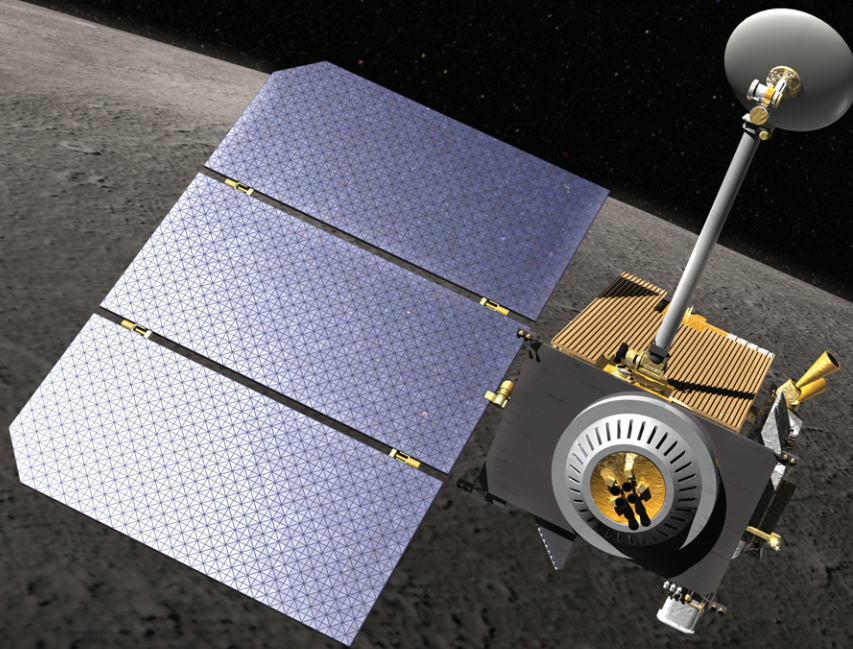




# LRO Educator Resource Kit



Funding for this kit was provided by the Lunar Reconnaissance Orbiter Mission, operated through the NASA Science Mission Directorate.

**Content for this kit contributed by the following institutions:**

- Adler Planetarium
- Arizona State University
- Denver Museum of Nature and Science
- Johns Hopkins University Applied Physics Laboratory
- Lunar and Planetary Institute
- University of California Los Angeles
- University of New Hampshire

# LRO Educator Resources Kit Standards/Benchmarks Alignment

|  | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|--|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| <b>AAAS Benchmarks</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>1B/1:</b> Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.  |                               | +                               | +                    | +             | +   | +                                       | +              |  | +                                | +  | +                    | +                  | +                                  | +      | +                         | +                             | +                                       |
| <b>3A/M2:</b> Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.  | +                             | +                               | +                    | +             | +   | +                                       | +              |  | +                                | +  |                      |                    | +                                  | +      | +                         | +                             | +                                       |
| <b>4A/H3:</b> Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed. |                               |                                 |                      |               |   |   |                | +  |                                  |  |                      |                    |                                    |        |                           |                               |   |

|   | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|---|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| <b>12E/H4:</b> Insist that the key assumptions and reasoning in any argument—whether one's own or that of others—be made explicit; analyze the arguments for flawed assumptions, flawed reasoning, or both; and be critical of the claims if any flaws in the argument are found. |                               |                                 |                      |               |   |   |                | +  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>12A/H1:</b> Exhibit traits such as curiosity, honesty, openness, and skepticism when making investigations, and value those traits in others.  |                               |                                 |                      |               |   |   |                | +  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>F/5:</b> Human eyes respond to only a narrow range of wavelengths of electromagnetic waves— visible light. Differences in wavelength within that range are perceived as differences of color.  |                               |                                 |                      |               |   |   |                |  |                                  |  | +                    | +                  |                                    |        |                           |                               |   |
| <b>11B/M3:</b> Different models can be used to represent the same thing. What model to use depends on its purpose.  |                               |                                 |                      |               |   | +                                       | +              |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>12D/M10:</b> Understand oral, written, or visual presentations that incorporate circle charts, bar and line graphs, two-way data tables, diagrams, and symbols.  |                               |                                 | +                    |               | +   |   |                |  |                                  |  |                      |                    | +                                  |        |                           |                               |   |
| <b>1C/M1:</b> Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.  | +                             |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |

|  | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|--|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| <b>NSES Standards</b>  |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Content Standard A (5-8): Abilities necessary to do scientific inquiry:</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| a. Identify questions that can be answered through scientific investigations.  |                               |                                 |                      | +             |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| c. Use appropriate tools to gather, analyze and interpret data.  |                               | +                               | +                    | +             |   |   | +              | +  |                                  | +  | +                    | +                  | +                                  | +      | +                         | +                             | +                                       |
| d. Develop descriptions and explanations using evidence.   |                               | +                               | +                    | +             |   |   | +              | +  |                                  | +  | +                    | +                  | +                                  | +      |                           | +                             |   |
| e. Think critically and logically to make relationships between evidence and explanations  |                               | +                               | +                    | +             | +   | +                                       | +              | +  | +                                |  | +                    | +                  | +                                  | +      | +                         | +                             | +                                       |
| <b>Content Standard B (5-8), Physical Science:</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| c. Transfer of energy: The Sun is a major source of energy for changes on the Earth's surface. The Sun loses energy by emitting light. A tiny fraction of that light reaches the Earth, transferring energy from the Sun to the Earth. The Sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation |                               |                                 |                      |               |   |   |                |  |                                  |  | +                    | +                  |                                    |        |                           |                               |   |
| <b>Content Standard D (5-8): Earth and Space Science</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| a. Space Science; Earth's History: The Earth processes we see today, including erosion, movement of lithospheric composition, are similar to those that occurred in the past.  |                               | +                               | +                    | +             |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |

|   | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|---|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| <b>Content Standard E (5-8): Science and Technology:</b>  |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis. | +                             | +                               | +                    | +             |   |   | +              | +  |                                  | +  |                      |                    | +                                  | +      |                           |                               |   |
| b. Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.   |                               |                                 |                      |               |   | +                                       |                |  | +                                |  |                      |                    |                                    |        |                           | +                             |   |
| <b>Content Standard F (5-8): Science and Technology in Society:</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| e. Science and technology have advanced through contributions of many different people, in different cultures, at different times in history.   | +                             |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Content Standard G (5-8): History and Nature of Science:</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| c. In historical perspective, science has been practiced by different individuals in different cultures.  | +                             |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
|   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>NRC Framework (K-12)</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Dimension 1: Scientific and Engineering Practices:</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Practice 1:</b> Asking Questions (for science) and Defining Problems (for engineering)   |                               | +                               |                      | +             | +   | +                                       | +              | +  |                                  | +  |                      |                    | +                                  | +      | +                         | +                             |   |

|   | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|---|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| <b>Practice 2:</b> Developing and Using Models  |                               | +                               |                      |               | +   | +                                       | +              |  | +                                | +  | +                    |                    | +                                  | +      |                           |                               |   |
| <b>Practice 5:</b> Using Mathematics and Computational Thinking                                 |                               | +                               |                      |               |   | +                                       |                |  | +                                | +  |                      |                    |                                    |        |                           |                               |   |
| <b>Practice 6:</b> Constructing Explanations and Designing Solutions                            | +                             | +                               | +                    | +             |   | +                                       | +              | +  |                                  | +  |                      |                    | +                                  | +      |                           |                               |   |
| <b>Practice 7:</b> Engaging in Argument from Evidence   |                               |                                 |                      |               | +   |   |                | +  |                                  |  | +                    | +                  | +                                  |        |                           |                               |   |
| <b>Practice 8:</b> Obtaining, Evaluating, and Communicating Information                         | +                             |                                 | +                    |               | +   | +                                       | +              | +  | +                                |  | +                    | +                  | +                                  |        | +                         | +                             | +                                       |
| <b>Dimension 2: Crosscutting Concepts</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| Systems and System Models   | +                             | +                               |                      |               |   | +                                       |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| Patterns  | +                             |                                 |                      | +             |   | +                                       |                | +  |                                  | +  | +                    |                    |                                    |        |                           |                               |   |
| Cause and Effect: Mechanism and Explanation Scale, Proportion, and Quality Stability and Change | +                             |                                 | +                    | +             | +   | +                                       |                |  |                                  | +  |                      |                    |                                    |        |                           |                               |   |
| System and System Models  |                               |                                 |                      |               |   |   |                | +  |                                  |  |                      |                    |                                    | +      |                           |                               |   |
| <b>Dimension 3: Disciplinary Core Ideas Earth and Space Sciences:</b>                           |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>ESS1:</b> Earth's Place in the Universe  |                               |                                 | +                    | +             |   |   |                |  |                                  |  |                      |                    |                                    |        | +                         |                               |   |
| <b>ESS1.B:</b> Earth and the Solar System   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    | +                                  | +      | +                         | +                             |   |
| <b>ESS1.C:</b> The History of Planet Earth  |                               | +                               | +                    | +             |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               | +                                       |
| <b>21st Century Skills*</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Learning and Innovation Skills</b>   |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| a. Creativity and Innovation  |                               |                                 | +                    | +             | +   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |

|  | Timeline of Lunar Exploration | Mapping the Surface of the Moon | Lunar Image Analysis | Question Moon | Exploring the Moon through Image Analysis | Making a 3D Model of the Moon's Surface | Making a Model | Planning a Mission to the Lunar South Pole | Lunar Image Processing with GIMP | Lunar Laser Altimetry: Studying the Topography of the Moon | Learning about Light | Seeing in the Dark | Using Radar to Search the Darkness | CRATER | How to Detect Cosmic Rays | How Cosmic Rays Affect Humans | The Discovery and Nature of Cosmic Rays |
|--|-------------------------------|---------------------------------|----------------------|---------------|---|---|----------------|--|----------------------------------|--|----------------------|--------------------|------------------------------------|--------|---------------------------|-------------------------------|---|
| b. Critical Thinking and Problem Solving                                 |                               |                                 | +                    | +             | +   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| c. Collaboration   |                               |                                 | +                    | +             | +   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Information, Media and Technology Literacy</b>                        |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| a. Information and Communication Technology (ICT) Literacy               |                               |                                 | +                    |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| b. Flexibility and Adaptability  |                               |                                 | +                    |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| <b>Life and Career Skills</b>  |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| a. Social and Cross-Cultural Skills                                      |                               |                                 | +                    |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
|  |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |
| * Please Note: 21st Century Skills have been aligned for select lessons. |                               |                                 |                      |               |   |   |                |  |                                  |  |                      |                    |                                    |        |                           |                               |   |

---

# NASA's Lunar Reconnaissance Orbiter (LRO) Teacher Kit

## Teacher Implementation Support

1. What's in this kit?
2. Why teach about the Moon and the LRO spacecraft?
3. What are the connections to other curriculum and standards taught?
4. Are there ways to adapt the lessons/activities in this curriculum?
5. What are the different ways to implement this curriculum?
6. How can students be assessed while using this curriculum?
7. What additional resources or extension activities are available for students related to the content of this curriculum?
8. What additional support is available for teaching lunar concepts and content?



---

# 1. What's in this kit?

## Curriculum

NASA Education and Outreach (E/PO) professionals who work for the Lunar Reconnaissance Orbiter spacecraft developed these lessons, activities and resources.

The LRO E/PO team is comprised of educators from diverse institutions including: Goddard Space Flight Center, Adler Planetarium and Astronomy Museum, Denver Museum of Nature and Science, John's Hopkins University's Applied Physics Laboratory, University of New Hampshire, Arizona State University, and University of California, Los Angeles.

Each of these lessons has successfully gone through the NASA Education Product Review. This process assesses them for scientific accuracy, developmentally appropriate resources and effective instructional strategies.

### **Lunar Exploration Timeline**

Lesson plan included

### **Mapping the Surface of the Moon**

Curriculum guide included

### **Lunar Image Analysis**

Student activity guide included

### **Question Moon**

Lesson plan included

### **Exploring the Moon through Image Analysis**

Lesson plan included

### **Making a 3D Model of the Moon's Surface**

Lesson plan included

### **Making a Model**

Lesson plan included

### **Planning a Mission to the Lunar South Pole**

Lesson plan included

### **Lunar Image Processing with GIMP**

Activity guide included

### **Lunar Laser Altimetry:**

#### **Studying the Topography of the Moon**

Lesson plan included

#### **Learning about Light**

Lesson plan included

#### **Using Radar to Search the Darkness**

Student and Teacher guide included with lesson plan

#### **CRaTER**

Lesson plan included

#### **How to Detect Cosmic Rays**

Lesson plan included

#### **How Cosmic Rays Affect Humans**

Lesson plan included

#### **The Discovery and Nature of Cosmic Rays**

Lesson plan included

#### **Seeing in the Dark**

Lesson plan included

## Various non-consumable materials for activities in the kit.

- Play-Doh
- Image sets
- Ping-pong balls

## Related LRO resources and enrichment materials

- Posters, lithographs, images, CD's etc.

---

## 2. Why teach about the Moon and the LRO spacecraft?

### Connections to National Science Education Standards and Benchmarks for Science Literacy (AAAS)

#### NATIONAL SCIENCE EDUCATION STANDARDS

##### **Content Standard A: Abilities necessary to do scientific inquiry**

- Identify questions that can be answered through scientific investigations.
- Use appropriate tools and techniques to gather, analyze and interpret data
- Develop descriptions, explanations, predictions and models using evidence
- Think critically and logically to make the relationships between evidence and explanations
- Communicate scientific procedures and explanations

##### **Content Standard B: Physical Science**

- The Sun is a major source of energy for changes on the Earth's surface. The Sun loses energy by emitting light. A tiny fraction of that light reaches the Earth, transferring energy from the Sun to the Earth. The Sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation

##### **Content Standard D: Earth and space science**

- The Earth processes we see today, including erosion, movement of lithospheric composition, are similar to those that occurred in the past.

##### **Content Standard E: Understanding about science and technology**

- Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.
- Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

##### **Content Standard F: Science and Technology in Society**

- Science and technology have advanced through contributions of many different people, in different cultures, at different times in history.

##### **Content Standard G: History and Nature of Science**

- In historical perspective, science has been practiced by different individuals in different cultures.

---

## ADVANCEMENT FOR SCIENCE LITERACY BENCHMARKS

**1B/1:** Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.

**1C/M1:** Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.

**3A/M2:** Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

**4A/H3:** Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.

**11B/M3:** Different models can be used to represent the same thing. What model to use depends on its purpose.

**12E/H4:** Insist that the key assumptions and reasoning in any argument—whether one’s own or that of others—be made explicit; analyze the arguments for flawed assumptions, flawed reasoning, or both; and be critical of the claims if any flaws in the argument are found.

**12A/H1:** Exhibit traits such as curiosity, honesty, openness, and skepticism when making investigations, and value those traits in others.

**F/5:** Human eyes respond to only a narrow range of wavelengths of electromagnetic waves— visible light. Differences in wavelength within that range are perceived as differences of color.

**12D/M10:** Understand oral, written, or visual presentation that incorporate circle charts, bar and line graphs, two-data tables, diagrams, and symbols.

## 21ST CENTURY SKILLS

### Learning and Innovation Skills

- Creativity and Innovation
- Critical Thinking and Problem Solving
- Collaboration

### Information, Media and Technology Literacy

- Information and Communication Technology (ICT) Literacy
- Flexibility and Adaptability

### Life and Career Skills

- Social and Cross-Cultural Skills

---

## Provides Access to Authentic Resources and Learning Experiences to Meaningfully Engage Students in Science

### AUTHENTIC EXPERIENCES, LEARNING AND RESOURCES

- Authentic experiences are rendered authentic through the expertise and authority of the people designing and facilitating them. For example, participating in a task that would be done by real people such as the scientists that work for NASA and the LRO spacecraft.
- Authentic learning is achieved in environments where students are presented with problem-solving activities that incorporate authentic, real-life questions and issues in a format that encourages interaction with authentic resources, collaborative effort, dialogue with informed expert sources, and generalization to broader ideas and application. In this curriculum, students have access to real scientific data straight from the spacecraft. This means the students and scientists are both looking at the same data at the same time, which is exciting for students!

### THE IMPACT OF AUTHENTICITY:

- Authentic resources and experiences can have a real impact on students that expand even beyond the classroom. Although some of the impacts are related to growth of knowledge, others are more affective in nature and just as significant. Some of the exciting ways in which authentic programs impact students include:
- Building knowledge that is lasting and meaningful to foster lifelong learning and citizenship.
- Encouraging students to extend and deepen their own knowledge about, interest in, and personal connections to the subject matter at hand.
- Inspiring and empowering students to sustain active participation in certain communities of practice.
- Building confidence in students as legitimate contributors to society.

## Opportunity to Connect Students with Current Science in a Professional Field and Teach the True Nature of Science

### ENCOURAGE AN INTEREST IN SCIENTIFIC FIELDS:

Part of our mission as educators is to prepare students to be successful in the real world. By introducing and exposing students to professional communities of practice and using examples of real scientific studies being done currently, teachers can present their students with a real world environment where what they learn in the classroom is being put to use outside of school.

### TEACHING THE NATURE OF SCIENCE:

Teaching the nature of science moves beyond the simplistic scientific method and seeks to portray science more authentically as a creative, social process of understanding the natural world. This process is modeled in these activities by implementing more inquiry –based instructional methods.

- The simplified, linear scientific method implies that scientific studies follow an unvarying, linear recipe. But in reality, in their work, scientists engage in many different activities in many different sequences. Scientific investigations often involve repeating the same steps many times to account for new information and ideas.

- 
- The simplified, linear scientific method implies that science is done by individual scientists working through these steps in isolation.  
But in reality, science depends on interactions within the scientific community. Different people may carry out different parts of the process of science at different times.
  - The simplified, linear scientific method implies that science has little room for creativity.  
But in reality, the process of science is exciting, dynamic, and unpredictable. Science relies on creative people thinking outside the box!

When students read about how the real LRO scientists do their work, they are provided evidence that real science works in ways they discussed earlier when solving problems and conducting investigations. By scaffolding students from their own investigation to learning about the investigations of the actual LRO science team, students can deepen their understanding of the Nature of Science and start to see science as a highly creative, dynamic, social and human endeavor.

---

## 3. What are the connections to other subject curriculum and standards taught?

### Earth Science/Geology

- Comparing and Contrasting the lunar surface with the Earth's surface
- Understanding geological processes that can change the surfaces of both the Earth and the Moon.
- Identifying landforms on the Moon similar to how we study the topography of the Earth.
- Finding locations on maps, interpreting information displayed on maps, and using maps to navigate.

### Mathematics

- Estimation of distances and actual sizes from scale drawings, models or maps
- Accurately taking measurement of objects and using those measurements to compare objects
- Use graphs, tables and formulas to interpret and communicate information

### Physics

- Applying an understanding of the electromagnetic spectrum: Human eyes only respond to a narrow wavelength of electromagnetic waves – visible light. The other wavelengths of light can be used to detect what is invisible to our eyes.
- Light can be absorbed, redirected, bounced back or allowed to pass through.

### Technology/Engineering

- Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments
- Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.
- Engineers use knowledge of science and technology, together with strategies of design, to solve practical problems.
- New technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research.

### English Language Arts

- Determine a central idea of a text and how it is conveyed through particular details; provide a summary of the text distinct from personal opinions or judgments.
- Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
- Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

---

## History/Social Studies

- History often involves scientific and technological developments.
- The human ability to influence the course of history comes from its capacity for generating knowledge and developing new technologies
- Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.

---

## 4. What are the different ways to teach this curriculum?

### Implement Individual Curriculum Component

If time and resources are limited, a single piece of this curriculum can stand-alone. Each lesson or activity was designed to be a complete experience in itself, related to a particular LRO instrument. Note the duration, materials and learning objectives of each lesson to choose the appropriate lesson for your classroom environment and the best fit with your other required curriculum.

### Complete Components of Curriculum with Extensions

If time and resources allow, the extension activities sections provide more in depth activities and interactions with the LRO mission and data.

### Choose a Topic Strand to Follow Part of Curriculum

Many of these lessons are connected by their content focus and learning goals. They can be taught in sequence, one building upon another to strengthen and reinforce learning goals, as well as increase student engagement and confidence.

There are three main strands:

1. **Lunar Exploration** – These are most appropriate for students who need an introduction to how we explore the Moon, especially in science classes. However, social studies classes can use these as well.
2. **Mapping the Moon** – These lessons are best for taking students who are familiar with the Moon one step further. These lessons involve more in-depth exploration of data and student inquiry. They include many connections to Earth Science and Geology.
3. **Tools of Investigation** – These lessons are more high-level lessons that challenge students to not just explore data but also understand the technology that is used to analyze and collect that data. They include many connections to technology, engineering and physics.

**Please note:** There are some lessons or activities that overlap between strands because they work well in both. See the full strands on the next few pages.

### Strand #1: Lunar Exploration

**Introduction:** Humans first observed the Moon with their eyes. The development of telescopes enabled us to learn even more about the Moon. Over time, we developed spacecraft that allowed us to learn even more about the Moon and even took people to the moon. As we continue to improve upon our technology and methods of exploration, we continue to develop a more sophisticated understanding of this familiar celestial object.

**Teacher Notes:** This strand provides students with more background information on lunar science. These lessons focus more on general knowledge about the Moon and provide an overview of lunar exploration both past and present. This strand is good for students who need to understand the process of science and make connections to how spacecraft technology can help us explore.



---

## SUGGESTED ACTIVITIES:

### **Lunar Exploration Timeline**

Lesson plan included

### **Mapping the Surface of the Moon**

Curriculum Guide included (sequence of eight activities)

### **Making a 3D Model of the Surface of the Moon**

Lesson plan included

### **Making a Model**

Lesson plan included

### **Lunar Image Analysis**

Student activity guide included

### **Question Moon**

Lesson plan included

## RECOMMENDED RESOURCES:

Lunar Educational Materials for Grades 6-8:

<http://lunar.gsfc.nasa.gov/educational-6-8.html>

LROC Images and Information:

<http://www.lroc.sese.asu.edu>

Lunar and Planetary Institute's My Moon:

<http://www.lpi.usra.edu/mymoon/>

## Strand #2: Mapping the Moon

**Introduction:** In order to better understand and explore the Moon and other rocky planetary bodies, scientists utilize sophisticated technology and methods for investigating features and mapping resources. The LRO spacecraft has seven individual scientific instruments. Many of these instruments help us study specific points of interest and make maps of them on the Moon. These include: high-resolution images of the surface, topographical data, mineralogical composition, possible locations of water ice, levels of atmospheric radiation in particular regions and more.

**Teacher Notes:** These activities focus on data from specific instruments on the LRO spacecraft and how scientists use that data to create maps of the Moon. Students will learn how technology is fundamental in our ability to map far away places. In the resources section you will find information about the instruments on LRO that are working to map the valuable resources on the Moon. Therefore these lessons can easily tie into other curriculum on geography, cartography, as well as geology and Earth science.

## SUGGESTED ACTIVITIES:

### **Mapping the Surface of the Moon**

Curriculum Guide included

---

### **Exploring the Moon through Image Analysis**

Lesson plan included

### **Planning a Mission to the Lunar South Pole**

Lesson plan included

### **Making a 3D Model of the Moon's Surface**

Lesson plan included

### **Making a Model**

Lesson plan included

### **RECOMMENDED RESOURCES:**

LROC Images and Information:

<http://www.lroc.sese.asu.edu>

Diviner Videos/Simulations: DVD/Flash Drive included

LAMP Videos/Simulations

Zooniverse's MoonZoo:

[www.moonzoo.org](http://www.moonzoo.org)

## **Strand #3: Tools of Investigation**

**Introduction:** In order to understand and explore rocky planetary bodies like our Moon, scientists have developed sophisticated technology and methods to investigate the features and characteristics of those foreign places. The LRO spacecraft has several scientific instruments that help us study specific points of interest about the Moon. These instruments provide us with detailed images of the surface, maps of lunar mineralogy, assist with the detection of water ice, and much more. Technology also plays an essential role in the way scientific data from the Moon is collected, processed and analyzed.

**Teacher Notes:** These activities allow students to learn the science behind the instruments that are studying the Moon on the LRO spacecraft and how scientists then use that information to inform their understanding. These lessons, by their nature, are interdisciplinary. Students will use math, physics, and technology skills that inform the overall science of LRO.

### **SUGGESTED ACTIVITIES:**

#### **Lunar Image Processing with GIMP**

Activity guide included

#### **Lunar Laser Altimetry: Studying the Topography of the Moon**

Lesson plan included

#### **Learning about Light**

Lesson plan Included

#### **Planning a Mission to the Lunar South Pole**

Lesson plan included

---

### **Using Radar to Search the Darkness**

Student and Teacher guide included with lesson plan

### **CRaTER**

Lesson plan included

### **How to Detect Cosmic Rays**

Lesson plan include

### **How Cosmic Rays Affect Humans**

Lesson plan included

### **The Discovery and Nature of Cosmic Rays**

Lesson plan included

### **RECOMMENDED RESOURCES:**

Scientific Instrument Specific Resources: Available off the LRO site:

<http://lro.gsfc.nasa.gov/index.html>

See extension suggestions for student image tools in this guide

---

## 5. How else can these lessons be used?

This kit can be used for Out-of-School time programming.

### AFTER SCHOOL CLUB

If there is little time during the school day for these types of activities they can be modified for an after school environment. It is recommended that students stick to the more hands-on inquiry related lessons in this type of setting.

### SCIENCE FAIR

If you have students who would like to use current space science as a topic for their science fair project, introducing them to some of the more in-depth analysis lessons may be a nice introduction to that type of investigation.

### SUMMER PROGRAM

This curriculum could lend itself to an in depth summer inquiry experience related to current lunar science. It is recommended that this curriculum be implemented interspersed with some of the other engaging extension activities to really connect students with the current science and the spacecraft technology.

---

## 6. How can students be assessed while using the curriculum in this kit?

Assessment tools are embedded into certain lessons.

- Alternative Assessments
- Rubric Scoring
- Observation
- And More...

Alternative Assessments can be applied throughout the curriculum:

Alternative assessments can be any type of assessment that is not a test. In alternative assessments, participants create a response to a question or task. They can include written or oral short answer questions, essays, performance assessments, oral presentations, demonstrations, exhibitions, and portfolios.

---

## 7. What additional resources or extension activities are available for students related to the content of this curriculum?

### LRO Scientific Instrument Resources

LROC Images and Information:

<http://www.lroc.sese.asu.edu>

Diviner Videos/Simulations:

<http://www.diviner.ucla.edu>

LAMP Videos/Simulations:

<http://www.boulder.swri.edu/lamp/index.html>

LOLA Resources:

<http://lunar.gsfc.nasa.gov/lola>

CRaTER Resources:

<http://crater.sr.unh.edu>

LEND Resources:

<http://lro.gsfc.nasa.gov/lend.html>

Mini-RF Resources:

<http://lro.gsfc.nasa.gov/mini-rf.html>

### Interactive Lunar Maps

LROC Quick Map:

<http://target.lroc.asu.edu/da/qmap.html>

Google Moon:

<http://www.google.com/earth/explore/showcase/moon.html>

### Student Imaging Tools

LROC Targeting Tool:

[http://target.lroc.asu.edu/output/lroc/lroc\\_page.html](http://target.lroc.asu.edu/output/lroc/lroc_page.html)

GRAIL Mission MoonKam Project:

<https://moonkam.ucsd.edu>

---

## Moon Related Citizen Science

Zooniverse's Moon Zoo:

[www.moonzoo.org](http://www.moonzoo.org)

CosmoQuest's Moon Mappers

## Other NASA Lunar Mission Resources

GRAIL:

<http://solarsystem.nasa.gov/grail/home.cfm>

LADEE:

[http://www.nasa.gov/mission\\_pages/LADEE/main](http://www.nasa.gov/mission_pages/LADEE/main)

ARTEMIS:

[http://www.nasa.gov/mission\\_pages/artemis/index.html](http://www.nasa.gov/mission_pages/artemis/index.html)

## Special Public Science Events

International Observe the Moon Night:

[www.observe-themoonnight.org](http://www.observe-themoonnight.org)

---

## 8. What additional support is available for teaching lunar concepts and content?

### Online Communities:

ZooTeach:

<http://teach.zooniverse.org>

Professional Development Opportunities:

[www.smdeponews.org](http://www.smdeponews.org)



# Lunar Reconnaissance Orbiter: (CRaTER)

## Audience

Grades 6-8

## Time Recommended

45-60 minutes

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Pencil and paper
- Make a Cosmic Ray Detector worksheet (one for each student)

# CRaTER: The Cosmic Ray Telescope for the Effects of Radiation

## Learning Objectives:

- Students will be able to explain CRaTER's purpose and how it works
- Students will "design" a cosmic ray detector to answer their own questions

## Preparation:

None.

## Background Information:

The Lunar Reconnaissance Orbiter (LRO) is a spacecraft orbiting the Moon. It launched June 19, 2009. It has three main goals:

1. Identify safe landing sites for future human missions to the Moon.
2. Discover potential resources on the Moon.
3. Characterize the radiation environment of the Moon.

The third goal is vital to protecting astronauts on long missions, not just to the Moon, but also to Mars or deep space travel.

LRO carries onboard seven scientific instruments. The primary one for analyzing the Moon's radiation environment is the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER (see **Figure 1**, and others, in the supplemental images/ materials/ resources section; also, see the misconception note in the assessment section). It studies both cosmic rays and how they might affect the human body. You can see in the picture (**Figure 1**) that CRaTER sticks out from the spacecraft. This keeps the spacecraft from blocking cosmic rays from the instrument.

**Figure 2** is a photograph of what CRaTER looked like before it was attached to LRO. The right-hand side of the instrument contains the particle detectors. A cut-away version is shown in **Figure 4c**. Inside are six detectors (D1, D2, D3, D4, D5, and D6). The detectors are made from silicon (see **Figure 4**). When a cosmic ray hits a detector, it can create a small current in the silicon. A computer then detects and records the amount of current created.

These detectors allow scientists to figure out how the number of cosmic rays arriving on the Moon changes over time. That number varies, so tracking it for the duration of LRO's mission is important. This tells scientists how the radiation dose changes over time, and how it can affect humans.

Scientists can also use the amount of current in the detectors to calculate how much energy the cosmic ray has and what type of ion it is (e.g. proton, helium

nucleus, etc.). You might think that a more energetic particle would create a bigger current, but it is actually much more complicated. Calculating the energy and type of nuclei requires careful computer modeling and testing of the instrument detectors.

CRaTER does more than tell us the number, energy, and type of cosmic rays near the Moon. It also helps scientists learn about how cosmic rays will affect humans on a long mission in space. Notice in **Figure 3** the six detectors are separated into three pairs. Two pieces of black plastic separate the three pairs of detectors. The plastic is a special type designed to mimic human tissue; it is called tissue-equivalent plastic, or TEP (see **Figure 5**). In other words, a cosmic ray will deposit the same amount of radiation in the TEP as it would in human tissue.

Basically, a cosmic ray will pass through the first pair of detectors. That tells us how much energy the particle had. If it has enough energy, it will also pass through the first piece of TEP. Along the way, however, it will lose some energy to the TEP. This means the TEP is receiving a small dose of radiation. The cosmic ray will then pass through the next pair of detectors. Analyzing that signal tells us the cosmic ray now has less energy. By comparing the cosmic ray's energy before and after it passed through the TEP, we can discover how much energy the cosmic ray lost. This energy is the radiation dose the TEP received.

## Procedure:

1. Discuss the three goals of the Lunar Reconnaissance Orbiter. Ask students which of LRO's three goals they find the most interesting? Why? Encourage a discussion.
2. Discuss the CRaTER instrument to provide context. See the background information or supplemental resources section for details.
3. Do the lesson activity:

Objective: Students will “design” a cosmic ray detector to answer their own questions.

Material: Pencil and paper

- a. Split up students into groups of three or four.
- b. Hand each student the “Make a Cosmic Ray Detector” worksheet.
- c. Have them complete the worksheet.

4. Note: Misconception

Even though CRaTER is called a telescope, it is not. A real telescope collects electromagnetic radiation to make distant objects appear closer. One example would be the type of telescope you may have used to look at the Moon; it collects and magnifies visible light. However, CRaTER, by contrast, detects particles and not electromagnetic radiation. It does not make distant objects appear closer. Calling it a particle detector rather than a telescope would be more accurate. But scientists enjoy making clever acronyms, so “telescope” it is! (Often they create acronyms that have nothing to do with an instrument's purpose—CRaTER does not actually study lunar craters)



Name \_\_\_\_\_

# Make a Cosmic Ray Detector

## Scenario:

You are a cosmic ray scientist and you need to design a cosmic ray detector for a spacecraft going to Mars. What questions would you like to answer? How will your instrument answer those questions? What do you need to consider when placing it on the spacecraft? Create a diagram of your instrument, and draw what it would look like on the spacecraft.

Answers will vary, but most detectors have some basic needs. They need an internal computer; this computer must connect to the main spacecraft computer, which in turn communicates with scientists on the ground. The instrument's computer needs to keep accurate records of time and the data it collects. Detectors also need electrical power, which comes via wires from the spacecraft itself. A human analogy would be an instrument needs at least one sense (a detector) to interact with its environment, a brain (computer) to interpret the information from that sense, and food (electricity) to keep it working.



**Assessment:**

**Discussion Question:** Write down three scientific questions that you have about cosmic rays that you think data from CRaTER could answer.

---

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

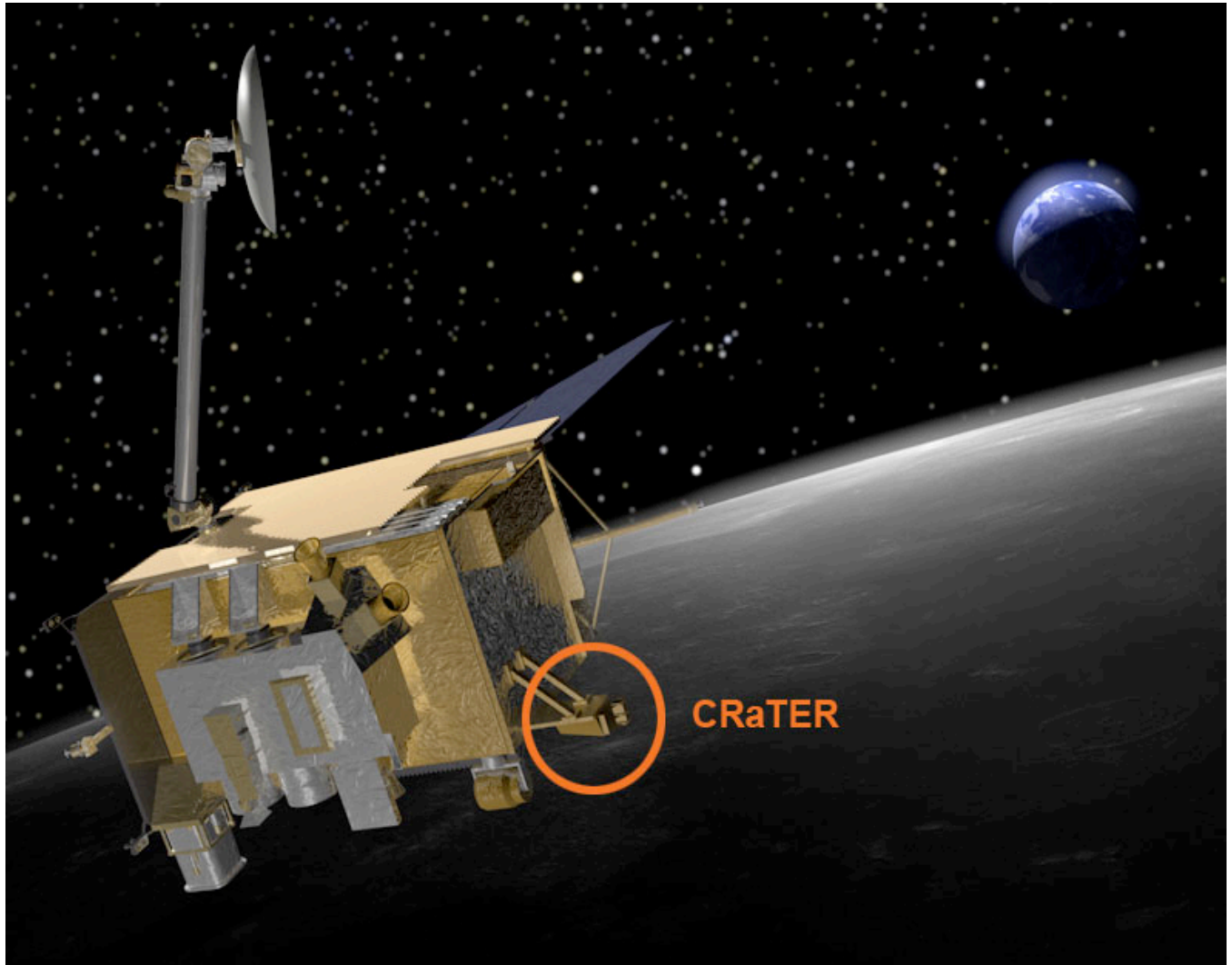


Figure 1. An artist's concept of the Lunar Reconnaissance Orbiter (LRO) above the Moon. The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) is circled.

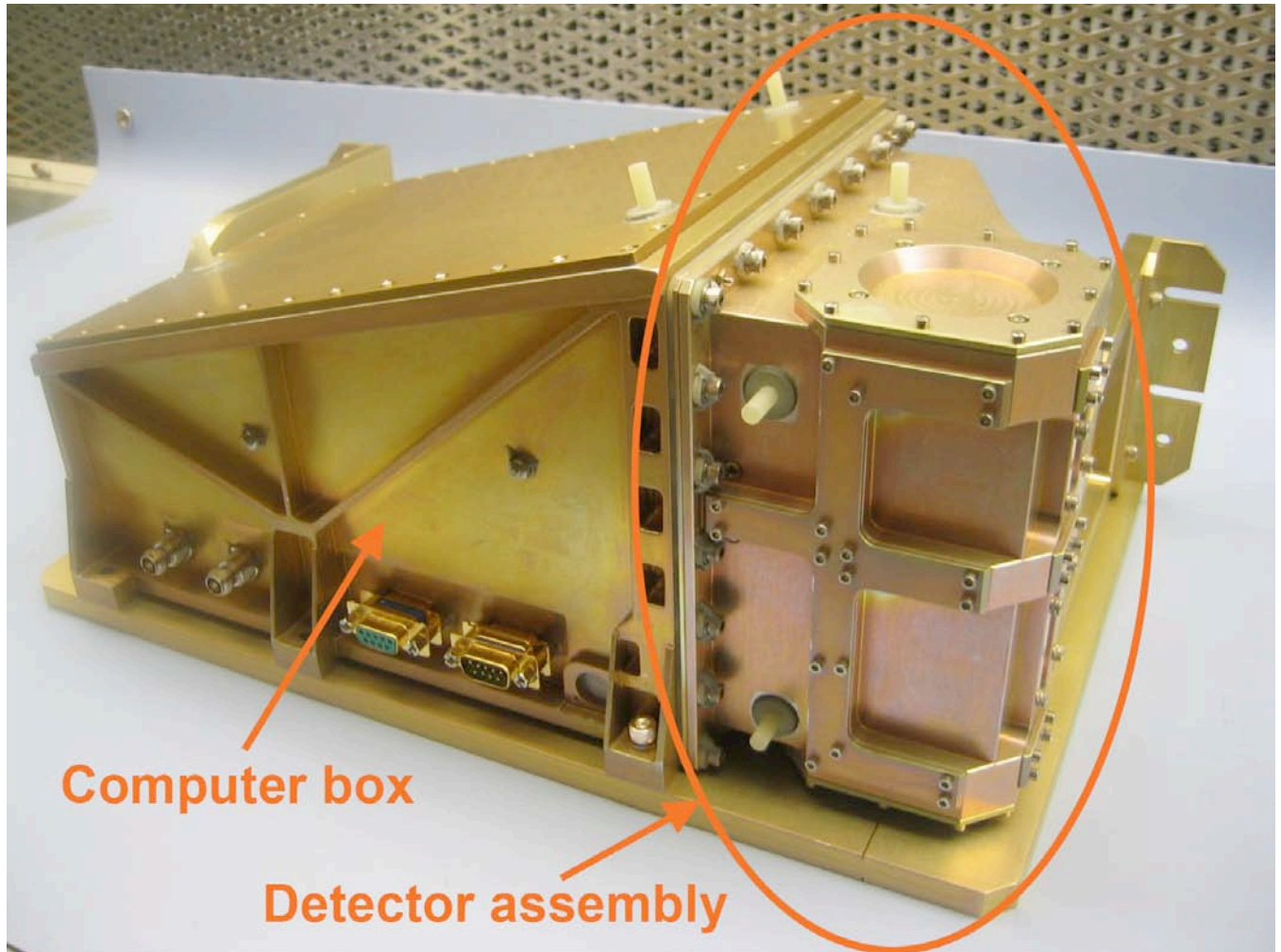


Figure 2. CRaTER before it was attached to LRO. It has two parts: the detector assembly and the computer box.

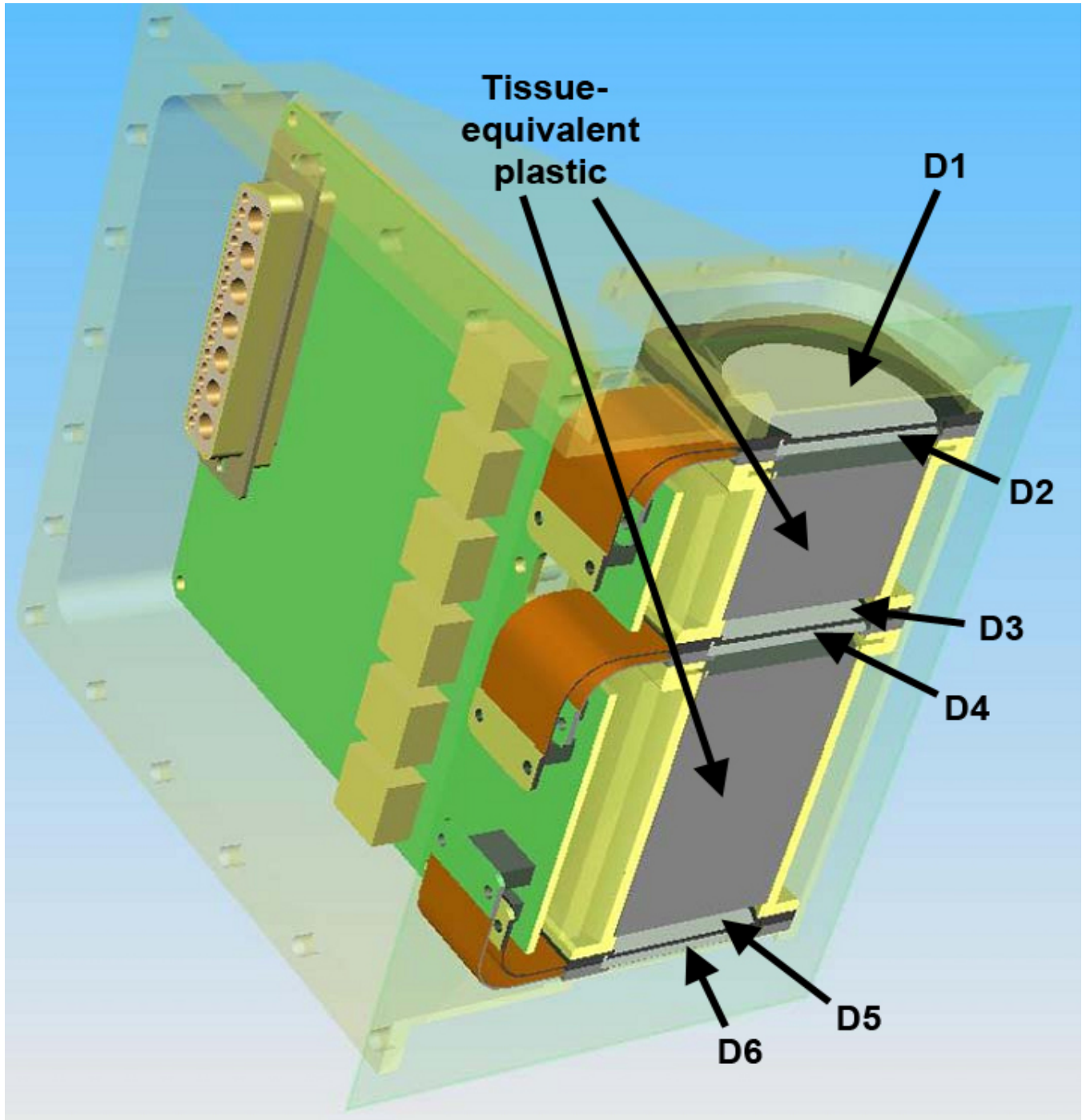


Figure 3. This is a view of CRaTER's detector assembly. It (see Figure 4b) has six "eyes," or detectors (D1, D2, D3, D4, D5, and D6) and two pieces of tissue-equivalent plastic. D6 faces the Moon, while D1 faces deep space. The "brain" of the assembly is the computer on the electronics board. This is plugged into the computer box shown in Figure 4.



Figure 4. This is an up-close view of a particle detector identical to the six in CRaTER (finger is there for scale). The black plastic frame holds the disk. The disk is 140 micro-meters thick and about 4 cm in diameter. The dark gray squares are the silicon, and the lighter edges of the squares are aluminum. The aluminum improves detecting the current created by cosmic rays. The wires run from the detector to a small computer. The detector is very reflective; in it you can see a fuzzy image of pictures hanging on my office wall.



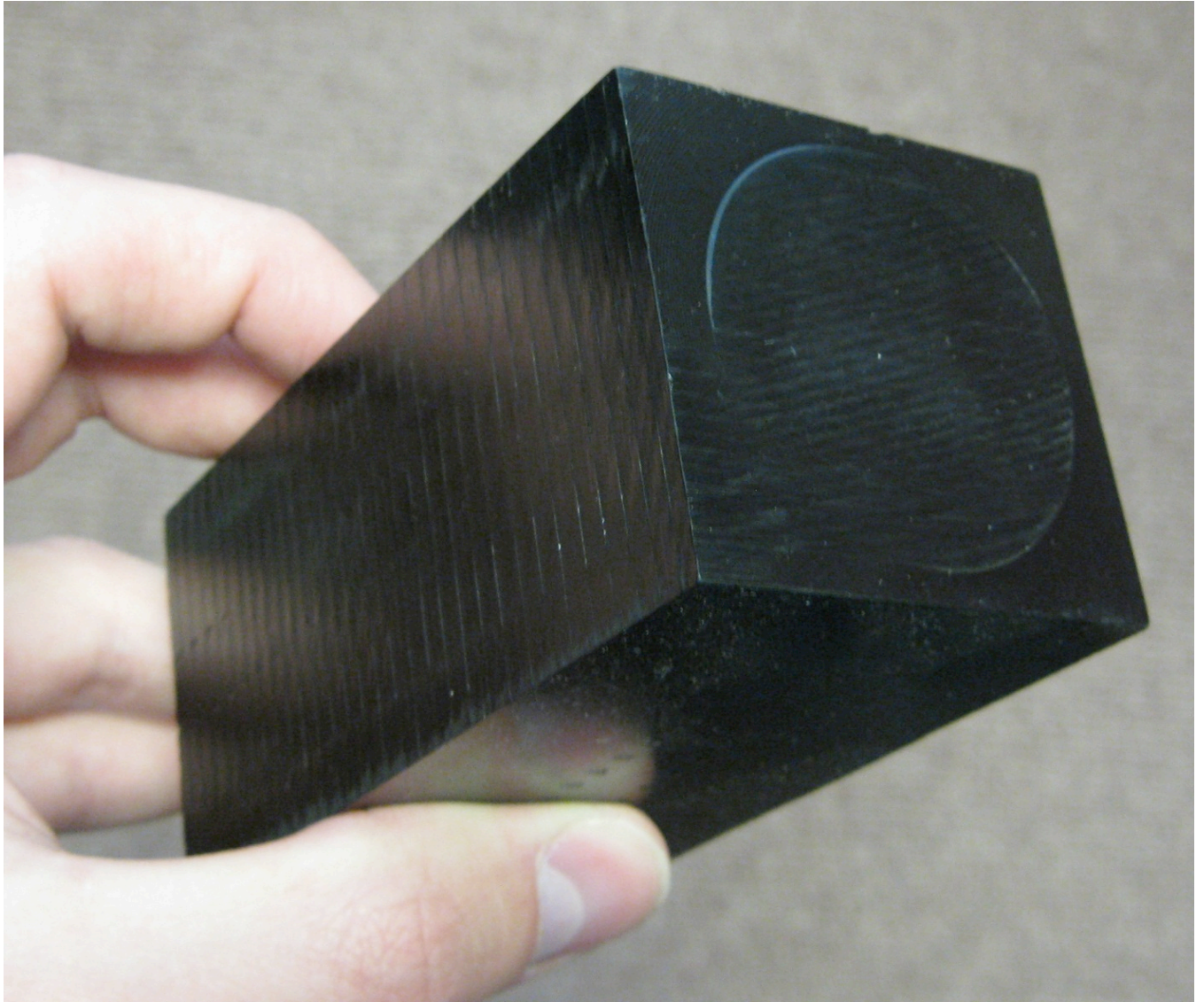


Figure 5. This is tissue-equivalent plastic, TEP: hard and black. Even though it does not look like much, radiation interacts with it almost the same way as with human tissue.

## Resources:

### Information about CRaTER and LRO

LRO site:

[lunar.gsfc.nasa.gov](http://lunar.gsfc.nasa.gov)

CRaTER's website:

[crater.unh.edu](http://crater.unh.edu)

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:

[www.nasa.gov/multimedia/nasatv/on\\_demand\\_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC\\_20090416\\_LRO\\_CRaTERvideo.asx](http://www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.asx)

### General information about cosmic rays

*A Thin Cosmic Rain: Particles from Outer Space* (previously published as *Cosmic Rays*), Cambridge, MA: Harvard, 2000.

Cosmicopia: An Abundance of Cosmic Rays (a NASA Goddard website about cosmic rays):

[helios.gsfc.nasa.gov/cosmic.html](http://helios.gsfc.nasa.gov/cosmic.html)

Cosmic ray comic book:

[www.scostep.ucar.edu/comics/books](http://www.scostep.ucar.edu/comics/books), then click on the file labeled *cosmicrays\_e.pdf*.

Air shower movies generated from the ARIES (Air shower Extended Simulations):

<http://astro.uchicago.edu/cosmus/projects/aires>

### Space Radiation

Space Radiation Analysis Group at Johnson Space Center:

<http://srag-nt.jsc.nasa.gov>

Eugene N. Parker, "Shielding Space Travelers," *Scientific American*, March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover*, June 2006.

Cosmic rays and cataracts:

[http://science.nasa.gov/science-news/science-at-nasa/2004/22oct\\_cataracts](http://science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts)

A NASA 6-12 educators guide to radiation math, with worksheets for students:

[www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation)

## Glossary:

**ALFMED:** Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision

**ALTEA:** Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain

**Atom:** the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons

**Cosmic ray:** an ion or electron in space that travels at a speed similar to that of light

**CRaTER:** Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon

**Electroencephalograph:** an instrument that records the brain's electrical activity

**Electromagnetic radiation:** energy emitted in the form of electric and magnetic waves

**Electron:** a negatively charge subatomic particle; one of three particles to comprise atoms

**Electroscope:** a scientific tool used to store electric charge

**Emulsion:** a gel-like substance used to detect electromagnetic or particle radiation

**ISS:** International Space Station

**LRO:** Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment

**NASA:** National Aeronautics and Space Administration

**Nucleus:** the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons

**Particle radiation:** energy emitted in the form of subatomic particles

**Phosphor:** a material that, when stimulated, emits electromagnetic radiation

**Proton:** a positively charged subatomic particle; one of two particles to comprise atomic nuclei

**TEP:** tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue

**Radioactivity:** the condition of a substance to emit ionizing particle or electromagnetic radiation

# Lunar Reconnaissance Orbiter: (CRaTER)

## Audience

Grades 6-8

## Time Recommended

45-60 minutes

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- e. Think critically and logically to make relationships between evidence and explanations

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Printed copy of the cartoon found in the activity (one per student)

# CRaTER: The Discovery and Nature of Cosmic Rays

## Learning Objectives:

- Students will learn how cosmic rays were discovered and what they are. They will understand how small and fast they are.

## Preparation:

None

## Background Information:

The Lunar Reconnaissance Orbiter (LRO) is a spacecraft orbiting the Moon. LRO carries onboard seven scientific instruments. The primary one for analyzing the Moon's radiation environment is the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER. With it, scientists study both the radiation itself and how it might affect the human body.

We usually think of astronomers studying very big things like stars and galaxies. Astronomers also talk about vast distances like thousands of light years. But, did you know astronomers also study some of the smallest known objects in the universe? An important example of such tiny objects is the cosmic ray. Even though cosmic rays are small, believe it or not, they are still the most energetic particles in the universe.

The discovery of these small but energetic particles began accidentally in the early twentieth century, when scientists found that their electroscopes could not store charge indefinitely. An electroscope is a device that stores electric charge. It contains a neutral gas to insulate the stored charge. The fact the charge could leak from electroscopes surprised scientists; this meant the gas was not neutral. Somehow the gas inside the electroscopes was becoming slightly ionized, creating a route to short out the charge. No matter the amount of shielding, such as lead, an electroscopes' charge still leaked. A very penetrative type of radiation must have been ionizing (charging) the gas.

Radiation refers to the emission of energy. There are two types: electromagnetic radiation and particle radiation. Electromagnetic radiation includes radio waves, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays. Scientists refer to all types of electromagnetic radiation as "light," though most non-scientists use the term "light" to refer only to the visible part of electromagnetic radiation. The latter, energetic particles, which can be protons, ions, or electrons, are types of particle radiation.

## Questions to be asked during the lesson:

### QUESTION 1:

**Can you think of some common examples of particle radiation?**

**Answers:**

- *Older TVs or computer monitors combine both particle and electromagnetic radiation. A small apparatus (electron gun) at the back of the monitor shoots electrons at the screen. These electrons are particle radiation—energy emitted in the form of particles. The screen has a special coating on the inside called phosphor. When electrons hit the screen, they transfer their energy to the phosphor atoms. These atoms re-emit the energy in the form of electromagnetic radiation. In other words, the visible light that we see was created by the energy from particle radiation.*
- *Radioactive materials, such as uranium, emit both particle and electromagnetic radiation.*
- *Particle accelerators accelerate particles to extremely high speeds (99% the speed of light). The largest example is in Switzerland and operated by CERN (a French acronym for European Organization for Nuclear Research). Some hospitals have much smaller particle accelerators to create energetic protons to treat cancer. So instead of using electromagnetic radiation in the form of X-rays, doctors at such hospitals use particle radiation to kill the cancer cells.*

### QUESTION 2:

**Some type of particle or electromagnetic radiation was creating the charge leakage in the electroscopes. What are the possible sources of radiation that could account for the leakage?**

**Answer:**

- *Three possible sources are radioactive materials in the Earth, radiation within the atmosphere, or radiation from outer space.*

### QUESTION 3:

**What would you do to discover whether one or more of those possible sources are correct?**

**Answer:**

- *There are three possible sources: Earth, the atmosphere, and space. Since we are near Earth but not space, a good idea would be to get as far away from Earth and as close to space as possible. If Earth were the source, the charge leakage would decrease with distance from Earth. If space were the source, then the leakage would increase with distance from Earth. If the atmosphere is the source, then the leakage would reach a maximum somewhere between Earth and space.*

## QUESTION 4:

**Can you guess how many protons are in your body?**

**Answer:**

- *Over ten octillion ( $10^{28}$ )! Write this number out: 10,000,000,000,000,000,000,000,000,000. That is one hundred thousand times the number of stars in the known universe! It's a good thing you don't have to keep track of all of them.*

## QUESTION 5:

**Is the energy from cosmic rays much less than, about equal to, or much more than the energy from starlight?**

**Answer:**

- *The energy from cosmic rays is about the same as the energy from starlight. The reason we notice starlight more is because our eyes can see the electromagnetic radiation (light) from the stars. Our eyes, however, do not detect particle radiation very well. (This question was adapted from Thinking Physics Is Gedanken Physics, by Lewis Carroll Epstein, San Francisco: Insight Press, 2005.)*

## QUESTION 6:

**How fast does your car go on the highway? How much faster does a cosmic ray go if it travels at one-tenth the speed of light?**

**Answer:**

- *Your car travels at about 130 km/hr (60 mph), or a little over 30 m/s. A "slow" cosmic ray will travel at about one-tenth the speed of light, or 30,000,000 m/s. That means a cosmic ray is one million times faster than your car. I wonder what the speeding ticket would be?*

## Procedure:

1. **Ask Question 1** and/or **Questions 2 and 3** here.
2. **Discuss the following background information:** in 1910, a Roman Catholic priest named Theodor Wulf created an experiment to determine the source of the leakage in electroscopes. He thought the source might be radioactive rocks within the Earth. He carried an electroscope to the top of the Eiffel Tower to see whether the leakage rate would decrease. It did decrease, which implied that some of the radiation was from radioactive materials in the earth. Thus, the farther from Earth Wulf moved his electroscope, the less radiation affected it. The decrease in the leakage, however, was less than expected. Another radiation source must also be at work. His results implied the source of radiation was outside the atmosphere in outer space.
3. **Discuss:** The next year, an Austrian physicist named Victor Hess began a series of balloon trips—some of them dangerous—with electroscopes to measure the leakage. He discovered with increasing altitude, the rate at first decreased and then began to increase. At an altitude of about 1.5 km (5000 ft.), the leakage was greater than at sea level. He measured the rates even up to 5 km (higher than the Rockies), where the leakage was several times greater than at sea level. (At that time, airplanes were unable to reach such altitudes, nor could they stay aloft for the amount of time necessary for his experiment.) His work conclusively demonstrated that the radiation had an extraterrestrial source. He received the Nobel Prize for his discovery. Fifteen years later, in 1926, Robert Millikan, better known for his work on the electron's charge, helped coin the term "cosmic ray" to describe this radiation raining down on the Earth.

4. **[Optional Information:** We now know that cosmic rays are charged subatomic particles. This is because charged particles do not travel in straight lines in the presence of a magnetic field. Earth has a large magnetic field; this is why you can use a small magnet called a compass to find magnetic north. The physicist Arthur Compton discovered in 1932 that Earth's magnetic field curved the cosmic rays' paths. That meant that the cosmic rays are charged particles and not electromagnetic radiation.] We now know that cosmic rays are subatomic particles. They are electrically charged particles. Cosmic rays are mostly protons and ions, which have positive charges. However, a small percentage are electrons, which have negative charges.
5. **[Optional Information:** About 83% are protons, 13% are helium nuclei (also called alpha particles), 3% are electrons, and the final 1% are atomic nuclei more massive than helium (some examples are carbon, oxygen, and iron nuclei).]
6. **Discuss:** cosmic rays, even though we call them "rays" (like light rays), are not a form of electromagnetic radiation; they are a type of particle radiation. Scientists used that name before they knew what cosmic rays were; some thought that they were high-energy gamma rays. We now know that cosmic rays are charged subatomic particles traveling almost at the speed of light. Most of them are protons, but the name still sticks.
7. **Ask Question 4.**
8. **Do the following activity:**
  - a. Provide a copy for each student of the cartoon (located in worksheets section).
  - b. Ask the following questions to students:

**Assume your classroom is 10 m (33 ft) across. Each hair on your head has a diameter (NOT length!) that is much smaller than the width of your classroom. How many hairs would you have to lay side by side to reach across the room?**

**Answer:**

*Each hair has a diameter of about 100 micrometers. Therefore 100,000 hairs laid side by side would reach across the room. That is about all the hairs you have on your head!*

**A hair from your head has a diameter of about 100 micrometers. Can you guess how many atoms would fit side by side along your hair's diameter?**

**Answer:**

*The atom hydrogen is about  $10^{-10}$  m across. That means that one million atoms could fit side by side along the diameter of a single hair!*

**A typical atom is about  $10^{-10}$  m across. Can you guess how many protons would fit side by side along the atom's diameter?**

**Answer:**

*A proton has a diameter of about  $10^{-15}$  m (that is one femtometer). That means that one hundred thousand protons would fit along the atom's diameter. To give you an idea of what this means, imagine increasing an atom to be the size of your classroom. The diameter of the increased proton at the center of the atom would be the same as the diameter of your hair, where as a classroom is 100,000 hairs across, and an atom is 100,000 protons across respectively.*

Essentially, atoms are mostly empty space! In this analogy, the simplest atom, hydrogen, would have a hair-sized proton at the center with an even tinier electron zipping along the walls of the classroom.

Atoms are very small objects, but subatomic particles, like protons, are much, much smaller. This exercise shows why cosmic rays can travel through your body without hitting anything: you are mostly empty space! The exercise also emphasizes the minuteness of cosmic rays.

- c. **Optional Information:** Energy in the form of electromagnetic radiation from the stars continually “rains” down on Earth. Similarly, the energy from cosmic rays (particle radiation) is “raining” down on Earth all the time. **[Ask Question 5 here.]**

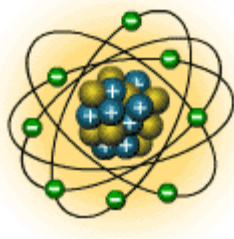
In addition to being subatomic charged particles, cosmic rays are very fast. They are so fast they travel at almost the speed of light, which is  $3 \times 10^8$  m/s (fast enough to go around the earth seven times in one second). Most cosmic rays travel at one-tenth that speed. But, some have been detected traveling at more than 90% of the speed of light. These cosmic rays have the same energy of a fastball thrown by a major league pitcher. Imagine all that energy crammed into a single subatomic particle!

9. **Ask Question 6.**

10. **Discuss:** cosmic rays are charged subatomic particles traveling almost at the speed of light. What makes them move so fast (i.e., have so much energy)? This question continues to puzzle astronomers. Many, if not most, cosmic rays apparently received their “energy boost” when stars much bigger than our sun explode—an event called a supernova. A supernova is one of the most energetic events in the universe. It releases an enormous amount of energy in a short time (more energy than all the other approximately hundred billion stars in the Milky Way galaxy!); some of this energy can go into boosting charged particles to high speeds. Scientists continue to search for other sources of cosmic rays.

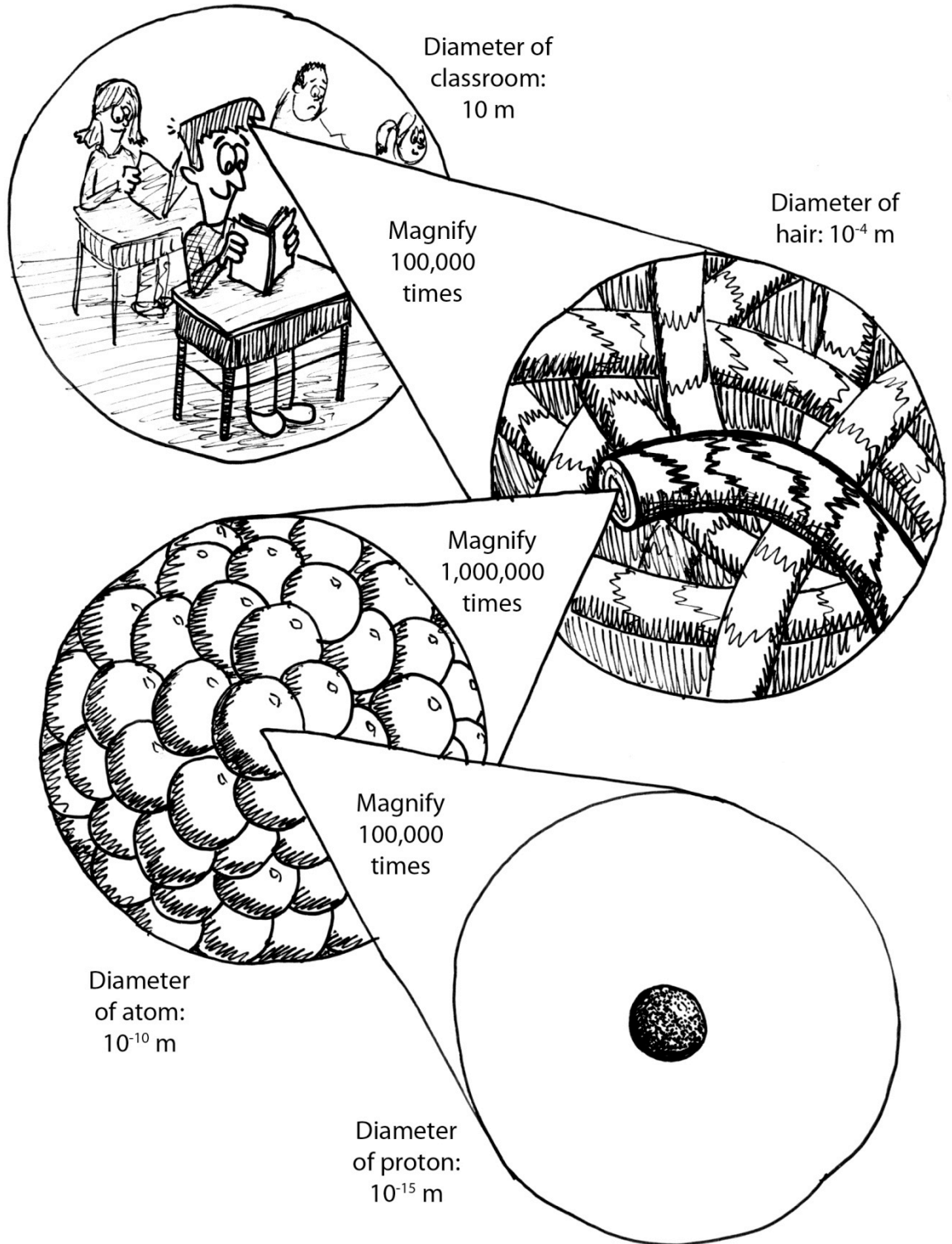
**Note: Misconception**

Many textbooks show pictures of atoms that look something like this (from a NASA web page):



While it is okay to have pictures that are not to scale, they can be misleading because they make the nucleus appear to be almost as big as the atom itself! In reality, the diameter of the nucleus is about 100,000 times smaller than that of the atom. You would be unable to see it in this picture!





## Assessment:

Write down three questions about cosmic rays that you now know the answers to. Trade your questions with a classmate and see if you can answer each other's questions.

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Resources:

#### Information about CRaTER and LRO

LRO site:

[lunar.gsfc.nasa.gov](http://lunar.gsfc.nasa.gov)

CRaTER's website:

[crater.unh.edu](http://crater.unh.edu)

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:

[www.nasa.gov/multimedia/nasatv/on\\_demand\\_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC\\_20090416\\_LRO\\_CRaTERvideo.aspx](http://www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.aspx)

#### General information about cosmic rays

*A Thin Cosmic Rain: Particles from Outer Space* (previously published as *Cosmic Rays*), Cambridge, MA: Harvard, 2000.

