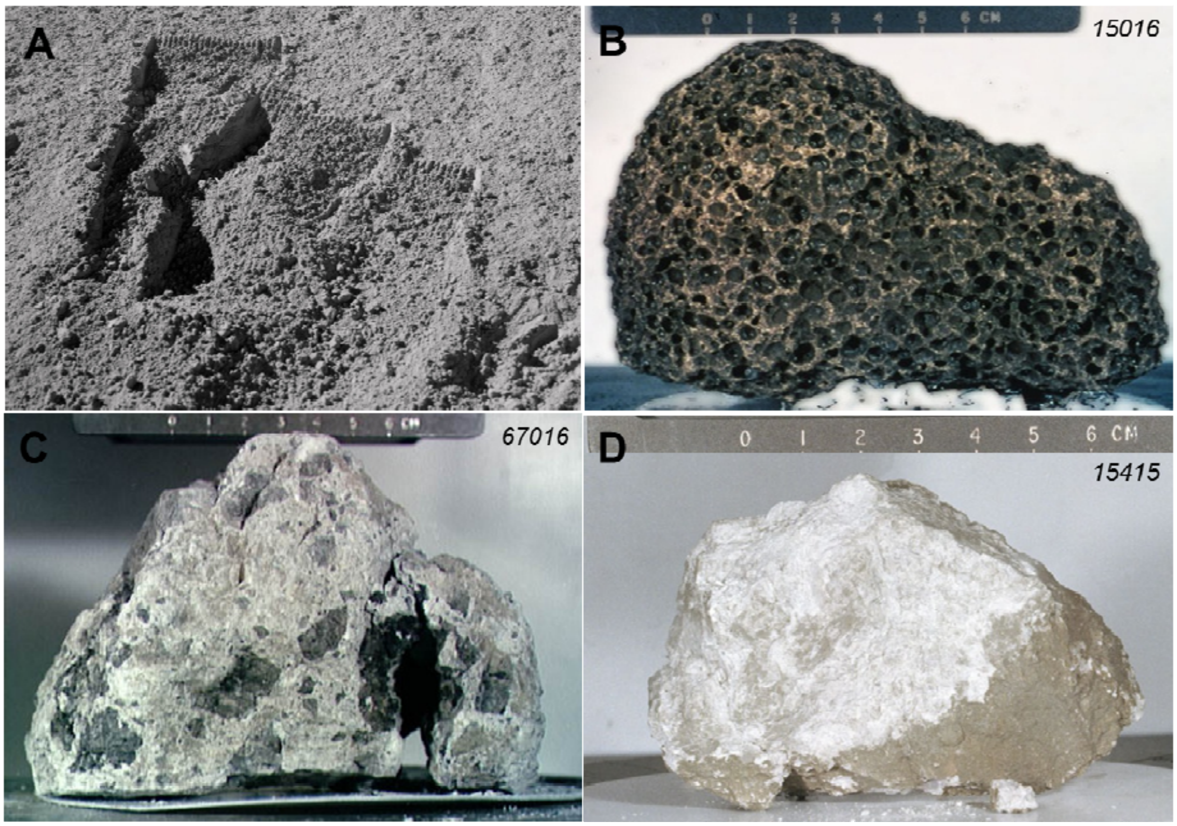
ROCKS, SOILS, AND SURFACES
Planetary Sample and Impact Cratering Unit

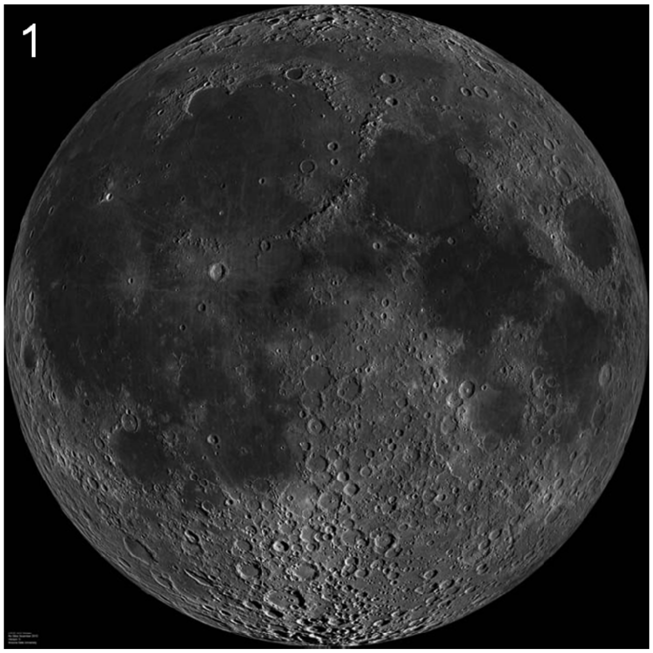
PART 1: OBSERVATIONS AND PRELIMINARY QUESTIONS

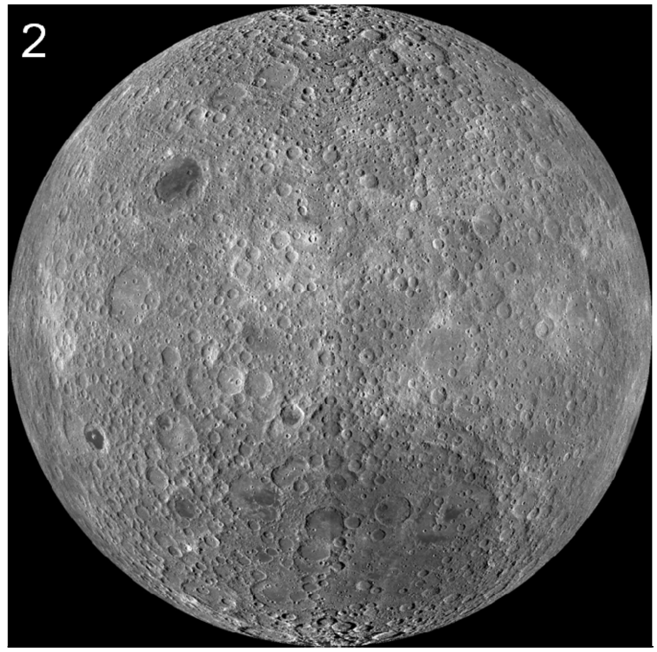
The images below are of rocks and “soil” from Earth’s Moon. List your observations of each image in the table below.



ROCK AND “SOIL” IMAGE OBSERVATIONS			
Image A	Image B	Image C	Image D

Now take a look at these two views of the Moon. List your observations of each view in the table below.





VIEWS OF THE MOON IMAGE OBSERVATIONS	
Image 1	Image 2

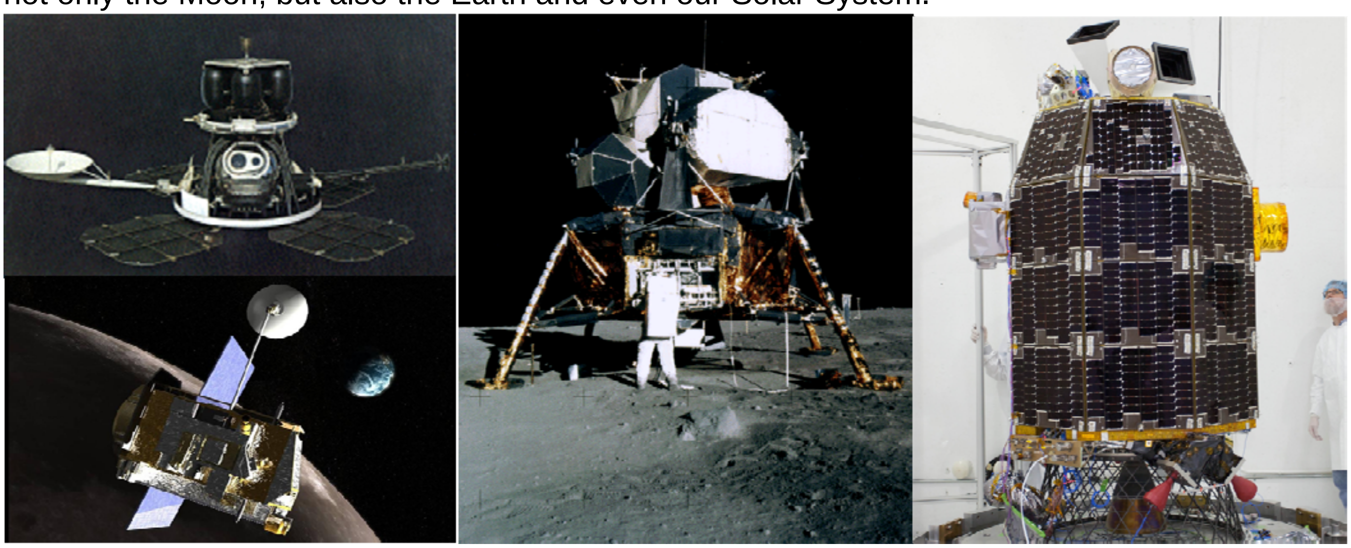
Based on your observations of the above sets of images, list at least 2-3 questions you have related to the Moon.

