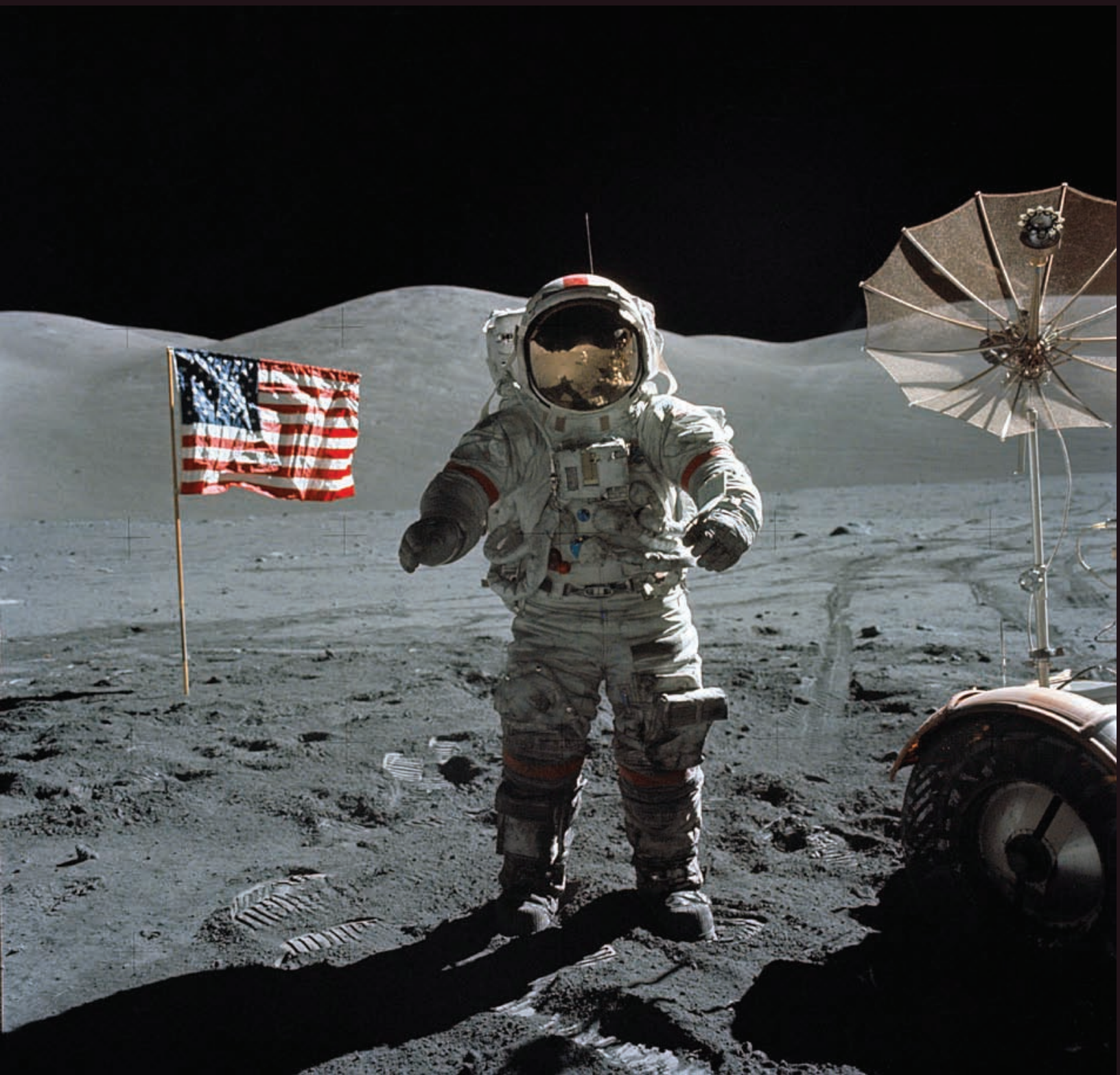
National Aeronautics and
Space Administration

Educational Product	
Educators and Students	Grades 3-5

Exploring the Lunar Surface

EDUCATOR'S INSTRUCTIONAL GUIDE



Exploring the Lunar Surface

EDUCATOR'S INSTRUCTIONAL GUIDE

This book was created by SpaceMath@NASA so that younger students can explore the lunar surface through the many photographic resources that have been collected by NASA over the years.

Students should be encouraged to look at each photograph in detail and study the changing appearance of the moon as we move closer to its surface. They should be encouraged to ask many questions about the details and features that they see, and how to move from one picture to another as the scale of the images change. They may also make a game of this process along the lines of 'I Spy'.

This book focuses on 'scale and proportion' as mathematical topics. A number of hands-on activities are also provided to allow students to create and explore scale-models for spacecraft and lunar craters.

This resource is a product of

SpaceMath@NASA

(http://spacemath.gsfc.nasa.gov)
and was made possible through a grant from the NASA, Science Mission Directorate, NNH10CC53C-EPO.

Author: **Dr. Sten Odenwald** - Astronomer
National Institute of Aerospace and
NASA/Goddard Spaceflight Center

Director of SpaceMath@NASA
sten.f.odenwald@nasa.gov

Co-Author: **Ms. Elaine Lewis** – Curriculum Developer
ADNET Systems, Inc.

Project Lead - Formal Education Coordinator
NASA Sun-Earth Day.

Director, Space Weather Action Center

Table of Contents

Cover Page:

Between 1969 and 1972, NASA's Apollo astronauts journeyed to the Moon and walked upon its surface. They discovered, first hand, that the surface is covered in powdery gray dust that caused unforeseen problems for NASA astronauts. Apollo 17 astronaut Harrison "Jack" Schmitt took this picture of Eugene Cernan during their third and last walk on the lunar surface in December of 1972.

Notice how dirty Astronaut Eugene Cernan's white spacesuit became after only few hours of kicking up 'Moon dust'. This dust is as fine as sifted flour, but is also as abrasive as sand. It can damage delicate instruments, and it will be a major environmental hazard for future lunar explorers.

Program Overview

Our Moon has been admired for thousands of years, and because of this is one of the most familiar astronomical objects to children of all ages. Its cyclical phase changes from full Moon to new Moon and back over the course of 28 days, has been an important source of time-keeping for many different civilizations. The dramatic landings of Apollo astronauts on the Moon starting in 1969 have made the Moon an almost common-place extension of humanities 'neighborhood' in space - one to which we may return in the coming decades. The activities in this book are designed to give students in grades 3-5 an opportunity to discover our Moon- Earth's only natural satellite and use mathematical concepts to understand size and proportion.

Note for the Teacher:

There are two periods involved with the orbit of the Moon around the Earth. This often leads to some confusion, but can be easily understood. Let's investigate!

<u>Sidereal Period versus Synodic Period</u>

Measuring the motion of the Moon around the Earth relative to the distant stars leads us to what is called the sidereal period. The sidereal period is the time required for a celestial body within our solar system to complete one revolution with respect to the fixed stars ‹i.e., as observed from some fixed point outside the system. The sidereal period of the Moon is the time needed for it to return to the same position against the background of stars. The Moon appears to move completely around the celestial sphere once in about 27.3 days as observed from the Earth. This is called a sidereal month. It represents the orbital period of the Moon around the Earth.

Measuring the motion of the Moon around the Earth relative to the Sun leads us to what is called the synodic (pronounced si-nod-ik) period. The synodic period is the time required for a body within the solar system, such as a planet, the Moon, or an artificial Earth satellite, to return to the same or approximately the same position relative to the Sun as seen by an observer on the Earth. The Moon's synodic period is the time between successive recurrences of the same phase; e.g., between full moon and full moon.

The Moon takes 29.5 days to return to the same point on the celestial sphere as referenced to the Sun because of the motion of the Earth around the Sun; this is called a synodic month (lunar phases as observed from the Earth are correlated with the synodic month).

So why are the sidereal and synodic lunar months not equal in length?

Remember that the Earth moves in its own orbit around the Sun. The synodic period is related to the lunar phases; it depends on the relative locations of the Sun-Earth-Moon. If we start measuring at Full Moon, then one sidereal month later we will not yet be back to a Full Moon, since the Moon must travel further in its orbit around the Earth to reach the same relative Sun-Earth-Moon alignment...all because during the 27.3 days of the sidereal month, the Earth moved along in its orbit around the Sun and now the Moon must "catch up" to this new position. It takes it just over 2 days to do so.

In grades 3–5, the math activities from ***Lunar Math*** were selected for application of proportional reasoning. The hands-on activities are used to excite the students about the Moon, what the surface of the Moon is like, what is needed to develop a spacecraft to learn about the Moon and what it was like for astronauts to walk on the Moon. The main use of Exploring the Lunar Surface is to provide a different way to practice proportional reasoning in the classroom. The activities include practice with measurements.

Moon Facts:

- 240,000 miles from Earth
- Moon is 1/4th the size of Earth-Equator diameter-3,476 km (Earth 12,756 km)
- Gravity of Moon is 1/6th that of Earth
- Mostly made of basalt, also found on Earth (show sample of basalt- volcanic rock)
- Temperature range -230° F to +292° F (-193°C to +111°C) night in polar region to the day at equator
- 3 days to reach the Moon an average distance of 383,022.9 Kilometers (238,00 miles) traveling at an average speed of 5319.69 Km/hour (3,305.5 mph)
- 4.5 billion year ago: The Moon was very hot. It began to cool slowly. Its surface changed from liquid to solid rock. The lighter lunar highlands solidified first.
- 4.0 billon years ago: Large objects crashed into the Moon. These impacts re-melted, crushed, and mixed the Moon's surface. New rocks formed from the broken and melted older rocks.
- 3.5 billion year ago: Hot liquid rock deep inside the Moon flowed to the surface. Lowlands filled with dark lava. New rocks formed as the lava quickly cooled. The darker basins are called mare or seas, although they contain no water.

Student Learning Components

Research: Students master an understanding of the size and surface of the Moon.

Analytic interpretation: Students collect and record data

Higher Level Thinking: Students summarize the data

Modalities for Learning

Auditory: This learner does best by listening and responding to verbal instructions. They solve problems by talking them out.

Visual: This learner does best through demonstrations and descriptions. They often make lists or drawings to develop solutions. They have well developed imaginations.

Tactile: This learner does well with projects or demonstrations. They like hands-on activities. They need to take notes when learning something new.

Kinesthetic: This learner does best when they are actively involved. They learn best by doing, and often have problems sitting still and may lose much of what is said or read.

Overarching Concepts

The following series of activities is meant to enhance the use of mathematical concepts through the integration of additional fun science activities into the math classroom.

> *Encourage the development of a classroom of integrated and active learning including the application of mathematics within science content.*

Provide education communities with research-based information and innovative resources that are compliant with the needs of a diverse audience and "universal design" methodologies

Instructional Objectives

1. Students will build models to enhance their understanding of a NASA spacecraft.
2. The students will complete simple science experiments to enhance understanding of weightlessness using buoyancy as the example.
3. Students will use classification skills a concept that integrates math and science
4. Students will use simple materials to understand the reason for variations of craters while practicing the use of measurement.
5. The students will practice math skills through real lunar data and images.

Next Generation State Standards Connections

Common Core State Standards (mathematics)

Geometry:

Grade 3: Reason with shapes and their attributes.
Grade 4: Represent and interpret data.
- Geometric measurement: understand concepts of angle and measure angles.

Measurement and Data:

Grade 3: Geometric measurement: understand concepts of area and relate area to multiplication and to addition.
- Geometric measurement: recognize perimeter as an attribute of plane figures and distinguish between linear and area measures.

Grade 4: Recognize angle measure as additive. When an angle is decomposed into non-overlapping parts, the angle measure of the whole is the sum of the angle measures of the parts. Solve addition and subtraction problems to find unknown angles on a diagram in real world and mathematical problems, e.g., by using an equation with a symbol for the unknown angle measure.

Number Operations:

Grade 5: Recognize angle measure as additive. When an angle is decomposed into non-overlapping parts, the angle measure of the whole is the sum of the angle measures of the parts. Solve addition and subtraction problems to find unknown angles on a diagram in real world and mathematical problems, e.g., by using an equation with a symbol for the unknown angle measure.

CROSSCUTTING CONCEPTS-NEXT GENERATION STATE STANDARDS

Scale, Proportion, and Quantity- Natural objects and observable phenomena exist from the very small to the immensely large. (5-ESS1-

Science and Engineering Practices
Analyzing and Interpreting Data - Analyzing data in 3–5 builds on K–2 and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. Interpret data to make sense of and explain phenomena, using, logical reasoning, mathematics, and/or computation. (5-ESS1-a)

Disciplinary Core Ideas - ESS1.B: Earth and the Solar System
The orbits of Earth around the sun and of the Moon around Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily and seasonal changes in the length and direction of shadows; phases of the Moon; and different positions of the sun, Moon, and stars at different times of the day, month, and year. (5-ESS1-b) (*Note: Seasons are addressed in middle school.*)

Video Resources:

NASAeClips has created many dramatic video programs describing the Moon and lunar exploration. Here are a few examples, but visit **http://tinyurl.com/4xm5sm** and find over 80 other videos for grade K-5 students.