Cosmicopia: An Abundance of Cosmic Rays (a NASA Goddard website about cosmic rays):

[helios.gsfc.nasa.gov/cosmic.html](http://helios.gsfc.nasa.gov/cosmic.html)

Cosmic ray comic book:

[www.scostep.ucar.edu/comics/books](http://www.scostep.ucar.edu/comics/books), then click on the file labeled cosmicrays\_e.pdf.

Air shower movies generated from the ARIES (Air shower Extended Simulations):

<http://astro.uchicago.edu/cosmus/projects/aires>

#### Space Radiation

Space Radiation Analysis Group at Johnson Space Center:

<http://srag-nt.jsc.nasa.gov>

Eugene N. Parker, "Shielding Space Travelers," *Scientific American*, March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover*, June 2006.

Cosmic rays and cataracts:

[http://science.nasa.gov/science-news/science-at-nasa/2004/22oct\\_cataracts](http://science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts)

A NASA 6-12 educators guide to radiation math, with worksheets for students:

[www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation\\_Math.htm](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation_Math.htm)

## Glossary:

**ALFMED:** Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision

**ALTEA:** Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain

**Atom:** the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons

**Cosmic ray:** an ion or electron in space that travels at a speed similar to that of light

**CRaTER:** Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon

**Electroencephalograph:** an instrument that records the brain's electrical activity

**Electromagnetic radiation:** energy emitted in the form of electric and magnetic waves

**Electron:** a negatively charge subatomic particle; one of three particles to comprise atoms

**Electroscope:** a scientific tool used to store electric charge

**Emulsion:** a gel-like substance used to detect electromagnetic or particle radiation

**ISS:** International Space Station

**LRO:** Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment

**NASA:** National Aeronautics and Space Administration

**Nucleus:** the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons

**Particle radiation:** energy emitted in the form of subatomic particles

**Phosphor:** a material that, when stimulated, emits electromagnetic radiation

**Proton:** a positively charged subatomic particle; one of two particles to comprise atomic nuclei

**TEP:** tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue

**Radioactivity:** the condition of a substance to emit ionizing particles or electromagnetic radiation

# Lunar Reconnaissance Orbiter: (CRaTER)

## Audience

Grades 6-8

## Time Recommended

30-45 minutes

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Pencil and paper
- Activity Worksheets (included)

# CRaTER: How Cosmic Rays Affect Humans

## Learning Objectives:

- Students will be able to describe why cosmic rays are dangerous to astronauts.
- Students will learn to design a scientific instrument.
- Students will think critically about how to protect astronauts from cosmic rays.

## Preparation:

None

## Background Information:

On their trips to and from the Moon, Apollo astronauts saw small white flashes of light while in the dark—even with their eyes closed. They usually saw no more than a couple each minute, although at least one astronaut saw so many he had trouble sleeping. What caused these flashes?

The answer is cosmic rays. Because of their high speeds, thousands of these cosmic rays were passing through the bodies of the Apollo astronauts every second. Most went straight through because atoms are mostly empty space. Some cosmic rays, however, hit atoms in the astronauts' bodies. The ones hitting atoms in the astronauts' eyeballs released a small amount of energy in the form of small flashes.

## Procedure:

1. Ask the main question of the entire lesson: how might cosmic rays affect astronauts in space?
2. Do activity 1:

**Time:** 15-20 minutes

**Materials:** Pencil and paper

Ask what experiment would you design to see whether cosmic rays hitting the eyeballs really do cause the flashes? Figure out what questions you need to answer. (Examples: are there cosmic rays in the spacecraft; do they go through the astronauts' eyeballs; do they go through their eyeballs when the astronauts see flashes? The experiment also requires timing of cosmic rays and timing of when the astronauts see flashes.) How does your design compare with what they actually did?

3. Discuss the following: To test whether cosmic rays were causing the flashes, scientists created the detector shown in **Figures 1, 2, and 3** (located in worksheets section; show them to students). It was the Apollo Light Flash Moving Emulsion Detector, or ALFMED. The emulsion was a gel-like chemical sensitive to cosmic rays. The astronauts would wear ALFMED over their heads for an hour and then time when they saw light flashes. The detector would keep track of when cosmic rays passed through itself and the astronauts' heads. It could also tell whether a cosmic ray had gone through the eye. On the ground, scientists found that when an astronaut saw a flash, a cosmic ray had passed through his eyeball!

**Background:** more recently, the Italian Space Agency created a similar cosmic ray detector for the International Space Station (ISS); it is the Anomalous Long Term Effects in Astronauts' Central Nervous System, or ALTEA. It was on the ISS for much of 2006 and 2007. Figure 4 (see worksheets section) shows an astronaut performing an experiment with it. Although it looks similar to ALFMED, it is more complex. The helmet portion contains cosmic ray detectors that can tell whether a cosmic ray has passed through the brain. A device called an electroencephalograph (EEG) simultaneously measures the astronaut's brain activity. The results from this experiment will help determine how cosmic rays can affect the brain. The data are still being analyzed (for more information, see [www.nasa.gov/mission\\_pages/station/research/experiments/ALTEA.html](http://www.nasa.gov/mission_pages/station/research/experiments/ALTEA.html)).

Cosmic ray collisions in the body can be harmful because they can damage the DNA in cells. Remember, a single cosmic ray has a large amount of energy. If it collides with DNA, it will destroy part of that DNA strand. DNA contains instructions for the cell to function properly. When the DNA is damaged, the cell will malfunction. Usually the cell will then die, but sometimes it can reproduce itself. If that happens on a large enough scale, the person may develop cancer.

Cosmic rays tend not to be a problem for a short mission. For example, the Apollo missions lasted no more than about a week. (A 2001 study, however, does indicate that even such a short mission increased the astronauts' likelihood of developing cataracts.) Long-term missions (at least six months) to the Moon, Mars, or deep space, however, will increase the radiation risk. Therefore we must understand how this particle radiation affects the body.

We also need to learn how to best shield astronauts from cosmic rays. Unfortunately, shields require much mass to be effective. The more mass a shield has, the more likely it is for a cosmic ray to deposit energy in the shielding and not in the astronauts. Increasing the mass of a spacecraft, however, makes it more difficult and expensive to launch into space and to land. Current and future engineers have an important task ahead: to keep astronauts as safe as possible on such missions.

4. Do activity 2:

**Time:** 10 minutes

**Materials:** Pencil and paper

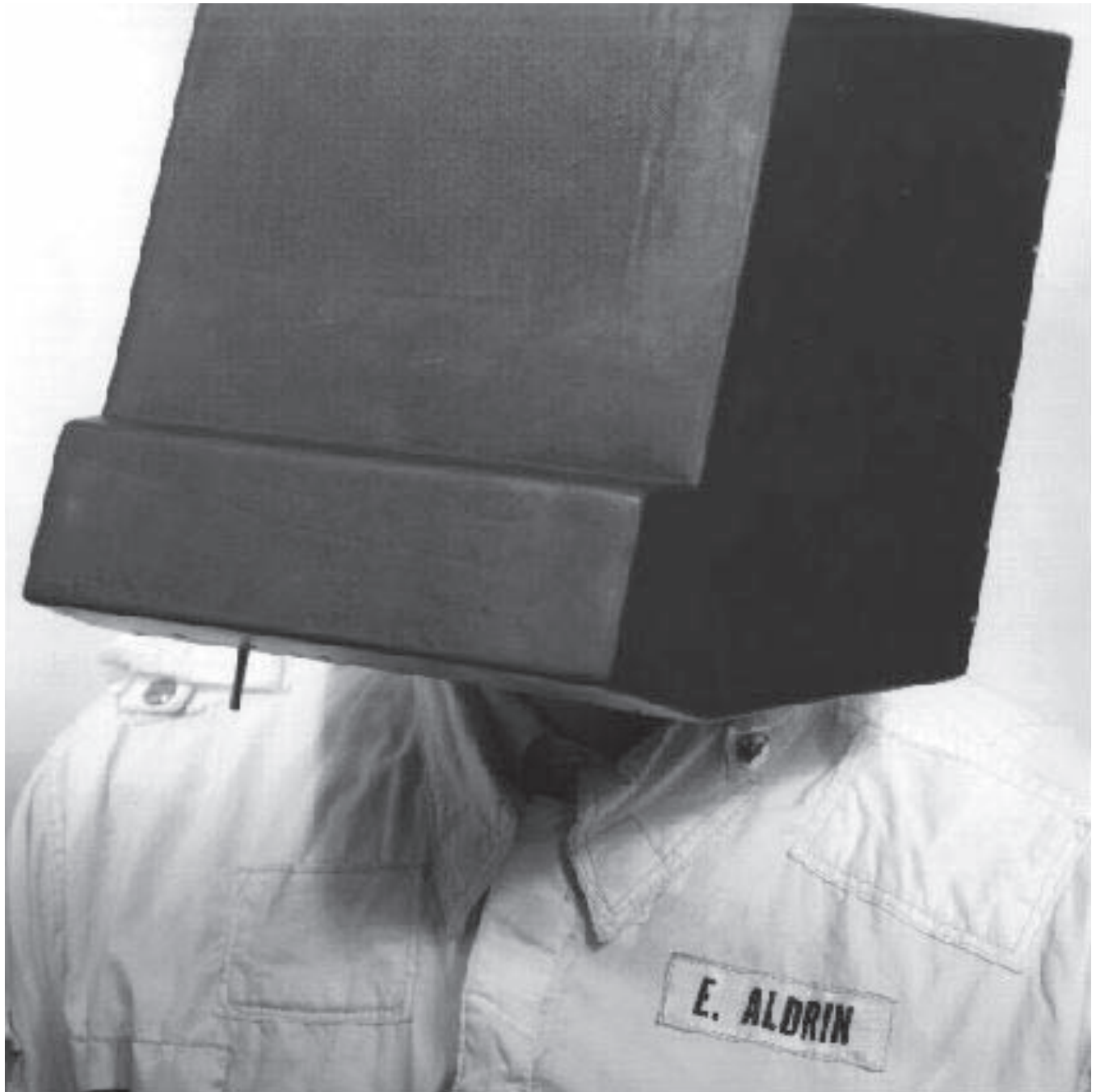
Imagine that you are an astronaut setting up a base on the Moon. What are some of the ways to protect you and your fellow crew members from the effects of cosmic radiation? What might make a good shield?

Possible ideas include creating an underground station or using a cave. Water is a good shield against cosmic rays, so students might decide to build a station near water ice. On the other hand, lead shielding is a dangerous idea (see the misconception section below). Trying a biological approach, such as repairing damaged DNA, is another possibility.

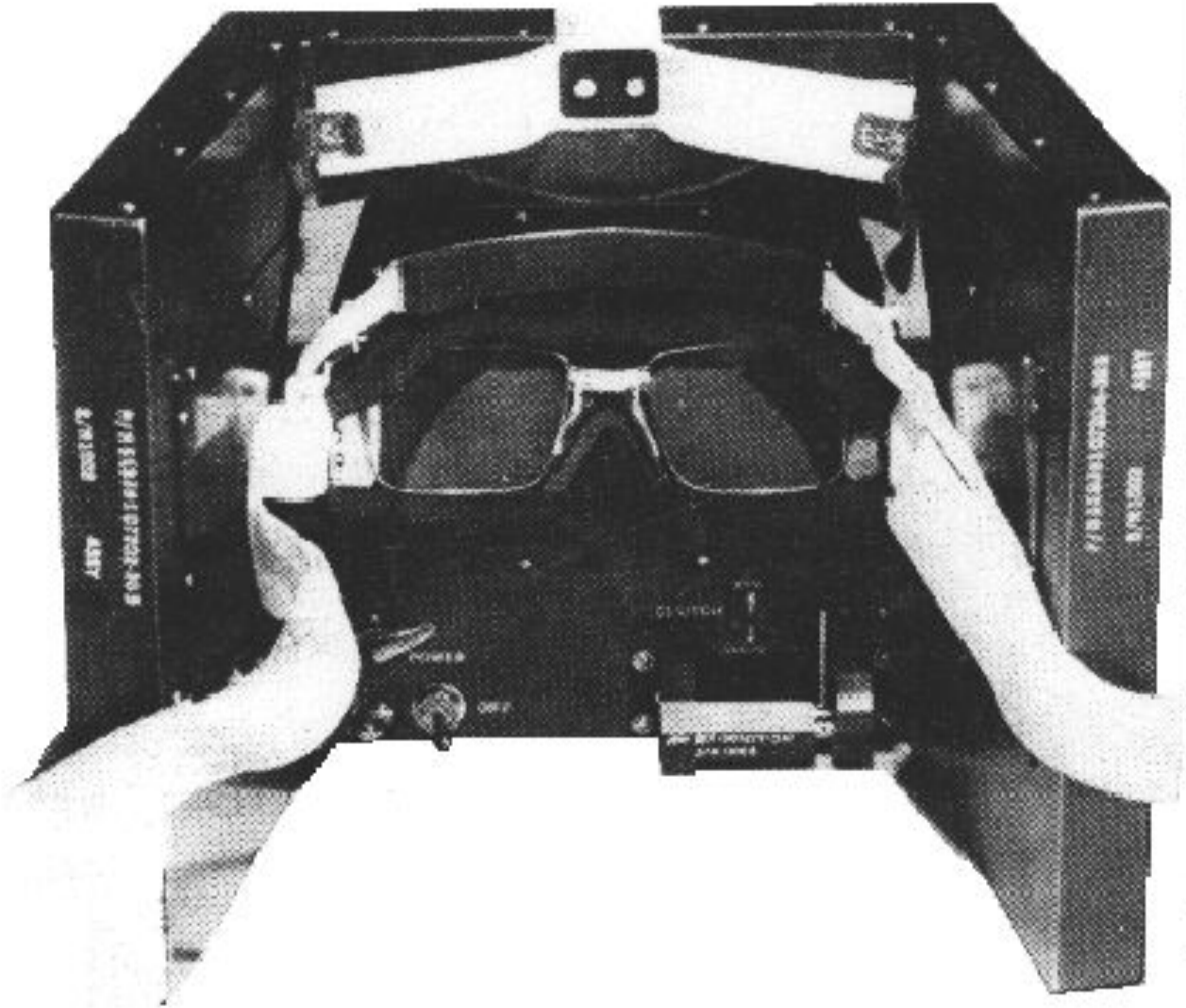
### **Note: Misconception**

An important misconception is that lead can protect astronauts from cosmic rays. This is incorrect. Lead can actually be more dangerous than having no shielding at all! The reason is that when cosmic rays collide with the lead nuclei, they split the nuclei. These new nuclei are energetic enough to collide with and split even more nuclei. An astronaut on the other side of the lead shield will thus be bombarded by many more particles than just the original cosmic ray. Unless the shield is very thick, the radiation dose is higher with the lead shielding.

This is true of all materials, except hydrogen. Because hydrogen has only one proton in its nucleus, its nucleus cannot split into smaller parts. Therefore materials with a large amount of hydrogen in them, such as water and some plastics, make good shields.



**Figure 1.** Apollo 11 astronaut Buzz Aldrin (the second man on the moon), sports an attractive cosmic ray detector called ALFMED (Apollo Light Flash Moving Emulsion Detector). This picture was taken on Earth. Other astronauts wore it in space.



**Figure 2.** Apollo 17 astronaut Ron Evans (facing right) wears ALFMED. You can see the back of his head and part of his ear on the left, just above the main head strap.



**Figure 3.** Apollo 17 astronaut Ron Evans (facing right) wears ALFMED. You can see the back of his head and part of his ear on the left, just above the main head strap.





**Figure 4.** Expedition 13 ISS (International Space Station) Science Officer Jeff Williams shows off Italian cosmic ray detecting headgear. He stayed in the ALTEA helmet for 90 minutes.

## Assessment:

**Homework Assignment:** Find a book at home or in the library that describes building a station in space, on the Moon, on Mars, etc. Does it describe how to protect the astronauts from cosmic rays? If so, what is the method? Is it a good idea? Why or why not? If the book does not talk about cosmic rays, do you think that the astronauts would be in danger in that station? Why or why not?

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Resources:

#### Information about CRaTER and LRO

LRO site:

[lunar.gsfc.nasa.gov](http://lunar.gsfc.nasa.gov)

CRaTER's website:

[crater.unh.edu](http://crater.unh.edu)

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:

[www.nasa.gov/multimedia/nasatv/on\\_demand\\_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC\\_20090416\\_LRO\\_CRaTERvideo.aspx](http://www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.aspx)

#### General information about cosmic rays

*A Thin Cosmic Rain: Particles from Outer Space* (previously published as *Cosmic Rays*), Cambridge, MA: Harvard, 2000.

Cosmicopia: An Abundance of Cosmic Rays (a NASA Goddard website about cosmic rays):

[helios.gsfc.nasa.gov/cosmic.html](http://helios.gsfc.nasa.gov/cosmic.html)

Cosmic ray comic book:

[www.scostep.ucar.edu/comics/books](http://www.scostep.ucar.edu/comics/books), then click on the file labeled cosmicrays\_e.pdf.

Air shower movies generated from the ARIES (Air shower Extended Simulations):

<http://astro.uchicago.edu/cosmus/projects/aires>

#### Space Radiation

Space Radiation Analysis Group at Johnson Space Center:

<http://srag-nt.jsc.nasa.gov>

Eugene N. Parker, "Shielding Space Travelers," *Scientific American*, March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover*, June 2006.

Cosmic rays and cataracts:

[http://science.nasa.gov/science-news/science-at-nasa/2004/22oct\\_cataracts](http://science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts)

A NASA 6-12 educators guide to radiation math, with worksheets for students:

[www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation\\_Math.htm](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation_Math.htm)

## Glossary:

**ALFMED:** Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision

**ALTEA:** Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain

**Atom:** the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons

**Cosmic ray:** an ion or electron in space that travels at a speed similar to that of light

**CRaTER:** Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon

**Electroencephalograph:** an instrument that records the brain's electrical activity

**Electromagnetic radiation:** energy emitted in the form of electric and magnetic waves

**Electron:** a negatively charge subatomic particle; one of three particles to comprise atoms

**Electroscope:** a scientific tool used to store electric charge

**Emulsion:** a gel-like substance used to detect electromagnetic or particle radiation

**ISS:** International Space Station

**LRO:** Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment

**NASA:** National Aeronautics and Space Administration

**Nucleus:** the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons

**Particle radiation:** energy emitted in the form of subatomic particles

**Phosphor:** a material that, when stimulated, emits electromagnetic radiation

**Proton:** a positively charged subatomic particle; one of two particles to comprise atomic nuclei

**TEP:** tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue

**Radioactivity:** the condition of a substance to emit ionizing particles or electromagnetic radiation

# Lunar Reconnaissance Orbiter: (CRaTER)

## Audience

Grades 6-8

## Time Recommended

45-60 minutes

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- e. Think critically and logically to make relationships between evidence and explanations

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

- e. Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

## MATERIALS

- Copies of the pictures (located in procedure section)
- Very clear jar with a metal lid
- Denatured alcohol
- Black construction paper
- Sponge
- Pen or pencil
- Flashlight
- Dry ice, which you may be able to find this at an ice cream shop or a grocery store
- (Optional) a small radioactive source that emits energetic helium nuclei (alpha particles), e.g. a lead-210 or polonium-210 needle source

# CRaTER: How to Detect Cosmic Rays

## Learning Objectives:

- The students will be able to explain two examples of a cosmic ray detector.
- Students will learn how cosmic rays can affect us here on Earth.

## Preparation:

See activity procedure for details.

## Background Information:

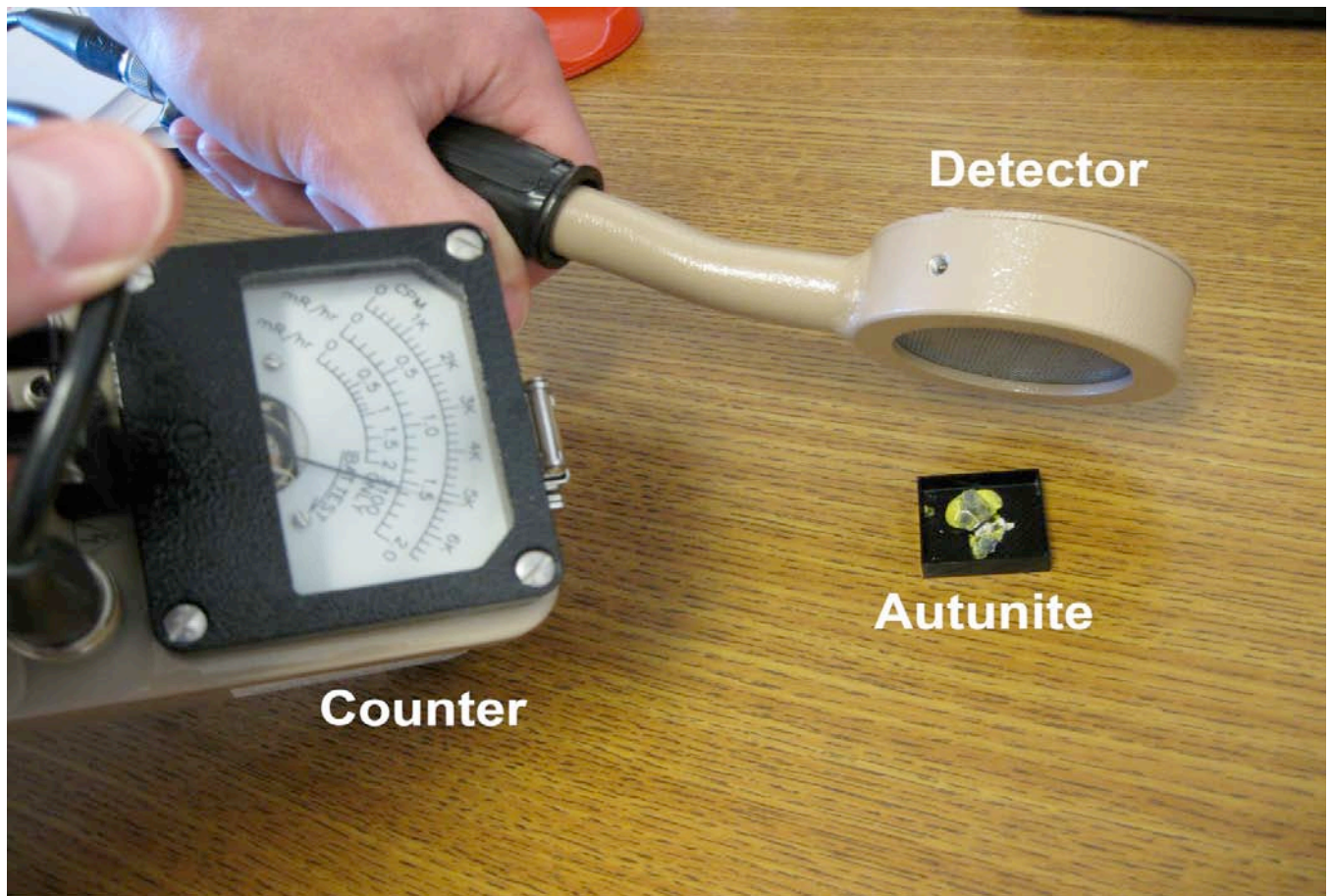
To understand the effects of cosmic rays, we need to be able to detect them. A variety of methods exist. One detector you may have seen or heard, especially in movies, is a Geiger counter (see Figure 1). This instrument can detect various forms of particle radiation and electromagnetic radiation, as discussed in the previous lesson. The sources of particle radiation can be radioactive materials, like uranium, or cosmic rays. (See picture on next page)

The Geiger counter has a small chamber of inert gas. When a photon or subatomic particle passes through the chamber, it can collide with some of the atoms in the gas, stripping them of their electrons. This creates a small current in the gas like the current in electroscopes. The Geiger counter detects the current. If the counter has a speaker, you will hear clicking sounds when the instrument detects radiation.

The Lunar Reconnaissance Orbiter (LRO) carries a detector called the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER. Instead of using gas like the Geiger counter, CRaTER uses a solid to detect cosmic rays. It contains six disks made from silicon; they are called solid-state detectors. Such detectors are much more compact than one which uses a gas. A cosmic ray that passes through this detector will create a small current CRaTER's computer measures.

Although the cloud chamber seems like a simple device, it was instrumental in discovering new subatomic particles. When cosmic rays collide with atoms in Earth's atmosphere, they create secondary subatomic particles. In 1932, a physicist named Carl Anderson discovered the positron (an antimatter electron, or "electron" with a positive charge) in his cloud chamber. He received the Nobel Prize for this. Anderson next discovered in 1936 a negatively charged particle called the muon. Both particles were the result of using a cloud chamber.

If you could take a cosmic ray detector into outer space, you would see many, many more cosmic rays than here on the ground. That is because the atmosphere shields us from all cosmic rays except for the most energetic. Outside the atmosphere, however, there is no protection against these particles.



**Figure 1.** A Geiger counter. The detector in the left hand is connected by a wire to the counter on the right. The radioactive source in the small black box on the right is the mineral autunite, which contains radioactive uranium. If you were to move the detector far away from the autunite, the counter would be very close to zero (but not quite, because of cosmic rays). Don't worry; autunite, although radioactive, is not dangerous.

## Procedure:

### PRE-ACTIVITY QUESTIONS:

- Do you think any cosmic rays are going through your classroom right now? How can you tell?

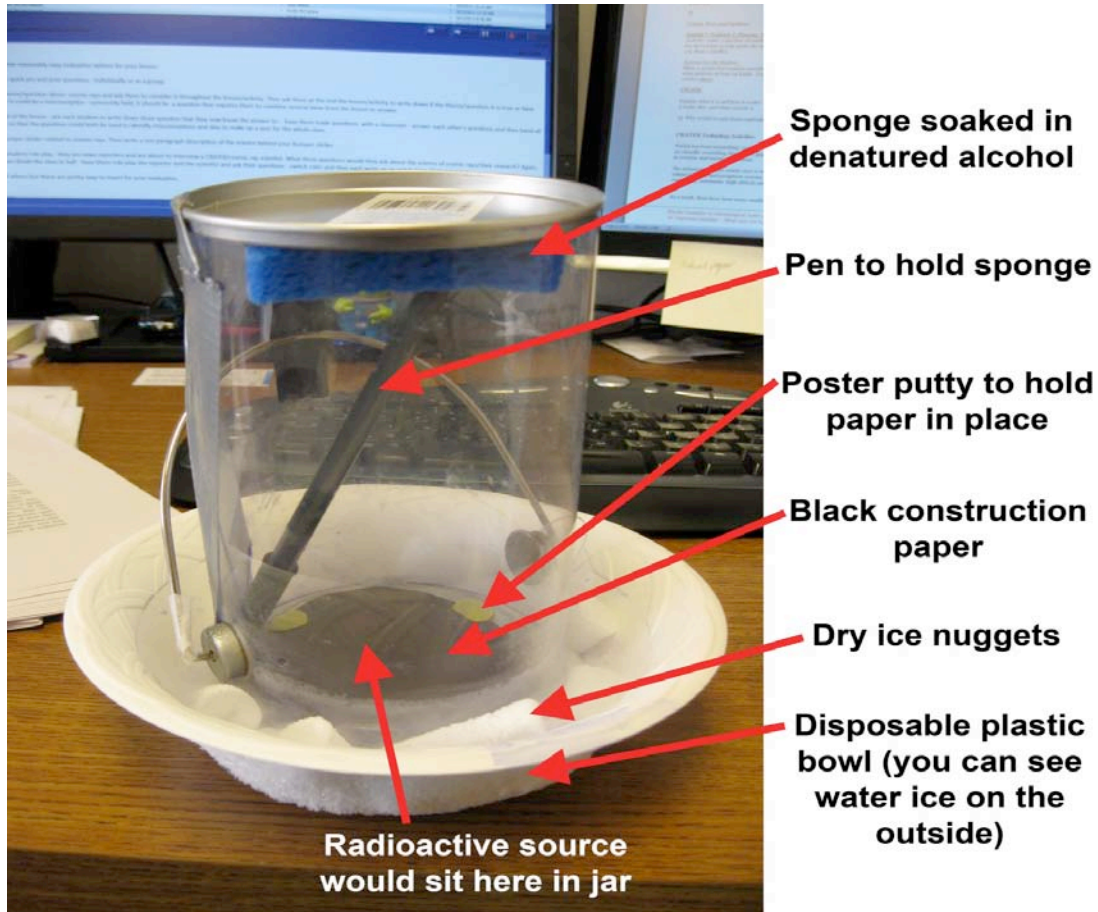
### MATERIALS:

- Very clear jar with a metal lid (using a transparent paint can from a craft store is helpful: about 6 inches tall and 4 inches in diameter)
- Denatured alcohol
- Black construction paper
- Sponge
- Pen or pencil (for propping the sponge)
- Flashlight (a small one with white LEDs works well)
- Dry ice, which you may be able to find this at an ice cream shop or grocery store (use gloves, such as oven mitts, when handling dry ice!)
- Optional: a small radioactive source that emits energetic helium nuclei (alpha particles), e.g. a lead-210 or polonium-210 needle source

## SETUP:

1. Before doing this experiment, you may want to watch a guided version of this activity done by Jefferson Lab ( [http://education.jlab.org/frost/cloud\\_chamber.html](http://education.jlab.org/frost/cloud_chamber.html) ). If you don't use a radioactive source, you won't see as many trails. The video, however, will give you an idea of what to look for.
2. Lay the black construction paper on the inside of the lid.
3. Thoroughly soak the sponge in the alcohol, and squeeze out just a bit of the excess.
4. Use the pen or pencil to jam (no looseness!) the sponge onto the bottom of the jar. This is important because you will be using the jar upside down.
5. Place the lid on. Make sure it seals completely. (If you use a radioactive source, it should sit on the lid.)
6. Turn the jar upside down. Make sure the pen or pencil is firmly in place; it will keep the sponge from falling. Also, make sure the construction paper stays on the lid.
7. Let the jar sit for between 5 and 10 minutes. This gives the alcohol vapor enough time to saturate the air inside the jar.
8. Place the jar, still upside down, on top of the dry ice. See **Figure 2** for examples of the following directions. Wait for no more than five minutes.
9. Darken the room.
10. Shine the flashlight perpendicularly to your eyes and near the jar's lid and watch carefully. You will see the fine mist of alcohol rain falling. As the air in the jar cools, the vaporized alcohol condenses and rains to the bottom. The dry ice cools the very lowest part of the jar (closest to the lid) so much the air becomes supersaturated with alcohol. Supersaturation means that the air contains more alcohol vapor than possible under normal circumstances. With patience and practice, you will see small contrails form near the lid every few seconds. A contrail looks like a miniature version of a jet contrail in the sky: a long, thin streak of cloud. Most people don't see the contrails until they know what they're looking for. It helps to focus on one spot on the lid. You may have to vary the angle between the light and your eyes to find the best angle.

EXAMPLE:



**Figure 2.** It's hard to imagine that this simple setup can detect such energetic and minute particles! (I put duct tape along a seam in the jar's side to improve air-tightness. This is optional.)

**FACILITATION QUESTIONS/ ANSWERS:**

*What is happening?* Alcohol vapor fills the jar. The lid sits on the dry ice. Therefore, the dry ice cools the air near the lid, allowing the air to become supersaturated with alcohol. The particles created by cosmic rays collide with and ionize the particles in the air. The newly formed ions are the seed particles onto which the alcohol can condense. Although subatomic particles are too small to see, the cloud chamber makes their effects visible.

The original cosmic rays don't cause the contrails you see. Primary cosmic rays do not make it all the way down to Earth's surface. They collide with molecules in the atmosphere. These collisions create secondary cosmic rays, which are other subatomic particles with less energy. These secondary cosmic rays can collide with other molecules and create even more secondaries, producing a cosmic ray air shower. Showers happen all the time, but they are invisible to your eyes. **Figure 3** (on next page) shows a computer simulation of an air shower. You can find air shower movies at:

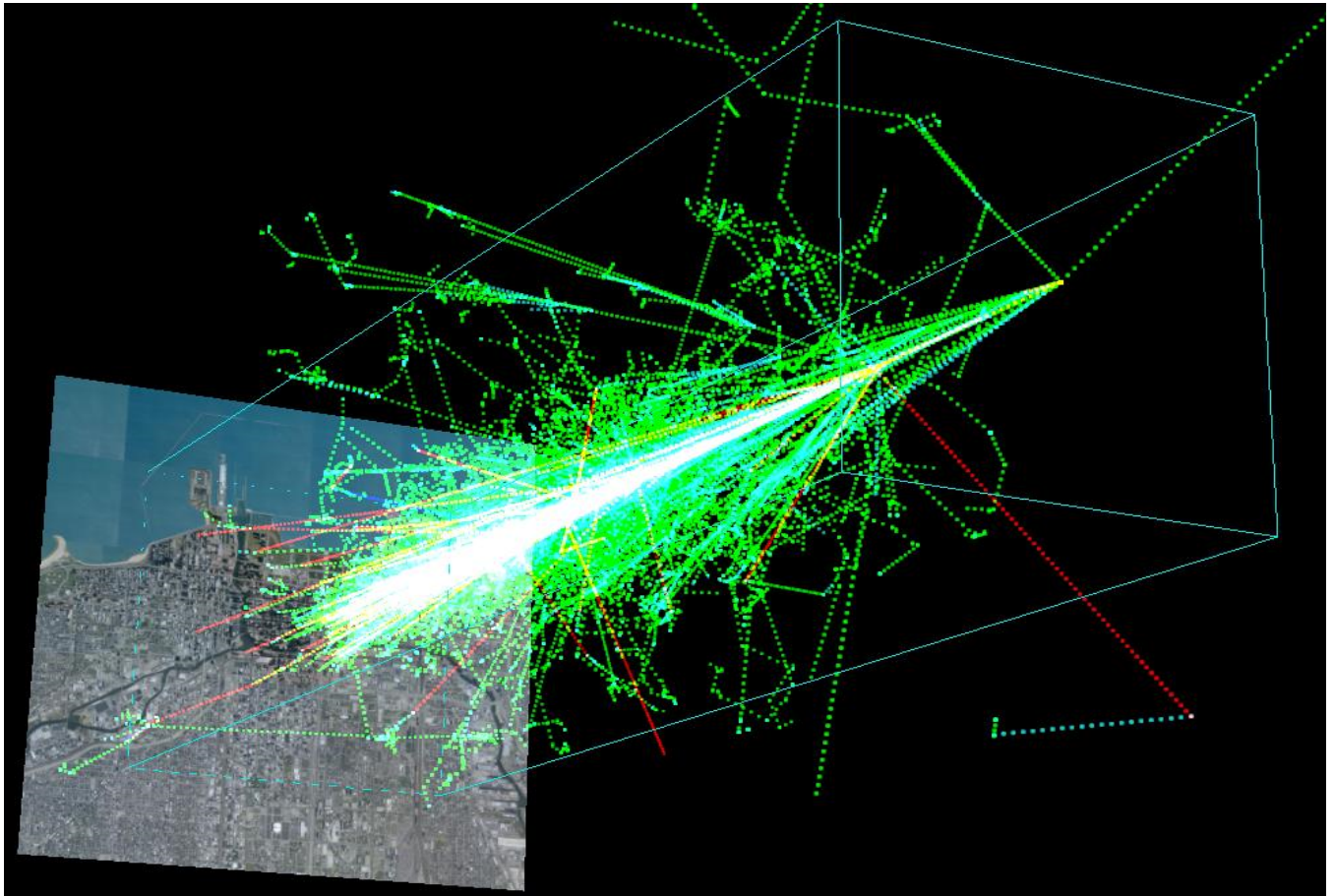
<http://astro.uchicago.edu/cosmus/projects/aires>.

Think about how far the cosmic rays might have traveled before hitting Earth's atmosphere and creating the tiny contrails you see. Some of them might have come from clear across the Milky Way galaxy! Some of their secondary cosmic rays (a little less than 100 each second) are even getting into your body or passing right through it. Thankfully, their effect is minimal.

## Optional Activity:

If dry ice is unavailable, you can construct an alternative cosmic ray detector using a digital camera able to keep its shutter open more than a minute. Cover the lens so no light penetrates the camera. Use the highest ISO (International Standards Organization) setting available; this makes the film as sensitive as possible to light. Then, set the exposure time for about 5 minutes. You should see small streaks in the resulting image. These are the tracks of secondary cosmic rays. Digital cameras have noise-reducing programming built into their computers, so some cosmic ray tracks may be erased. For further details, see Kendra Sibbersen's article, "Catching Cosmic Rays with a DSLR," in *Astronomy Education Review*, vol. 9, issue 1, 5 August 2010.

This cosmic ray "noise" is a big problem with highly sensitive digital cameras used for astronomy. Astronomers need to detect faint objects, so they must keep the shutter open for many minutes. The long exposure time, however, means that there will be many cosmic ray tracks in the image. The problem is worse for the Hubble Space Telescope because it is outside the atmosphere where there are more cosmic rays. Astronomers must take multiple images and then carefully subtract the cosmic ray tracks. See <http://blogs.zooniverse.org/galaxyzoo/2010/04/12/how-to-handle-hubble-images> for more information and images. (This website is part of Zooniverse, a scientific project in which the public can help classify galaxies.)



**Figure 3.** This figure from a computer model shows an extremely energetic proton (coming in from the upper right) creating an air shower. The path of the original proton is labeled. (Image courtesy Maximo Ave, Dinoj Surendran, Tokonatsu Yamamoto, Randy Landsberf, Mark SubbaRao, and Sergio Sciutto and his ARIES package.)

### **Note: Misconception**

Some people think space is completely empty, except for stars and planets. If you could use your cloud chamber in space, you would actually find that the space contains many particles (not to mention electromagnetic fields). It is important to remember, however, the "vacuum" of space is still more vacuous than anything achievable in a laboratory. The density is only a few particles per cubic centimeter!



## Assessment:

**Time:** 10-15 minutes

**Materials:** Pencil and paper

**Objective:** The student will use what they have learned to create concise descriptions of cosmic rays.

Create a bumper sticker about cosmic rays. Then, write one paragraph describing the science behind your bumper sticker.

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Resources:

#### Information about CRaTER and LRO

LRO site:

[www.lunar.gsfc.nasa.gov](http://www.lunar.gsfc.nasa.gov)

CRaTER's website:

[www.crater.unh.edu](http://www.crater.unh.edu)

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:

[www.nasa.gov/multimedia/nasatv/on\\_demand\\_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC\\_20090416\\_LRO\\_CRaTERvideo.aspx](http://www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.aspx)

#### General information about cosmic rays

*A Thin Cosmic Rain: Particles from Outer Space* (previously published as *Cosmic Rays*), Cambridge, MA: Harvard, 2000.

*Cosmicopia: An Abundance of Cosmic Rays* (a NASA Goddard website about cosmic rays):

[helios.gsfc.nasa.gov/cosmic.html](http://helios.gsfc.nasa.gov/cosmic.html)

Cosmic ray comic book:

[www.scostep.ucar.edu/comics/books](http://www.scostep.ucar.edu/comics/books), then click on the file labeled cosmicrays\_e.pdf.

Air shower movies generated from the ARIES (Air shower Extended Simulations):

<http://astro.uchicago.edu/cosmus/projects/aires>

#### Space Radiation

Space Radiation Analysis Group at Johnson Space Center:

<http://srag-nt.jsc.nasa.gov>

Eugene N. Parker, "Shielding Space Travelers," *Scientific American*, March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover*, June 2006.

Cosmic rays and cataracts:

[http://science.nasa.gov/science-news/science-at-nasa/2004/22oct\\_cataracts](http://science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts)

A NASA 6-12 educators guide to radiation math, with worksheets for students:

[www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation\\_Math.htm](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation_Math.htm)

## Glossary:

**ALFMED:** Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision

**ALTEA:** Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain

**Atom:** the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons

**Cosmic ray:** an ion or electron in space that travels at a speed similar to that of light

**CRaTER:** Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon

**Electroencephalograph:** an instrument that records the brain's electrical activity

**Electromagnetic radiation:** energy emitted in the form of electric and magnetic waves

**Electron:** a negatively charge subatomic particle; one of three particles to comprise atoms

**Electroscope:** a scientific tool used to store electric charge

**Emulsion:** a gel-like substance used to detect electromagnetic or particle radiation

**ISS:** International Space Station

**LRO:** Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment

**NASA:** National Aeronautics and Space Administration

**Nucleus:** the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons

**Particle radiation:** energy emitted in the form of subatomic particles

**Phosphor:** a material that, when stimulated, emits electromagnetic radiation

**Proton:** a positively charged subatomic particle; one of two particles to comprise atomic nuclei

**TEP:** tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue

**Radioactivity:** the condition of a substance to emit ionizing particle or electromagnetic radiation

# Lunar Reconnaissance Orbiter: (Diviner)

## Audience

Grades 9-10

## Time Recommended

1-2 hours

## AAAS STANDARDS

- 12A/H1: Exhibit traits such as curiosity, honesty, openness, and skepticism when making investigations, and value those traits in others.
- 12E/H4: Insist that the key assumptions and reasoning in any argument—whether one's own or that of others—be made explicit; analyze the arguments for flawed assumptions, flawed reasoning, or both; and be critical of the claims if any flaws in the argument are found.
- 4A/H3: Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- One set of handouts per group, consisting of:
  - » Student Guide
  - » Four individual worksheets:
    - » Thermal Analyst worksheet
    - » Hydrologist worksheet
    - » Communications Technician worksheet
    - » Energy Technician worksheet
- Four color laminates (one corresponding to each role/ worksheet):
  - » Diviner temperature map
  - » LEND neutron map
  - » Earth visibility map
  - » Sun visibility map
- Calculators
- Pens
- Whiteboard/flip chart for recording student responses

# Planning a Mission to the Lunar South Pole

## Learning Objectives:

- Learn about recent discoveries in lunar science.
- Deduce information from various sources of scientific data.
- Use critical thinking to compare and evaluate different datasets.
- Participate in team-based decision-making.
- Use logical arguments and supporting information to justify decisions.

## Preparation:

See teacher procedure for any details.

## Background Information:

The Moon's surface thermal environment is among the most extreme of any planetary body in the solar system. With no atmosphere to store heat or filter the Sun's radiation, midday temperatures on the Moon's surface can reach 127°C (hotter than boiling water) whereas at night they can fall as low as -173°C, which is almost as cold as liquid oxygen.

In addition, there are places in the lunar-polar regions where temperatures as low as -248°C have been measured— these are the coldest places observed to date within our entire solar system!

The primary reason for the extremely low temperatures measured at the lunar poles is due to the Moon's axial tilt of only 1.5°, compared to 23.5° on Earth. This means that at the lunar poles the Sun is constantly low on the horizon, thus the insides of polar impact craters receive no direct energy from the Sun. They are what have become known as '**permanently-shadowed regions.**'

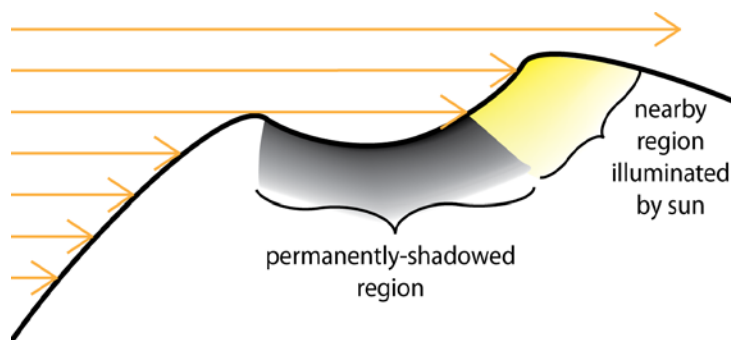


Figure 1. Diagram of a permanently-shadowed region within a crater at the lunar pole (not to scale).

## TIP:

Using a bowl and a desk lamp is a simple way to demonstrate the concept of permanently-shadowed regions.

## THE KELVIN TEMPERATURE SCALE:

When describing extremely cold temperatures such as those observed on the Moon, scientists use the Kelvin (K) unit of measurement. Unlike the Celsius or Fahrenheit temperature scales, there are no negative values of Kelvin. This is because 0K corresponds to “absolute zero”— the coldest possible temperature at which point an object’s molecules would cease to vibrate and therefore no longer produce any heat.

One Kelvin is equivalent in magnitude to one degree Celsius (°C). This means that intervals in the two scales are equally spaced, for example, the melting and boiling points of water, which are 273K (0°C) and 373K (100°C) respectively. This is not the case with the Fahrenheit scale (32°F and 212°F).

## KEY POINTS:

- Kelvin is a unit of temperature used by scientists.
- It contains only positive values.
- 0 Kelvin—“Absolute Zero”—is the lowest temperature possible.

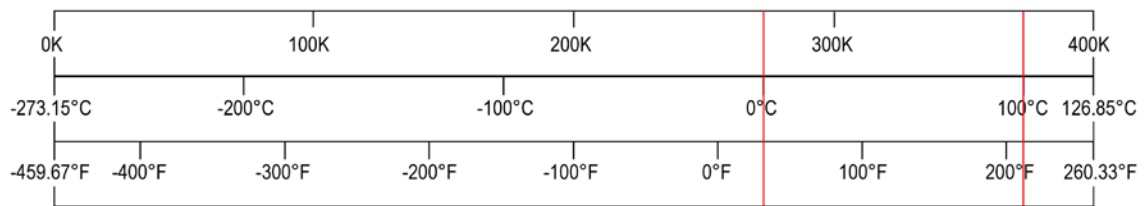


Figure 2. Temperature scales: Kelvin (top), Celsius (middle) and Fahrenheit (bottom). Red lines represent melting and boiling points of water.

The relationship between Kelvin and Celsius can be expressed as the following mathematical equation:

$$K = ^\circ C + 273$$

## PERMANENTLY-SHADOWED REGIONS AND ICE:

Due to the extremely low temperatures inside permanently-shadowed regions, scientists have long theorized that these locations could act as ‘cold traps’— places where water and other compounds become frozen within the soil, accumulating over billions of years.

However it wasn’t until 2009, when the Lunar Crater Observation and Sensing Satellite (LCROSS) was deliberately crashed into the floor of Cabeus crater near the Moon’s south pole, that scientist’s theories were finally proven - the material excavated as a result of that impact was found to contain around 5% water!

It’s still too early to know for certain where the ice stored in these polar cold traps comes from or how it got there, but scientists predict that it was most likely delivered to the Moon during impacts from water-bearing comets, asteroids and meteoroids.

## KEY POINTS:

- Permanently-shadowed regions on the Moon are cold enough to store water and other ices.
- Lunar ice most likely derives from comet and asteroid impacts.



Figure 3. LCROSS

## THERE ARE CURRENTLY TWO INSTRUMENTS INVOLVED IN INVESTIGATING LUNAR COLD-TRAPS:

### The Diviner Lunar Radiometer:



Figure 4. The Diviner Lunar Radiometer

The Diviner Lunar Radiometer is one of seven instruments aboard NASA's Lunar Reconnaissance Orbiter (LRO), which has been orbiting the Moon since June 2009. It is the first instrument to measure the entire range of temperatures experienced on the Moon's surface.

#### KEY POINTS:

- Diviner measures infrared and visible radiation.
- These observations tell scientists how warm the lunar surface is and how much light it receives.

#### How it works:

When solar radiation hits the Moon, some of it is reflected back out to space, while some is absorbed and re-emitted as infrared radiation. Diviner measures the amount of emitted infrared and reflected visible radiation. From these measurements, scientists are able to determine the temperature of the Moon's surface along with other information such as the amount of illumination the surface receives.

### The Lunar Exploration Neutron Detector:

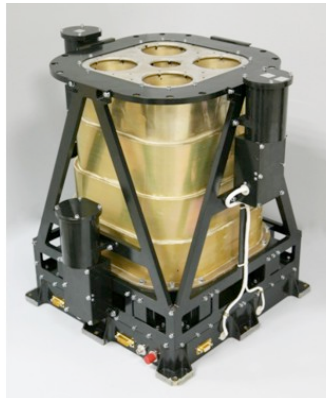


Figure 5. The Lunar Exploration Neutron Detector (LEND)

The Lunar Exploration Neutron Detector (LEND) is another instrument aboard LRO. It measures the amount of neutrons coming off of the Moon's surface, which can be used to infer the presence of water.

#### How it works:

When cosmic rays (fast moving subatomic particles originating from outer space) bombard the surface of the Moon, they collide with atoms in the lunar soil. The collisions break down the atoms and send high-energy neutrons flying out into space.

#### KEY POINTS:

- Diviner measures infrared and visible radiation.
- These observations tell scientists how warm the lunar surface is and how much light it receives.

The path of these high-energy or 'epithermal' neutrons is obstructed by the atoms of other elements present within the soil. Hydrogen, similar in size, is particularly effective at slowing down and absorbing them. The number of epithermal neutrons can therefore be used as an indicator of the concentration of hydrogen beneath the lunar surface, and as hydrogen is a key component of water, this can help determine the likelihood that water ice is present. The lower the epithermal neutron count, the higher the concentration of hydrogen and the greater chance there is of finding ice beneath the surface.

## WHY BUILD A LUNAR OUTPOST?

For years, humans have envisioned one day building an outpost on the Moon. With the recent discovery of ice at the lunar poles, the prospect has become more of a reality.

### We know what to expect:

The Moon is our closest neighbor. Back in the 1960s, it only took three days for the Apollo astronauts to make the trip there, and there's a good chance we can improve on this time with future technology. In addition, the communication delay between Earth and the Moon is less than 1.5 seconds, allowing for almost instantaneous audio and visual contact.

### Learning about the Moon will help us understand the evolution of Earth...

Early in its history, the Earth was impacted by a Mars-sized object, which resulted in a huge amount of debris being blown into space. Some of the debris remained in orbit around Earth, eventually coalescing to form our Moon. The Moon is the only planetary body in our solar system that shares the same origins as Earth, and therefore an ideal place to look for answers to questions such as “Where do our oceans come from?”

### ...and the Solar System:

The Moon doesn't have an atmosphere or oceans, and it's not subject to any of the geologic processes that continuously modify the Earth's surface. As a result, the Moon's surface is a near perfect record of what was going on in the early solar system, including the mysterious 'Late Heavy Bombardment' – a period around 3.9 billion years ago during which an unusually large number of impacts appear to have occurred on the Earth, Moon and other rocky planets.

### It will give us good practice:

Our Moon will be the first 'off planet' destination where mankind will learn to live and work on other planets and it will be the dress rehearsal for manned missions to Mars. Building a lunar outpost will not only provide us with most of the skills and knowledge required to build a base on another planet, it could also act as a physical stepping-stone. With a gravitational field only 1/6th of Earth's, the Moon is an ideal base for launching rockets out into the solar system and beyond.

## Teacher Procedure:

1. Divide students into groups; there are four roles per group, however, teachers may divide the class into smaller or larger groups depending on class size and time constraints. The roles are Thermal Analyst, Hydrologist, Communications Technician and Energy Technician.
2. Pose the question: “If humans were to build an outpost on another planet, what are the essentials that we would need?” Allow students to discuss the question within their groups have each group volunteer an agreed upon answer. Record student answers on a whiteboard or flip chart.
3. Ask students which answers they think are the most important and circle, highlight or otherwise indicate these answers in the list.
4. Review background material. Discuss with the class as a whole prior the main activity.
5. Distribute one set of handouts per group: see Supplemental Images/ Materials/ Resources section.
6. Ask one student from each group to read the student guide to the rest of the group.

### PREP QUESTIONS:

7. Before starting the student guide, ask students to look at the Earth Visibility Map (located in the worksheets section). Explain that this map shows the number of Earth days each year the Earth is visible above the local horizon, which is a requirement for direct line of sight communication.

Ask the following ►

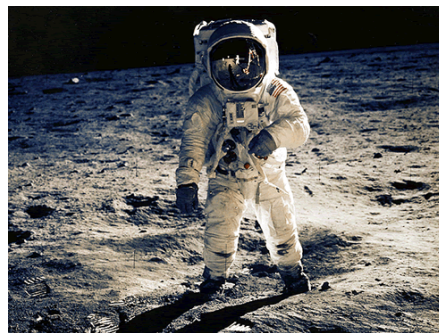


Figure 6. Astronaut Buzz Aldrin on the lunar surface during the Apollo 11 mission, 1969.

## COMPREHENSION QUESTIONS:

### Q. What do you notice about the pattern of earth visibility?

*Earth visibility increases towards the top half of the map and towards the lower half there is a communication shadow.*

### Q. What is the reason for this pattern?

*The top half of the map represents the nearside of the Moon, which is the side always facing Earth. Locations on the farside always face away from Earth and are obstructed from view by the curvature of the Moon's surface.*

8. Ask students to look at the Sun Visibility Map. Explain that the map shows the number of Earth days each year that the Sun is visible in it's entirety above the local horizon.

Ask the following ➤

9. Ask the class to compare the Sun visibility map and temperature map, which shows model-calculated yearly average surface temperatures from Diviner temperature measurements.

Ask the following ➤

10. Lastly, ask students to examine the LEND neutron map. Explain that the map shows measurements of epithermal neutrons from the uppermost half meter of lunar soil.

Ask the following ➤

11. If necessary, before starting the activity, review the information in the student guide.
12. Instruct students that at the end of the 30 minute exercise, each group will give a presentation to the rest of the class so that everyone can compare results.
13. Start student activity.

### COMPREHENSION QUESTIONS:

- Q. The scale at the top of the map only goes up to 182.5 days (half a year). Why is that?**

*The sun is only up for half of the day.*

- Q. What color are the permanently-shadowed regions?**

*Gray – 0 days Sun visibility.*

### COMPREHENSION QUESTIONS:

- Q. How do temperatures correlate with illumination?**

*Temperature is strongly correlated with illumination.*

- Q. Is this the same on Earth? Why or why not?**

*Temperature is not so strongly correlated with illumination on Earth because the Earth has an atmosphere, which redistributes heat.*

### COMPREHENSION QUESTIONS:

- Q. What happens to the epithermal neutron count as more frozen water is present in the soil?**

*It decreases.*

- Q. Why is this?**

*Each molecule of frozen water is composed of two hydrogen atoms and one oxygen atom. Hydrogen slows down high-energy 'epithermal' neutrons leading to a low count of these type of neutrons.*



## STUDENT GUIDE

# Planning a Mission to the Lunar South Pole

## Objective

Your goal is to work as a team to determine the best location for a future lunar outpost. You will analyze scientific data and models of the Moon's south polar region to determine the potential habitability of sites, based on four environmental factors: temperature, access to water, potential for solar energy, and for communications.

Seven potential locations, each with advantages and disadvantages, have been pre-selected based on the fact they represent a range of different environments. It will be your job to evaluate which environmental factors are the most important and therefore which location is the most suitable for a lunar base.

### KEY POINTS:

- There are no right or wrong answers.
- All decisions should be justified with supporting evidence.

## Plan of Action

1. Form a group of four. Divide the group into the following roles and distribute worksheets and datasets accordingly, based on the role given:

| Role:                     | Analyzes:                | To determine:                |
|---------------------------|--------------------------|------------------------------|
| Thermal Analyst           | Diviner Temperature Data | Temperature                  |
| Hydrologist               | LEND Neutron Data        | Access to water              |
| Communications Technician | Earth Visibility Model   | Potential for communications |
| Energy Technician         | Sun Visibility Model     | Potential for solar energy   |

2. Complete the worksheets individually, following the instructions provided with each one.
3. When everyone has completed their worksheet, transfer the individual scores for each location onto the group worksheet.
4. Discuss your observations as a group and come to a decision about the relative importance of the four environmental factors.
5. Rank them accordingly and calculate final scores using the method described on the next page.
6. Grade the sites based on their scores.
7. Prepare a brief, 5 minute presentation for the rest of the class. You will need to cover the following points:
  - a. The location that you deem most suitable for a lunar base;
  - b. The grade you gave each of the datasets and why;
  - c. If you ruled out any sites and why;
  - d. The drawbacks of your chosen location, and how these might be overcome;
  - e. What additional data/ information would have been helpful in coming to a decision.





## How to Weigh Factors

If you decide that each of the four environmental factors is equally important, the final score for each location can be determined by the following equation:

$$X = T + W + I + C$$

Where: X = final score, T = score for temperature, W = score for water supply, I = score for illumination, and C = score for communication.

**This equation is only valid if you deem that all factors are equally important.** If you decide that some factors are more important than others, you should adjust the above equation by multiplying each score by a fraction.

For example, if you decide that temperature is the most important factor, communication is the least important, and water and illumination are equally important, the following weighting might therefore apply:

| Factor        | Weight   |
|---------------|----------|
| Temperature   | 0.5      |
| Water         | 0.2      |
| Illumination  | 0.2      |
| Communication | 0.1      |
| <b>Total</b>  | <b>1</b> |

\*Note: the sum of all the weights must equal 1.

The formula would now read:  $x = (0.5)T + (0.2)W + (0.2)I + (0.1)C$



# GROUP WORKSHEET

Names \_\_\_\_\_

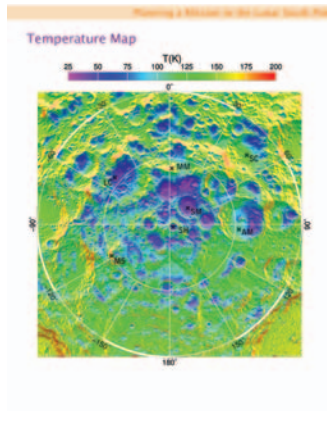
\_\_\_\_\_

\_\_\_\_\_

| Site               | Temperature |        |                | Water |        |                | Illumination |        |                | Communication |        |                | Total Score | Rank |
|--------------------|-------------|--------|----------------|-------|--------|----------------|--------------|--------|----------------|---------------|--------|----------------|-------------|------|
|                    | Score       | Weight | Weighted Score | Score | Weight | Weighted Score | Score        | Weight | Weighted Score | Score         | Weight | Weighted Score |             |      |
| Amundsen Crater    |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| LCROSS Impact Site |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| Malapert Mountain  |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| M5                 |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| Scott Crater       |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| Shackleton Crater  |             |        |                |       |        |                |              |        |                |               |        |                |             |      |
| Shoemaker Crater   |             |        |                |       |        |                |              |        |                |               |        |                |             |      |

# THERMAL ANALYST WORKSHEET

## Planning a Mission to the Lunar South Pole



|    |                    |
|----|--------------------|
| AM | Amundsen Crater    |
| LC | LCROSS impact site |
| MM | Malapert Mountain  |
| M5 | M5                 |
| SC | Scott Crater       |
| SH | Shackleton Crater  |
| SM | Shoemaker Crater   |

Table 1. Location Key

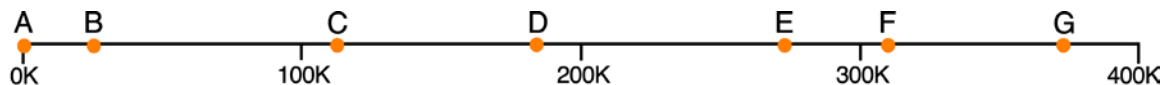
### TEMPERATURE MAP

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to  $-85^\circ$  latitude and the outer circle corresponds to  $-80^\circ$  latitude. The map shows the model-calculated yearly average surface temperatures for the lunar south polar region. The temperatures were calculated using data from the Diviner Lunar Radiometer.

### Keeping Warm on the Moon

With modern technology, we are able to substantially regulate our thermal environment. Spacesuits have been designed to withstand temperatures much lower than those on Earth, and a well-insulated, underground shelter could make even the harshest climates livable. However, extremely low temperatures can pose a risk to mechanical equipment.

Here are some key temperatures in the Kelvin scale (remember:  $K = ^\circ C + 273$ ):



- A** (0K) = Absolute Zero
- B** (25K) = Coldest temperature measured on the Moon (Hermite Crater, North Pole)
- C** (113K) = Coldest temperature spacesuits are capable of withstanding
- D** (184K) = Coldest temperature measured on Earth (Antarctica)
- E** (273K) = Melting point of water on Earth
- F** (310K) = Average human body temperature
- G** (373K) = Boiling point of water on Earth



## Worksheet Instructions

1. Measure and record the temperature at each of the seven locations.
2. Using the information on the group worksheet, and what you learned at the beginning of the lesson, decide:
  - a. How you are going to order the sites in terms of suitability and;
  - b. If there are any conditions the sites have to meet in order to be considered.
3. Eliminate sites which do not meet any conditions you deem essential.
4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a given score. If two or more sites are tied, give them each the same score.
5. Answer the questions.



**Names** \_\_\_\_\_

\_\_\_\_\_

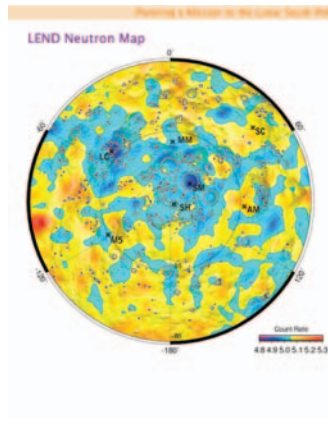
\_\_\_\_\_

| Site               | Temperature (K) | Score |
|--------------------|-----------------|-------|
| Amundsen Crater    |                 |       |
| LCROSS Impact Site |                 |       |
| Malapert Mountain  |                 |       |
| M5                 |                 |       |
| Scott Crater       |                 |       |
| Shackleton Crater  |                 |       |
| Shoemaker Crater   |                 |       |

1. Explain your reasoning behind scoring the sites in the way that you have.
2. Based on your criteria, are any of the locations unsuitable? If so, why?
3. Describe how you think the Diviner data should be weighted in relation to the three other datasets and why.

## HYDROLOGIST WORKSHEET

## Planning a Mission to the Lunar South Pole



|    |                    |
|----|--------------------|
| AM | Amundsen Crater    |
| LC | LCROSS impact site |
| MM | Malapert Mountain  |
| M5 | M5                 |
| SC | Scott Crater       |
| SH | Shackleton Crater  |
| SM | Shoemaker Crater   |

Table 2. Location Key

## LEND NEUTRON MAP

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to  $-85^\circ$  latitude and the outer circle corresponds to  $-80^\circ$  latitude. The “count rate” located on the key is the number of epithermal (high energy) neutrons emitted from the uppermost 0.5m of lunar soil, as measured by the Lunar Exploration Neutron Detector. Locations outlined in black indicate permanently-shadowed regions.

## Water on the Moon

The human body needs water to stay alive, without it we would only survive for a few days. We also need it for growing food, cooking and bathing. It would be prohibitively expensive to transport all the water required from Earth, so it is imperative that a future lunar outpost has access to a clean water supply.

## Worksheet Instructions

1. Measure and record the count rate at each of the seven locations (remember that the presence of water would result in a low count rate).
2. Using the information above, and what you learned at the beginning of the lesson, decide:
  - a. How you are going to order the sites in terms of suitability and;
  - b. If there are any conditions that the sites have to meet in order to be considered.
3. Eliminate sites which do not meet any conditions you deem essential.
4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a score. If two or more sites are tied, give them each the same score.
5. Answer the questions.



**Names** \_\_\_\_\_

\_\_\_\_\_

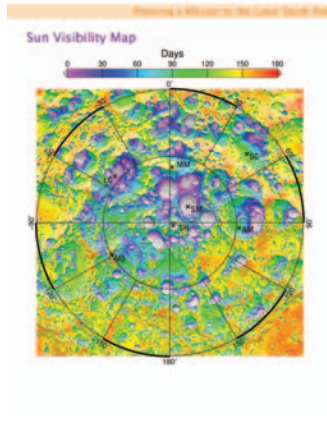
\_\_\_\_\_

| Site               | Neutron Count | Score |
|--------------------|---------------|-------|
| Amundsen Crater    |               |       |
| LCROSS Impact Site |               |       |
| Malapert Mountain  |               |       |
| M5                 |               |       |
| Scott Crater       |               |       |
| Shackleton Crater  |               |       |
| Shoemaker Crater   |               |       |

1. Explain your reasoning behind scoring the sites in the way that you have.
2. Based on your criteria, are any of the locations unsuitable? If so, why?
3. Describe how you think the LEND data should be weighted in relation to the three other datasets and why.

# ENERGY TECHNICIAN WORKSHEET

## Planning a Mission to the Lunar South Pole



|    |                    |
|----|--------------------|
| AM | Amundsen Crater    |
| LC | LCROSS impact site |
| MM | Malapert Mountain  |
| M5 | M5                 |
| SC | Scott Crater       |
| SH | Shackleton Crater  |
| SM | Shoemaker Crater   |

**Table 3. Location Key**

### SUN VISIBILITY MAP

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to  $-85^\circ$  latitude, and the outer circle corresponds to  $-80^\circ$  latitude. The map shows the number of Earth days each year the Sun is visible in its entirety above the local horizon.

## Generating Power on the Moon

Everything that runs on electricity requires a power supply; this includes lighting, vehicles, communications equipment, air pressurization units (machinery used to create a breathable atmosphere inside a structure), and hydroponic equipment (used for growing crops under artificial conditions). Thus, solar energy is the most viable power source for a lunar outpost.

## Worksheet Instructions

1. Measure and record the number of days of Sun visibility at each of the seven locations.
2. Using the information above, and what you learned at the beginning of the lesson, decide:
  - a. How you are going to order the sites in terms of suitability and;
  - b. If there are any conditions that the sites have to meet in order to be considered.
3. Eliminate sites which do not meet any conditions you deem essential.
4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a score. If two or more sites are tied, give them each the same score.
5. Answer the questions.





**Names** \_\_\_\_\_

\_\_\_\_\_

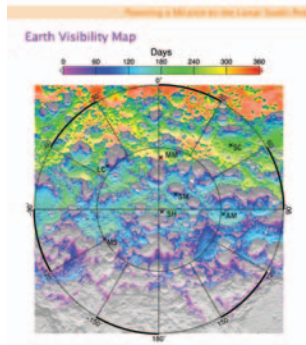
\_\_\_\_\_

| Site               | Sun Visibility (days/yr) | Score |
|--------------------|--------------------------|-------|
| Amundsen Crater    |                          |       |
| LCROSS Impact Site |                          |       |
| Malapert Mountain  |                          |       |
| M5                 |                          |       |
| Scott Crater       |                          |       |
| Shackleton Crater  |                          |       |
| Shoemaker Crater   |                          |       |

1. Explain your reasoning behind scoring the sites in the way that you have.
2. Based on your criteria, are any of the locations unsuitable? If so, why?
3. Describe how you think the Sun visibility model should be weighted in relation to the three other datasets and why.

