know this.
4. What happened last? Explain why you think this is so.
5. Now, try to put all of the structures in order from A-F in list form as shown in the following example:

For example, we might say that:

1. 'E' as the oldest
2. 'B' as younger than '1'
3. 'A' is younger than '2' and so on.

This sounds very similar to the Principle of Superposition; however, superposition is what features came first, second, and so on. Crosscutting is also related to the sequence of faults, magma or lava. It is difficult to look at a lunar image and decide which is which. So, let's work on superposition again.

worksheet

Below is another image of the crater Gauss. It is one of the larger crater formations on the Moon with a diameter of 110 km.

Directions: Draw the image in your journal. Answer the questions there, too! The largest crater in the upper right is the Gauss crater. The large crater in the lower left is the Hahn crater. Be sure to use the resources in the supplemental materials section.

1. Including Gauss Crater (the largest one that is only partially visible), how many craters can you find in this image?
2. Can you identify any craters that are superimposed on other craters?
3. Can you tell which crater was formed first? Second?
4. Explain your answers to question 3.
5. Locate and label the cracks (fractures). Can you tell whether the fractures came before or after the impact crater? How did you come to know this?

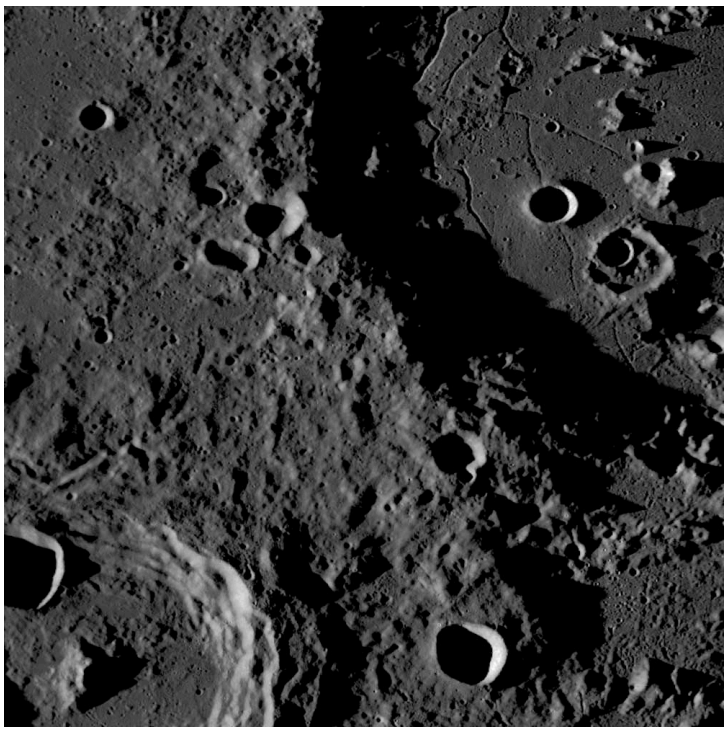


Figure 42.

C. The principle of original horizontality usually refers to sedimentary rocks on Earth. As sediments are deposited on the surface, the oldest sediments are on the bottom and the youngest at the top unless they have been moved, bended or folded tectonically. On the Moon there is some discussion about some features that may apply to this principle. These features may include:

- Debris flows
- Impact melts (lava flows on the surface following impact crater formation)
- Ejecta

Directions: Look carefully at the three images below. Can you tell which one is a debris flow? Impact melt? Ejecta? How did you reach this decision? Write your responses in your journal. Be sure to use the supplemental resources.

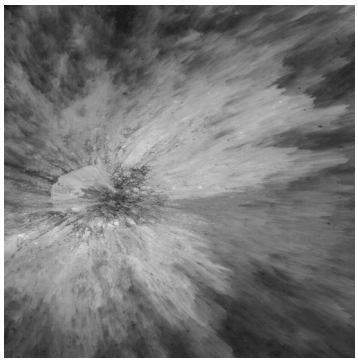


Figure 43.

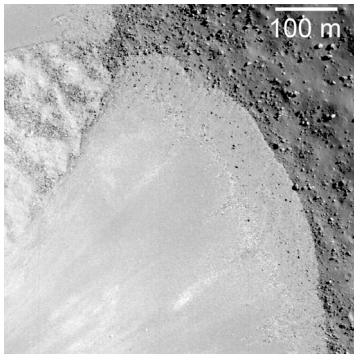


Figure 44.

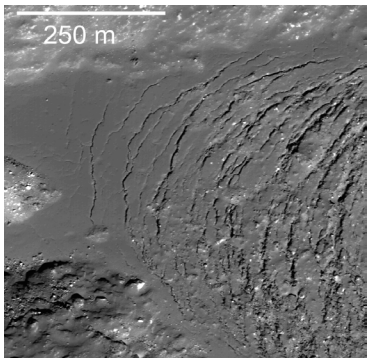


Figure 45.

And Now LOLA, the Lunar Orbiter Laser Altimeter!

With lunar crater features, volcanoes and the principles of geologic structures in mind, let us take a trip into the amazing LOLA instrument aboard the Lunar Reconnaissance Orbiter (LRO) and the images the data creates. LOLA provides a precise global lunar topographic model to create detailed topographical maps of the lunar surface. It produces a geodetic grid (size, shape and orientation of coordinates) that will aid future missions by providing topographical data for safe landings, and enhances exploration-driven mobility on the Moon. LOLA will also contribute to decisions as to where to explore by looking at the evolution of the lunar surface.

LOLA works by sending a single infrared laser pulse through a Diffractive Optical Element (DOE) that splits the single laser pulse into five beams (see Figure 46). These beams strike the lunar surface and are then bounced back to the spacecraft from the lunar surface. The LOLA detectors determine the lapsed time of flight for the spacecraft, the motion of the Moon during the pulse and return bounce of the laser beam, and the time/distance relative to the speed of light (which remains the same at 300,00 km/s or 186,000 m/s) providing a precise measurement for the distance the pulse traveled. Simply put, as the laser beams pulse toward the surface of the Moon, the spacecraft and the Moon are in motion. These motions are taken into account as the LOLA instruments record the time between the pulse and bounce of the laser beams (see Figures 46–49).

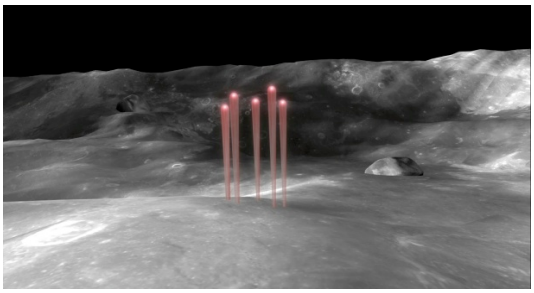


Figure 46. Credit: NASA/ASU.

Figure 46: The Diffractive Optical Element (DOE) splits the single laser beam into 5 separate, straight beams. Once the laser beams have struck the surface of the Moon and bounce back to the spacecraft, a detector picks up the bounced beams, calculating the flight distance of the spacecraft and the speed of light. This determines the distance from the lunar surface to the spacecraft. In this way, LOLA can map the topography and smoothness of the lunar surface.

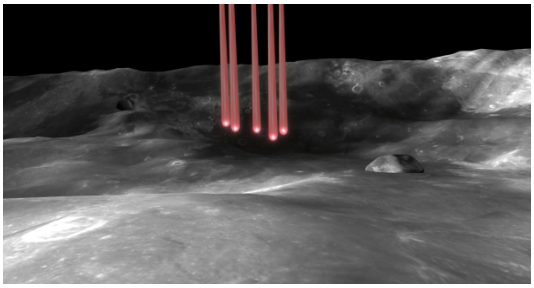


Figure 47. Credit: NASA/ASU.

Figure 47: The image on the right is an example of an even laser pulse from the LOLA instrument. Bottom-left is the even bounce back to the spacecraft. What is the difference between a pulse and a bounce?

In regions where the topography is rough (varied elevations) the laser pulses to the surface are even, but the bounce from the surface is uneven as seen in the images below.

Figures 48 and 49: The image to the left is the even pulse. On the right is an uneven bounce due to the varied elevation at the surface of the Moon at this location. Note the difference between the even bounce above and this uneven bounce. Can you explain the difference?

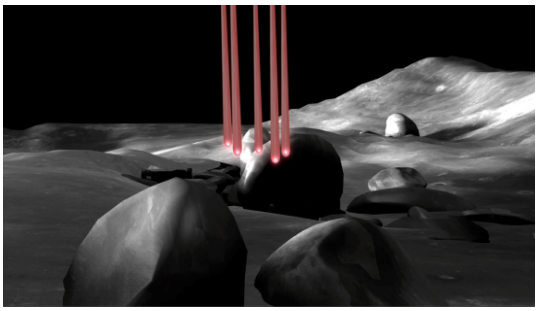


Figure 48. Credit: NASA/ASU.

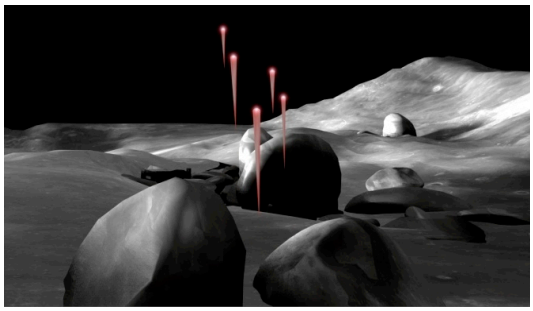
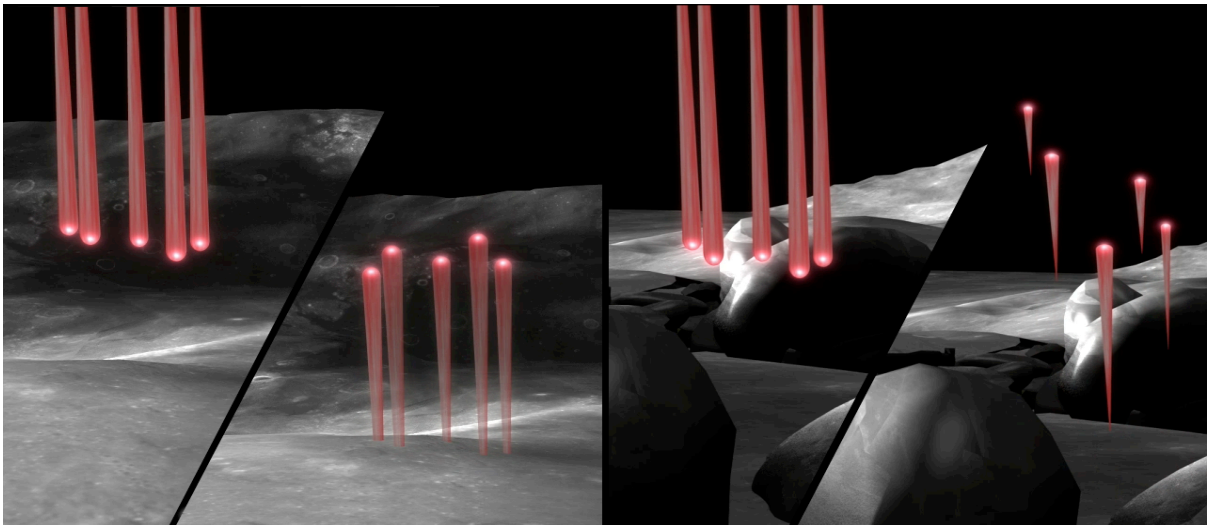


Figure 49. Credit: NASA/ASU.