PART 2: WHY EXPLORE THE MOON?

People from countries all around the world can share the beauty and intrigue of Earth's Moon. As a matter of fact, every year, generally in October, there are International Observe the Moon Nights (InOMN). These annual celebrations, held all around the world, are designed to encourage people to look up, observe the Moon, and participate in exciting activities that help celebrate our nearest planetary neighbor. After all, our Moon holds secrets that can help uncover some of the mysteries of the history of our Solar System.

If you haven't done so lately, step outside and look up at our Moon. What do you notice? What do you think the rocks, "soil", and surface really look like? Do you know how the Moon formed? Have you ever imagined what it would be like to walk on the Moon? There are so many questions scientists and the general public have wondered and asked about our Moon. Through human and robotic exploration, NASA and international space agencies all over the world have uncovered answers to many of these questions. But, just as quickly as questions are answered, new questions arise. This is simply the nature of science. It is human nature to wonder and continually ask questions. That is one of the reasons humans explore.

Robotic lunar exploration began in 1959 and has continued throughout history. The images below are examples of four of the many different missions that have enabled scientists to study Earth's Moon. Just as we never stop learning about planet Earth, ongoing exploration of the Moon is also important. Through lunar exploration, studies conducted with the collection of lunar samples and remote sensing data of the surface help scientists decipher the history of not only the Moon, but also the Earth and even our Solar System.



Images of spacecraft that have explored or are exploring the Moon. From left to right: Lunar Orbiters (top), Lunar Reconnaissance Orbiter (LRO) (bottom), Apollo Missions, Lunar Atmosphere and Dust Environment Explorer (LADEE). Images courtesy of NASA.

While robotic spacecraft like the Lunar Orbiters (1960's) and the Lunar Reconnaissance Orbiter (LRO) (2010's) have provided invaluable remote sensing data for scientists to study, the six Apollo missions and astronauts (from 1969 to 1972) brought back 382 kilograms (842 pounds) of lunar rocks, core samples, pebbles, sand, and dust from the lunar surface. The Apollo missions returned 2,200 separate samples from six different landing sites. Three automated Soviet spacecraft returned an additional 300 grams (~3/4 of a pound) from three other lunar sites. Specialized “clean rooms” at the Lunar Curatorial Facility at the NASA Johnson Space Center in Houston, Texas house these precious lunar samples. The samples are stored in glass and stainless steel cabinets filled with pure nitrogen. As pure nitrogen is relatively inert, this ensures the lunar samples are not exposed to oxygen, water, or dust particles from Earth and can remain in pristine condition.

Working with a lunar sample in the Lunar Curatorial Facility at NASA JSC.

Today scientists continue to study rock and “soil” samples from the Moon in their laboratories. These continued studies have enabled progress in the understanding of the early history of the Moon, Earth, and the inner solar system. Among the useful contributions, one significant debate the lunar samples have helped settle is related to the formation of our Moon. There have been different scientific theories put forth about the formation of the Moon including that it is a captured object (planet or protoplanet) or that is it part of a dual planet system, but the data have never completely supported these scientific theories. Progress in lunar science, especially through research conducted on the collected lunar samples, has led scientists to formulate what is now considered to be the leading scientific theory about the formation of the Moon. Scientific data indicate that the Moon formed from a giant impact on Earth ~4.5 billion years ago, by a planetary body about the size of Mars. The debris resulting from this impact is what accreted (joined together) through the force of gravity, and formed the Moon. This scientific theory is strongly supported by data including the chemical composition of the Moon derived from studies of lunar rocks. By studying the rock and “soil” samples, scientists have also learned that a crust formed on the Moon ~4.5 to 4.3 billion years ago. Lunar samples record crust formation, the intense meteoroid bombardment occurring afterward, subsequent lava outpourings, and a permanent record of solar activity and radiation spewed out by the Sun.

Together, rocks, “soil” and remote sensing data of a planetary surface provide significant clues about its history. This applies to whether you are studying Earth, the Moon, or any other rocky world. The collected lunar samples, along with remote sensing imagery of lunar surface features, especially impact craters, have enabled scientists to answer important questions about our Moon and so much more. Are there still questions to answer? Absolutely! Robotic spacecraft will continue to provide data from the Moon that will enhance our understanding as new discoveries are made. Lunar missions such as LADEE (Lunar Atmosphere and Dust Environment Explorer), launched in 2013, are even helping scientists understand the thin tenuous atmosphere and the dust environment of the Moon. It is important to remember, the more we explore the Moon, the better scientists can piece together the history of our nearest planetary neighbor, and in turn, the history of Earth and our Solar System.

To help you gain your own perspective and understanding of rocks, “soils”, and surfaces, let’s take a closer look at the surface of the Moon, along with lunar rocks and “soil”. For each section of this activity, we will touch upon what we know about Earth to help us better understand the Moon, which we can then apply to other planetary worlds in our Solar System.

PART 3: EXPLORING ROCKS, SOILS, AND SURFACES

A. Exploring the Surface of a Planetary World

If we wanted to get a sense of the different features that make up Earth as a whole, one way to do that is to look at a global image, globe, or map of our planet. By simply observing Earth from a global perspective, you can immediately start to notice the variety of features that make up our planet. The Google Earth screenshot (shown on the left) allows us to easily detect that Earth has ocean basins, land masses (continents) and even ice sheets. If we were to zoom in, we could detect additional details. This includes identifying areas with high elevations and rough terrains such as mountainous areas. We could also identify low elevation areas such as flat plains. Zooming in also allows you to observe other bodies of water aside from Earth's oceans such as lakes and even river channels. Observing a planetary world from a global perspective and being able to zoom in to observe greater detail and smaller features allows you to gain valuable insight into the planetary world as a whole.

Screenshot image from Google Earth

What did you observe from the two views of the Moon from Part 1 of this activity? Perhaps you noticed two somewhat distinct regions of the Moon – one that appears brighter and the other that appears darker. Initial telescopic observations of the Moon led early scientists like Galileo Galilei and Johannes Kepler, to refer to these regions as terrae (Latin for "land") and maria (Latin for "seas"). Unlike Earth, however, the Moon does not have oceans and has never had any flowing water on its surface. So what do these darker and lighter regions of the Moon represent and what types of features exist on the surface of the Moon?

Scientists today refer to these two distinct regions of the Moon as the highlands and mare (lowlands). The highlands are the brighter grayish regions (see image 2), which are mostly found on the far side of the Moon, the side we do not see from Earth. These areas consist mostly of numerous overlapping craters. The craters formed when meteoroids (cosmic projectiles such as asteroids) and comets slammed into the surface creating bowl shaped holes. You will look at these features more closely later in this guide. The maria or mare (singular for maria), are much lower in elevation and are mostly found on the near side of the Moon, the side we always see from Earth (see image 1). These areas are lower in elevation than the far side of the Moon and are composed mostly of lava flows. In many cases, you can actually see where the lava has flooded and filled in low elevation areas such as impact basins.