The Lunar Reconnaissance Orbiter Mission **(http://tinyurl.com/7vzrmwb)**

Get a new perspective on Moon resources with NASA's Lunar Reconnaissance Orbiter. See how NASA plans to gather data about the unique lunar poles. Scientists will use the light reflected off the surface to identify different minerals on the Moon

Other resources found on NASA eClips: **(http://tinyurl.com/4xm5sm)**

Our World: The Moon - Students explore the basic properties of the Moon and its influence on Earth.

Our World: Digging in Moon Dirt
NASA scientists are working to develop a machine capable of digging in the fine, razor sharp dirt on the Moon. Go behind the scenes at the NASA lunar backhoe competition where researchers compete to find out whose machine rises to the challenge. Other activities and current information about the Moon and the missions can be found at http://moon.nasa.gov

5E Learning Cycle Lesson Plan

Using the 5E Learning Cycle provides an opportunity for students to build their own understanding from experiences and new ideas.

More information:
http://www.nasa.gov/audience/foreducators/nasaeclips/5eteachingmodels/index.html

Engage: In this section the teacher creates interest, generates curiosity, raises questions and elicits responses that uncover what the students know or think about the topic. The students first encounter and identify the instructional task. They make connections between past and present learning experiences, lay the organizational ground work for the activities ahead and stimulate their involvement in the anticipation of these activities. (Lesson 1) Students will talk about the Moon stating what they know and wonder about the Moon.

Explore: In this section the students have the opportunity to get directly involved with the content and materials. By involving themselves in these activities, they develop a grounding of experience with the content. As they work together in teams, students build a base of common experience, which assists them in the process of sharing and communicating. The teacher encourages the students to work together with minimum supervision, observes and listens to the students, and asks probing questions to redirect the students' investigations when necessary. The teacher provides time for students to work through problems, and acts as a facilitator. (Lesson 2)Students build a model of a spacecraft and see how each part relates to something they know- a human to gather information about the world around them.
(Lesson 3)Students will recall some of their own experiences with “weightlessness” on an amusement park ride or in a swimming pool. They will understand why an astronaut needs to practice in a swimming pool, the closest thing on Earth to weightlessness in space, buoyancy.

Explain: In this section the student begins to put the abstract experience through which she/he has gone, into a communicable form. Language provides motivation for sequencing events into a logical format. Communication occurs between peers, the facilitator, or within the learner himself. Working in groups, learners support each other's understanding as they articulate their observations, ideas, questions and hypotheses. The teacher encourages the students to explain concepts and definitions, asks for justification (evidence) and clarification from students. In some cases the student can provide definitions, explanations, and new labels, based on their previous experiences, as the basis for explaining new concepts. (Lesson 4) and (Lesson 5)Students will use materials to represent the surface of the Moon, rocks commonly found in their own backyard or easily provided in an inexpensive rock collection for the the classroom (costs vary from $8.00- 80.00) are used as a method to collect data and recognize some rocks present on Earth and on the Moon. (Lesson 5) Cratering has been used for many years and does require adult supervision to be sure objects impact the designated surface of flour and

cocoa. Students practice measurements and understand the results of impact from different angles and heights. This also provides an understanding of what causes the appearance of the Moon's surface, craters. The activity provides an understanding of the images used in the math activities.

Elaborate: In this section, the students expand on the concepts they have learned, make connections to other related concepts, and apply their understandings to the world around them. The teacher expects the students to use formal labels, definitions, and explanations provided previously, and encourage the students to apply or extend the concepts and skills in new situations. The teacher reminds students of the existing evidence and data and asks: What do you already know? Why do you think . . Math Activity

Evaluate: This is an on-going diagnostic process that allows the teacher to determine if the learner has attained understanding of concepts and knowledge. Evaluation and assessment can occur at all points along the continuum of the instructional process. The Space Math activities can be used throughout the activity to determine the mastery of proportional reasoning.

Lesson 1: Lunar Pre-assessment

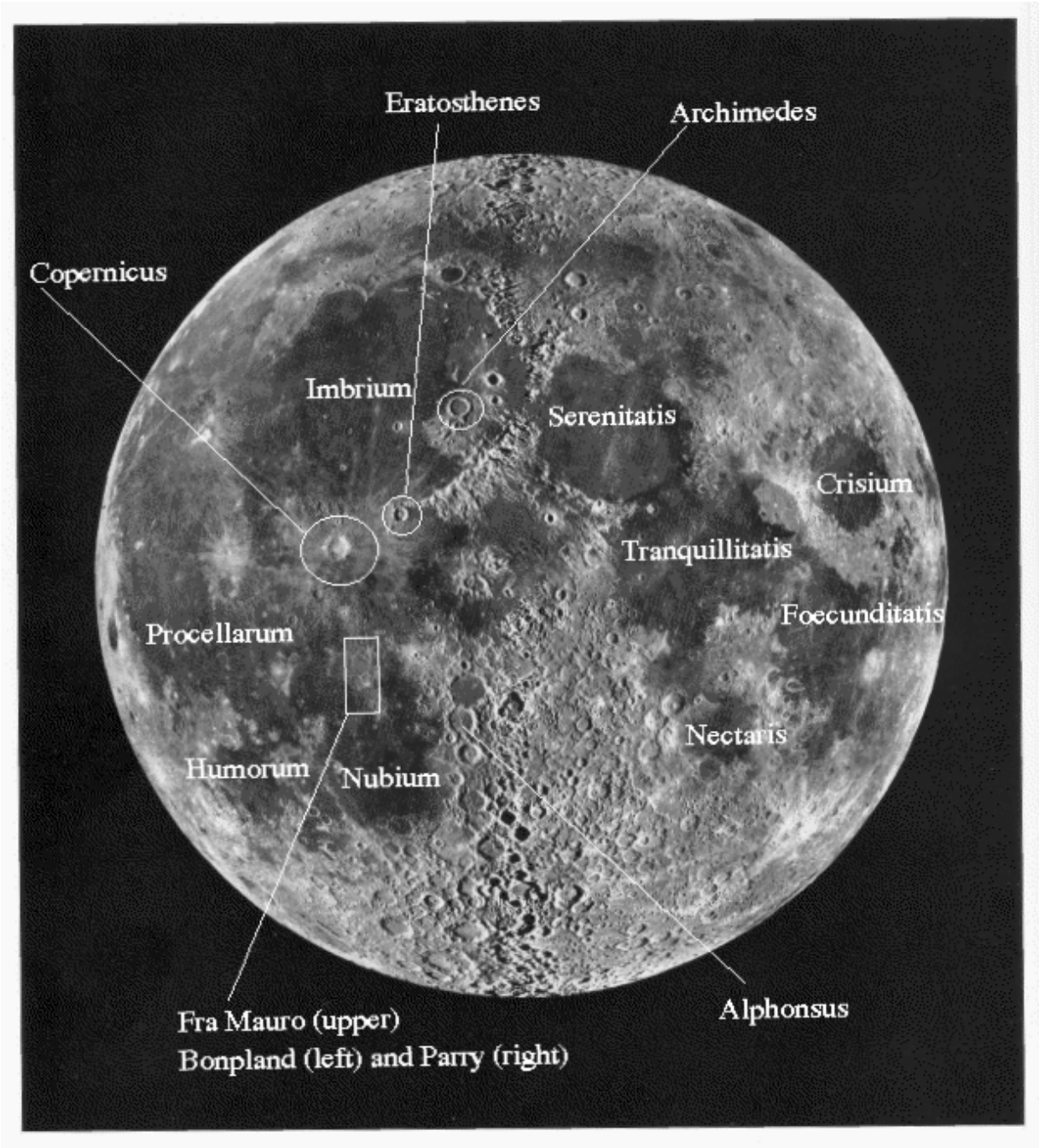
Time: 30 minutes
Materials:

- Drawing supplies (paper, pencils, markers, etc.)
- Images of the surface of the Moon
- Earth Observations- Phases of the Moon

To get started, ask all of the students to draw a picture of the Moon. Encourage them to include as many labeled parts as they can recall. Reassure them that their drawings will not be graded.

Doing a "K-W-L" chart is a great way to have students begin a new project: a chart that lists columns for "What We Know", "What We Want to Know", and "What We Learned". This strategy helps students focus on and share what they already know about a subject. You, as the teacher, will become aware of the general knowledge basis that different students possess, and will be alerted to possible misconceptions that your students may have about particular topics. Use the images of the Moon surface to discuss craters if the term is provided, review the phases of the Moon when these are also mentioned (good place to recognize some common misconceptions and the need to re-teach a topic).

One student can act as a recorder and can compile a KWL chart for the class using the topics, "***What We Know about the Moon***", "***What We Wonder about the Moon***" and "***What We Learned about the Moon***". Ask the students to complete the last section, "***What We Learned about the Moon***" after they finish this entire lesson.


Eratosthenes
Archimedes
Copernicus
Imbrium
Serenitatis
Crisium
Tranquillitatis
Foecunditatis
Procellarum
Nectaris
Humorum
Nubium
Alphonsus
Fra Mauro (upper)
Bonpland (left) and Parry (right)

Lesson 2: The Edible LRO Spacecraft

Source: Based on NASA's Saturn Educator Guide)
If there are rules within schools that do not allow students to consume an edible science model, an educator can present the activity as a demo.

Lunar Reconnaissance Orbiter

Other Names: **LRO**
Launch Date: October 1, 2008
Launch Site: Kennedy Space Center
Launch Mass: Fully fueled-1,000 to 1,200 kg; Dry-500 to 600 kg
Power System: About 400 W by solar arrays and stored in lithium-ion battteries

The Lunar Reconnaissance Orbiter (LRO) is a Moon-orbiting mission scheduled to launch in the fall of 2008. The first mission of NASA's Robotic Lunar Exploration Program, it is designed to map the surface of the Moon and characterize future landing sites in terms of terrain roughness, usable resources and radiation environment with the ultimate goal of facilitating the return of humans to the Moon. The following measurements are listed as having the highest priority:

- Characterization of deep space radiation environment in lunar orbit.
- Geodetic (geodesic-line) global topography.
- High spatial resolution hydrogen mapping.
- Temperature mapping in polar shadowed regions.
- Imaging of the lunar surface in permanently shadowed regions.
- Identification of appreciable near-surface water ice in polar cold traps.

Source: IRO at <http://nssdc.gsfc. nasa.gov/database/MasterCatalog?sc=IUNARRO>.

Time: 45 Minutes

Materials:

Per student:
Student Data Sheets
5 Crème Wafers
1 individual graham cracker (one-half of a sheet)
2 Starburst fruit chews
2 pieces of candy corn
2 individual skittles (a pack can be divided among students)
1 Tootsie roll
1 jumbo marshmallow
3 pretzel sticks
Marshmallow crème or icing (small containers or shared jar)
1 small paper/plastic plate
1 plastic knife
Paper towels
Wet wipes

Procedure:

- Distribute the materials. Tell the teams that they will now build a model of the LRO spacecraft with the materials provided.
- Students can use a diagram of the spacecraft and some imagination to add instruments.
- Go over the definition of the term 'robot' before the students design their edible model

Spacecraft (body/torso/skeleton) The base is the core structure (or framework) to which spacecraft components are attached. This is made out of aluminum, the same metal used in soft-drink cans. Graham Crackers

Computers (brain)
Computers manage a variety of intelligent functions such as navigation and propulsion, storing information from scientific instruments and sending information to Earth. Tootsie roll

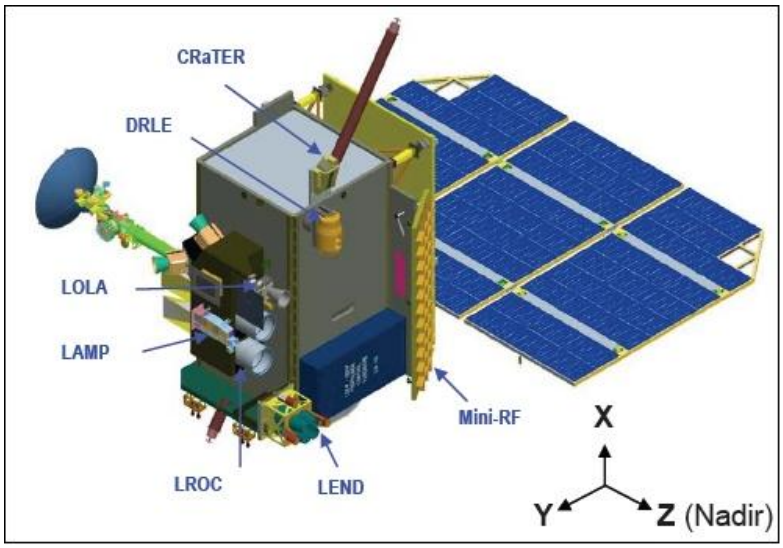
Spacecraft cameras (eyes)
Lunar Reconnaissance Orbiter Camera (LROC) will collect very detailed pictures of possible future landing sites and places for habitats. The camera's pictures will help scientists learn about different lunar soils. Skittles