# COMMUNICATIONS TECHNICIAN WORKSHEET

## Planning a Mission to the Lunar South Pole



|    |                    |
|----|--------------------|
| AM | Amundsen Crater    |
| LC | LCROSS impact site |
| MM | Malapert Mountain  |
| M5 | M5                 |
| SC | Scott Crater       |
| SH | Shackleton Crater  |
| SM | Shoemaker Crater   |

**Table 4. Location Key**

### EARTH VISIBILITY MAP

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to  $-85^\circ$  latitude, and the outer circle corresponds to  $-80^\circ$  latitude. The map shows the number of Earth days each year the Earth is visible above the local horizon, which is a requirement for line-of-sight communication.

## Communicating from the Moon

In order for a lunar outpost to coordinate back and forth transportation of goods and people, and to be able to request help or supplies in the case of an emergency, it would need a means of communicating with Earth. The simplest way to do this – “line-of-sight” communication – requires an unobstructed path between a radio transmitter on the Moon and a receiver on Earth.

## Worksheet Instructions

1. Measure and record the number of days of earth visibility at each of the seven locations.
2. Using the information above, and what you learned at the beginning of the lesson, decide:
  - a. How you are going to order the sites in terms of suitability, and
  - b. If there are any conditions that the sites have to meet in order to be considered.
3. Eliminate sites that do not meet any conditions that you deem essential.
4. Score the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable and so on until each of the sites has a score. If two or more sites are tied, give them each the same score.
5. Answer the questions.



**Names** \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

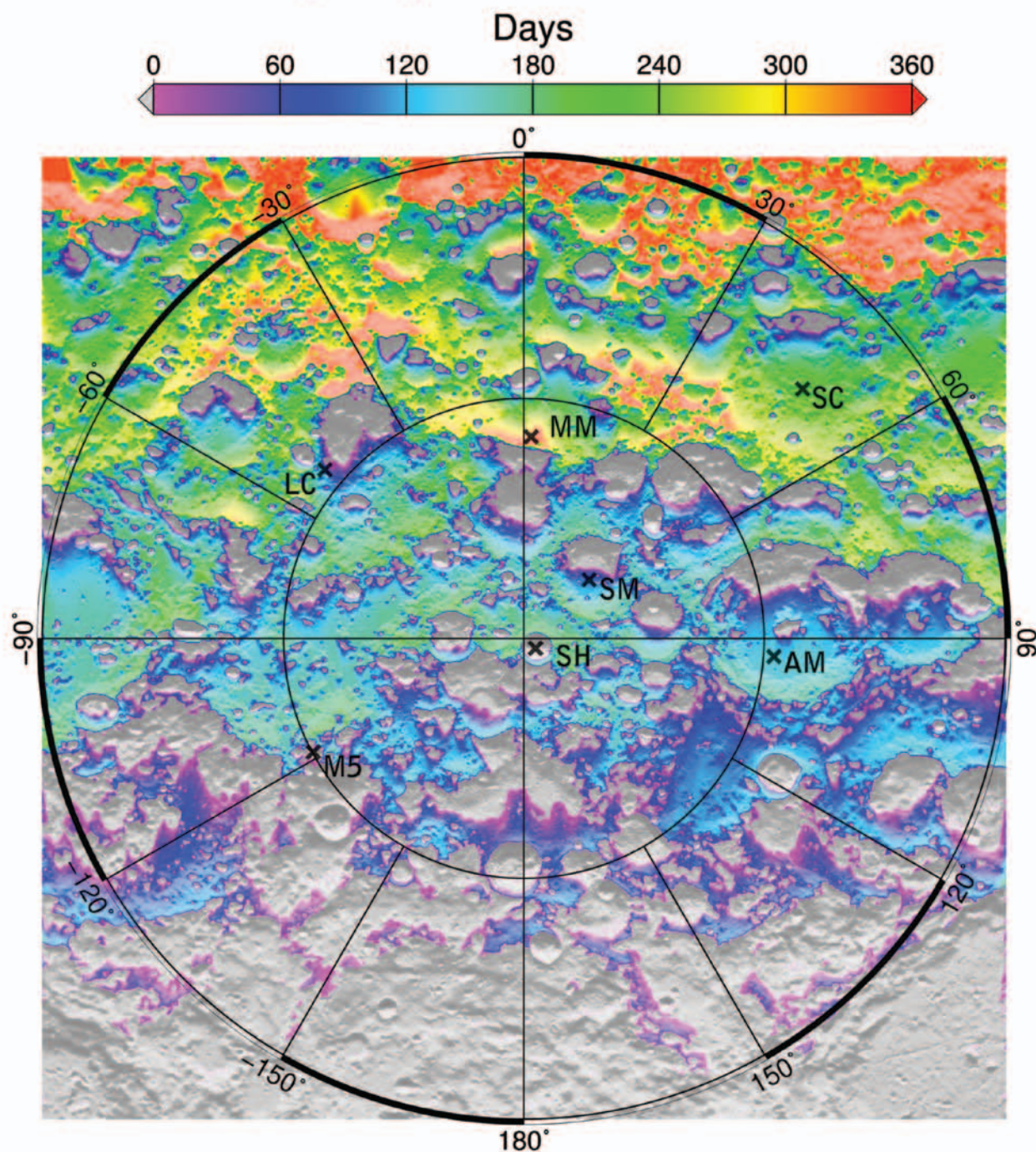
| Site               | Earth Visibility (days/yr)t | Score |
|--------------------|-----------------------------|-------|
| Amundsen Crater    |                             |       |
| LCROSS Impact Site |                             |       |
| Malapert Mountain  |                             |       |
| M5                 |                             |       |
| Scott Crater       |                             |       |
| Shackleton Crater  |                             |       |
| Shoemaker Crater   |                             |       |

1. Explain your reasoning behind scoring the sites in the way that you have.

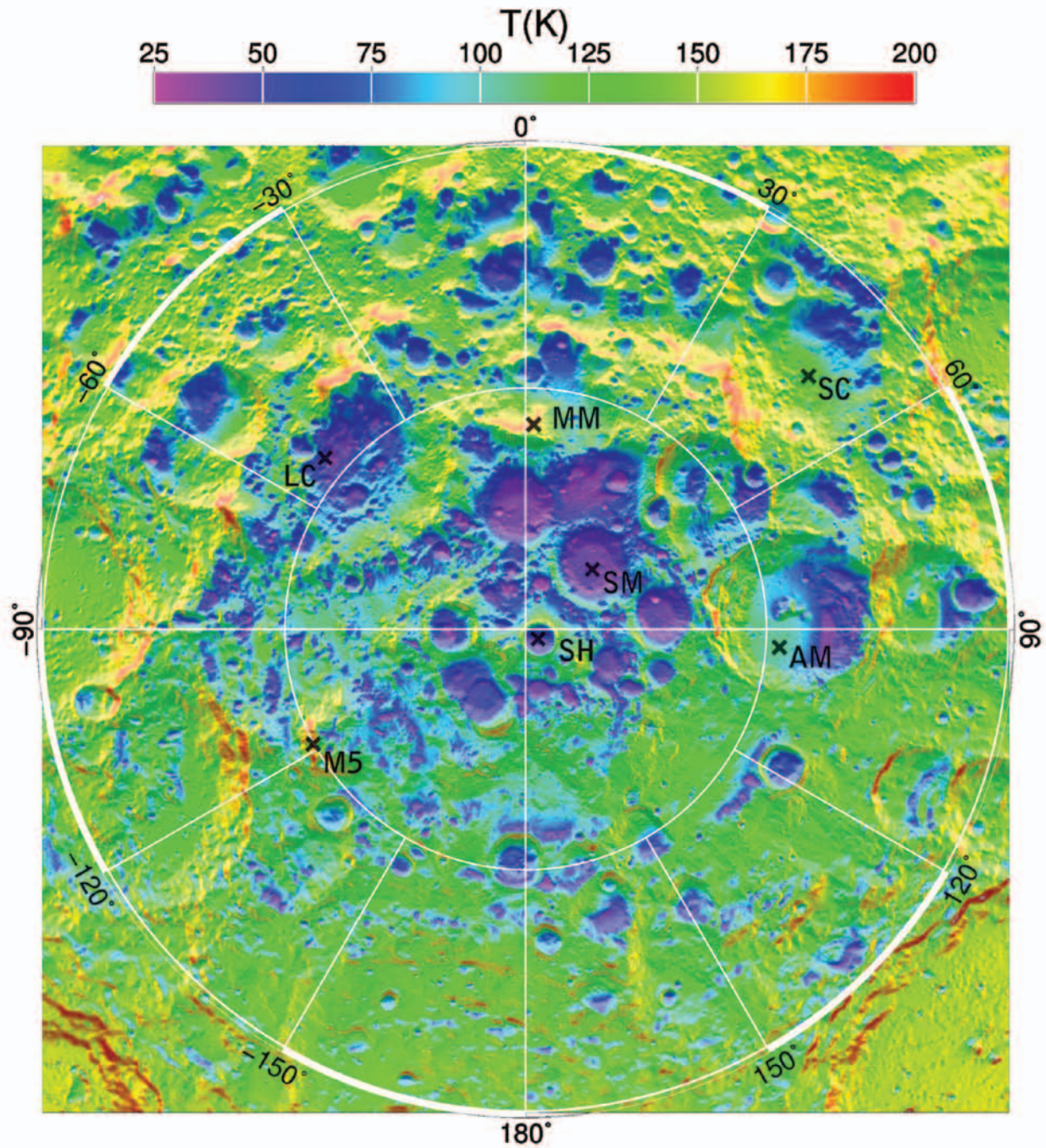
2. Based on your criteria, are any of the locations unsuitable? If so, why?

3. Describe how you think the Earth visibility model should be weighted in relation to the three other datasets and why.

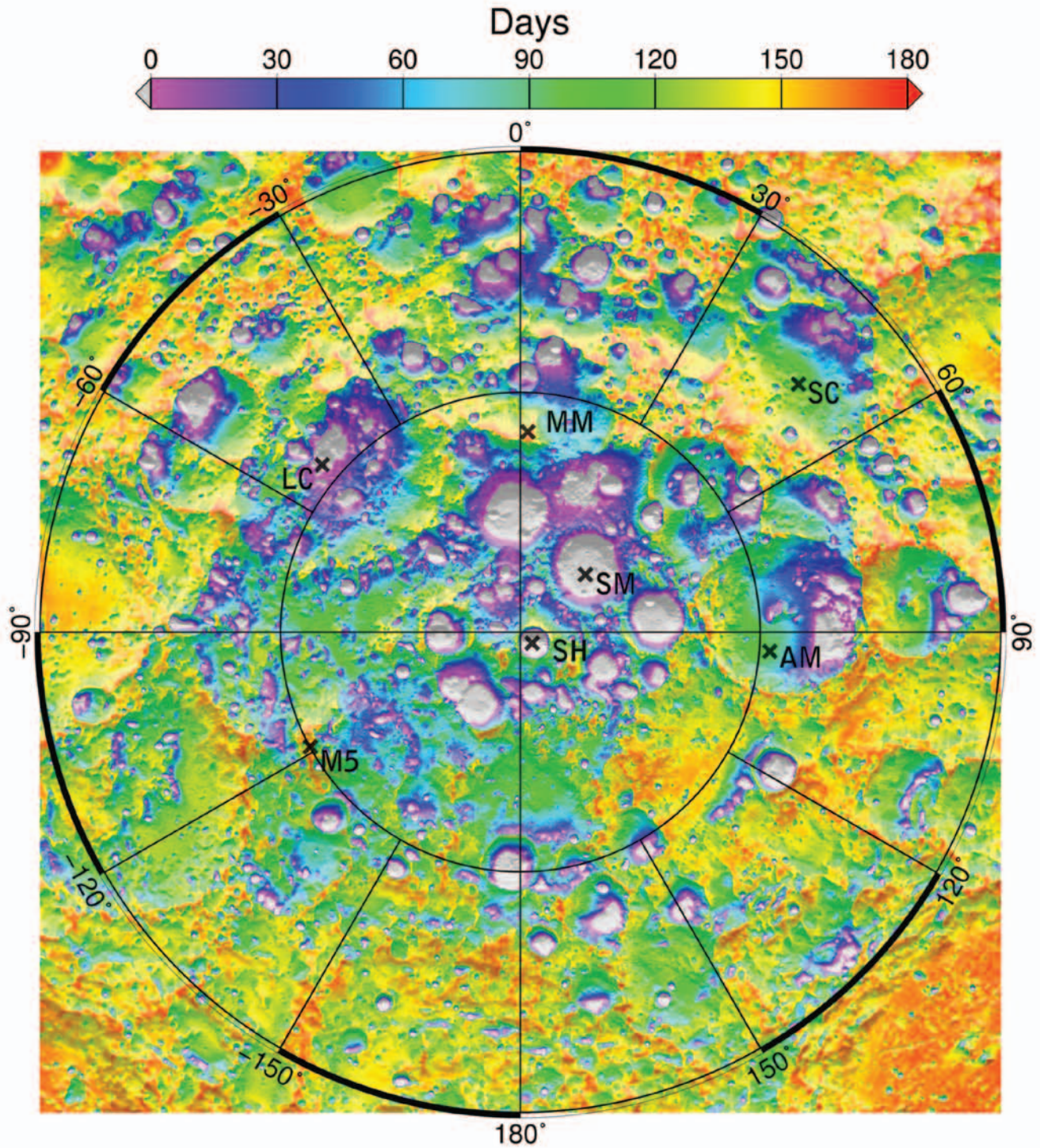
## Earth Visibility Map



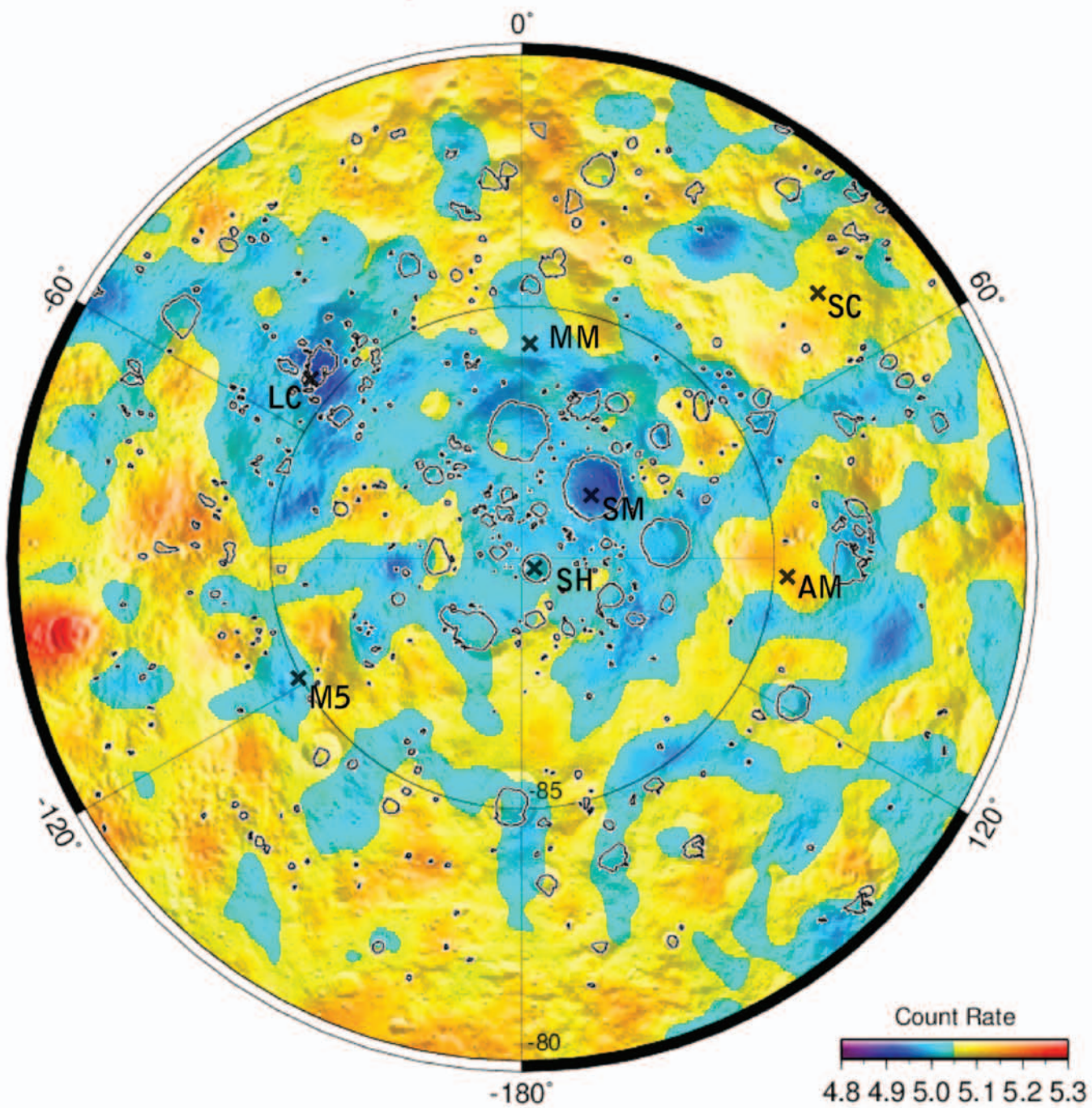
## Temperature Map



## Sun Visibility Map



## LEND Neutron Map



# TEACHER PROCEDURES

## Assessment:

Use the chart below and the answer sheet on the next page to record student levels of achievement for each of the tasks in the group activity. The chart uses a scale of 5-1, with 5 representing the highest level of achievement and 1 representing the lowest. Score students for each task, and total up the scores for the entire activity. The corresponding letter grades are as follows:

**A:** 60 and above

**B:** 45-59

**C:** 30-44

**D:** 15-29

**F:** Below 15

| Student Product              | Indicator of Achievement  | 5 | 4 | 3 | 2 | 1 |
|------------------------------|---|---|---|---|---|---|
| <b>Individual Worksheets</b> |   |   |   |   |   |   |
| Table                        | I. Table is complete  |   |   |   |   |   |
|                              | II. Readings are accurate   |   |   |   |   |   |
|                              | III. Student has ranked locations in a logical order  |   |   |   |   |   |
| Questions                    | I. All questions have been answered   |   |   |   |   |   |
|                              | II. Student uses complete sentences   |   |   |   |   |   |
|                              | III. Student provides detailed explanations to back up their decisions  |   |   |   |   |   |
|                              | IV. Student uses information provided in this activity to justify their decisions   |   |   |   |   |   |
|                              | V. Student draws on outside information to justify their decisions  |   |   |   |   |   |
| <b>Group Worksheets</b>      | I. Table is complete.   |   |   |   |   |   |
|                              | II. Group has weighted factors correctly - weighting reflects relative importance as described in presentation, calculations are free of errors |   |   |   |   |   |
| <b>Group Presentations</b>   | I. Student participates in presentation   |   |   |   |   |   |
|                              | II. Group provides detailed explanations for its decisions  |   |   |   |   |   |
|                              | III. Group uses information provided in the background to justify its decisions   |   |   |   |   |   |
|                              | IV. Group draws on outside information to justify its decisions   |   |   |   |   |   |
|                              | V. Group uses logical arguments   |   |   |   |   |   |



Teacher Answer Sheet:

| Site              | Thermal Analyst<br>Temperature (+/-10K)   | Hydrologist<br>Neutron Count (+/-0.05)  | Communications Tech.<br>Earth Visibility (+/-20 days)   | Energy Technician<br>Sun Visibility (+/-10 days)   |
|-------------------|---|---|---|--|
| AM                | 100K  | 5.1   | 140   | 100  |
| LC                | 35K   | 4.95  | 70  | 0  |
| MM                | 175K  | 5.02  | 320   | 150  |
| M5                | 180K  | 5.03  | 0   | 170  |
| SC                | 125K  | 5.1   | 210   | 100  |
| SH                | 40K   | 5.02  | 0   | 0  |
| SM                | 40K   | 4.95  | 70  | 0  |
| <b>Question 1</b> | <ul style="list-style-type: none"> <li>• Scores locations from high to low temperature.</li> <li>• Recognizes that even warmest locations are colder than the coldest temperatures measured on Earth.</li> <li>• Acknowledges limitations of spacesuits and equipment.</li> </ul> | <ul style="list-style-type: none"> <li>• Scores locations from low to high neutron count.</li> <li>• Recognizes water content (hydrogen) is inversely correlated with neutron count.</li> <li>• Acknowledges limitations of transporting water from Earth.</li> </ul> | <ul style="list-style-type: none"> <li>• Scores locations from high to low earth visibility.</li> <li>• Recognizes potential for communication in locations with more days of earth visibility per year.</li> </ul>                                       | <ul style="list-style-type: none"> <li>• Scores locations from high to low Sun visibility.</li> <li>• Recognizes increased potential for solar power in locations with more days of Sun visibility per year.</li> </ul>                    |
| <b>Question 2</b> | <ul style="list-style-type: none"> <li>• Eliminates sites with temperatures lower than 113K (spacesuit temperature).</li> </ul>   | <ul style="list-style-type: none"> <li>• Takes into account surrounding regions of sites with high neutron count.</li> </ul>  | <ul style="list-style-type: none"> <li>• Takes into account surrounding regions of sites with low earth visibility.</li> </ul>  | <ul style="list-style-type: none"> <li>• Takes into account surrounding regions of sites with low Sun visibility.</li> </ul>   |
| <b>Question 3</b> | <ul style="list-style-type: none"> <li>• Acknowledges that warmer sites pose less risk to humans and machines.</li> <li>• Considers potential to regulate thermal environments.</li> </ul>  | <ul style="list-style-type: none"> <li>• Acknowledges the advantages of a local water supply.</li> <li>• Recognizes water supply doesn't have to be onsite.</li> <li>• Considers potential to recycle water.</li> </ul>   | <ul style="list-style-type: none"> <li>• Acknowledges benefits of continuous line of communication with Earth.</li> <li>• Recognizes communications facility doesn't have to be onsite.</li> <li>• Suggests alternatives (satellites, relays).</li> </ul> | <ul style="list-style-type: none"> <li>• Acknowledges importance of exploitable energy resource.</li> <li>• Recognizes power supply doesn't have to be onsite.</li> <li>• Suggests alternatives (nuclear, geothermal, biomass).</li> </ul> |

\*This is not a definitive list of answers. Students should be given credit for demonstrating an understanding of the background material and for using logical reasoning to explain their decisions. For example, in Q2 of the thermal analyst worksheet, students might argue that spacesuit capability is likely to improve in the future and therefore choose to include locations colder than 113K.

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Teacher Glossary

**Absolute Zero:** the lowest temperature possible, corresponding to 0 Kelvin. This is a theoretical temperature, which could only be achieved in the complete absence of molecular motion.

**Cold-trap:** a location with a low enough temperature to instantly freeze water and other molecules, preventing them from being able to escape.

**Epithermal neutron:** a neutron with a relatively high kinetic energy.

**Late Heavy Bombardment:** a period of time early in the solar system's history during which the inner "rocky" planets experienced a higher than usual flux of impacts.

**Line-of-sight:** the type of propagation characteristic of high-frequency radio, which requires that there is an unobstructed path between a transmitting antenna and a receiving antenna.

**Permanently-shadowed region:** a region within the lunar polar regions, such as a crater-floor, which because of its low elevation never receives any sunlight.

### Teacher References

NASA's Lunar Reconnaissance Orbiter website:

<http://lunar.gsfc.nasa.gov>

Diviner Lunar Radiometer website:

<http://diviner.ucla.edu>

Lunar Exploration Neutron Detector website:

[http://ps.iki.rssi.ru/lend\\_en.htm](http://ps.iki.rssi.ru/lend_en.htm)

Lunar CRaTER Observation and Sensing Satellite website:

<http://lcross.arc.nasa.gov>

Information about permanently-shadowed regions and ice:

[http://www.messenger-education.org/library/pdf/ice\\_shadows.pdf](http://www.messenger-education.org/library/pdf/ice_shadows.pdf)

The arguments for building a lunar outpost:

[http://www.nasa.gov/centers/goddard/news/series/moon/why\\_go\\_back.html](http://www.nasa.gov/centers/goddard/news/series/moon/why_go_back.html)

Class discussion: Do humans have the right to colonize other planets?

<http://school.discoveryeducation.com/lessonplans/programs/discovermagazine-solarsystem/index.html>

# Lunar Reconnaissance Orbiter: (LAMP)

## Audience

Grades 6-8

## Time Recommended

2-4 Hours

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- F/5: Human eyes respond to only a narrow range of wavelengths of electromagnetic waves— visible light. Differences in wavelength within that range are perceived as differences of color.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

Content Standard B (5-8), Physical Science:

- c. Transfer of energy: The Sun is a major source of energy for changes on the Earth's surface. The Sun loses energy by emitting light. A tiny fraction of that light reaches the Earth, transferring energy from the Sun to the Earth. The Sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

## MATERIALS

- Student science notebook
- Student worksheet Part One
- Student worksheet Part Two
- Student worksheet Part Three
- Flashlight (one per group)
- Variety of light sources (lamps, fluorescent lights, sunlight; optional as available)
- Spectroscopic glasses or spectroscope (one per group)
- Prism (one per group)
- Gas Spectrum Emission Tubes (optional)
- Colored pencils, markers, or crayons

# Learning About Light: Searching for Water on the Moon

## Learning Objectives:

- To understand the electromagnetic spectrum.
- To understand the relationship between wavelength and frequency.
- To observe visible (white) light through a diffraction grating.
- To understand how NASA's Lunar Reconnaissance Orbiter uses different wavelengths to map the lunar surface of the Moon.

## Preparation:

1. Photocopy the Part One worksheet for each group of three students.
2. Photocopy Part Two and Part Three worksheets for each student.
3. Make a color transparency of the electromagnetic spectrum for your class discussion (see supplemental resources section).
4. Mark off an approximately 10x20 foot area for students to walk either in the classroom or hallway. Designate a starting line and finish line. Make sure to equally divide areas for each group to walk so as to not cause collisions from amongst students.
5. If you plan on having the students build their own spectroscopes, they would need to complete this task before part three of this lesson.
6. Gather a variety of light sources for students to view through a spectroscope (flashlight, lamps, fluorescent lights, sunlight, etc.).
7. Obtain gas emission tubes for students to view and compare different spectra to that of visible light (optional).
8. Make a copy of the Lunar Reconnaissance Orbiter image for your class discussion (see supplemental resources section).

## Background Information:

The electromagnetic spectrum is made of electromagnetic waves that span a large range of frequencies and wavelengths. Students should be familiar with various regions of the spectrum. Visible, or white light, is actually only a small region of the entire spectrum. When visible light is bent through a prism, it separates into distinct wavelengths, each with a particular color. The longest wavelengths in the visible light spectrum are red, while the shortest are violet. Beyond the violet range of the visible light spectrum is ultraviolet light. As a result, ultraviolet light is higher in frequency but shorter in wavelength than visible light.

## Procedure:

### PART ONE – VOCABULARY BUILDING

1. Display a transparency of the electromagnetic spectrum on the overhead. Inform students they will be learning about the electromagnetic spectrum.
2. Before students can explore the diagram of the spectrum, discuss some of the vocabulary concepts students will need to know- i.e. frequency, wavelength, visible light.
3. Assemble students into groups of three. Allocate each student in the group an activity assignment. One student will be the “long” walker; one student will be the “short” walker; one student will be the timer/counter. Give each group of students the Part One worksheet and discuss. Instruct groups to work together to complete the roles above. Note: make sure to provide enough room for each group of students to walk across from start to finish so as to not cause groups walking into one another. It will be important to monitor this situation throughout the activity— safety first.
4. Before allowing students to begin this activity, model the procedure in order to make sure all students understand the underlying instructions. Choose students to act as demonstrators regarding how to walk across the start/ finish line properly.
5. Discuss the group results as a class (see teacher answer key). Be sure to explain the relationship between frequency and wavelength in more detail (have students reference their results), so as to not perpetuate any misconceptions.

### PART TWO – EXPLORING THE SPECTRUM

1. Give each student a copy of the Part Two worksheet. Students will be using the diagram of the electromagnetic spectrum to answer the questions on the worksheet.
2. Allow students to work with a partner or in a group of two/ three to explore the electromagnetic spectrum and answer the questions.
3. Review the worksheet as a class (see teacher answer key).

### PART THREE – PLAYING WITH LIGHT

1. Assemble students into groups of three or four.
2. Provide the Part Three worksheet to each student.
3. Direct students to the diagram of the electromagnetic spectrum on the worksheet. Ask them about the section of the spectrum dealing with visible light. Discuss how the visible light range of the spectrum looks like a rainbow.
4. Give each group a pair of spectroscopic glasses (or a spectroscope) and a flashlight.
5. Allow students to explore light (using the flashlight and any other available light sources) with the spectroscope. Ask the students to record their observations in their science notebooks (they will use this data to produce a “Claims-Evidence” chart).
6. Collect the spectroscopes and give each group a prism. Ask the students to see if they can use the prism to separate “white” light into its component colors.
7. Allow students to explore. Ask them to record their specific procedures and observations again in their science notebooks.
8. Ask students to complete the “Claims-Evidence” chart, listing some conclusions about the focus question stated at the beginning of the worksheet. Remind them to look at their observations made in their science notebooks.

9. Lead a class discussion about the results of the activity. Students should share their observations/ conclusions (found in their science notebooks/ individual worksheets) and use them to support their answers to the focus question in the Part Three worksheet.
10. Optional: if you have the resources available, allow students to view gas emission tubes through the spectroscopes. Have them record their observations and compare their results to the spectrum of visible light. Have a discussion with students regarding how scientists use this type of information in the study of astronomy (see teacher resources).

#### PART FOUR – CONNECTION WITH LRO

1. Discuss that a spacecraft, the Lunar Reconnaissance Orbiter (LRO), is currently detecting wavelengths other than visible light in order to map the lunar surface of the Moon. Specifically mention one of the instruments, LAMP, is measuring the ultraviolet wavelength to identify locations on the Moon that previously were permanently shadowed, or unseen to us. This instrument is specifically searching these lunar dark regions for any exposed water ice deposits. It can do so because water ice on the surface will leave a distinct imprint in the reflected light detected by the LAMP instrument, definitively confirming its presence. This is one of the main goals for the entire LRO mission.



# ELECTROMAGNETIC SPECTRUM BASICS

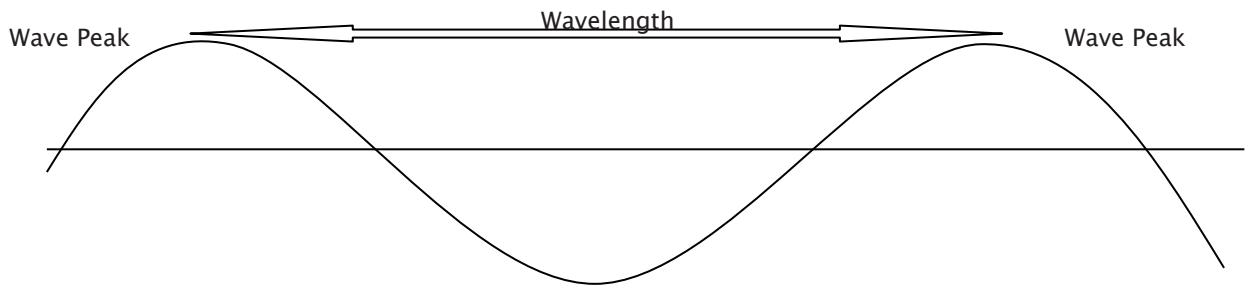
## Part One

Name \_\_\_\_\_

1. Using the longest strides (or steps) possible, the long walker will walk from the start to the finish line. Record the number of steps taken.
2. Using the shortest strides (or steps) possible, the short walker will walk from the start to the finish line. Record the number of steps taken.
3. The long walker and short walker will now walk at the same time. The walkers **MUST** stay together the entire distance and reach the finish line at the same time.
4. Whose feet were moving the fastest during step 3?
5. The long walker will take one step. The short walker will take as many steps as it takes to reach the long walker. Record the number of steps it takes for the short walker to make one long walker step.

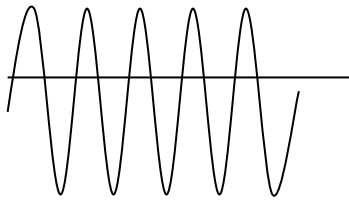


6. The electromagnetic spectrum uses two terms to describe waves of light. The **wavelength** is the distance between two peaks of a wave.

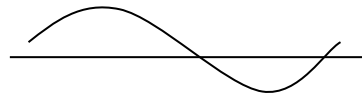


Which part of the walking activity could represent **wavelength**?

7. The second term used to describe waves on the electromagnetic spectrum is **frequency**. The **frequency** of a wave is the number of waves that pass a certain point in a given amount of time.



**High frequency wave**



**Low frequency wave**

Which part of the walking activity could represent **frequency**?

8. Think about the long walker.

Did the long walker have a long or short wavelength?

Did the long walker have a high or low frequency?

9. Think about the short walker.

Did the short walker have a long or short wavelength?

Did the short walker have a high or low frequency?



10. Write a rule about wavelength and frequency.

If a wave has a long wavelength, it has a \_\_\_\_\_ frequency.

If a wave has a short wavelength, it has a \_\_\_\_\_ frequency.

11. Look at the electromagnetic spectrum. Which type of wave could the long walker represent?

12. Look at the electromagnetic spectrum. Which type of wave could the short walker represent?





# LEARNING ABOUT LIGHT

## Part Two

Name \_\_\_\_\_

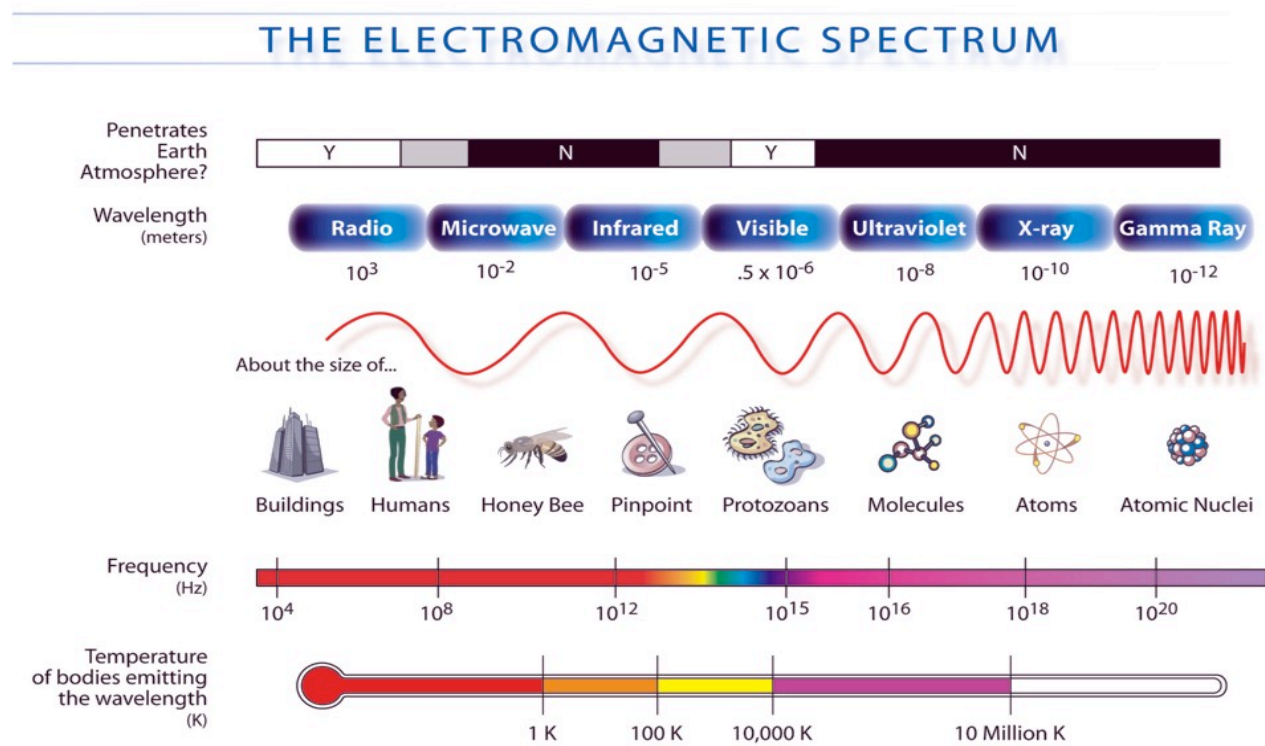
### Building Background Knowledge:

You may know things about the electromagnetic spectrum. The words on the left of this table are some regions of the electromagnetic spectrum. Think about how or where you have heard these words before and describe what you know.

| Region of the EM Spectrum | I know... |
|---------------------------|-----------|
| Radio                     |           |
| Microwave                 |           |
| X-Ray                     |           |
| Ultraviolet               |           |



Review the diagram of the electromagnetic spectrum. Use the diagram to answer the questions.



1. The area of the electromagnetic spectrum with the largest waves (wavelength) is \_\_\_\_\_.
2. The area of the electromagnetic spectrum with the smallest waves (wavelength) is \_\_\_\_\_.
3. Visible light falls between the \_\_\_\_\_ and \_\_\_\_\_ regions on the electromagnetic spectrum.
4. Ultraviolet waves are \_\_\_\_\_ than visible light waves. (shorter or longer)
5. Look at the visible light section on the frequency scale of the electromagnetic spectrum. It is split into a rainbow of colors. Which color is on the side with the longest wavelengths in the spectrum?
6. Which color is on the side of the visible range with the shortest wavelengths in the electromagnetic spectrum?
7. Look at the electromagnetic spectrum. Color the chart below to show the visible light region on the electromagnetic spectrum. Pay particular attention to how much of the visible light spectrum is made of each color.



Long  
Wavelength

Short  
Wavelength



# VISIBLE LIGHT

## Part Three

Name \_\_\_\_\_

**Question:**

“How do we know visible light is made up of the colors within the rainbow?”

Make a Claim/ Evidence chart related to the question above. Use your notes of the procedures and observations made in your science notebook while working with visible light:

| Claim | Evidence |
|-------|----------|
|       |          |

# SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

## THE ELECTROMAGNETIC SPECTRUM

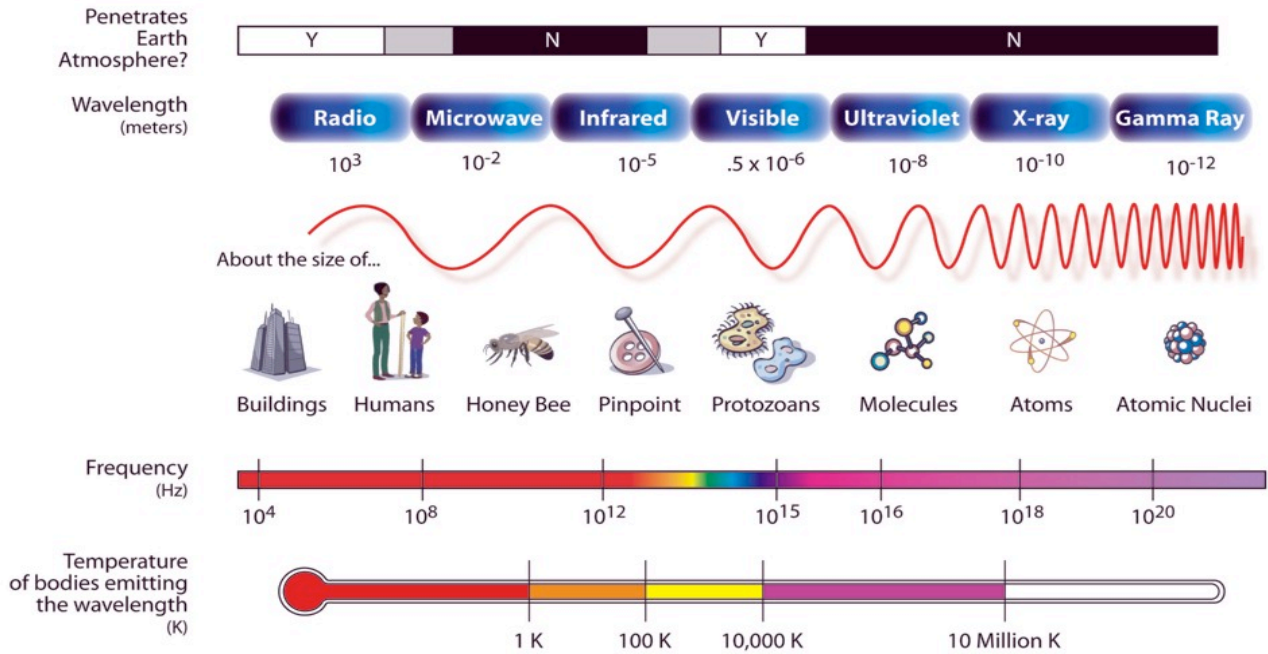


Image from: [http://www.google.com/imgres?imgurl=https://myasadata.larc.nasa.gov/images/EM\\_Spectrum3-](http://www.google.com/imgres?imgurl=https://myasadata.larc.nasa.gov/images/EM_Spectrum3-)

## ELECTROMAGNETIC SPECTRUM BASICS

# Part One

1. Using the longest strides (or steps) possible, the long walker will walk from the start to the finish line. Record the number of steps taken.

**Answer Varies**

2. Using the shortest strides (steps) possible, the short walker will walk from the start to the finish line. Record the number of steps taken.

**Answer Varies**

3. The long walker and the short walker will now walk at the same time. The walkers **MUST** stay together the entire distance and reach the finish line at the same time.

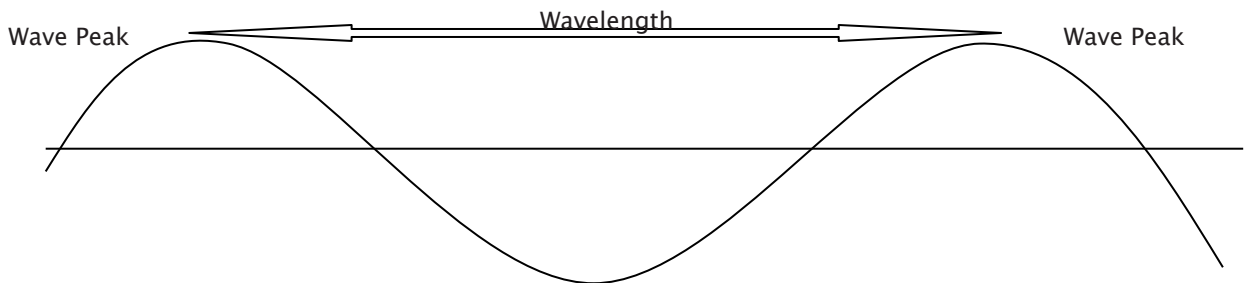
4. Whose feet were moving the fastest during step 3?

**Short Walker**

5. The long walker will take one step. The short walker will take as many steps as it takes to reach the long walker. Record the number of steps it takes for the short walker to make one long walker step.

**Answer Varies**

6. The electromagnetic spectrum uses two terms to describe waves of light. The **wavelength** is the distance between two peaks of a wave.

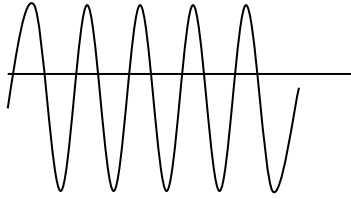


Which part of the walking activity could represent **wavelength**?

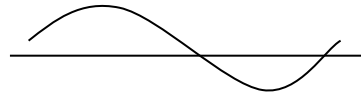
**The length of student strides**

## Teacher Answer Key

7. The second term used to describe waves on the electromagnetic spectrum is the **frequency**. The **frequency** of a wave is the number of waves that pass a certain point in a given amount of time.



**High frequency wave**



**Low frequency wave**

Which part of the walking activity could represent **frequency**?

**The number of steps each student was taking**

8. Think about the long walker.

Did the long walker have a long or short wavelength? **Long**

Did the long walker have a high or low frequency? **Low**

9. Think about the short walker.

Did the short walker have a long or short wavelength? **Short**

Did the short walker have a high or low frequency? **High**

10. Write a rule about wavelength and frequency.

If a wave has a long wavelength, it has a **Low** frequency.

If a wave has a short wavelength, it has a **High** frequency.

11. Look at the electromagnetic spectrum. Which type of wave could the long walker represent?

**Radio waves, microwaves**

12. Look at the electromagnetic spectrum. Which type of wave could the short walker represent?

**Gamma rays, x-rays**

## LEARNING ABOUT LIGHT

### Part Two

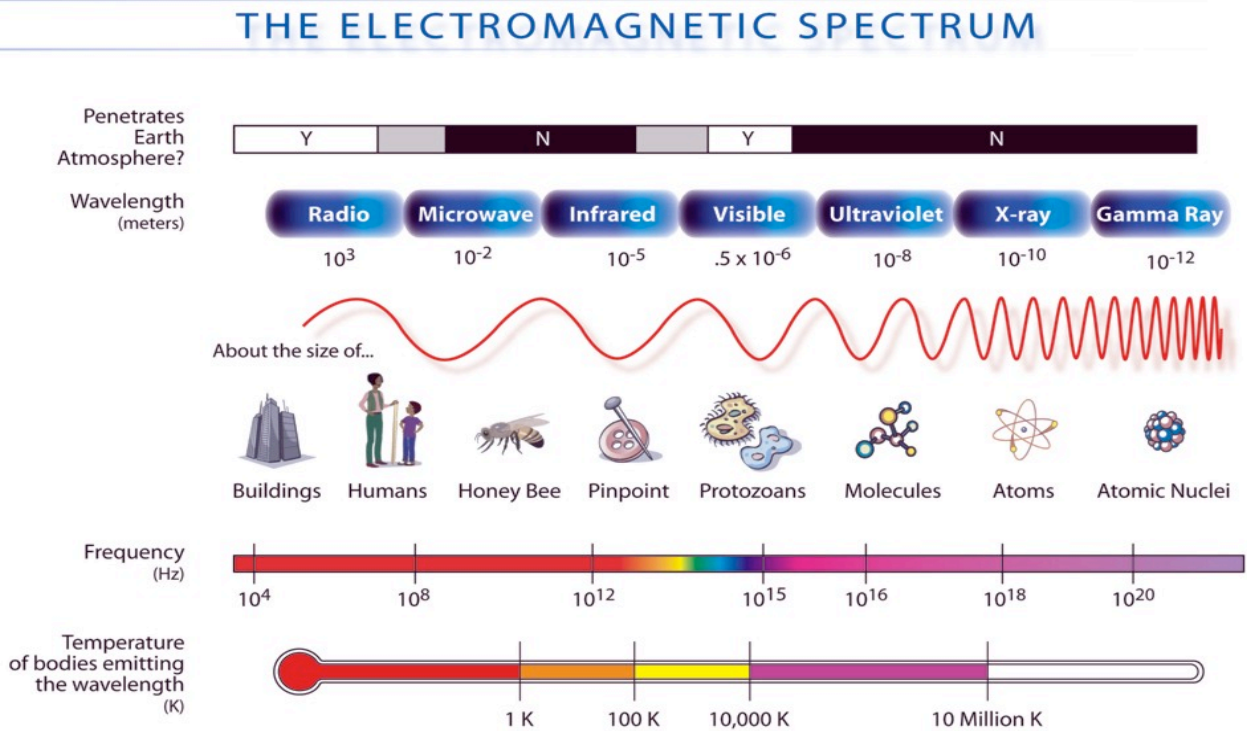
#### Building Background Knowledge:

You may know things about the electromagnetic spectrum. The words on the left of this table are some regions of the electromagnetic spectrum. Think about how or where you have heard these words before and describe what you know.

| Region of the EM Spectrum | I know...                         |
|---------------------------|-----------------------------------|
| Radio                     | <b>Student answers will vary.</b> |
| Microwave                 | <b>Student answers will vary.</b> |
| X-Ray                     | <b>Student answers will vary.</b> |
| Ultraviolet               | <b>Student answers will vary.</b> |

# Teacher Answer Key

Review the diagram of the electromagnetic spectrum. Use the diagram to answer the questions.



1. The area of the electromagnetic spectrum with the largest waves (wavelength) is **Radio**.
2. The area of the electromagnetic spectrum with the smallest waves (wavelength) is **Gamma rays**.
3. Visible light falls between the **Infrared** and **Ultraviolet** regions on the electromagnetic spectrum.
4. Ultraviolet waves are **Shorter** than visible light waves. (shorter or longer)
5. Look at the visible light section on the frequency scale of the electromagnetic spectrum. It is split into a rainbow of colors. Which color is on the side with the longest wavelengths in the spectrum? **Red**
6. Which color is on the side of the visible range with the shortest wavelengths in the electromagnetic spectrum? **Violet**
7. Color the chart below to show the visible light region on the electromagnetic spectrum. Pay particular attention to how much of the visible light spectrum is made of each color.



Long  
Wavelength

Short  
Wavelength



## Teacher Resources:

Build your own spectrosopes:

<http://www.exploratorium.edu/spectroscope>

[http://sci-toys.com/scitoys/scitoys/light/cd\\_spectroscope/spectroscope.html](http://sci-toys.com/scitoys/scitoys/light/cd_spectroscope/spectroscope.html)

Additional activities about light, color, and the EM spectrum:

[http://spaceplace.jpl.nasa.gov/teachers/eo3\\_spectroscopy.pdf](http://spaceplace.jpl.nasa.gov/teachers/eo3_spectroscopy.pdf)

[http://www.exploratorium.edu/spectra\\_from\\_space/ultra\\_activity.html](http://www.exploratorium.edu/spectra_from_space/ultra_activity.html)

<http://imagine.gsfc.nasa.gov/docs/teachers/lessons/roygbiv/roygbiv.html>

More information about the electromagnetic spectrum:

[http://imagine.gsfc.nasa.gov/docs/science/know\\_l1/emspectrum.html](http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html)

Electromagnetic spectrum graphic:

[http://www.google.com/imgres?imgurl=https://mydasdata.larc.nasa.gov/images/EM\\_Spectrum3-](http://www.google.com/imgres?imgurl=https://mydasdata.larc.nasa.gov/images/EM_Spectrum3-)

Lunar Reconnaissance Orbiter graphic/ information:

[http://www.nasa.gov/mission\\_pages/LRO/multimedia/lroconcept3.html](http://www.nasa.gov/mission_pages/LRO/multimedia/lroconcept3.html)

<http://www.boulder.swri.edu/lamp>

For purchasing rainbow glasses or diffraction gratings:

<http://www.rainbowsymphonystore.com>

<https://www.scitoyscatalog.com>

<http://sciencekit.com/diffraction-grating/p/IG0024032>

# Lunar Reconnaissance Orbiter: (LAMP)

## Audience

Grades 6-8

## Time Recommended

2-4 Hours

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- F/5: Human eyes respond to only a narrow range of wavelengths of electromagnetic waves— visible light. Differences in wavelength within that range are perceived as differences of color.

## NSES STANDARDS

Content Standard A (5-8), Science as Inquiry:

- c. Use appropriate tools to gather, analyze and interpret
- d. Develop descriptions and explanations using evidence
- e. Think critically and logically to make the relationships between evidence and explanations.

Content Standard B (5-8), Physical Science:

- c. Transfer of energy: The Sun is a major source of energy for changes on the Earth's surface. The Sun loses energy by emitting light. A tiny fraction of that light reaches the Earth, transferring energy from the Sun to the Earth. The Sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

## MATERIALS

- Return to the Moon: Lunar Exploration (LAMP) DVD
- Student worksheet: How can ultraviolet light help us detect water on the Moon?
- Several black flashlights (one for each group of students)
- Black T-shirt or cloth squares
- White T-shirt or cloth squares
- Any or all samples of the following:
  - » Tonic water
  - » Laundry detergent
  - » White paper
  - » Vinegar
  - » B-12 tablets
  - » Highlighters
  - » Teeth whitener paste
  - » Toothpaste

# Seeing in the Dark: Searching for Water on the Moon

## Learning Objectives:

- To understand where ultraviolet waves lie on the electromagnetic spectrum.
- To understand scientists can detect a variety of substances using ultraviolet light.
- To explore samples of materials not easily seen by the naked eye.
- To understand that a spacecraft, the Lunar Reconnaissance Orbiter (LRO), is equipped with an instrument, LAMP, which uses ultraviolet light to detect water ice on the surface of the Moon.

Students will use an ultraviolet flashlight to search for materials that cannot be seen with the naked eye. Students will make connections between their experiments/ observations and the LAMP technology used on LRO to detect water on the Moon's surface. Note: students must have learned about the electromagnetic spectrum before starting this lesson.

## Preparation:

1. Prepare liquid samples of several of the substances located on the materials list to the right. If the substance is solid, dilute it in water. Place several drops of each prepared liquid on some cut-up white T-shirt pieces or cloth.
2. Cut several squares from a black T-shirt, or black cloth, that have been washed and dried in a dryer. (This should leave lint particles on the black material that is difficult for students to see with a naked eye).
3. Photocopy the related worksheet for each student.
4. Obtain at least one black flashlight for each group of students. Black lights can be purchased for under \$10 at <http://blacklightonline.us>

## Background Information:

There are many everyday materials that fluoresce, or glow, when placed under a black light. A black light gives off highly energetic ultraviolet light. Ultraviolet waves are found beyond violet wavelengths (located within the visible light spectrum) on the electromagnetic spectrum. Fluorescent substances absorb the ultraviolet light and then re-emit it almost instantaneously. But, some energy gets lost in the process, so the emitted light has a longer wavelength than the absorbed radiation, which makes this light visible and causes the material to appear to "glow."

The LAMP instrument uses ultraviolet light to search for water ice on the surface of the Moon. Using ultraviolet waves from the Sun and stars, LAMP’s sensory equipment will read the spectra of materials reflected off of the Moon’s surface. A part of the ultraviolet spectrum of hydrogen atoms is called the Lyman series. The brightest of this series (the Lyman alpha) has a specific wavelength that LAMP has been calibrated to “see.” When Lyman alpha light emitted by hydrogen bounces off the surface of the moon, LAMP is able to detect and record it. This data is then used to detect water ice.

## Procedure:

1. Watch Chapter 4 of the Return to the Moon: Lunar Exploration (LAMP) DVD, Lights, Camera, Action!
2. Tell students they will be working with ultraviolet light, a light not normally visible to the naked eye. Hand each student the lesson worksheet: **How can ultraviolet light help us detect water on the Moon?**
3. Place students into groups of 3 or 4. Give each group of students several samples of the prepared white T-shirt pieces or cloth. Ask the students to observe the white fabric before giving them a black flashlight. Have them record their preliminary observations of the prepared samples on the worksheet provided.
4. Give each group an ultraviolet (black) flashlight. While the students are at their desks, turn off the lights in the classroom and instruct each group to turn their black flashlights on. Instruct students to shine the black flashlight over the prepared samples. Observe what happens carefully. Provide ample time for this part of the experience.

**Note:** instruct students to be absolutely careful of these flashlights. Do not point them in another’s eyes (as this can potentially damage them) and handle them with great care.

**Note:** while it does not need to be completely dark, dimming the lights will help with seeing things that one’s naked eye cannot see (objective), as well as providing the ideal conditions to view a black light experiment.

5. After groups have had enough time to experiment, turn on the classroom lights and ask each group to turn off their black light. Ask students to record his or her observations with ultraviolet light on the worksheet provided.
6. Repeat steps 3 and 4 with the black cloths containing lint. Again, have students observe and record their before/ after observations on the worksheet charts related to the black samples.
7. Have each group use their observation data charts to complete the “Claims and Evidence” chart located in their worksheets. See the sample Claims and Evidence chart below for guidance. (Model this activity if necessary)

**Note:** this chart provides possible responses. The students should generate their own claims and evidence based on their individual group’s findings.

8. Using the completed Claims and Evidence chart, conduct a discussion with students to ensure they have made the appropriate connections between the activity and the mission of the LAMP instrument: finding water ice on the Moon using ultraviolet light.

### Example here:

| Claim   | Evidence   |
|---|--|
| <ul style="list-style-type: none"> <li>• I claim you can use ultraviolet light to detect substances that cannot be seen with the naked eye.</li> <li>• I claim you can use ultraviolet light to better detect materials on a dark surface.</li> </ul> | <ul style="list-style-type: none"> <li>• I claim this because we could not see the stain on the cloths until we turned on the black light.</li> <li>• I claim this because we did not really notice anything on the black cloth, but when we shone the black light on it there were many fibers glowing on the cloth.</li> </ul> |



# HOW CAN ULTRAVIOLET LIGHT HELP US DETECT WATER ON THE MOON?

Name \_\_\_\_\_

1. Record your preliminary observations for each white material sample in the chart below:

| List White Material Samples: | Observations: |
|------------------------------|---------------|
|                              |               |

2. After shining the ultraviolet flashlight over the prepared white samples, write your observations in the following chart below:

| List White Material Samples (under ultraviolet): | Observations: |
|--|---------------|
|  |               |



3. Record your preliminary observations for each black material sample in the chart below:

| <b>List Black Material Samples:</b> | <b>Observations:</b> |
|-------------------------------------|----------------------|
|                                     |                      |

4. After shining the ultraviolet flashlight over the prepared black samples, write your observations in the following chart below:

| <b>List Black Material Samples (under ultraviolet):</b> | <b>Observations:</b> |
|---|----------------------|
|   |                      |



- Using data from your observation charts regarding both the white and black samples, fill in the Claims and Evidence chart on the next page. Think about ultraviolet light: make claims based on the evidence you found when experimenting with the various samples.

| <b>Claim:</b> | <b>Evidence:</b> |
|---------------|------------------|
|               |                  |

## Assessment:

In order to check for understanding, make sure students have a clear meaning of the following after completing the worksheet and overall lesson (see teacher resources for additional guidance):

- The main idea: “How can ultraviolet light help us detect water on the Moon?”
- To explore samples of materials not easily seen by the naked eye; however, using a different wavelength like ultraviolet, can in fact view the “unseen.” (Just like the LAMP instrument on the Moon!)

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Teacher Resources:

Denver Museum of Nature and Science. (2006). The Lyman alpha mapping project: Seeing in the dark. Retrieved September 20, 2008, from <http://www.boulder.swri.edu/lamp/index.html>

Introduction to spectroscopy: [http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray\\_spectra/background-spectroscopy.html](http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/background-spectroscopy.html)

Build your own spectroscopes:

<http://www.exploratorium.edu/spectroscope>

[http://sci-toys.com/scitoys/scitoys/light/cd\\_spectroscope/spectroscope.html](http://sci-toys.com/scitoys/scitoys/light/cd_spectroscope/spectroscope.html)

More information about the electromagnetic spectrum:

[http://imagine.gsfc.nasa.gov/docs/science/know\\_11/emspectrum.html](http://imagine.gsfc.nasa.gov/docs/science/know_11/emspectrum.html)

Helmenstine, A. (2008). What materials glow under a black or ultraviolet light? Retrieved September 20, 2008 from <http://chemistry.about.com/cs/howthingswork/f/blblacklight.htm>

Information on ultraviolet light:

[http://missionscience.nasa.gov/ems/10\\_ultravioletwaves.html](http://missionscience.nasa.gov/ems/10_ultravioletwaves.html)

### Extension Activities:

Allow students to design and conduct their own experiments using the ultraviolet light.

### Glossary:

**Lyman alpha line:** A spectral line of hydrogen (specifically within the ultraviolet spectra) emitted when the electron falls from the  $n=1$  orbital to the  $n=2$  orbital, where  $n$  is the principal quantum number. Note: the LAMP instrument of the Lunar Reconnaissance Orbiter uses the Lyman Alpha spectrum to detect water ice on the Moon.

**Wavelength:** The distance between one peak or crest of a wave of light, heat, or other energy and the next corresponding peak or crest (expressed in Angstroms).

**Frequency:** Number of waves that pass a fixed point in unit time (expressed in Hertz). Note: the greater the energy, the larger the frequency and shorter (smaller) the wavelength. Given the relationship between wavelength and frequency, the higher the frequency, the shorter the wavelength. Thus, short wavelengths are more energetic than long wavelengths.

# Lunar Reconnaissance Orbiter: (LOLA)

## Audience

Grades 6-8

## Time Recommended

45-60 minutes

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8), Scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.

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

- b. Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique.

## MATERIALS

- Data worksheets (one per student)
- Science notebook
- Ping-pong ball
- Wooden blocks of various sizes (could substitute other objects like hard boxes or large textbooks)
- Masking tape: 2 pieces, 10 cm each (optional)
- Meter stick
- Stop watch
- Graph paper (enough for 3 graphs per group)
- Pen/pencil

# Lunar Laser Altimetry Studying the Topography of the Moon

## Learning Objectives:

- Students will understand, through a hands-on experience, the basic concepts behind the use and working of a laser altimeter for the study of solar system topography.
- Students will plot and graph data they have collected using a hands-on version of laser altimetry.
- Students will gain an understanding of the use of laser altimetry in the study of planetary topography.

## Preparation:

Provide the included worksheets and procedure to each student participating in the activity.

## Background Information:

In order to be prepared for further exploration on the Moon's surface we need to map the topography of the surface to ensure its safe and successful exploration. There are multiple methods to determine topography, including photogrammetry (a method that uses algorithms informed by Sun angles and the observation of shadow lengths of features on the surface). Currently, one of the best methods for determining topography is to use laser altimetry. While photogrammetry provides relative measurement, laser altimetry can provide more accurate, absolute measurements.

The spacecraft currently orbiting and studying the Moon's surface is called the Lunar Reconnaissance Orbiter (LRO). It includes such an instrument — the Lunar Orbiter Laser Altimeter (LOLA). The LOLA instrument is used to take topographical measurements of the surface of the Moon using sophisticated laser technology. Topographic maps and 3 dimensional models are created using this data. This activity will introduce you to the concept of laser altimetry and how the data are used in order to create maps and model solar system bodies. For more background on the LRO spacecraft mission and the laser altimetry instrument onboard please visit: <http://lunar.gsfc.nasa.gov>

## Procedure:

Take some time with students to brainstorm about why it may be important to know the topography or physical terrain of the surface of the Moon? This is a good time to connect Lunar exploration and exploring here on Earth. Also, have students take a moment to discuss what might be the challenges of measuring and mapping a terrain as far away as the Moon's surface.



Briefly introduce students to the Lunar Reconnaissance Orbiter (LRO) mission and the Lunar Orbiter Laser Altimeter (LOLA) instrument. You can find background information here: <http://lunar.gsfc.nasa.gov/>. Explain to students they will be modeling the technology behind the LOLA science instrument.

This activity requires at least two people per group; however, three people per group would be the optimum amount. The jobs can be rotated if group members so desire. Read through the whole activity before beginning. Model if necessary.

### STEP ONE:

1. Choose a spot on a wall 2.2 m or higher from the floor and place one 10 cm length of tape on the wall, at that height, parallel to the floor. (You may need a chair)
2. Holding the ball next to the tape on the wall (about an inch away from the wall), between your first finger and thumb, drop it and watch to see how high it bounces back up. Mark that spot on the wall with your finger. It is best to do this particular step two or three times to determine the highest point of return. (Using the mortar lines on cinder block walls will work well, too, if you have them. Be sure to use the same two lines throughout the whole activity.)
3. Measure 45 cm from the tape down toward the floor and mark this spot with the second piece of tape. This will be the constant for measuring the time of the ping-pong ball's period.
4. Measure the distance from the first piece of tape (or mortar line) to the floor and back up to the second tapeline. Record this on Data Table I. This distance will be used to create a baseline for all other measurements, so be as precise as you can.
5. Just like "number two," one partner should hold the ping-pong ball next to the higher piece of tape, between the first finger and thumb, and approximately one inch from the wall.
6. One partner should have a stopwatch (the "timer") and have his or her eyes level with the second piece of tape. A third partner, if available, should be recording the results of each ball drop using the data sheet provided. Note: A spreadsheet would work well for recording and calculating this data.
7. Drop the ball, and as you do say, "go," the "timer" will then start the stopwatch.
8. The timer will stop the watch when the ball rebounds and reaches the lower line. (His/her eyes should be level with the lower piece of tape. The time should be stopped as soon as any part of the ball touches any part of the line.) Record the time on Data Table I. Repeat this step four more times.
9. Calculate the velocities ( $V=D/T$ ). After finding the velocity for each of the trials, find the average velocity of the ping-pong ball. This average will be used later in this activity. It will be your baseline for comparing data.

### STEP TWO:

Now that you have found the velocity of the ping-pong ball, you will use this information to plot the topography along a line of latitude on the Moon. You will be creating your own lunar terrain on the floor against the wall where you just completed Step One.

1. Create the topography model of your Moon, along the wall where Step One was performed. In order to do so, place the wooden blocks against the wall in a line about 2-2.5 m long. Be sure that you build in some hills, mountains, valleys, etc. (See Figure A for example).

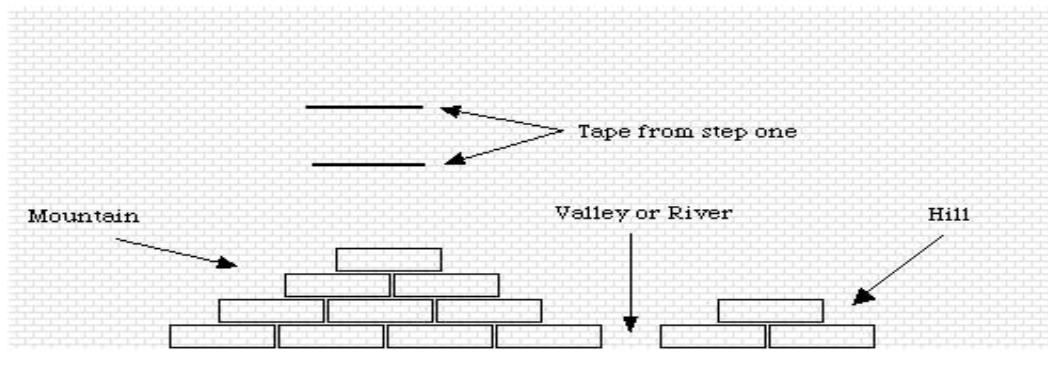


Figure A

2. If you used tape in Step One instead of the mortar lines, you will probably want to add new lengths of tape to the originals that extend over the entire length of your topographical model. Be sure that the new lines remain parallel to the floor so that the heights don't change along the length of the model.
3. Starting at the beginning of the top piece of tape, place a mark every 20 cm. The bottom piece does not need to be marked.
4. Again, starting at the first interval mark made at the beginning of the tape, drop the ping-pong ball as you did in Step One, and have the "timer" record the time in Data Table II. Drop the ball and record the results two more times for each interval. Be sure to be as accurate as you can with the timing.
5. Repeat "number four" for each of the interval marks placed on the wall.
6. Find the average time/ distance for each of the intervals and record it on the Data Table II worksheet.
7. Put all related data into Data Table III from the previous tables (I and II).