Figures 50 and 51: The image below is of the even pulse. Comparing the even pulses to the uneven bounces (the image to the right, below), one can see that the beam pulse is the point of contact on the lunar surface, and the bounce is the laser beam backscatter to the spacecraft. Laser detectors on the LOLA tool capture these bounces. Together with the flight of the spacecraft, the known speed of light, and the time it takes for a pulse to bounce back to the instrument, LOLA data creates the most precise lunar topographic map known to date.



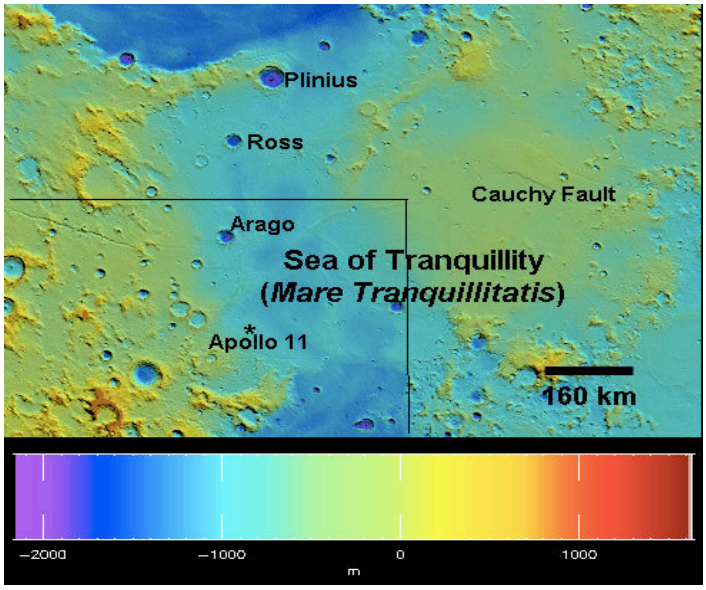
Figures 50 and 51. Credit: NASA/ ASU.

Now, let us compare traditional photography with the new technology for LOLA. Comparing a black and white picture of the Moon to a LOLA image is an excellent way to look at the advances in imaging technology and precision.

Figures 52 and 53: A black and white photo of the Moon taken during the Apollo 11 mission is compared with the LOLA topographical image below of the same region, the Sea of Tranquility. The area inside the black rectangle in the LOLA image is the area represented by the black and white scene.

Observe the two images carefully. What can you see in the LOLA image that is not noticeable in the older photograph?

VIDEO: Here is a video that demonstrates how LOLA works. The LOLA tool: http://www.youtube.com/watch?v=RghDys8nEmo



Figures 52 and 53. Credits: NASA JSC and NASA GSFC.

worksheet

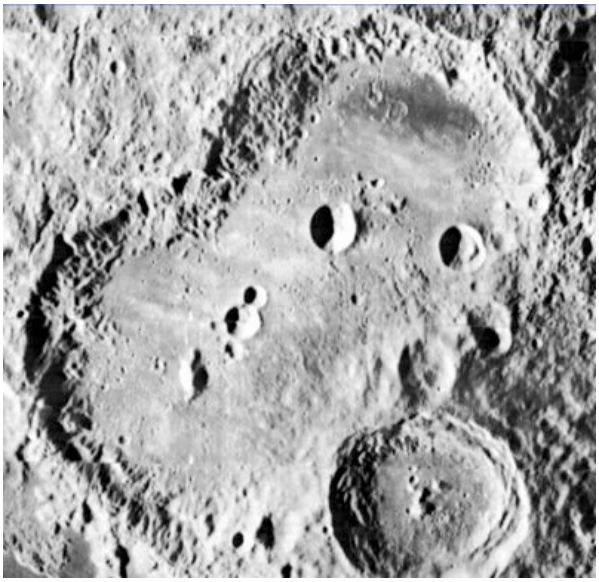
STUDENT ACTIVITY 5

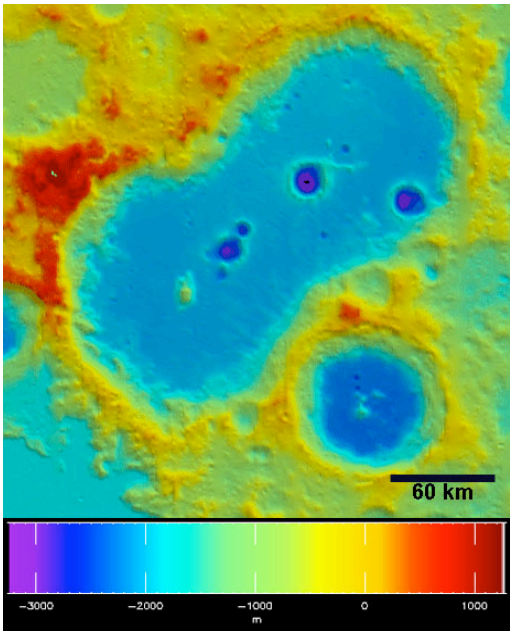
So, what does the Lunar Reconnaissance Orbiter and its instruments have to do with the Moon?

The Lunar Orbiter Laser Altimeter (LOLA) instrument is controlled from NASA's Goddard Space Flight Center in Greenbelt, Maryland. It sends an infrared laser pulse toward the Moon. Then the pulse is split into five beams using a diffractive optical element (DOE). LOLA measures the time it takes for the laser beams to travel from LRO to the lunar surface, bounce off the lunar surface and return to the spacecraft. The amount of time it takes for the beam of laser light to strike the lunar surface and return to the spacecraft determines the distance from the spacecraft to the surface of the Moon at any given point. How? Because light always travels at the same speed! And, LOLA is a very sensitive instrument. It can measure the distance from the spacecraft to the surface with accuracy.

The images you will use in the next two activities show the topography, or elevation, of the region surrounding the Van de Graaff crater in activity 'A' and the Moon's south pole in activity 'B'. A computer generates the LOLA images by assigning colors to represent different heights above or below the datum, or "sea level" on the Moon. Purple areas have the lowest elevation. Red areas have the highest elevation. A color key is provided with each LOLA image so it is easy to find the value for each color. Now that you know a lot about the features of the Moon, let's compare a photograph with an image created from LOLA data!

A. The two images below are of the same area on the Moon, Van de Graaff crater. The black and white image is an older photograph of the Van de Graaff crater on the Moon! The color image is the result of LOLA data and shows the topography of the same area. Note that some features are very noticeable in the photograph that are not really noticeable in the LOLA image. Also, some of the features in the photograph are not as easily noticed as they are in the LOLA image.





Figures 54 and 55. Van de Graaff Crater: To the right is a LOLA image, Credit NASA/JSC/ASU. To the left is a black and white image of the same place on the lunar surface. Credit NASA/JSC Apollo Program.

Worksheet

Directions: Draw or trace each image in your journal and label the features that you can identify. Answer all of the following questions in your journal as well once your drawings and labels are complete. Be sure to use the supplemental resources.

1. Compare the two images carefully and explain the following:

   a. Which image do you believe shows a better view of the craters?
   b. What can the LOLA image tell you that the black and white image cannot?
   c. Count the craters in each image. Write the numbers down and compare them.
   d. Are they the same? Explain.

2. What is the highest elevation found in the LOLA image?

3. What is the lowest elevation in the LOLA image?

4. What is the diameter of the large crater near the scale that reads 60 km?

5. Can you use the same scale on the LOLA image to find the diameter of the craters in the black and white image? Explain.

6. Scientists are puzzled by the shape of the Van de Graaff crater. How is it different from the other craters you have been studying?

7. Let us say that you are a lunar scientist and know all about the cratering process. You see the Van de Graaff crater and are puzzled by its shape. How would you explain its odd shape to another scientist? Be prepared to defend your explanation with scientific information!!

B. Topography of the Humboldtianum Basin on the Moon! What a great LOLA image!

Directions: Note that the map of the Humboldtianum Basin includes a thin circle showing the perimeter of the 650 km basin. There are quite a number of features superimposed on the older basin, including other craters. The key at the top of the image provides information about the elevation of the surface. Along the edges of the image is a coordinate system of latitude and longitude lines. Using this information, answer the following questions in your journal (Be sure to use the resources in the supplemental materials section):

1. Which craters have a central peak? Explain how you have come to know this?

2. Based on your readings, describe the geologic history of Humboldtianum Basin.

3. Notice the labeled craters in the image, A-E. What are the diameters of the craters (in kilometers)? Label them in your journal as A, B, C, etc., then write their diameters in kilometers.

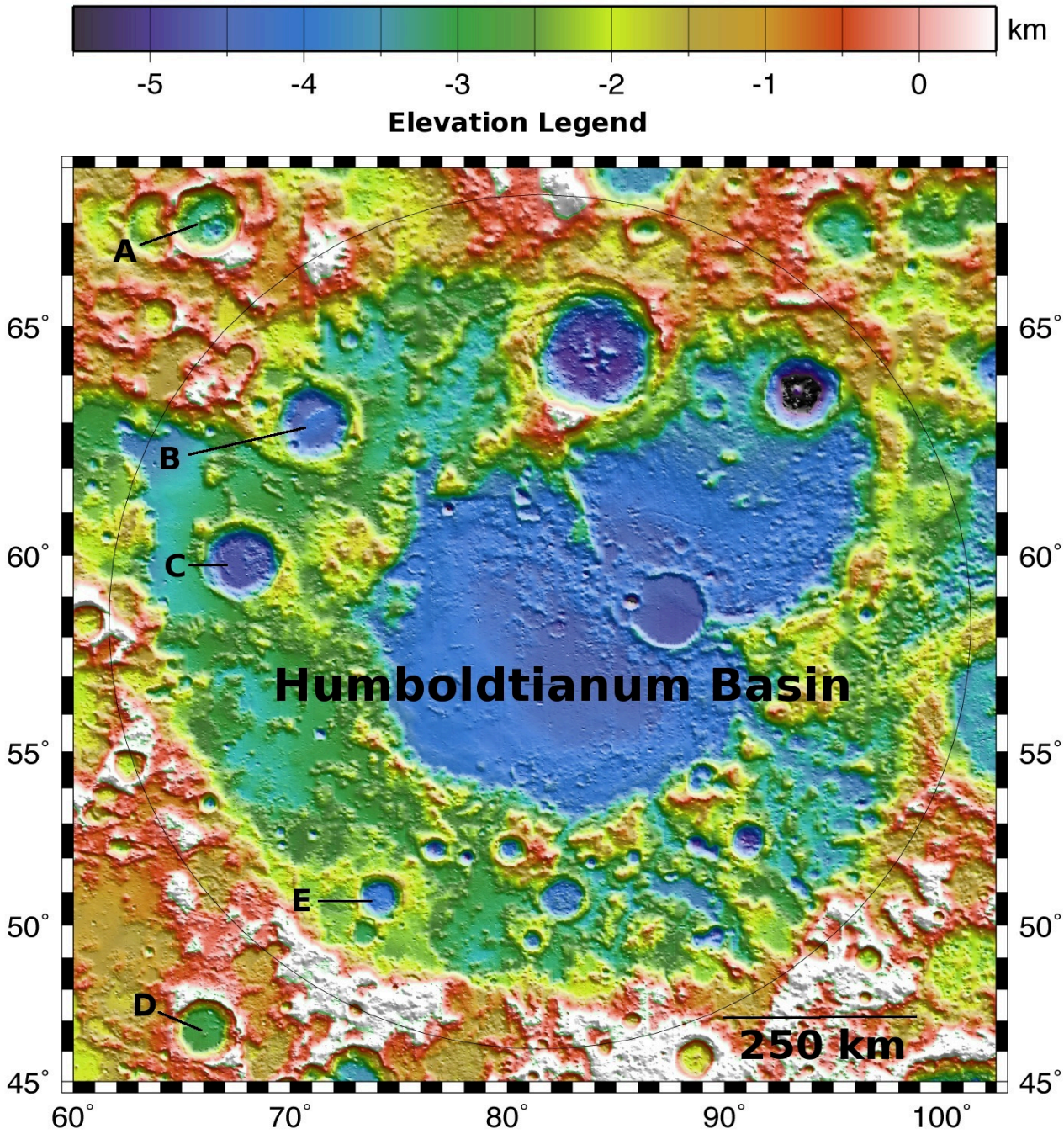
4. Which crater is deeper, A or B? How have you come to know this?