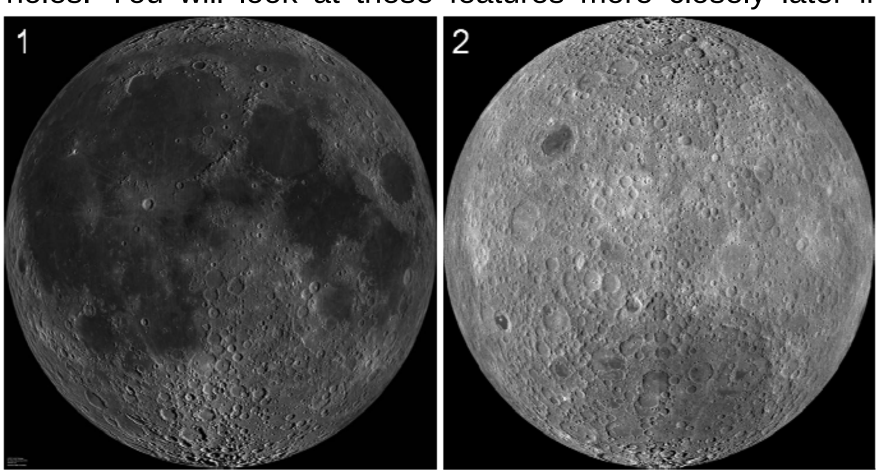


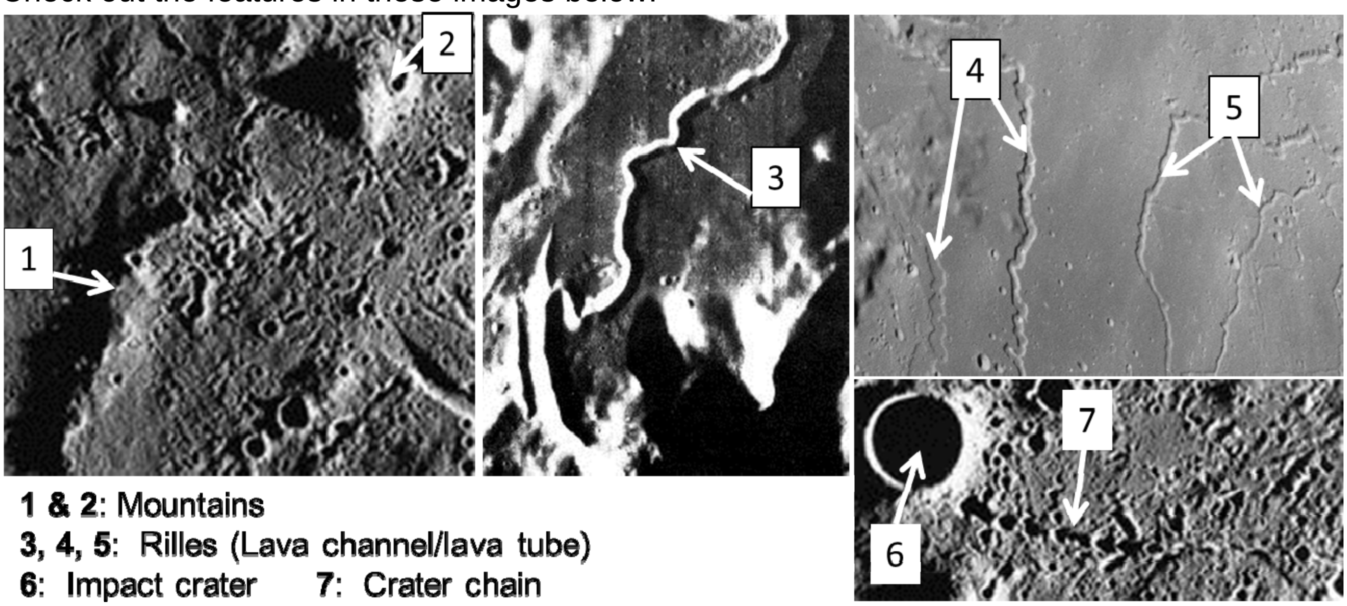
Image 1 (Left): Lunar mare observed on the near side of the Moon. Image 2 (Right): Lunar highlands (far side of the Moon) loaded with impact craters.

Although impact craters and lava flows are two of the most prominent features visible when looking at a global view of the Moon, there are other features that exist on the lunar surface.

Remote sensing images of the Moon allow us to zoom into the surface and identify other surface features that can help provide additional information about the Moon. The following surface features are commonly found on the Moon:

- **Impact Craters**: Bowl-shaped holes formed when meteoroids (cosmic projectiles) strike the surface.
- **Rilles**: Long valleys that formed 1) as lava flowed across the surface; or 2) when lava flowed underground forming lava tubes that eventually collapsed.
- **Crater Chains**: A pattern of multiple circular depressions that could be evidence of 1) a lava tube that has not completely collapsed (an incompletely formed rille); 2) a record of rocks that were thrown out during an impact event that fell in a linear or arc-like pattern forming secondary craters. (Note: Secondary craters are not just found in crater chains. They are often found alone, and some cannot be distinguished from primary craters.)
- **Mountains**: Raised features found on the surface. These mountains can be identified as 1) the rims and other features of large craters; 2) a central mound (uplift) found in the center of some large craters; or 3) low, circular, rounded hills called domes.

Check out the features in these images below:



1 & 2: Mountains
3, 4, 5: Rilles (Lava channel/lava tube)
6: Impact crater **7**: Crater chain

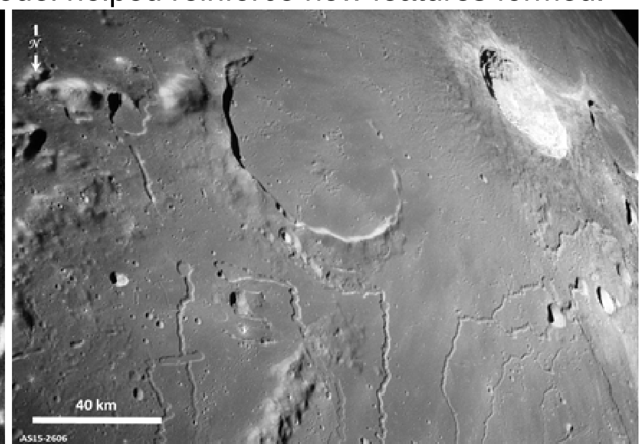
Certainly there are multiple features that are visible in each of these images, but these annotated images at least give you an idea as to what some of the described surface features look like in remote sensing imagery. Perhaps you noticed that the feature labeled #3 looks similar to a river channel on Earth. Although it may look similar, the Moon has never had water flow across its surface. So, although you may be tempted to call these features river channels, they should be referred to as rilles or as lava channels or lava tubes and are associated with flowing lava.