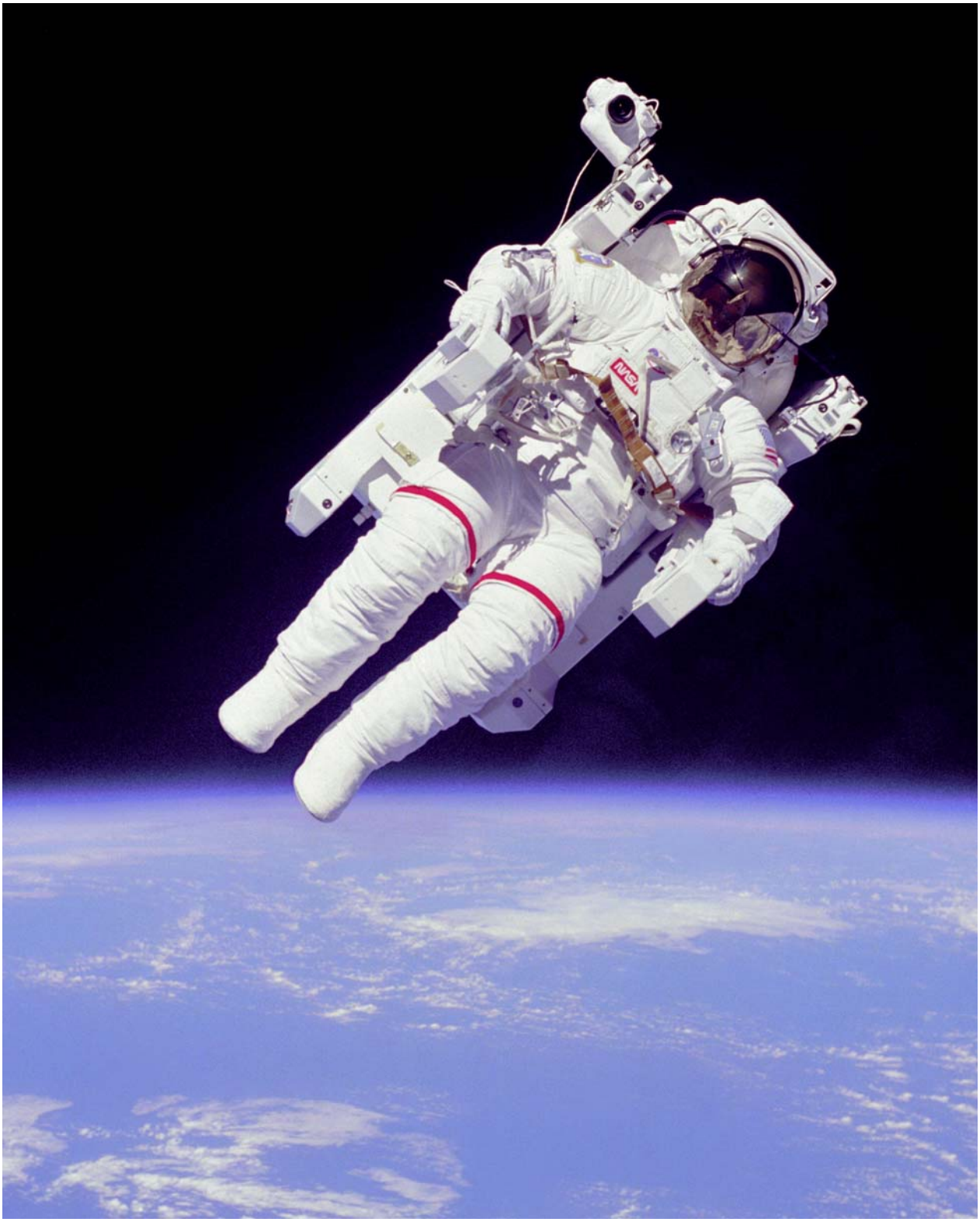
High-gain/low-gain antennas (ears and mouth)
Receivers and transmitters are used for communication between the spacecraft and Earth-based controllers. The antennae hear and speak for the spacecraft. Pretzel sticks and marshmallow

Thermal Control (sweat glands)
Mechanism that dissipates heat generated from the spacecraft out into space. Starburst

Solar Arrays (food and drink)
These are the source of energy for instruments and transmitters. The solar power is then stored in the onboard battery. Cream waffers

Orientation thrusters (dancing feet or legs)
These are small rocket thrusters that are used for delicate maneuvers that rotate the spacecraft. This is useful for aiming instruments and pointing the antennae toward Earth. Candy corn




NASA

Lesson 3: Exploring Weightlessness

(*Challenger Center- Return to the Moon-source)*

Once you have built the spacecraft, to gather data about the Moon, you need to understand what it is like to be weightless, just as astronauts needed to do when they went to the moon and on the International Space Station todayHave you ever felt weightless? Have you ever felt lifted from your seat while riding a roller coaster? If you have, you have felt a moment of weightlessness. Astronauts practice in a weightless situation. In order to practice what it feels like they use a large swimming pool at Johnson Space Flight Center. Astronauts feel that this is the next best thing to working in "zero G". In a swimming pool you are actually feeling buoyancy, when the downward force of gravity is equal to the upward force, so you float.

Common Misconception: *We sometimes say 'zero-G' and interpret this to mean that gravity has vanished in space. This is very wrong. Gravity is present everywhere in space, which is why the Moon orbits Earth. Because gravity can be balanced by other forces that astronauts feel, the net force can be zero, which means you feel no weight. Weightlessness is NOT the same as gravity vanishing.*

Time: 45 minute

Materials:

- 2 liter plastic bottle container
- Egg
- Salt
- Graduated Cylinder or balance
- Data Sheet (sample included)
- Warm Water

Procedure:

1. Measure 500 mL of warm water and pour it into your plastic container.
2. Carefully place the egg in the container. The egg should sink to the bottom.
3. Measure out 10 grams of salt. You can use your graduated cylinder- 10 mL =10 grams.
4. Using your ruler, measure the distance of the egg from the bottom of the container. Record the distance on your Data Sheet.
5. Keep adding salt in 10 gram measures. Record the distance of the egg from the bottom after each addition of salt.

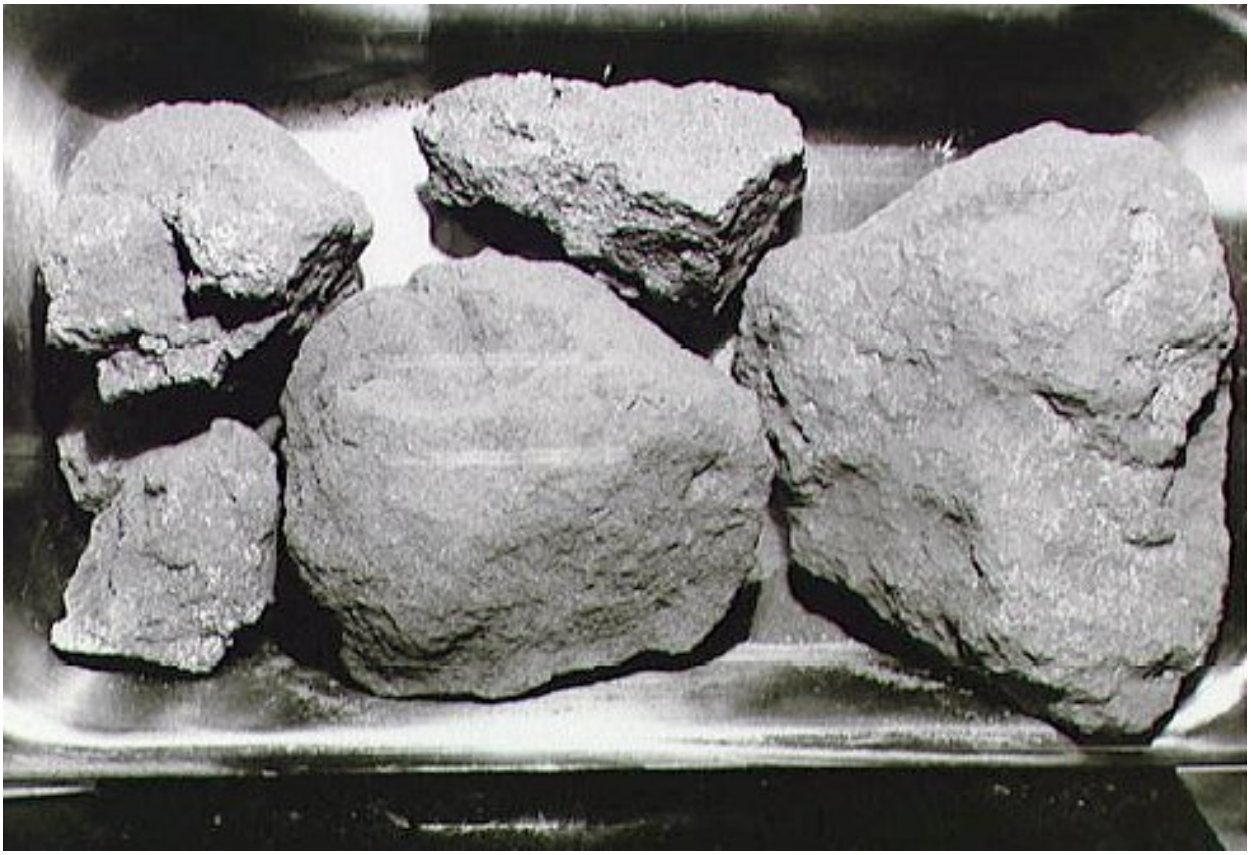
Concluding Questions:

1. What happens to the egg as you add salt?

2. Why does the egg appear to become weightless? (Hint-Density!)

Lesson 4: Rock Classification- Backyard Rocks!

(*Challenger Center- Return to the Moon-source)*



The next step is to practice collecting and classifying rock samples. For example, the picture above shows actual Moon rocks collected by Apollo astronauts. They were classified as igneous rocks. You might want to look at the lunar surface as future astronauts return to the lunar surface in these videos from **NASA eClip**s:

Our World: The Altair Lunar Lander
NASA's New Moon Robot
Digging in Moon Dirt
Lunar Habitat Structure
NASA's Lunar Crane

There is also an animation you can watch on YouTube
http://www.youtube.com/watch?v=IDDRu6k35R4&NR=1)

Time 60 Minutes

Materials:

- Rock samples-Have students collect backyard rock samples to use for the activity.
- Penny
- Nail
- Vinegar
- Plastic cup
- Magnet

TEST ONE: HARDNESS

- Rocks are scaled in hardness in a range from 1 to 10 with 1 being the softest and 10 the hardest. Hardness can be tested by trying to scratch a rock with a substance or another rock. Have the students collect rocks from their home yard or school yard.
- Select two rocks from the collection.
- Try to scratch one with the other. The harder one will scratch the other.
- Keep the harder rock.
- Choose another rock from the collection and do the scratch test between the two rocks.
- Keep testing until you find the hardest rock in your collection.
- Continue the scratch test until you have all your rocks lined up from softest to hardest.
- Complete a Data Chart numbering your samples from softest to hardest.
- Develop a Histogram from the data sheet that demonstrates the most common rock hardness from your collection. (A histogram is a graphical representation showing visually the distribution of data.)

TEST TWO: COLOR STREAK TEST

Some rocks make a streak of color when rubbed against a piece of tile or paper. The color of the streak is usually different than the color of the rock. Try to make a streak on the tile or paper with each rock. Record the color of the streak on your Data Chart.