The following questions relate to the area inside the ring that indicates the perimeter of the Humboldtianum Basin.

5. Based on what you know about superposition and relative dating, describe the cratering history of the area inside the ring. How do you know which craters are older compared to other craters? Explain how you know this.

6. Copy the Data Log (attached) into your journal. Identify as many features in the ring as you can recognize. Record the grid coordinates (latitude and longitude) of each feature in the Log so that you can find them later. Using the color key in the image, estimate the height of the rim of each feature. After you have identified these features, use the information you determined in question 5 to rank the features from oldest to youngest. Finally, in your own words, “tell the story” about what happened to form the features seen in the image. Be sure to include everything in your journal.

worksheet



Figures 56. Credit SUNY New Paltz/NASA GSFC/Rosemary Millham

worksheet

Topography of the Moon's South Pole - Data Log

Feautre	Coordinates	Age Rank	Elevation of Crater Rim

Worksheet

Assessment:

Pre-assessment

Answer the following questions to the best of your ability. Use your journal to record your answers. This is not a graded test or assignment. The results will help determine what topics still need to be covered in class.

1. What do you think you know about the Moon?
2. What are some of the similarities between the Earth and Moon?
3. What are some of the differences between the Earth and Moon?
4. How is the surface of the Moon different from the surface of the Earth?
5. What are some of the features on the surface of the Moon?
6. Describe the features on the surface of the Moon that you are familiar with.
7. How can you determine which features occurred first, second, third, and so on?

Post-Assessment

Informal/Formative: The journal entries and discussions/ explanations for these activities are an excellent way to assess student understandings of the content and process skills necessary to successfully complete the lesson activities. A general rubric can be used to provide students with a value for formative assessment and is also included below. Additionally, projects, presentations, experiments, etc. can be used as informal or formal assessments.

Formal/Summative: The possibilities here, as you know, are endless. However, choose questions that are relevant to the activities that you conduct with your students.

Lunar Mapping Module Lesson Rubric

Assessment	0–2 Points	3–4 Points	5–6 Points
Activities are completed with care and neatness	Little attention to detail or thought	Is somewhat neat and does show attention to some details	Well done and meets expectations
Interpretations are thoughtful and complete	Little effort shown to interpret data	Interpretations are somewhat thoughtful but not complete	Interpretations are thoughtful and meet the expectations
Calculations are correct	Calculations are incorrect or not completed	Calculations are completed and show some effort although not all calculations are correct	All calculations are well done and most/all are correct meeting expectations
Illustrations are neat and carefully created	No effort demonstrated; sloppy or not completed	Somewhat neat and/or complete	Well done and meets expectations
Descriptions and explanations are well written and comprehensive	Minimal effort demonstrated	Explanations are somewhat well written and somewhat comprehensive	Well done and meets expectations
All directions were followed	No effort to meet directions	Some effort to meet directions	Well done and meets expectations
TOTALS			

worksheet

Mapping the Surface of the Moon: Formal Assessment

Answer the following questions to the best of your ability.

1. What are impact craters?
2. How do impact craters form?
3. What are the two main types of impact craters?
4. What are the differences between the two types of impact craters?
5. How does the activity responsible for crater formation make them different?
6. What kinds of objects impact the surface of the Moon?
7. What makes the near side of the Moon 'the near side'?
8. Explain what you believe would happen to our view of the Moon if it did not rotate.
9. Why do you suppose 'the far side' of the Moon has more craters than the near side?
10. Explain how the maria form on the Moon.
11. Explain how you would determine the relative dates of lunar features (example: looking at an image with multiple craters and maria, how would you decide the order in which each feature was formed?)
12. How can scale be used to determine the elevation of surface features on the Moon?
13. How can scale be used to determine the distance between specific places on the lunar surface?
14. What significance is there to having a latitude and longitude grid for the surface of the Moon?
15. What similarities and/ or differences do you believe exist between the surface of the Earth and the surface of the Moon?

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Supplemental Information in Identifying Surface Features:

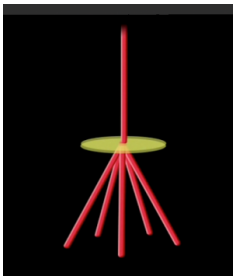
The National Aeronautics and Space Administration (NASA) launched the Lunar Reconnaissance Orbiter (LRO) on June 18, 2009. The purpose of LRO is to image and map the Moon's surface and to collect data that will help NASA in understanding the geologic history of the Moon and Earth system. The Apollo missions taught NASA that the Moon is a hazardous place to land if we do not have enough information. LRO images and data will help us to make the right landing choices.

The LRO is mapping the Moon from an altitude of 50 km (31 miles) above the surface. The imaging instrument on LRO is the Lunar Reconnaissance Orbiter Camera, known as LROC. The LROC instrument has of a pair of narrow-angle cameras (NAC) and a single wide-angle camera (WAC). At this altitude, 50 km, images from the Narrow Angle Cameras (NAC's) have a half-meter resolution. Half-meter resolution means the instruments can record images with enough resolution to make it possible to identify objects as small as a half-meter across (about 19 inches). With the aid of these cameras and other scientific instruments aboard LRO, scientists are collecting data to create images of the surface of the Moon. These images help scientists determine what geologic processes occurred that caused the Moon to appear as it does today. The most noticeable geologic features are impact craters, lunar maria, volcanoes, and the lunar highlands.

Additionally, LRO carries an instrument called the Lunar Reconnaissance Laser Altimeter (LOLA) that collects data about the topography of the lunar surface. Together, LROC and LOLA help us to better understand the lunar surface.

LOLA, the Lunar Orbiter Laser Altimeter

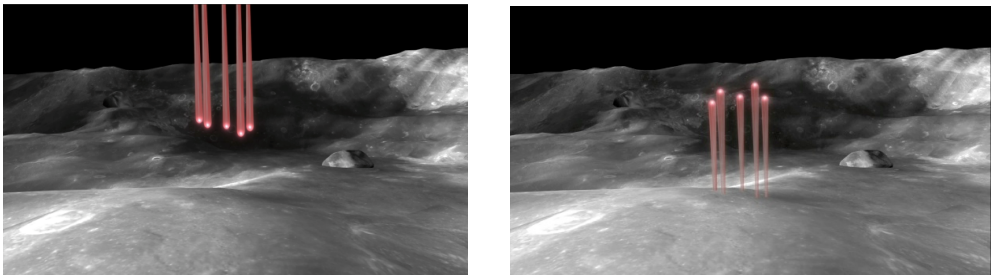
With lunar crater features, volcanoes and the principles of geologic structures in mind, let us take a trip into the amazing LOLA instrument aboard the Lunar Reconnaissance Orbiter (LRO) and the images the data creates. LOLA provides a precise global lunar topographic model (the elevation of specific locations on the surface of the Moon) to create precise topographical maps of the lunar surface. It produces a **geodetic** grid (size, shape and orientation of coordinates).



LOLA works by sending a single infrared laser pulse through a Diffractive Optical Element (DOE) that splits the single laser pulse into five beams. These beams strike the lunar surface and are then bounced back to the spacecraft from the lunar surface. The LOLA detectors determine the lapsed time of flight for the spacecraft, the motion of the Moon during the pulse and return bounce of the laser beam, and the time/distance relative to the speed of light (which remains the same at 300,00 km/s or 186,000 m/s) providing a precise measurement for the distance the pulse traveled. Simply put, as the laser beams pulse toward the surface of the Moon, the spacecraft and the Moon are in motion. These motions are taken into account as the LOLA instruments record the time between the pulse and bounce of the laser beams. Each pulse-bounce time is recorded as numerical data. The numerical data has elevation assignments.

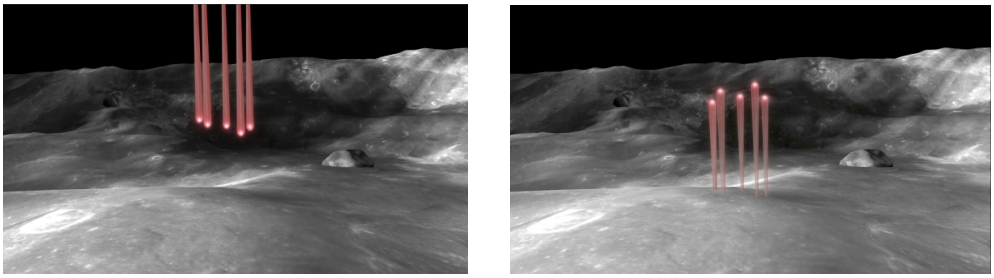
The Diffractive Optical Element (DOE) splits the single laser beam into 5 separate beams. Once the laser beams have struck the surface of the Moon and bounce back to the spacecraft, LRO, a 5-part laser detector picks up the bounced beams, calculates the flight distance of the spacecraft and the speed of light, and determines the distance from surface to spacecraft. Any 'spray' of the beams due to strikes on a rough surface, can be used to measure the smoothness (or roughness) of the surface as well. In this way, LOLA can map the topography and smoothness of the lunar surface. Image Credit NASA.

LOLA measures the 'spreading' of the return pulse (surface roughness) and the change in the transmitted versus return energy of the pulse (surface reflectance) as well as any scattering that takes place in the pulse due to varying heights and roughness of surface features. With its two-dimensional spot pattern, LOLA determines slopes along and across the orbit track.



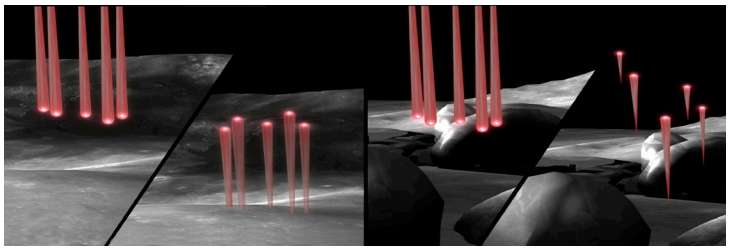
The image on the left is an example of an even laser pulse from the LOLA instrument. To the right is the even bounce back to the spacecraft. What is the difference between a pulse and a bounce? Credit NASA/ASU.

In regions where the topography is rough (varied elevations) the laser pulses to the surface are even, but the bounce from the surface is uneven as seen in the images below.



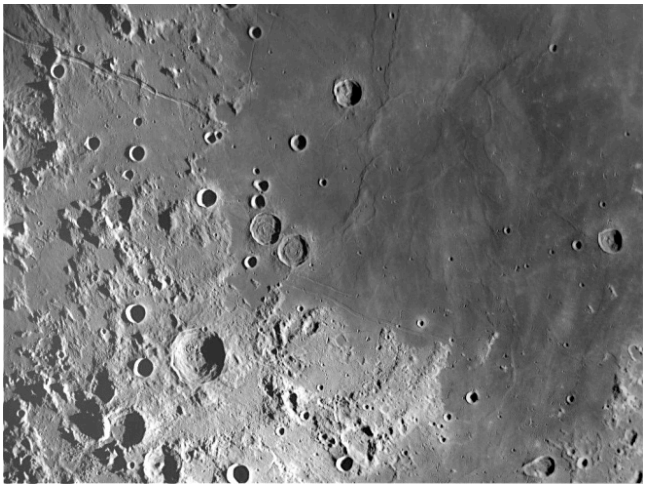
The image to the left is the even pulse. On the right is an uneven bounce due to the varied elevation at the surface of the Moon at this location. Note the difference between the even bounce above and this uneven bounce. Can you explain the difference? Credit NASA/ASU.