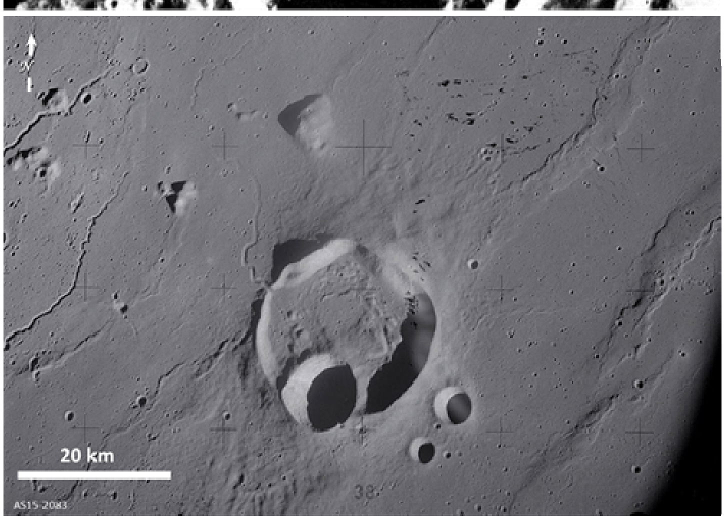
HANDS-ON ACTIVITY: CREATING A MODEL SURFACE OF THE MOON

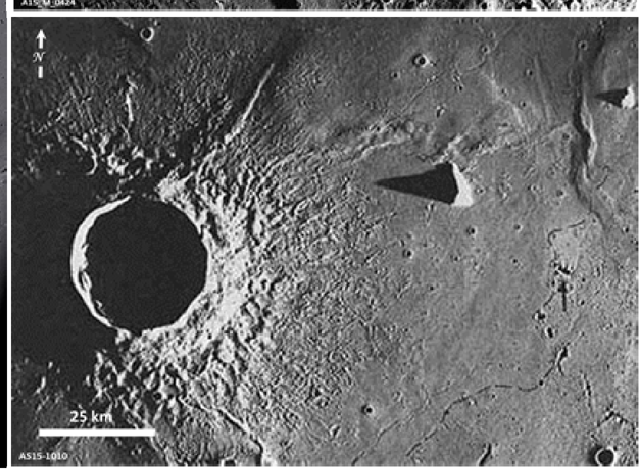
Now that you are aware of some of the features on the Moon, let's have you use your knowledge to create a labeled model surface. In groups you will be assigned to create a model of 1 of the 5 images of the Moon below. Use modeling clay or Play-Doh, along with sculpting tools (pencil, popsicle sticks, toothpicks, round objects of varying sizes) to create your model.

To complete this exercise, do the following:

- Create your model and label at least 5 surface features.
- Include measurements in km of 5 surface features in your model. (HINT: Use the scale bar provided on the image to help you figure out the sizes of features.)
- Discuss how creating the features in your model helped reinforce how features formed.







B. Exploring the Rocks on a Planetary World

The rocks on Earth, or any other planetary world, are a product of the processes that exist or have existed throughout the history of that planetary surface. For example, Earth is affected by wind, water, impact, volcanic, and tectonic processes. These geologic processes help create the rocks we find on our planet.

Rocks on Earth can be sorted into three general classifications:

- Igneous: Rocks formed when magma cools and hardens either below the surface (example: granites) or on the surface during volcanic events (example: basalts).
- Sedimentary: Rocks formed by the collection, compaction, and cementation of mineral grains, rocks fragments, and sand. They can form from deposits accumulated through weathering, biological, or chemical processes (examples: sandstone, chert, limestone).
- Metamorphic: Rocks formed when heat and/or pressure deep within the planet cause a change in the mineral composition and grain size of existing rocks (example: limestone to marble).

Throughout its history, Earth's Moon has not experienced the same geologic processes as Earth. After the initial crust formation, the two dominant processes that have sculpted the surface of the Moon are the impact and volcanic processes.

In thinking about the initial lunar crust formation, let's think about the lunar magma ocean concept. When the Moon formed, it was thought to be surrounded by a layer of molten rock (ocean of magma) hundreds of kilometers thick. As the magma crystallized, the minerals more dense than the magma sank, while those less dense (such as feldspar) floated. This process is known as differentiation and was instrumental in forming the anorthosite crust. The dense minerals (olivine and pyroxene) later remelted to produce the basalts that make up the lunar maria. As you will see, the rocks found on the surface of the Moon are a reflection of these processes.

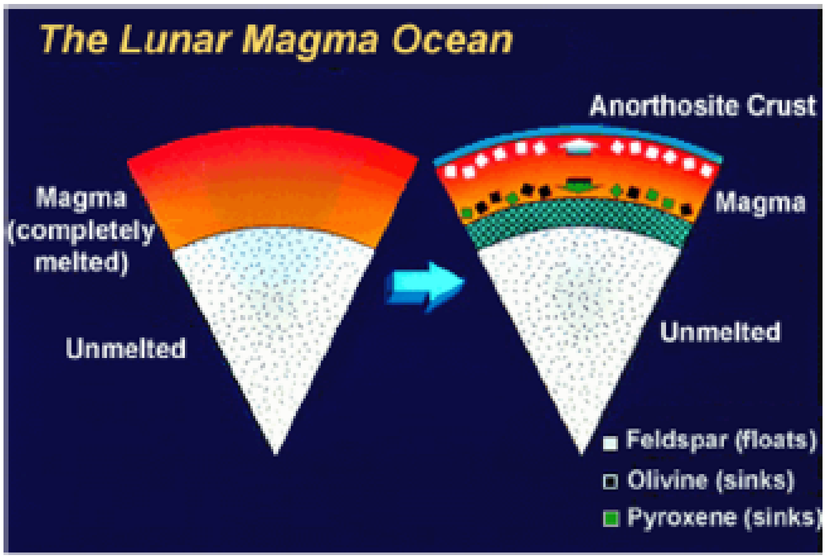


Image Credit: Brooks G. Bays Jr., PSRD graphic artist, University of Hawaii

Now let's focus on the lunar rocks. Lunar rocks can be classified into three general categories: 1) pristine highland rocks (anorthosites), 2) mare basalts, and 3) impact breccias.

1) PRISTINE HIGHLAND ROCKS (ANORTHOSITES)

One type of lunar rock brought back by Apollo astronauts is known as pristine highland rocks

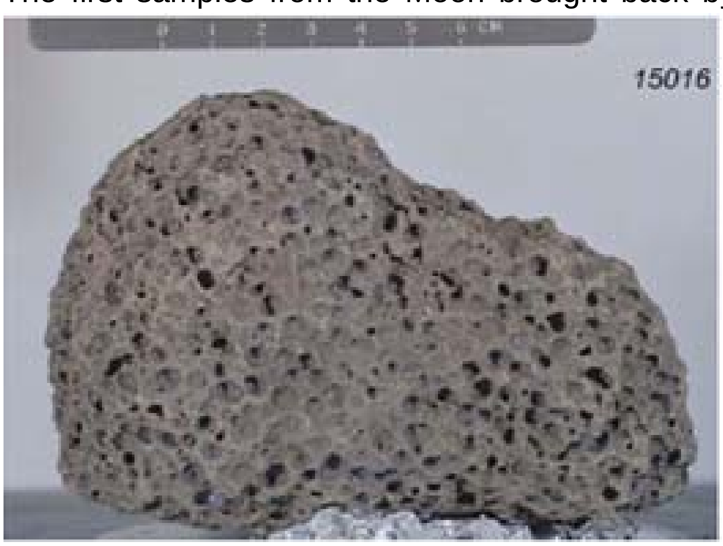
or anorthosites. Although astronauts did not collect many of this type of lunar rock, laboratory research on these samples has provided an abundance of information related to the formation of the Moon. These igneous (volcanic) rocks were collected in the lunar highlands and contain minerals such as feldspar. Feldspar minerals floated in a layer of molten rock (magma) and were thought to be part of the rocks that made up the original lunar anorthosite crust that formed between ~4.5 to ~4.3 billion years ago. These samples are considered to be "pristine" as they do not show evidence of being substantially altered by reheating since they were first formed. The most famous of these rocks (shown above) is the "Genesis Rock" collected by Apollo 15 astronauts.

Characteristics of Pristine Highland Rocks/Anorthosites:

- Brighter/lighter in color than the mare basalts
- Very friable (easily breakable)
- Generally coarse grained (can see individual minerals)

2) MARE BASALTS

The first samples from the Moon brought back by Apollo 11 astronauts were from a region



called Mare Tranquillitatis. These igneous rocks were black volcanic basalts. These mare basalts are located both at the surface as well as below the surface. On Earth, basalts are associated with volcanic activity. Laboratory research has shown that the lunar basalts are very similar to Earth basalts except for some minor chemical differences which have provided important clues into the history and formation of the Moon.