TEST THREE: ACID TEST

Some rocks contain calcium. These rocks will fizz in the presence of acid. You will use vinegar as the acid for this test. Fill your plastic cup half full with vinegar. Put the rock sample in the cup. Observe the rock for fizzing or bubbles. Record the results on your Data Chart. (yes/no)

TEST FOUR: MAGNETISM

Some rocks contain metals that will attract a magnet. Select one of the rocks and touch it with the magnet. Is the rock attracted by the magnet? Record your results on your Data Chart. (yes/no)

Lesson 5: Craters-Moon Study Activity

(*Challenger Center- Return to the Moon-source)*
Time 90 minutes-this does not include set up time

Materials:

For each group:
- Pie pan
- Ruler
- Meter stick
- Pebbles (meteoroid)
- Protective eye ware

For the class:
- 2 -5 lb. bags flour
- 1 tin cocoa

Procedure:

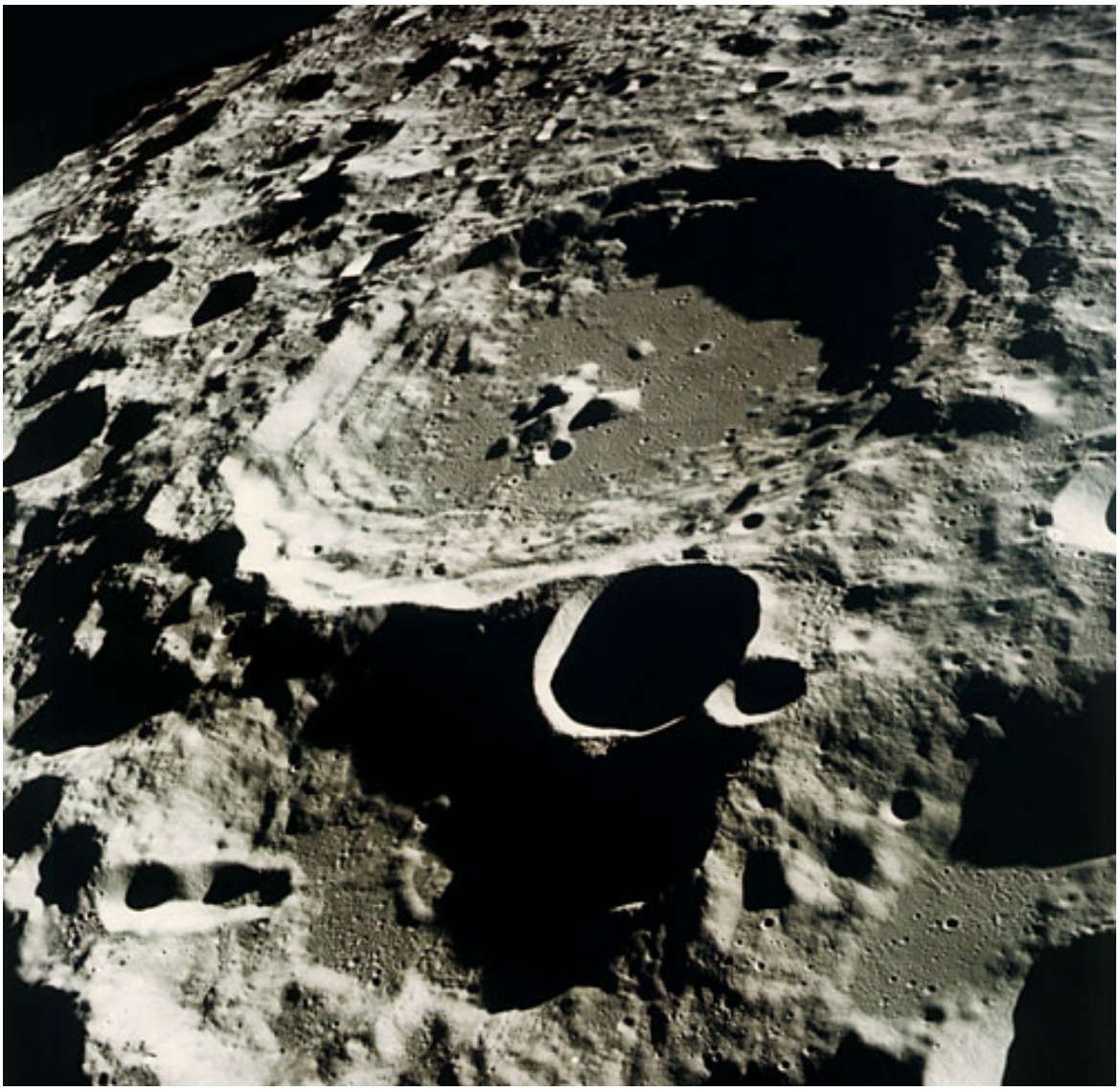
1. Cover the floor with newspaper.
2. Fill the pie pan with a layer of flour.
3. Cover the top of the flour with a light dusting of cocoa.
4. Place the pie pan on the floor or the ground.
5. Place your meter stick on the floor and measure up 30 cm from the pan.
6. Drop 3 pebbles into the pan from the 30 cm height.
7. Measure the diameter and the depth of the crater using your ruler. Record the information on your data sheet.
8. Remove the pebbles.
9. Smooth out the surface and sprinkle on another light dusting of cocoa.
10. Repeat steps 6-9 using the heights of 50 cm and 90 cm.
11. Drop all three pebbles into the pan using some force.

Record the depth and diameter of the craters.

12. Throw all three pebbles into the pan so that they strike the pan at an angle. Record the depth and diameter of the craters.
13. Suggested data sheet columns:
    a. **Height, Force Increased, Angle**
    b. **Depth of crater**
    c. **Diameter of crater**
    d. **Draw the crater**

Concluding Questions:

1. How were the craters different when the pebbles were dropped from different heights?
2. Are the craters in step 11 different from the rest?
3. Are the craters in step 12 different from the rest? Why?



Lesson 6: Lunar Math

This activity is designed to be used as a supplement for teaching mathematical topics. The *SpaceMath@NASA* problems can be used to enhance understanding of a specific mathematical concept, or as a good assessment of student mastery. The entire book on *Lunar Math* is available on line at **http://www.nasa.gov/pdf/377727main_Lunar_Math.pdf**

Lunar Math is designed to be used as a supplement for teaching mathematical topics. The problems can be used to enhance understanding of the mathematical concept, or as a good assessment of student mastery.

Problem 1 – Zooming in on the Moon! This activity is suitable for Grade 3 and 4 students and allows students to explore the lunar surface at various scales in a series of images from the full Moon to the Apollo 11 landing area photographed by the Lunar Reconnaissance Orbiter satellite. Students will learn about resolution and field-of-view by comparing how the amount of detail they can see in each picture changes as the scale of the image becomes smaller. At the lowest resolution they may only see craters and features that are ten miles across, but at the highest resolution they can see features only a few feet across. They will also explore how one picture 'fits into' another picture at a lower resolution. A picture that is 1 mile wide will only cover an area that is 1/100th of a picture that is 10 miles wide.

Problem 2 – The Lunar Surface (Low Resolution) Students in Grade 5, who can work with dividing whole numbers and are learning about the metric system will use an image of the Moon taken by NASA's Lunar Reconnaissance Orbiter to learn about how to measure the scale of an image, and to study image features quantitatively in terms of their physical size in kilometers.

Problem 3 – The Lunar Surface (Medium Resolution) Students use a medium-scale image of the lunar surface obtained by the Lunar Reconnaissance Orbiter, to study the sizes of lunar features compared to familiar objects in a student's environment such as houses and neighborhoods.

Problem 4 – The Lunar Surface (High Resolution) Students use a high-resolution image of the lunar surface obtained by the Lunar Reconnaissance Orbiter to study the Apollo-15 landing area at meter-resolution.

Problem 1 – Zooming in on the Moon

Scientists often explore an object in space by studying it at different scales. This means that for some kinds of questions, you need to see the 'big picture' such as what is the most common surface feature on the object? For the Moon, we would want to know the location and sizes of the largest craters and mare. For other questions, such as what kinds of rock and mineral types make up the surface, we need to use images at a higher resolution to see small details that are missed in the Big Picture.

In the following 15 images obtained by ground-based telescopes, astronauts on the Apollo mission, and the Lunar Orbiter and Lunar Reconnaissance Orbiter (LRO) satellites, students will study a sequence of lunar images from the Big Picture all the way down to the scale of the Apollo11 Lunar Lander.

Purpose: To see how an image at one scale connects with an image at another scale in a consistent way.

Procedure: Starting with the first image of the full Moon, students will look at the next image and identify where this second image is located within the first image. In successive images, they will repeat this process by finding where the current image is located within the previous image studied.

Students should look carefully to find one or more landmarks in the current image that appear in the previous image. In some instances, a clue is provided to facilitate this step in particularly confusing images.

Although the explanatory text may not be needed to carry out this procedure, there are clues provided in the text for advanced students that will help them identify the scale of the images in question and narrow the search. For example, the width of the image will be given in kilometers or meters, and with a millimeter ruler, the student can determine the scale of each image in meters per millimeter, and from this understand how big the current image will be within the previous image at a different scale.

Concluding questions:
How does the amount of detail you can see in each image change from different vantage points?

About how big is the smallest thing you can see in each image?

What kind of technology do you need to see details on the Moon only a meter across?

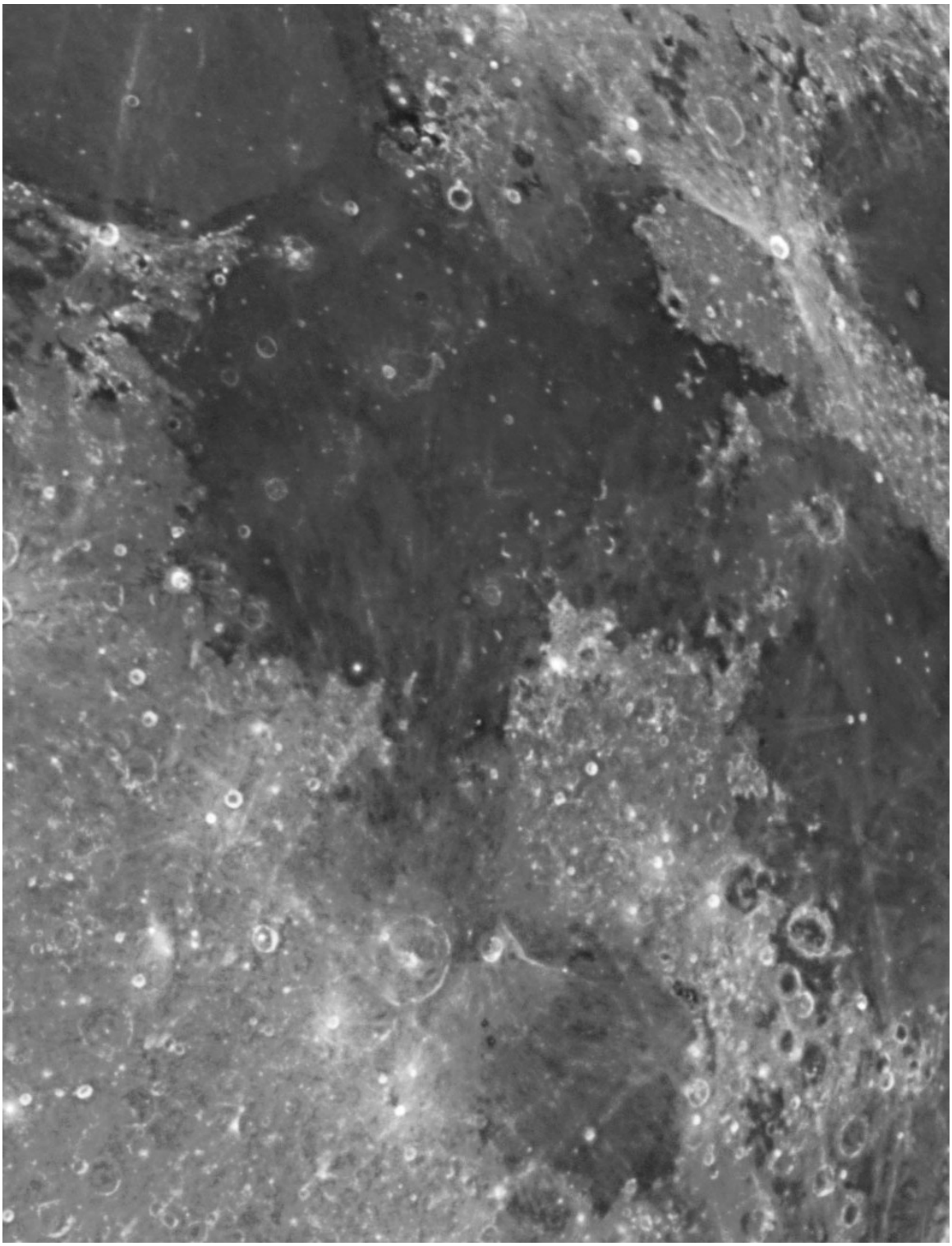
A

This is an image of the full Moon taken from Earth with a telescope. The Moon is about 2,200 miles in diameter (3,500 kilometers)

The dark areas are called mare, and the circular marks and white spots are called craters.

Not all craters are as big as the ones you see here, which can be over 100 miles across. Some are only a few feet in diameter!

B



The large dark area is called Mare Tranquillitatis. It was formed billions of years ago when molten lava flowed out of the interior of the Moon and flooded the low-lying lunar planes in this area.

Scene width = 700 miles (1126 km)

C

The large crater with the central mountain in the lower left-hand corner is called Theophilus. Can you see some of the ‘ghost craters’ that were covered over by the mare lava flows?