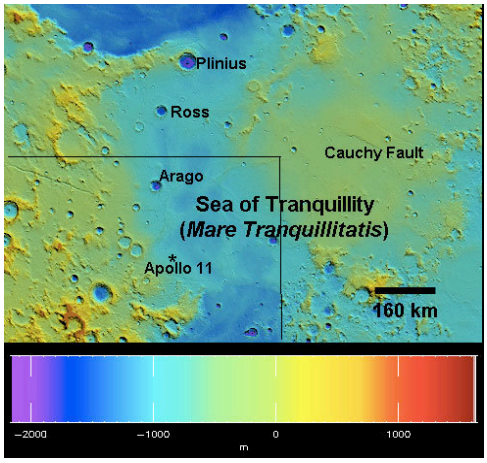
The image on the left (above) is an image of the even pulse. Comparing the even pulses to the uneven bounces (the image to the left, above), one can see that the beam pulse is the point of contact on the lunar surface, and the bounce is the laser beam backscatter to the spacecraft. Laser detectors on the LOLA tool capture the bounces. Together with the flight of the spacecraft, the known speed of light, and the time it takes for a pulse to bounce back to the instrument, LOLA data creates the most precise mapping data topographically known to date.



The image to the left is the even pulse. On the right is an uneven bounce due to the varied elevation at the surface of the Moon at this location. Note the difference between the even bounce above and this uneven bounce. Can you explain the difference? Credit NASA/ASU.

Now, let us compare traditional photography with the new technology for LOLA. Comparing a black and white picture of the Moon to a LOLA image is an excellent way to look at the advances in imaging technology and precision.





Credits: NASA JSC and NASA GSFC

Here, a black and white photo of the Moon taken during the Apollo11 mission is compared with the LOLA topographical image of the same region, The Sea of Tranquility. The area inside the black rectangle in the LOLA image is the area represented by the black and white scene. Observe the two images carefully. What can you see in the LOLA image that is not noticeable in the older photograph?

A Look at the Full Moon:

Let's look at the full Moon on a clear night (see image on the next page). The dark areas on the Moon are called maria (MAH-ree-uh), which is Latin for seas. Its singular form is mare (Mahr-ay). The term comes from the relative smoothness of the dark areas and their resemblance to large bodies of water from a distance. The maria are cratered features that were partly flooded by basalt lavas. Molten rock flowed onto the lunar surface through cracks in the crust, spreading out and filling the low regions in the impact basins. The lava cooled quickly forming the fine-grained, dark rocks — basalt — collected during the Apollo missions. Since the Moon formed, interplanetary bodies such as meteors, asteroids and comets (called impactors or impacting bodies) have impacted the maria forming thousands of impact craters. It is important to note, however, not all depressions on the lunar surface are caused by impactors.

The light colored areas, the oldest rocks on the Moon, are the lunar highlands. They are heavily cratered and covered with a thick layer of regolith, a mixture of fine dust and fragmented rock debris generated by the impacts over several billions years. Beneath the regolith, two crustal rocks types dominate the lunar highlands:

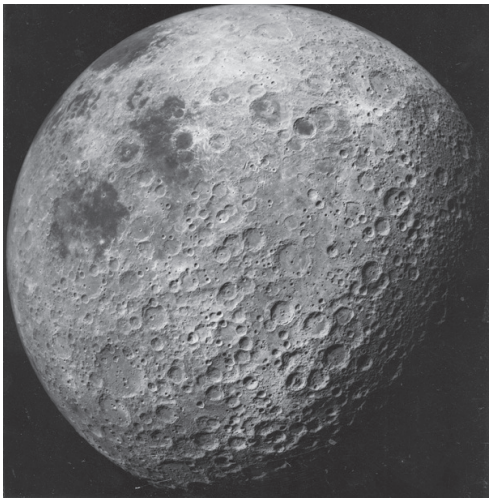
- **Breccia:** referring to the Moon: a coherent rock of broken and welded fragments of anorthosite rock and regolith produced during impacts on the lunar surface.
- **Anorthositic Feldspars:** the most abundant lunar highlands rock; an igneous feldspar-rich variety of feldspar with minor amounts of pyroxene, olivine, and iron oxides.

Before the Apollo program, the far side of the Moon was a mystery. From Earth, only the near side is visible, except for small perturbations that allow us to see small slivers of the far side on occasion. The Apollo program and lunar orbiting spacecraft have provided us with far side images and even more questions about our nearest neighbor.

Now, you might remember hearing the far side of the Moon are the dark side. Not true!! It is true we cannot see the far side from Earth, but the Moon revolves around Earth and rotates on an axis, so day and night occur on all parts of the Moon at least once a month. So why do we only see one side? It takes about 27.5 days for the Moon to make one complete orbit around Earth. At the same time, that is about how long it takes the Moon to make one rotation around its axis. Because the Moon's rotation period is equal to its period of revolution about Earth, we always see the same face of the Moon — no matter when we look at it. This condition where the spin of one body is equal to (or synchronized with) its revolution around another body, is known as a synchronous orbit.

If the Moon didn't rotate, we would be able to see all sides of its surface. Likewise, if the Moon's rotation were faster or slower, we'd eventually get a glimpse of the entire Moon. So why does the Moon rotate only once each time it orbits Earth? The short answer is gravity. The pull on the Moon from Earth has slowed the Moon's rotation down to its current speed. Its rotation is locked with the time it takes to orbit Earth.

By the time the Apollo program got under way, the U.S. had its first clear pictures of what the far side really looked like.



The image on the left is the far side of the Moon. The amazing differences apparent when viewing the far side were unknown until the first images were taken during the first spacecraft orbiting the Moon. The far side is a compilation from satellite orbits; the near side is a Clementine image. Credit NASA.

Resources:

BOOKS

Crelinstein, J. (1989). Living and Learning in Space Age. Markham, Ontario. Fitzhenry & Whiteside Limited Publishers.

Heath, R. (1998). Sun, Moon & Stonehenge. Cwm, St Dogmaels, Cardigan, Pembrokeshire, Wales, SA43 3JF. Bluestone Press.

Heiken, G. H., Vaniman, D. T., & French, B. (Eds.).(1991). The Lunar Sourcebook; A User's Guide to the Moon. Cambridge, MA. Cambridge University Press.

Michaels, S., Shouse, A. w. & Schweingruber, H. A. (2007). Ready, Set, Science: Putting Research to Work in K-8 Science Classrooms.

National Research Council (NRC). (1996). National Science Education Standards. Washington, DC: National Academies Press.

Ross, D.A. 1995. Introduction to Oceanography. New York, NY: HarperCollins. pp. 236- 242.

Wilhelms, D. (1987). Geologic History of the Moon. Reston, VA. U.S. Geological Survey; #1348.

PRESENTATION

Barbour, P. (2007). Rhone Alps (The Thaïs Cave). Département de la Drôme. Département de la Drôme, France. p. 1-3.

OTHER GOVERNMENT/ PUBLISHER COLLABORATION

National Oceanic & Atmospheric Administration (National Ocean Services division). (2005).Welcome to Tides and Water levels. Arlington, VA. SciLinks; NSTA.

WEBSITES:

Lunar Reconnaissance Orbiter Mission. Retrieved 2009-2012 from:

LOLA http://lunar.gsfc.nasa.gov/lola.html

Diviner http://lunar.gsfc.nasa.gov/diviner.html

CrATER http://lunar.gsfc.nasa.gov/crater.html

LAMP http://lunar.gsfc.nasa.gov/lamp.html

LROC Arizona State University http://wms.lroc.asu.edu/lroc

NASA and Collaborators Lunar Education and Outreach. Retrieved 2009-2012 from:

http://www2.semo.edu/mast/mlc/moon.htm

http://lunar.arc.nasa.gov/education/activities/index.htm

http://lroc.sese.asu.edu/EPO/Educator/educatorslessons.php

http://www.spacegrant.hawaii.edu/class_acts/MoonDoc.html

http://worldwind.arc.nasa.gov/moon.html

http://lunarscience.nasa.gov/kids/moonshine

http://www.nasa.gov/worldbook/moon_worldbook.html

http://www2.semo.edu/mast/mlc/moon.htm

http://lunar.arc.nasa.gov/education/lesson.htm

http://www.lpi.usra.edu/education/explore/LRO/activities/mission_moon

http://www.uwgb.edu/dutchs/GeolColBk/MoonSPAitken.HTM

http://www.uwgb.edu/dutchs/GeolColBook.HTM

Soil Simulants. Retrieved 2009-2012 from:

http://www.enasco.com/product/SB45846M However, search the web as some have found cheaper prices. Quality unknown.

http://highered.mcgraw-hill.com/sites/0072482621/student_view0/interactives.html#

http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/78778/Lunar_Nav.swf::Lunar%20Phases%20Interactive

http://www.youtube.com/watch?v=exIpL0Uhr_k&feature=related

http://astro.unl.edu/naap

Interactive Paperwork: http://astro.unl.edu/interactives

Lunar Phases Simulator: http://astro.unl.edu/classaction/animations/lunarcycles/lunarapplet.html

Celestial Sphere: Simulator http://astro.unl.edu/classaction/animations/coordsmotion/radecdemo.html

http://www.physics.hku.hk/~nature/CD/regular_e/lectures/chap02.html

http://astro.unl.edu/naap/lps/animations/lps.swf

http://projects.astro.illinois.edu/data/MoonPhases/index.html

http://www.harcourtschool.com/activity/moon_phases

http://www.chabotspace.org/vsc/planetarium/themoon/moonphases/default.asp

IDL for GRIDVIEW to work:

www.ittvis.com registration site for GRIDVIEW

www.youtube.com/bhsu978 directions for GRIDVIEW program

Lunar and Planetary Institute:

http://www.lpi.usra.edu/education/resources/s_system/moon.shtml

http://www.lpi.usra.edu/education/other_programs/lunar_eclipse/activities.shtml

Universe Today:

http://www.universetoday.com/guide-to-space/the-moon/moon-activities-for-kids

DePaul:

http://analyzer.depaul.edu/paperplate/lunareclipse2007-08.htm

General:

http://atozteacherstuff.com/Themes/Space

http://www.middleschoolscience.com/earth.htm

http://www.lpb.org/education/classroom/MoonMania/lessons/index.htm

http://school.discoveryeducation.com/lessonplans/programs/lightofthemoon

http://www.teach-nology.com/teachers/lesson_plans/science/astronomy

http://www.windows2universe.org/teacher_resources/lunar_edu.html

http://spacemath.gsfc.nasa.gov

http://www.stellarium.org

http://science.nasa.gov

http://www.enchantedlearning.com/subjects/astronomy/activities/label/labelmoonphases.shtml

http://www.newpaltz.edu/lunarlander

http://www.newpaltz.edu/lunarlander/videos.html

http://mset.rst2.edu/portfolios/g/gallagher_p/ToolsVisWeb/process.htm

http://www.earthmagazine.org

http://www.astrosociety.org/education/family/resources/moon.html

VIDEOS: ALPHABETICAL ORDER BY TITLE

Finding a safe landing on the Moon: http://www.youtube.com/watch?v=dySd8l6rSEI

General video on LRO South Pole First Light Data:
http://www.youtube.com/watch?v=SN2kdavy-wA&feature=results_main&playnext=1&list=PL20FB3CA56CF49779

NASA Evolution of the Moon: http://www.youtube.com/watch?v=UIKmSQqp8wY

NASA Apollo 40th Anniversary video: http://www.youtube.com/watch?v=V6Kv07bfRdE&feature=relmfu

NASA Electric Rover: http://science.discovery.com/videos/build-it-bigger-season-3-lunar-electric-rover.html

LOLA tool: http://www.youtube.com/watch?v=RghDys8nEmo

LRO videos about LOLA: http://news.discovery.com/videos/space-new-moon-crater-video-pops-with-color.html

Simulated Meteor impact in slow motion: http://www.youtube.com/watch?v=XzIw0c_MjTc

Glossary:

Impact Basins: similar to impact craters (see below) except impact basins are significantly larger.