The mare basalts, like the anorthosites, are igneous (volcanic) rocks. They contain dense minerals such as olivine and pyroxene. Mare basalts formed by remelting the dense materials that sank out of the magma ocean which erupted on to the surface as lava. This lava, in many cases, filled up large impact basins of the Moon. The age of mare basalts range from ~3.9 to ~3.2 billion years old.

Characteristics of Mare Basalts:

- Dark gray to black in color
- Fine grained (you cannot easily see the individual minerals that make up the rock)
- Usually includes holes (vesicles) created by gases that escaped before the lava solidified into rock
- Rough texture
- Hard surface

3) IMPACT BRECCIAS

This type of lunar rock makes up the majority of samples collected by Apollo astronauts.

Breccias are composite rocks made by the solidification of a mix of various irregularly sized and shaped pieces of rocks. They were formed by impact events, which first shattered and then compacted pieces of rock from different places, fusing them together. Lunar breccias usually consist of grains of various sizes. They can have a wide variety of ages depending on the rock fragments incorporated within them. The fact that most of the Apollo samples are breccias demonstrates how significant the impact process has been throughout lunar history.

Characteristics of Impact Breccias include:

- Mixture of both fine and coarse grained rock and mineral fragments
- Appear to have features that look similar to basalts and/or pristine highland rocks
- Appear to have fragments (clasts) that have been "cemented together" to form the rock

HANDS-ON ACTIVITY: LUNAR GEOLOGIST PRACTICE

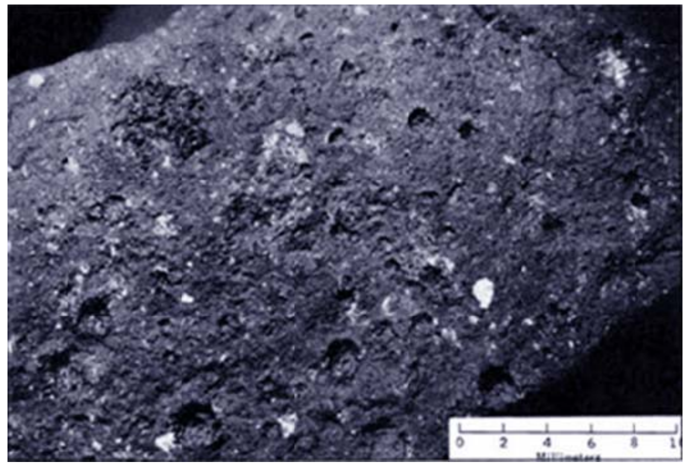
Now that you have had a chance to gain some information about the three general classifications of rocks on the Moon, let's have you put your lunar geologist skills to work. Examine the set of images of lunar samples. Use the characteristics provided (and create your own additional criteria) to identify the classification of each rock. Be sure to include your justification.

ROCK	ID#	CLASSIFICATION (Anorthosite, Basalt, Impact Breccia)	JUSTIFICATION
A	71055	Basalt	Vesicles, rough texture, dark in color
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
L			
M			
N			
O			
P			

Lunar Geologist Practice Images

C. Exploring the “Soil” on a Planetary World

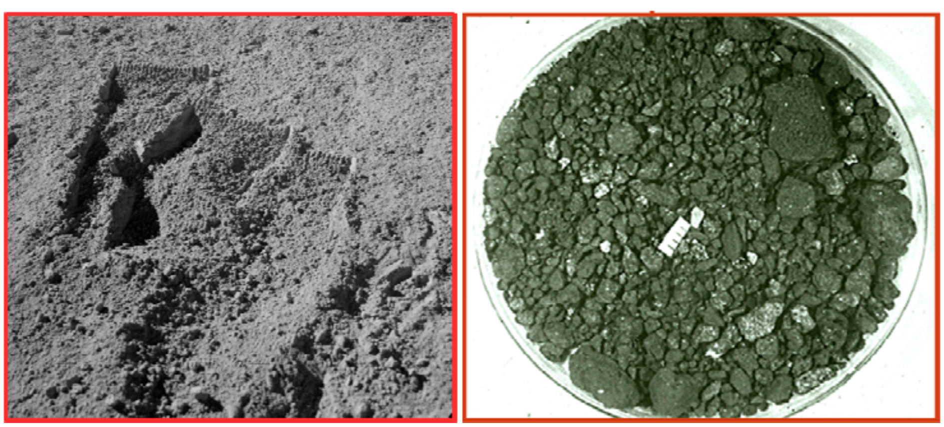
Planetary geologists are able to use the precious lunar samples you examined in the last section to learn about the history of the Moon. For some of the rock images you observed, you should have noticed there were small holes in the samples. In the case of the mare basalts, those holes are referred to as vesicles, which are a characteristic associated with the volcanic nature of these igneous rocks. In other cases, the holes are evidence of micrometeoroids (small meteoroids) that have struck the rock. This is a very common occurrence on lunar rocks. These micrometeoroid impacts are related to the formation of “soil” on the surface of the Moon. Before we examine how “soil” is formed on the Moon in too much detail, let’s first think about soil formation on Earth.



“Zap pits” (small holes) on Apollo 11 breccia sample (10019) created by micrometeoroids striking the rock.

On Earth, when we refer to soil, we are generally talking about loose material on the surface that contains organic material. Earth soil is formed from the effects of weathering processes on rocks. Weathering can cause rocks to fragment, crack, crumble, or decay. Physical weathering processes, like freezing water, can cause rocks to crack. Chemical processes, such as the decay of minerals in water or acids, or even biological weathering, from plant roots, can widen cracks in rocks contributing to the formation of soil. Additionally, erosional processes from water (rivers, rain, ocean waves, etc), wind, and ice (glaciers) can also further break down rocks into soil and transport these loosened materials.

When looking at planetary worlds in our Solar System, scientists more commonly use the term *regolith* to refer to the loose “soil” that covers a surface. By using the term *regolith*, the assumption of organic material being included in the sample is removed. Some scientists will only use the term *regolith* when talking about other planetary worlds, while others sometimes use soil and *regolith* almost interchangeably. The lunar *regolith* is a loose "soil" that covers the Moon. The texture and composition of the lunar *regolith* varies from place to place. The depth of the *regolith* can also vary from being a few meters to tens of meters. In general, the older the surface, the thicker the *regolith*.



Left: Lunar regolith on the surface of the Moon (Image Credit: NASA)
Right: Image of Apollo 11 regolith sample (Image Credit: John Wood et al, Smithsonian Astrophysical Observatory)

So how did the *regolith* form on the Moon? The Moon is not affected by the same weathering and erosional processes that we have on Earth. Therefore, some other process has been responsible for the formation of the lunar *regolith*. That process is the impact process. Lunar *regolith* was actually created by the continuous impact of the lunar surface by meteoroids. As micrometeoroids and larger meteoroids slam into the surface of the Moon, they impact the rocks and actually break them down into "soil". Lunar *regolith* is made up of a wide range of particle sizes and compositions. The main composition reflects the local underlying rock. On the mare surfaces, the *regolith* is basaltic rich, while on the highland surfaces, there is a greater abundance of pristine highland rock/anorthosite fragments. Since impacts eject rock materials great distances and distribute broken rock from one part of the Moon to another; *regolith* is usually a mixture of the different rock types as you will see in the hands-on activity.

HANDS-ON ACTIVITY: REGOLITH FORMATION ACTIVITY

Making *regolith* on the Moon is an ongoing process that continues today. In this hands-on activity, you will gain an understanding of how *regolith* is formed.

In a large plastic tub your teacher will put some light and dark graham crackers. The graham crackers represent the surface of the Moon, made up of anorthosite and basaltic rocks. Make sure you wear safety glasses as you use an actual rock (simulating a meteoroid) to impact the simulated surface of the Moon.

Before you begin, write your prediction to the following two questions. Once you have completed the simulation, write in the actual answers. Be prepared to discuss your predictions and actual results.

1. How many times will you need to have the rock impact the graham crackers before you <u>begin</u> to create *regolith*?