1. From the clues in this image, can you find Theophilus in the previous Image B?

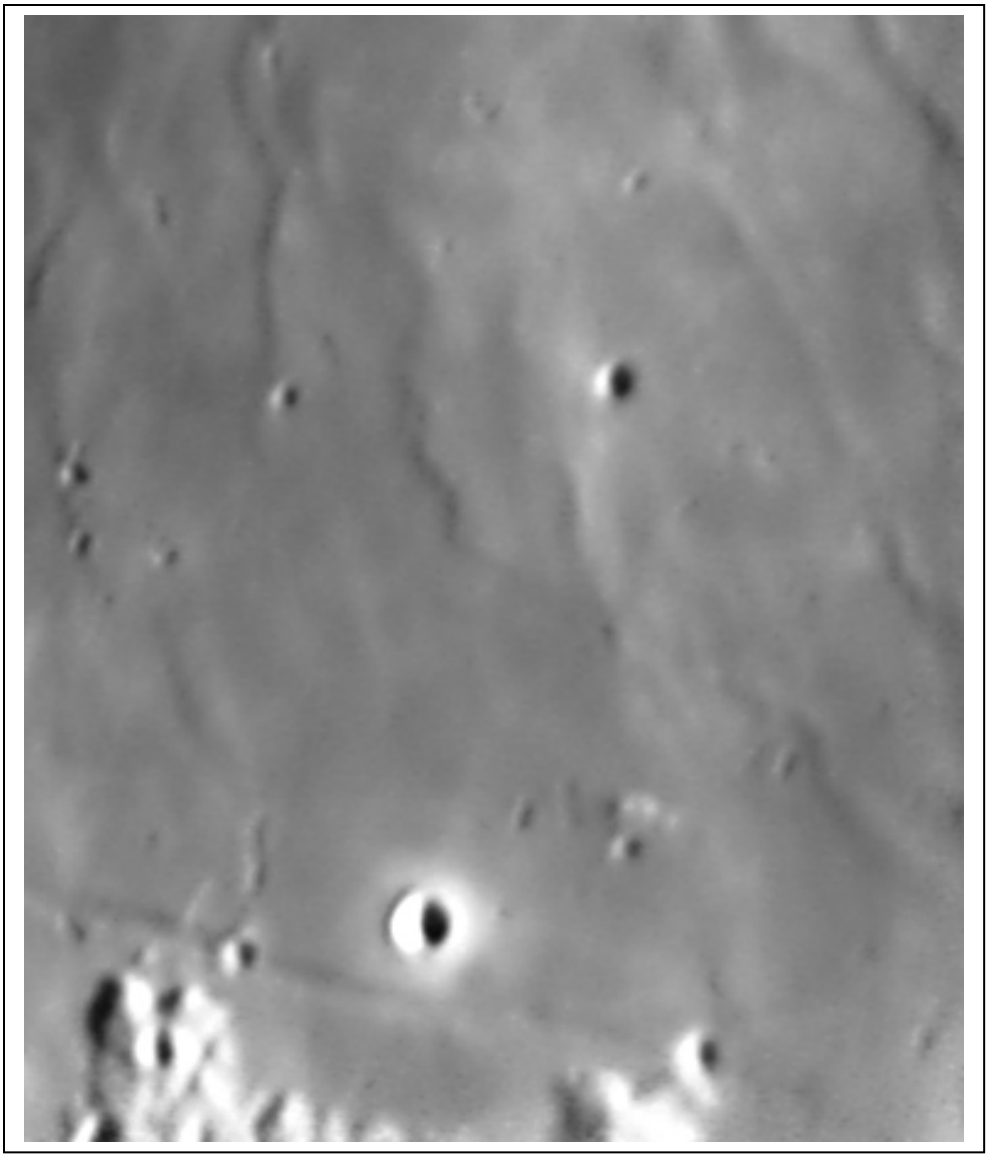
Scene width = 600 miles (966 km)

D

The crater that you see on the right edge of this image is not at all a circular crater. It might once have been two craters side-by-side whose common wall collapsed.

Scene width = 150 miles (241 km)

E

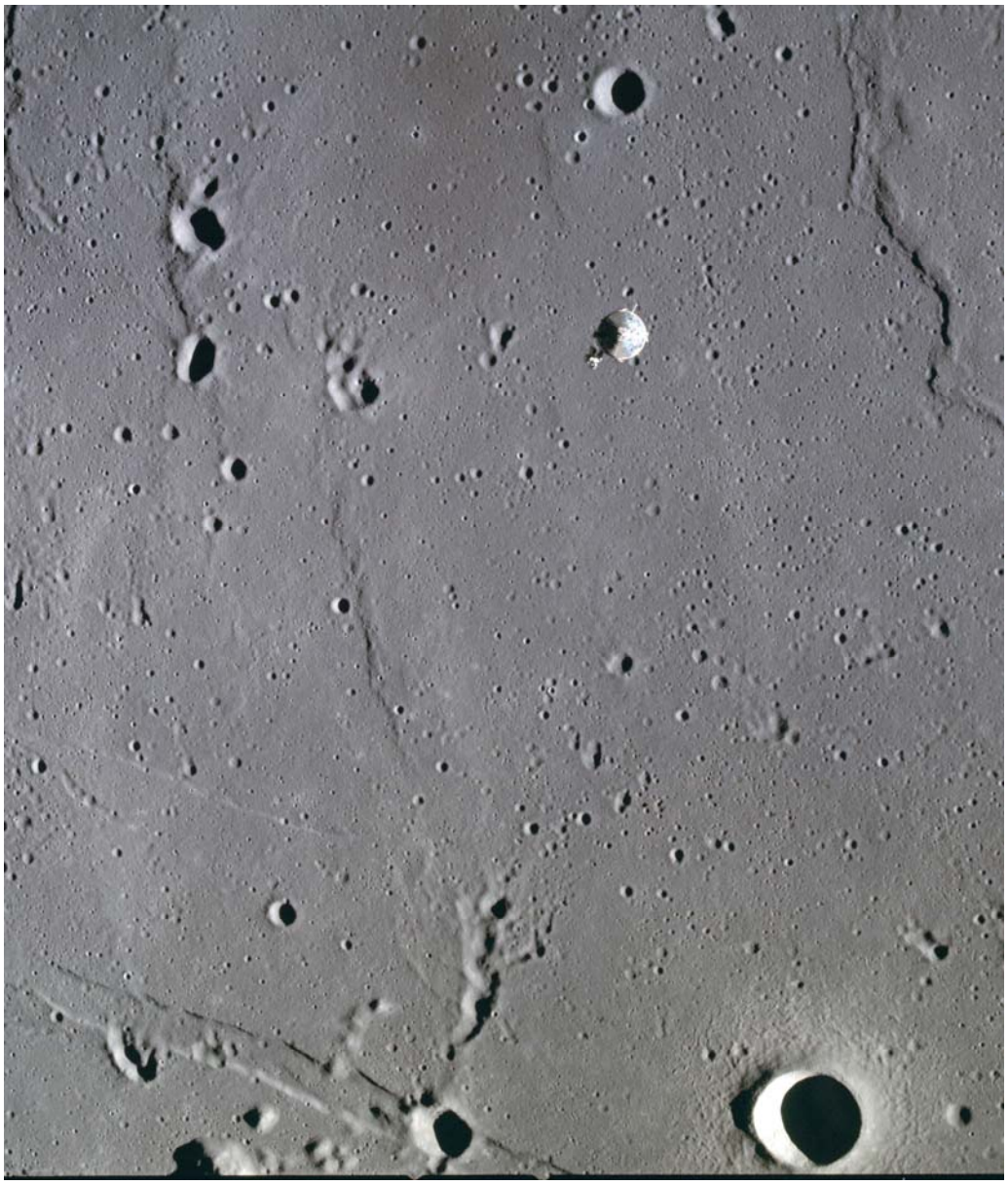


This telescopic picture taken from Earth shows the crater Moltke. This crater is about 4 miles in diameter and 3,000 feet deep! Moltke crater is located to the north of a ridge of mountains that make up the edge of Mare Tranquillitatis. The small crater near the middle of the picture in the upper-right corner is called Armstrong Crater. To its left, and half way to the left edge of the image, is Collins Crater, which was used as a landmark by Apollo11 astronauts. Craters look half-black because of the shadow of the crater wall.

1. Can you guess from what direction sunlight is coming from?

2. Can you find the boundaries of this image inside Image D (easy) or Image C (hard)?

Scene width = 50 miles (80 km)

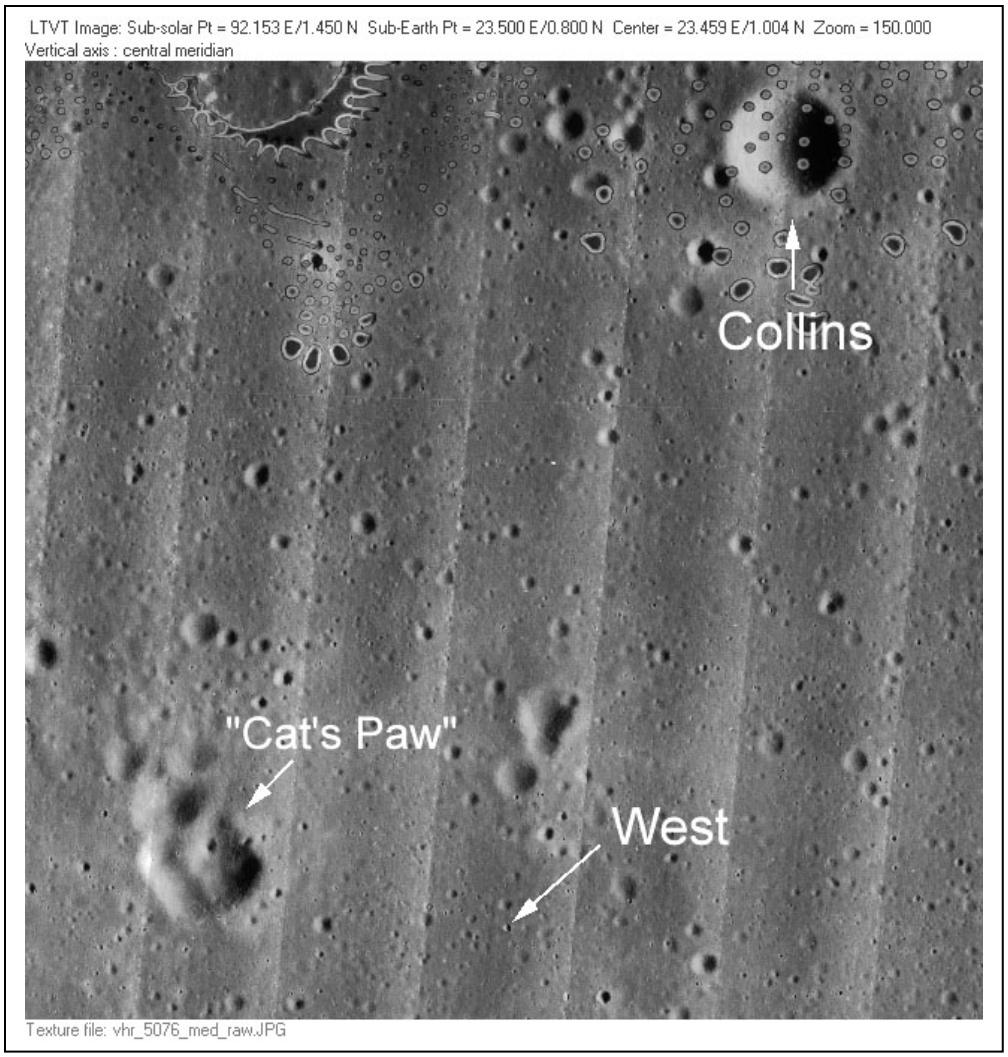


This high resolution image was taken by Apollo 11 Astronaut Michael Collins as the Lunar Module was headed for a landing in 1969. You can see the Lunar Module as the circular object towards the top of this image and just below Collins Crater. Moltke Crater is located in the lower-right corner.

1 - About what is the diameter of Collins Crater in miles?

Scene width = 30 miles (48 km)

G

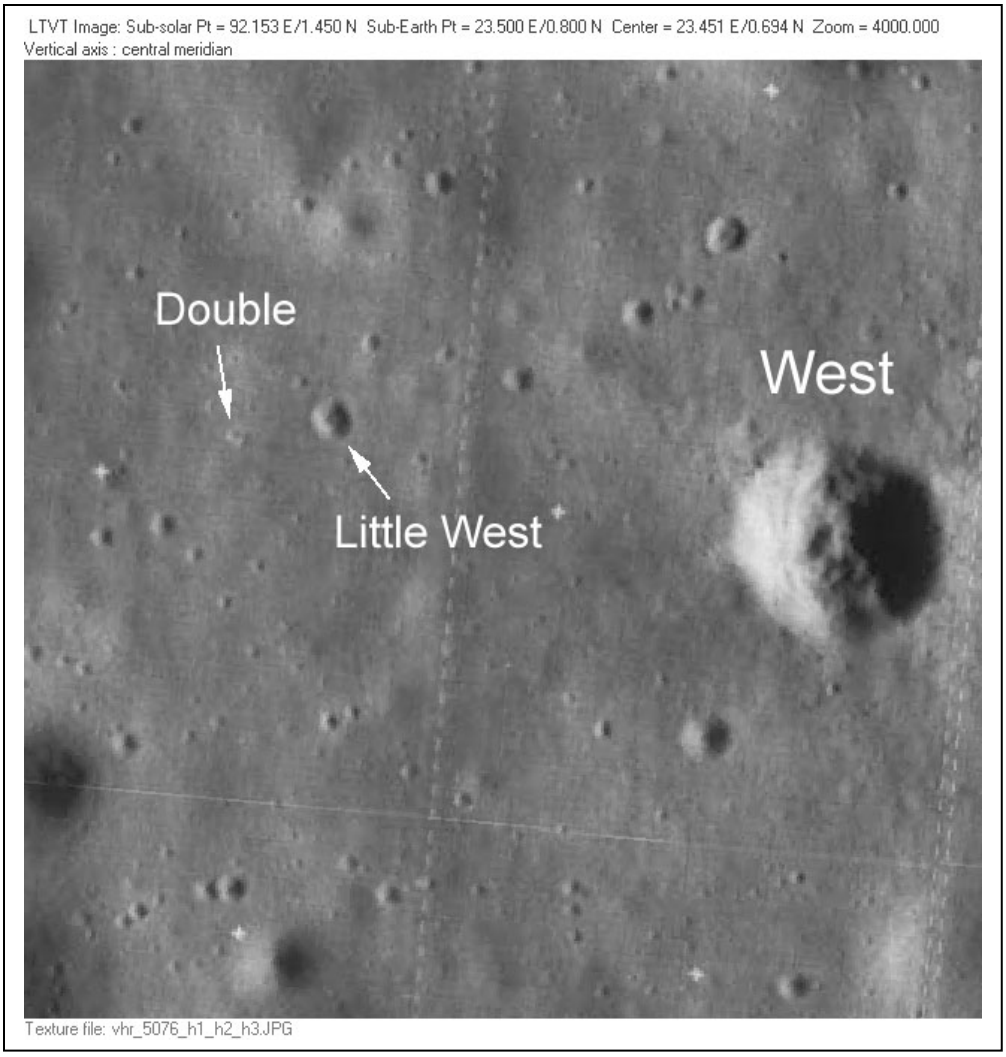


This view was taken by the medium resolution camera onboard Lunar Orbiter V spacecraft in 1968. The image shows the location of Collins Crater, and the "Cat's Paw" crater. Both of these lunar features can be seen from Earth, but only under the best conditions.