Impact Craters: craters formed on a planetary surface by the impact of an interplanetary body such as an asteroid, comet, or meteoroid.

Impactors: the objects that impact other objects, such as a meteor impacting the Moon.

Interplanetary Bodies: objects existing between planets— examples: meteoroids, asteroids, and comets.

Intrusion: in geology, when molten rock is forced into existing solid rock.

Lava: molten rock above the surface of the crust.

Lithosphere: the solid part of a celestial body (as Earth); specifically the outer part of the solid Earth composed of rock like that exposed at the surface consisting of the crust and outermost layer of the mantle; usually considered to be about 60 miles (100 kilometers) in thickness.

Lobate Scarp: has two parts: lobate means having deeply indented margins and a scarp is a steep slope. Together, the definition is a steep slope with heavily indented margins.

Lunar Highlands: the light colored areas of the Moon that are at higher elevations. They are the oldest rocks on the lunar surface and are composed mainly of anorthosite rocks. The lunar highlands are heavily cratered.

Mafic: rock rich in magnesium and iron.

Magma: molten rock below the surface of the crust.

Mantle: the layer of Earth between the crust and the core. It is divided into the lower (closest to the core), middle and upper mantle. The uppermost part of the mantle includes the lithosphere.

Mare: the darks regions on the Moon. They are composed of basalt materials. (Pronounced MAH-ray)

Maria: plural for mare (pronounced MAH-ree-uh).

Meteor: a meteoroid that has entered Earth's atmosphere and appears as a bright streak of light across the sky.

Meteorite: a meteor that has actually landed on Earth's surface. Usually, a meteor burns up in Earth's atmosphere long before it reaches the surface of Earth.

Meteoroid: one of many interplanetary bodies that orbit the Sun along with the planets, moons, etc.

Morphology: the study of structures (features). In geology, it is the study of the processes which create features on the surface of a solid body.

Natural Satellite: any natural planetary object, such as our Moon, that orbits another body. The Moon is Earth's only natural satellite.

Plutonic: igneous rock that has solidified beneath Earth's surface; granite, diorite, gabbro and anorthosite are examples.

Pyroclastic: clastic (broken and fragmented) rock material formed by volcanic explosion or aerial expulsion from a volcanic vent.

Radiating Dikes (see dikes): blade-like fingers formed by magma moving laterally in the shallow crust. When the dikes form outward from a central point, they are radiating.

Rays: bright streaks radiating outward from a lunar crater.

Rebound: movement of the crust upward and back from an impact; after an impact, compression occurs as the rocks are forced together. Afterward, the surface rocks rebound upward.

Regolith: broken down rock into a powdery dust. The dusty "soil" found on the surface of the Moon is NOT truly soil— it has no biogenic material.

Relative Dating: way of determining the order of events that have happened

Rilles: long, narrow depressions in the lunar surface that resemble channels; river channel shapes with no water.

Secondary Craters: craters formed when ejecta from impacts falls back to the surface of the Moon and creates new craters.

Shield Volcanoes: a broad, low volcano shaped like a flattened dome and built of basaltic lava; also known as a basaltic dome or lava dome.

Superposition: the deposition or intrusion of one geologic feature on another.

Synchronous: refers to occurring or existing at the same time or having the same period of rotation or revolution or both.

Tectonic/ Tectonically: the structure or movement of Earth's crust.

Viscous: a materials resistance to movement/flow. Lower viscosity means flowing more easily; high viscosity means more resistant to flow.

Volcano: a vent or crack in Earth's crust (or in the surface of some other planet) through which molten lava and gases erupt.

Wrinkle Ridges: low, sinuous ridges formed on the mare of the Moon— tectonic features created when basalt lava flows first cooled and contracted.

WELCOME TO GRIDVIEW AND IMAGE MANIPULATION FOR LOLA TOPOGRAPHICAL DATA

NOTE: The GRIDVIEW document (see below) that explains how to download the software programs and use gridded data can be obtained from the NASA portal, or by contacting the Lunar Planetary Institute's website.

Why use GRIDVIEW? The program is a great tool for manipulating images and zooming in on craters on the Moon, measuring diameters and other distances, creating topographical profiles, and for counting craters. GRIDVIEW is a visual program that compliments the 2-dimensional aspect of this mapping guide that is fun and great for the technologically savvy students we have.

What is GRIDVIEW? GRIDVIEW is an IDL compatible software interface application designed to aid researchers in their efforts to analyze, measure and visualize gridded data products such a planetary topography. It can also be used by teachers and students to conduct authentic research in the classroom.

What is IDL? IDL (Interactive Data Language) is a language for creating visualizations based on scientific or other data. It is a generic term for a language that allows one program or object written in one language communicate with another program written in an unknown or other language. In distributed object technology, it is important that new objects are allowed to be sent to any platform environment and discover how to run in the new environment. An IDL works by requiring that a program's interfaces be described as a slight extension of the program that is combined for use with it. The extensions in each program are used through a connecting program that allows the two programs to communicate.

IDL is popular in particular areas of science such as in astronomy. For example, we will visualize an image of the topography of the Moon. To be more specific, the IDL software (also called IDLVM for our GRIDVIEW interface) interfaces with GRIDVIEW to produce maps of the Moon using LOLA data that we can then manipulate to illustrate lunar topography. The VM in IDLVM stands for 'virtual machine'. However, when you go to the ITT site later to download the IDL software, it does not mention 'VM'. At some sites where IDL can be accessed, the VM is part of the title, hence, IDLVM. Additionally, the IDL software is sometimes called IDLVM32.

Now, what is gridded data? Gridded data is data taken at points separated by fixed intervals like fixed points in longitude and latitude on the surface of a planet or moon. The data we will work with in these lessons are topographical data collected in values determined by the timing between the pulse and return bounce of laser beams sent to the lunar surface from the Lunar Reconnaissance Orbiter instrument called LOLA (Lunar Reconnaissance Orbiter Altimeter) and returned to the spacecraft. An explanation for the LOLA tool, and the pulse-bounce of the laser tool, is located in appendix A of this document.

So, simply stated, the IDL program takes data values working in conjunction with the GRIDVIEW software, and allows the data to become a visual image based on the data. Once an image is created with the IDL software interface with GRIDVIEW, the program allows you to manipulate parameters to zoom in, zoom out, crop, and change layers in the images created. There are many other tools for manipulating images in GRIDVIEW, but we will work with the basic functions in this document. But first, how do we get the IDL software and GRIDVIEW software so the interface works?

GETTING STARTED WITH YOUR FREE IDL AND GRIDVIEW SOFTWARE

GRIDVIEW is an exciting tool for lunar research and connecting technology with content in science classrooms, especially topographical and mathematics content. When teaching concepts related to elevation of the surface of the Earth, determining the circumference of a circle, creating topographical profiles, and a host of other activities, GRIDVIEW can provide educators with a wealth of interesting applications for these concepts using lunar data.

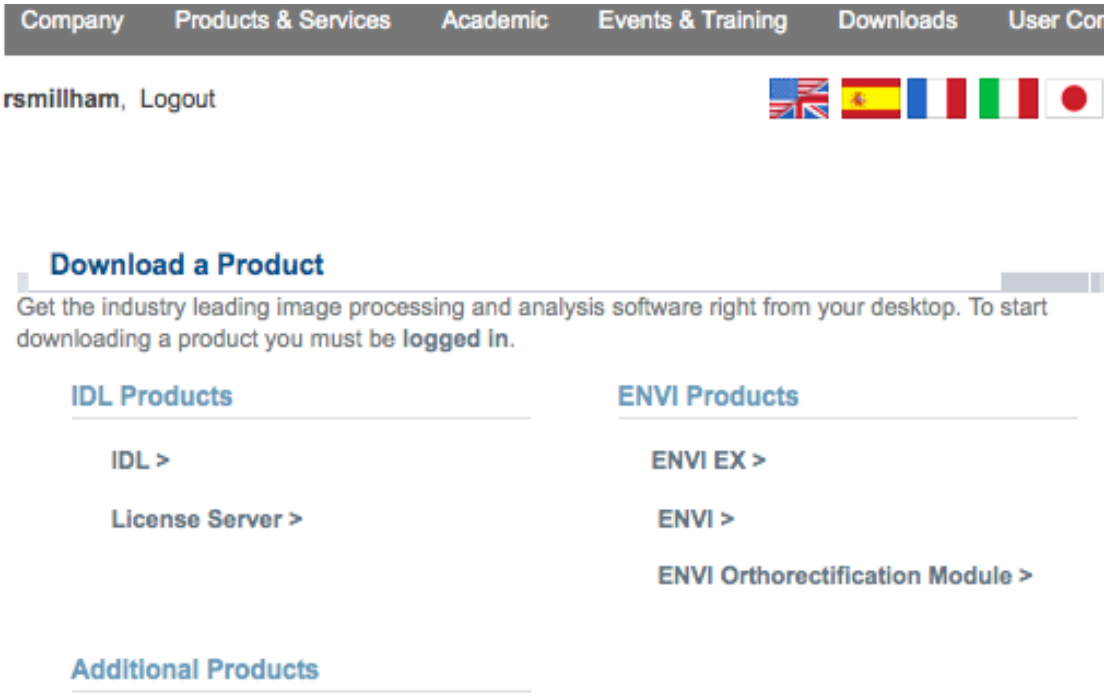
IMPORTANT: Before you get started, find a place to put the files for GRIDVIEW in one place. On a PC, you might choose to keep the GRIDVIEW folder with your documents folder. On a Mac, we often go to "Finder" and set up a folder in our house. You will want to place all of your GRIDVIEW files in this folder. This will be repeated later in the directions.

There are really TWO parts to the software issue for using GRIDVIEW. First, you need the free IDL software from www.ittvis.com, and you need the GRIDVIEW software from http://core2.gsfc.nasa.gov/gridview/gridview_win.html . They will not work at all independently. Additionally, if you have a Mac, you will need to check to see if your computer has XII installed as the image software for IDL and GRIDVIEW will require XII operations on a Mac.

At the ITT site where you will download the IDL software, be sure to download the correct software for your computer. In addition, there is a specific way in which the software programs must be opened in order for them to work correctly on your computer depending on whether you are using a PC or a MAC. So, what do you do?