   - Prediction:

   - Actual:

2. The more the rock is dropped into the graham crackers, the more the particle size of the graham crackers will change. How do you predict the particle size of the graham crackers will change after dropping the rock into the plastic tub 5 times? How about after 15 times?

   - Prediction:
     - 5 drops:

     - 15 drops:

   - Actual:
     - 5 drops:

     - 15 drops:

Additional Questions (after completing the simulation):

3. If you used a new rock for each impact and never removed any material from the simulated surface in the tub, how would the volume of material in the tub change? Why?

4. Circle the best answer to complete the statement below:
   The Moon has been impacted by meteoroids for ________________________________.
   a. tens of years
   b. hundreds of years
   c. millions of years
   d. billions of years

5. Based on your observations of the Moon, which side of the Moon (near side or far side) appears to have experienced a higher number of impacts? Explain.

6. Which surface of the Moon would you hypothesize has a thicker coating of *regolith,* the lunar maria or lunar highlands? Why?

7. How might you determine the "soil" type when looking at an actual sample from the Moon?

8. Discuss how this model reflects a good representation of illustrating *regolith* formation.

9. Discuss the limitations of this model in illustrating *regolith* formation.

D. UTILIZING YOUR OBSERVATION SKILLS: EXPLORING A LUNAR SAMPLE DISK
You now have experience identifying the three different classifications of lunar rocks (mare basalts, anorthosites, and impact breccias) and have also learned a bit about lunar *regolith*.

Did you know that NASA has actual samples of the Moon that can be sent to your teacher? The Curatorial Facility at the NASA Johnson Space Center has created and is able to distribute 6-inch lunar disks that contain lunar samples to disk-certified teachers (see image below). It is very exciting to hold a set of extraterrestrial materials in your own hands!

Below is an image of one of the lunar sample disks. Take a look at the image and using the skills you have acquired throughout this activity, indicate which sample number corresponds to the correct lunar sample type. (Note: Sample #3, Orange soil, has not been previously discussed, but is a "soil" that contains volcanic glass that erupted on the surface of the Moon.)

____ Mare Basalt

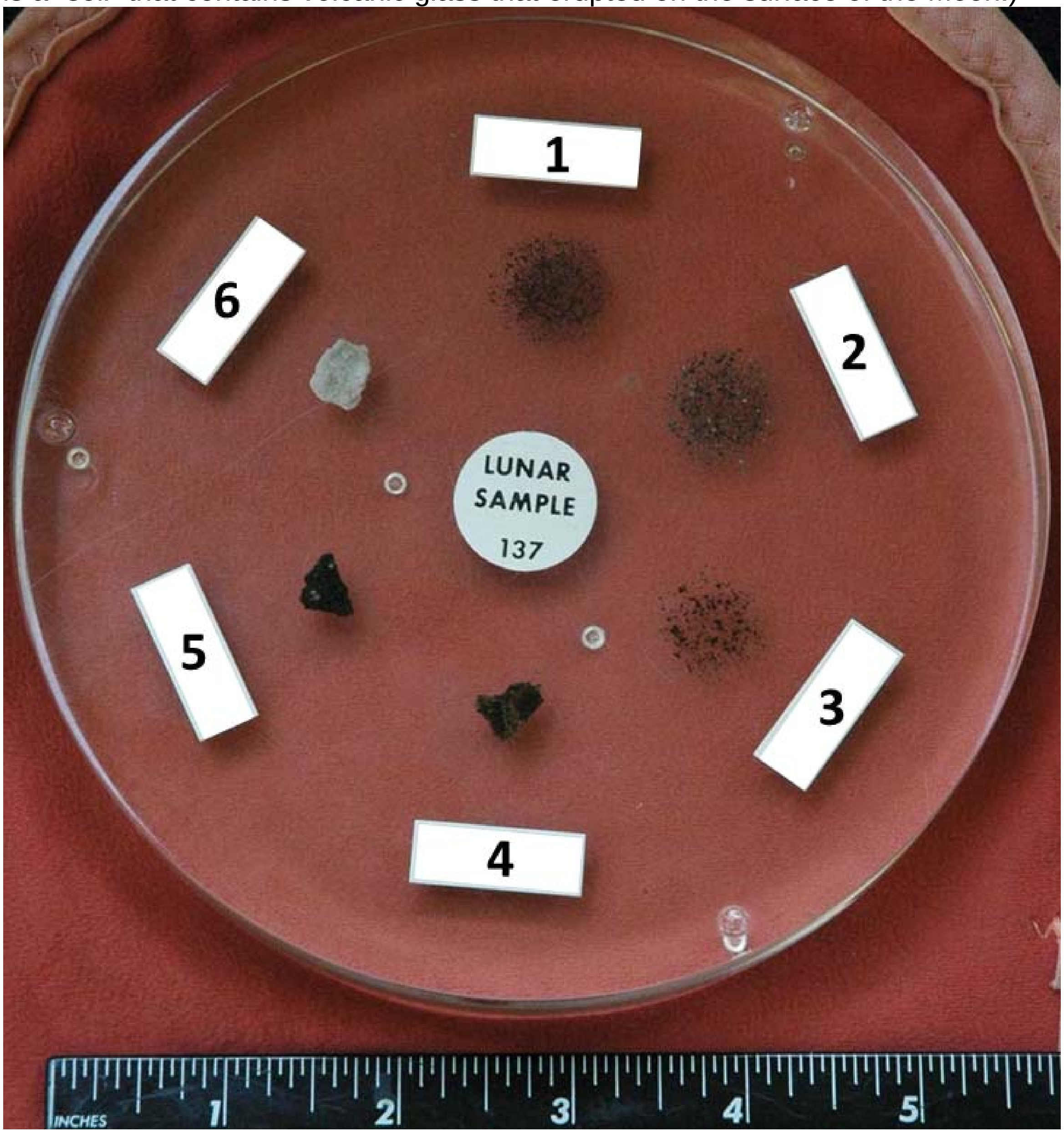
____ Anorth-osite

____ Impact Breccia

____ High-land "soil"

____ Mare "soil"

__3__ Orange "soil"



PART 4: CLOSER LOOK AT IMPACT CRATERS THROUGH EXPERIMENTS

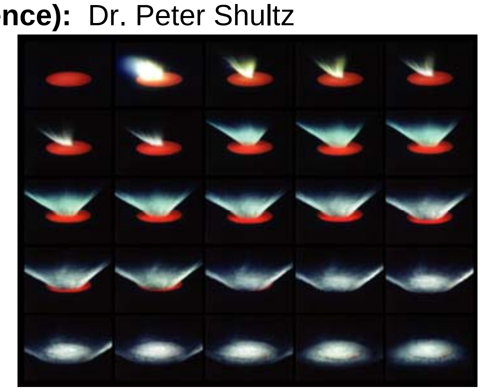
Studies of rocks and *regolith* are two very significant aspects of the Moon that have helped scientists understand the history of the Moon. Let's think about how meteoroids impacting the surface of the Moon can have an even bigger "impact" than just making *regolith*.

This section of the activity gives you an introduction to the impact process as well as a challenge to design a team experiment focusing on impact craters. Keep in mind that the impact process basically works the same way whether you are studying this process on Earth, the Moon or other planetary worlds. Of course certain planetary factors influence the final crater results on the surface of a planetary world. These factors include aspects such as the composition, mass, and gravity of the planet, temperatures, the atmosphere (if one exists), the interior, and any active geologic process affecting that planetary surface. The mass and the speed of the incoming projectiles also are major factors for crater size and the amount of ejecta that is thrown out of the crater during the impact process.

Now take a closer look at impact craters.

A: Impacts and Big Explosions

1. Initial Impact Viewing: View the videos and images related to the Moon and impacts. Think about what you see and what questions you have as you watch.