1. About how big is West Crater?

2. Where is West Crater located in Image F?

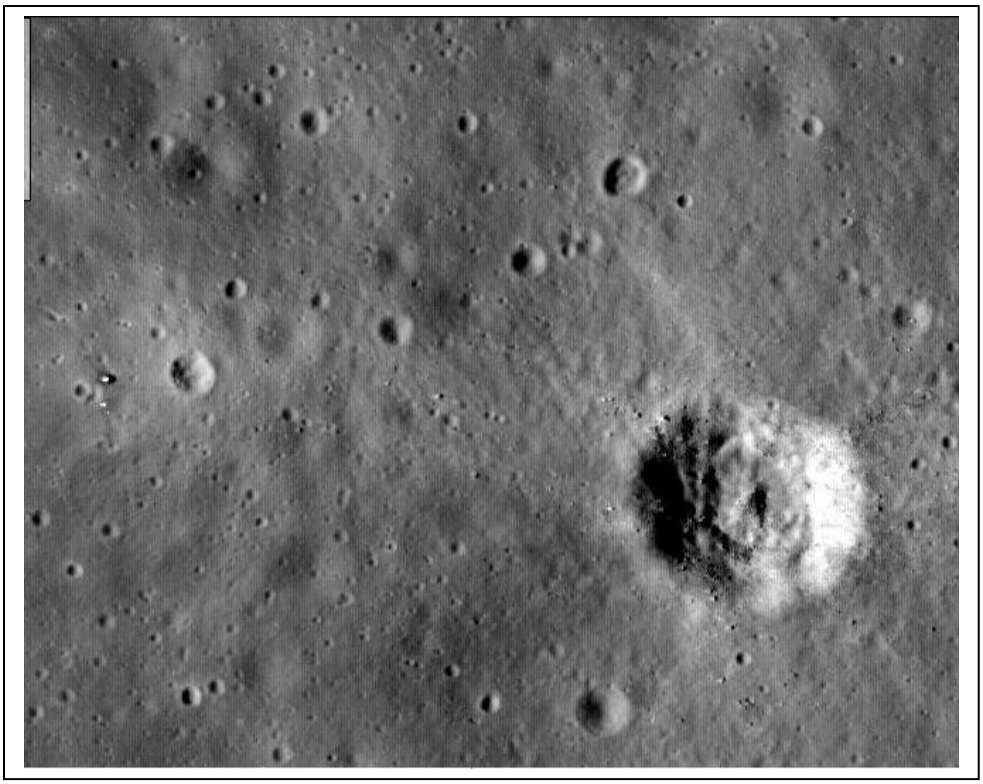
Scene width = 15 miles (24 km)



This image was also taken by the Lunar Orbiter V's high resolution camera, and shows West Crater in more detail. The craters named "Double" and "Little West are informal names assigned by the Apollo11 astronauts to help guide them to a safe landing.

1. If West Crater is about 500 feet in diameter (180 meters), how big is Little West Crater?

Scene width = 2500 feet (762 m)



This Lunar Reconnaissance Orbiter (LRO) image shows Little West Crater and hundreds of other lunar craters and features. Little West Crater is about 100 feet in diameter. Sunlight strikes the surface from the left to the right with the sun located far to the left.

1. Can you draw the boundaries of this image inside the previous Image H at the correct scale?

2. How big is the smallest crater you can find in this image?

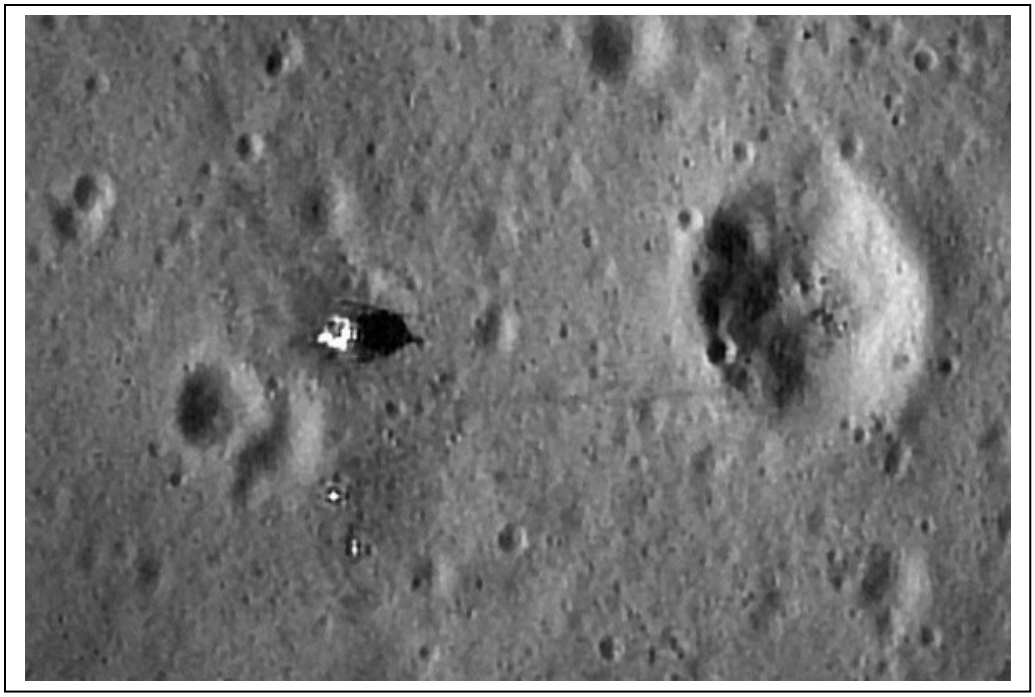
3. Where would you expect the shadow to be formed inside a crater?

4. Where would you expect the shadow to form from a boulder sitting on the surface?

5. Can you find any boulders in this image?

Scene width = 400 feet (122 m)

J



The Lunar Reconnaissance Orbiter took this high-resolution image of the Apollo11 landing area. The picture shows the Lunar Module sitting on the surface after the Apollo11 astronauts had returned to Earth.

1. Where is this image located in relation to Little West Crater in the previous image I?

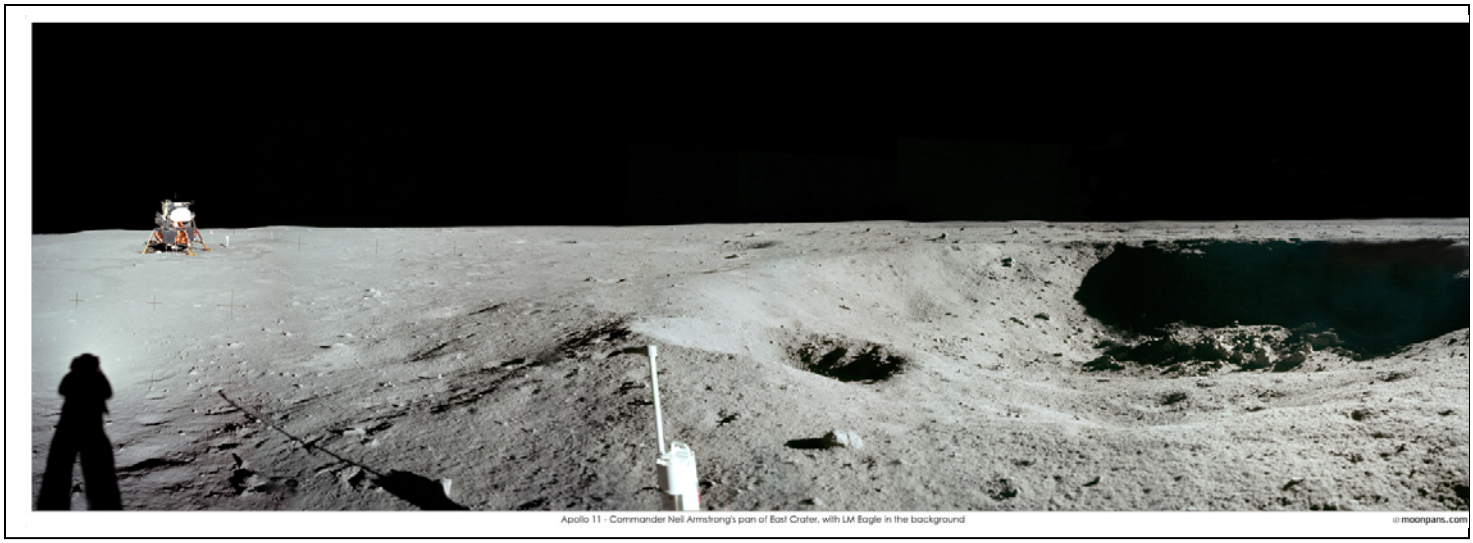
2. The Lunar Module is about 14 feet wide (4.2m) How big is the crater located to the left of the Lunar Module?

3. What is the diameter of the smallest crater you can see in this image?

4. Can you find any features in the image that might be the scientific equipment that was left behind by the astronauts?

Scene width = 60 feet (18 m)

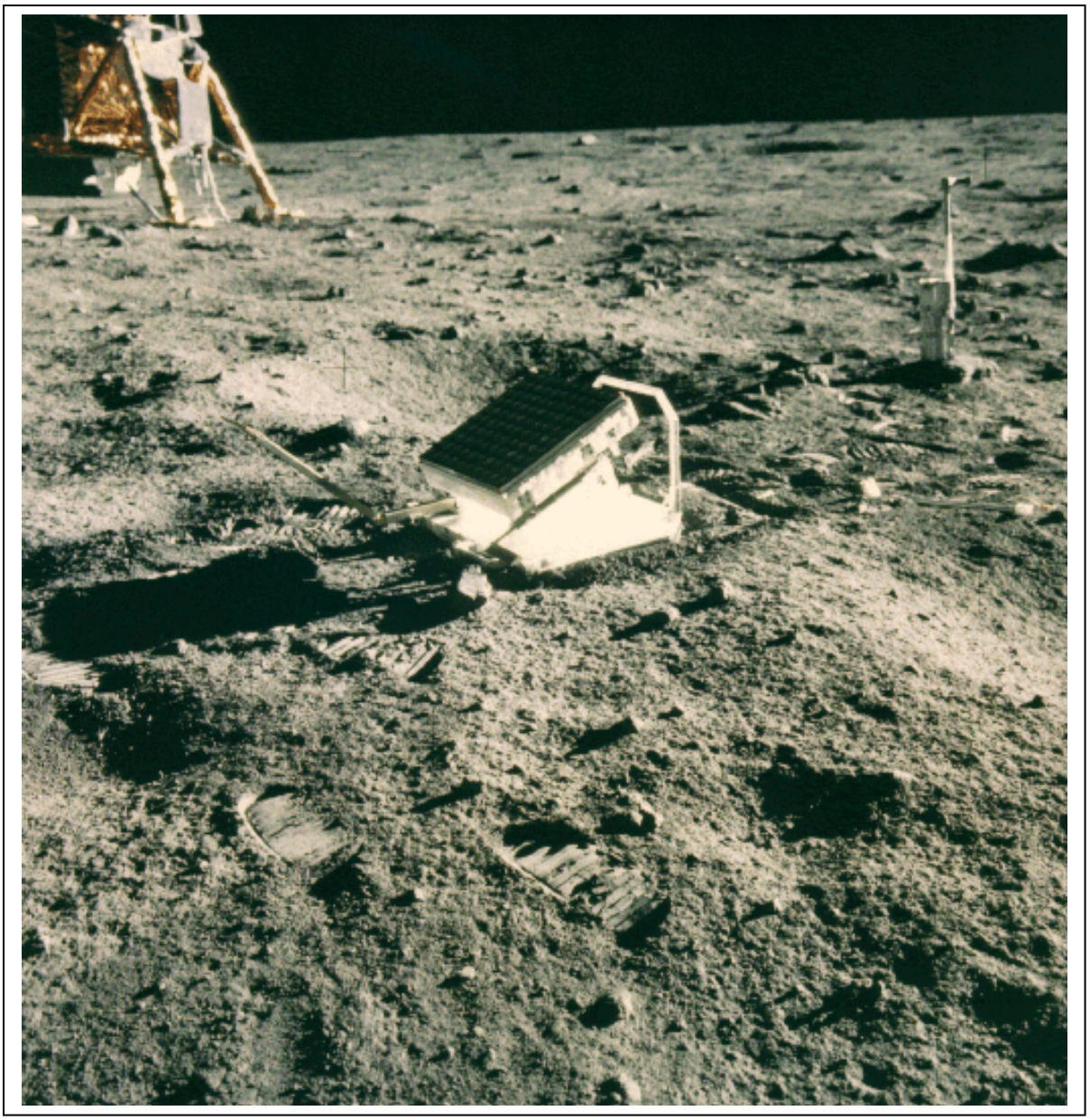
K



East Crater, about 30 meters wide and 4 meters deep, is on the right and was so named because it is about 60 meters east of the Apollo 11 Lunar Module. Neil Armstrong had piloted the Eagle safely over the crater.