A. DOWNLOADING THE IDL SOFTWARE FROM ITT

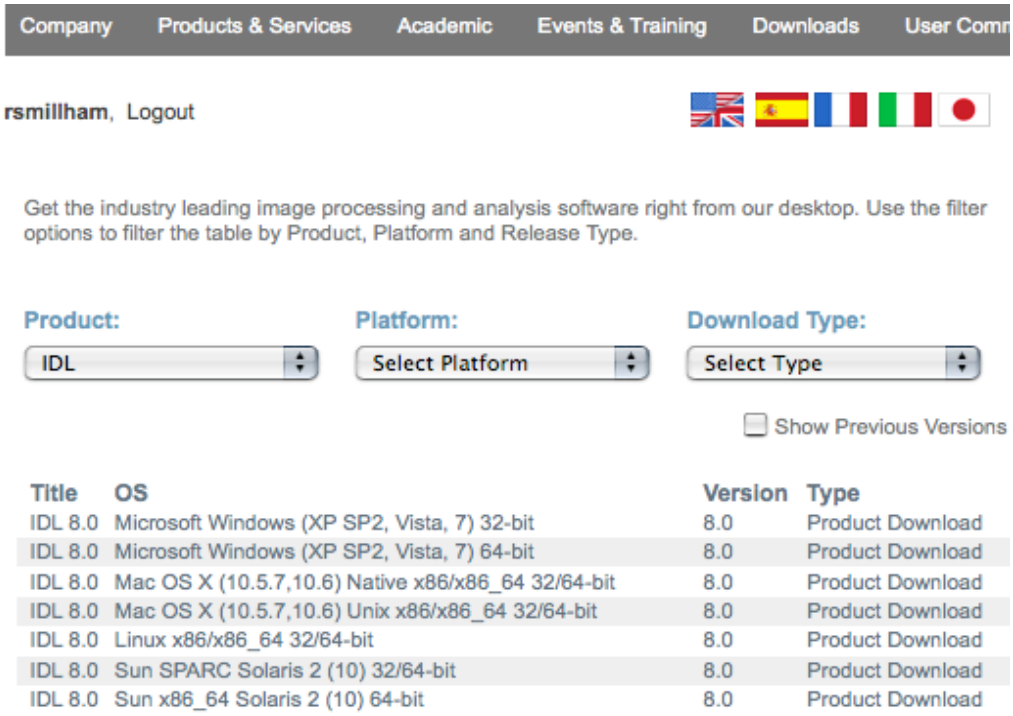
1. First, go to the ITT website at www.ittvis.com/idl
2. Go to the **'Downloads'** dropdown on the top bar and choose **'product downloads'** from the drop-down menu.
3. Under IDL Products, choose **IDL>**
4. You will get a page for a login name and password. **Below this is a line item that says, 'register'**. Click on this. It will send you to the registration page.
5. You are now on the 'Create a User Account' page that you will need to complete. Fill in all of the required information and hit 'register' at the bottom of the form.
6. Within 2-3 days, ITT will send you the **FIRST of two emails**. The first is providing you with an access code to download your IDL software. They are also verifying who you are and that you are a real person with a legitimate email address. IF you do not hear from ITT within 3 days, email their tech support staff and they will assist you. The email address for tech support at ITT to get the IDL software is: support@ittvis.com and the phone number for tech support is 303-413-3920.
7. The **SECOND e-mail** will arrive, usually, within 24 hours. This is the e-mail that actually provides you access to the software providing your 'approved' status. NOW you can go to the www.ittvis.com/idl and download the software. How?
8. Once you have the approval and access code you can log in to ITT for the IDL like you did before, but now you have a login, and password, and approval, and are good to go! Log in now! The login button is on the upper left of the screen along with the logout.



9. The next page will look much like the original page. Go to the 'Downloads' button on the top bar and choose the 'products download' from the drop-down menu.

10. Click on the IDL> under the IDL products title (see above). Choose the right product for your computer. Be careful!

    a. IF you have a PC with Windows XP, download and install the windows version that meets the requirements for your computer. If you do not have Windows XP, check the list of download options to find the one you will need.
    b. IF you have a MAC, download and install the correct MAC software for your computer. Note that if you do not have a MAC 10.5.7 or greater, the IDL software will not work on your computer. If you do not know what version your Mac is, go to the apple icon in the top left corner of your computer and click on 'About This Mac'. It will tell you what version you have.



11. When you click on the software of choice, you will be sent to another page where you can choose your software. In addition, you MUST check the box for **evaluating** the product and check the box for **'I agree to comply…'** before you will be allowed to download.

IDL 8.0 - Click here to go back

IDL 8.0

Purpose of Download

Please select one of the following to complete your download:

○ I have recently purchased, or upgrading an existing license

◉ I am evaluating

Export regulation compliance

Licensee acknowledges that it is not a citizen, national, or resident of, and is not under the control of the government of Cuba, Iran, North Korea, Sudan or Syria, and that Licensee will not download or otherwise export or re-export the Software Product and any related technical data directly or indirectly to the above mentioned countries nor to citizens, nationals, or residents of those countries. Licensee will comply with all applicable export, re-export and foreign policy controls and restrictions imposed by the United States and will take the necessary actions and precautions to ensure that it complies with all such laws or regulations.

I am not located in and that I am not a national of Cuba, Iran, North Korea, Syria, or Sudan, and I agree not to transfer the Software Product to any such locations or individuals;

I am not listed or affiliated with anyone on any of the following lists:

Denied Persons List - U.S. Department of Commerce, Unverified List - U.S. Department of Commerce, Entity List - Supplement No. 4 to part 744 of the Export Administration Regulations, Specially Designated Nationals - U.S. Treasury

I also agree to comply with all U.S. and international laws (including the obtaining of any required import license or authorization), and I understand and agree that ITT Visual Information Solutions is not responsible for my failure to comply with any such laws.

☑ I agree to comply with all U.S. and international laws, including the obtaining of any required import license or authorization. More Details

Downloadable Files	Size	Product	Type
IDL 8.0 - Mac OS X (10.5.7,10.6) Unix x86/x86_64 32/64-bit	276	IDL	Product Download
IDL 8.0 - Installation Instructions	1	IDL	Instructions
IDL 8.0 - Release Notes	1	IDL	Release Notes

Click here to have the media shipped.

To find product **service packs** and **patches**, please select "Product Update" on the Download Type drop down menu

12. Once you have downloaded the software, install it!

B. DOWNLOADING THE GRIDVIEW SOFTWARE AND IMAGING FILES.

You should have access to the following website to download and install GRIDVIEW at http://core2.gsfc.nasa.gov/gridview/gridview_win.html and the MOLA and LOLA files (MOLA is Mars data, and LOLA is Moon data).

1. BEFORE you download the GRIDVIEW software, create a 'GRIDVIEW' folder.
   a. IF you have a PC, create the folder in the 'My Documents' section or other space where all files for GRIDVIEW can be stored.
   b. IF you have a Mac, it is best to place the GRIDVIEW files in your user file that can be found in 'finder'. It usually has a small house icon.
2. Go to the website and choose the correct GRIDVIEW software for your computer and download the software. BE SURE to save it as **gridview.sav.**
3. Install the software, and place this file in the file you created for GRIDVIEW before you download GRIDVIEW.
4. Download any of the GRIDVIEW mapping files you may want to work with. For example, "ldem_16.grd" is a file for mapping a portion of the Moon and can be downloaded and placed in your GRIDVIEW folder. There are several of these files for the Moon and Mars available on the GRIDVIEW site.
5. IF you have a Mac, you will also need to have the XII Window System software installed in order for GRIDVIEW to work. It is free from the Internet from several websites if it is not already installed on your computer.

Now you are ready to begin using GRIDVIEW!

GRIDVIEW DIRECTIONS:

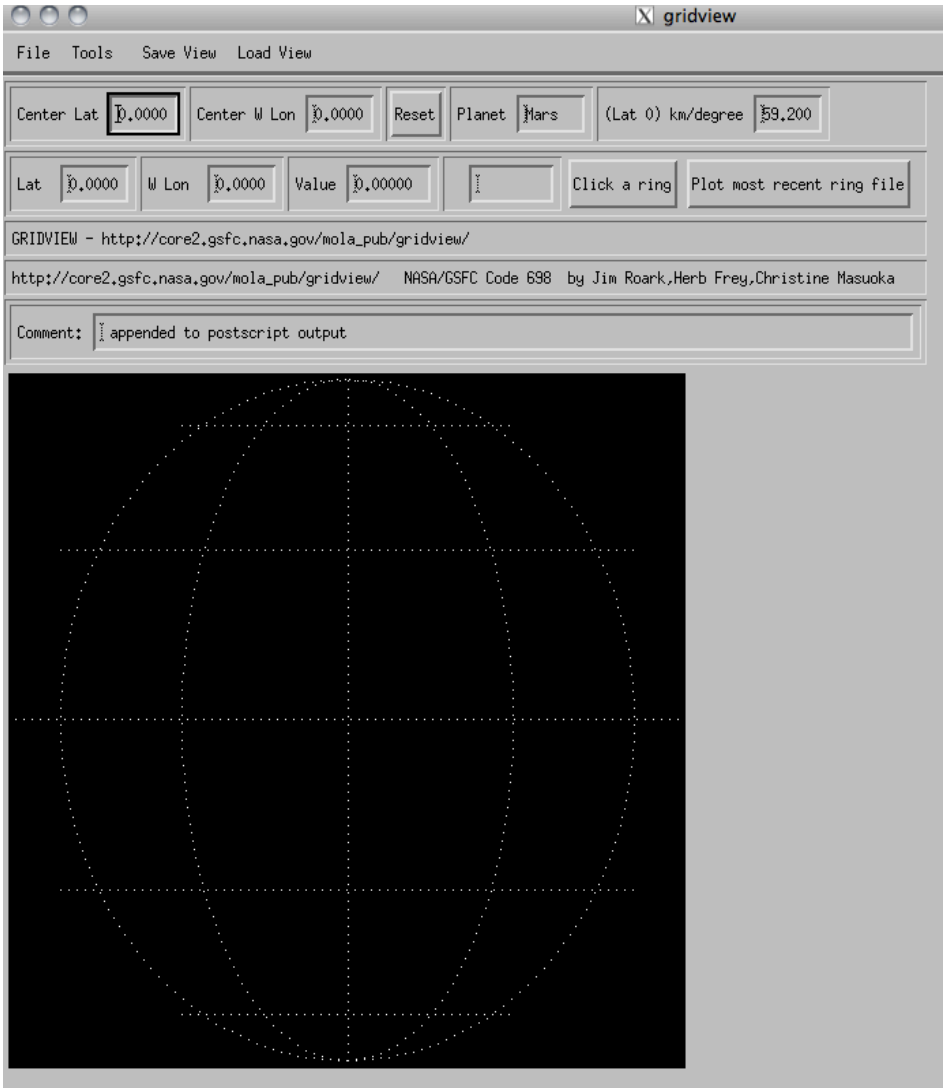
Remember, you have two software programs working together to manipulate the images, with GRIDVIEW being the first thing you double-click causing the IDL virtual machine to open first. Go figure! Once the IDL Virtual machine box pops up, click on continue. IDL will now open up GRIDVIEW! Please note that responses to mouse clicks will be different on Windows, Macs, and X-based systems.

This is how GRIDVIEW-IDL works:

TO START GRIDVIEW:

1. Go to your GRIDVIEW directory (the folder you created for GRIDVIEW) and double click to open the "gridview.sav" file. Or, if you have a shortcut to the "gridview.sav" file on your desktop, you can double click on the file there. IDLVM should automatically open on a PC. With a Mac, there is a second step the first time you open gridview.sav when the computer asks you what application you want to open GRIDVIEW. Browse for your IDL file and click on it, then follow the directions listed below.