### STEP THREE: PLOTTING AND GRAPHING THE DATA

Plot the data for the average times and create graphs in your science notebook of the altimetry readings for your topographic model. These graphs will use different intervals between readings, so compare the preciseness of different levels of accuracy (called spatial resolution). Model is necessary.

#### Graph 1

1. Plot the average time for every 60 cm interval. (0 cm, 60 cm, 120 cm, etc.)
2. Connect the points with a smooth line.
3. Label the graph appropriately.

#### Graph 2

1. Plot the average time for every 40 cm interval.
2. Connect the points with a smooth line.
3. Label the graph appropriately.

#### Graph 3

1. Plot the average time for every 20 cm interval.
2. Connect the points with a smooth line.
3. Label the graph appropriately.

#### STEP FOUR: REFLECT AND ANALYZE YOUR RESULTS

Use the measurements taken from the experiment to complete the questions on the worksheet (see attached). Be thinking about how this investigation and process could be similar to and different from the real laser altimeter instrument onboard the LRO spacecraft.



# PING-PONG ALTIMETER

Name \_\_\_\_\_

## Data Table I

| Drop                     | Distance ball traveled | Time (seconds) | Velocity (distance/time) |
|--------------------------|------------------------|----------------|--------------------------|
| 1                        |                        |                |                          |
| 2                        |                        |                |                          |
| 3                        |                        |                |                          |
| 4                        |                        |                |                          |
| 5                        |                        |                |                          |
| <b>Average Velocity:</b> |                        |                |                          |

## Data Table II

| Interval | Trial 1 | Trial 2 | Trial 3 | Average Time (sec) | Distance Ball Traveled (cm) |
|----------|---------|---------|---------|--------------------|-----------------------------|
| 0cm      |         |         |         |                    |                             |
| 20cm     |         |         |         |                    |                             |
| 40cm     |         |         |         |                    |                             |
| 60cm     |         |         |         |                    |                             |
| 80cm     |         |         |         |                    |                             |
| 100cm    |         |         |         |                    |                             |
| 120cm    |         |         |         |                    |                             |
| 140cm    |         |         |         |                    |                             |
| 160cm    |         |         |         |                    |                             |
| 180cm    |         |         |         |                    |                             |
| 200cm    |         |         |         |                    |                             |
| 220cm    |         |         |         |                    |                             |
| 240cm    |         |         |         |                    |                             |
| 260cm    |         |         |         |                    |                             |
| 280cm    |         |         |         |                    |                             |
| 300cm    |         |         |         |                    |                             |





3. What does the graph look like in comparison to your model (i.e.. the same, inverted, etc.)?
  
  
  
  
  
  
  
  
  
  
4. Which looks more like the model, the graph you generated from the shorter or longer distances between readings (intervals)? Why do you think that is?
  
  
  
  
  
  
  
  
  
  
5. What will you have to do to the data to make the graph look right-side up?
  
  
  
  
  
  
  
  
  
  
6. The Lunar Orbiter Laser Altimeter aboard LRO sends out a laser beam and “catches” it as it returns from being reflected by the surface of the Moon. The instrument records how long it takes the beam to reach the surface and bounce back up. The scientists know how fast the beam is traveling; therefore, they can calculate how far it traveled. By measuring this time and multiplying by the velocity of the beam, they calculate how far the laser has traveled. They must then divide the distance the beam traveled in half.

Why did you not divide in half to find the distance to the object in your topography model? How does this experiment work in comparison to the laser altimeter instrument on LRO?



7. Next, the scientist must compare this distance to a “baseline” distance we will call zero. On Earth, we might use sea level as the baseline. Another way to set the baseline is to start at the center of the planetary body being studied and draw a perfect circle as close to the surface of the body as possible. Using this baseline, the altitude compared to zero can be calculated and graphed. (Here, on Earth, we often say that some point is a certain number of feet above of below sea level.)

Why do we not use the term “sea level” for Mars and other planets?

8. You will now calculate the altitude of the points along your model. To do this, subtract the distance the ball traveled, at each interval (from Data Table II) from the distance the ball traveled in Step One (see Data Table I). The number you come up with will be zero or greater. Use Data Table III to do your calculations. {The number in column B of this table should be the same for every interval. Remember, it was the baseline altitude and does not change.}

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Further Investigation:

The LRO spacecraft has six other scientific instruments onboard in addition to the Lunar Orbiter Laser Altimeter (LOLA). Check out <http://lunar.gsfc.nasa.gov> to find out more about the current science being done with the many different types of data from LRO.

To learn more about the LOLA instrument and view real laser altimetry data from the LRO spacecraft check out <http://lunar.gsfc.nasa.gov/lola>

This lesson is modified from the “Ping Pong Altimetry” lesson:  
<http://education.gsfc.nasa.gov/experimental/all98invProject.Site/Pages/ping.html>

### Extension Activities:

Look into how else NASA uses laser technology. Relate and compare that to how it is used onboard a spacecraft like LRO (examples include laser ranging and laser sensors).

How does the laser altimetry technology we use to study the topography of the Moon compare to the way in which we study the topography of the ocean floor?

Before we had laser altimetry instruments to collect precise or more absolute measurements many studies used more basic methods of determining topography through utilizing the observation of shadow length and sun angles. These measurements are more relative than absolute, however this method is still valued and employed by many scientific investigations. Can you determine why photogrammetry would still be valuable?



# Lunar Reconnaissance Orbiter: (LRO)

## Audience

Grades 6-8

## Time Recommended

1-2 Hours

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information
- 11B/M3: Different models can be used to represent the same thing. What model to use depends on its purpose.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Student science notebooks
- Computer and projector
- Modeling clay or Play-Doh
- Construction paper
- Cardboard
- Ruler
- Dental floss or string
- Scotch tape

# Making a Model: Mapping the Moon

## Learning Objectives:

- To build a topographic map of a “Moon mountain.”
- To use a topographic map to determine a safe landing place for a Moon mission

Students will learn about NASA’s mission to find safe landing sites on the surface of the Moon. After seeing a visualization of surface mapping, students will create a topographic map and use this map to consider questions about landing sites on the surface of the Moon.

## Preparation:

1. Preview the LRO visualization before viewing with students.
2. Prepare a computer with projector for students to be able to view the visualization.

## Background Information:

At the core of NASA’s future in human space exploration is the potential return to the Moon. Once there, we would build a sustainable, long-term human presence with new spacecraft, robotics and life-sustaining technologies. In order to accomplish these goals, the Lunar Reconnaissance Orbiter (LRO) is an unmanned mission tasked with creating a comprehensive atlas of the Moon’s features, searching for safe and engaging landing sites, identifying important lunar resources, and characterizing how the lunar radiation environment will affect humans long-term.

Building safe lunar land sites requires detailed topographic data, which LRO is currently gathering as it orbits around the Moon. This will better aid the continued quest for human space exploration.

## Procedure:

1. Have students begin the lesson by setting up their science notebooks for the day. Instruct the students to write the focus question in their science notebooks. **What kind of surface is necessary for a spacecraft to land safely on the Moon?**
2. Share the student information sheet about the mapping of the Moon with students. Have students record notes in the observations/data section of their science notebook.
3. Watch the visualization of the Moon mapping that LRO will do. See the supplemental resources section for the link to this visualization. Have the students record notes in the observations/ data section of their notebooks.

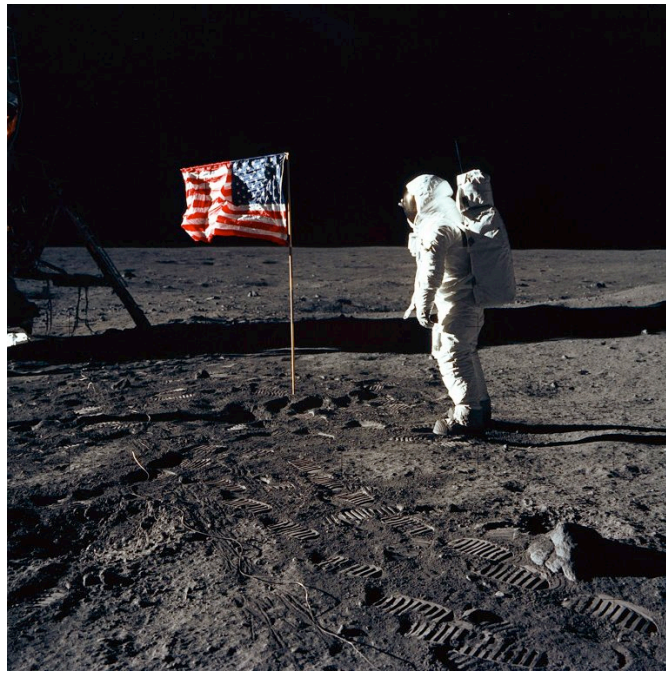
4. Lead a discussion with students about why it is important to map the surface of the Moon. See background information for assistance.
5. Tell students they will be making their own model and map of an area of the Moon.
6. Give each pair of students a large ball of modeling clay—about the size of a softball.
7. Have the students mold the clay into a large mountain about 4 to 5 inches tall. Instruct them to make the mountain oddly shaped (but flat on the bottom), as this will make their maps more interesting. They can also put a small crater in the top of their mountain shape if they wish.
8. Using their pencil and a ruler, have the students make ½-inch pencil marks starting from the top of the mountain.
9. Have the students use a pencil to make two holes through the middle of the mountain, from the top of the mountain to the cardboard underneath. Make sure the pencil holes go all the way through the mountain.
10. Ask the students to take the string, wrap it around their fingers, and hold it tight. Use the string to cut the top ½-inch of the mountain.
11. Have the students place the slice of mountain on the white construction paper and trace around it. Have them put the pencil through the holes in the slice to make marks on the paper to help them line up the slices of clay. Put the slice to the side.
12. Ask them to cut a second slice and line up the holes with the marks on the paper. Lay the slice on top of the first slice tracing. Trace around the second slice. Again, put this slice to the side.
13. Continue tracing each slice of the mountain until all slices have been traced. After all the slices have been traced, have the students color each slice a different color.
14. Have students place their slices of mountain back together, lining up the slices using the pencil holes.
15. Have the students tape their maps into their science notebooks. Then have them answer the discussion questions listed below before making their claims/ evidence charts.
  - a. Why are some of the traced lines closer together than others?
  - b. What kind of mountain slope makes lines that are closer together?
  - c. What kind of mountain slope makes lines that are far apart?
  - d. Where are the steepest slopes on your mountain?
16. Have students make a claims/ evidence chart for the focus question. Have them use the article (see worksheet section), the visualization (see supplemental resources sections), and their topographic maps to make claims.
17. Using the claims/evidence chart, have students consider the following questions to make a conclusion about the focus question.
  - a. Looking at your map, where would be the best place to land a spacecraft?
  - b. Why is this location an ideal spot to land a spacecraft? Use your claims/evidence chart to make this claim.
18. Have a discussion with students. Make a claims/ evidence chart with students and discuss the conclusions students made. (See sample claims/ evidence chart below)

| Claims  | Evidence   |
|---|--|
| <ul style="list-style-type: none"> <li>• I claim inside the crater will be the safest landing spot on our piece of the moon.</li> <li>• I claim that the flat base of our mountain is the safest landing spot.</li> </ul> | <ul style="list-style-type: none"> <li>• I claim this because there are no large rocks and the surface is flat and not sloped.</li> <li>• I claim this because it is flat and the spacecraft would not land on a steep surface.</li> </ul> |

## MAPPING THE MOON

# Student Information Sheet

When Buzz Aldrin and Neil Armstrong were just seconds from landing on the Moon, they realized their landing was in danger. Only 400 feet from the surface of the Moon, they saw that their ship, Apollo 11, was on course to land in a crater full of SUV-sized boulders. They averted danger by taking control of their ship's computer and landing in a smoother area beyond the crater's rim.



**Image 1: Buzz Aldrin and the U.S. Flag on the Moon, 1969.** Photo courtesy of NASA Image Database, <http://www.nasaimages.org/luna>

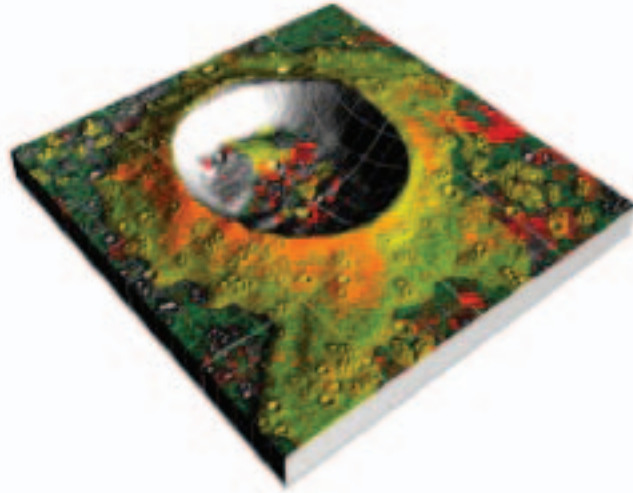
Part of the challenge of landing on the Moon is finding a surface safe enough to land upon. Generally, a good landing site is level and free from large objects that could damage the spacecraft as it lands.

In order to help get astronauts back on the Moon by 2020, part of the Lunar Reconnaissance Orbiter's (LRO) mission is to find safe landing spots on the surface. One of the instruments designed to help in achieving this goal is the Lunar Orbiter Laser Altimeter (LOLA). LOLA was created to calculate the height of lunar terrain. It is a laser ranging system that records the time it takes for a pulse to travel from the spacecraft to the surface and back. After orbiting the Moon for a year, LOLA will create an elevation map of the Moon's polar regions.

A second instrument, named Diviner, will measure temperatures in LOLA's mapping area to analyze potential landing sites. Because temperatures change more quickly in areas with lots of rocks, Diviner can analyze temperature change to determine areas on the surface that appear to be smooth but are more likely rocky.

Finally, the LRO also will carry a pair of cameras called the Narrow Angle Cameras (NAC's). These eagle-eyed cameras will work together to take images of the lunar surface that can show details of the Moon as small as a half-meter. As the LRO orbits, the

Moon rotates beneath it and the NAC's will take pictures to build a detailed view of the lunar poles. This information will be used to identify landing zones that are safe for spacecraft and free of large boulders and craters (unlike the technology available during the Apollo missions).



---

**Image 2:** The LRO's imaging cameras will provide highly detailed images of the lunar surface. From these images, scientists can determine where large rock hazards exist. Large rock hazards found in or near level surfaces will make landing in those areas unsafe. Artist depiction above from NASA's Scientific Visualization Studio, <http://svs.gsfc.nasa.gov/vis/a000000/a003500/a003533>

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Resources:

Visualization: Friedlander, J. (2008). How will LRO find safe landing sites on the moon? Retrieved September 13, 2008, from <http://svs.gsfc.nasa.gov/vis/a000000/a003500/a003533>

# Lunar Reconnaissance Orbiter: (LROC)

## Audience

Grades 6-8

## Time Recommended

1-2 hours

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

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

- c. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Image of the near side of the Moon
- Class example transparency of specific location on the Moon (Moscoviense Region)
- Images of specific locations on the Moon for student groups
- Transparencies of specific locations on the Moon (three different regions, wide-angle and close up images of each region)
- Image Analysis worksheets (one per student)
- Image Analysis Transparency (class example)
- Rulers
- Calculator
- Chart paper or blackboard/ whiteboard for recording student responses

# Exploring the Moon through Image Analysis

## Learning Objectives:

- Students will classify lunar features based on their characteristics.
- Students will use the scale of a lunar image to determine the actual size of certain features.
- Students will explain how a 2D image can provide information about the surface of the Moon.

Students will explore what they can learn from lunar images taken by a camera on the LRO spacecraft (LROC) and how these images can help to select a future landing site.

## Preparation:

Make sure to have all the materials ready, prior to the lesson.

## Background Information:

For more background information on the LRO spacecraft mission:

<http://lunar.gsfc.nasa.gov>.

Additionally, please see the LROC instrument website:

<http://lroc.sese.asu.edu>.

## Procedure:

1. Ask students to share their ideas about what they would expect to see in images of the Moon that might help them determine whether or not the area would make a good landing site.
2. Show the transparency of the near side of the Moon. Ask students to describe the surface. Do they see any areas that look like safe landing sites? Can they see enough to make a decision about where to land? Note: students should recognize that we would need to look at more detailed images to make decisions about where we should land.
3. Explain to the students they will be working in groups to evaluate a possible landing site by investigating some of the features of specific sites on the surface of the Moon.
4. Introduce the mission of LROC (Lunar Reconnaissance Orbiter Camera). Explain that LROC is one instrument on the Lunar Reconnaissance Orbiter (LRO). It is taking very high-resolution images of the Moon so that we can learn more about the lunar surface. Teachers, if you would like more background information on LROC check out <http://lroc.sese.asu.edu>.

Ask students how this spacecraft will help NASA? Explain to students they will be working with real images from the LROC instrument on-board the LRO spacecraft.

5. Display the Moscoviense Region #1 image (wide-angle) as a class sample (a transparency is recommended). Locate feature A. Record its coordinates, measure the image in centimeters, observe the scale, calculate the actual size, and describe the feature demonstrating the process for each task. Locate feature B on the other Moscoviense Region #2 image (close up). Record its coordinates, measure the image in centimeters, observe the scale, calculate the actual size in kilometers, and describe the feature demonstrating the process for each task. **Point out to students that the different images use different scales for distance. It is important that we pay attention to the scale for the image we are working with.**
6. Distribute the Image Analysis worksheet.
7. Describe and demonstrate the work of the following jobs using the projected image:
  - a. **Map technician** (determine location and size of feature)
  - b. **Observer** (describes the feature in their own words)
  - c. **Mathematician** (calculate size of the feature based on the scale)
  - d. **Recorder** (records the responses from the other group members)
8. Divide students into groups of four, designating a particular role above (if it is not possible to have four per group, roles noted above can be combined as needed and completed by one student).
9. Groups will gather information about the four, labeled features on their Moon image, as well as five features of their choosing. Have students label the additional features with letters (E-I) directly below the feature they choose. Once data has been collected on each of the nine features, the whole group will work together to classify the objects based on their size (small, medium, large) and define each category.

**Note: the feature “A” on both images of each region is the same feature but at a different resolution (one is wide-angle, the other a close up). Be sure NOT to reveal this to students at this point, as they will discover this later on.**

10. Give each group of students one of the six images. Please note that you may need to give the same image to more than one group. Note that different groups will look at different site regions at different resolutions (wide-angle/close-up).
11. Students should work as a team for 15-20 minutes to identify features in their image and record information/ complete the Image Analysis worksheet.
12. Put up Moscoviense Region transparencies (#1 wide-angle and #2 close-up) for a class example. Point out that both images are of the same site region but with a different resolution. The close up image includes much more detail about a smaller area. **Teacher can now reveal that feature “A” is the same in both images.** Note: in the Moscoviense Region # 2 image, “A” refers to the brighter half circle on the left side of the image that fills more than half of the image area.
13. Put up Humboldtianum Region transparencies (#1 wide-angle and #2 close-up).
14. Have the groups who worked with the Humboldtianum Region (both images #1 and #2) share their classification system (what constitutes small, medium and large) and then point out one feature in each class. The teacher should record information about which features the Image #1 (wide angle) group and Image #2 (close-up) group defined as small, medium, and large in a chart on butcher paper, blackboard or whiteboard.
15. Repeat this comparison for the Goddard Region and Reiner Region transparencies.
16. Look at the recorded information about what constitutes small, medium, and large for each region and particular resolution. Lead a discussion on the similarities and differences within and between resolution type and region.

17. Ask the students to reflect on how each of these images can play a role in selecting a future lunar landing site. What information do the images provide? What are they lacking? Share with students that when Apollo 11 astronauts were landing on the Moon, a site had been selected that appeared to be smooth and appropriate for landing. Interestingly, as they approached the site, they found the area was covered in boulders that would make it impossible to land. The boulders were not visible on the lunar maps available at the time. Astronaut Neil Armstrong was forced to steer the spacecraft to avoid the boulders.

(Optional video resource: interview clips with astronaut Buzz Aldrin about the experience:

<http://www.history.com/videos/buzz-aldrin-on-approach-to-moon#how-the-lunar-landing-site-was-chosen>).

LROC images help us create a more detailed map of the Moon so we can avoid these difficulties.

18. Return to the initial question of how these lunar images help us to understand various scientific understandings related to the surface of the Moon.





## IMAGE ANALYSIS

**Group Members:** \_\_\_\_\_

**Region Site:** \_\_\_\_\_

**Image #:** \_\_\_\_\_

Study the lunar image. Know who will undertake the following roles explained by the teacher: recorder, map technician, mathematician, and observer. Select features in the image to study. For each feature, complete the following information:

1. Locate the feature on the image.
2. Fill in each part of the chart (Recorder)
3. Measure the size of the feature (diameter for circles and longest side for other shapes) in the image (Map Technician)
4. Calculate the actual size of the feature (Mathematician)
5. Describe the characteristics of the feature (Observer)
6. After finishing steps 1-6 for each feature, classify the features as small, medium or large (Whole Group)

| Feature                                 | Coordinates | Size in Image (cm) | Multiplier for cm to km | Actual Size (km) | Description | Classification (S, M, L) |
|---|-------------|--------------------|-------------------------|------------------|-------------|--------------------------|
| A                                       |             |                    | x                       | =                |             |                          |
| B                                       |             |                    | x                       | =                |             |                          |
| C                                       |             |                    | x                       | =                |             |                          |
| D                                       |             |                    | x                       | =                |             |                          |
| Choose and label 5 additional features: |             |                    |                         |                  |             |                          |
| E                                       |             |                    | x                       | =                |             |                          |
| F                                       |             |                    | x                       | =                |             |                          |
| G                                       |             |                    | x                       | =                |             |                          |
| H                                       |             |                    | x                       | =                |             |                          |
| I                                       |             |                    | x                       | =                |             |                          |



**After studying the image, based on your observations answer the following questions:**

1. Based on what you have observed in your image, how would you describe this area of the Moon?
2. Do you think there are any parts of this area that would make a good landing site for spacecraft or probes? Be sure to support your response with evidence from the research your group completed.
3. After hearing what your classmates learned about other lunar landing sites, which do you think might be the best for landing? Be sure to support your response with evidence.
4. What questions does your group still have about your image? Where could you get information to help you answer those questions?

---

# TEACHER SCORING GUIDE

**Assignment:** Image Analysis

**Student Name(s):** \_\_\_\_\_

**Date:** \_\_\_\_\_

| Performance Indicator  | 0 | 1 | 2 | 3 | 4 |
|--|---|---|---|---|---|
| Students completed all sections of the worksheet.                |   |   |   |   |   |
| Students' math is careful and accurate.                          |   |   |   |   |   |
| All descriptions of image objects are complete and are accurate. |   |   |   |   |   |
| Students support their responses with appropriate evidence.      |   |   |   |   |   |
| Students make reasonable conclusions about site selection.       |   |   |   |   |   |
| <b>Point Total</b>   |   |   |   |   |   |

**Point total from above:** \_\_\_\_\_ / (20 possible)

**Grading Scale:**

A = 18 - 20 points

B = 16 - 17 points

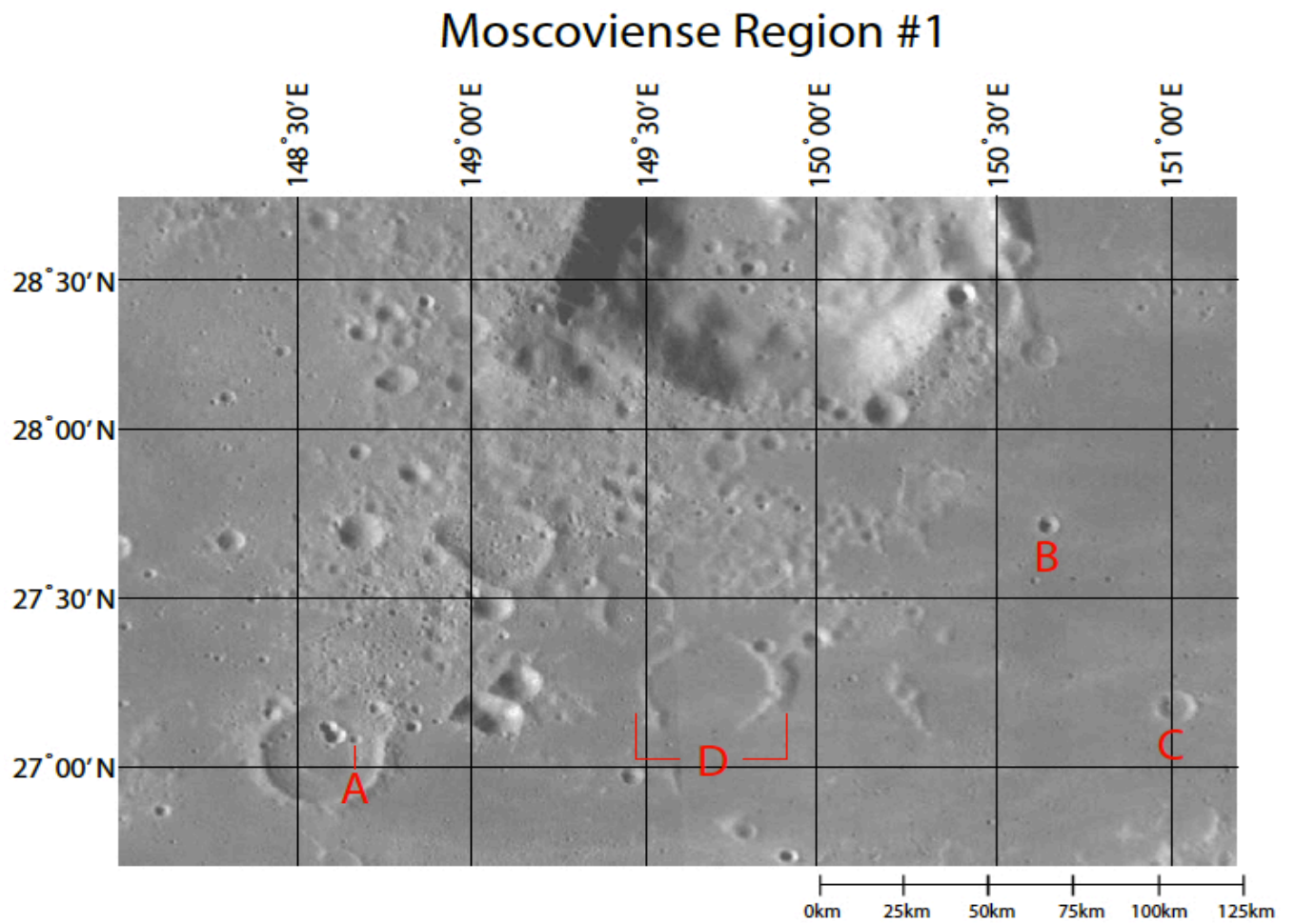
C = 14 - 15 points

D = 12 - 13 points

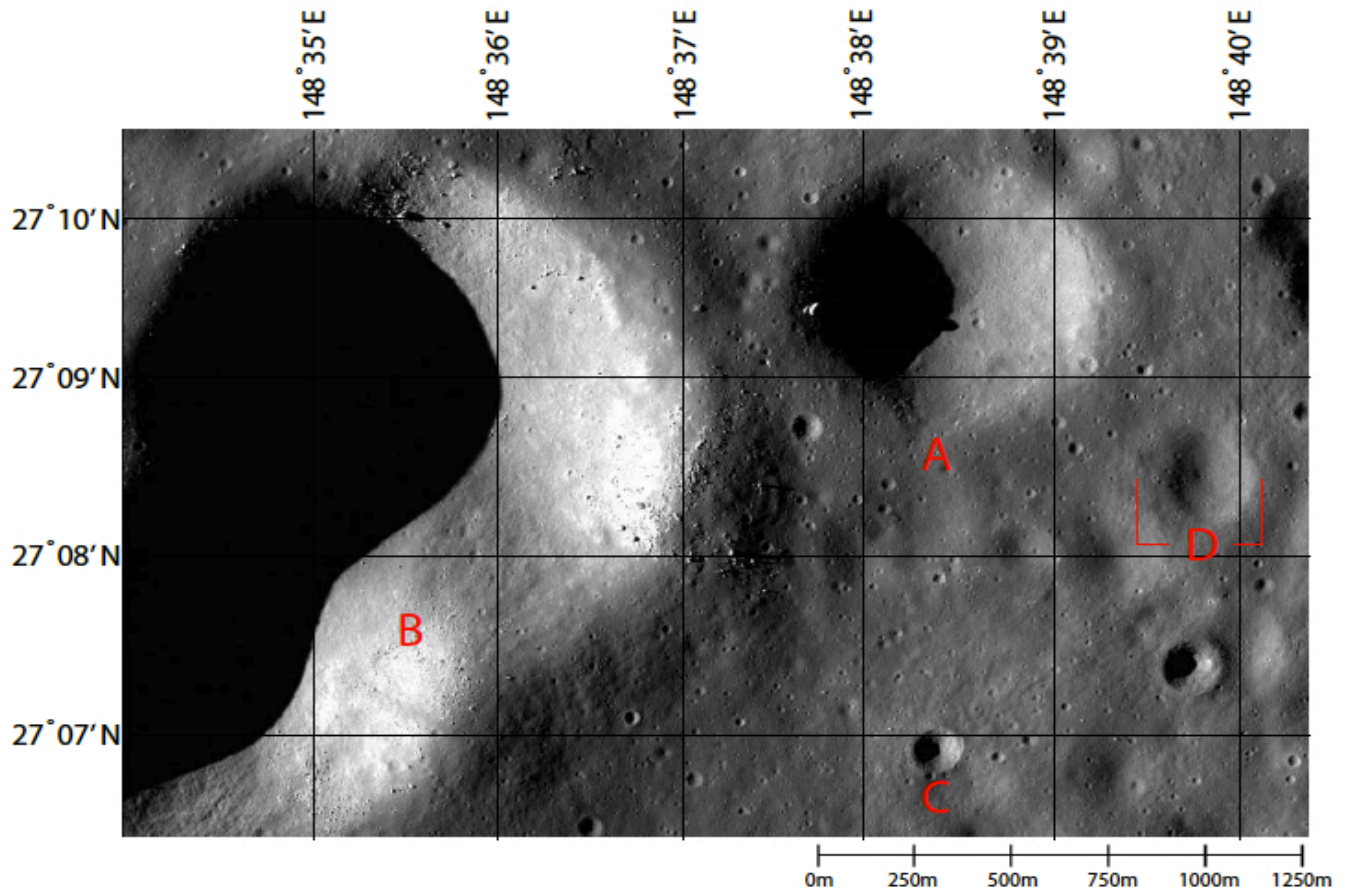
F = 0 - 11 points

**Grade for this Assignment:** \_\_\_\_\_

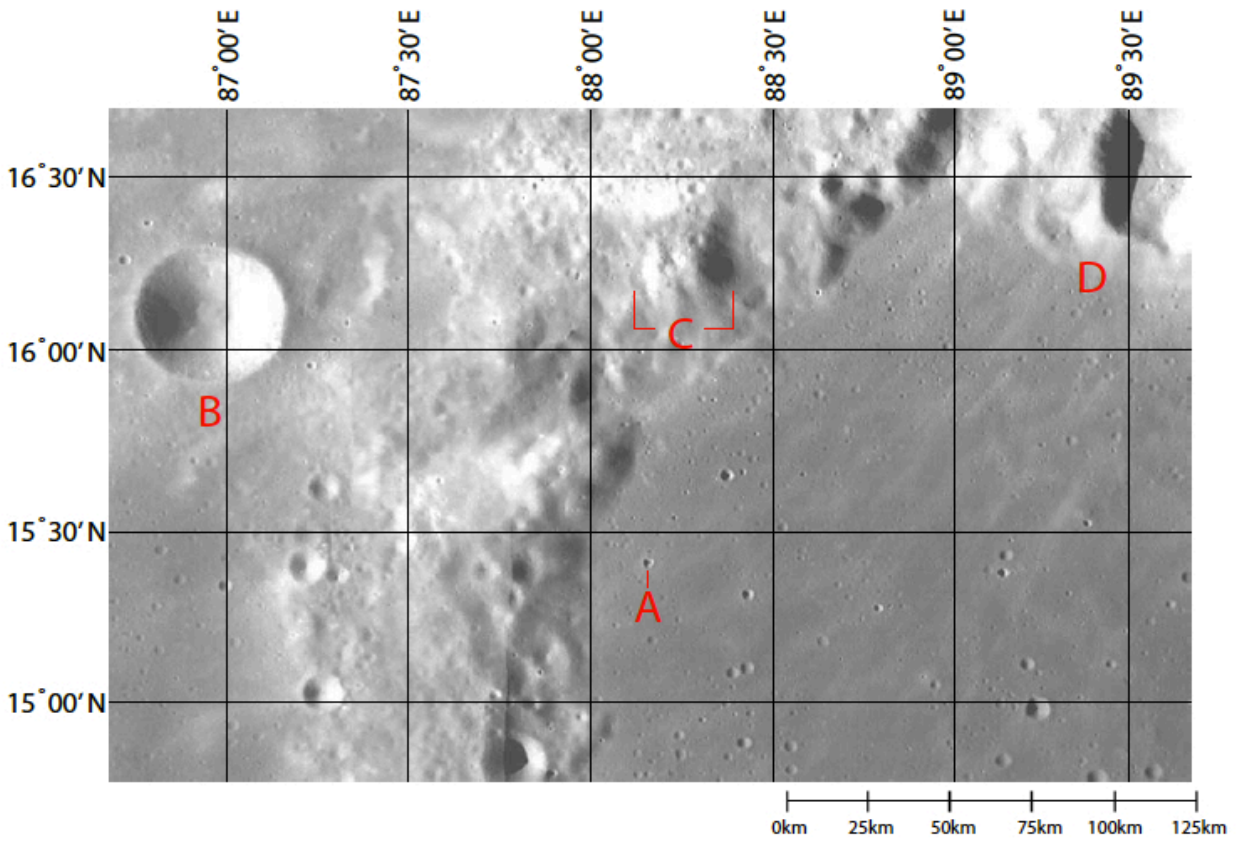
SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:



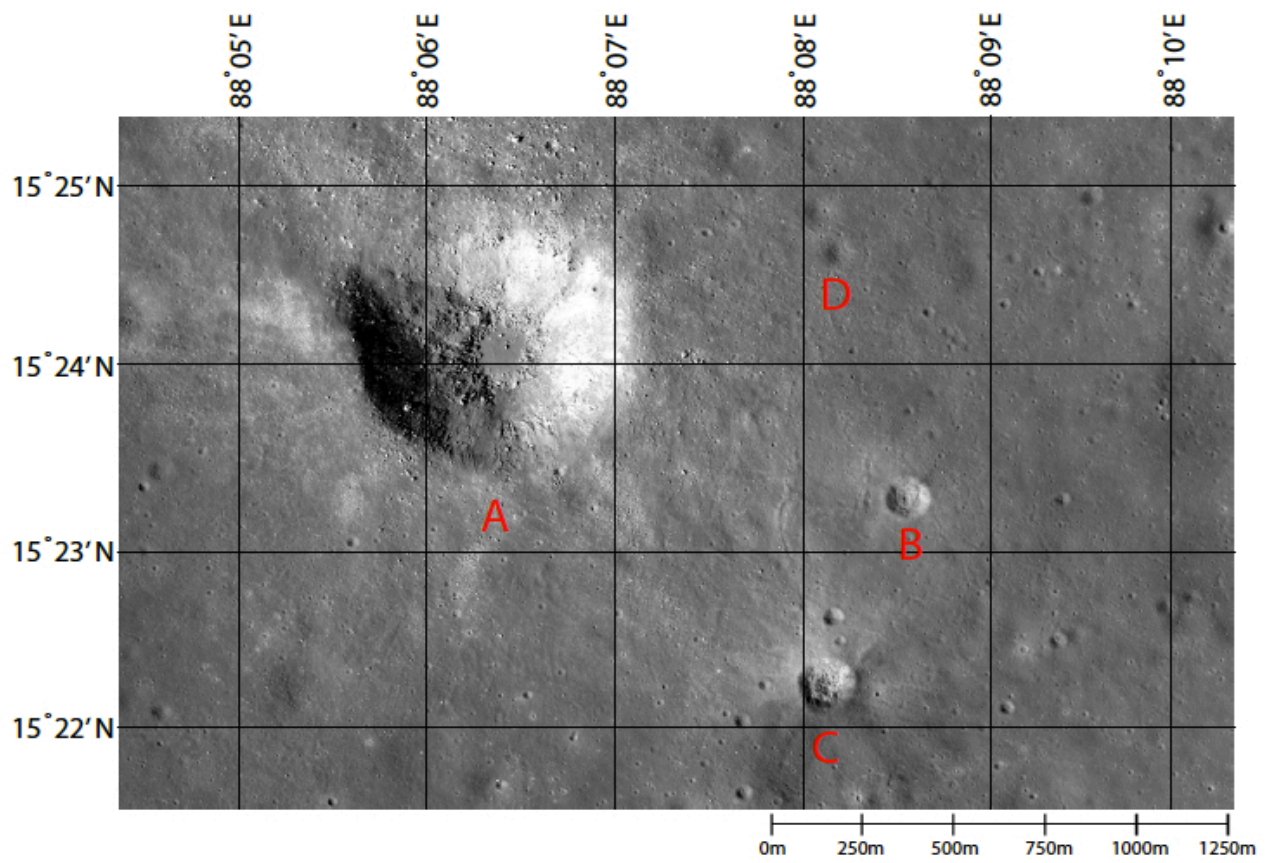
## Moscoviense Region #2



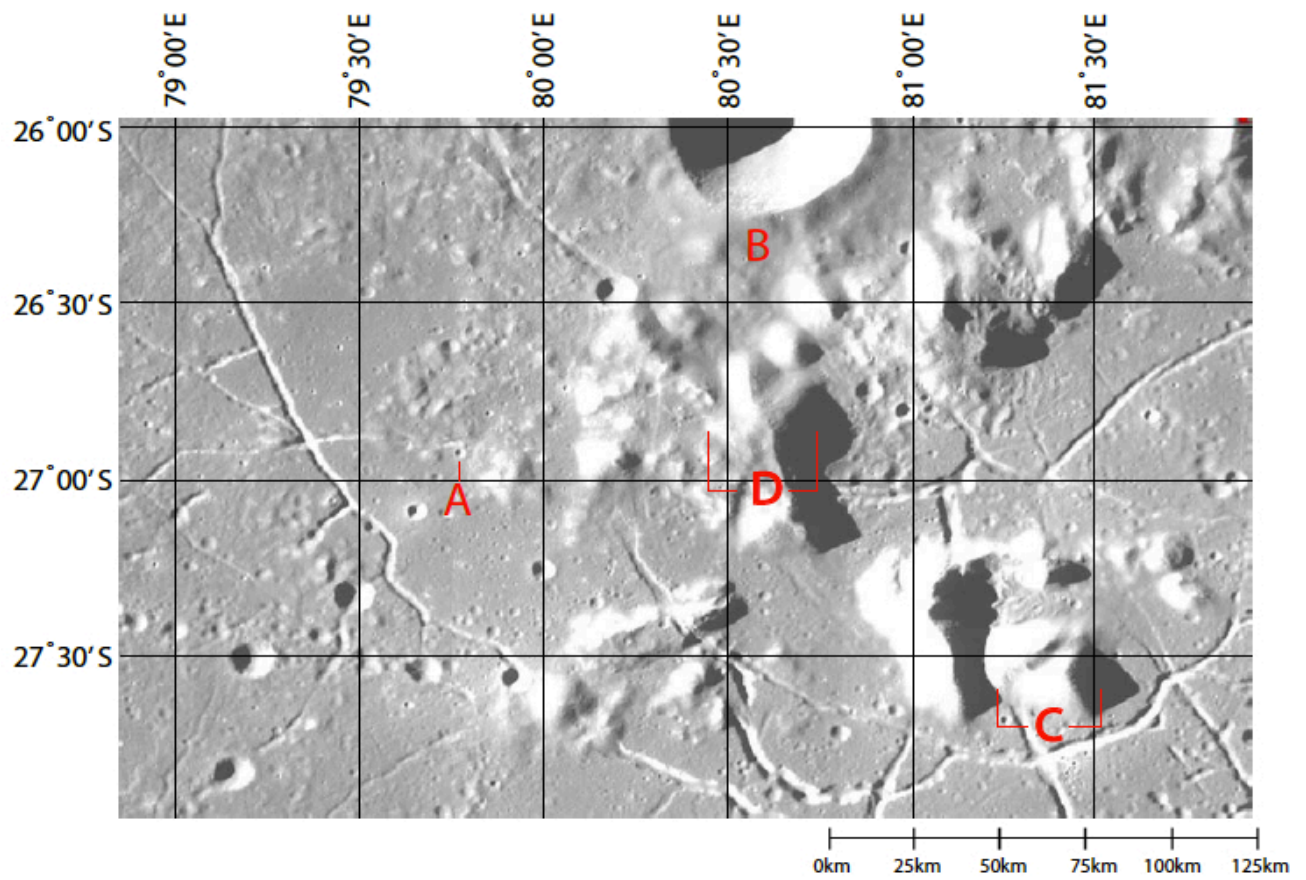
# Goddard Region #1



## Goddard Region #2

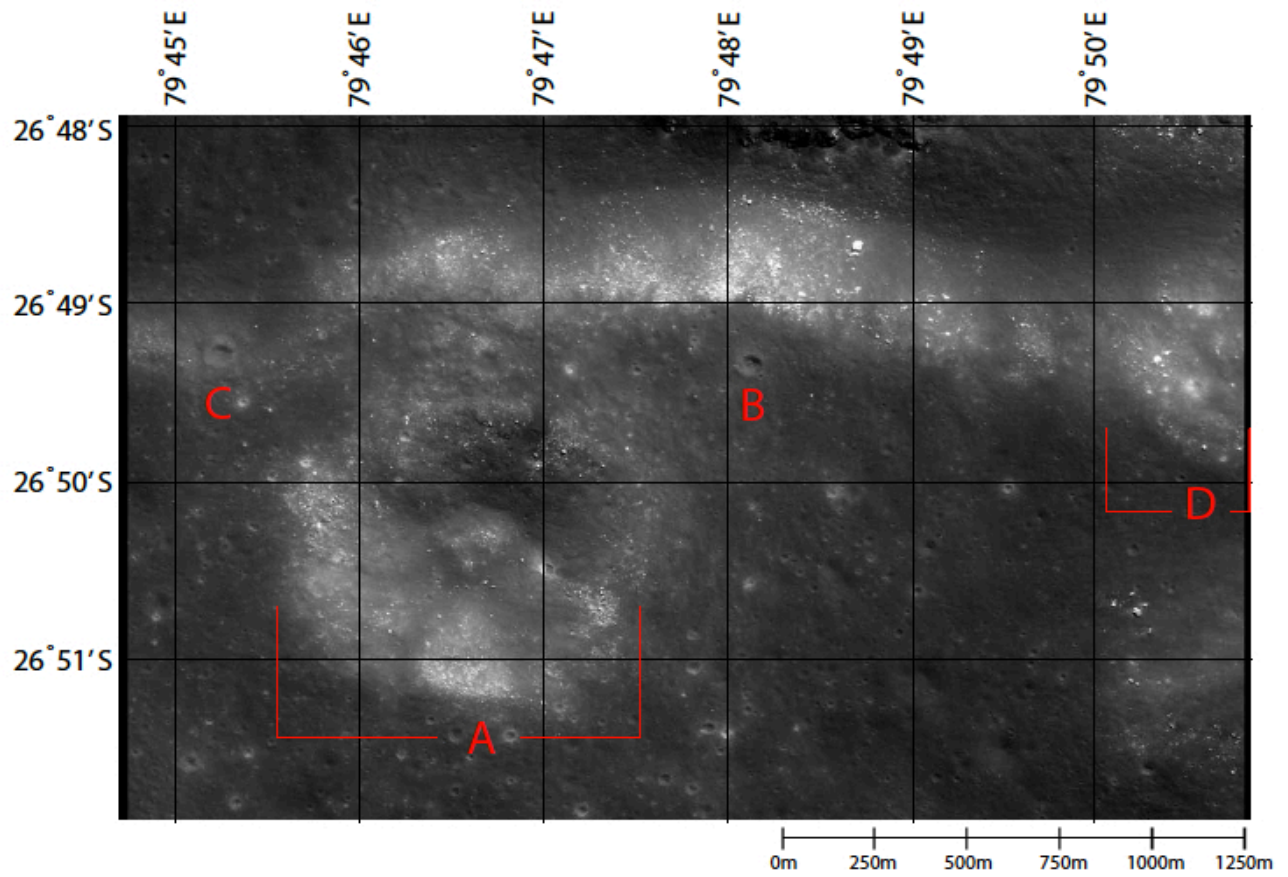


# Humboltanium Region #1

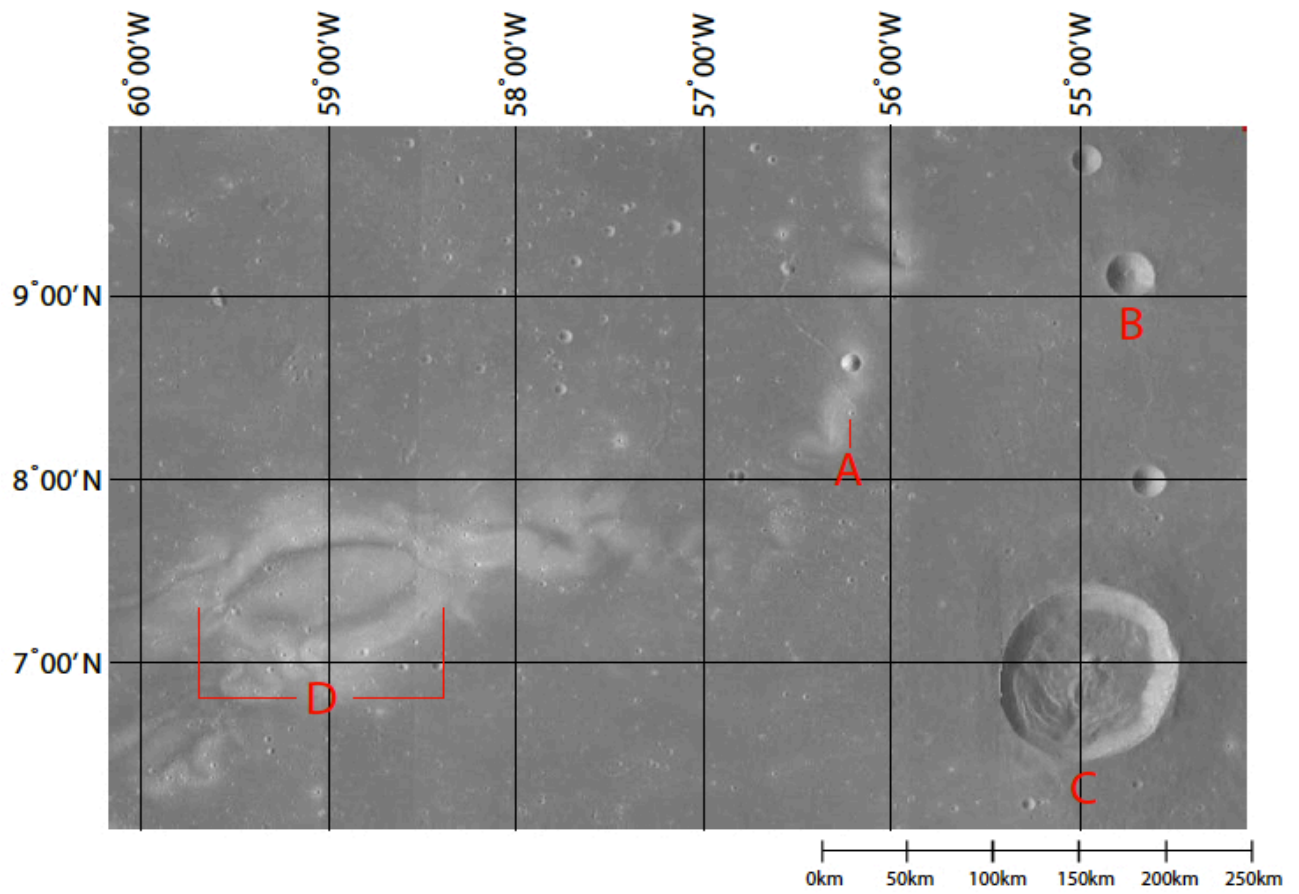




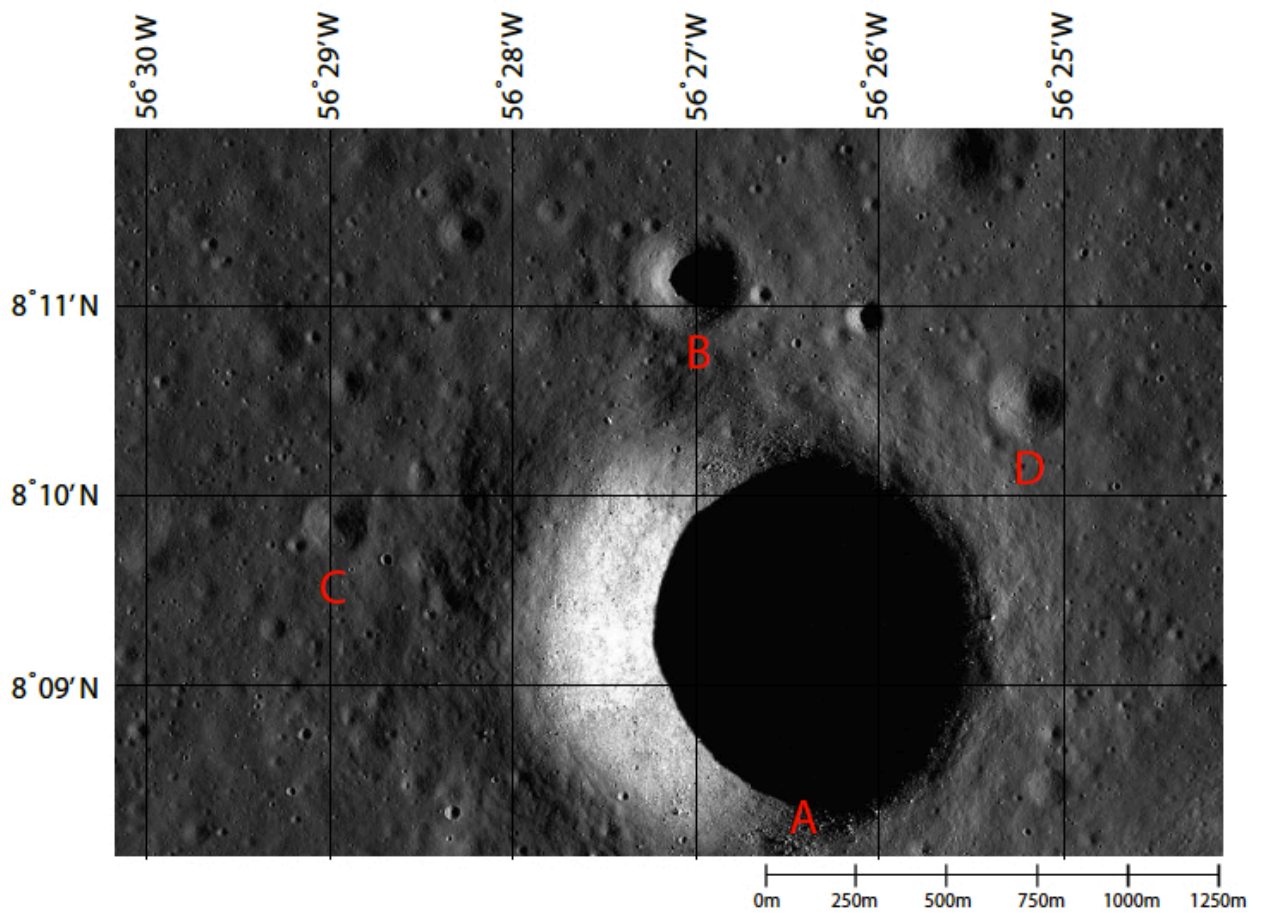
## Humboltanium Region #2



# Reiner Region #1



## Reiner Region #2



## Assessment:

Review the Image Analysis worksheets for evidence of complete and accurate descriptions of objects in the image. Review the landing site selection question for evidence and reasonable conclusions. See attached rubric for a suggestion of how to grade your students' work.

## Extension Activities:

You and your students can help scientists manage and classify images taken by the LROC instrument through a citizen science program called Moon Zoo (<http://www.moonzoo.org>). Students have an opportunity to learn about different features on the Moon and classify images based on their own scientific observations of those features.

Continue to examine other sites on the Moon's surface with a neat tool called "Quickmap" on the LROC website:

<http://target.lroc.asu.edu/da/qmap.html>

This tool will take you from a mosaic of wide angle images of the Moon all the way in to corresponding narrow angle images, so students can really explore in great detail over the whole surface of the Moon!

# Lunar Reconnaissance Orbiter: (LROC/ LOLA)

## Audience

Grades 5-12

## Time Recommended

30-45 Minutes Per Activity (Lesson contains 5 activities)

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

Content Standard D (5-8): Earth and Space Science- Earth's History:

- a. The Earth processes we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. Earth's history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Copies of the student activities (one for each group of 2-3 students)
- Science journals/ notebooks used in class (used throughout each activity)
- Colored pencils
- Pencil/ pens
- Metric rulers
- Scrap paper
- Calculators
- Magnifying glasses (optional)

# Mapping The Surface of the Moon

## Learning Objectives:

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

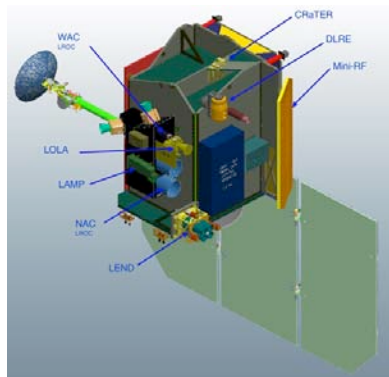
## Preparation:

1. Read and review the background content for all sections you plan to teach and have fun conducting the mapping activities embedded in the teacher background content section and in the student lesson activities before you work with your students!
2. Check the materials list provided to be sure your students will have everything needed to conduct the activities.
3. Conduct a pre-assessment piece to check for prior knowledge and misconceptions. A sample pre-assessment piece is located in the assessment section.
4. Assign groups of 2-3 students. Be sure each group member has a task/ role. One student could be the note-taker, another student the reader, and a third the illustrator. All students would need to complete their science journal work as they progress through the activities you choose to teach.
5. Before delivering the content the students will need, begin a KWL to find out what students already know, what they want to know and to guide them away from misconceptions. Of course, the "L" is done at the end of the activities (what they learned).

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

## Background Information:

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



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

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

### Instruments onboard LRO.

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

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

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

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

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

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

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

## Procedure:

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

## STUDENT ACTIVITY 1

# What Do We See When We Look at the Moon?

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

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

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

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

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

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

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

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

**B.** Before we take a look at the far side of the Moon, let's talk about the motion of Earth and Moon. There is really no 'dark side' of the Moon.

As the Moon orbits Earth, it rotates in a synchronous orbit. This means that it rotates at the same rate that it revolves around Earth. You can model these motions with a classmate and see how it works. Ask a friend to be the Sun and have him/ her stand in one place off to the side of the room. Ask another friend to be the Moon. Ask him/her to move around you in a

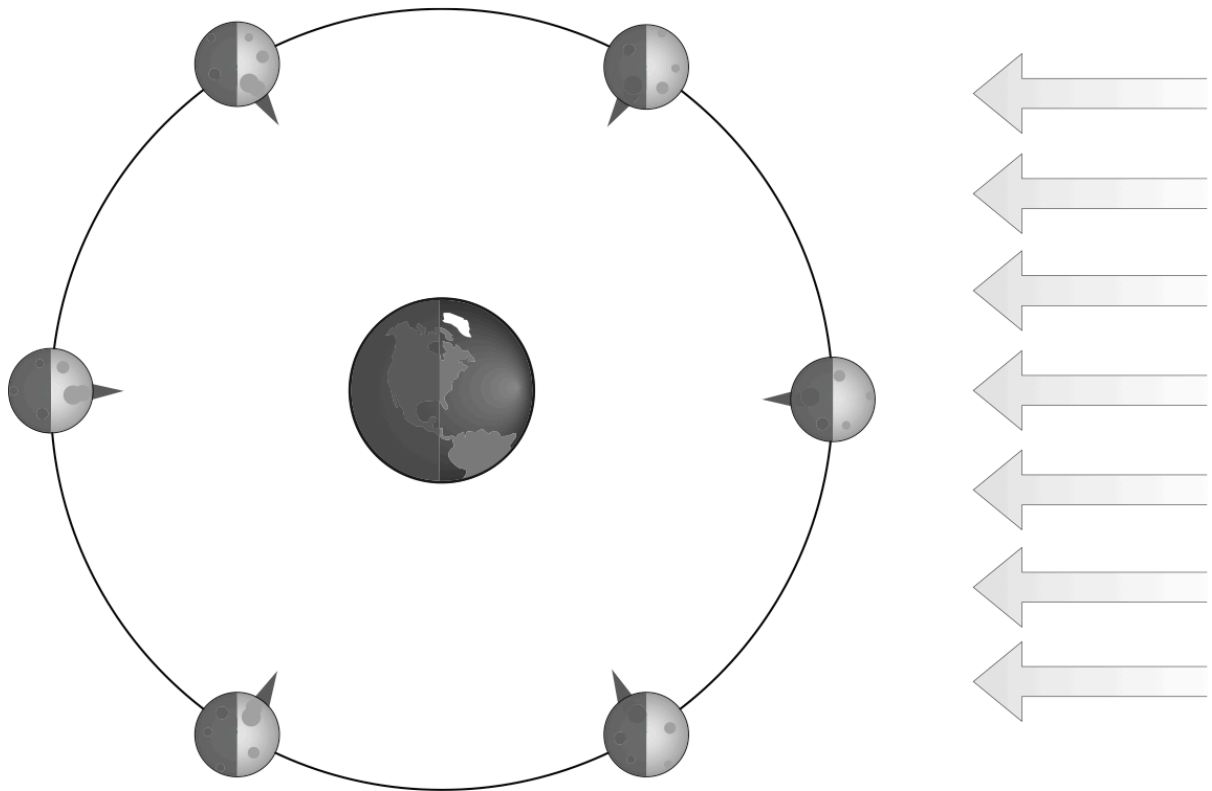


Figure 1. The Moon.





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



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

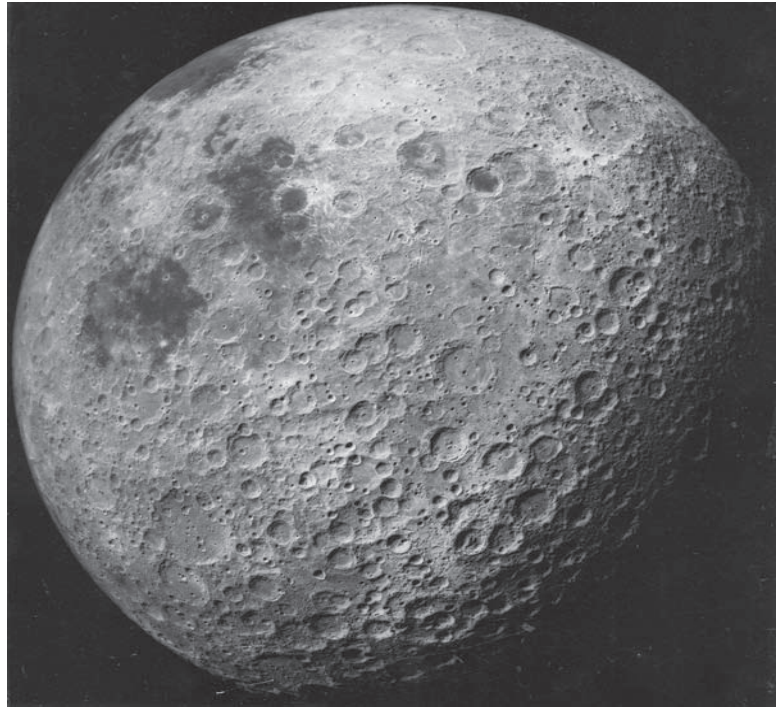
1. What does the drawing tell you about the Moon's far side?
2. Does the far side ever see sunlight? Explain how you have come to know this.
3. Does the way the Moon orbits Earth allow us to see the far side? Explain how you know this.
4. Can you truthfully call the far side the 'dark side'? Explain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

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

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

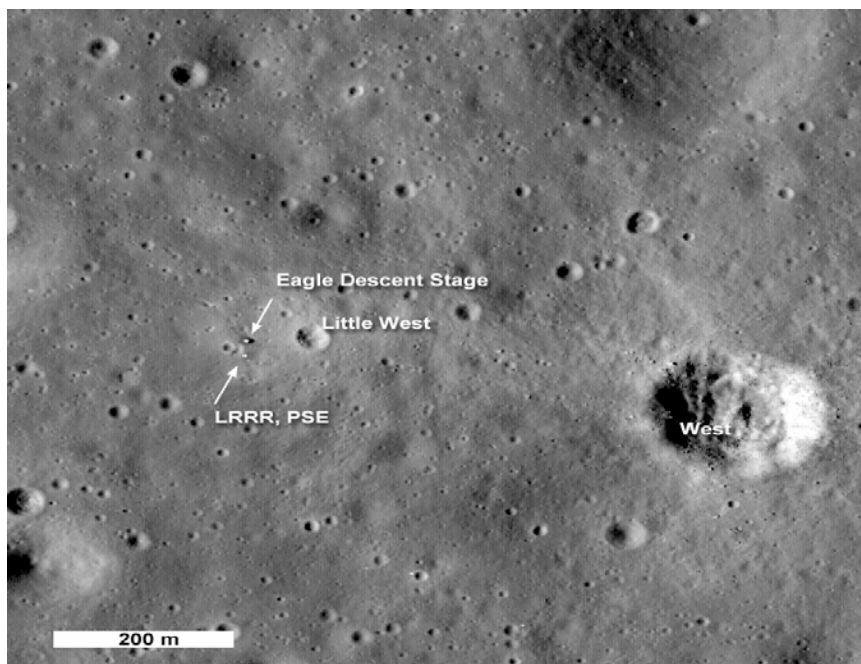
1. Label the mare and lunar highland areas
2. When finished, compare the near side drawing you created with the far side drawing.

3. Answer the following questions and statements in your journal:
  - a. Describe the similarities and differences.
  - b. What are the most noticeable similarities?
  - c. What are the most noticeable differences?
  - d. What makes these features more noticeable to you?
  - e. Why do you think they look so different?



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

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



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

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



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

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

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

## Resources:

**VIDEO:** Here is a video resource that demonstrates how an impactor forms a crater. Simulated Meteor impact in slow motion:  
[http://www.youtube.com/watch?v=Xzlw0c\\_MjTc](http://www.youtube.com/watch?v=Xzlw0c_MjTc)

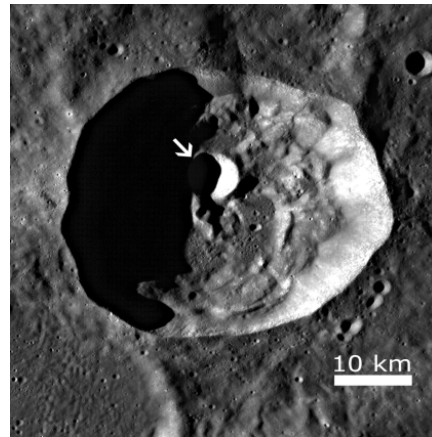
**VIDEO:** Here is a video demonstrating how LRO determines a safe landing place on the Moon:  
<http://www.youtube.com/watch?v=dySd8l6rSEI>

## Impact Craters

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

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

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



**Figure 4.** Credit NASA GSFC/ASU.



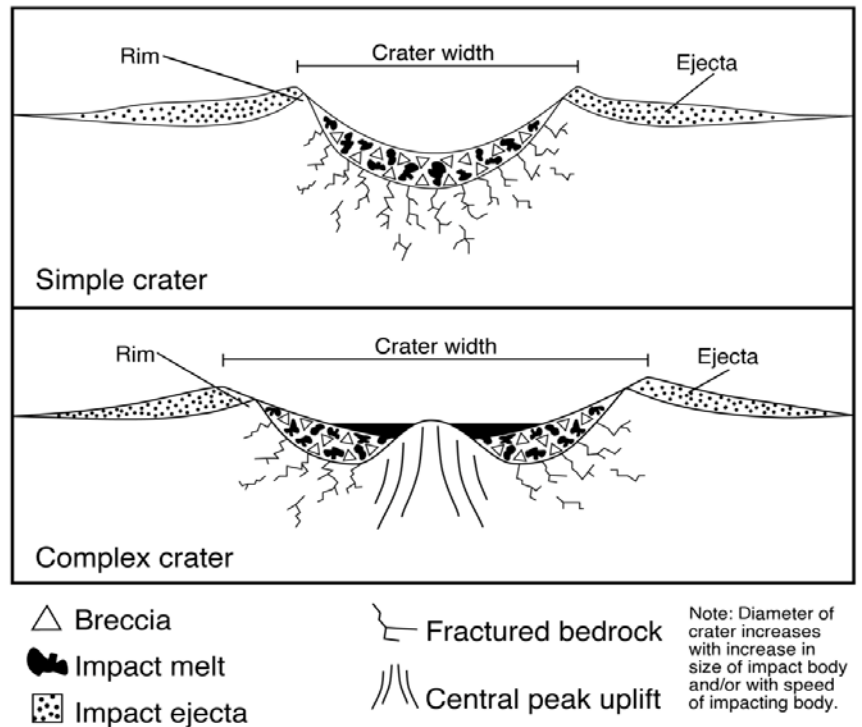
**Figure 5.** Credit NASA GSFC/ASU.