1. Using the clues in Image J, where do you think this crater is located?

2. What is the smallest detail you can see in this photograph, and how big is it?



A number of instruments were left on the surface of the Moon by Apollo 11 astronauts. This view shows the Laser Ranging Retroreflector Experiment. Also note all the footprints and small rocks on the surface. The surface of our moon is actually very black and resembles dark cement or even asphalt in its color!

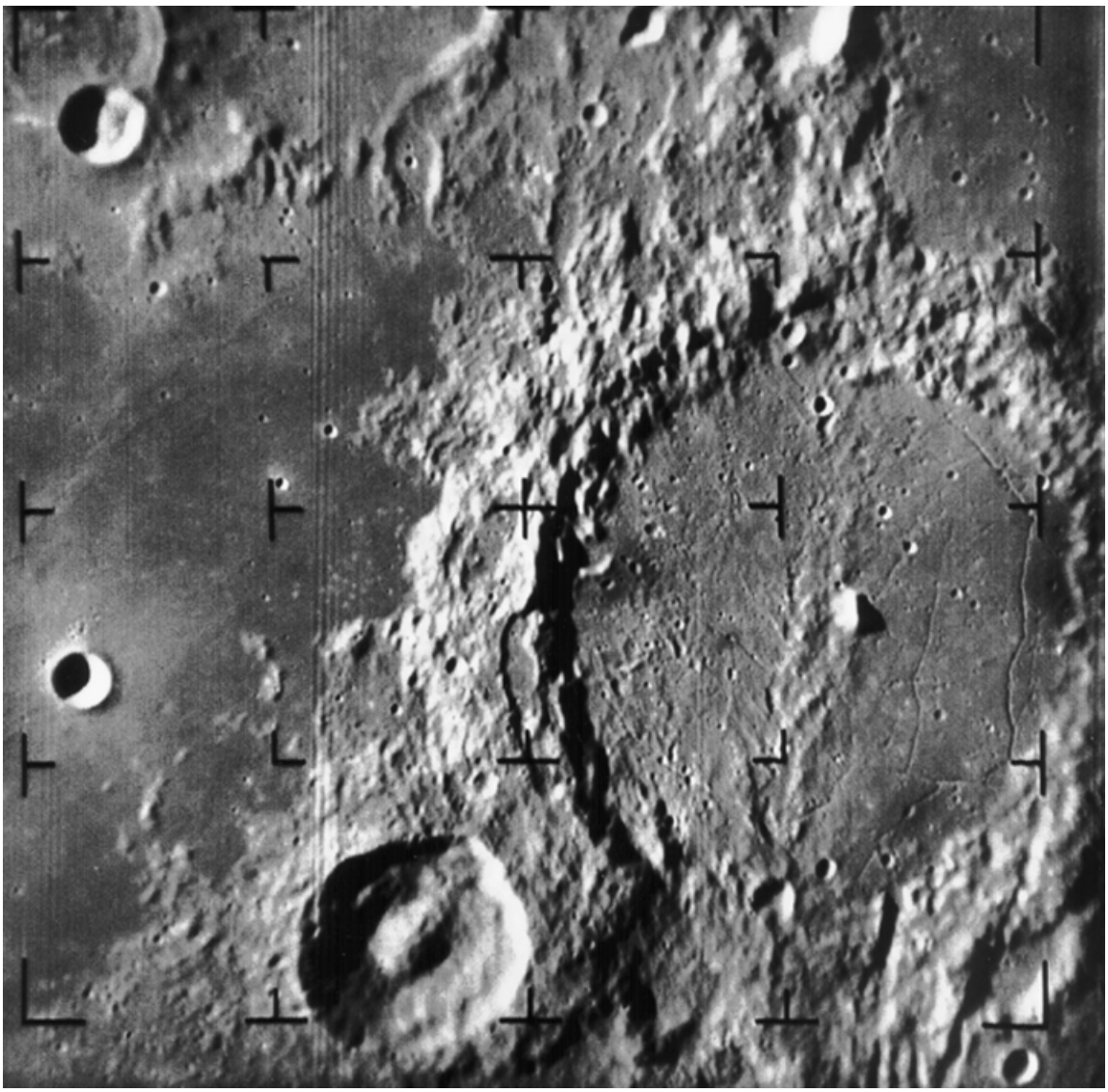
1. How big are the rocks in the foreground?

2. How big is the smallest pebble you can see?

Scene width 7 feet (2.5 meters)

Problem 2 - The Lunar Surface (Low Resolution)

In 2009, NASA's Lunar Reconnaissance Orbiter (LRO) orbited the Moon and took high-resolution images of the lunar surface. This was to be the beginning of the 'return to the Moon' program that was to lead to astronauts landing on the Moon sometime between 2018 and 2025. The image below shows the Alphonsus crater from a distance of 442 km, taken about three minutes before impact of the Ranger 9 spacecraft on 24 March 1965 at 14:08:20 UT.



Question 1 - Using a millimeter ruler, what is the scale of this image in kilometers per millimeter if the width of this picture is 183 kilometers?

Question 2 - What is the size of the smallest thing you can see in the picture, in meters?

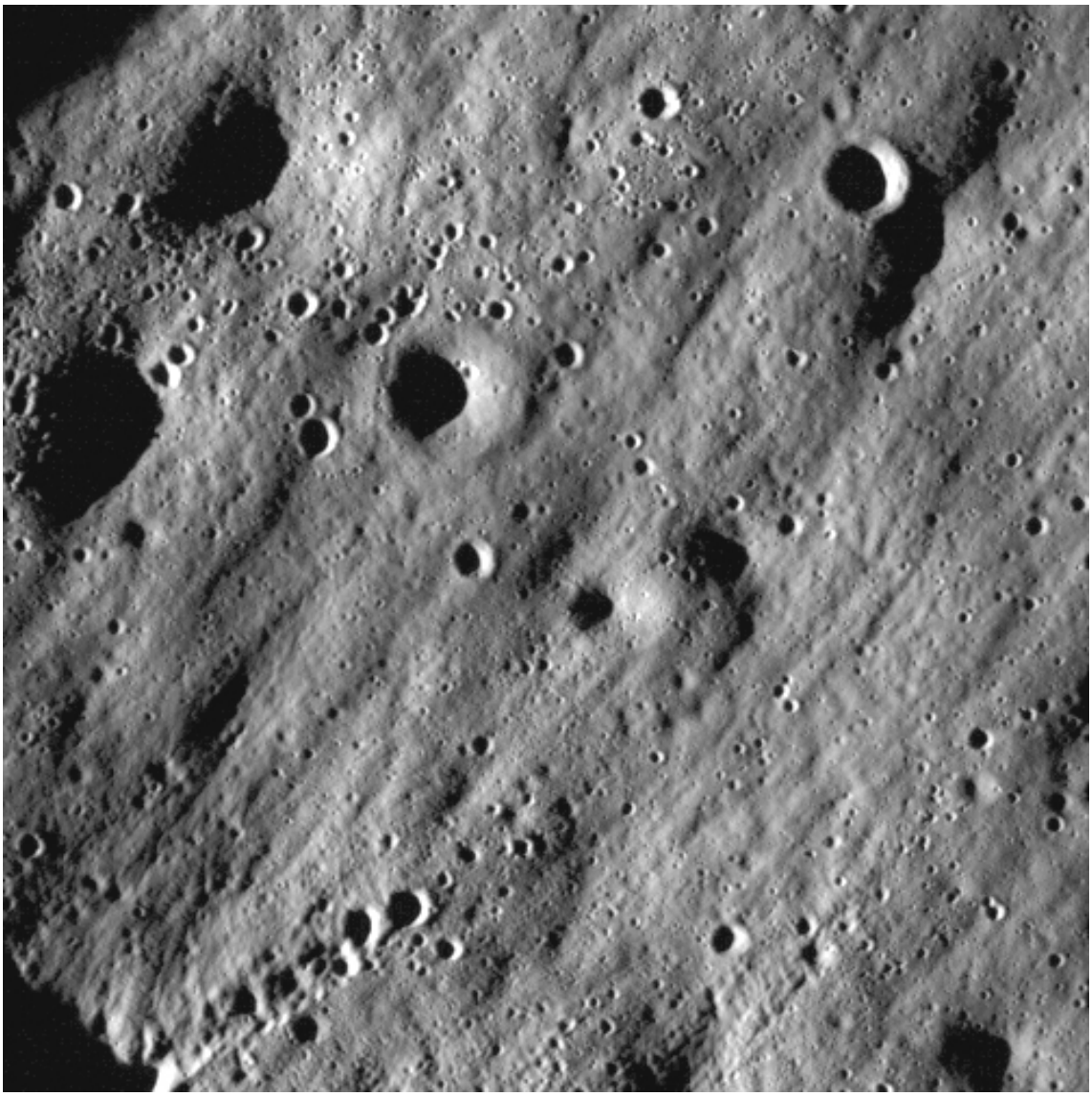
Answer 1 - The image measures 153 millimeters wide, so if this equals 183 kilometers, then the scale of the image is 183 km/153 mm = 1.2 kilometers/millimeter.

Answer 2 - By carefully looking at the printed image, the smallest craters are about 0.5 millimeters across. This equals 0.5 mm x 1.2 km/mm = 0.6 km or 600 meters.

Extension Question - Where do you think the safest place would be to land in this image?

Answer: The safest place is where there are the fewest features that you can see in the photograph above (right). This is in the dark 'basin' areas to the left of the crater where you can't see any rough spots at the scale of this image. The Lunar Reconnaissance Orbiter Camera (LROC) will take high-resolution pictures of places like this on the Moon. The Lunar Orbiter Laser Altimeter (LOLA) will gather topography data to aid in the search for large boulders that may pose a safety and landing hazard for future astronauts.

Problem 3 - The Lunar Surface (Medium Resolution)



This is one of the first images taken by LRO showing details in Mare Nubium. The width of the image is 700 meters (500 pixels).

Question 1 - Use a millimeter ruler to determine the scale of the image in meters per millimeter, and meters per pixel.

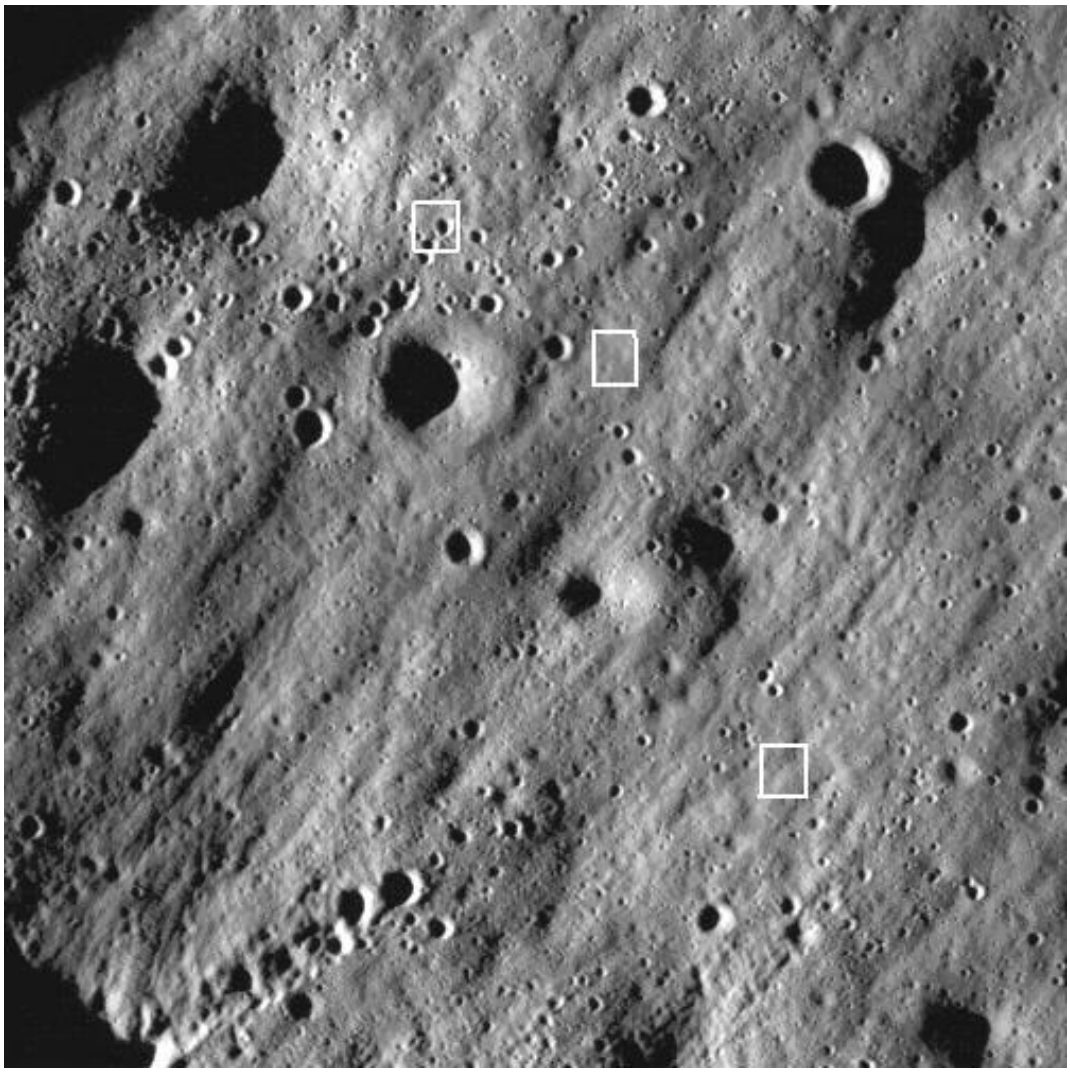
Question 2 – What is the diameter, in meters, of the smallest recognizable crater you can find?