2. Click on “Click to continue” when the IDLVM window appears. GRIDVIEW should now be running and you will see a page that looks like this:



Now you need to choose a file to work with, so open a LOLA file as follows:

TO OPEN ANY OF THE LOLA TOPOGRAPHY DATA FILES:

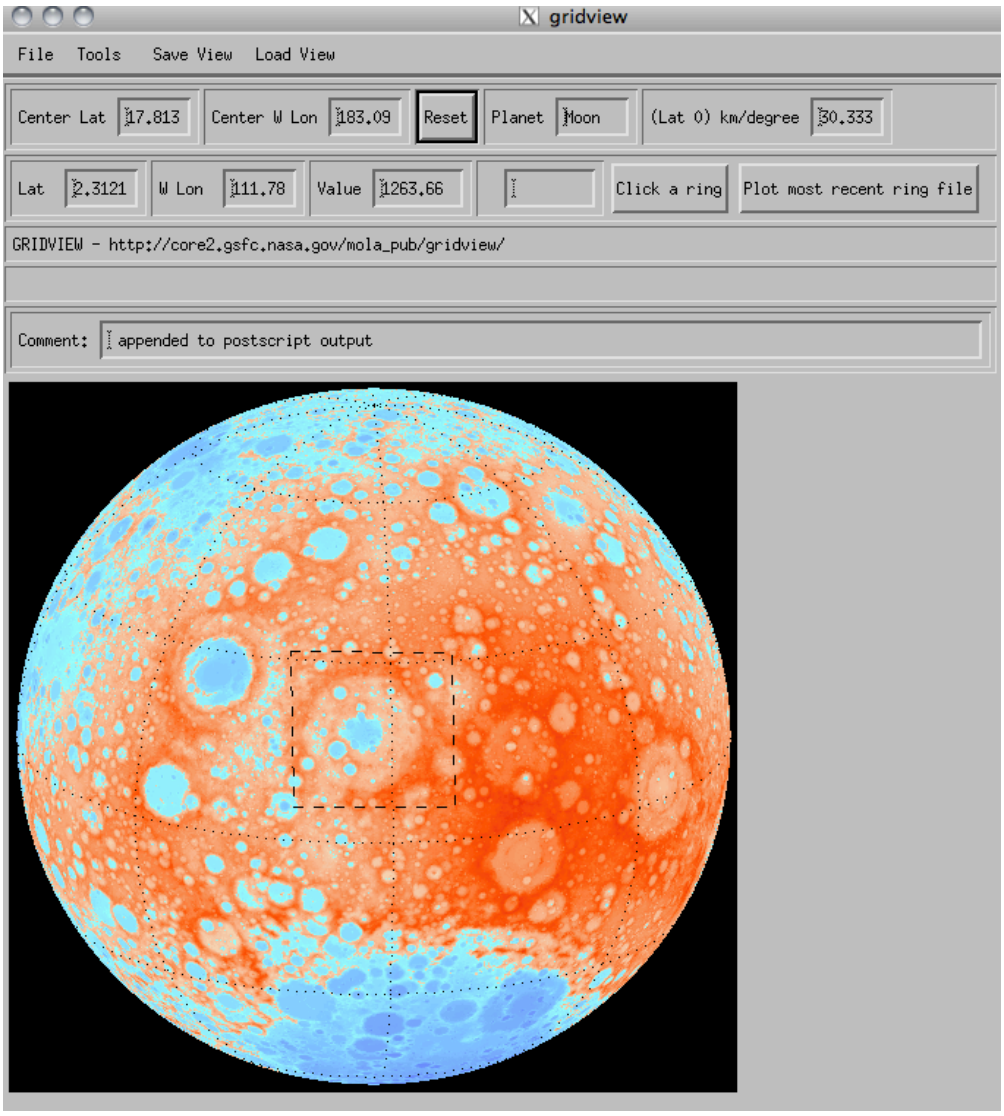
1. Once GRIDVIEW has opened, click on “File” and then choose “Load LOLA (.grd) grid” to work specifically with LOLA data.

2. Select the file called “ldem_16.grd” and then click “OK”. It takes a little while for the data to download into GRIDVIEW depending on your computer. Once it is loaded, you should see a colorful data image of the Moon. If your planet information under “planet” in the top bar says something other than “Moon”, type Moon in place of the planet. ****BE sure that the box for planet says “Moon” and not Mars.** If it says Mars, simply type moon in the box.

3. Now you’re ready to analyze lunar topography data from the Lunar Orbiter Laser Altimeter onboard the Lunar Reconnaissance Orbiter! You could pick any of the LOLA files you have in your directory, but start with this simple one to practice using the software.

Before you start working with GRIDVIEW, look at the toolbar along the top of the GRIDVIEW window and become familiar with their titles. IF you are working with a Mac, be careful not to use the XII application to manipulate the image data. Only use the GRIDVIEW window options file, tools, save view and load view, not the XII tools.

Look at the toolbar at the top of the image below. These options have dropdowns with manipulation tools we will use in this document to orient you in the use of GRIDVIEW.



Now let's see what we can do in GRIDVIEW with the LOLA data

GRIDVIEW ORIENTATION:

- Note that in the top bar "Center Lat" and "Center W Lon" show you the latitude and longitude of the center of your LOLA data image. This will be different for many of the individual files you choose to work with as they are for different portions of the Moon (or Mars if you happen to also have Mars data in your files).
- You can manually change the latitude and longitude for your view of the image by entering in the latitude and longitude values you want to work with.
- Note the "Reset" button in the top bar will reset your view back to the original global grid. (If you zoomed into an area, discussed later, the reset button will also show the area that was zoomed in earlier).

- The “Lat”, “W Lon” and “Value” show the location and elevation of the spot on which your cursor is located on your area of interest. Move your cursor over portions of the map and watch the “Lat” and “Lon” values change.
- When the grid loaded, it automatically centered your image on the far side. To get a near side view, manually type in 0 for the latitude and 0 for the longitude. This will center your image on the near side.
- GRIDVIEW displays the location in West longitude. Lunar scientists and engineers typically list locations on the Moon in East positive longitude.

HOW TO USE SOME OF THE USEFUL GRIDVIEW TOOLS

Zoom In

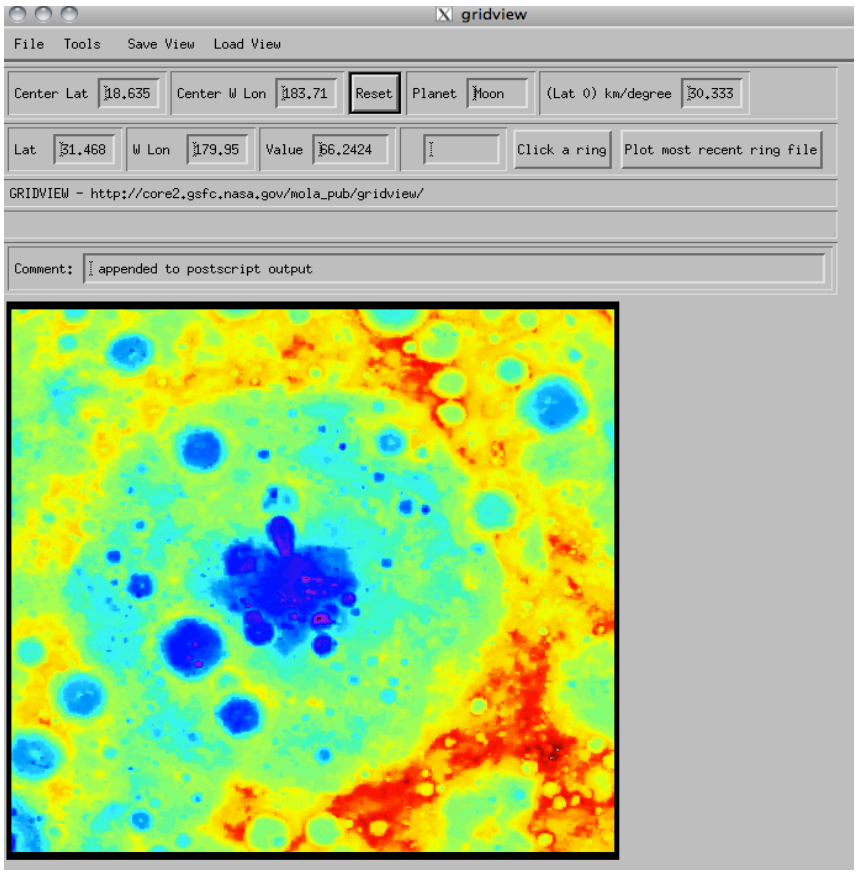
- This tool allows you to zoom in to an area of interest. How do you do this?
- With your cursor, click and hold on the Moon globe and slide your cursor to draw a rectangular shape in the location you would like to zoom in to. After the rectangle has been drawn, go to the “Tools” in your toolbar and click on “Zoom In”. You should now be zoomed in to the rectangular area that you created.

Stretch Colors

- This tool allows you to manually adjust the colors used to represent high and low topographic values so that you can pull out the most detail possible.
- Under “Tools”, click on “Stretch Colors”. A pop-up window will appear that will let you choose the range of colors that you’d like to display for the data. For example, in the scroll down menu you can choose such options as “Haze” or “Nature”. Examine your area of interest with different color choices to see if you can pull out more detail with one choice over another. For example, can you see more craters in your area of interest in one color range versus another? In this pop-up window you can also stretch the bottom and top of your color range. Play with these features to see if they help you to pull out more details in your image. You can always reset!

Maximize Color Stretch

- This tool automatically uses the Rainbow color scale (RGB) to stretch the colors. If you’re not interested in looking for specific features or details and just want to look at the topography of a region in general, consider using this tool instead of manually stretching the colors. How do you do this?
- Under “Tools” select “Maximize Color Stretch”. GRIDVIEW will maximize the colors automatically. Below is an example of how the tool works.

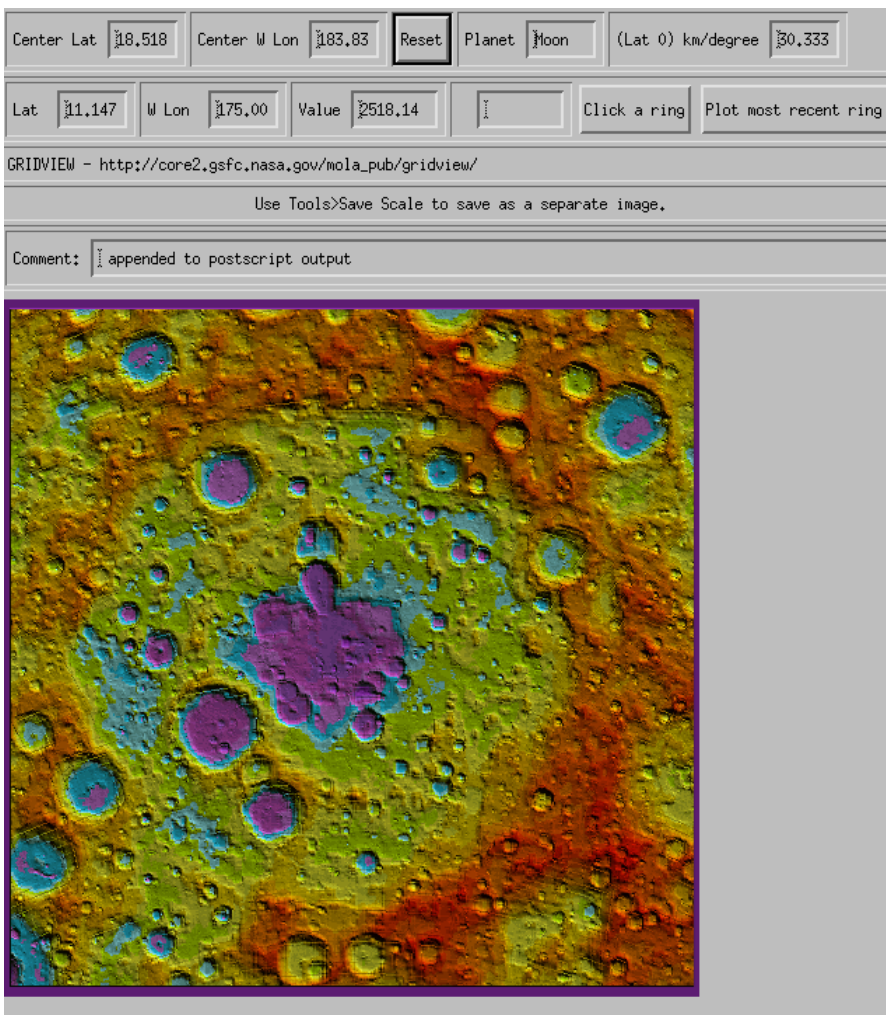


Show Color Scale

- This tool provides an elevation scale to match your color stretch.
- Under “Tools” select “”Show Color Scale”. Choose the type of orientation you want for your scale, vertical or horizontal. The default units for the scale are meters. Choose whether you want your labels on the top, middle, or bottom of your scale. Then click “accept” and you are done.
- **Note:** The “Show Color Scale” feature **does not work with shaded relief maps** (see below). If you want a color scale to go with your shaded relief map, you must use the “Show Color Scale” tool before using the “Shaded Relief 2” tool on your area of interest.