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

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

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

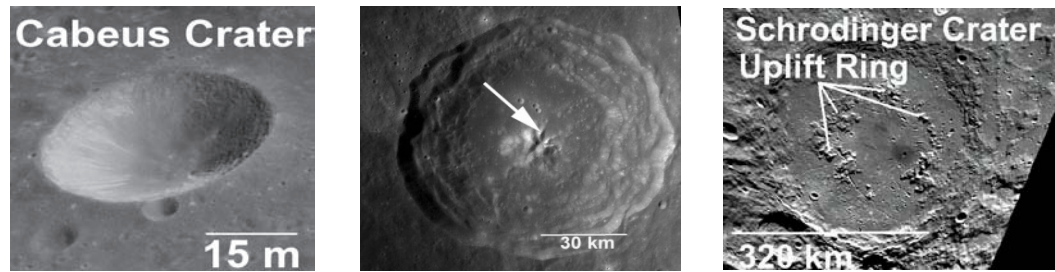
**Figure 6:** This figure shows idealized cross-sections of smaller simple craters (left, top) and of larger, more complex craters (left, bottom). Simple craters have bowl-shaped depressions with rim diameters of less than about 15 kilometers. Craters with diameters larger than 15 kilometers have more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



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

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

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

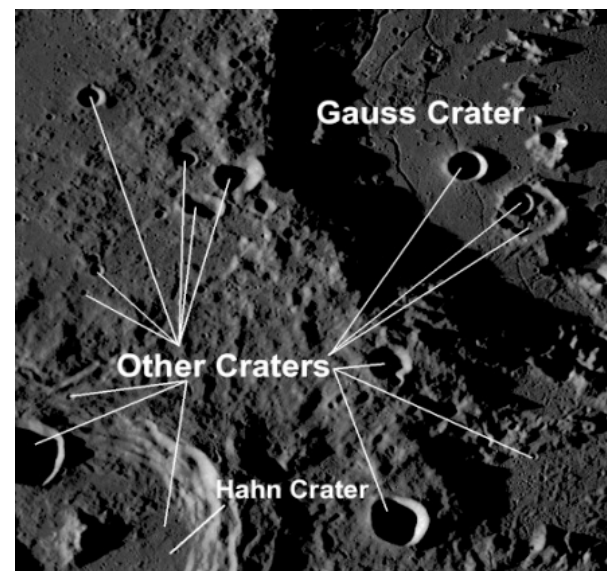


**Figure 7. Credit: NASA GSFC/ASU.**

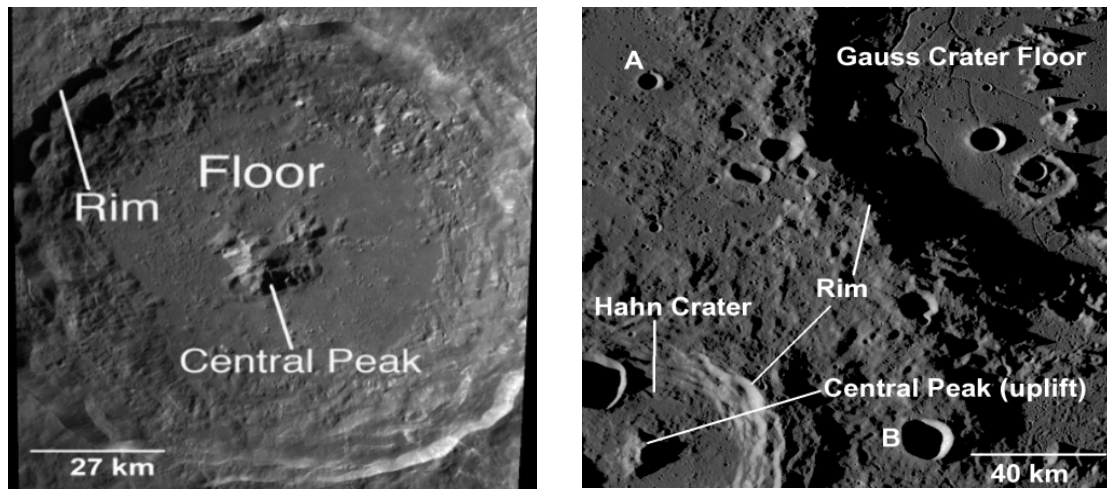
Now, let us look at images of real craters on the Moon and apply what we now know, one feature at a time. The image below is of the craters Gauss and Hahn, both being complex craters. Craters similar to these are found on the Moon, Earth and Mars. So, you might ask why we do not see all of these craters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

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

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



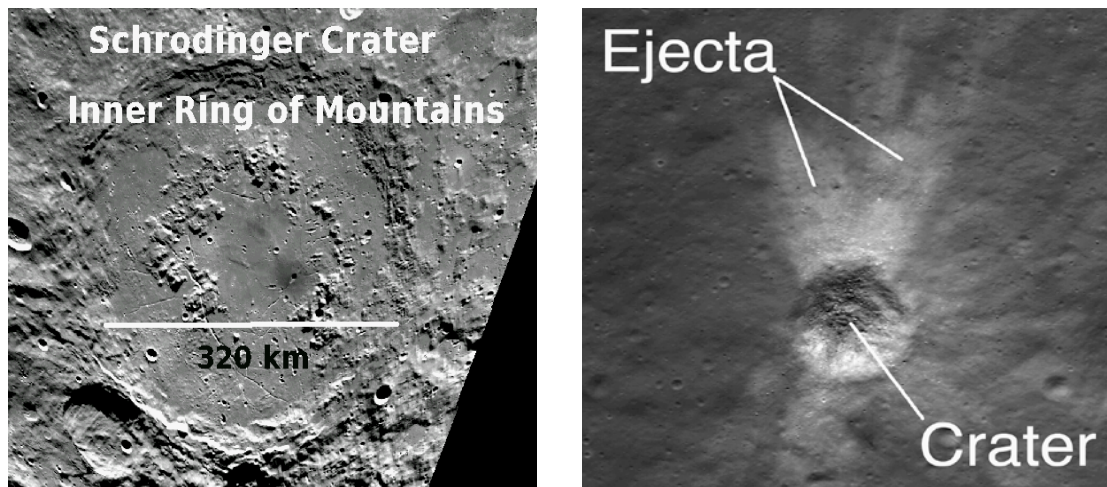
**Figure 8. Credit NASA GSFC/ASU.**



Figures 9 and 10. Credit NASA GSFC/ASU.

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

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



Figures 11 and 12. Credit NASA GSFC/ASU.

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

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

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

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

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



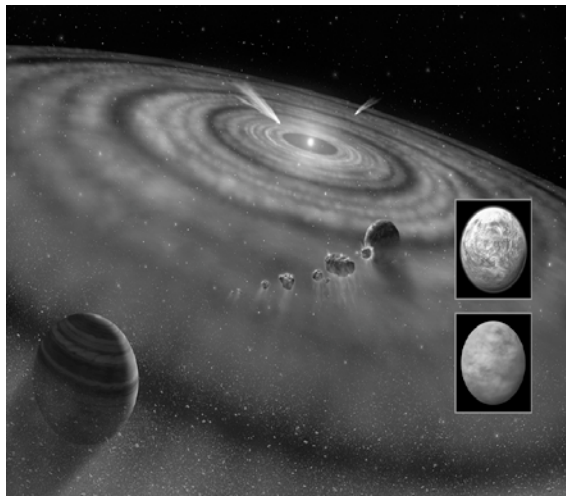
**Figure 13.** Credit NASA GSFC/ASU.



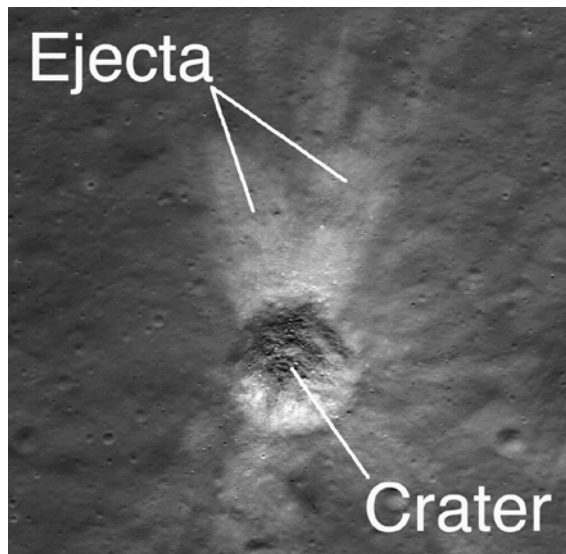
**Figure 14.** Credit NASA GSFC/ASU.

## STUDENT ACTIVITY 2

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



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



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

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

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

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

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

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

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

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



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

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

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

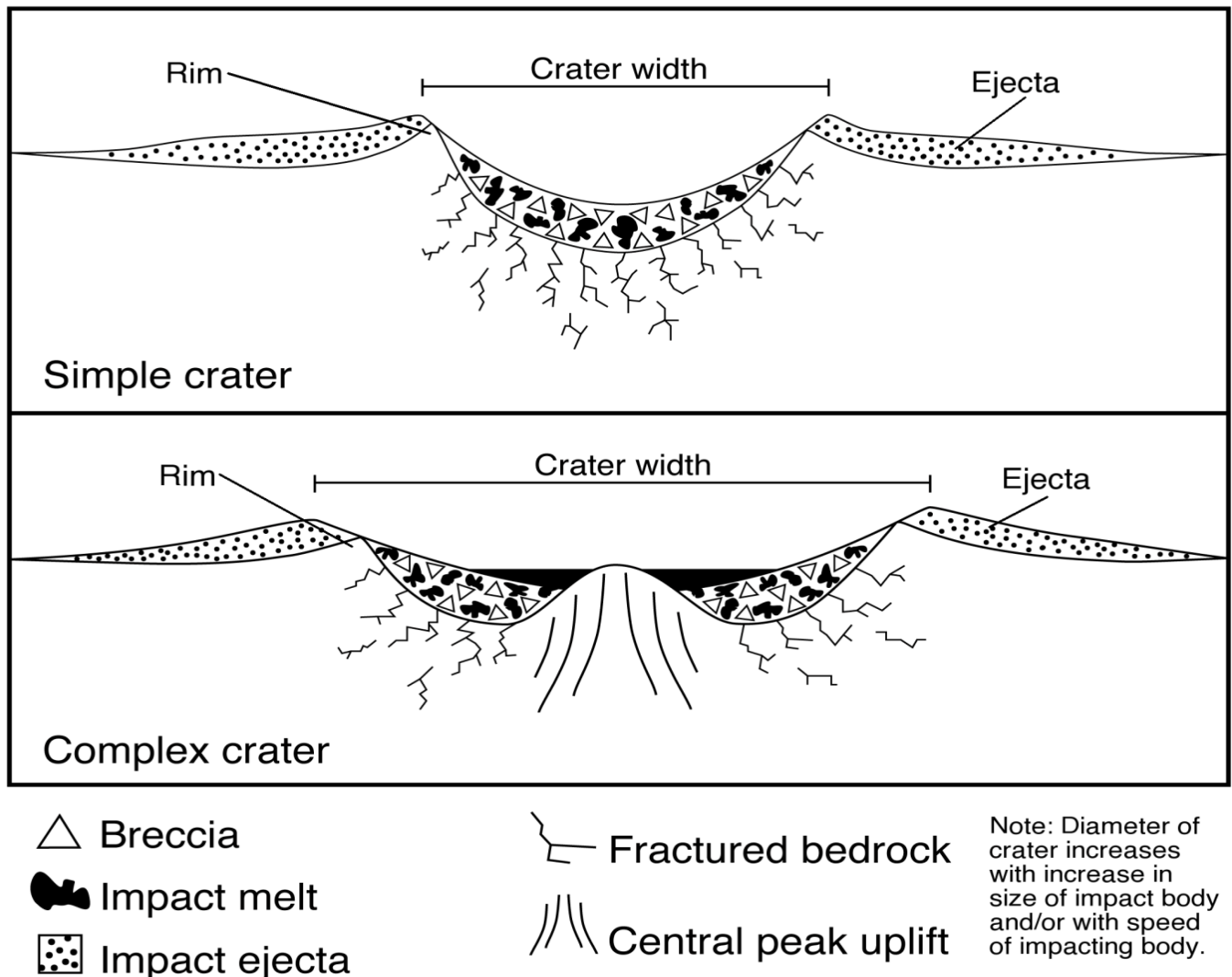
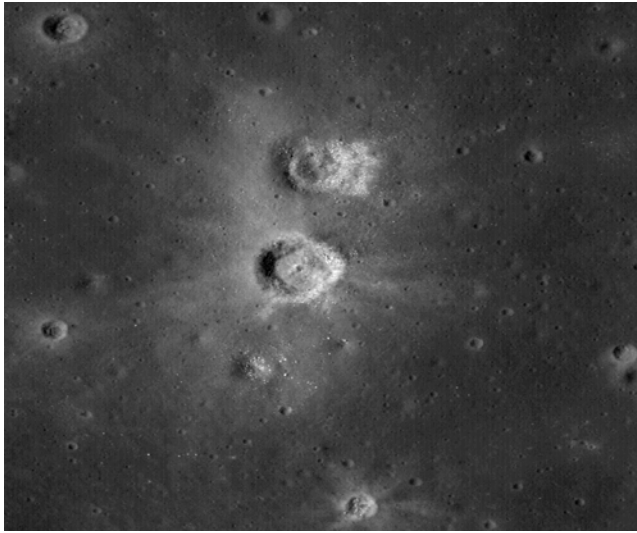


Figure 17.

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

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

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



**Figure 18.**



**Figure 19.**

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

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



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

[www.nasa.gov](http://www.nasa.gov)

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

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

Here are some helpful hints to get you started:

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

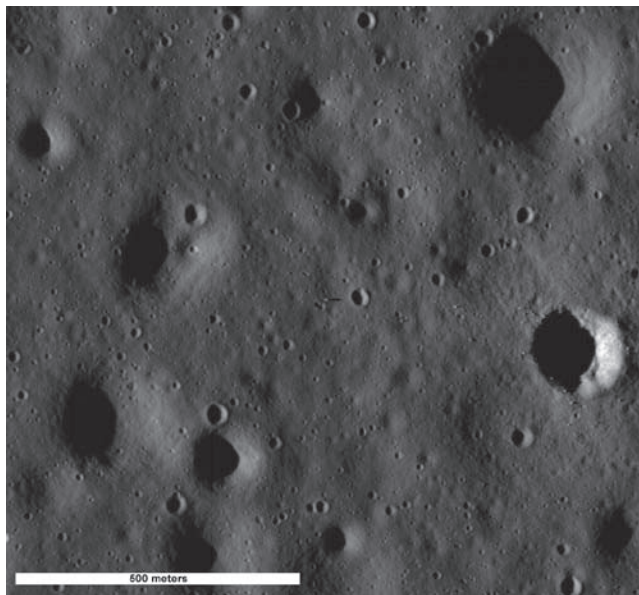
5. Can you see any central peaks or inner rings of mountains?
6. Can you identify the crater floors?
7. If the top of the image is north, from what direction is the Sun shining?
8. How do shadows change how you can see features on the surface of the Moon?
9. There are some craters on the Moon that are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

**D.** How does sunlight change what you see?

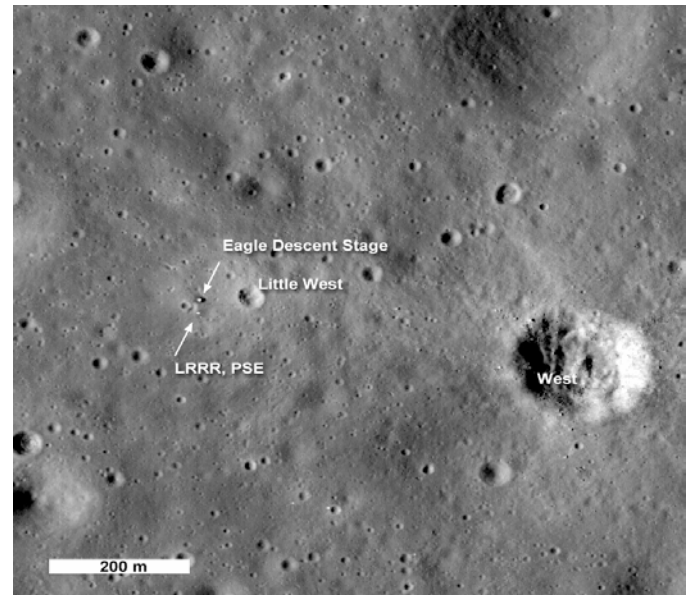
**Directions: The different angles of the Sun allow scientists to see surface features in different ways. In images A and B below, look at the shadows and light, read the following questions, and answer them in our journals (Be sure to use the resources in the supplemental materials section):**

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

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



**Figure 21.**

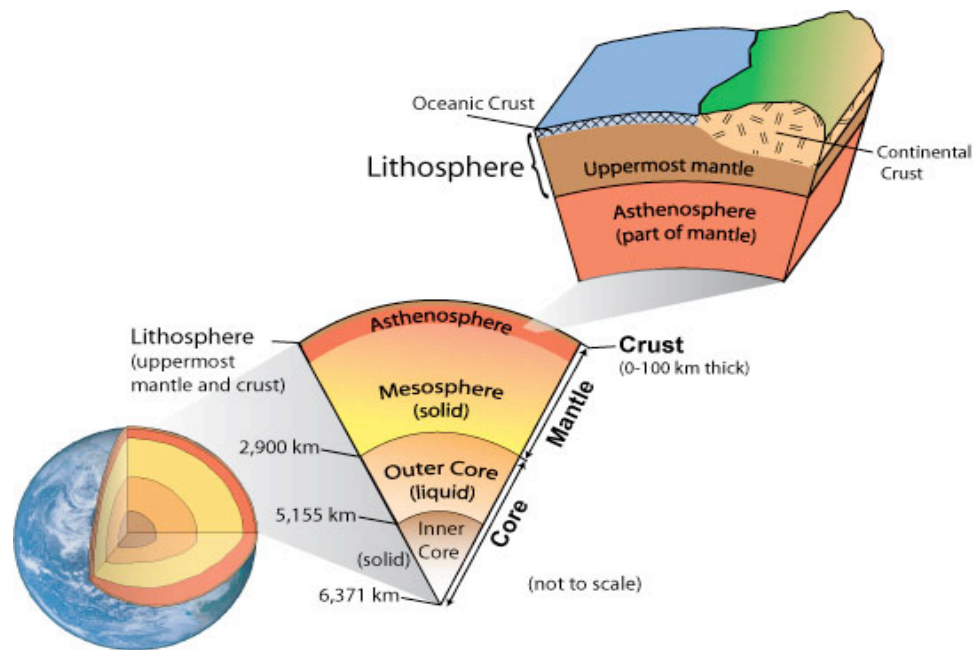


**Figure 22.**

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

## Volcanoes

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



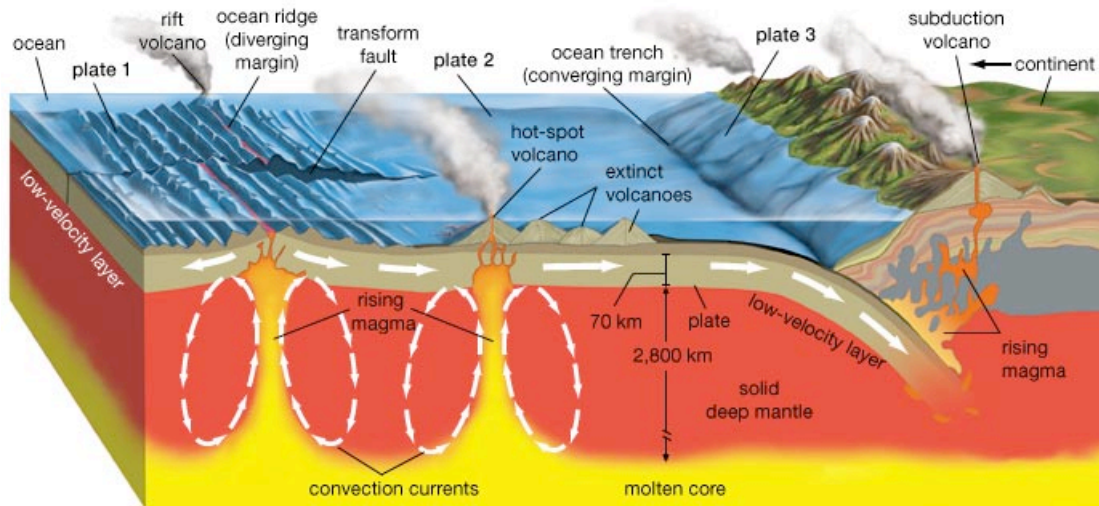
**Figure 23. A schematic of the layers of the Earth illustrating the layers and the approximate depth for each layer. Credit: USGS**

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

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

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

Also important to note is that the type of volcano, and the kind of volcano that forms as a result of volcanic activity, is usually dependent upon the composition of the melted rock below the surface, or magma. Continental crust is composed mainly of lighter, less dense silicate minerals, such as feldspars and quartz (SiO<sub>2</sub> quartz). Oceanic and mantle materials are darker, denser basaltic rocks higher in iron and magnesium. The higher silica (SiO<sub>2</sub> quartz) content in continental crust causes the magma



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

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

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

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

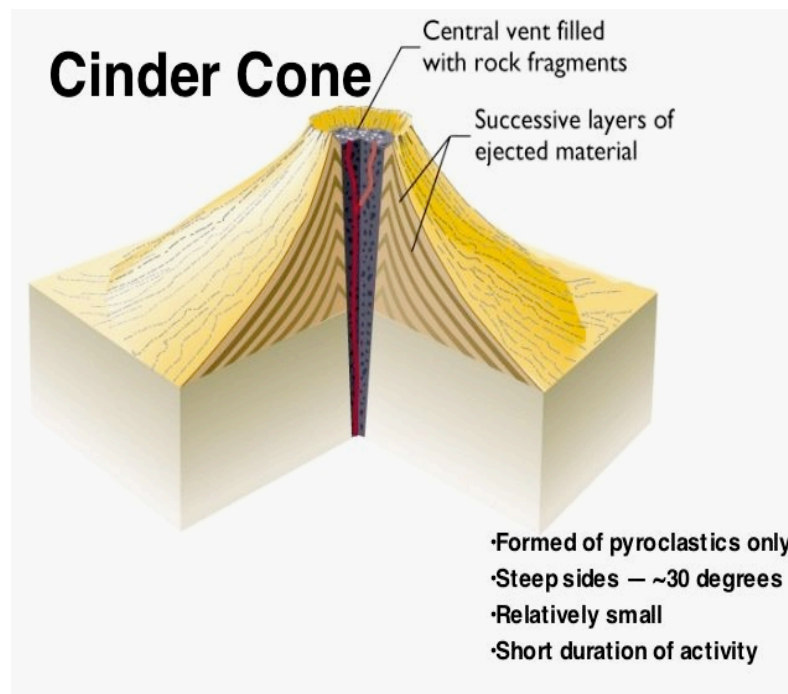
There are three major types of volcanoes with classifications based on how they erupt and how they form. Remember that volcanic eruptions and formation is dependent upon the composition of the magma. The major volcano types are shield, cinder cone, and composite (stratovolcanoes).

Shield volcanoes are low in silica ( $\text{SiO}_2$  quartz), usually contain higher amounts of iron and magnesium, and lava flows are generally not explosive (less resistant to movement means lower viscosity). The domes of shield volcanoes are much wider than they are high (shaped like a shield) and have very low-angle slopes (see Figure 25 on next page). They are formed from hot, free-flowing silica-poor basalt in non-explosive lava flows. The largest volcano on Earth is a shield volcano called Mauna Loa. It rises over 9 km (5.4 miles) from its base on the sea floor! The uppermost portion of Mauna Loa is the "Big Island" of Hawaii. The largest volcano in the solar system, Olympus Mons on Mars, is also a shield-like volcano. Olympus Mons is almost 27 km (17 miles) high and its base is almost 700 km (430 miles) across. On Earth, it would cover an area the size of Arizona!



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

Cinder cones are the simplest type of volcano. They are built from particles and blobs of congealed lava usually ejected from a single vent (Figure 26). Gas-charged lava is blown violently into the air and breaks into small fragments that solidify and fall as cinders around the vent forming a circular or oval cone (Figure 27). Most cinder cones have a bowl-shaped crater at the summit and rarely rise more than a thousand feet or so above the surrounding land. Cinder cones are numerous in western North America and throughout other volcanic terrains of the world. The most famous cinder cone on Earth appeared in a Mexican farmer's cornfield in Parícutin in 1943. The cinder cone erupted for nine years and reached a height of over 400 meters (1300 feet)! Fact or Fiction, it is reported the farmer charged a fee for tourists to watch this awesome site, and made more money in tourism than he ever made farming.



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



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

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

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

# Composite volcano

- Alternating pyroclastic layers and lava flows
- Slopes intermediate in steepness
- Intermittent eruptions over long time span
- Mostly *andesite*

**Distribution of stratovolcanoes is primarily on the Pacific rim and the Mediterranean**

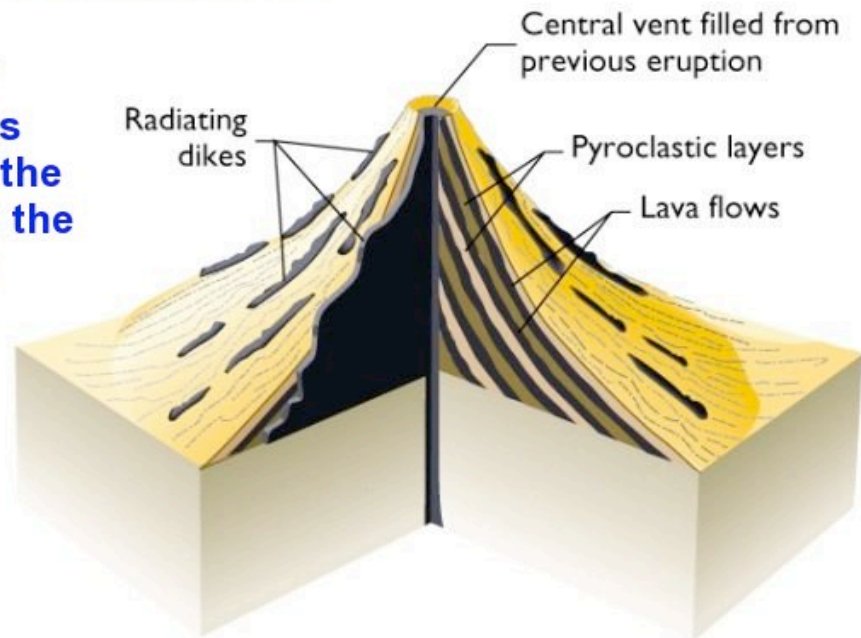


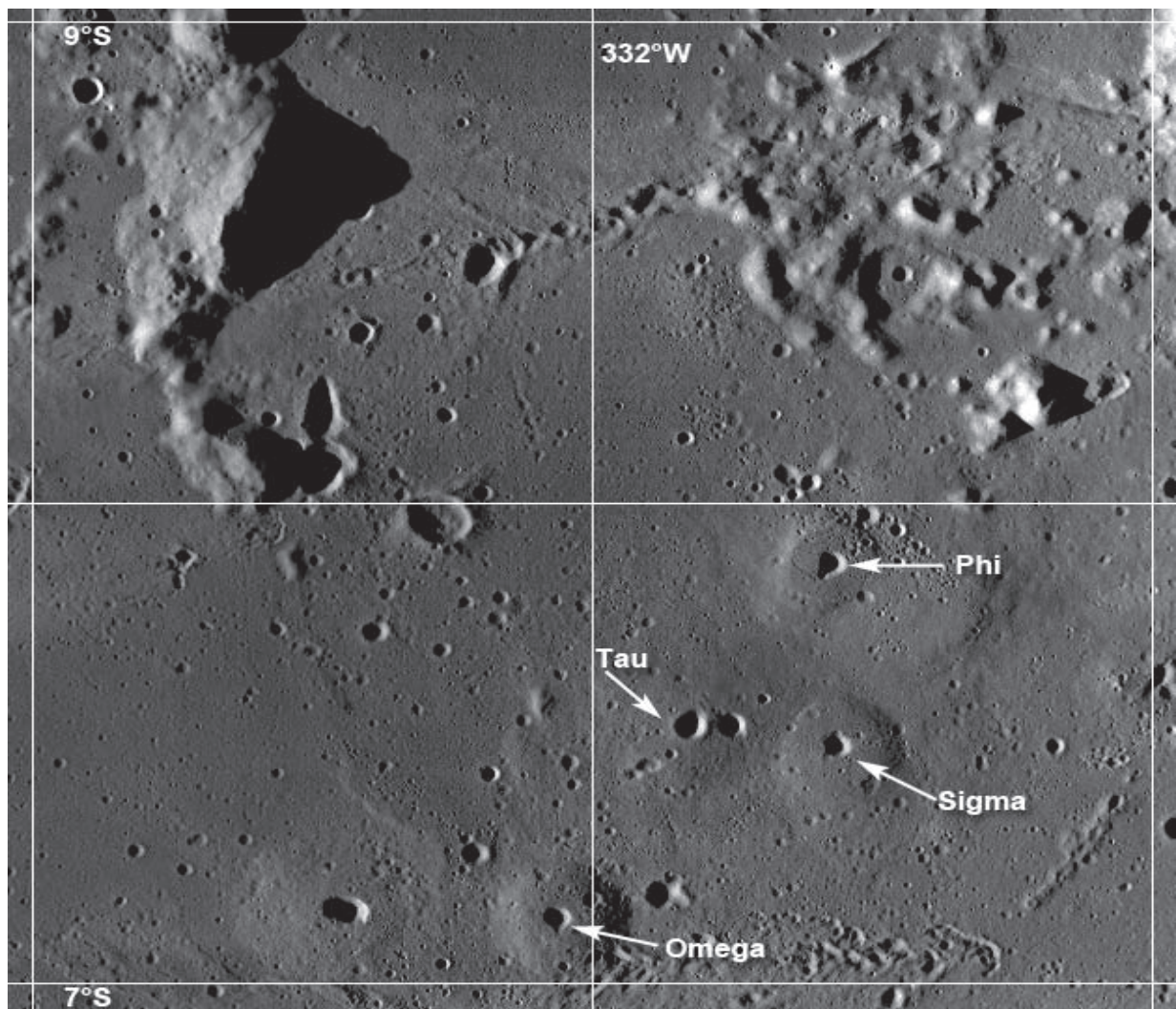
Figure 28. Classic example of the composite or stratovolcano, this diagram illustrates the alternating types of eruptions that identify the volcano type. Alternating eruptions of pyroclastic layers and lava flows composed of highly viscous silica minerals, these volcanoes can explode viciously spewing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



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

## Volcanoes and the Moon

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



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



## Rilles

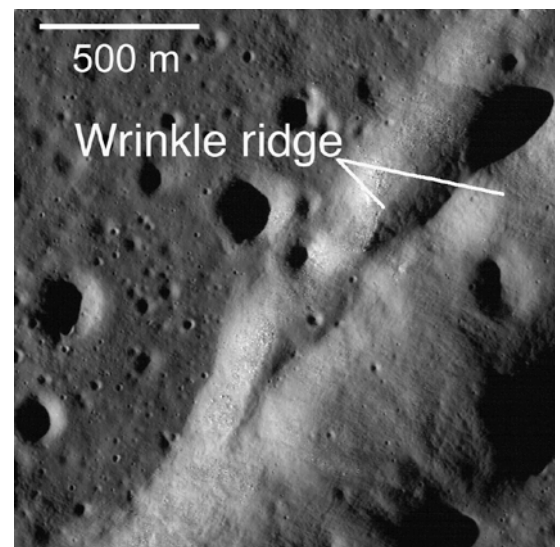
A rille is any of the long, narrow depressions in the lunar surface that resemble channels. They may be linear or sinuous (curvy) and can stretch up to several kilometers wide and hundreds of kilometers in length. They often originate and occur down slope from irregular depressions. They are believed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



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

## Wrinkle Ridges

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



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

## STUDENT ACTIVITY 3

# Volcanoes on the Moon

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

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

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

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

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



Figure 34. Credit: NASA JSC.

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

1. Knowing that the volcanic dome located at the arrow on the right is 13 km wide, what is the distance between the two arrows (volcanoes)?
2. The flat areas in the image are maria. What other features can you identify in this image?

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

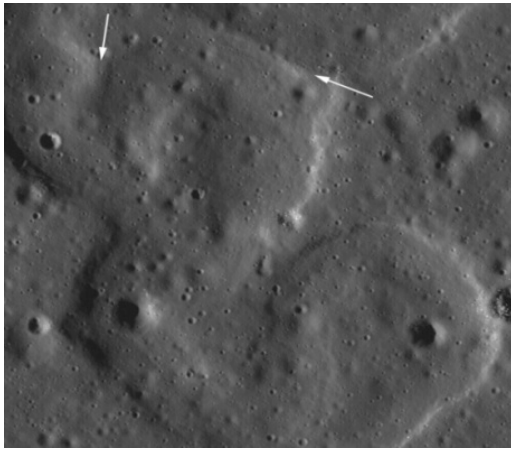


Figure 35.

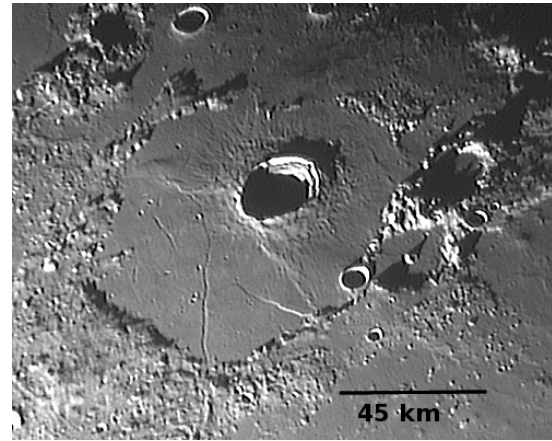


Figure 36.

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

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

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

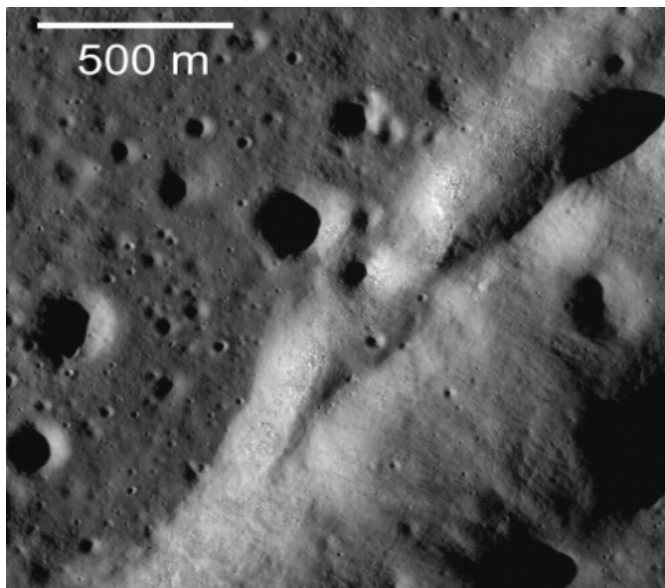


Figure 37. This wrinkle ridge image is found on the Moon. It cuts across the plains of Mare Imbrium. The overall ridge is about 4.5 km wide. Credit: NASA GSFC/ASU.

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

## Determining the Surface History

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

### The Principle of Superposition

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

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



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

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

### The Principle of Crosscutting Relationships

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

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

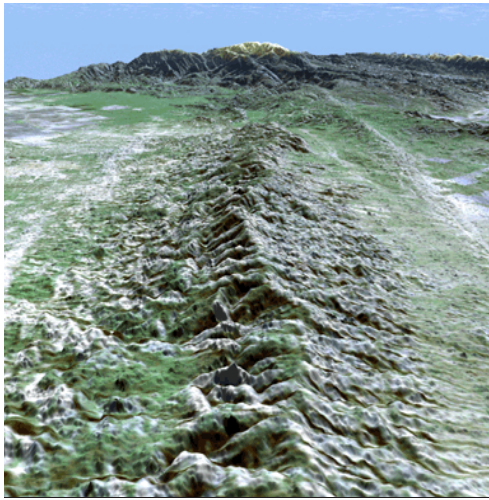


Figure 39. Credit: NASA APOD

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

## The Principle of Horizontal Bedding

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

## STUDENT ACTIVITY 4

# Studying the Geologic Past

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

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

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



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

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

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

1. Label the craters in your drawing of the image above. Now, can you identify which craters happened before other craters? In other words, can you recreate the history of when each impact crater was formed?
2. Look at the shadows in the craters. If the top of the image is north, from what direction is sunlight hitting the craters?

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

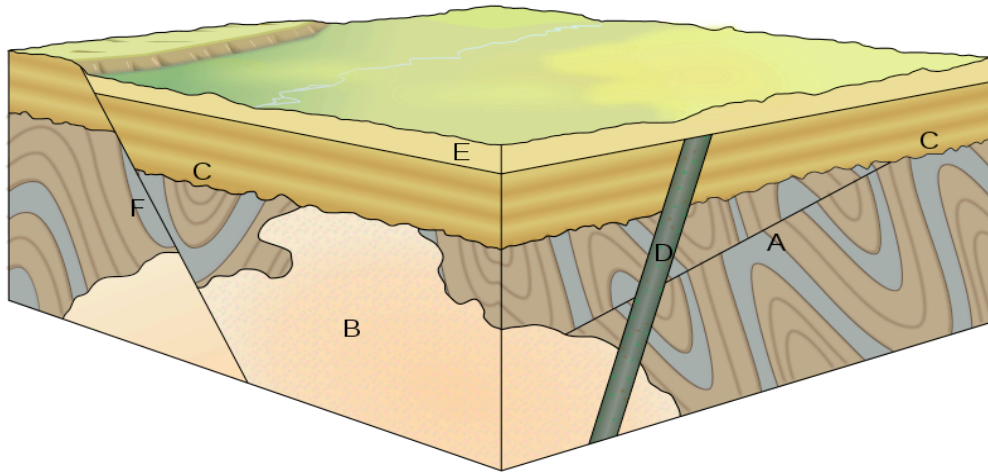


Figure 41.

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

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

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

For example, we might say that:

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

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



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

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

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

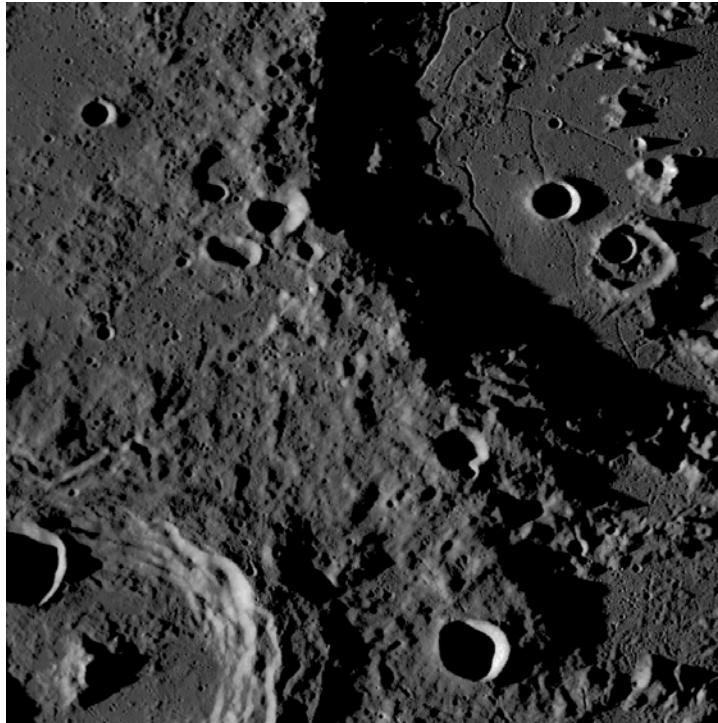


Figure 42.



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

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

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

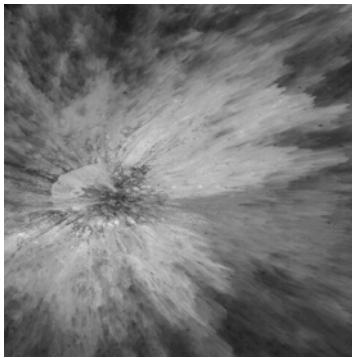


Figure 43.

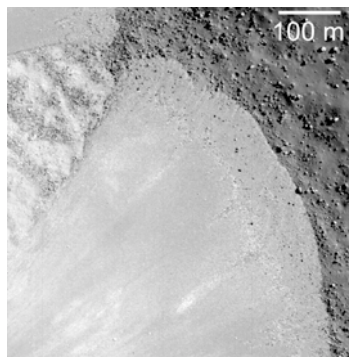


Figure 44.

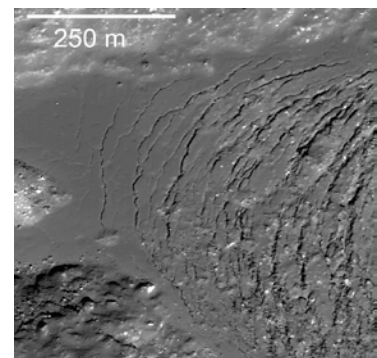


Figure 45.

## And Now LOLA, the Lunar Orbiter Laser Altimeter!

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

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

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

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

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

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

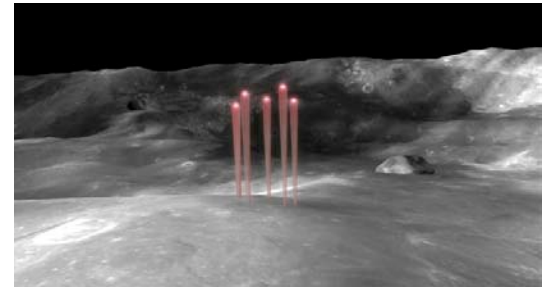


Figure 46. Credit: NASA/ASU.

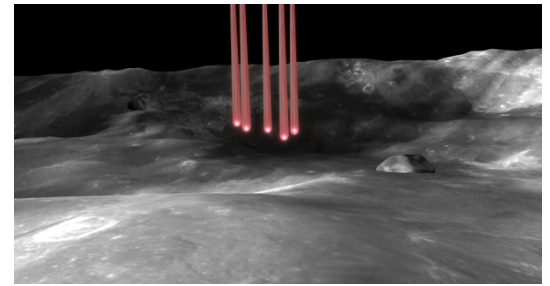


Figure 47. Credit: NASA/ASU.

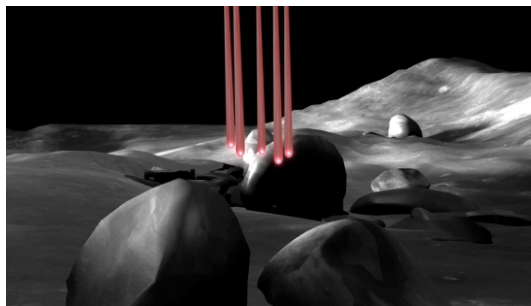


Figure 48. Credit: NASA/ASU.

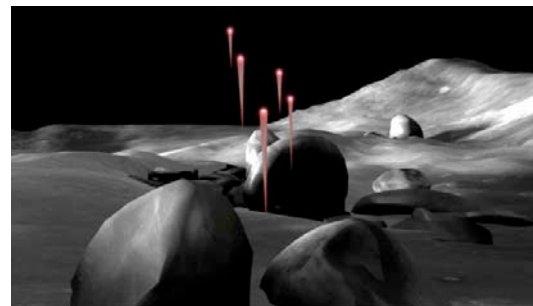
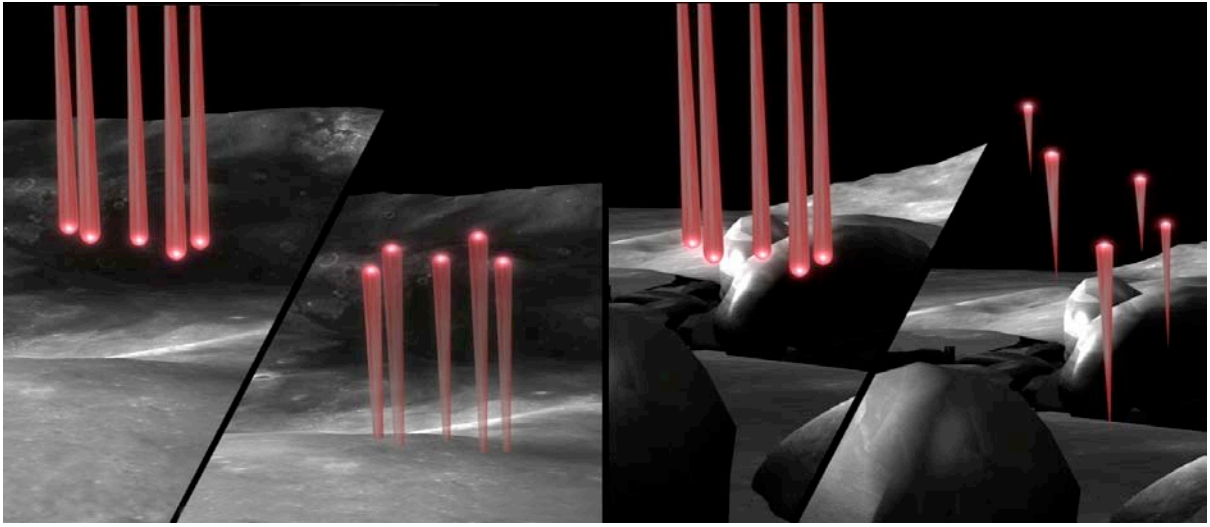


Figure 49. Credit: NASA/ASU.

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



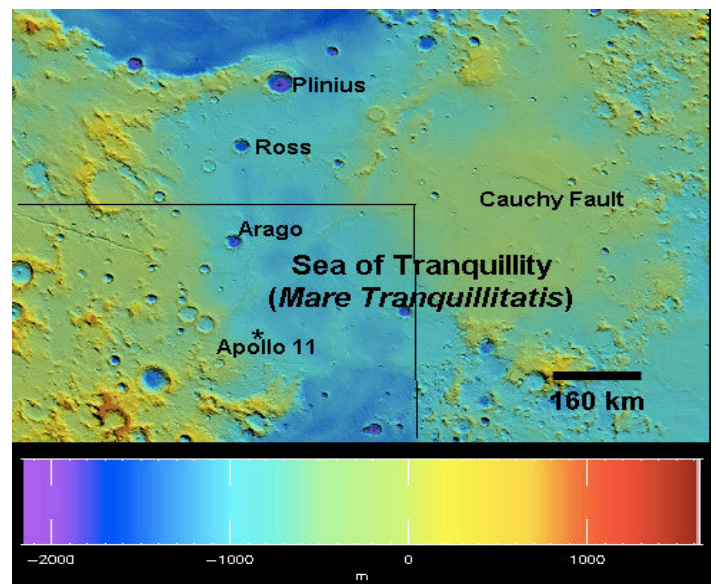
**Figures 50 and 51. Credit: NASA/ ASU.**

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

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

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

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



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

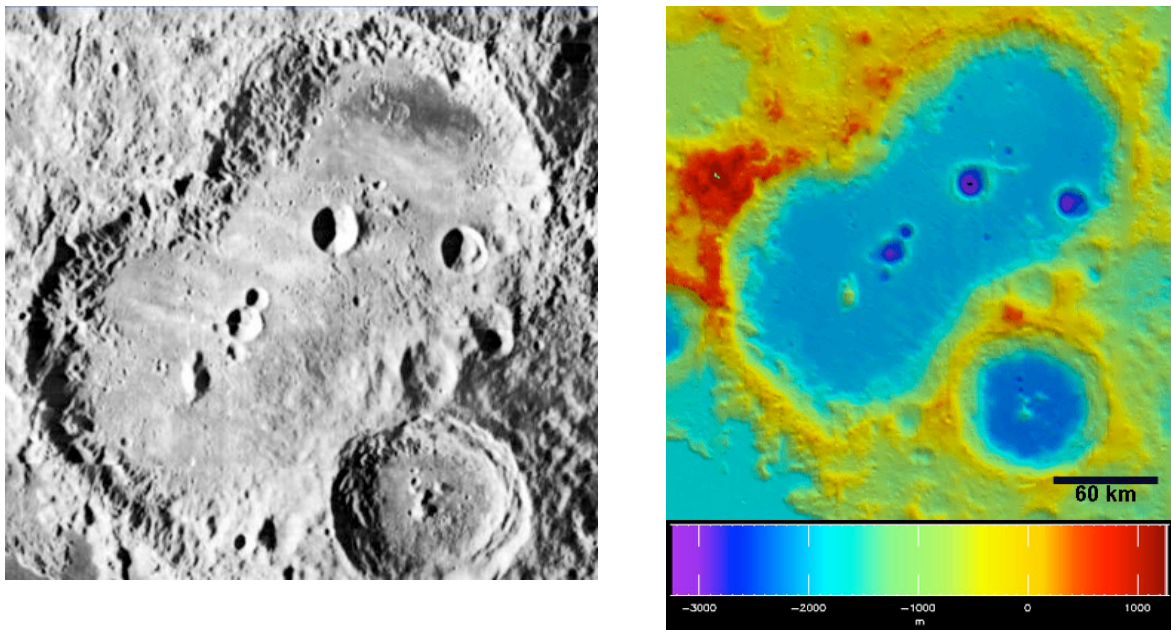
## STUDENT ACTIVITY 5

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

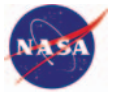
The Lunar Orbiter Laser Altimeter (LOLA) instrument is controlled from NASA's Goddard Space Flight Center in Greenbelt, Maryland. It sends an infrared laser pulse toward the Moon. Then the pulse is split into five beams using a diffractive optical element (DOE). LOLA measures the time it takes for the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

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

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



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



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

1. Compare the two images carefully and explain the following:
  - a. Which image do you believe shows a better view of the craters?
  - b. What can the LOLA image tell you that the black and white image cannot?
  - c. Count the craters in each image. Write the numbers down and compare them.
  - d. Are they the same? Explain.
2. What is the highest elevation found in the LOLA image?
3. What is the lowest elevation in the LOLA image?
4. What is the diameter of the large crater near the scale that reads 60 km?
5. Can you use the same scale on the LOLA image to find the diameter of the craters in the black and white image? Explain.
6. Scientists are puzzled by the shape of the Van de Graaff crater. How is it different from the other craters you have been studying?
7. Let us say that you are a lunar scientist and know all about the cratering process. You see the Van de Graaff crater and are puzzled by its shape. How would you explain its odd shape to another scientist? Be prepared to defend your explanation with scientific information!!

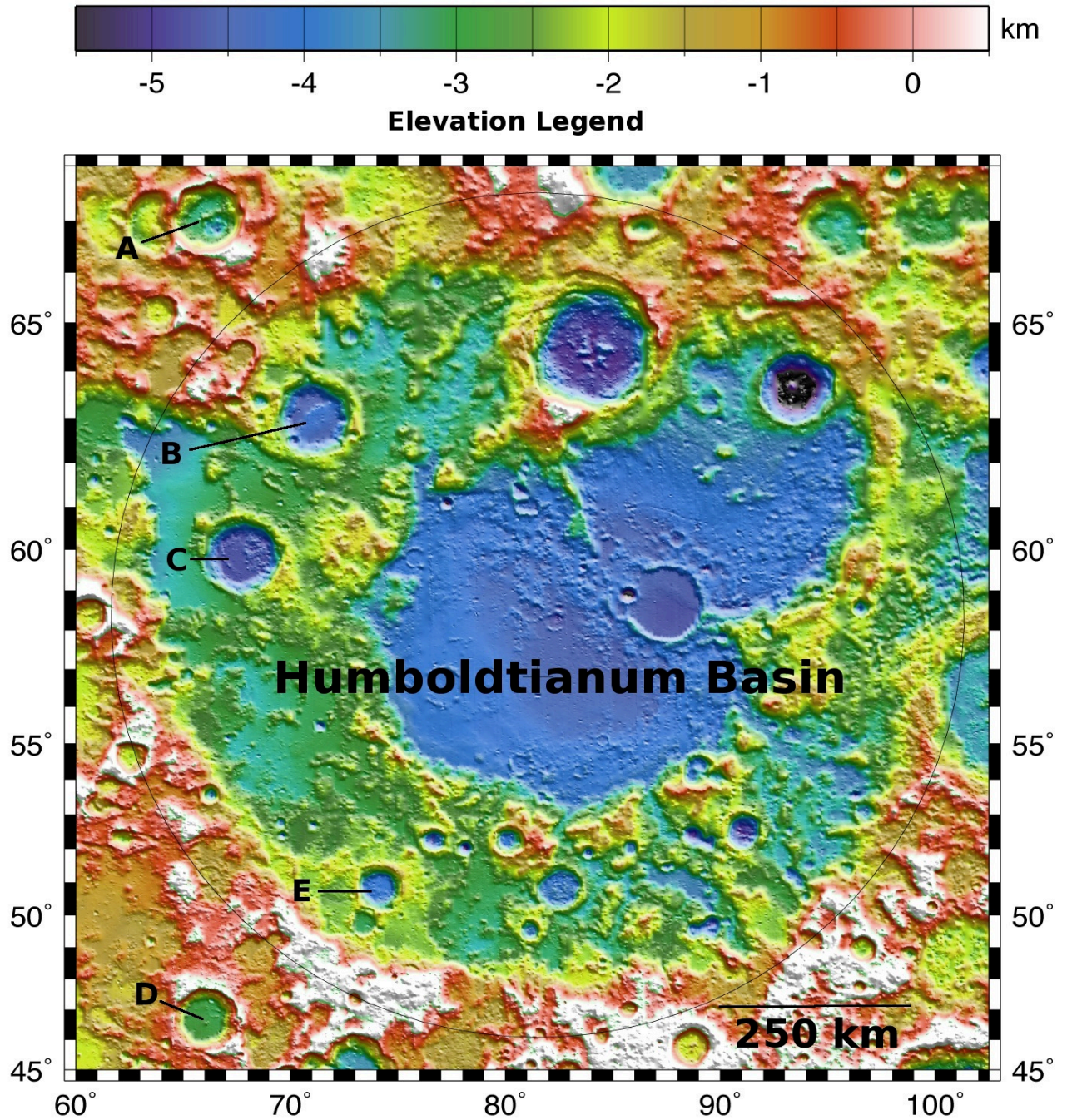
**B. Topography of the Humboldtianum Basin on the Moon! What a great LOLA image!**

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

1. Which craters have a central peak? Explain how you have come to know this?
2. Based on your readings, describe the geologic history of Humboldtianum Basin.
3. Notice the labeled craters in the image, A-E. What are the diameters of the craters (in kilometers)? Label them in your journal as A, B, C, etc., then write their diameters in kilometers.
4. Which crater is deeper, A or B? How have you come to know this?

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

5. Based on what you know about superposition and relative dating, describe the cratering history of the area inside the ring. How do you know which craters are older compared to other craters? Explain how you know this.
6. Copy the Data Log (attached) into your journal. Identify as many features in the ring as you can recognize. Record the grid coordinates (latitude and longitude) of each feature in the Log so that you can find them later. Using the color key in the image, estimate the height of the rim of each feature. After you have identified these features, use the information you determined in question 5 to rank the features from oldest to youngest. Finally, in your own words, “tell the story” about what happened to form the features seen in the image. Be sure to include everything in your journal.



Figures 56.





## Assessment:

### Pre-assessment

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

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

### Post-Assessment

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

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

### Lunar Mapping Module Lesson Rubric

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





### Mapping the Surface of the Moon: Formal Assessment

Answer the following questions to the best of your ability.

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

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

### Supplemental Information in Identifying Surface Features:

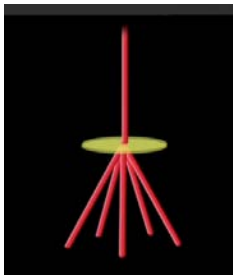
The National Aeronautics and Space Administration (NASA) launched the Lunar Reconnaissance Orbiter (LRO) on June 18, 2009. The purpose of LRO is to image and map the Moon's surface and to collect data that will help NASA in understanding the geologic history of the Moon and Earth system. The Apollo missions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

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

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

### LOLA, the Lunar Orbiter Laser Altimeter

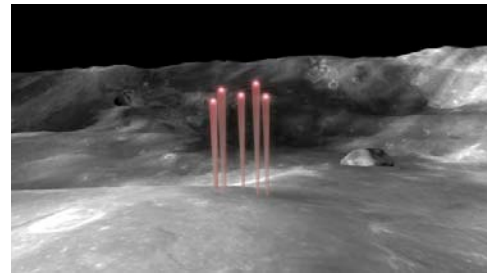
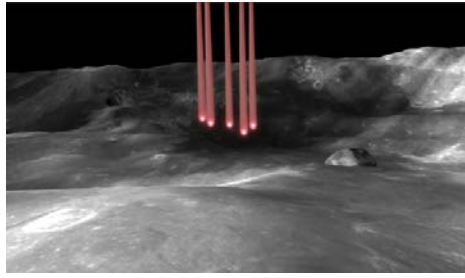
With lunar crater features, volcanoes and the principles of geologic structures in mind, let us take a trip into the amazing LOLA instrument aboard the Lunar Reconnaissance Orbiter (LRO) and the images the data creates. LOLA provides a precise global lunar topographic model (the elevation of specific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



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

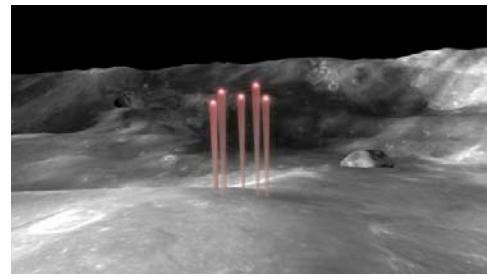
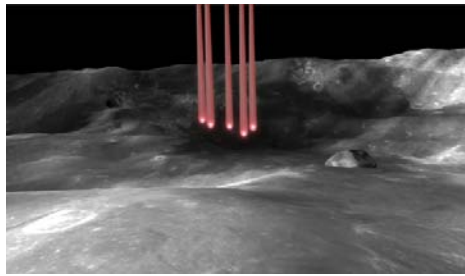
The Diffractive Optical Element (DOE) splits the single laser beam into 5 separate beams. Once the laser beams have struck the surface of the Moon and bounce back to the spacecraft, LRO, a 5-part laser detector picks up the bounced beams, calculates the flight distance of the spacecraft and the speed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

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



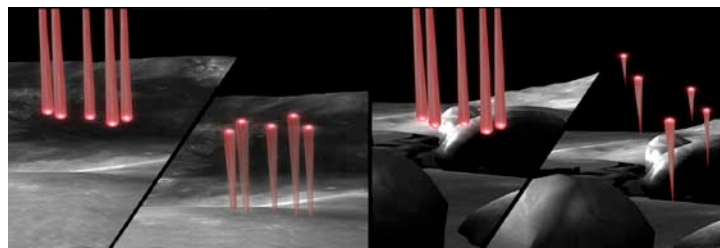
The image on the left is an example of an even laser pulse from the LOLA instrument. To the right is the even bounce back to the spacecraft. What is the difference between a pulse and a bounce? Credit NASA/ASU.

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



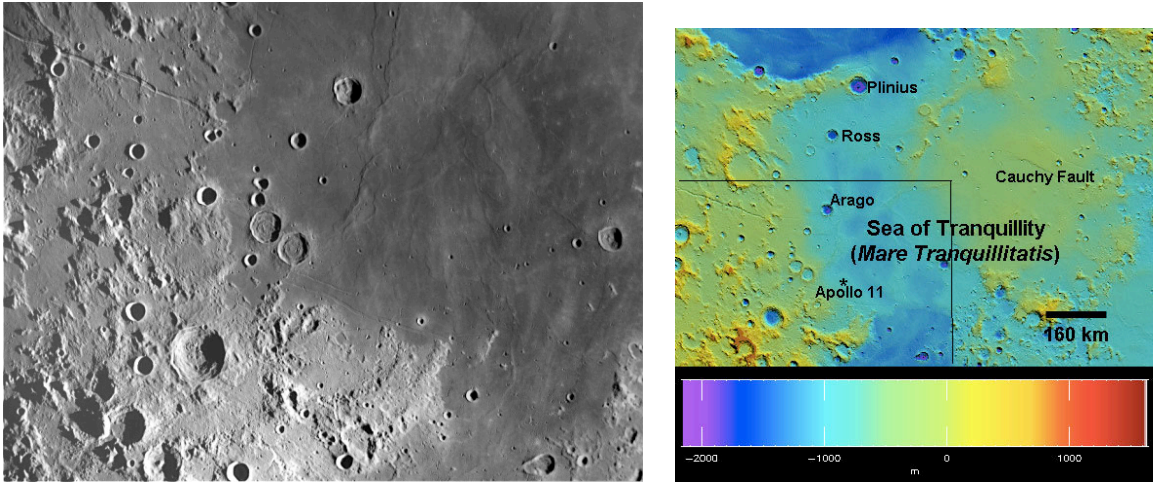
The image to the left is the even pulse. On the right is an uneven bounce due to the varied elevation at the surface of the Moon at this location. Note the difference between the even bounce above and this uneven bounce. Can you explain the difference? Credit NASA/ASU.

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



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

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



Credits: NASA JSC and NASA GSFC

Here, a black and white photo of the Moon taken during the Apollo 11 mission is compared with the LOLA topographical image of the same region, The Sea of Tranquility. The area inside the black rectangle in the LOLA image is the area represented by the black and white scene. Observe the two images carefully. What can you see in the LOLA image that is not noticeable in the older photograph?

## A Look at the Full Moon:

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

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

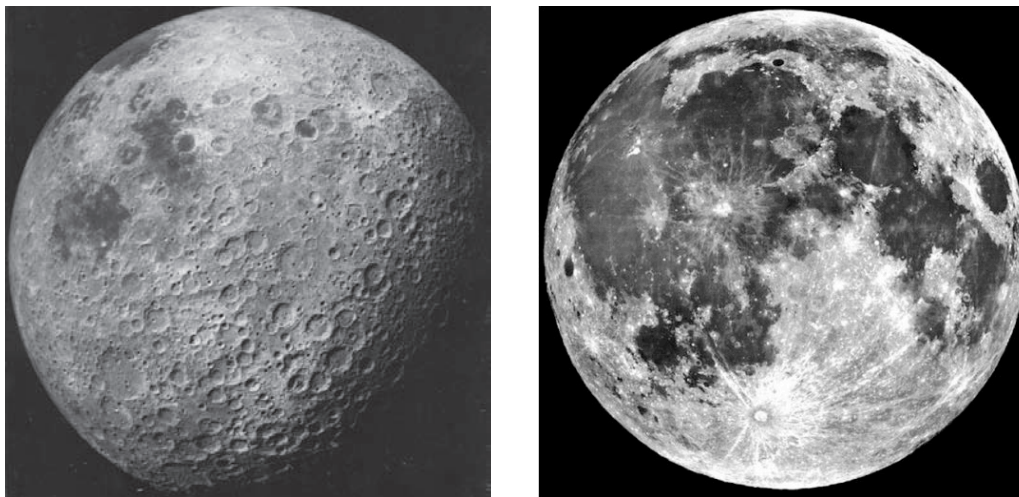
- **Breccia:** referring to the Moon: a coherent rock of broken and welded fragments of anorthosite rock and regolith produced during impacts on the lunar surface.
- **Anorthositic Feldspars:** the most abundant lunar highlands rock; an igneous feldspar-rich variety of feldspar with minor amounts of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

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

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

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

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



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

## Resources:

### BOOKS

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

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

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

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

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

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

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

### PRESENTATION

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

## OTHER GOVERNMENT/ PUBLISHER COLLABORATION

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

## WEBSITES:

### **Lunar Reconnaissance Orbiter Mission. Retrieved 2009-2012 from:**

LOLA <http://lunar.gsfc.nasa.gov/lola.html>  
Diviner <http://lunar.gsfc.nasa.gov/diviner.html>  
CrATER <http://lunar.gsfc.nasa.gov/crater.html>  
LAMP <http://lunar.gsfc.nasa.gov/lamp.html>  
LROC Arizona State University <http://wms.lroc.asu.edu/lroc>

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

<http://www2.semo.edu/mast/mlc/moon.htm>  
<http://lunar.arc.nasa.gov/education/activities/index.htm>  
<http://lroc.sese.asu.edu/EPO/Educator/educatorslessons.php>  
[http://www.spacegrant.hawaii.edu/class\\_acts/MoonDoc.html](http://www.spacegrant.hawaii.edu/class_acts/MoonDoc.html)  
<http://worldwind.arc.nasa.gov/moon.html>  
<http://lunarscience.nasa.gov/kids/moonshine>  
[http://www.nasa.gov/worldbook/moon\\_worldbook.html](http://www.nasa.gov/worldbook/moon_worldbook.html)  
<http://www2.semo.edu/mast/mlc/moon.htm>  
<http://lunar.arc.nasa.gov/education/lesson.htm>  
[http://www.lpi.usra.edu/education/explore/LRO/activities/mission\\_moon](http://www.lpi.usra.edu/education/explore/LRO/activities/mission_moon)  
<http://www.uwgb.edu/dutchs/GeolColBk/MoonSPAitken.HTM>  
<http://www.uwgb.edu/dutchs/GeolColBook.HTM>

### **Soil Simulants. Retrieved 2009-2012 from:**

<http://www.enasco.com/product/SB45846M> However, search the web as some have found cheaper prices. Quality unknown.  
[http://highered.mcgraw-hill.com/sites/0072482621/student\\_view0/interactives.html#](http://highered.mcgraw-hill.com/sites/0072482621/student_view0/interactives.html#)  
[http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/78778/Lunar\\_Nav.swf::Lunar%20Phases%20Interactive](http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/78778/Lunar_Nav.swf::Lunar%20Phases%20Interactive)  
[http://www.youtube.com/watch?v=explL0Uhr\\_k&feature=related](http://www.youtube.com/watch?v=explL0Uhr_k&feature=related)

<http://astro.unl.edu/naap>

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

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

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

[http://www.physics.hku.hk/~nature/CD/regular\\_e/lectures/chap02.html](http://www.physics.hku.hk/~nature/CD/regular_e/lectures/chap02.html)

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

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

[http://www.harcourtschool.com/activity/moon\\_phases](http://www.harcourtschool.com/activity/moon_phases)

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

### **IDL for GRIDVIEW to work:**

[www.itvis.com](http://www.itvis.com) registration site for GRIDVIEW

[www.youtube.com/bhsu978](http://www.youtube.com/bhsu978) directions for GRIDVIEW program

### **Lunar and Planetary Institute:**

[http://www.lpi.usra.edu/education/resources/s\\_system/moon.shtml](http://www.lpi.usra.edu/education/resources/s_system/moon.shtml)

[http://www.lpi.usra.edu/education/other\\_programs/lunar\\_eclipse/activities.shtml](http://www.lpi.usra.edu/education/other_programs/lunar_eclipse/activities.shtml)

### **Universe Today:**

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

### **DePaul:**

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

### **General:**

<http://atozteacherstuff.com/Themes/Space>

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

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

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

[http://www.teach-nology.com/teachers/lesson\\_plans/science/astronomy](http://www.teach-nology.com/teachers/lesson_plans/science/astronomy)

[http://www.windows2universe.org/teacher\\_resources/lunar\\_edu.html](http://www.windows2universe.org/teacher_resources/lunar_edu.html)

<http://spacemath.gsfc.nasa.gov>

<http://www.stellarium.org>

<http://science.nasa.gov>

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

<http://www.newpaltz.edu/lunarlander>

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

[http://mset.rst2.edu/portfolios/g/gallagher\\_p/ToolsVisWeb/process.htm](http://mset.rst2.edu/portfolios/g/gallagher_p/ToolsVisWeb/process.htm)

<http://www.earthmagazine.org>

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

## VIDEOS: ALPHABETICAL ORDER BY TITLE

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

General video on LRO South Pole First Light Data:

[http://www.youtube.com/watch?v=SN2kdavy-wA&feature=results\\_main&playnext=1&list=PL20FB3CA56CF49779](http://www.youtube.com/watch?v=SN2kdavy-wA&feature=results_main&playnext=1&list=PL20FB3CA56CF49779)

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

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

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

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

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

Simulated Meteor impact in slow motion: [http://www.youtube.com/watch?v=Xzlw0c\\_MjTc](http://www.youtube.com/watch?v=Xzlw0c_MjTc)

## Glossary:

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

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

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

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

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

**Lava:** molten rock above the surface of the crust.

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

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



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

**Mafic:** rock rich in magnesium and iron.

**Magma:** molten rock below the surface of the crust.

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

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

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

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

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

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

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

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

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

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

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

**Rays:** bright streaks radiating outward from a lunar crater.

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

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

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

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

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

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

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

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

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

**Viscous:** a material's resistance to movement/flow. Lower viscosity means flowing more easily; high viscosity means more resistant to flow.