Video #1: Evolution of the Moon  http://www.nasa.gov/mission_pages/LRO/news/vid-tour.html	**Video #2: From the Earth to the Moon**  http://www.lpi.usra.edu/nlsi/moonVideo/
Video #3: Deep Impact - Mission to a Comet  http://www.nasa.gov/mission_pages/deepimpact/multimedia/experiment.html	**High velocity impact experiments (Image sequence):** Dr. Peter Shultz  http://www.nasa.gov/centers/ames/images/content/119167main_impact_sequence.jpg

Record your observations and questions about impacts and impact craters:

- I noticed…

- Why are they…?

- I wonder…

- What if…

2. HANDS-ON ACTIVITY: MAKING CRATERS IN IMPACT BOXES

In class you will make impact craters using materials provided by your teacher. Be sure to follow your teacher's instructions and obey all safety rules.

Write observations and questions about the impact box activity in the spaces below:

- Wow, I saw…

- I didn't expect…

- I wonder what happened when…

- I don't understand…..

B. Impact Experiments

Your teacher will regroup the class into teams consisting of 4 students per team.

1. In your team, discuss the observations and questions from the videos and the hands-on impact activity. Consolidate the team information and report the observations and questions to the class.

- We observed:

- We wondered:

2. BACKGROUND INFORMATION ON IMPACTS AND CRATERS

Impact craters form when meteoroids (including pieces of asteroids) or comets strike the surface of a planetary body. There are craters on all the terrestrial planets, on Earth's Moon, and on all rocky objects in the solar system. Impacts occur everywhere in our Solar System – comets and asteroids even hit the Sun!

Geological evidence in the lunar rocks returned by the Apollo missions indicates that about 3.9 billion years ago asteroid-size chunks of matter were abundant in the solar system. This was a time of intense bombardment of the young planets, affecting Earth by breaking up and modifying parts of the crust. Mountain building, plate tectonics, weathering and erosion have largely removed the traces of Earth's early cratering period. But the near absence of weathering on the Moon has preserved much of the evidence of this ancient time.

Impact craters form through the transfer of energy from a moving mass (asteroid fragment or comet) to a planetary world. Kinetic energy is the energy of motion. It is defined as one half the mass of an object, times the velocity of the object squared ($KE = \frac{1}{2} * m * v^2$). Objects in space have mass and move very fast, so there is a huge transfer of energy as objects smash into planetary worlds, cause huge explosions, and form craters! During an impact event, the kinetic energy of an incoming mass is transferred into heat and shock waves. This transfer of energy melts rocks, pulverizes and ejects or excavates rocks.

As your team designs and conducts impact experiments, keep in mind that you will not be able to generate the same amount of kinetic energy involved in the actual impact process. Your experiments, however, will allow you to gain a better understanding of how the impact process works.

3. Design and Conduct Your Team Experiment

Your team challenge is to design a simple experiment that will allow you to gather data to help answer a question that you have about impact crater formation. Use your experience with watching impacts and making craters in the impact boxes to guide your question and experiment design.

- What question will your team will try to answer?

- Write a short summary of the experiment your team plans to conduct:

- How will this experiment give you results that you can use to answer your question?

- What variable will your team test and what controls do you need to make the data valid? (Controls are parts of the experiment that stay the same each time you conduct the experiment and a variable is the part that changes or is being tested.)

- How will you record and display your data?

- Write a procedure for the experiment; include all the steps needed and who will be responsible for each part. Record the experimental procedure on paper or on your computer. Be sure to include how you will address any safety concerns as part of your procedures.

- Draw/design your experiment set up including all equipment:

- How many times will you need to repeat the experiment to get useful results and enough data?

- How long is the experiment process going to take?

- List the equipment, including safety equipment, your team will need:

- Draft a data table you will use to collect and record your data and notes:

Submit your team experimental plan including materials list and safety precautions to your teacher for review.

When the teacher approves your plan, conduct your experiment. Record data, take good notes, and make drawings in your notebooks. Document your experiment with photos or videos if possible.

C. Interpret Data and Report Conclusions

As you look at the data your team collected, it is important to discuss what the data can help you conclude about your question. It is also useful to reflect on your experiment and its application towards studying impacts throughout our Solar System.

- What does your data tell you? Discuss all interpretations of the data – there may be different interpretations.

- Do you have enough data to make a conclusion? Should you repeat the experiment to get more data?

- What conclusions can you draw about the answer to your question based on your experiment?

- What changes would you make to the procedure and experimental process if you conducted the experiment again?

- How can this experiment and results be applied to better understanding the impact process on Earth, the Moon, or other planetary worlds?

- Prepare a team report that includes your team question, experimental design, data, conclusions and recommendations for further experimental work. See your teacher for the proper format for the report and the report deadline. Be prepared to answer questions from other teams that may challenge your process or conclusions. Critical review by peers and courteous critique is a major part of the scientific process.

PART 5: CRATER INVESTIGATORS

Now that you have experimented with impact craters, let's think about where you find impact craters not only on the Moon, but also on Earth.

The study of impact craters can help scientists better understand the history of a planetary world. Impact craters expose sub-surface layers of the planetary world. How those craters and layers are modified over time can also reveal important information about geologic processes affecting that surface.

Let's first think about where we find impact craters on Earth. Here are some questions for you to initially think about and discuss:

1. How many impact craters do we have on Earth?
2. Do you think the impact craters on Earth are concentrated in certain areas or are they randomly distributed around the planet?
3. How do scientists find impact craters on Earth?
4. Is it possible to confuse an impact crater with another type of feature on Earth? Why or why not?

Let's become more familiar with impact craters on Earth. Although you may think it is easy to locate and detect impact craters on Earth, it is not as easy as you think. On Earth, dynamic geologic forces have the ability to erase most of the evidence of impacts on our surface. Between weathering, erosion, deposition, volcanism, and tectonic activity, many of the impact craters on Earth have been erased. Despite this, there are numerous impact structures that have been identified on the surface of Earth. These structures vary in size, age, modification, and location.

As for identifying impact craters on the surface of Earth, this is not always as straight forward as you may think. Take a look at the impact crater shown on the top right. This is an image of Barringer Crater (also known as Meteor Crater) in Arizona. For years, scientists were not sure whether this was an impact crater or a volcanic crater. Like impact craters, volcanic craters are also roundish in shape but are associated with volcanic activity (see image on bottom right). It wasn't until scientists studied the rocks in and around Barringer Crater that they finally realized this feature was associated with an impactor striking the surface of Earth as opposed to volcanic activity. When studying the Moon or other planetary worlds, scientists have also had to consider the process in which the numerous visible circular depressions were created. Studying the lunar rocks and using remote sensing data has helped confirm the numerous impact craters on the Moon.

Barringer Impact crater (top) versus Pinacate volcanic crater (bottom). Can you easily tell the difference? (Credits: Barringer: Meteorcrater.com; Pinacate: D.Lynch)

Let's investigate impact craters….

A. EARTH CRATER INVESTIGATORS

Take a look at the *Earth Impact Database* handout. This handout provides the following data about impact craters found on Earth:

- Crater Name
- General Geographic Location
- Specific Geographic Location (latitude and longitude)
- Crater Age (in millions of years)
- Crater Diameter (distance from one side of the crater to the other, through the center.)

Scan the *Earth Impact Database* handout. Describe what you notice about the following:

1. Number of craters found on Earth:

2. Size range of craters:

3. Age range of craters:

4. Location of craters:

You could conduct quite an in-depth investigation with this data set, but at the same time you may not have enough time to work with all this data. Professional scientists can sometimes be overloaded with overwhelming amounts of data to work with as well. The more data you have to work with, however, the more confidence you can have in your results and conclusions. Sometimes limitations, such as time constraints, make it necessary to decide to use a subset of data that represents what you are aiming to study. You will be asked to make such decisions with this very complete and large dataset.