Shaded Relief 2

- This tool creates a shaded relief map of your area of interest. Shaded relief is a technique used to illustrate where lighting effects are added to a map based on elevation variations within the landscape. It is generally intended to mimic the Sun’s effect - illumination, shading and shadows - on hills and craters.
- Under “Tools” select “Shaded Relief 2”. A pop-up window will appear that will ask you to set the light angle, azimuth, and exaggeration. Feel free to play with these but we suggest using the default settings. You can choose whether or not you want to create a shaded relief map using your current color stretch, the maximum color stretch (see explanation above), or grayscale. Most often the maximum color stretch is used, hence it is the default setting.
- Note that the “Show Color Scale” tool does not show up correctly after you’ve created a shaded relief map of your area of interest. It’s best to create a color scale for your area of interest before using the shaded relief tool.
- Below is an example of the same image that has been changed to a shaded relief map.

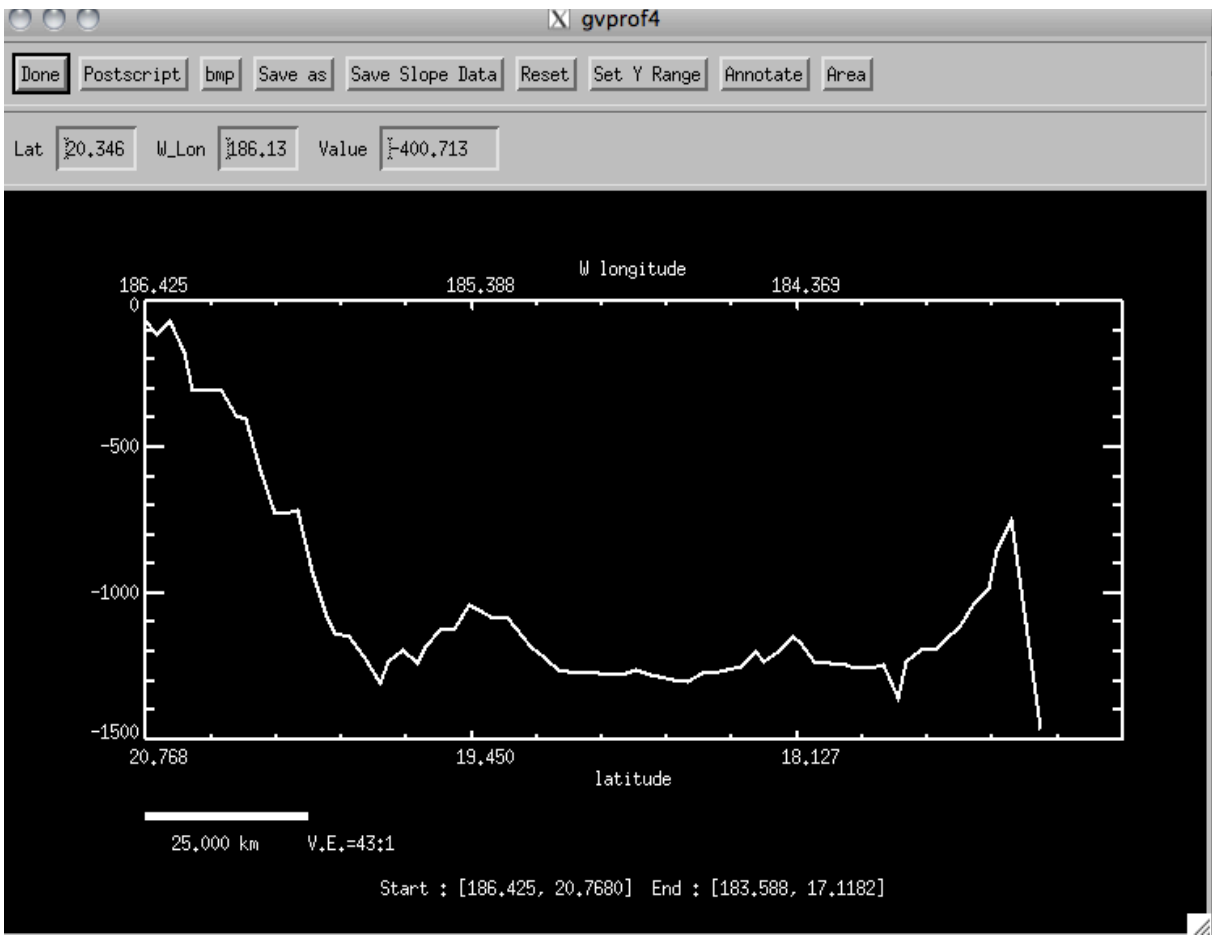


Calculate Distance

- This tool is used to determine the distance between two points on your map. How?
- Under “Tools” select “Calculate Distance”. Then, using your cursor, click on one point on the lunar surface and release. Move the cursor to another point of your choosing and click again. When you let go of the cursor a line will appear automatically through the distance you want to measure. The distance is displayed in the second from the bottom gray text area above the image.

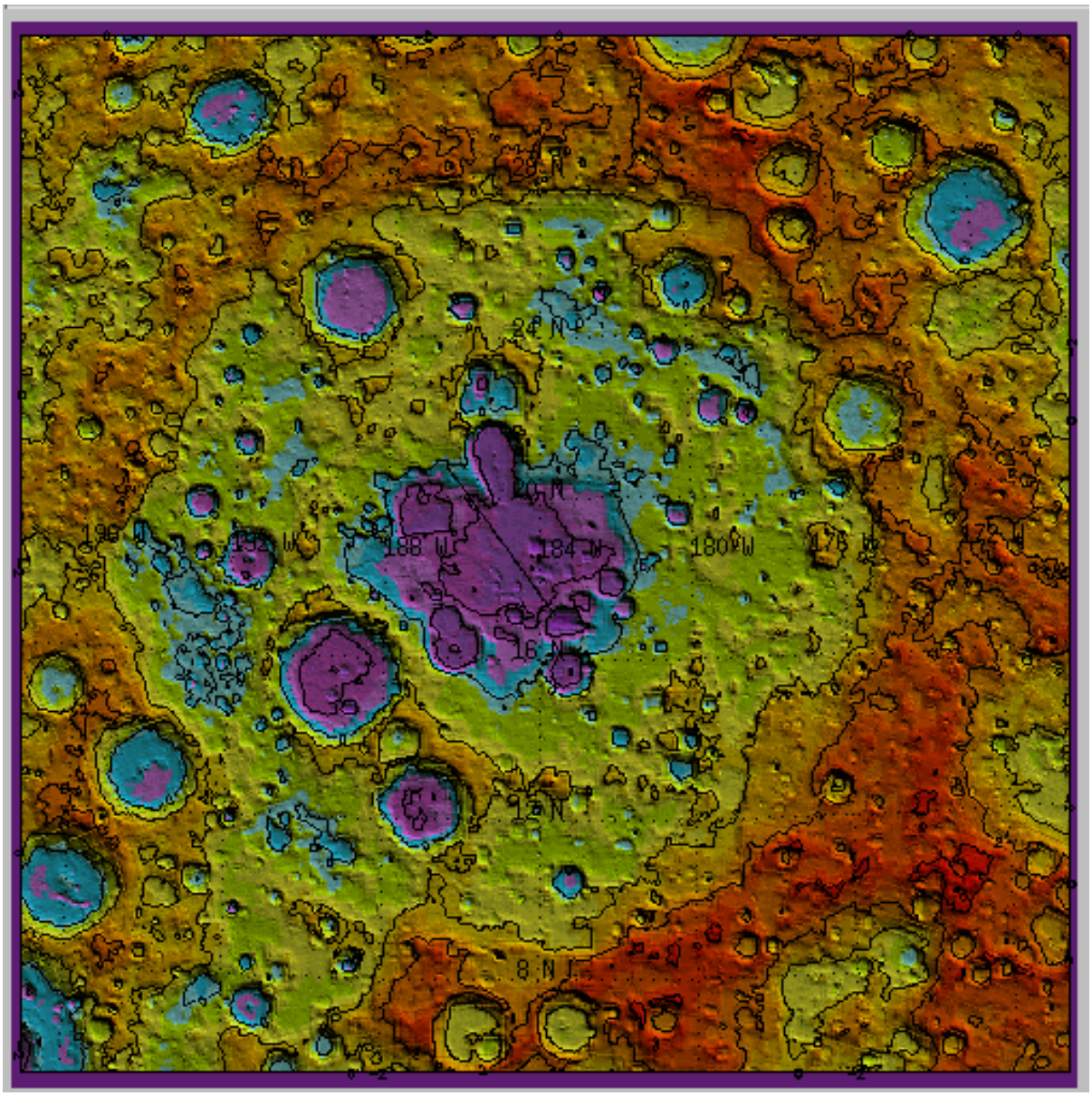
Profile

- This tool can be used to create a topographic profile (showing elevation), which is a cross-sectional view along a line drawn through a portion of a topographic map.
- Under “Tools” select “Profile”. Use your cursor to click on a starting point on the lunar surface. Release the cursor and move to the end location you want for the profile and click again. A pop-up window will show up with your profile. If you move your cursor over the profile, a grid line will show up so you can see the exact elevation of a particular spot on your profile!
- Below is a sample profile of a region on the same map.



Show Contours

- This tool adds contour lines to your area of interest. Contour lines are curved lines on a map that connect areas of equal elevation.
- Under “Tools” select “Show Contours”. A pop-up window will appear that tells you the minimum and maximum elevation range for your area of interest. You have the option of defining the minimum and maximum contour range, contour label factor, and contour interval that you would like to display if you do not wish to use the defaults that the program automatically selects for you.
- Contour lines have been added to the image posted below. In addition, labeled grid lines have been added (see next set of directions).



Show labeled grid lines

- This tool shows the labeled latitude and longitude grid lines on your area of interest. Look carefully at the image above. The gridline labels are there in a narrow font. Can you find 180W?
- How is this done? Under “Tools” select “ Show labeled grid lines”. They appear like magic!

Now you are ready to go from start to finish on an image to create a gridded topographical map of a specific place on the Moon of your choosing! Find a crater or highland area you are interested in, and begin a mapping activity. If you are unsure of what region/crater/highland you would like to work with, you can find a labeled map of the Moon at:

http://www.popastro.com/moonwatch/moon_guide/moonmap.html

or http://www.lunarrepublic.com/atlas/index.shtml

or http://the-moon.wikispaces.com/Consolidated+Lunar+Atlas the Consolidated Atlas

or http://www.oarval.org/MoonMapen.htm

or http://cseligman.com/text/moons/moonfar.htm (Far Side Map)