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

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

---

## WELCOME TO GRIDVIEW AND IMAGE MANIPULATION FOR LOLA TOPOGRAPHICAL DATA

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

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

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

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

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

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

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

## GETTING STARTED WITH YOUR FREE IDL AND GRIDVIEW SOFTWARE

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

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

There are really TWO parts to the software issue for using GRIDVIEW. First, you need the free IDL software from [www.itvis.com](http://www.itvis.com), and you need the GRIDVIEW software from [http://core2.gsfc.nasa.gov/gridview/gridview\\_win.html](http://core2.gsfc.nasa.gov/gridview/gridview_win.html) . They will not work at all independently. Additionally, if you have a Mac, you will need to check to see if your computer has X11 installed as the image software for IDL and GRIDVIEW will require X11 operations on a Mac.

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

### A. DOWNLOADING THE IDL SOFTWARE FROM ITT

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

rsmillham, Logout



**Download a Product**

Get the industry leading image processing and analysis software right from your desktop. To start downloading a product you must be **logged in**.

**IDL Products**

- [IDL >](#)
- [License Server >](#)

**ENVI Products**

- [ENVI EX >](#)
- [ENVI >](#)
- [ENVI Orthorectification Module >](#)

**Additional Products**

9. The next page will look much like the original page. Go to the 'Downloads' button on the top bar and choose the 'products download' from the drop-down menu.
10. Click on the IDL> under the IDL products title (see above). Choose the right product for your computer. Be careful!
  - a. IF you have a PC with Windows XP, download and install the windows version that meets the requirements for your computer. If you do not have Windows XP, check the list of download options to find the one you will need.
  - b. IF you have a MAC, download and install the correct MAC software for your computer. Note that if you do not have a MAC 10.5.7 or greater, the IDL software will not work on your computer. If you do not know what version your Mac is, go to the apple icon in the top left corner of your computer and click on 'About This Mac'. It will tell you what version you have.

rsmillham, Logout



Get the industry leading image processing and analysis software right from our desktop. Use the filter options to filter the table by Product, Platform and Release Type.

**Product:** 
**Platform:** 
**Download Type:**

Show Previous Versions

| Title   | OS   | Version | Type             |
|---------|--|---------|------------------|
| IDL 8.0 | Microsoft Windows (XP SP2, Vista, 7) 32-bit        | 8.0     | Product Download |
| IDL 8.0 | Microsoft Windows (XP SP2, Vista, 7) 64-bit        | 8.0     | Product Download |
| IDL 8.0 | Mac OS X (10.5.7,10.6) Native x86/x86_64 32/64-bit | 8.0     | Product Download |
| IDL 8.0 | Mac OS X (10.5.7,10.6) Unix x86/x86_64 32/64-bit   | 8.0     | Product Download |
| IDL 8.0 | Linux x86/x86_64 32/64-bit                         | 8.0     | Product Download |
| IDL 8.0 | Sun SPARC Solaris 2 (10) 32/64-bit                 | 8.0     | Product Download |
| IDL 8.0 | Sun x86_64 Solaris 2 (10) 64-bit                   | 8.0     | Product Download |

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

**IDL 8.0** - [Click here to go back](#)

IDL 8.0

**Purpose of Download**

Please select one of the following to complete your download:

- I have recently purchased, or upgrading an existing license
- I am evaluating

**Export regulation compliance**

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

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

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

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

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

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

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

[Click here to have the media shipped.](#)

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

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

## B. DOWNLOADING THE GRIDVIEW SOFTWARE AND IMAGING FILES.

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

1. BEFORE you download the GRIDVIEW software, create a 'GRIDVIEW' folder.
  - a. IF you have a PC, create the folder in the 'My Documents' section or other space where all files for GRIDVIEW can be stored.
  - b. IF you have a Mac, it is best to place the GRIDVIEW files in your user file that can be found in 'finder'. It usually has a small house icon.
2. Go to the website and choose the correct GRIDVIEW software for your computer and download the software. BE SURE to save it as **gridview.sav**.
3. Install the software, and place this file in the file you created for GRIDVIEW before you download GRIDVIEW.
4. Download any of the GRIDVIEW mapping files you may want to work with. For example, "Idem\_16.grd" is a file for mapping a portion of the Moon and can be downloaded and placed in your GRIDVIEW folder. There are several of these files for the Moon and Mars available on the GRIDVIEW site.
5. IF you have a Mac, you will also need to have the X11 Window System software installed in order for GRIDVIEW to work. It is free from the Internet from several websites if it is not already installed on your computer.

**Now you are ready to begin using GRIDVIEW!**

### GRIDVIEW DIRECTIONS:

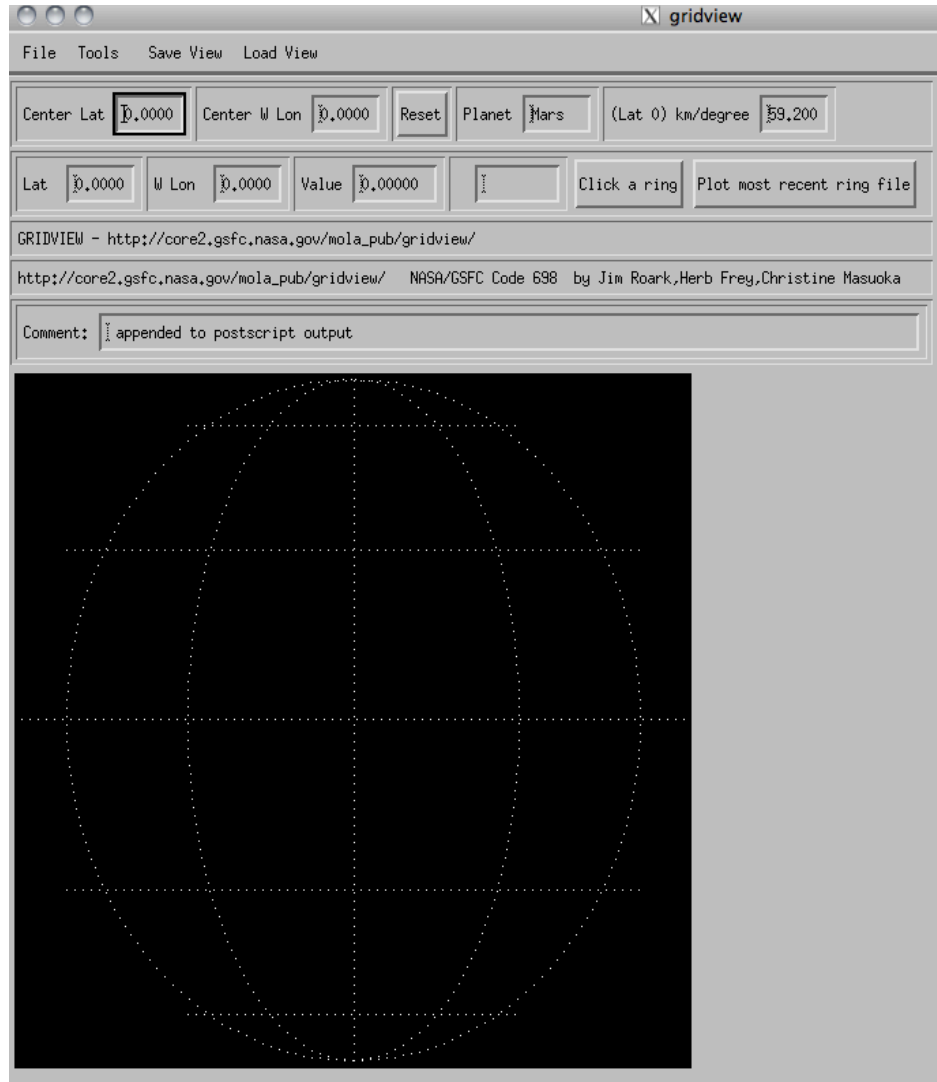
Remember, you have two software programs working together to manipulate the images, with GRIDVIEW being the first thing you double-click causing the IDL virtual machine to open first. Go figure! Once the IDL Virtual machine box pops up, click on continue. IDL will now open up GRIDVIEW! Please note that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

This is how GRIDVIEW-IDL works:

### TO START GRIDVIEW:

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

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



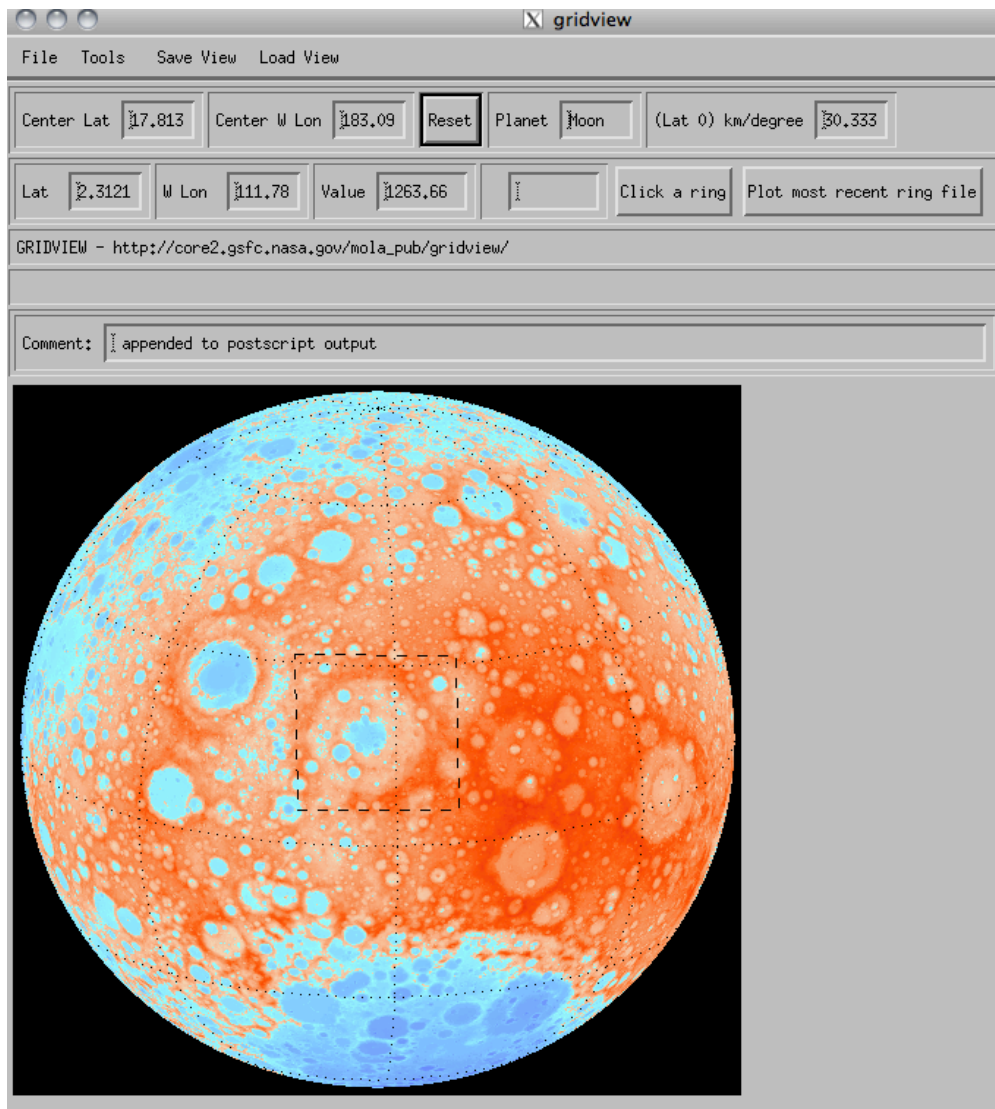
**Now you need to choose a file to work with, so open a LOLA file as follows:**

**TO OPEN ANY OF THE LOLA TOPOGRAPHY DATA FILES:**

1. Once GRIDVIEW has opened, click on “File” and then choose “Load LOLA (.grd) grid” to work specifically with LOLA data.
2. Select the file called “Idem\_16.grd” and then click “OK”. It takes a little while for the data to download into GRIDVIEW depending on your computer. Once it is loaded, you should see a colorful data image of the Moon. If your planet information under “planet” in the top bar says something other than “Moon”, type Moon in place of the planet. **\*\*BE sure that the box for planet says “Moon” and not Mars.** If it says Mars, simply type moon in the box.
3. Now you’re ready to analyze lunar topography data from the Lunar Orbiter Laser Altimeter onboard the Lunar Reconnaissance Orbiter! You could pick any of the LOLA files you have in your directory, but start with this simple one to practice using the software.

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

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



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

#### GRIDVIEW ORIENTATION:

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



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

## HOW TO USE SOME OF THE USEFUL GRIDVIEW TOOLS

### Zoom In

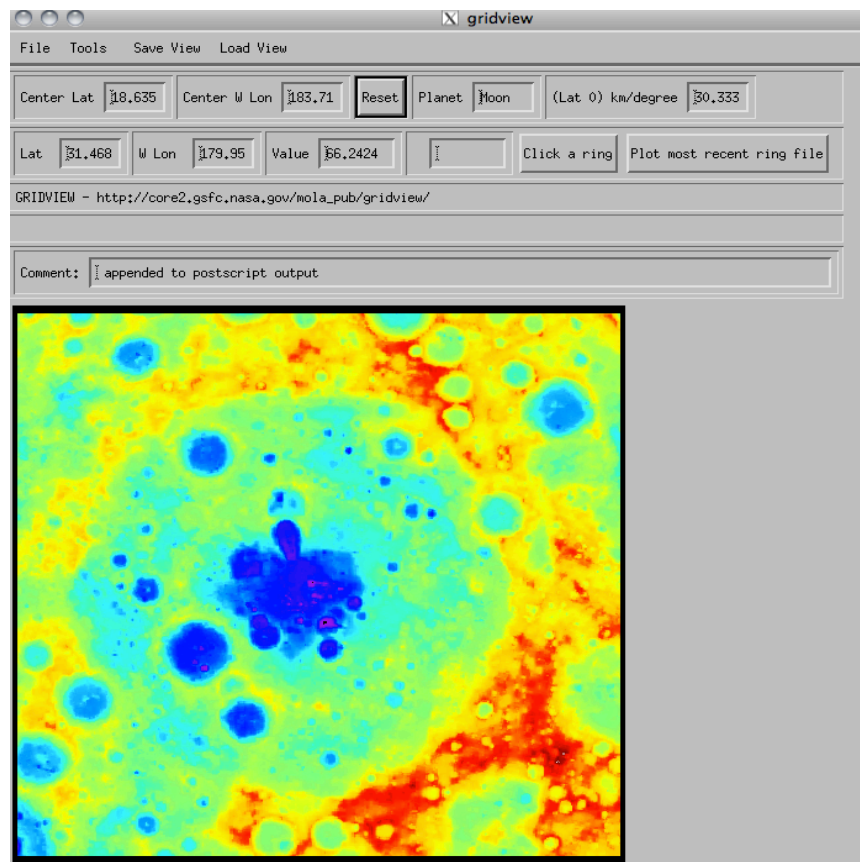
- This tool allows you to zoom in to an area of interest. How do you do this?
- With your cursor, click and hold on the Moon globe and slide your cursor to draw a rectangular shape in the location you would like to zoom in to. After the rectangle has been drawn, go to the “Tools” in your toolbar and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

### Stretch Colors

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

### Maximize Color Stretch

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

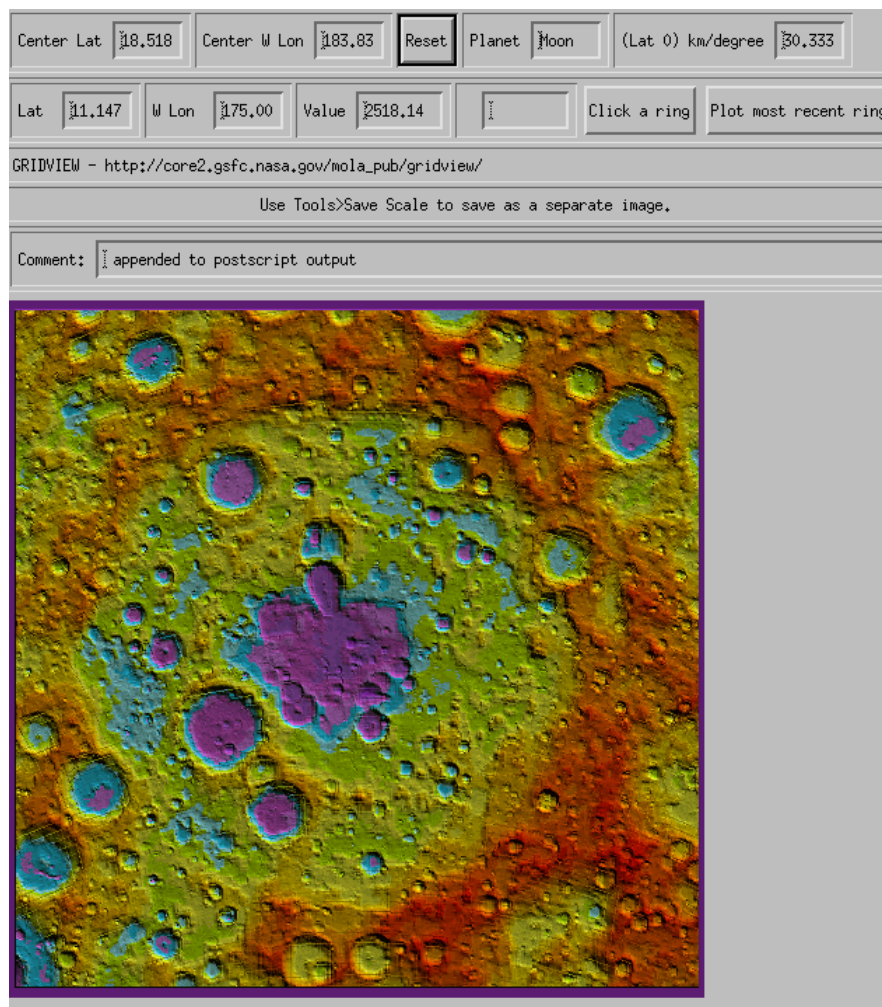


## Show Color Scale

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

## Shaded Relief 2

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

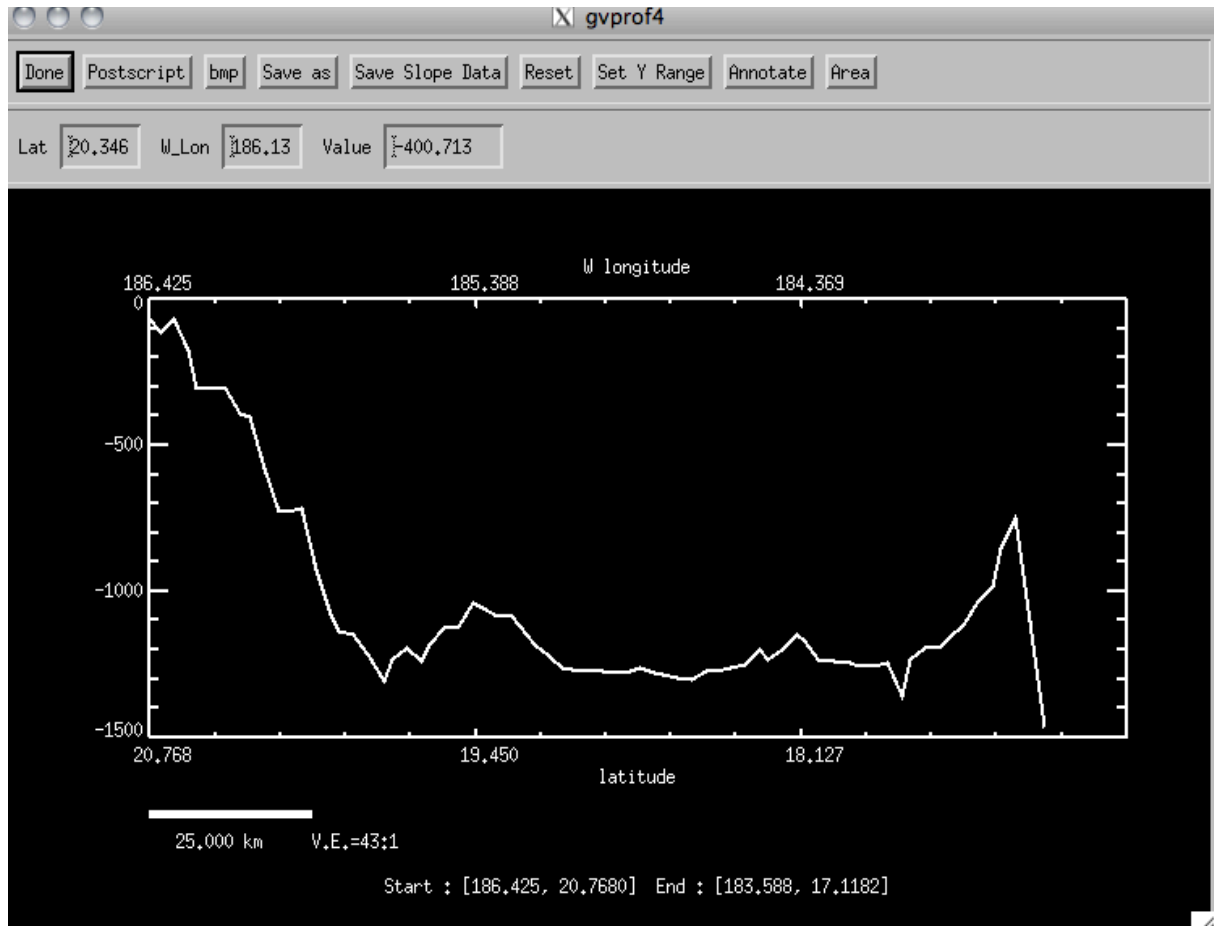


## Calculate Distance

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

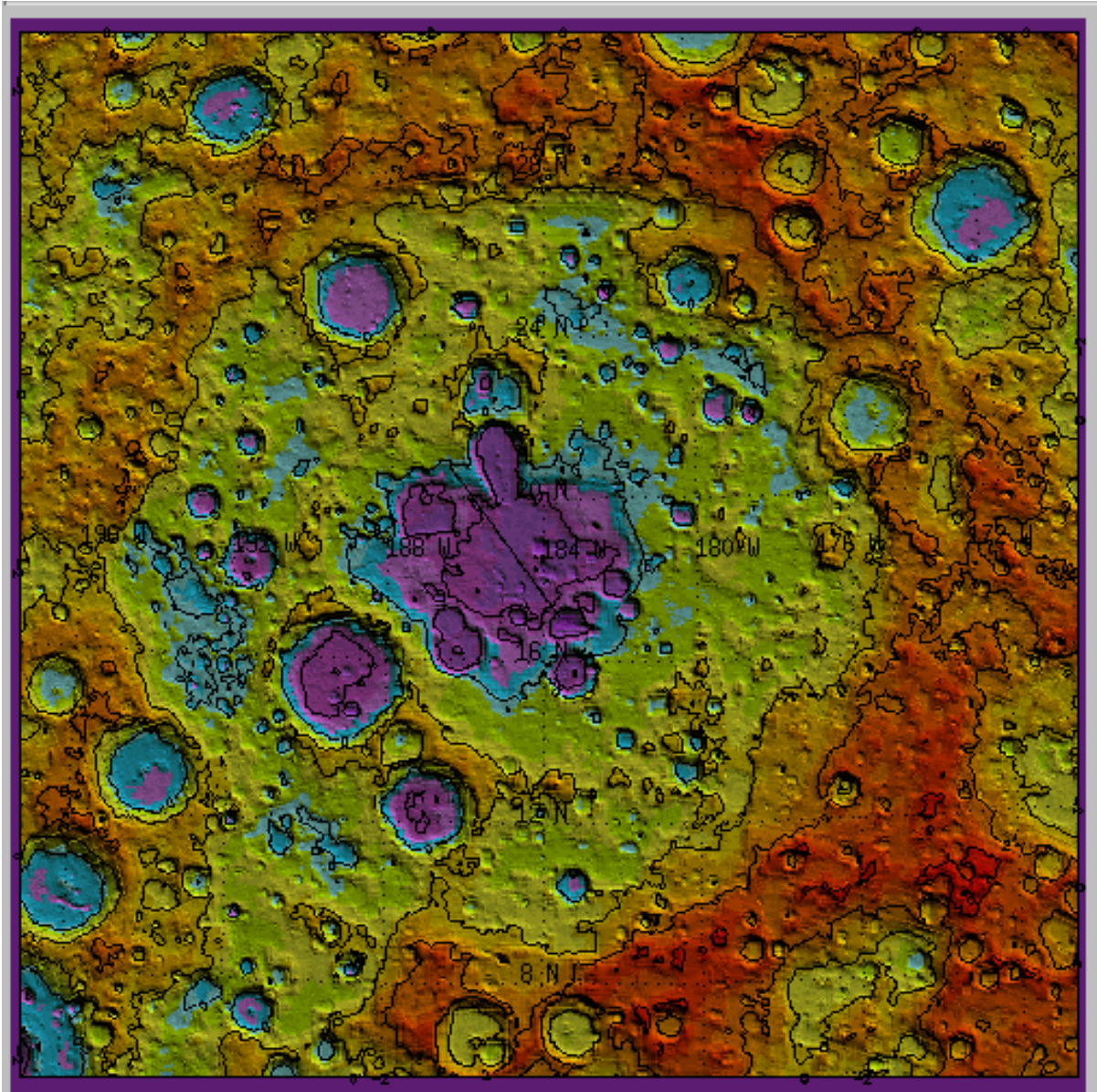
## Profile

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



## Show Contours

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



### Show labeled grid lines

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

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

[http://www.popastro.com/moonwatch/moon\\_guide/moonmap.html](http://www.popastro.com/moonwatch/moon_guide/moonmap.html)

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

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

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

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

# Lunar Reconnaissance Orbiter: (LROC)

## Audience

Grades 5-9

## Time Recommended

Two 60-minute sessions

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.
- 12D/M10: Understand oral, written, or visual presentations that incorporate circle charts, bar and line graphs, two-way data tables, diagrams, and symbols.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

Content Standard D (5-8): Earth and Space Science; Earth's History:

- a. The Earth processes we see today, including erosion, movement of lithospheric composition, are similar to those that occurred in the past.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Feature ID Charts
- LROC-WAC Equatorial Mosaic
- Wet-erase markers
- LROC-WAC Maps
- Student Data Log/ rulers
- Set of task worksheets for each student
- Index cards

# Lunar Image Analysis: Revealing the Geologic History Through Mapping

## Learning Objectives:

- Differentiate between everyday and scientific observations.
- Generate the series of geologic events that occurred in a region of the Moon.
- Integrate new understanding of a Moon-related topic through scientific observations.
- Collaborate and communicate results through identification.

Overview: In this activity, students step into the shoes of real planetary scientists and experience one of the first steps in the process of science — making observations. Students will be tasked with identifying lunar features and determining the geologic history of the area.

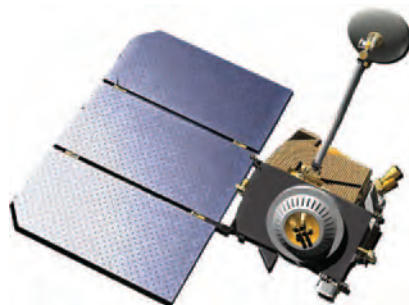
## Preparation:

1. Before starting the first activity, take time to give the students a brief introduction of the Lunar Reconnaissance Orbiter (LRO) mission and Lunar Reconnaissance Orbiter Camera (LROC) using the background Information below. You can have students read these pages or present the data using slides, videos and images, which can be downloaded from NASA's LRO website (<http://lunar.gsfc.nasa.gov>) and LROC's specific website (<http://lroc.sese.asu.edu>).
2. Read the procedure section thoroughly so as to understand the overall progression of each lesson. Review the student worksheets at the end of the lesson and decide how you will use each one.

## Background Information:

### NASA RETURNS TO THE MOON WITH LRO:

At the core of NASA's future in space exploration is the return to the Moon. Once there, we will build a sustainable long-term human presence with new spacecraft, robotics and life-sustaining technologies. The Lunar Reconnaissance Orbiter (LRO) is an unmanned mission to create a comprehensive atlas of the Moon's features, search for safe and interesting landing sites, identify important lunar resources, and characterize how the lunar radiation environment will affect humans.



Lunar Reconnaissance Orbiter

At the core of NASA's future in space exploration is the return to the Moon. Once there, we will build a sustainable long-term human presence with new spacecraft, robotics and life-sustaining technologies. The Lunar Reconnaissance Orbiter (LRO) is an unmanned mission to create a comprehensive atlas of the Moon's features, search for safe and interesting landing sites, identify important lunar resources, and characterize how the lunar radiation environment will affect humans.

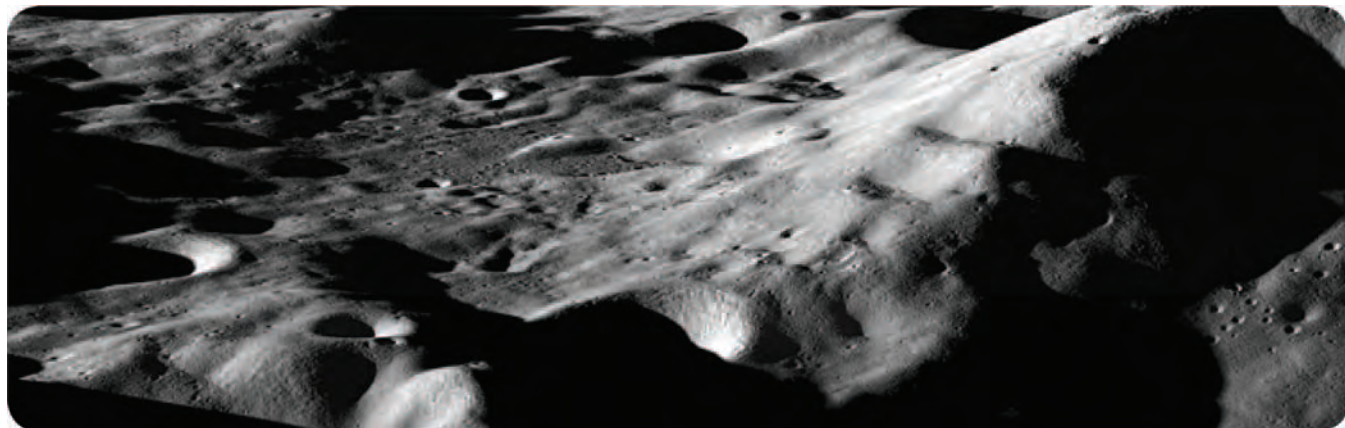


Image: taken by the Lunar Reconnaissance Orbiter Camera facing from the northeast across the north rim of Cabeus crater as the spacecraft rolled 70° to the side. Foreground is about 10 km wide. Credit: NASA/GSFC/ASU.

## Procedure:

(5E APPLICATION)

### ENGAGE:

#### Warm-up: What can you tell from a picture?

1. Display the landscape picture for all students. Students should make observations of the image. What are they certain of based on the photo? Can they tell where the photo was taken?
2. Give students approximately 5 minutes to observe, then discuss as a group.
3. Now, ask students what information is missing? If we had to pick an exact location where this image was taken, what else would we need to do that? (Students should say they need more observations, more distinguishing characteristics, or possibly a wider-angle view to see the area around.)
4. Make reference to the fact that images provide the simplest means of exploring another world. We use images of the Moon to make observations and identify what other information we need. We zoom in and zoom out to get better detail or more information about our image. Let's look at some of these Lunar images.

### EXPLORE:

#### Tasks 1 and 2: Identify Surface Features

(Hand out Feature ID Charts, Sunlight and Shadows sheet, dry-erase markers, and Student Data Log; see Teacher Resource #1 and #2 for an orientation of these materials in the supplemental materials section)

1. Before distributing materials, have students brainstorm analogous features they know exist on Earth that may also exist on the Moon. This will help students build knowledge and make connections to prior knowledge throughout the activity.
2. Familiarize and distribute Feature ID Charts, Sunlight and Shadows sheet, and LROC WAC Equatorial Mosaic images to students.
3. Have students use dry-erase markers to identify features on laminated images. Have students initially work with one image.

4. After approximately 10-15 minutes, have students trade images they have analyzed so other students can make observations of other images.
5. End this part of the activity with a discussion of features observed in images.
6. Ask students to record the identified features into the Student Data Log and the geologic processes involved in their creation.

**Teacher Tip:**

The observations students will make here are most likely considered “everyday observations.” This means they will be simplified to examples such as “There are 30 craters in the image.” While this is a true observation, it most likely will not lead to an experimental question. Providing extra time, even when students appear to be done and off-task, will allow them to make better observations; however students may need more content knowledge about the topic they choose before they can make scientific observations. This will be addressed later in the lesson.

**Task 3: Determine the Relative Ages of Features**

(Hand out Lunar Crater Classification, Crater Density, and Relative Age Dating Principles sheets— see Teacher Resources #2)

1. Before distributing materials, discuss with students how they may know when one lunar feature is older or younger than another. This discussion will help students build knowledge and make connections to previous knowledge throughout the activity.
2. Familiarize and distribute the Relative Age Dating Principles handout to students.
3. Have students use dry-erase markers to identify relative ages of features on the original image they were working with. Have students at least label the “oldest” and “youngest” features. Students can then identify relative ages of other features.
4. After about 8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of the Moon) as part of their discussion.
5. Ask students to go back to their Student Data Log and include the order of which the features have occurred in the “Relative Age” column and the evidence they used to determine this rank in the Evidence column.

**Task 4: Making Measurements**

(Hand out rulers and the Student Data Log/ Measurements sheet)

1. Prior to starting this segment, choose a known distance in meters (you can borrow a measuring tape wheel from your track and field coach to measure out the distance ahead of time.)
2. When your class returns, ask them how far they think they walked. Write these numbers on the board. One of the goals of Task 4 will be to help students understand the concept of scale. You will revisit these later.
3. The students will use the directions in Task 4 to make conversions and measurements of their LROC WAC Equatorial Mosaic image and record them on their Student Data Log-Measurement sheet.



## EXPLAIN:

### Identify Surface Features:

End this part of the activity with a discussion of features observed in images.

### Determine the Relative Ages of Features:

After About 8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of the Moon) as part of their discussion.

### Making Measurements:

Review the distances of your walk on the board. Ask students which is more likely the correct distance. To get a sense of how large a feature is compare it to the distance they walked. How many times would they need to take that walk to walk all the way across the feature?

## ELABORATE:

1. Have students take their list of geologic features they have identified on the Moon and make a list of similar Earth geologic features and their locations.
2. Compare and contrast the geologic features on both planets.
3. Present a hypothesis as to why the geologic features might differ.

## EVALUATE:

### Identify Surface Features:

Ask students to record the identified features into the Data Log Sheet and the geologic processes involved in their creation.

### Determine the Relative Ages of Features:

Ask students to go back to their Student Data Log and include the order of which the features have occurred in the Relative Age column and the evidence they used to determine this rank in the Evidence column.

## Tasks 5 and 6: Making Scientific Observations and Establishing a Research Topic

For students to make scientific observations instead of “everyday observations,” they will need to understand a particular topic very well. To do that, they will need to establish a topic that interests them on the Moon and do in-depth research on that topic. Scientific observations lead to testable research questions. A rubric has been provided (located in assessment section) to evaluate the student’s ability to write scientific observations and to actively debate the qualities of a strong research topic.

### Establishing a Research Topic:

#### Materials Needed:

- Task 5 Sheet (Establishing a Research Topic)
  - Background Research Sheets
  - Index cards (3”x5”)
  - Dry-erase Markers
1. Have each student find a partner and work together to fill in list #1 on the Establishing a Research Topic worksheet. They should spend about 3-5 minutes doing this and can come up with topics from any aspect of lunar exploration or geology that interests them.
  2. Encourage Student Discussions!

The image shows two overlapping worksheets from NASA. The top worksheet is titled "TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST" and contains instructions for students to write a general topic and a specific question about the Moon. The bottom worksheet is titled "Background Research" and features a table with three columns: "How can the question be tested?", "Where can they typically find out the answer?", and "How can they control or influence their observations or experiments?" The table has three rows for data entry.

3. As a class, the students will need to debate and establish their research topic of interest. Should the class be evenly split on this decision, they could possibly combine the two topics to form a relationship.
4. After the students have established a topic, they will need to do some research about it. The goal is to learn how the lunar features are similar or different to features on Earth or other planetary bodies. They will become experts on their topic. This understanding will help the students make scientific observations in the next activity. For example, their observations will improve from “there are 30 craters in the image” to “there are 5 modified craters, 25 destroyed craters, 10 craters less than 2 km wide, 20 greater than 2 km wide, and all of the modified craters lack a central peak, etc.” Photocopy as many background research sheets you believe they will need.
5. Students may need help getting started with their research, depending how much experience they previously have. Here are a couple of sources they can use to learn more about their topic of interest (print out any information you deem necessary):

- <http://www.lroc.asu.edu/lrolive/#loc=video&category=sci&vid=102>
- <http://www.lpi.usra.edu/lunar/moon101>
- <http://lroc.sese.asu.edu/news/index.php?/categories/2-Featured-Image>
- [http://wms.lroc.asu.edu/lroc\\_browse](http://wms.lroc.asu.edu/lroc_browse)
- <http://lunar.gsfc.nasa.gov/moonfacts.html>
- <http://lunar.gsfc.nasa.gov/faq.html>
- <http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html>
- [http://www.nasa.gov/multimedia/videogallery/index.html?media\\_id=135568801](http://www.nasa.gov/multimedia/videogallery/index.html?media_id=135568801)

### **Making Scientific Observations:**

Now that students have background knowledge on their topic, they should be adequately prepared to make scientific observations about their selected topic, as opposed to everyday observations. It will be important to point out to the students the primary difference between these types of observations is the understanding of the topic. A scientist who understands how craters are formed will notice a crater(s) with a different pattern or shape, or possibly even different features, which are not common to the crater itself. Simply observing that a crater exists is an everyday observation— more must be extracted to prove useful, scientifically speaking.

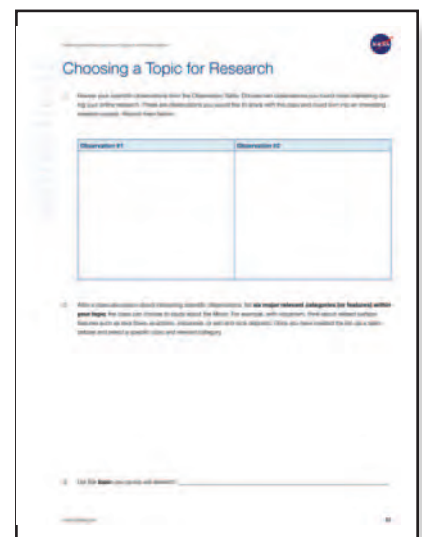
### **Choosing a Final Research Topic:**

Students should take time to share their most interesting scientific observations. These will guide the potential discussion and will allow them to group topics or concepts. It may be helpful to use index cards for topics and scientific observations. Students may even find they can incorporate a couple of topics of interest for primary and secondary science. Allow students to debate and come to a consensus on the final topic for research. This is an opportunity to experience authentic science and debate. Scientists typically do not work individually, but discuss ideas and interesting topics for research with other scientists in the particular field of study.

Some research topic examples, but are not limited to:

Impacts:

- |                  |                  |
|------------------|------------------|
| • impact melt    | • terraced walls |
| • central peak   | • crater chains  |
| • ejecta         | • straw field    |
| • simple crater  | • impact basin   |
| • complex crater | • rim            |





## LUNAR IMAGE ANALYSIS

**Lesson Overview:** For this activity, you will be completing 6 total tasks:

### WARM-UP:

Look at the picture and answer the questions.

### TASK 1: LOCATING IMAGES ON THE MOON

In this task, you will use the latitude and longitude of the image to find its location on the Moon.

### TASK 2: IDENTIFYING LUNAR FEATURES

In this task, you will be using Feature ID Charts to identify geologic features on the LROC-WAC Lunar image.

### TASK 3: UNRAVELING THE HISTORY

In this task, you will use Relative Age Dating Principles to create a sequence of events for your LROC-WAC Lunar image.

### TASK 4: MAKING MEASUREMENTS

In this task, you will be using a scale bar to determine how large certain features are on the lunar surface.

### TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST AND BACKGROUND RESEARCH

In this task, your team will decide on a topic you are all interested in most for conducting research, in order to become an expert in that topic.

### TASK 6: MAKING SCIENTIFIC OBSERVATIONS

In this task, you will be making scientific observations on your topic using your new understanding from background research.

### KEY WORDS:

- **Scientific Observation:** An observation made using scientific knowledge from background research on the topic.
- **Initial Observation:** Observations that lead to an experimental question.
- **Experimental Observation:** Observations made during data collection. These may change the direction of the research or lead to future experimental questions.
- **Analysis Observation:** Observations made as a result of graphing. These could be interesting data points, such as outliers. Also, these may lead to future experimental questions.
- **Qualitative:** Observations based on a physical characteristic such as color, shape, or texture.
- **Quantitative:** Observations based on numbers, such as number counts or measurements.
- **Bias:** The purposeful or unintentional influence of observations or data that results in an expected answer, instead of a real answer.

## WARM-UP: WHAT CAN YOU LEARN FROM A PICTURE?

**Name** \_\_\_\_\_

**Directions:** Look at the picture below and answer the following questions.

1. What do you know for sure from this picture?
2. Can you tell where it was taken?
3. What information is missing?
4. If we had to pick an exact location where this image was taken, what else would we need to do that?



Photo Courtesy of Stefan Seip and NASA Astronomy Picture of the Day



## TASK 1: LOCATING IMAGES ON THE MOON

### Core Question: How do people reconstruct and date events in Earth's planetary history?

For this activity, you will be acting as a scientist. You will complete four tasks as part of an introduction to the Lunar Reconnaissance Orbiter Camera (LROC) images. Your investigation will include the following:

1. Recording observations of geologic features on the Moon,
2. Discovering what geologic features can be identified on the surface of the Moon, and
3. Determining the surface history of an area (i.e. which features are older, younger, and what has happened in the area to make it look the way it does today).

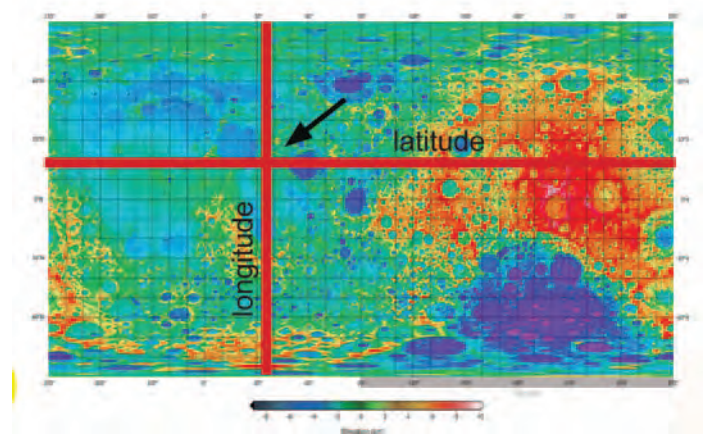
During this activity you will complete a **Student Data Log**. A variety of tools are available to help you in this activity. Your teacher will show you each of these throughout the activity.

In this section, you will learn how to locate **LROC images** on the Moon. To find an image location, you will need to know its latitude and longitude:

- The **longitude** gives the location east of the Moon's **prime meridian** ( $0^{\circ}\text{E}$ ), which is the line passing through the middle of the Moon as seen from the Earth during a full-moon.
- The **latitude** gives the location north or south of the lunar **equator** ( $0^{\circ}\text{N}$ ). Both latitude and longitude are given in terms of degrees.

Once you receive materials from your teacher, work with a partner to do the following:

1. Find the **latitude** and **longitude** of your LROC image. The coordinates are printed on your image.
2. Using a dry-erase marker, draw a line across the WAC Topographic Map marking your image's latitude.
3. Now, draw a line across the WAC Topographic Map marking your image's longitude. Your image is located where the lines cross!



The Topography of the Moon by LROC WAC and LOLA

# TASK 2: IDENTIFYING LUNAR FEATURES

For this activity, you will analyze images of the Moon provided by your teacher. As you observe images, be sure to use the **Feature ID Charts** to help you identify and label features with a dry-erase marker. Your teacher will explain the materials and information you have available for this part of the activity and when to fill information into the **Student Data Log**. Here, you will see a sample of the **LROC-WAC Equatorial Mosaic, Feature ID Charts**, and the **Sunlight and Shadows Sheet** you will be using.

## Sample LROC WAC Equatorial Mosaic Image

**Lunar Image Analysis**

**Aristarchus Crater** Lat: 23.69° N Lon: -47.48° Sun angle: Low

WAC ELEVATION

CONTEXT IMAGE

10 km

**1: LUNAR FEATURE IDENTIFICATION CHART**  
Primary Craters and Their Features

| Feature         | Feature Example | Feature Description  |
|-----------------|-----------------|--|
| Simple Craters  |                 | • Small fresh-shaped craters   |
| Complex Craters |                 | • Small secondary impact craters arranged in chains near larger craters<br>• Produced by the impact of objects from a larger impact<br>• Often radiate out from larger craters<br>• Less than 1 km in diameter |

**2: LUNAR FEATURE IDENTIFICATION CHART**  
Secondary Craters and Other Features

| Feature       | Feature Example | Feature Description  |
|---------------|-----------------|--|
| Crater Chains |                 | • Small secondary impact craters arranged in chains near larger craters<br>• Produced by the impact of objects from a larger impact<br>• Often radiate out from larger craters<br>• Less than 1 km in diameter |
| Craters       |                 | • Small secondary impact craters in clusters formed by the impact of objects from larger impacts<br>• These craters can be found in areas around larger craters  |

**3: LUNAR FEATURE IDENTIFICATION CHART**  
Volcanic Features

| Feature                | Feature Example | Feature Description  |
|------------------------|-----------------|--|
| Maria (Singular: Mare) |                 | • Large flows of basaltic lava that eroded, wetted and flowed into low-lying impact basins (intrusions)<br>• Molten rocks and gabbro-rich crust flow |

**4: LUNAR FEATURE IDENTIFICATION CHART**  
Tectonic Features

| Feature   | Feature Example | Feature Description  |
|-----------|-----------------|--|
| Fractures |                 | • Cracks in areas where the crust has been pulled apart<br>• Can be linear (straight) or curved<br>• Usually occur in groups<br>• Often found in impact walls in the bottom of craters |

**5: LUNAR FEATURE IDENTIFICATION CHART**  
Mass Wasting Features and Layers

| Feature        | Feature Example | Feature Description   |
|----------------|-----------------|---|
| Debris Flow    |                 | • Loose rocks and debris that has slid down a steep slope<br>• Material often piles up at the bottom of a slope like at the base of a water scull<br>• Triggered by nearby impacts<br>• The flow sometimes that are long or thin<br>• Small-scale features only visible in NAC images   |
| Boulder Trails |                 | • Linear features (trails) formed by boulders that have rolled down slopes<br>• Some trails are smooth and others are bumpy (representing the the shape of the boulder and surface of the sediment)<br>• Often found in areas near smaller craters near slopes made large craters<br>• Small-scale features that are only visible in NAC images |
| Layers         |                 | • Layers are stacked by impacts and can be seen in walls of craters<br>• They can be visible in the central peaks of craters<br>• Layers build up over time and contain a record of successive large flows<br>• Layer thickness can give important information on the history of lava flows   |

## Lunar Feature Identification Charts (set of five)

## Sunlight and Shadows Sheet

**Interpreting Surface Features**  
Illumination Effects

Observing the placement of shadows and sunlit areas on the surface will help you identify areas of positive (high) relief like volcanoes and ridges, and negative (low) relief like craters and fractures.

See the key below for some pointers on what to look for:

Overview:

**Top View**

Shaded (Positive) Feature      Shaded (Negative) Feature

Raised Volcanic Feature      Sunken Crater Feature

**Side View**

ILLUMINATION (Sunlight)

Raised Volcanic Feature      Sunken Crater Feature

positive relief      negative relief

## TASK 3: UNRAVELING THE HISTORY

### Relative Age: What came first; what came later?

Now that you've identified surface features on your LROC image, take some time to think about the geologic changes that have taken place in this area over time. Scientists use several methods to reconstruct the sequence of geologic events. This is called **Relative Age Dating**.

#### Relative Age of Features:

While scientists have used instruments to precisely date lunar rock samples (absolute age) collected by Apollo astronauts, these dates are limited to the very small number of specimens collected and only from a few specific areas on the lunar surface (where Apollo astronauts explored). Thus, scientists must rely on other methods to determine geologic age. Another method of dating, called Relative Age Dating, uses several techniques to infer a sequence of geologic events. The downside is exact dates cannot be determined, but it is possible to reconstruct a history by placing geologic events in their order of occurrence. Lunar scientists do this by studying collections of images taken by orbiting spacecraft such as LRO.



Like Earth, geologic processes such as impacts and volcanic activity have been at work on the Moon for several billion years. What story does your image tell? Use the Age Dating Charts to explore. Credits: NASA and Chris Butler/Science Photo Library.



Worksheet

# TASK 3: UNRAVELING THE HISTORY

In this part of the activity, you will further analyze images of the Moon. Now, you will think about the history of the area using relative age dating principle. The most common techniques used for determining the relative age of features on the Moon are:

- **Crater Classifications:** Simple, Complex, and Secondary
- **Relative Age Dating Principles:** Principle of Superposition and Crosscutting
- **Crater Density:** More or less cratering on the Moon

1. Use your dry-erase marker and the Relative Age Dating techniques sheet. Create an order in which these features were formed by marking the oldest feature as a “1,” the next oldest as a “2,” and so on until all of the features have been appropriately numbered. The youngest feature will have the highest number. If two or more features appear to have the same relative age, mark them with the same number.
2. Once your group has agreed on the order of events, fill in your Student Data Log with this order.

The collage consists of several overlapping worksheets:

- Crater Density:** Explains that higher crater density indicates an older surface. It lists characteristics of high crater density surfaces (many craters, irregular shapes, etc.) and low crater density surfaces (fewer craters, smoother terrain, etc.).
- Relative Age Dating Principles:** Discusses the Principle of Superposition (younger features on top of older ones) and Cross-Cutting Relationships (a feature that cuts across another is younger).
- Lunar Crater Classification:** Defines three types of craters: Simple (flat floor, central peak), Complex (terraced walls, central peak, ringed), and Secondary (formed by impact of a smaller body).
- Relative Age of Craters:** Provides a classification key for Simple Craters (6-18 km diameter) and Complex Craters (18-130 km diameter) based on features like central peaks and terraced walls.

Relative Age Dating Principles Crater Density Charts Lunar Crater Classification (set of three)





# Student Data Log

Name \_\_\_\_\_

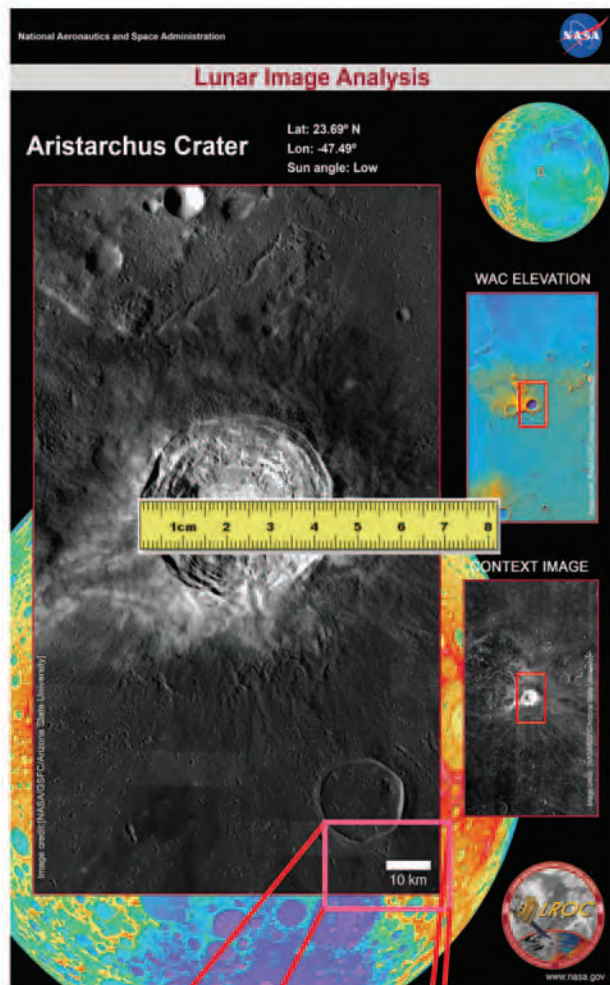
Use this table to order the major (most noticeable) features according to their relative ages chosen. The oldest feature should be numbered 1, next oldest 2, 3, 4, 5, to the youngest number 6.

| Feature Name | Age Rank      | Describe How Feature Formed |
|--------------|---------------|-----------------------------|
|              | Oldest<br>↑   |                             |
|              |               |                             |
|              |               |                             |
|              |               |                             |
|              |               |                             |
|              | ↓<br>Youngest |                             |

Write out a short “history” of the major events that took place in your area. Use the relative age of the features that you listed in your table:

## TASK 4: MAKING MEASUREMENTS

For each LROC-WAC Equatorial Mosaic image, you will find a scale bar in the lower right corner. This scale bar can be used to calculate the size of a particular feature on the Moon. Below you will find an example.



**Scale Bar**

### Step 1:

Measure the width of the scale bar in centimeters.

2cm

### Step 2:

Divide the scale by the width of the scale bar. This will give you a scale factor.

$$10\text{km}/2\text{cm} = 5 \text{ km/cm}$$

This means for every cm you measure, it will represent 5 km on the ground.

### Step 3:

Measure the width of the feature in centimeters using a ruler. In this case, we will measure the large crater.

8 cm

### Step 4:

Multiply the width of the feature by the scale factor.

$$8\text{cm} \times 5\text{km/cm} = 40\text{km}$$



# Student Data Log – Measurements

Use this table to record your feature measurements

Name \_\_\_\_\_

**Step 1:** Measure the scale bar \_\_\_\_\_ cm

**Step 2:** Divide the scale by the width of the scale bar

\_\_\_\_\_ km / \_\_\_\_\_ cm = \_\_\_\_\_ km/cm

This is your **Scale Factor**. Write this number in the column titled “Scale Factor.”

| Feature Name | Feature Measurement | × | Scale Factor | = | Feature Actual Size |
|--------------|---------------------|---|--------------|---|---------------------|
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |
|              |                     |   |              |   |                     |



## TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST

Name \_\_\_\_\_

1. Within your group, brainstorm four **general topics** that can be studied about the Moon. For example: volcanism, cratering, water, human exploration, etc. These can be whatever interests you and your group regarding the Moon.

2. As a class, vote on the topic that is most interesting for your research.

Your class topic for research is: \_\_\_\_\_

## Why Background Research?

Knowing a lot about your topic will help you make better, informed observations. Better observations make for better research questions.

Many of your LROC-WAC Equatorial Mosaic image observations are everyday observations. Everyday observations are very general. These observations are good, but we want to learn more about the Moon. We need to look for features that are important to scientists.

Important observations make great research questions. Great research questions help scientists understand the Moon, where it came from, and its history.

### Examples:

#### Everyday observation:

- There are many craters in the image.

#### Scientific observations:

- There are 20 craters in the image that are over 10 km wide.
- 25 craters are destroyed craters.
- There are 34 craters in the rocky areas, but only 2 in the flat areas.
- Not all of the craters with central peaks have rough walls.

Use the next page as a guide for completing your background research. Remember, your goal is to become an expert on your topic.





# Background Research

Name \_\_\_\_\_

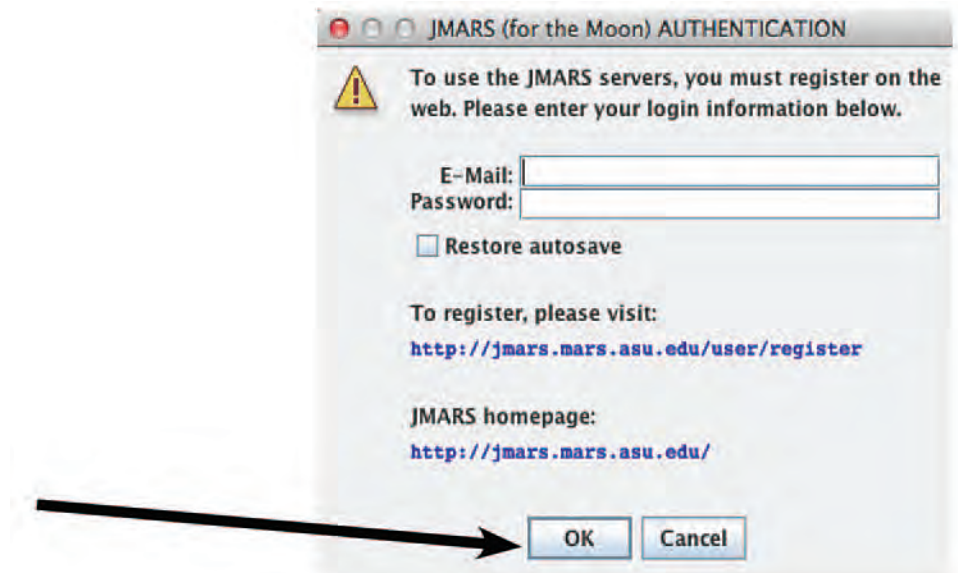
|                                    |  |  |
|------------------------------------|--|--|
| <b>Citation (Source):</b>          |  |  |
| <b>How was the feature formed?</b> | <b>Where are they typically found on the Moon?</b> | <b>How are they similar or different from what can be found on Earth or other planetary bodies (planets/ moons?)</b> |
|                                    |  |  |
| <b>Drawing:</b>                    | <b>Drawing:</b>                                    | <b>Drawing:</b>  |
|                                    |  |  |



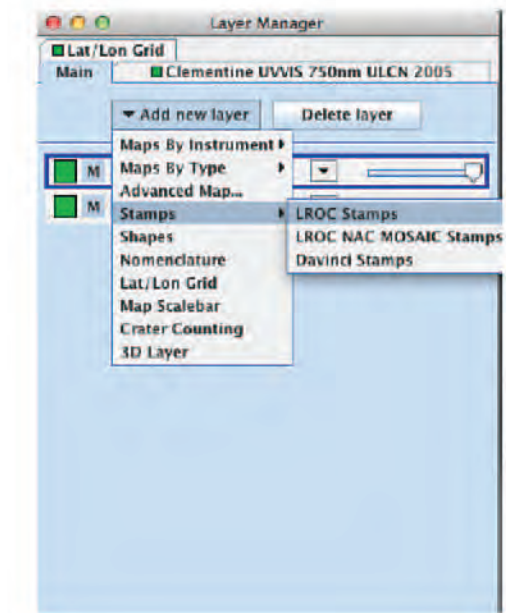
## TASK 6: MAKING SCIENTIFIC OBSERVATIONS

This activity will focus on LROC images that show details of many of the geologic features seen on the lunar surface. In this exercise, you will look at LROC-**NAC (Narrow Angle Camera)** and **WAC (Wide Angle Camera)** images and log specific information about each image you observe. Here's what to do:

1. To find images, go to the <http://jmars.asu.edu/> website. Choose the JMARS for Moon Cross-platform WebStart Installer. (You may be asked to register or login with a user name/password. Registration is NOT required to use the tool. Click "OK" to start the application.)



2. Once the JMARS for Moon window opens, you will choose the following:
  - a. Add New Layer > LROC Stamps



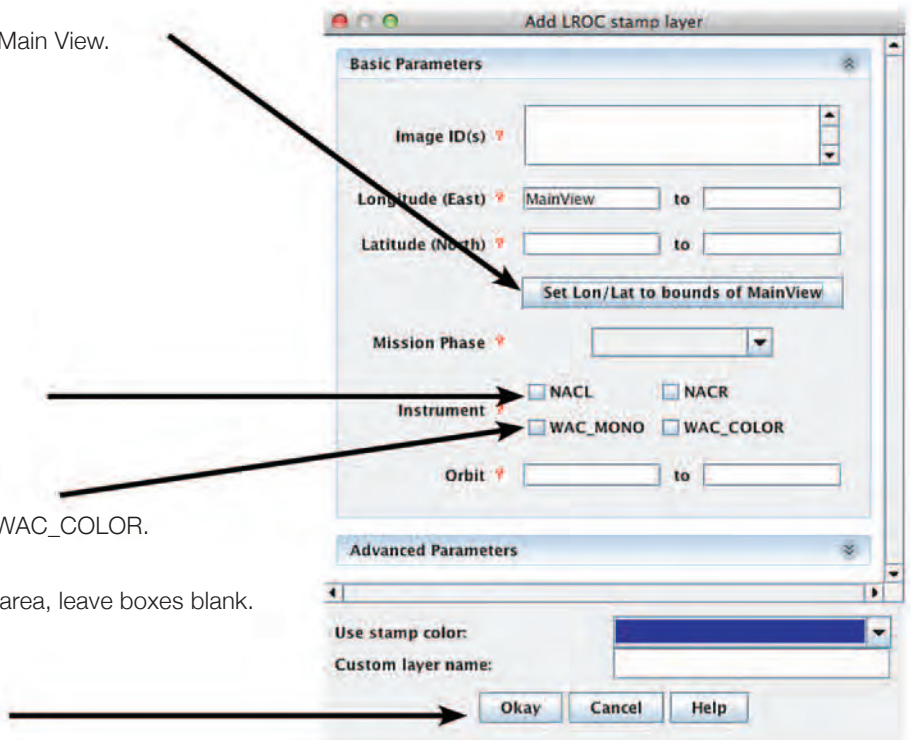


3. To pull up LROC image stamps:
  - a. Click Set Lon/Lat to bounds of Main View.

- b. If you want NAC images only, click next to NACL and NACR.
  - c. If you want WAC images only, click next to WAC\_MONO and WAC\_COLOR.

- d. To load all image stamps in the area, leave boxes blank.

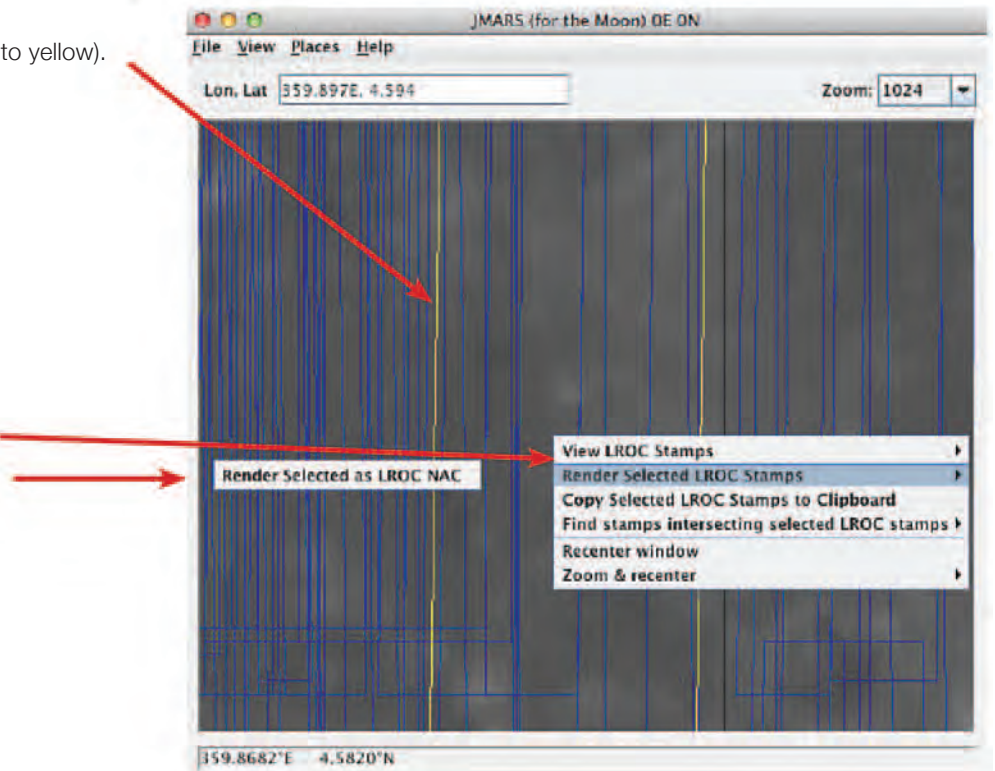
- e. Then click Okay at the bottom



4. To view a specific stamp, select the stamp in the map window

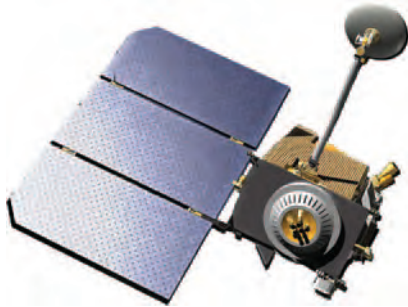
(the outline will turn from blue to yellow).

- a. Right click > Render Selected LROC Stamps.
  - b. Render Selected as LROC NAC.