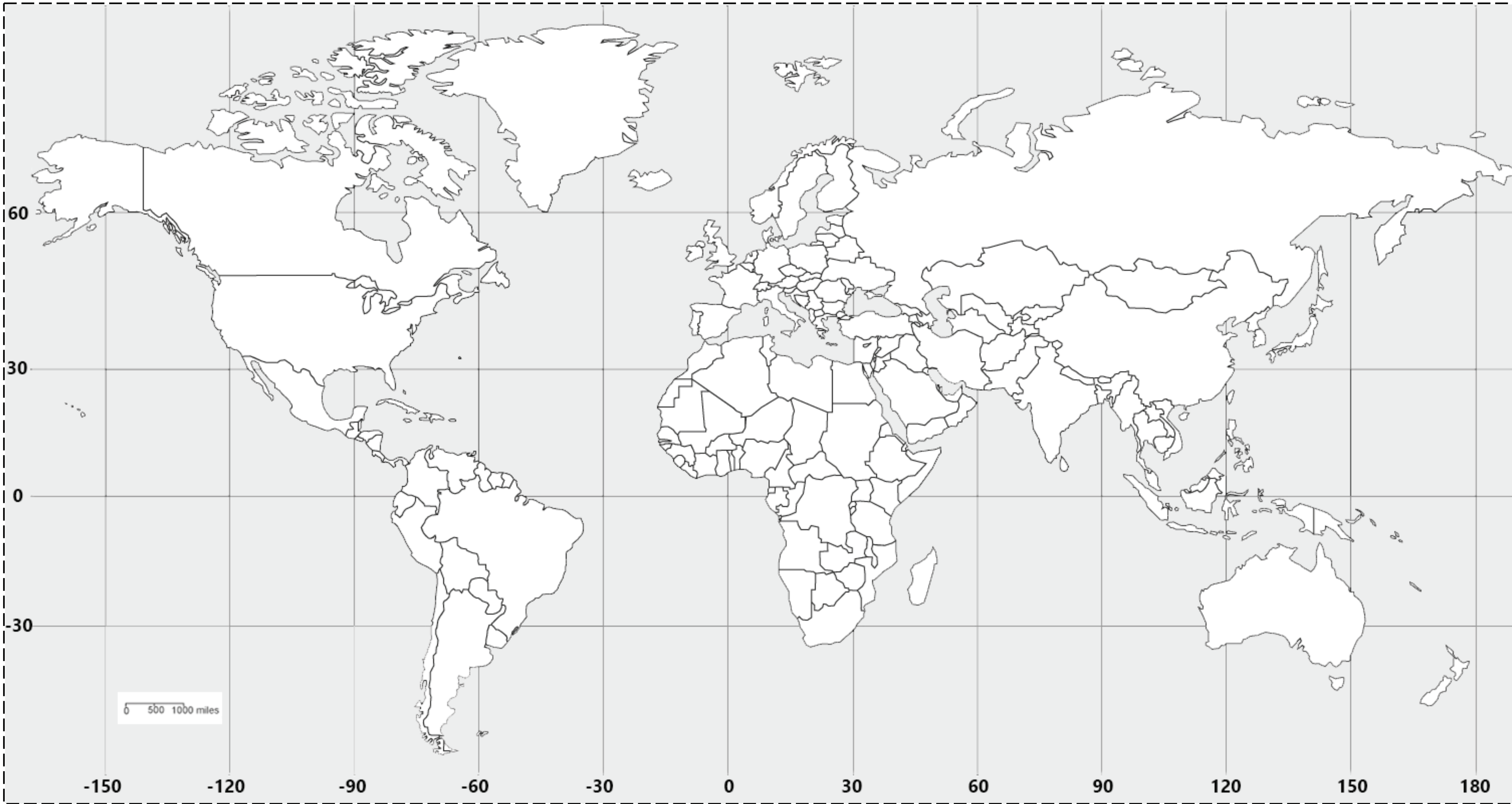
In small groups, scan the data provided more closely and decide how you can use a subset of the data provided to help illustrate something about craters on Earth. There are certainly a lot of choices, but let's start by having you choose at least 20 different craters to plot on the map provided. Think about and plan what you want to illustrate and discuss ways to plot the data.

First, elaborate on your plan by answering the questions below. Second, plot your crater data on the map on the next page. At the top of your map include a title that represents the information you displayed.

- What do you want your map to illustrate about craters on Earth?

- How will you select your subset of data to plot on your map? How many data points will you plot on your map?

- Describe what type(s) of symbols you will use to represent your plotted data. Be sure to include a key/legend on your map as necessary:



Base map from www.freeusandworldmaps.com

Astromaterials Research and Exploration Science (ARES) Education
NASA Johnson Space Center

Look at the maps created by others in the class. Keep in mind that a subset of data was used to create these maps. By choosing a subset of data, someone may draw a conclusion about craters on Earth that is not quite complete or valid. It is important to avoid causing potential misinterpretations related to the data you are displaying, especially when using a subset of data.

Choose two different maps of data that were created (including your own). In the table below, list the following: 1) map title and brief description of what the plotted data illustrates about craters on Earth; 2) at least one potential misinterpretation that could be formulated about craters on Earth based on the subset of plotted data; and 3) consider how you could address each potential misinterpretation to ensure a suitable understanding of impact craters on Earth.

Map Title and **Brief Description of What Plotted Data is Illustrating**	**Potential Misinterpretations**	**Ways to Address Potential Misinterpretations**
Map title: Description:		
Map title: Description:		

B. LUNAR CRATER INVESTIGATORS

Think about how many craters you noticed in the global views of the near and far sides of the Moon. There are certainly many more impact craters on the Moon than there are on Earth. For an investigation related to craters on the Moon, you would definitely need to use a subset of data.

Think about an aspect of impact craters on the Moon you could focus on for an investigation. How would you go about conducting that investigation? What data would you need to collect? How would you plot that data on a map of the Moon? What potential misinterpretations might there be and how could you address them to ensure a suitable understanding about lunar craters? Write a brief overview of a potential investigation plan in the table below. Be prepared to discuss your plan in class.

LUNAR CRATER INVESTIGATION	
Investigation Focus	
Data You Would Collect for Investigation	

Brief Description of Data you would Plot on a Map	
Potential Misinterpretations	
Ways to Address Potential Misinterpretations	

THE IMPORTANCE OF ROCKS, SOILS, AND SURFACES: TYING IT ALL TOGETHER

The rocks, “soils”, and surfaces of any planetary world help reveal important information about that planetary world. They reflect processes that have helped sculpt the surface of a planet throughout its history. Scientists can use rock and “soil” samples collected from a planetary world to better understand the features observed on the surface. NASA has numerous samples that were collected from identified locations on the Moon. This allows scientists to more easily piece together the story of those specific locations and the Moon itself. In addition to the lunar samples, NASA has also retrieved and brought back samples from a comet (Wild 2) and the Sun. Scientists have also collected meteorites in Antarctica, though it can be challenging to identify what planetary world those meteorites may have come from. There are future plans to collect samples from other planetary worlds including Mars and asteroids. Future samples will allow scientists to piece together a stronger understanding of the history of those planetary worlds, sample locations, and the Solar System as a whole.

So what ties together and influences the rocks, “soils”, and surfaces of a planetary world? The answer is the geologic processes that sculpt the surface of that planetary world. What is the most dominant geologic process that has sculpted the inner planetary worlds of our Solar System like the Earth, Moon, Mars, Venus and Mercury? You may have guessed it -- the answer is the impact process.

As you reflect on what you have learned in this activity, you should be able to identify the role of the impact process on the lunar rocks, regolith, and certainly on the surface of the Moon, which is loaded with impact craters. The impact process is even likely responsible for the formation of the Moon itself! The impact process has played a major role in the formation and history of not only our Moon, but also Earth and Solar System. By studying impact craters, along with studying rock and “soil” samples from the Moon, or even other planetary worlds, you are able to trace changes within our Solar System over time.

Interested in better understanding of the history of our Solar System? You could further investigate lunar samples or conduct an investigation of impact craters across the Solar System. Use and apply the knowledge you have gained from this activity and investigate impact craters on Earth, the Moon, and other planetary worlds. As you do, you will begin to unlock the history of our Solar System, as well as be able to ponder the future of Earth and influences on future human and robotic exploration.