Question 3 – Suppose your house sits on a property that is 25 meters wide and 30 meters long. Can you draw a square on the above image the same size as your yard ?

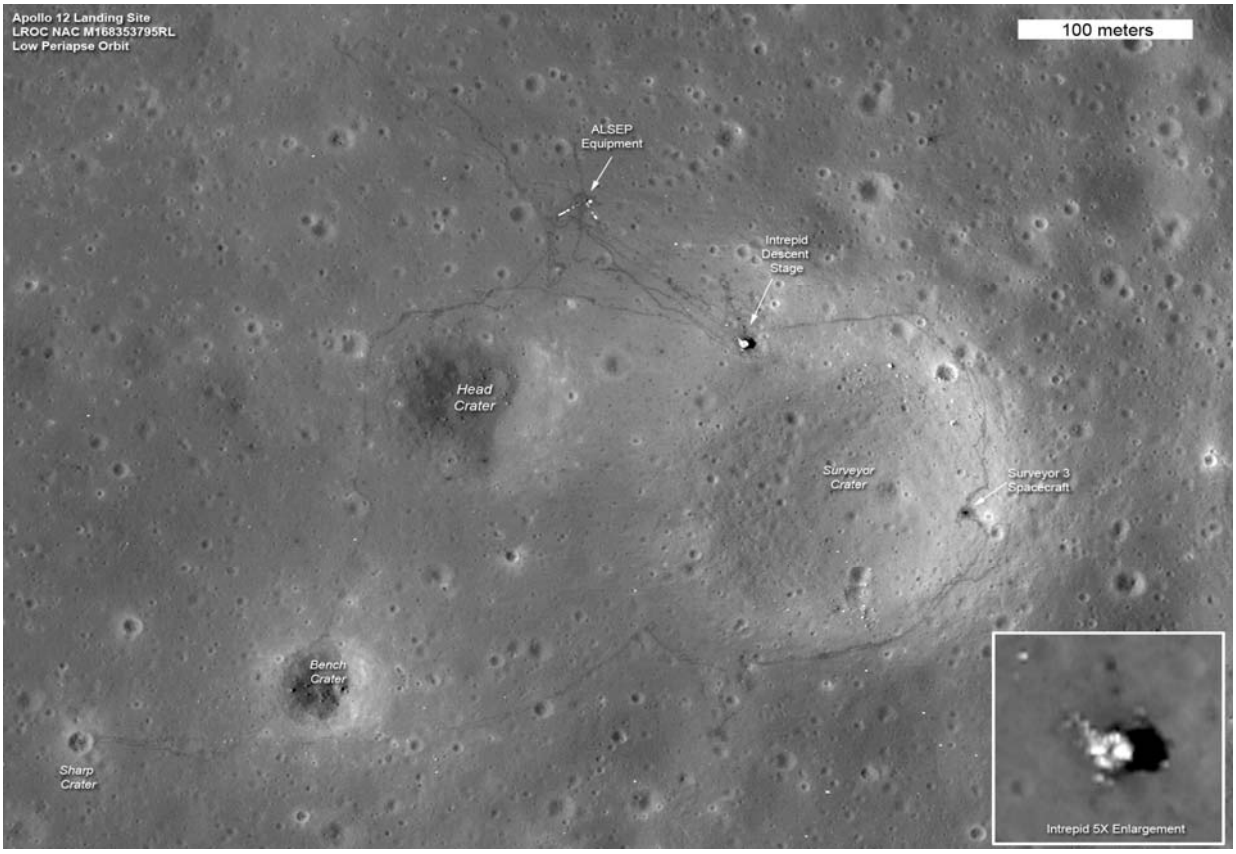
Answer 1- Width = 153 millimeters so the scale is 700 meters/153 mm = 4.6 meters/mm, and 700 meters/500 pixels = 1.4 meters/pixel.

Answer 2- Students should see craters as small as 0.5 millimeters or 0.5 mm x 4.6 m/mm = 2.3 meters.

Answer 3- At the scale of the LRO image of 4.6 meters/mm, the property is a rectangle measuring 6 mm x 7 mm on the image. The figure below shows some squares with about this size.



Problem 4 - The Lunar Surface (High Resolution)



NASA's Lunar Reconnaissance Orbiter (LRO) from a lunar orbit of 21 kilometers (13 miles) captured the sharpest images ever taken from space of the Apollo 12, 14 and 17 landing sites. Images show the twists and turns of the paths made when the astronauts explored the lunar surface. One of the details that appears as a bright L-shape in the Apollo 12 image. It marks the locations of cables running from Apollo Lunar Surface Experiment Package (ALSEP's) , scientific experiments for the first manned Apollo *lunar* landing *mission*,central station to two of its instruments. Although the cables are much too small for direct viewing, they show up because they reflect light very well.

Question 1 – Following one of the walking paths, about how many meters did the astronauts have to walk from A) the ALSEP to the Descent Stage, and then around Surveyor Crater to finally reach the Surveyor spacecraft? B) The Surveyor spacecraft to Sharp Crater?

Question 2 – Using your favorite method, about how many craters can you see across this entire area?

Question 3 - If the craters were created over a period of about 3 billion years, about what may have been the average time between impacts to form the craters you see?

Answer 1 – Print out the problem on a typical laser printer and measure the '100 meter' bar with a millimeter ruler. An answer of about 23 millimeters yields an image scale of about 100 meters/23 mm = 4.3 meters/mm.

A) Using a piece of string or a millimeter ruler, measure the segments of the thin black 'track' that astronauts took. An answer of about 90 millimeters will be adequate. Using the image scale of 4.3 meters/mm you will get a distance of 90 mm x (4.3 m/mm) = 387 meters. This can be rounded to 390 meters.

B) Measuring the track segments, a string length of about 200 millimeters is adequate. From the scale factor, this equals a physical distance of 200 x 4.3 = 860 meters traveled.

Answer 2 – Divide the area into a grid of squares. Count the number of craters you can see in one square, and multiply by the total number of squares. For example, if you make the squares 40mm x 40mm, you can fit 4 columns and 3 rows. Selecting the one in the second column, first row, you can count about 80 craters (from 0.5 to 2 millimeters across on the image) so the total number of craters is about 80 x 12 = 960 craters. Answers between 800 and 1100 are also reasonable estimates.

Note: From the image scale, the most common craters range in size from 0.2 millimeters to 2 millimeters, which corresponds to an actual size between 0.9 meters and 8.6 meters.

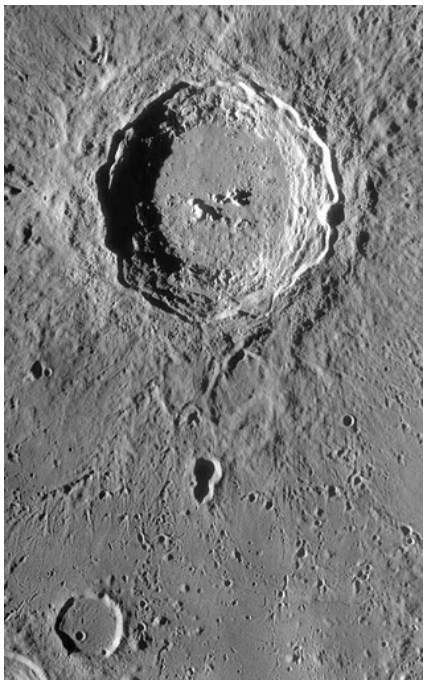
Answer 3 - If we select 1000 craters as the average estimate, then the rate of cratering is about 1000 craters / 3 billion years or 1 crater every 3 million years.

For more information about these images, see the NASA press release at:

NASA Spacecraft Images Offer Sharper Views of Apollo Landing Sites
September 6, 2011

http://www.nasa.gov/mission_pages/LRO/news/apollo-sites.html

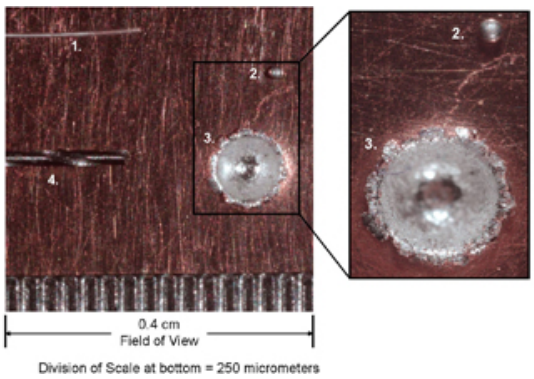
Vocabulary



Craters: Craters are depressions or pits formed by impacts.
Size: .001 cm to 200 kilometers in diameter
Depth: Centimeters to 10 kilometers.

Large craters (Copernicus diameter 60 miles) – The majority have sharp peaks at center. Some have huge rays made of rock fragments thrown from the crater upon impact. These rays may be up to 1000 kilometers long, and can be seen from earth with the naked eye during full Moon. The most notable large craters are Copernicus, Kepler and Tycho.

Small craters (size less than one kilometer). These craters number in the millions. Caused by direct impact of small meteorites, or debris thrown from large craters.



Micro-craters (size range from .001 cm to 1 cm). Caused by high speed micro-meteors.

Micro-meteoroids are not slowed down by the atmosphere so impacts form particles like glass.

Meteor: A streak of light seen in the night sky caused by a meteroid entering the atmosphere. Meteors that range in size from 100 grams to 1000 kilograms still strike the Moon at a rate of 70 to 150 impacts per year.

Meteoroid- a particle of rock traveling through space.

Meteorite- a meteoroid that has struck a planet or other solid body, usually creating a crater.

This picture shows a piece of the Shikote-Alein meteorite fall in 1947 and measures about 1 inch across. It weighs only a few ounces.

The largest recovered meteorite was found in 1920 and weighs 66 tons. It struck the Earth about 60,000 years ago. (Picture courtesy Simon Collins.)

Meteorites are collected mostly by amateur rock collectors and can be worth between $1.00 per gram for a common iron-type meteorite, to $10,000 per gram for a rare lunar or martian sample!

Fun Facts:

Over 10,000 tons of meteoritic material enter the atmosphere each year

They enter the atmosphere traveling at over 20,000 miles per hour.

Some meteorites actually 'stink' like rotten eggs because of all the complex organic molecules they contain.

You can find micrometeorites by collecting rainwater and using a magnet.

A 20-meter diameter meteorite delivers an impact equal to 1 million tons of TNT

The dinosaurs became extinct soon after Earth was struck by an asteroid 10 miles across!

K
What I know about the Moon:

W
What I want to know about the Moon:

L
What I learned about the Moon:

Lesson 2

Example of a spacecraft:

Lesson 3:

Data Sheet

Number of grams of salt	***Distance of egg from bottom of container***
0 g	cm
10 g	cm
20 g	cm
30 g	cm
40 g	cm
50 g	cm
60 g	cm
80 g	cm
100 g	cm

Lesson 4
Data Sheet

	Rocks- Hardest to Softest	***Color Streak***	***Acid (yes/no)***	***Magnetic (yes/no)***	***Name the rocks (Put a check next to the most common rock collected)***
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Lesson 5
Data Sheet

Type of Meteor Strike	***Depth of Crater***	***Diameter of Crater***	***Drawing of Crater***
30 cm			
50 cm			
90 cm			
From above with force			
Angle			

National Aeronautics and Space Administration

Space Math @ NASA
Goddard Spaceflight Center
Greenbelt, Maryland 20771
spacemath.gsfc.nasa.gov

www.nasa.gov