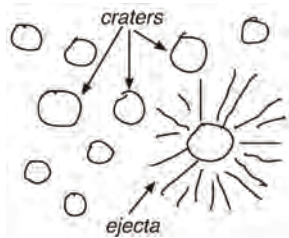
5. Log the following information on your observation worksheets:
  - a. **Surface Geologic Feature(s) Observed:** Name the specific surface geologic features you find interesting in each image. Use the Lunar Feature Identification Charts to help identify types of surface features.
  - b. **Image ID Number:** LROC images have an image ID number called a "Product Number." This number is at the top of the LROC Observation page and listed in the Image details section that appears when you click on an image footprint.
  - c. **Sketch the Geologic Feature(s):** Make a sketch or drawing of the portion of the LROC image that shows the feature(s) you are observing. Do not sketch the entire image.
  - d. **Specific Observations of Geologic Feature(s):** Write down specific observations of the feature(s) you sketched. Consider patterns you may look for with these features in other images.



In 2009, NASA returned to the Moon by sending a spacecraft called the Lunar Reconnaissance Orbiter (LRO) to gather crucial data of the lunar environment. LRO was launched in June of 2009 and orbits approximately 50 kilometers (31 miles) above the lunar surface, while its seven instruments find safe landing sites, locate potential resources, characterize the radiation environment and test new technology.



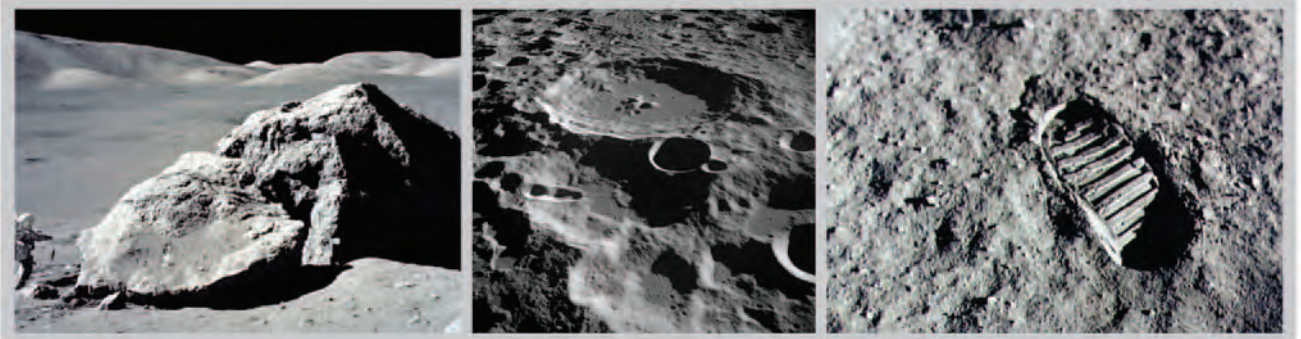
# Example Observation Table

| Surface Geologic Features Observed & Image ID #   | Sketch of Surface Geologic Features   | Text Description of Surface Features (use bullets)  |
|---|---|---|
| Image ID #:<br>M122218152R<br><br>Area showing many small simple cratersome with white and gray ejecta visible. |  | <ul style="list-style-type: none"> <li>• Some craters show bright white ejecta rays that spread out around the rim while other areas show gray rays</li> <li>• Craters seem to be about the same size in this area</li> </ul> |

## Make scientific observations:

1. Fill out the following set of observation tables.
2. Be as detailed as possible as you enter the data in the tables. Remember: your goal is to make scientific observations, not everyday observations. Use your completed Background Research for details on your topic.
3. Think about the surface features that you are observing— what interests you?
4. Work with students on your team to find other areas on the Moon that have features you all are interested in.

Credit: NASA





# Observation Table

Name \_\_\_\_\_

## Making Observations of LROC Images

| Surface Geologic Features Observed & Image ID # | Sketch of Surface Geologic Features | Text Description of Surface Features (use bullets) |
|---|-------------------------------------|--|
| Image ID #:<br><br>Features:                    |                                     |  |
| Image ID #:<br><br>Features:                    |                                     |  |
| Image ID #:<br><br>Features:                    |                                     |  |
| Image ID #:<br><br>Features:                    |                                     |  |



# Choosing a Topic for Research

Name \_\_\_\_\_

1. Review your scientific observations from the Observation Table. Choose two observations you found most interesting during your online research. These are observations you would like to share with the class and could turn into an interesting research project. Record them below:

| Observation #1 | Observation #2 |
|----------------|----------------|
|                |                |

2. After a class discussion about interesting scientific observations, list **six major relevant categories (or features) within your topic** the class can choose to study about the Moon. For example, with volcanism, think about related surface features such as lava flows, eruptions, volcanoes, or ash and rock deposits. Once you have created the list, as a team debate and select a specific topic and relevant category.

3. List the **topic** your group will research: \_\_\_\_\_

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Figure 1: Pathways

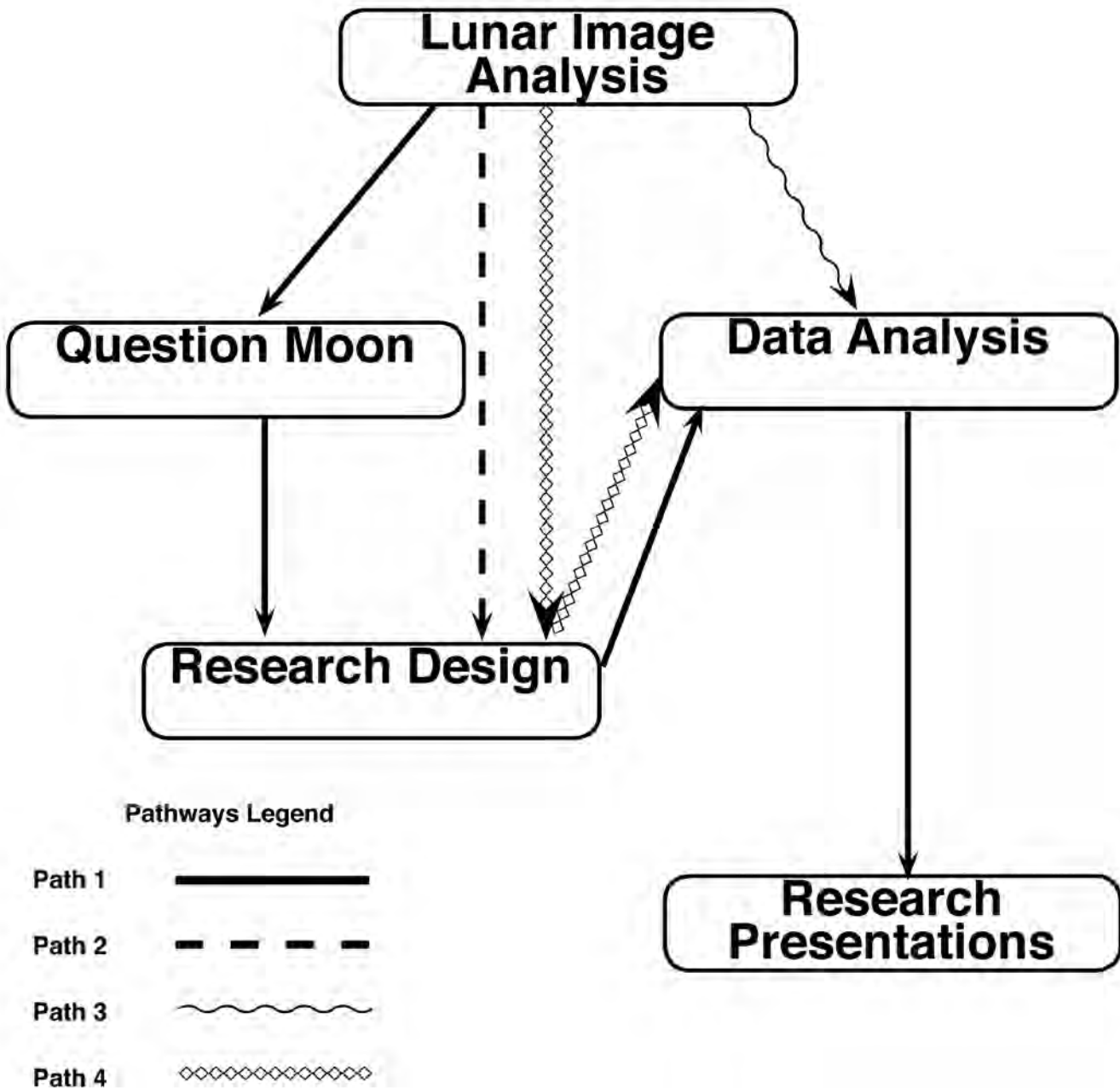


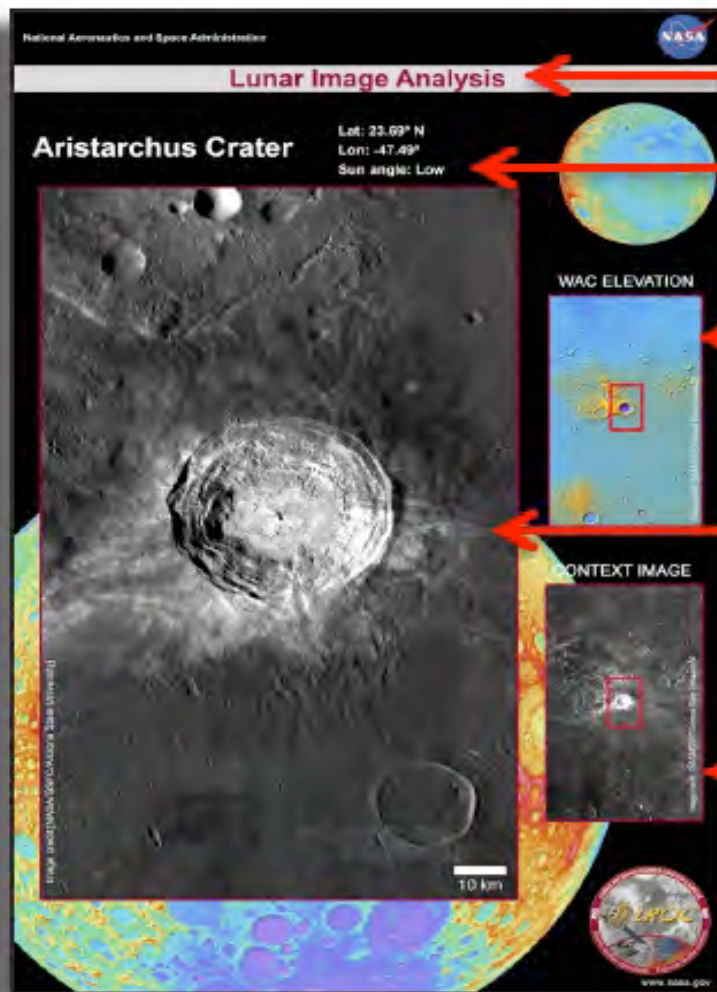
Figure 2: Pathways

| Emphasis  | Lessons in the Path   | National Standards   | Est. # of Class periods (45 min segments) |
|---|---|--|---|
| <p><b>Path 1</b><br/>Full scientific process of research</p>  | <p>Lunar Image Analysis<br/>Question Moon<br/>Moon Research Design<br/>Moon Data Analysis<br/>Moon Research Publication</p> | <p>Science<br/>Dimension 1: Practices<br/>1, 2, 3, 4, 5, 6, 7, 8<br/>Dimension 2: Concept<br/>1, 2, 3, 4<br/>Dimension 3: ESS<br/>ESS1C<br/>Some types of research:<br/>ESS2A, ESS2B, ESS2C,<br/>ESS2D</p> | <p>25</p>                                 |
| <p><b>Path 2</b><br/>Developing observation skills and controlled experimental procedures</p>   | <p>Lunar Image Analysis<br/>Moon Research Design</p>  | <p>Science<br/>Dimension 1: Practices<br/>2,3<br/>Dimension 2: Concept<br/>2, 3, 4<br/>Dimension 3: ESS<br/>ESS1C</p>  | <p>5</p>                                  |
| <p><b>Path 3</b><br/>Developing observation skills, graphing techniques, and graphical interpretation</p>                                     | <p>Lunar Image Analysis<br/>Moon Data Analysis</p>  | <p>Science<br/>Dimension 1: Practices<br/>4, 5, 6<br/>Dimension 2: Concept<br/>1, 2, 3, 4<br/>Dimension 3: ESS<br/>ESS1C</p>   | <p>5</p>                                  |
| <p><b>Path 4</b><br/>Developing observation skills, controlled experimental procedures, graphing techniques, and graphical interpretation</p> | <p>Lunar Image Analysis<br/>Moon Research Design<br/>Moon Data Analysis</p>   | <p>Science<br/>Dimension 1: Practices<br/>2, 3, 4, 5, 6, 7<br/>Dimension 2: Concept<br/>1, 2, 3, 4<br/>Dimension 3: ESS<br/>ESS1C</p>  | <p>8</p>                                  |

## Scientific Observations and Debate Skills Rubric

|                         | Expert  | Proficient   | Intermediate  | Beginner   |
|-------------------------|---|--|---|--|
| Scientific Observations | <ul style="list-style-type: none"> <li>Differentiates between common features and unique features on the Moon and begins hypothesizing about why these features appear or establishing patterns.</li> <li>Illustrations of these features demonstrates the connection to a possible pattern.</li> <li>Explains the differences between the common and unique features of the Moon using specific criteria and subject specific knowledge</li> </ul> | <ul style="list-style-type: none"> <li>Differentiates between common features associated with a surface feature on the Moon, and those that appear unique.</li> <li>Illustrates these unique and common features of the Moon.</li> <li>Explains the differences between the common and unique features of the Moon.</li> </ul> | <ul style="list-style-type: none"> <li>Identifies features on the Moon that are both common and unique.</li> <li>Illustrates each feature.</li> <li>Explains each feature using correct terminology in feature identification and specific details in the descriptions</li> </ul> | <ul style="list-style-type: none"> <li>Identifies features on the Moon.</li> <li>Illustrates each feature.</li> <li>Uses correct terminology in feature identification.</li> <li>Uses specific details in descriptions.</li> </ul> |
| Debate Skills           | <ul style="list-style-type: none"> <li>Identifies and critiques arguments in which the claims are not consistent with the evidence given using the claims, evidence, and reasoning model.</li> <li>Exemplifies scientific discussions to allow for differing opinions, observations, experiences, and perspectives.</li> <li>Uses self-created hypotheses to explain the meaning in observations.</li> </ul>  | <ul style="list-style-type: none"> <li>Uses claims, evidence, and reasoning.</li> <li>Exemplifies scientific discussions to allow for differing opinions, observations, experiences, and perspectives.</li> <li>Infers the meaning of the observations (starts hypothesizing).</li> </ul>                                      | <ul style="list-style-type: none"> <li>Explains reasoning behind agreement and/or disagreement with participants.</li> <li>Uses claim and reasoning portion of the model.</li> </ul>  | <ul style="list-style-type: none"> <li>Generates a claim.</li> <li>Participates in discussion.</li> <li>Uses previous knowledge to support a claim in discussion.</li> <li>Agrees and/or disagrees with participants.</li> </ul>   |

# Teacher Resource #1



**Title:** Names the general region where the image is located on the Moon.

**Latitude and Longitude:** Exact location of this image on a map of the Moon.

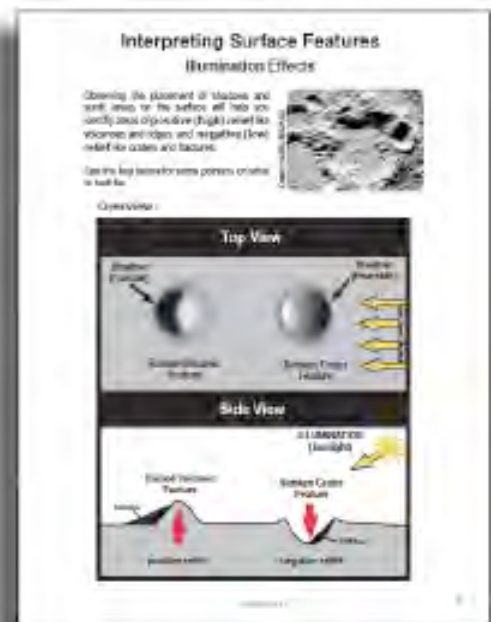
**LROC-WAC with LOLA elevation:** Colorized elevation of the surface of the Moon.

**LROC-WAC Equatorial Mosaic:** The long, rectangular image of the Moon. Mosaic of LROC WAC images.

**Context Image:** Shows the area surrounding the LROC-WAC Equatorial Mosaic.

## SUNLIGHT AND SHADOWS

The Sunlight and Shadows sheet will help students to identify features in their LROC-WAC Mosaic by orienting them to how shadowing is used to identify a raised or carved feature. Some students may need additional practice with this concept, using concrete materials such as a cup and flashlight. Have students discover how the lighting works with the cup turned right-side up and up-side down.



**Context Image:** Shows the area surrounding the LROC-WAC Equatorial Mosaic.

# Teacher Resource #2

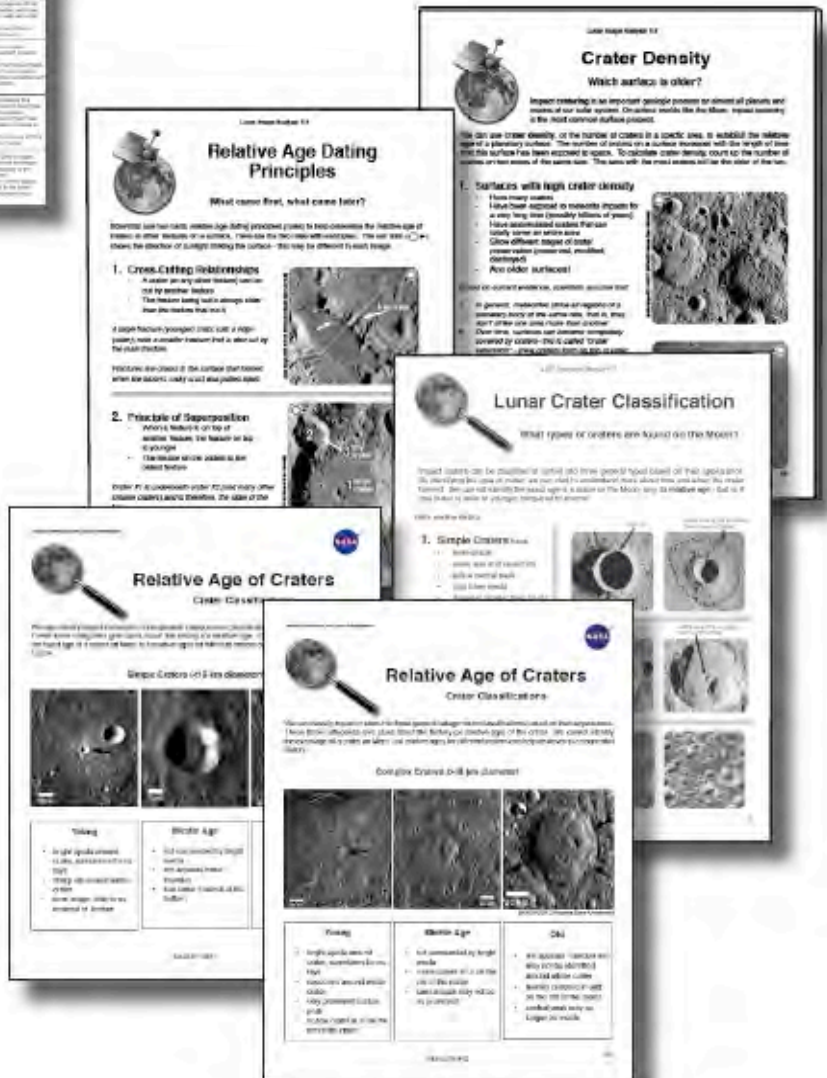


## ◀ FEATURE IDENTIFICATION CHARTS

The Feature ID Charts will help students learn the names of different geologic features on the Moon. They also provide information on how features form. The information at the top of each chart indicates what geologic process the listed features are associated with. There are many other features students may observe in images that are not included on these charts. Encourage students to share other features they may know.

## RELATIVE AGE HANDOUTS ▶

Students will be able to use the Crater Density, Lunar Crater Classification, Relative Age of Craters, and Relative Age Dating Principles sheets to identify what features are older or younger. This will help them better understand the geologic history of the surface.





## Sunlight and Shadows

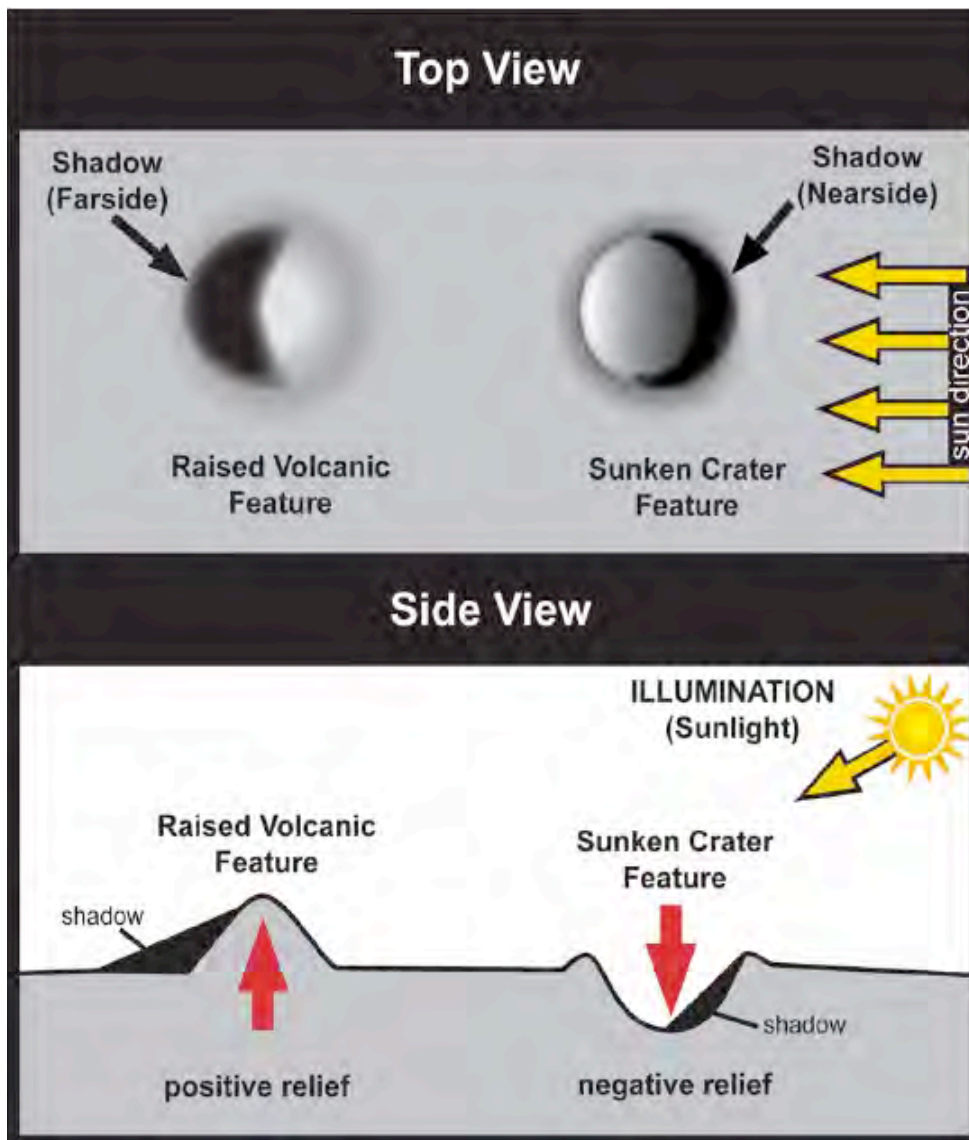
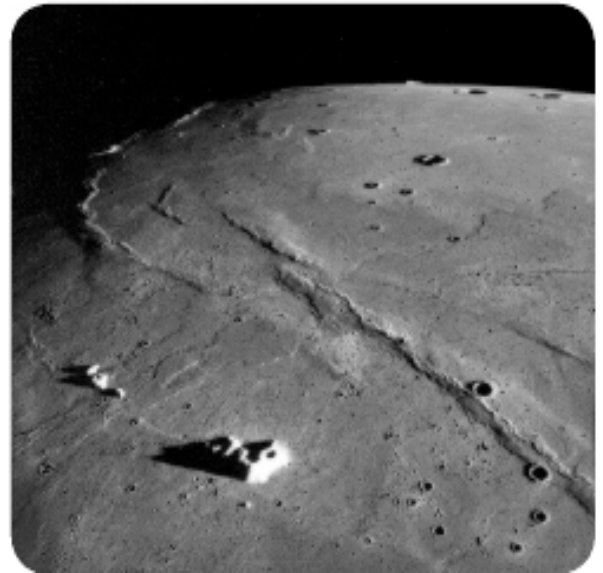
Observing the position of shadows and sunlit areas on the Moon's surface will help you identify areas of **positive (high) relief** like volcanoes and ridges, and **negative (low) relief** like craters and fractures.

See the key below for some pointers on what to look for as you start working with lunar images.

When the Sun is low in the horizon, light strikes the surface at low angles making long shadows. This geometry enhances surface features (image at right). See the key below for some pointers on what to look for as you start working with lunar images.

When the Sun is low in the horizon, light strikes the surface at low angles making long shadows. This geometry enhances surface features (image at right).

ApolloImageAS15-M-1555[NASA/JSC/ASU]



# Lunar Crater Classification

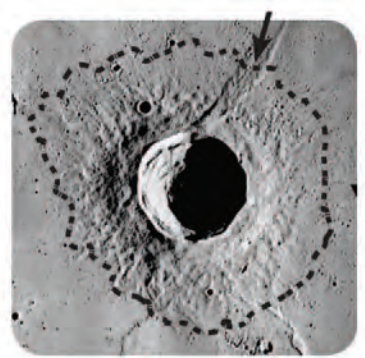
## WHAT TYPES OF CRATERS ARE FOUND ON THE MOON?

Impact craters can be classified or sorted into three general types, based on their appearance. By identifying the type of crater, we can start to understand more about how and when the crater formed.

Here are the basics:

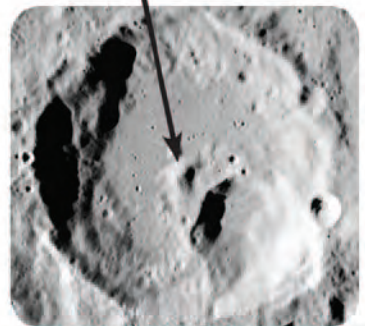
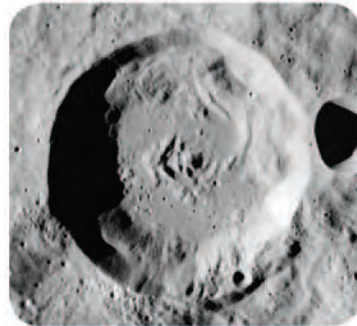
### 1. Simple Craters have:

- bowl-shape
- steep wall and raised rim
- lack a central peak
- may have ejecta
- diameter smaller than 10-20 kilometers (6-12 miles)



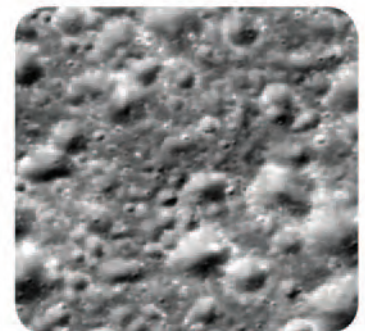
### 2. Complex Craters have

- central peaks
- terraced walls (where walls have slumped inward)
- flat floors
- may have ejecta
- diameter larger than 10-20 kilometers (6-12 miles)



### 3. Secondary Craters are:

- clusters or chains of small craters
- occur near large impacts
- often observed radiating out from larger impacts

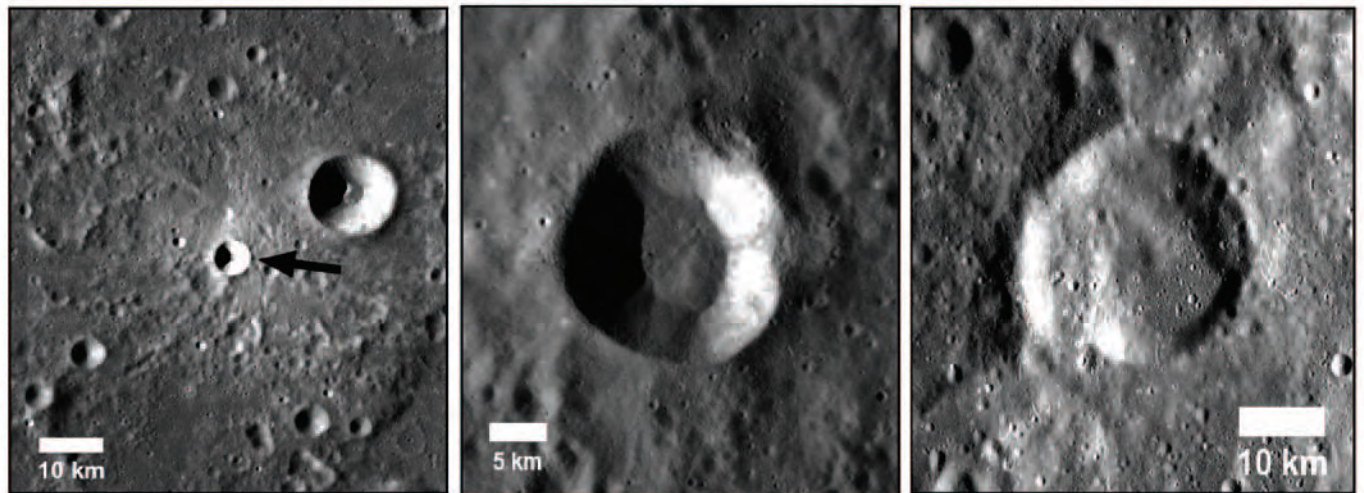


## Relative Age of Craters

### CRATER CLASSIFICATIONS

These three categories give clues about the history (or relative age) of the crater. We cannot identify the exact age of a crater on the Moon, but relative ages for different craters can help us develop a sequential history.

### Simple Craters (<15 km diameter)



NASA/GSFC/Arizona State University

#### Young

- Bright ejecta around crater, sometimes forms rays
- Sharp rim around whole crater
- Bowl shape, little to no material at bottom

#### Middle Age

- Not surrounded by bright ejecta
- Rim appears more rounded as some material at the bottom

#### Old

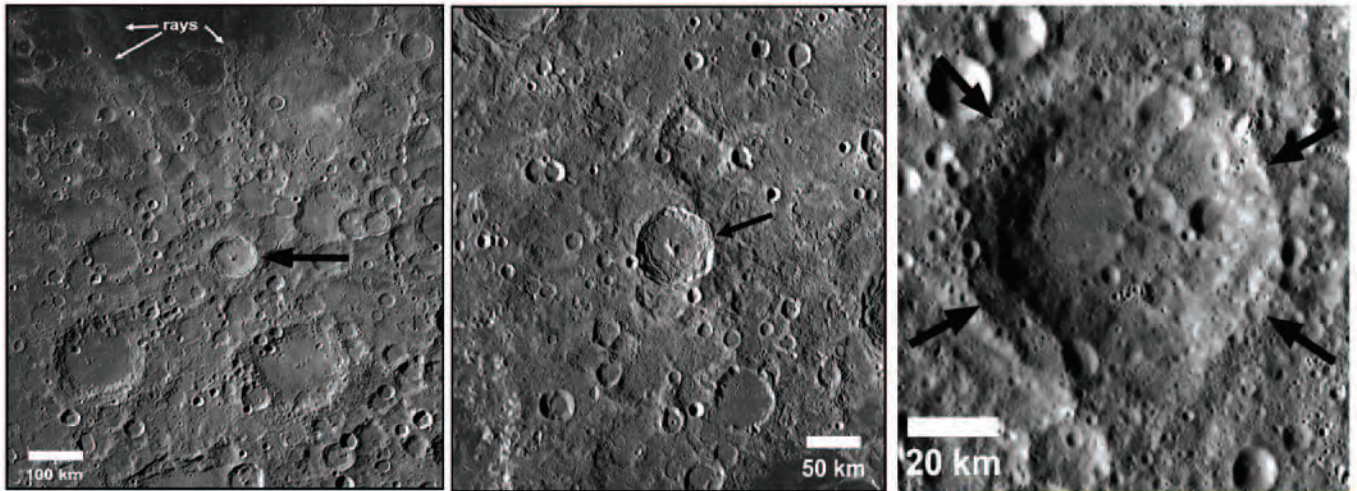
- Rim is very rounded
- May have younger crater on/in crater
- May be almost complete filled in

# Relative Age of Craters

## CRATER CLASSIFICATIONS

We can classify impact craters into three general categories or classifications based on their appearance. These three categories give clues about the history (or relative age) of the crater. We cannot identify the exact age of a crater on Mars, but relative ages for different craters can help us develop a sequential history.

### Complex Craters (>15 km diameter)



NASA/GSFC/Arizona State University

#### Young

- Bright ejecta around crater, sometimes forms rays
- Raised rim around whole crater
- Very prominent central peak
- No/few craters in or on the rim of the crater

#### Middle Age

- Not surrounded by bright ejecta
- More craters in or on the rim of the crater
- Central peak may not be as prominent

#### Old

- Rim is very rounded and may not be identified around whole crater
- Heavily cratered in and on the rim of the crater
- Central peak may no longer be visible

# Crater Density

## WHICH SURFACE IS OLDER?

Impact cratering is an important geologic process on almost all planets and moons of our solar system. On the Moon, impact cratering is the most common surface process. We can use crater density, or the number of craters in a specific area, to establish the relative age of a planetary surface. The number of craters on a surface increases with the length of time the surface was exposed to space. To calculate crater density, count up the number of craters on two areas of the same size. The area with the most craters will likely, though not always, be the older of the two.

### 1. Surfaces with high crater density

- Have many craters
- Have been exposed to meteorite impacts for a very long time (possibly billions of years)
- Have accumulated craters that can totally cover an entire area
- Show different stages of crater preservation (preserved, modified, destroyed)
- **Are older surfaces!**

Based on current evidence, scientists assume that:

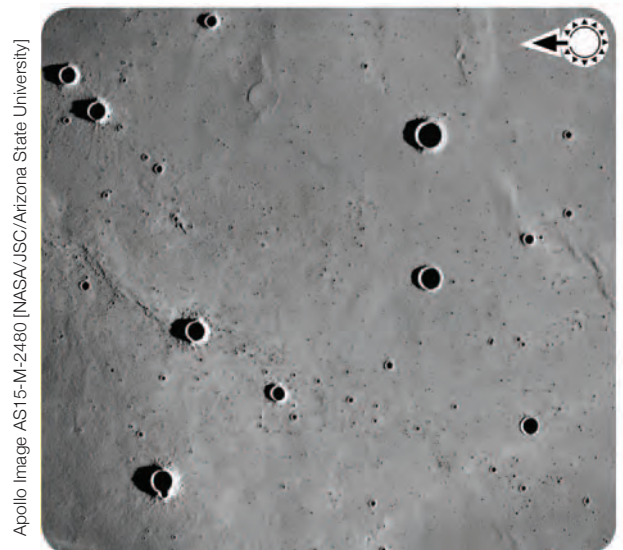
- In general, meteorites strike all regions of a planetary body at the same rate; that is, they don't strike one area more than another
- Over time, surfaces can become completely covered by craters— this is called “crater saturation” (new craters form on top of older craters until the surface is completely covered)



Apollo Image AS15-M-2211 [NASA/JSC/Arizona State University]

### 2. Surfaces with low crater density

- Have fewer craters
- Have been recently covered by materials such as lava flows and sediments
- Show similar crater preservation, often preserved craters
- Are younger surfaces!



Apollo Image AS15-M-2480 [NASA/JSC/Arizona State University]



Direction of sunlight striking the surface.

# Relative Age Dating Principles

## WHICH FEATURES CAME FIRST? WHICH CAME LATER?

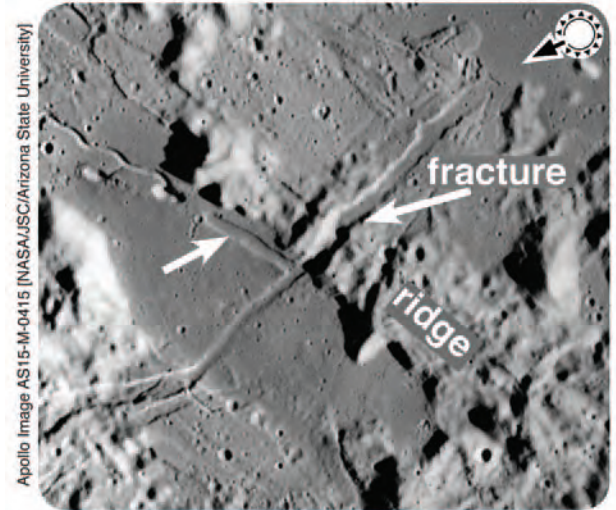
Scientists use two basic relative age dating principles to help determine the relative age of craters or other features on a surface. Here are the two principles with examples. The Sun icon shows the direction of sunlight striking the surface and may be different in each image.

### 1. Cross-Cutting Relationships

- A crater (or any other feature) can be cut by another feature
- The feature being cut is always older than the feature that cut it

A large fracture (younger) cross cuts a ridge (older); note a smaller fracture that is also cut by the main fracture.

Fractures are cracks in the surface that formed when the Moon's rocky crust was pulled apart.

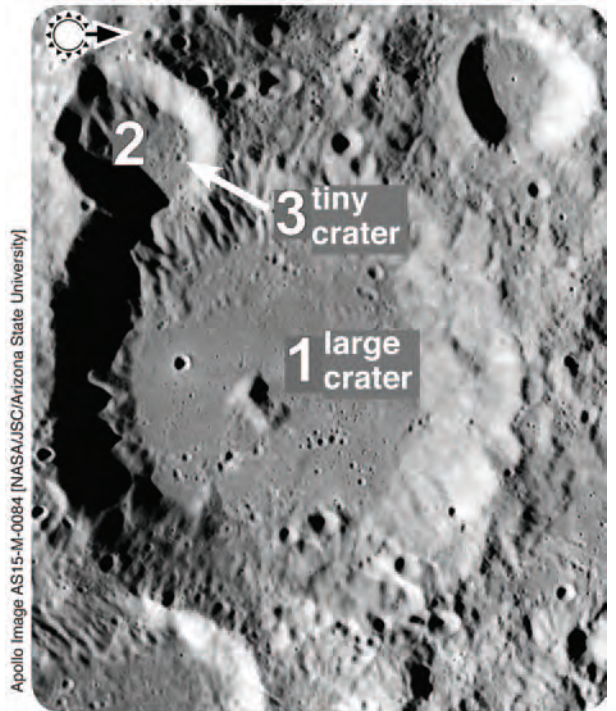


### 2. Principle of Superposition

- When a feature is on top of another feature, the feature on top is usually younger
- The feature on the bottom is usually the oldest feature

Crater #1 is underneath Crater #2 (and many other smaller craters) and is therefore the older of the two.

The tiny crater #3 is on top of crater #2 (or inside) so it is the youngest of all.



# Supplemental #1

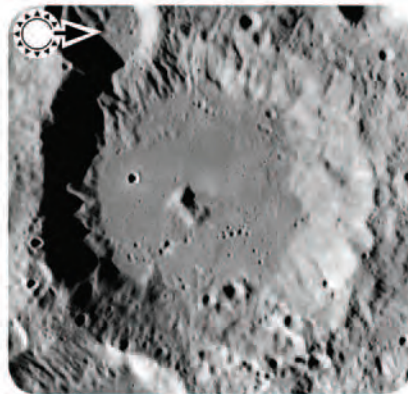
## CLASSIFYING CRATERS

Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

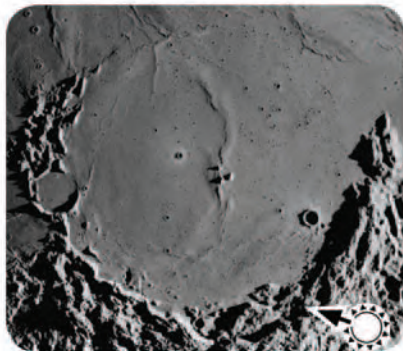
| Crater Image | Crater Classification (Simple, Complex, Secondary & Preserved, Modified, Degraded) | Explain Your Reason |
|--------------|--|---------------------|
| Crater A     |  |                     |
| Crater B     |  |                     |
| Crater C     |  |                     |
| Crater D     |  |                     |



**Crater A**



**Crater B**



**Crater C**

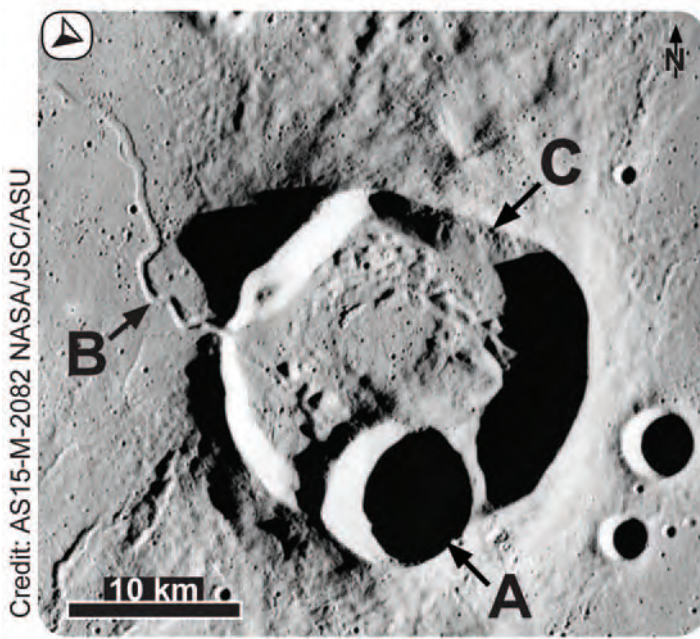


**Crater D**

## Supplemental #2

### RELATIVE AGE DATING PRINCIPLES

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



#### 1. Krieger Crater, Moon

Oldest Crater: \_\_\_\_\_

Younger Crater: \_\_\_\_\_

Youngest Crater: \_\_\_\_\_

Please explain your answers: \_\_\_\_\_

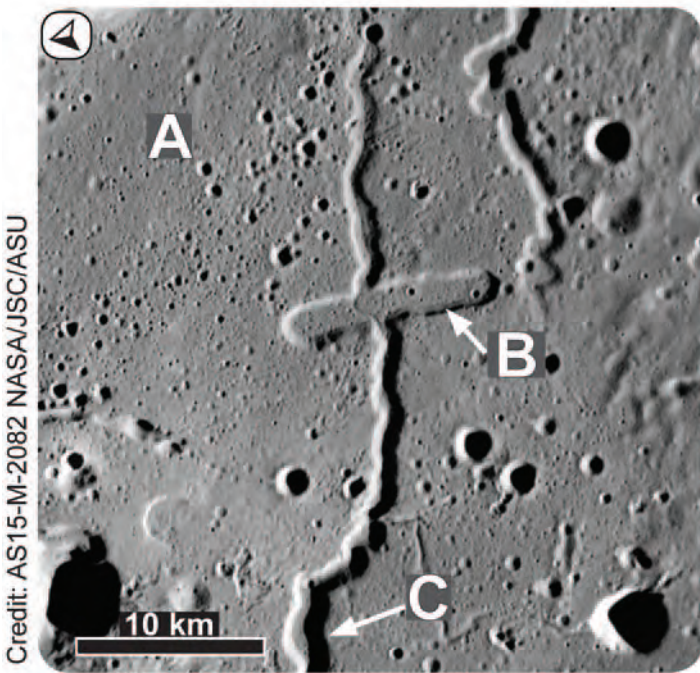
\_\_\_\_\_

\_\_\_\_\_

Which principle(s) did you use to choose your answer?

\_\_\_\_\_

\_\_\_\_\_



#### 2. Aristarchus-Prinz region, Moon

Oldest Feature: \_\_\_\_\_

Younger Feature: \_\_\_\_\_

Youngest Feature: \_\_\_\_\_

Please explain your answers: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Which principle(s) did you use to choose your answer?

\_\_\_\_\_

\_\_\_\_\_



## Supplemental #1: SAMPLE ANSWERS

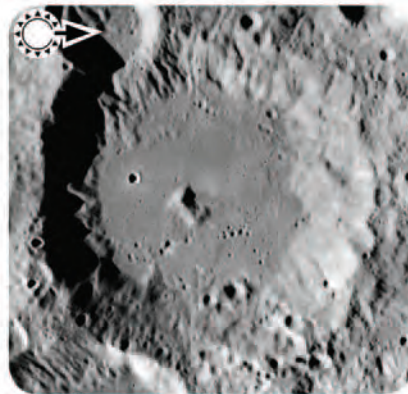
### CLASSIFYING CRATERS

Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

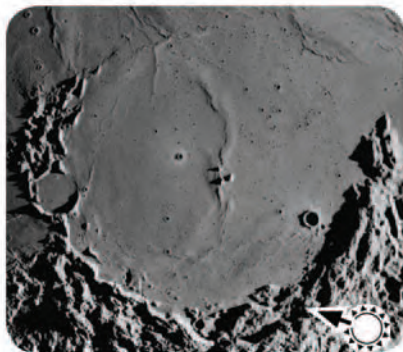
| Crater Image | Crater Classification (Simple, Complex, Secondary & Preserved, Modified, Degraded) | Explain Your Reason  |
|--------------|--|--|
| Crater A     | Simple & Preserved   | Raised, circular rims with bowl shape; ejecta visible; crater looks new      |
| Crater B     | Complex & Degraded   | Rim no longer raised and crater floor flat; remnant of a central peak        |
| Crater C     | Simple & Secondary   | Small cluster of craters, arranged in a line, simple structure               |
| Crater D     | Simple & Preserved   | Raised, circular rims with bowl shape; some ejecta visible; crater looks new |



**Crater A**



**Crater B**



**Crater C**

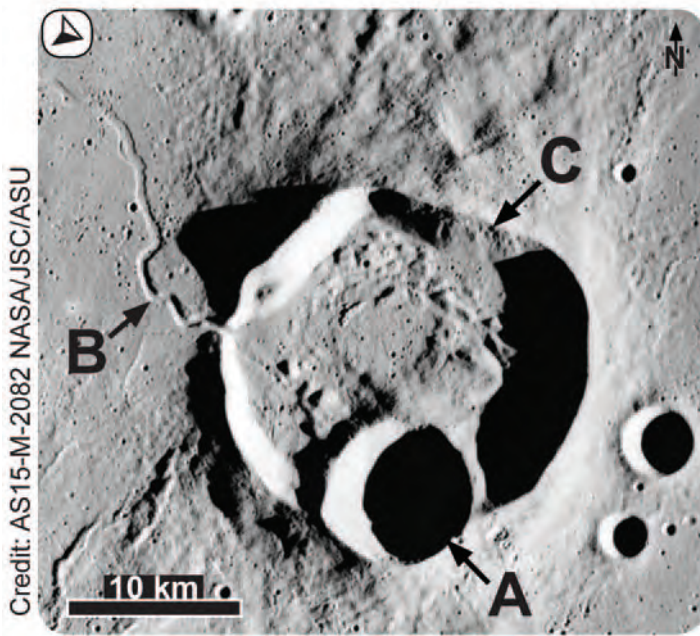


**Crater D**

## Supplemental #2: SAMPLE ANSWERS

### RELATIVE AGE DATING PRINCIPLES

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



#### 1. Krieger Crater, Moon

Oldest Crater:           **C**          

Younger Crater:           **B**          

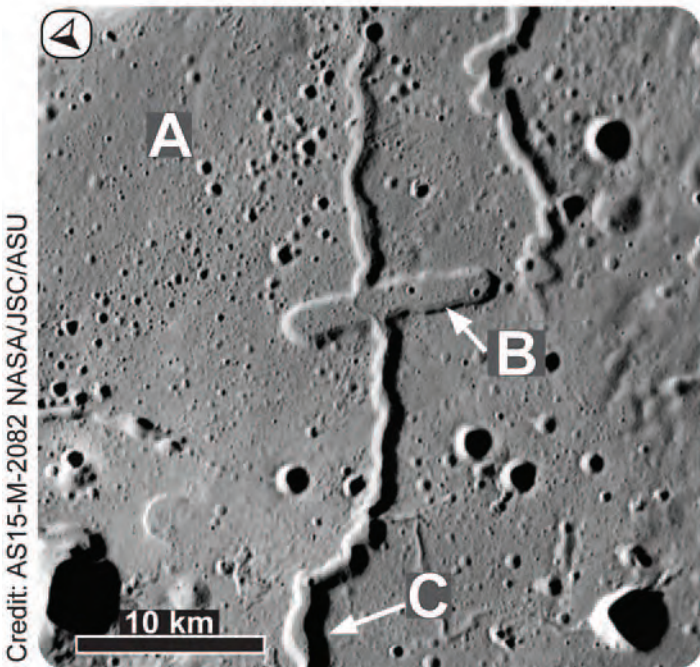
Youngest Crater:           **A**          

Please explain your answers:

**The channel (B) is younger than crater C since it cuts it. Crater A is the youngest since it sits on top of crater C and the channel.**

Which principle(s) did you use to choose your answer?

**Principle of Superposition**



#### 2. Aristarchus-Prinz region, Moon

Oldest Feature:           **A**          

Younger Feature:           **C**          

Youngest Feature:           **B**          

Please explain your answers:

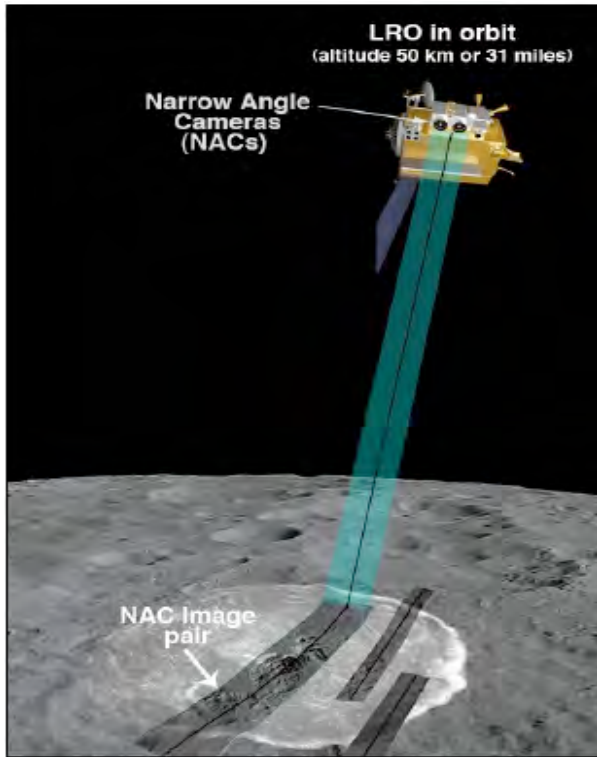
**A is the oldest feature (original surface); the channel C is younger since it cuts across the surface; and, the valley B cuts C and is youngest.**

Which principle(s) did you use to choose your answer?

**Cross-cutting Relationships**

## What is LROC?

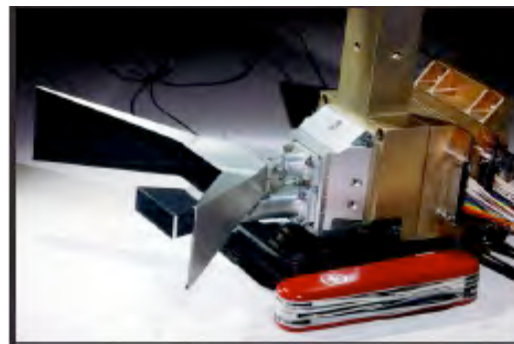
The **Lunar Reconnaissance Orbiter Camera (LROC)** is the camera system on the Lunar Reconnaissance Orbiter (LRO), which orbits the Moon. LROC has two **Narrow Angle Cameras (NACs)**, taking 0.5 meter-scale black and white images over a 5 kilometer area (~3 miles), one **Wide Angle Camera (WAC)**, taking images at a scale of 100 meters (about the length of a football field), and a common **Sequence and Compressor System (SCS)** to organize image data before transmitting it to Earth.



### Narrow Angle Camera (NAC)

#### NAC Stats:

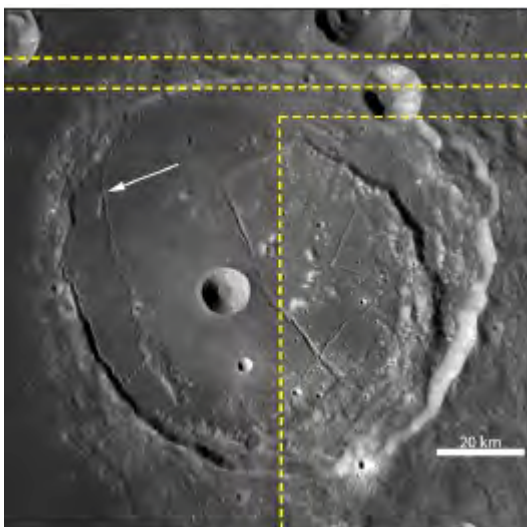
- Black & white image pairs (right and left images)
- 0.5 meters/pixel resolution
- 2.5x26 kilometers image size
- Good for viewing small features



### Wide Angle Camera (WAC)

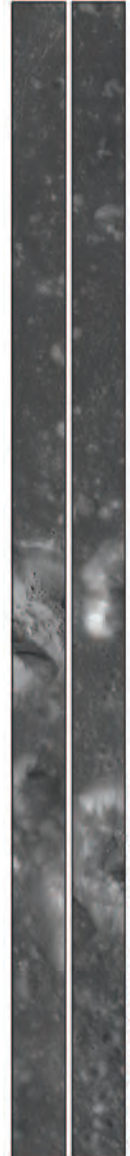
#### WAC Stats:

- Images in 7 color bands
- 74.3 meters/ pixel resolution for visible (black and white)
- Good for viewing large features and context areas



### WAC Mosaic

Composed of many WAC images (yellow dotted lines mark the boundary of individual images)



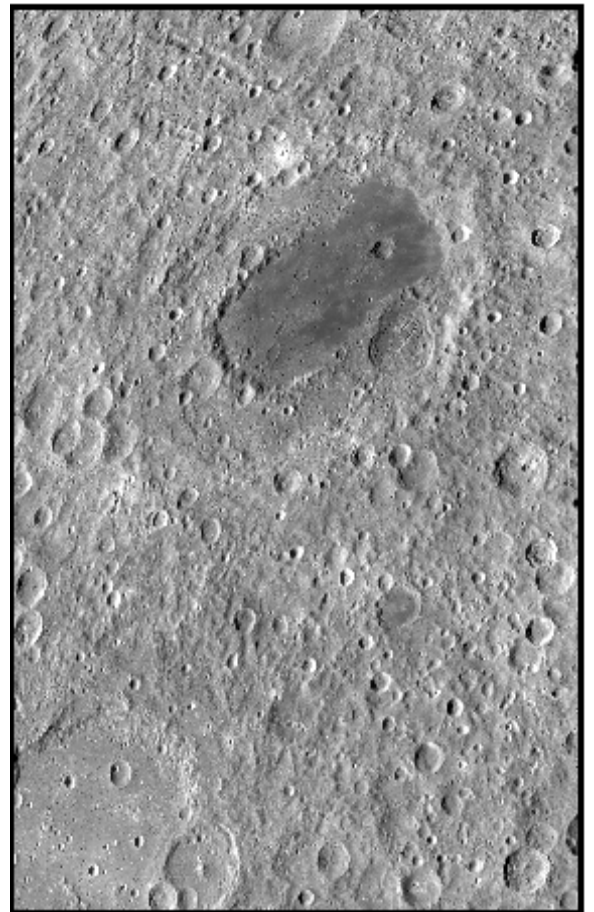
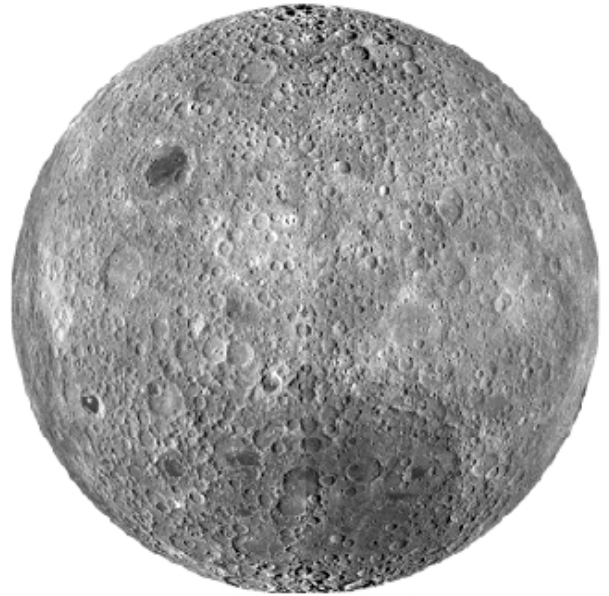
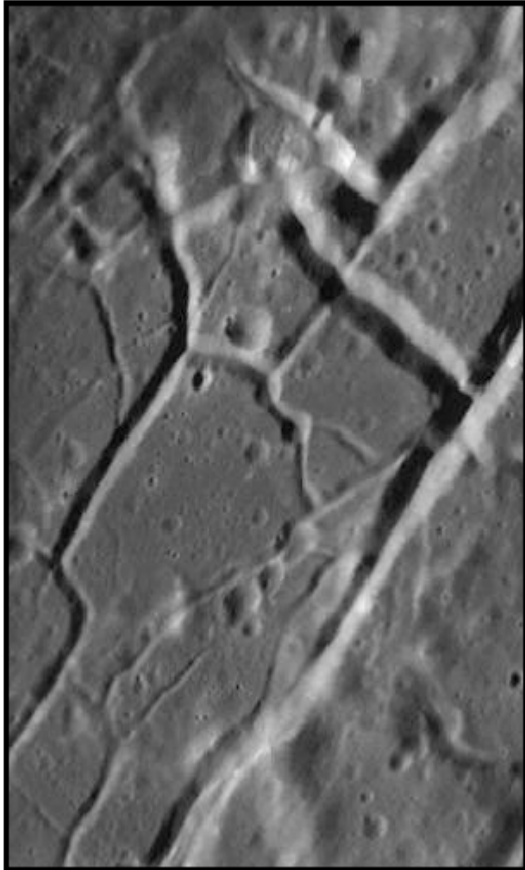
left right

NAC Image Pair

Credit: NASA/GSFC/Arizona State University

## How are these images related?

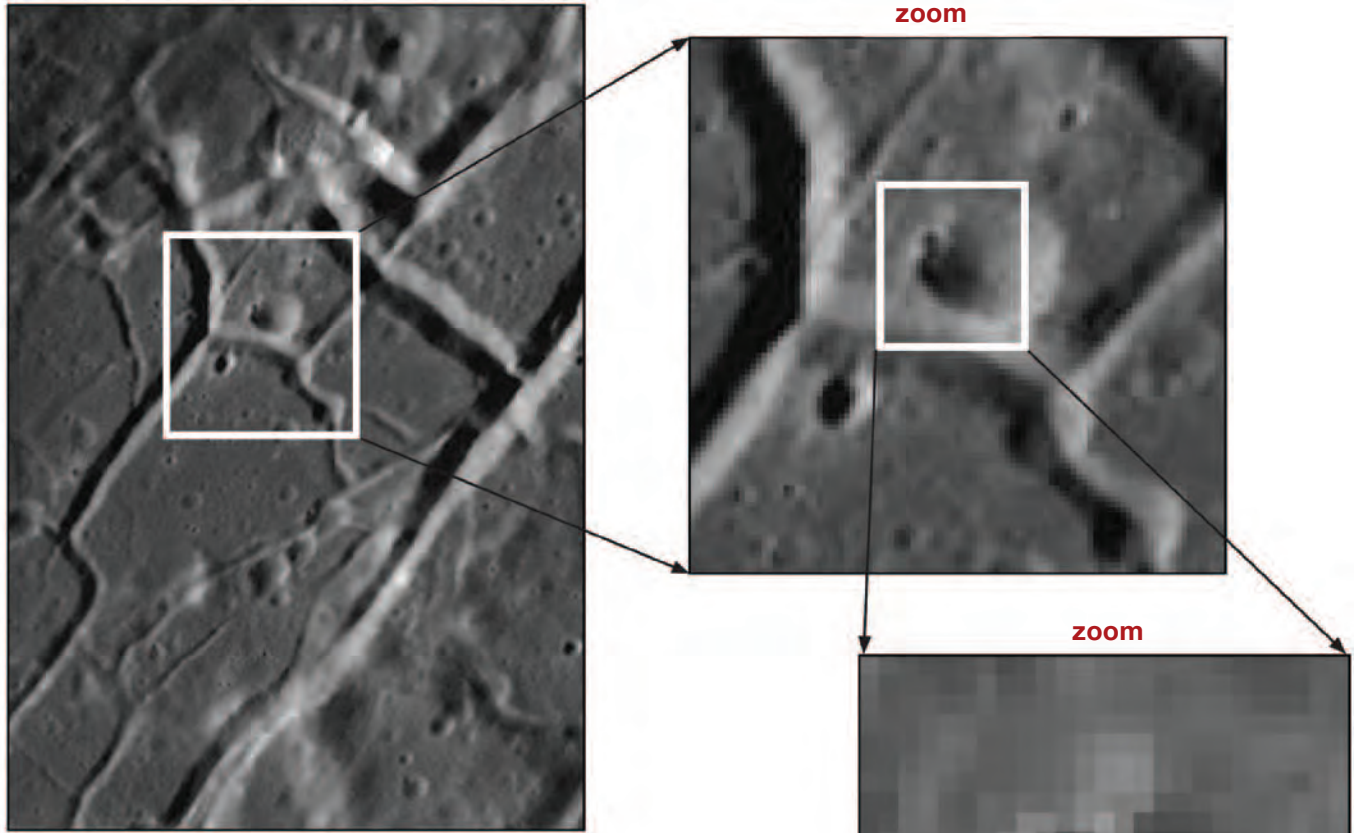
Here are four LROC images of the Moon's surface. How are they related? Look carefully at them and see if you can figure out how they are connected. Draw arrows or labels to help explain your answer.



# What is image resolution?

## LROC Wide Angle Camera (WAC) Image

Image Resolution = 100 meters per pixel



### How big is a pixel on the Moon?

This LROC image has an image resolution of 100 meters per pixel meaning every pixel in this image represents 100 meters by 100 meters on the surface of the Moon! Each pixel has a foot-print on the surface that is roughly the size of a football field!



football field

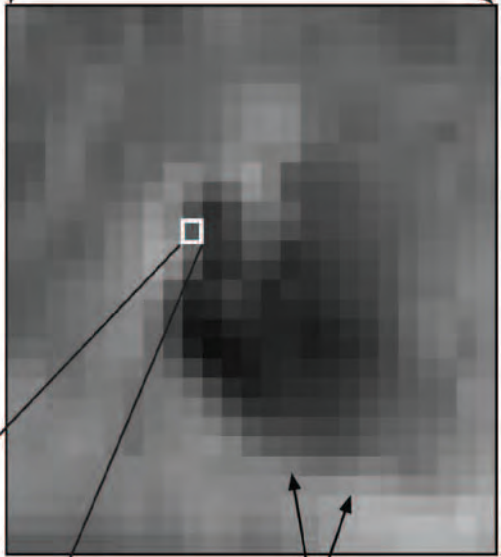


Statue of Liberty

100 meters



100 meters



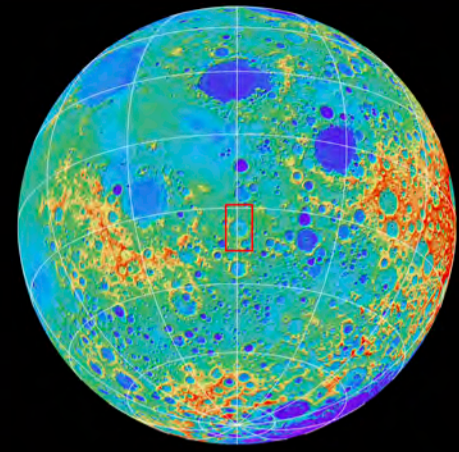
pixels

A **pixel** - short for "picture element" - is the smallest unit of an image. It's shown as a square or dot of a single color or shade.

# Lunar Image Analysis

## Rimae Petavius

Lat:  $-25.25^{\circ}$  N  
Lon:  $60.70^{\circ}$  E  
Sun angle: Low



WAC ELEVATION

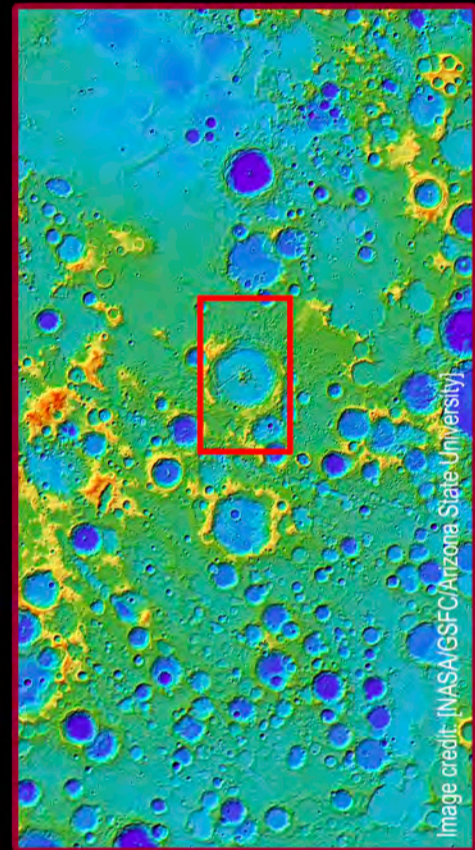


Image credit: [NASA/GSFC/Arizona State University]

CONTEXT IMAGE

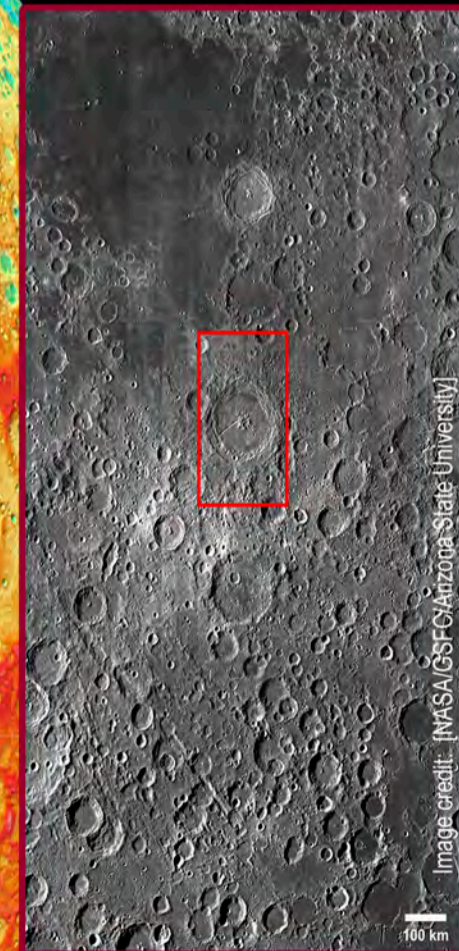


Image credit: [NASA/GSFC/Arizona State University]

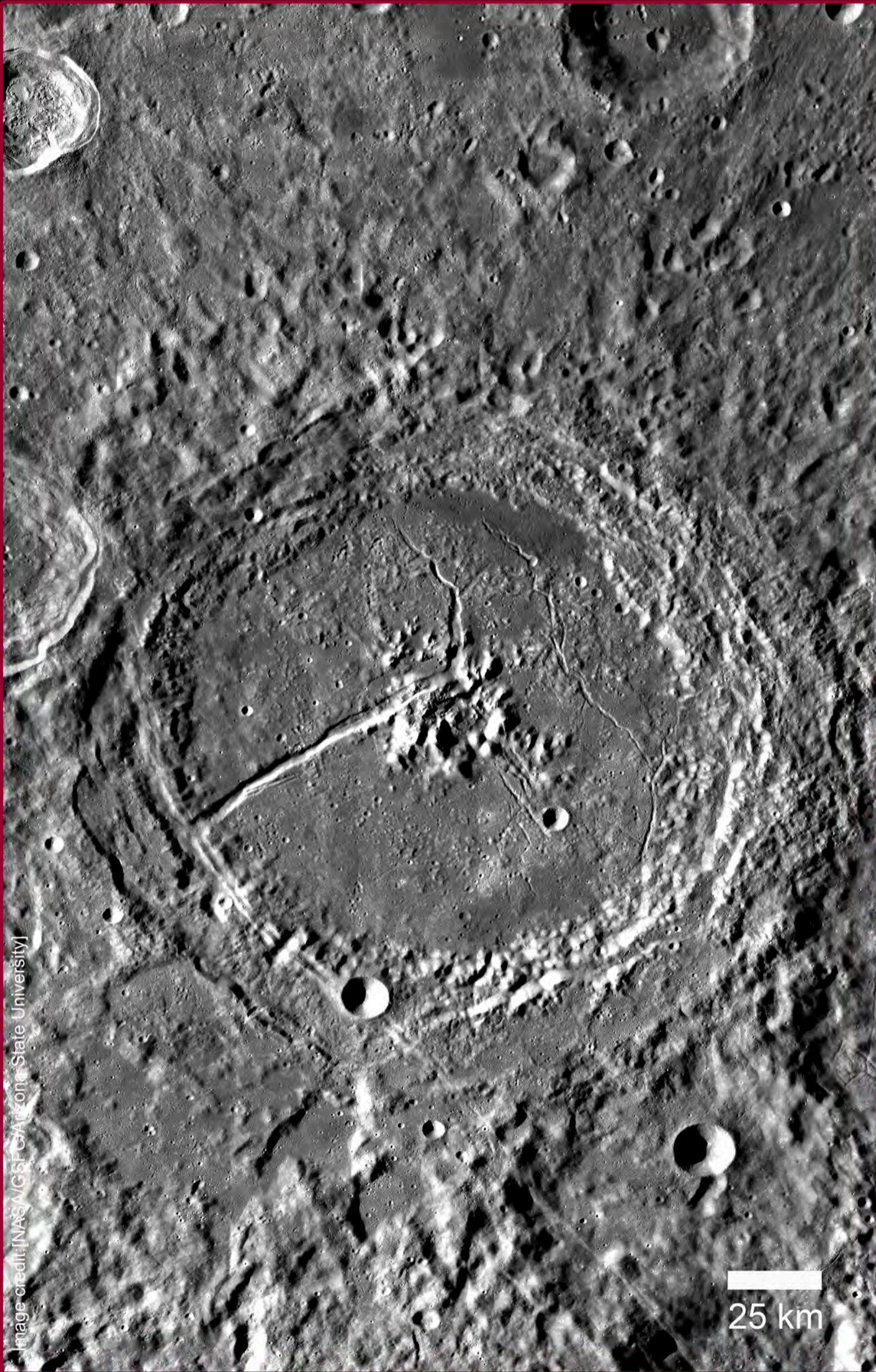


Image credit: [NASA/GSFC/Arizona State University]

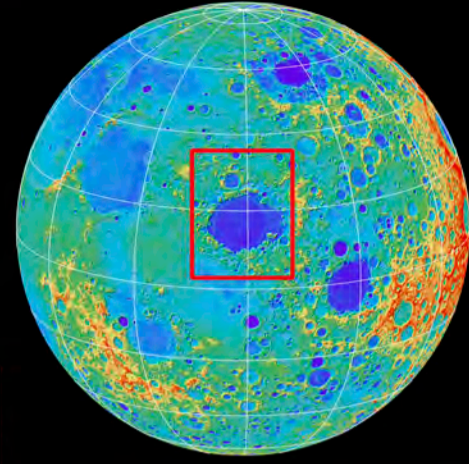
25 km



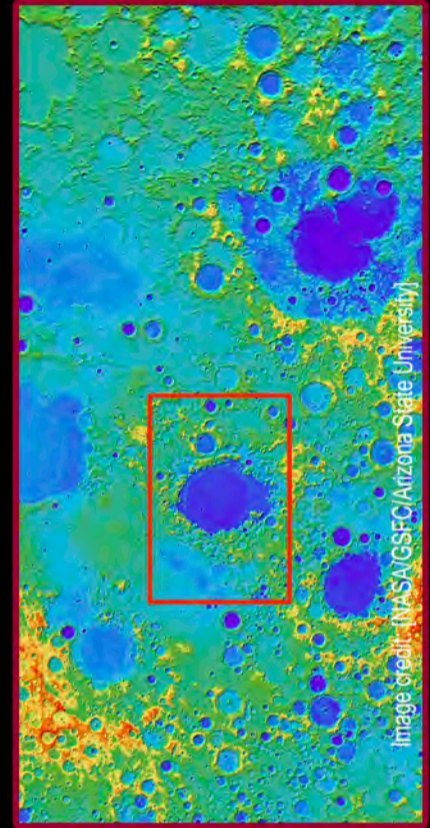
# Lunar Image Analysis

## Mare Crisium

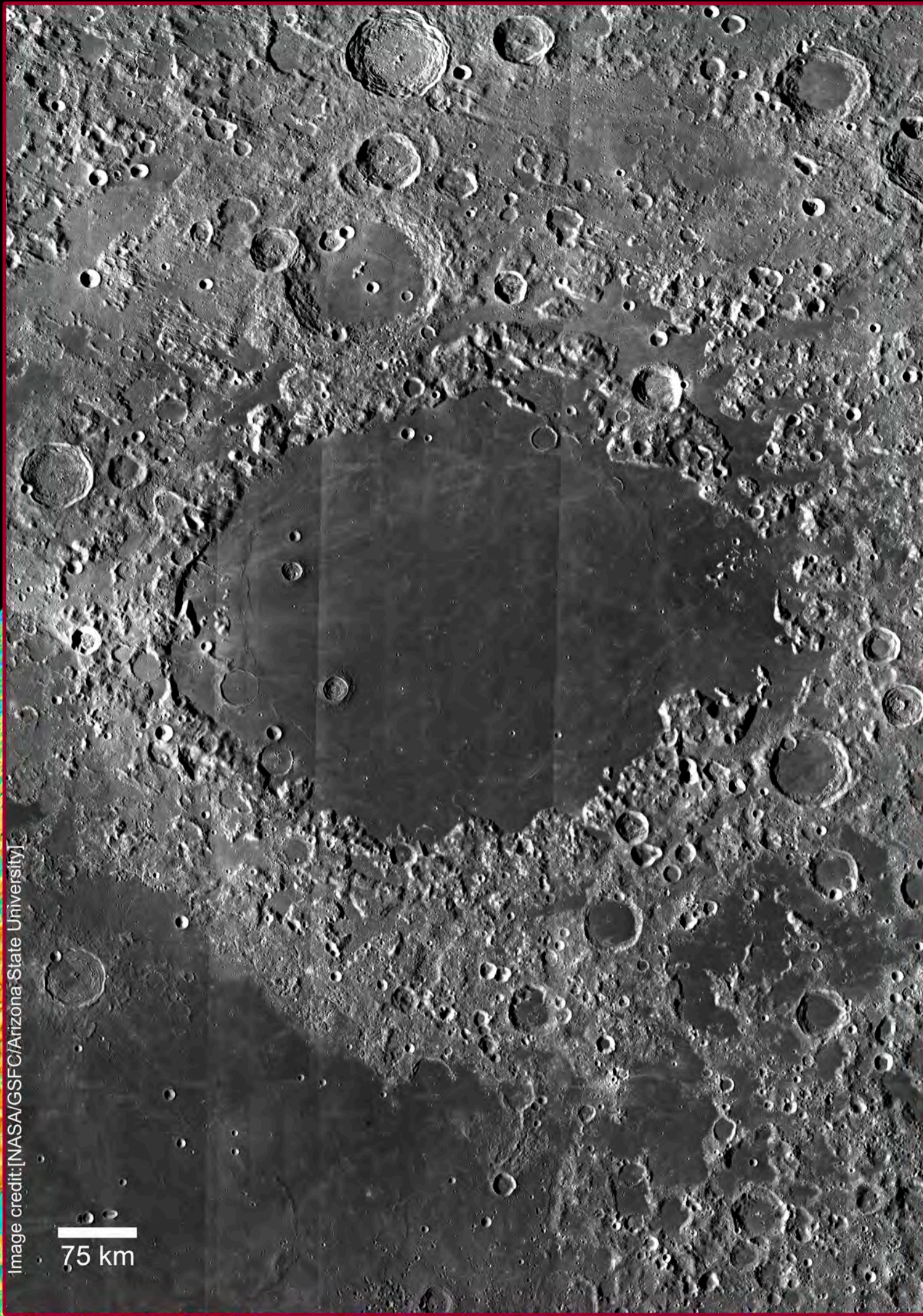
Lat: 15.50° N  
Lon: 58.80° E  
Sun angle: Low



WAC ELEVATION



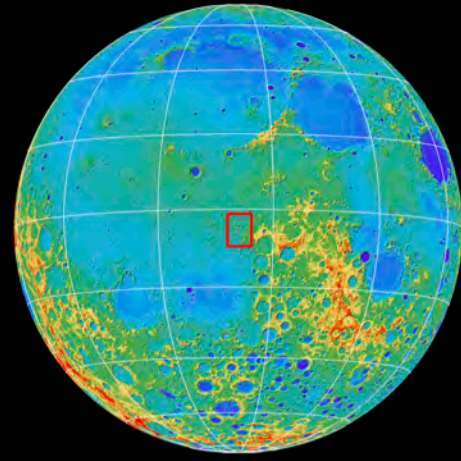
CONTEXT IMAGE



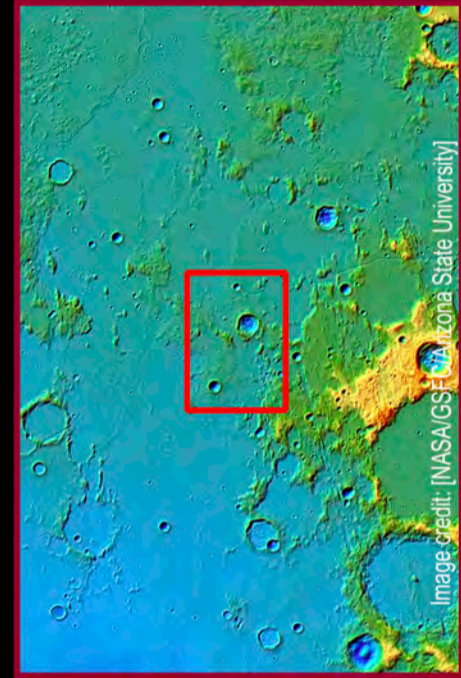
# Lunar Image Analysis

## Lalande Crater

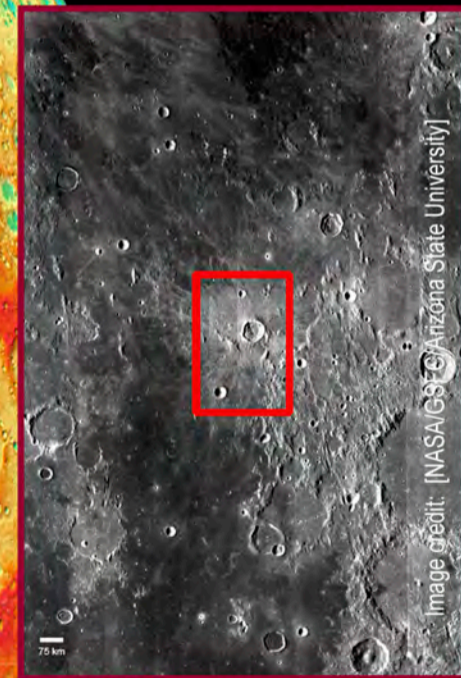
Lat:  $-4.49^\circ$   
Lon:  $351.34^\circ$  E  
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

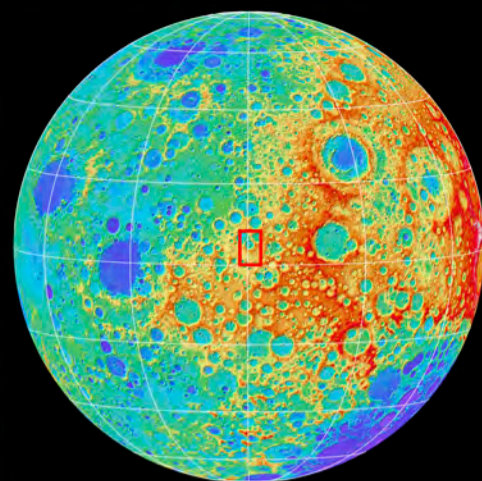




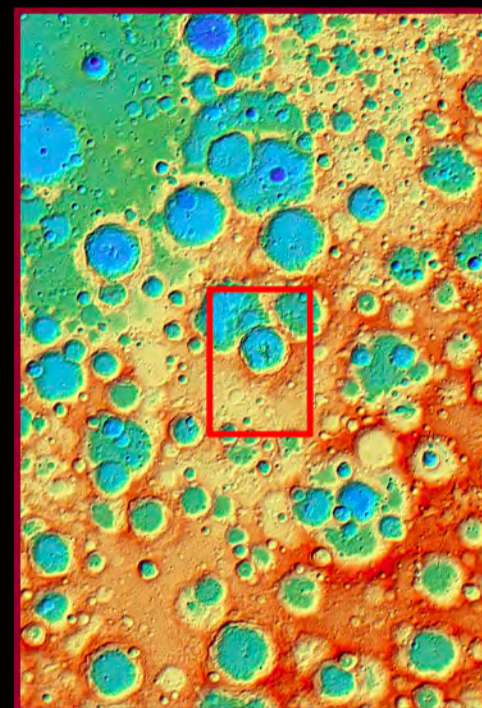
# Lunar Image Analysis

## King Crater

Lat: 5.01° N  
Lon: 120.60° E  
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

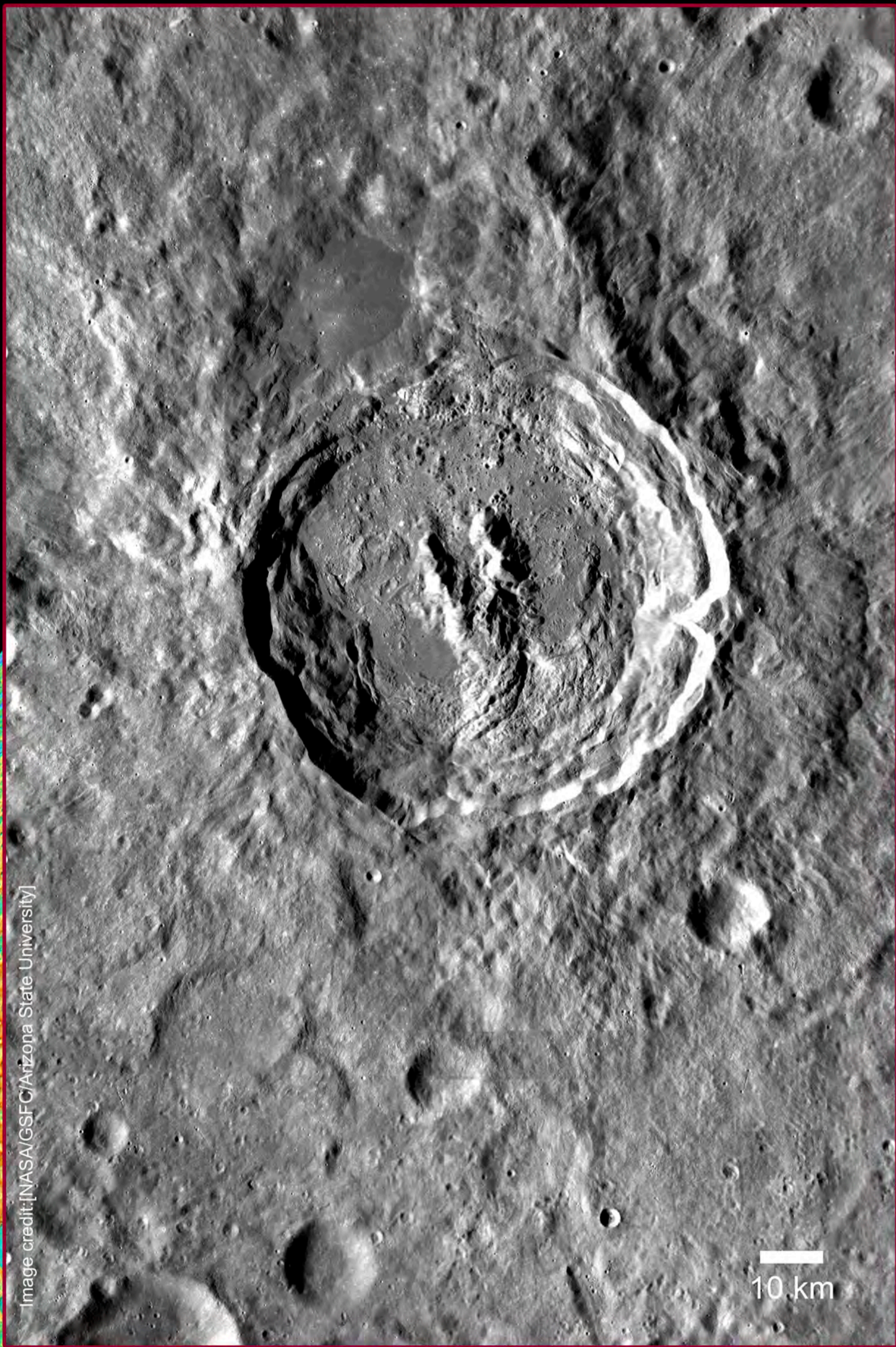
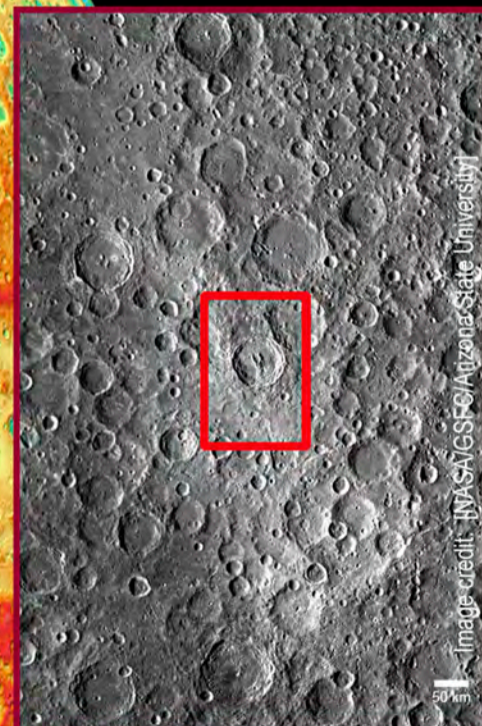


Image credit: [NASA/GSFC/Arizona State University]

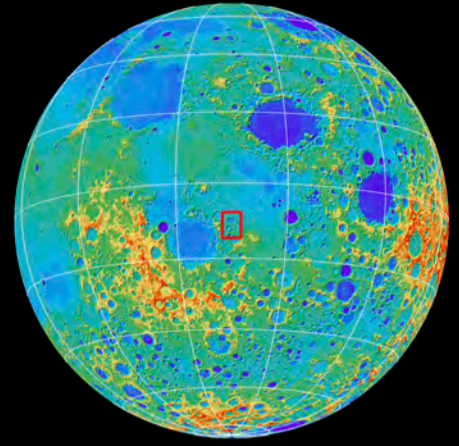
Image credit: [NASA/GSFC/Arizona State University]



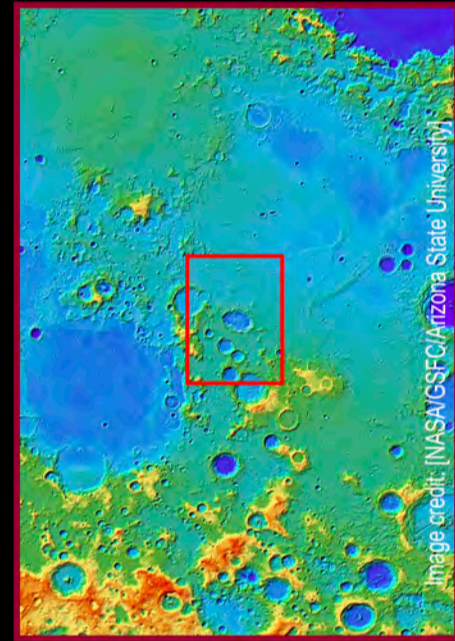
# Lunar Image Analysis

## Goclenius Crater

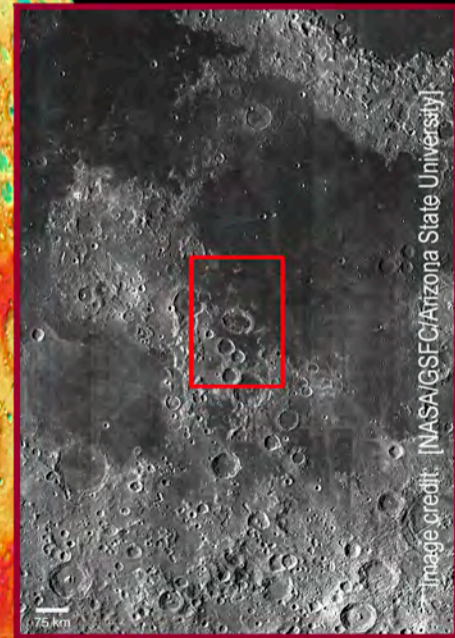
Lat:  $-10.05^{\circ}$  N  
Lon:  $45.00^{\circ}$  E  
Sun angle: Low



WAC ELEVATION



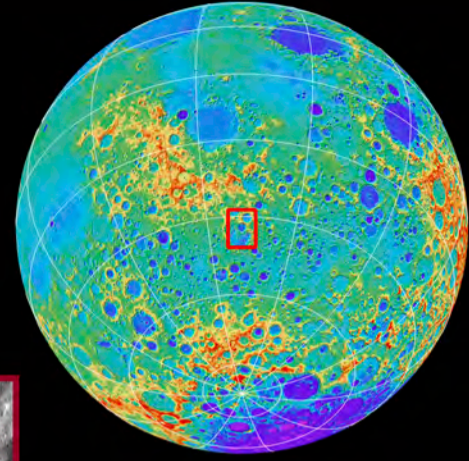
CONTEXT IMAGE



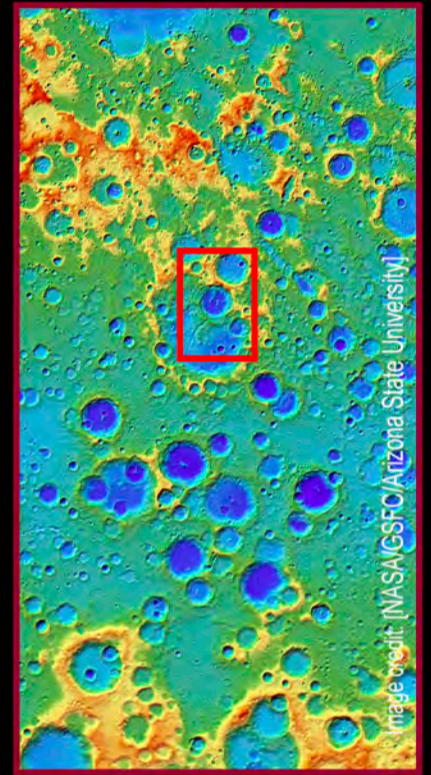
# Lunar Image Analysis

## Fabricius Crater

Lat:  $-42.92^{\circ}$  N  
Lon:  $41.95^{\circ}$  E  
Sun angle: Low



WAC ELEVATION



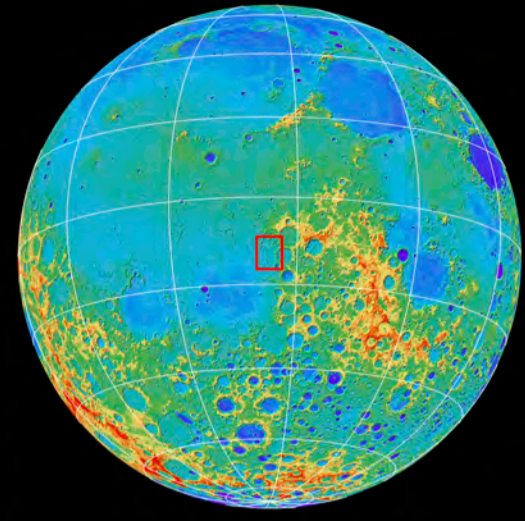
CONTEXT IMAGE



# Lunar Image Analysis

## Davy Crater

Lat: -11.19° N  
Lon: 353.18° E  
Sun angle: Low



WAC ELEVATION

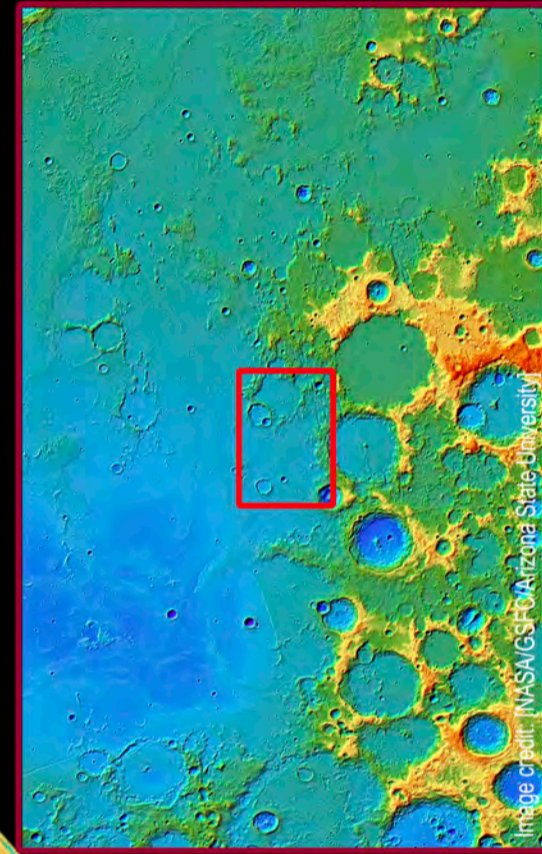


Image credit: [NASA/GSFC/Arizona State University]

CONTEXT IMAGE

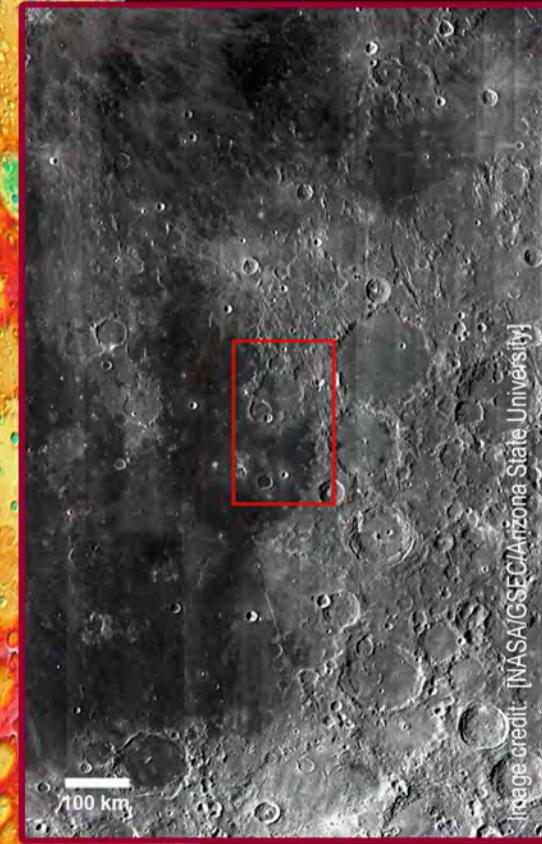


Image credit: [NASA/GSFC/Arizona State University]



Image credit: [NASA/GSFC/Arizona State University]

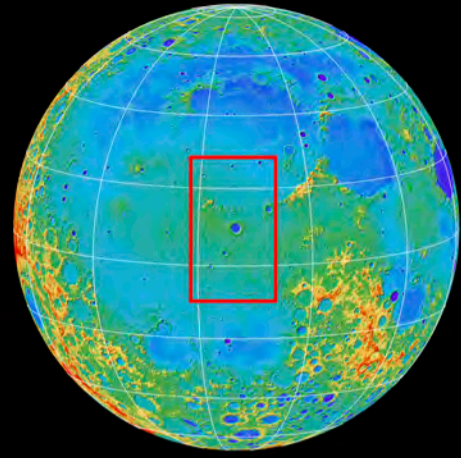
20 km



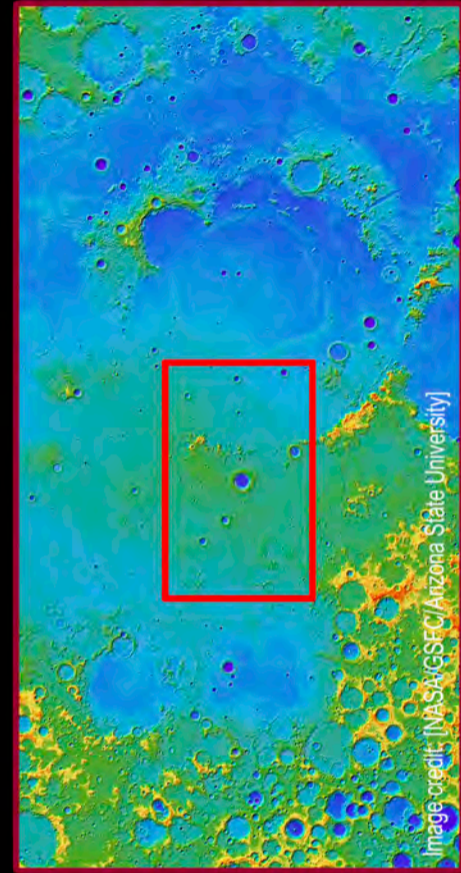
# Lunar Image Analysis

## Copernicus Crater

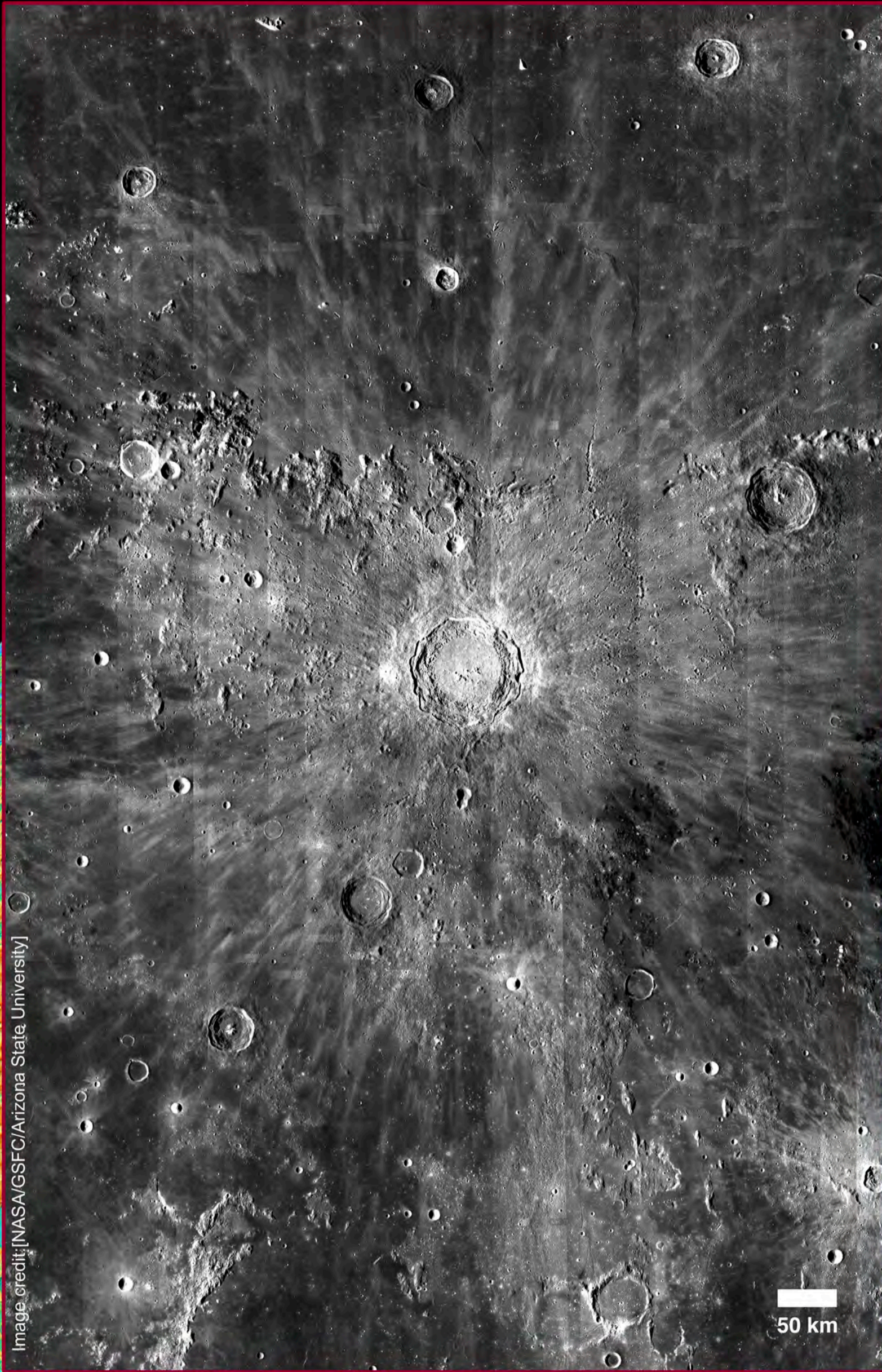
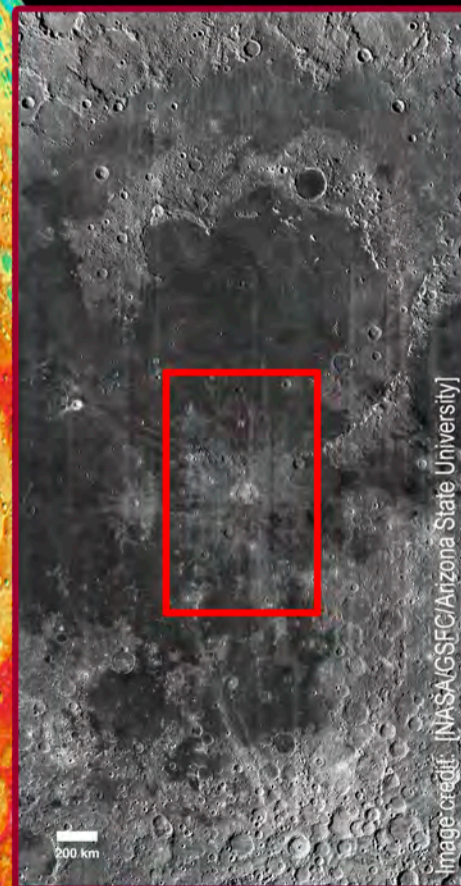
Lat: 9.62° N  
Lon: 339.89° E  
Sun angle: Low



WAC ELEVATION

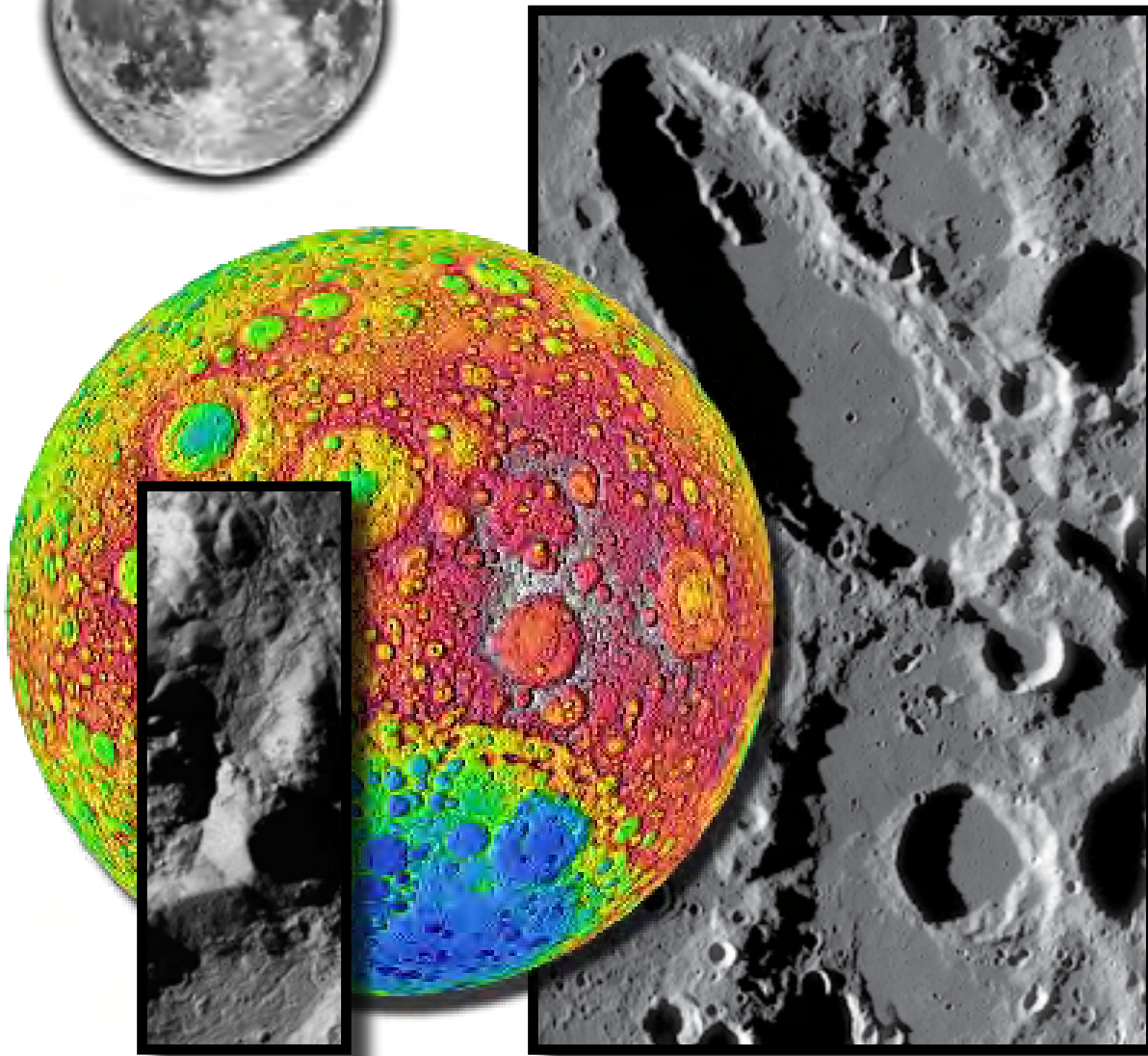


CONTEXT IMAGE





# LUNAR FEATURE IDENTIFICATION CHARTS



A GUIDE TO THE IDENTIFICATION OF SURFACE FEATURES  
ON THE MOON

---

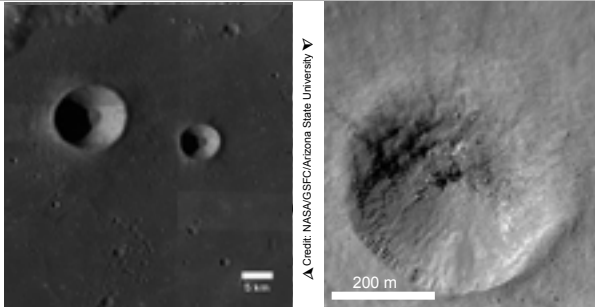
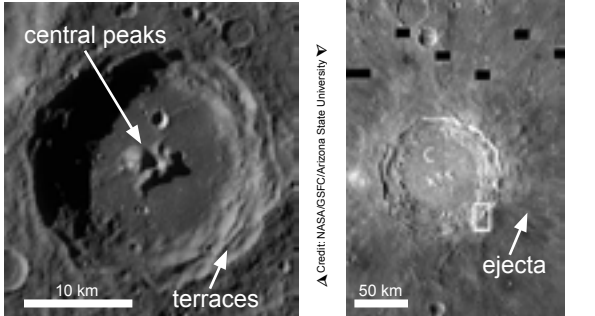
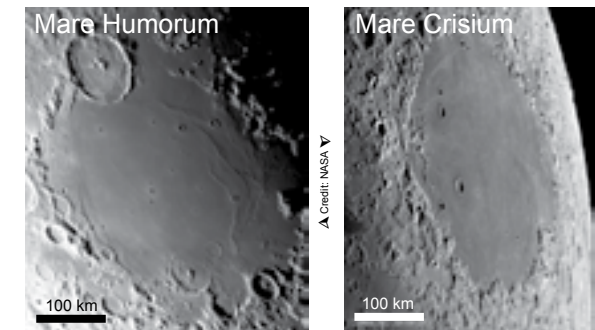
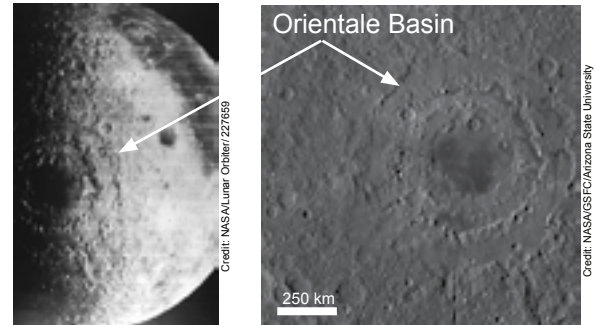
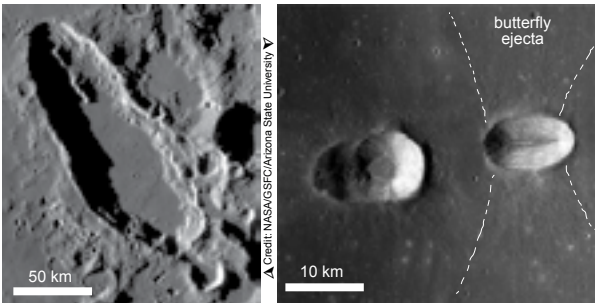
# CHARTS

---



# 1. LUNAR FEATURE IDENTIFICATION CHART

## Primary Craters and Their Features

| Feature                           | Feature Example   | Feature Description  |
|-----------------------------------|---|--|
| <p><b>Simple Craters</b></p>      |  <p>Credit: NASA/GSFC/Arizona State University</p>  | <ul style="list-style-type: none"> <li>• Small bowl-shaped craters</li> <li>• Steep wall and raised rim</li> <li>• Most common type of craters on the Moon</li> <li>• Diameter less than 15 kilometers (10 miles)</li> <li>• Lack a central peak</li> <li>• May have ejecta</li> </ul> |
| <p><b>Complex Craters</b></p>     |  <p>Credit: NASA/GSFC/Arizona State University</p>  | <ul style="list-style-type: none"> <li>• Medium to large craters (10-20km)</li> <li>• Uplifted central peak(s) and flat floor</li> <li>• Many have inward slumping of walls to form terraces</li> <li>• May have ejecta</li> </ul>   |
| <p><b>Impact Basins</b></p>       |  <p>Credit: NASA</p>   | <ul style="list-style-type: none"> <li>• Largest impact on the Moon</li> <li>• Diameter greater than 300 kilometers</li> <li>• Associated with faulting and deformation</li> <li>• Many are flooded with lava (maria)</li> </ul>   |
| <p><b>Multi-ringed Basins</b></p> |  <p>Credit: NASA/Lunar Orbiter/227669</p> <p>Credit: NASA/GSFC/Arizona State University</p> | <ul style="list-style-type: none"> <li>• Type of impact basin</li> <li>• Multi-ringed basins formed by the largest lunar impacts</li> <li>• Can have two to four rings</li> <li>• Looks like a target or bull's eye pattern</li> <li>• Formed by asteroid impacts</li> </ul>           |
| <p><b>Irregular Craters</b></p>   |  <p>Credit: NASA/GSFC/Arizona State University</p>  | <ul style="list-style-type: none"> <li>• Non-circular craters with an oval or irregular shape</li> <li>• Formed by low angle impacts (15° or less)</li> <li>• Often have “butterfly” shaped ejecta pattern</li> </ul>  |

# 2: LUNAR FEATURE IDENTIFICATION CHART

## Secondary Craters and Other Features

| Feature                  |                        | Feature Example | Feature Description   |
|--------------------------|------------------------|-----------------|---|
| <b>Secondary Craters</b> | <b>Crater Chains</b>   |                 | <ul style="list-style-type: none"> <li>• Small secondary impact craters arranged in chains near larger craters</li> <li>• Produced by the impact of ejecta from a larger impact</li> <li>• Less than 1 km in diameter</li> </ul>  |
|                          | <b>Crater Clusters</b> |                 | <ul style="list-style-type: none"> <li>• Small secondary impact craters in clusters formed by the impact of ejecta from larger impacts</li> <li>• These craters can be found in areas around larger craters</li> </ul>  |
| <b>Impact Melt</b>       |                        |                 | <ul style="list-style-type: none"> <li>• Melted rocks and regolith (“soil”) that flows like lava and then solidifies</li> <li>• Formed from heat generated by impacts</li> <li>• Can show flow features</li> <li>• Often found at the base of craters where it can “pond” or fill in the floor</li> </ul> |
| <b>Terraces</b>          |                        |                 | <ul style="list-style-type: none"> <li>• Terraces form as crater walls slump down onto the crater floor creating a series of flat steps</li> <li>• Often have a concentric “stair-step” pattern with circular, nested steps</li> </ul>  |
| <b>Ejecta Rays</b>       |                        |                 | <ul style="list-style-type: none"> <li>• Ejected or “excavated” during an impact</li> <li>• Can form radial streaks that look like the spokes of a wheel around a crater</li> <li>• Ejecta may be bright or dark depending on composition</li> <li>• May indicate direction of impact</li> </ul>          |



# 3:

## LUNAR FEATURE IDENTIFICATION CHART Volcanic Features



| Feature   | Feature Example                                   | Feature Description   |  |
|---|---|---|--|
| <p><b>Maria</b><br/>(Singular: Mare)</p>  | <p>Credit: NASA/USGS</p>                          | <ul style="list-style-type: none"> <li>• Large flows of lava that erupted within and flowed into low-lying impact basins (extremely large craters)</li> <li>• Most occur on the near-side of the Moon (side facing Earth)</li> <li>• Basins are older than the lava filling them</li> <li>• Basalt (lava rock) is darker than the surrounding rock of the highlands and stands out as dark, circular areas</li> </ul> |  |
| <p style="writing-mode: vertical-rl; transform: rotate(180deg);"><b>Non-Maria Volcanism</b></p> | <p><b>Volcanic Domes</b></p>                      | <p>A Credit: NASA/GSFC/Arizona State University</p>   | <ul style="list-style-type: none"> <li>• Dome-shaped that may have a central pit crater at the summit (top)</li> <li>• Occur at edges of maria and large craters</li> <li>• Often low relief (height above the surface) and can occur in clusters</li> </ul> |
|   | <p><b>Pyroclastic Vents</b></p>                   | <p>Credit: NASA/LPI</p> <p>Credit: NASA/GSFC/Arizona State University</p>   | <ul style="list-style-type: none"> <li>• Irregular holes that look like craters</li> <li>• Vents may appear to have dark "halos" surrounding them called Dark Mantle Deposits (DMD's)</li> <li>• Small-scale features and hard to identify</li> </ul>        |
|   | <p><b>Sinuuous Rilles</b><br/>(Lava Channels)</p> | <p>Credit: ASI 16M-1420 NASA/USC/Arizona State University</p> <p>Credit: NASA/GSFC/Arizona State University</p>   | <ul style="list-style-type: none"> <li>• Long, narrow depressions that look like channels</li> <li>• Have a sinuous path (often with tight curves)</li> <li>• Intersected channels may be large rilles</li> </ul>  |

# 4: LUNAR FEATURE IDENTIFICATION CHART

## Tectonic Features

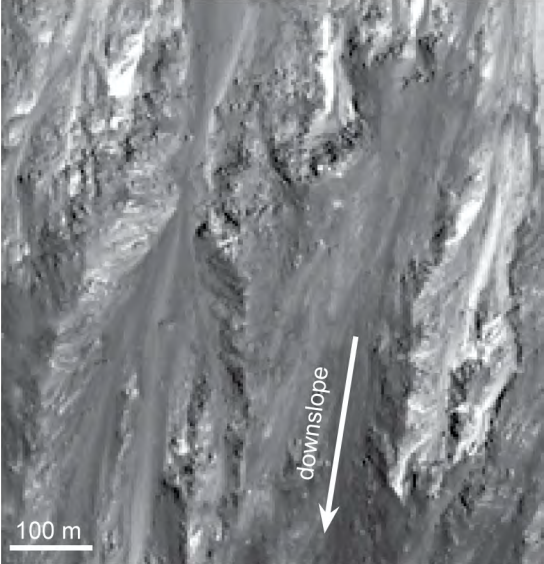
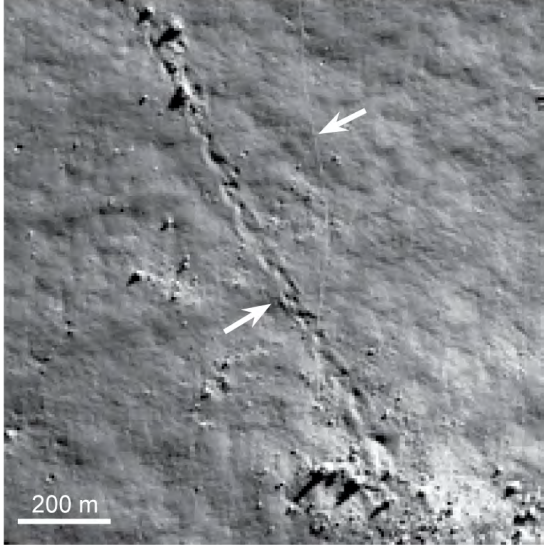
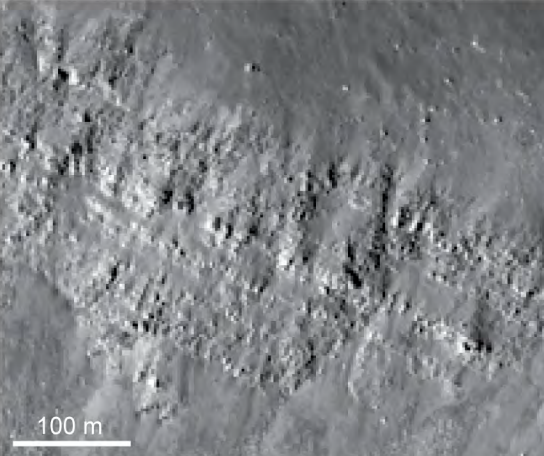


|                        | Feature                       | Feature Example | Feature Description  |
|------------------------|-------------------------------|-----------------|--|
| Tensional Features     | <b>Fractures</b>              |                 | <ul style="list-style-type: none"> <li>Cracks in areas where the crust has been pulled apart</li> <li>Can be linear (straight) or curved</li> <li>Usually occur in groups</li> <li>Often found in impact melt in the bottom of craters</li> </ul>  |
|                        | <b>Graben</b>                 |                 | <ul style="list-style-type: none"> <li>A block of land is pulled apart by faults on either side (see diagram at top)</li> <li>Forms a valley with steep scarps and a flat floor</li> <li>Often are very linear and straight and long</li> </ul>    |
|                        | <b>Crater Floor Fractures</b> |                 | <ul style="list-style-type: none"> <li>Fractures or cracks occur in volcanic craters</li> <li>Found in the floors of large to medium sized craters</li> </ul>  |
| Comtractional Features | <b>Wrinkle Ridges</b>         |                 | <ul style="list-style-type: none"> <li>Irregular features that display positive relief (rise above the surface)</li> <li>Main ridge normally has many smaller wrinkles on top</li> <li>Often found in areas of thick lava flows (maria)</li> </ul> |
|                        | <b>Lobate Scarps</b>          |                 | <ul style="list-style-type: none"> <li>Irregular cliffs or ridges formed by the contraction of the lunar crust</li> <li>Similar to wrinkle ridges, but found in the more rugged highland areas</li> </ul>  |

# 5:

## LUNAR FEATURE IDENTIFICATION CHART Mass Wasting Features and Layers



| Feature               | Feature Example  | Feature Description   |
|-----------------------|--|---|
| <b>Debris Flow</b>    |  <p>Credit: NASA/GSFC/Arizona State University</p>   | <ul style="list-style-type: none"><li>• Loose rocks that have slid down a steep slope</li><li>• Material often piles up at the bottom of a slope like at the base of a crater wall</li><li>• May be caused by a nearby impact shaking rocks loose</li><li>• The flows may have lobes that are tongue or finger shaped</li><li>• Small-scale features only visible in NAC images</li></ul> |
| <b>Boulder Trails</b> |  <p>Credit: NASA/GSFC/Arizona State University</p>  | <ul style="list-style-type: none"><li>• Linear features (trails) formed by boulders that have rolled down slope</li><li>• Some trails are smooth and others are bumpy depending on the shape of the boulder and surface material</li><li>• Often found in areas near central peaks inside large craters</li><li>• Small-scale features only visible in NAC images</li></ul>               |
| <b>Layers</b>         |  <p>Credit: NASA/GSFC/Arizona State University</p> | <ul style="list-style-type: none"><li>• Layers may be seen in the walls and central peaks of craters</li><li>• Layers build up over time and show a history of lava flows</li><li>• Layer thickness can give information about the eruption that formed the flow</li><li>• Small-scale features only visible in NAC images</li></ul>  |

## Extension Activities:

### PARTICIPATING IN THE LUNAR STUDENT IMAGING PROJECT:

This activity can be used as an introduction to participation in the Lunar Student Imaging Project (LSIP). The Lunar Student Imaging Project allows students to conduct research about the Moon using the LROC-WAC visible images from the Lunar Reconnaissance Orbiter spacecraft.

### RESEARCH DESIGN

Students will have the opportunity to design a research project using a provided question with the LROC-WAC Equatorial Mosaic images.

### DATA ANALYSIS

Students will have the opportunity to collect data and graph the data using a provided question with the LROC WAC Equatorial Mosaic images.

### RESEARCH DESIGN AND DATA ANALYSIS

Students will have the opportunity to design a research project, collect data, and graph the data using a provided question with the LROC-WAC Equatorial Mosaic images.

# Lunar Reconnaissance Orbiter: (LROC)

## Audience

Grades 6-8

## Time Recommended

5-60 Minutes (Two Class Periods)

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 11B/M3: Different models can be used to represent the same thing. What model to use depends on its purpose.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Image of the near side of the Moon
- Space shuttle image (transparency)
- Space shuttle model
- Visible light images of possible landing sites (camera angle 0 and with a known sun angle, preferably lower than 30 degrees)
  - » (Moscoviense #1, Humboldtianum #1, Goddard #1, and Reiner #1) (attached)
- Color relief (topographical) images of the same possible landing sites (Moscoviense #3, Humboldtianum #3, Goddard #3, and Reiner #3) (attached)
- Rulers
- Calculators
- Clay, Play-Doh or another material
- 1 shallow tray/paper plate per group
- Sealable bag to fit over tray/plate and model
- Rolling pin
- Object for making indentations in clay or Play-Doh
- Wax paper
- Digital cameras (if available)
- Flashlights
- Making a Model Day 1 and Day 2 reflection worksheets (attached)

# Making a 3D Model of the Moon's Surface

## Learning Objectives:

- Students will make estimates about the relative height/ depth of objects from images.
- Students will use the relationship between sun angle and shadow to determine the actual height of objects from images.
- Students will use the color representations on an image to determine the height and depth of objects.
- Students will create a 3D model using a 2D image and evaluate its accuracy

Students will explore the ways 2D images from the LRO mission can help us to understand the topography of the lunar surface. In groups, students will create models that will help them determine what makes a safe lunar landing site.

## Preparation:

Fill trays with modeling material and level them off with the rolling pin so each group can start with a uniformly sized, flat surface. Reserve some modeling material for each group to use to add material to their model.

## Procedure:

### DAY 1

Show students an image of a space shuttle (transparency). What can we learn about the object in the image from looking at it? What information are we lacking? What additional information could we learn from a 3D model of the space shuttle? Show the students a 3D model of the space shuttle. What can we learn about the space shuttle from looking at the model? Discuss similarities/ differences.

When would you use each one? Is one better than the other? To understand more about the images we are getting from the Moon, it will help us to look at a model of the Moon. The images can help us create that model and making such a model will help us understand more about the image. The first day of this activity will prepare students to examine shadows as a tool for determining the altitude of features on the Moon on day two.

1. Explore the types of features that we would expect to see on the Moon. Ask students to share ideas. Teachers, browse this website <http://lroc.sese.asu.edu/news/index.php?/categories/2-Featured-Image> for detailed images of features on the surface of the Moon.

2. Explain that the Lunar Reconnaissance Orbiter Camera (LROC) is one tool on the Lunar Reconnaissance Orbiter (LRO). It is taking very high-resolution images of the Moon so we can learn more about the surface of the Moon. Teachers, for more background information about LRO and LROC visit:  
<http://lroc.sese.asu.edu/EPO/LROC/lroc.php?pg=what>
  3. Distribute visible light images (#1 image of one of the regions) of the Moon and put up a transparency of a visible light image up to help with discussion. How can we tell what the surface of this area is like from this image? Students should mention placement of features, relative sizes, etc.
  4. Ask them about the height and depth of features in the image. Is there any way we can determine the height or the depth of the features? Help students understand ways we can figure this out. In this image, we can make estimates by examining the shadows. Point out the shadows in the images and ask students to describe what is causing these shadows. Do all of the features make the same size shadow? How does the size of the shadow give us information about the size of a feature? As mentioned above, day two will examine this concept in more detail. At this point, students should just be thinking about this idea.
  5. Explain that groups will work to create a 3D model of an image of the Moon. What will help us make these shapes? Introduce modeling materials.
  6. Remind students to think about relative scale of height/depth and distances.
  7. Remind students about what shadows can tell us about height. Groups will be given a flashlight to help them evaluate and revise their models.
  8. Divide students into small groups (about four) and distribute the "Making a Model Day 1" worksheets. In each group of four, students can take on the following roles:
    - a. **Materials Manager** (keep track of the different items used to manipulate the modeling material and use the camera to take a picture of the model),
    - b. **Flashlight Monitor** (adjust and hold the flashlight based on feedback from the group)
    - c. **Timekeeper** (watch the time and keep the group on task)
    - d. **Reporter** (record and report group members' comments about the model using the student worksheet).
- All members of the group are responsible for manipulating the modeling material and comparing the model to the image in order to create an accurate model.**
9. Students should work as a team for 15-20 minutes to create their model based on their respective image. As students are working on their models, dim the lights and allow students to explore the way the position of the light source affects the shadows. Can they find a position where the shadows on their model match the ones in their image? Are their features the correct height/ depth? Remind students that for the Moon, the light source is the Sun. As the Moon orbits Earth, and the Earth orbits the Sun, the shadows change. Students should continue to revise their model to best represent their image.
  10. If digital cameras are available, challenge students to take a picture of their model that matches their image. Students should continue to revise their models to reflect what they have learned from the shadows and camera images. Ask them to think about how flashlight and camera position effect the way their model looks.
  11. With 5-10 minutes left in class, ask students to stop working on their models and complete the "Making a Model Day 1" reflection questions. Collect student responses. Students should put their model in a sealable bag (keeps fresh) so they are able to continue revisions on day two.

## DAY 2

1. Redistribute “Making a Model Day 1” sheets and visible light images (#1 image of one of the lunar regions) to students to guide review of the previous day’s work. Have students share their reflections from the previous day specifically focusing on additional information that would be helpful. If students do not bring it up on their own, ask them to think about how confident they are about the heights and depths of the features in their model. Did they make them the right height/ depth?
2. Ask the students to think back on their experiences with the flashlight. What did the flashlight represent? How did its position affect the shadows? Have the students think about the way that shadows change on Earth over the course of a day. You can demonstrate this by dimming the lights and asking a volunteer to stand. Move the flashlight to approximate the position of the Sun at different points in the day as seen from Earth. Students should see the shadow length changes depending on the angle of the Sun in the sky. This works the same way on the Moon.
3. Explain to students that if we know the Sun’s angle and the length of the shadow, we can use ratios to determine the height of the feature making the shadow. This process can be used to determine the heights and depths of each of the features on the Moon (see the Extension Activities section for suggestions on investigating this in more depth). Once we determine the heights and depths of features, we can create other kinds of images.
4. Distribute the color relief (topographical) #3 image of the same region as before to each group and put up a transparency of the Moscoviense Region #3 (topographical) color relief image to help with discussion. Ask students to share what they can learn from this lunar image. Make sure students understand on this image elevation is represented by the variant colors. These colors are added to the image to represent height and depth. The Moon is not really this colorful. To determine the colors, the image/ map-makers figured out the height of the features using the information they had about the Sun’s angle and the shadow lengths.
5. Explain to students these images are based on data from a different instrument on the Lunar Reconnaissance Orbiter (LRO) spacecraft called the Lunar Orbiter Laser Altimeter (LOLA). This instrument uses laser technology to determine the height and depths of features on the surface of the Moon. Teachers, if you would like more background information on LOLA, check out <http://lunar.gsfc.nasa.gov/lola>
6. Ask the students to find the colors on the image that represent a certain range of height and depth. What is the range that is represented? The range of elevations on the Moon is very similar to the range on Earth. The height of mountains on Earth is similar to the high points on the Moon. The depths of the ocean floors on Earth are similar to the depths of the deepest places on the Moon.
7. To model how high and deep these features are, use blocks, drawings or meter sticks. To help students understand a kilometer, use the Willis (Sears) Tower in Chicago as an example. The Willis Tower is 315 m (.315 km) tall. Three Willis Towers stacked on top of each other would be about 1 km (.945 km) tall.
8. Use the information on the next page to help students understand how high and deep the colors are compared to the average surface level of the Moon. This average surface level on the Moon is similar to sea level on Earth. Have students determine what color that object would relate to based on the color scale from their #3 image. **Note: The color scale for each region’s color relief (topographical), or #3 image, is different. Make sure students use the scale particular to their respective image when referencing it for the activity.**

| Location   | Height                              |
|--|-------------------------------------|
| Chicago  | .179 km above sea level             |
| Mt. St. Helens   | 2.6 km above sea level              |
| Mt. Everest (highest elevation on Earth)   | 8.8 km above sea level              |
| Grand Canyon   | 1.6 km above sea level              |
| Puerto Rico Trench (deepest part of the Atlantic Ocean)                            | 8.6 km above sea level              |
| Mariana Trench (deepest point in the Pacific Ocean and the deepest point on Earth) | Approximately 11 km below sea level |

9. Using information from the color relief (topographical), or #3 image, ask students to return to their model and make revisions. They can continue to check their work using the flashlight.
10. If digital cameras are available, challenge students to take a picture of their model with the camera that matches the image they were working from. Students can make changes to improve their model.
11. Ask students to think about why scientists would still value methods of determining topography through observing shadows at various sun angles when we have more sophisticated technology like laser altimeters. The laser altimeter instruments, like LOLA, can get specific, absolute measurements only to a certain scale. Determining relative topography utilizing observations of shadows is still useful for high-resolution data or small scale features like what can be observed in the NAC images coming from the LROC instrument.
12. With 5-10 minutes left in class, ask students to stop working on their models and complete the “Making a Model Day 2” reflection questions. Collect student responses.





# MAKING A MODEL

## Day 1

Names: \_\_\_\_\_

**Materials Manager:** keep track of the different items used to manipulate the modeling material and use the camera to take a picture of the model

**Flashlight Monitor:** adjust and hold the flashlight based on feedback from the group

**Timekeeper:** watch the time and keep the group on task

**Reporter:** record and report group members' comments on the model using the student worksheet.

All members of the group are responsible for manipulating the modeling material and comparing the model to the image in order to create an accurate model. With your group, complete the following steps:

1. Study your image.
2. Work with your group to decide who will work on which parts of your model and how you will represent the sizes of the features in your image.
3. Use the available tools and materials to create a 3D model of your image.
4. Use a flashlight to check your model by adjusting the light source.
5. Keep working with your image and model to represent things as accurately as you can.
6. Use a digital camera to take a picture of your model. Does the picture look like the original image?
7. If time allows, continue to improve your model.
8. Reflect on the 3D model your group has created by answering the following questions.

### Questions:

What parts of your model do you feel are most accurate? Be sure to give specific examples and support your examples with evidence from your image and model.

What parts of your model do you want to improve? Be sure to give specific examples and support your examples with evidence from your image and model.

How could you make those improvements?

What tools or information could help you make a better model?



# MAKING A MODEL

## Day 2

Names: \_\_\_\_\_

**Materials Manager:** keep track of the different items used to manipulate the modeling material and use the camera to take a picture of your model

**Flashlight Monitor:** adjust and hold the flashlight based on feedback from the group

**Timekeeper:** watch the time and keep the group on task

**Reporter:** record and report group members' comments on your model using the student worksheet.

All members of the group are responsible for manipulating the modeling material and comparing your model to your lunar image in order to create an accurate model. With your group, complete the following steps:

1. Study both of your images.
2. Use the available tools and materials to refine a 3D model of your area on the Moon.
3. Use a flashlight to check your model by adjusting the light source.
4. Keep working with your images and model to represent things as accurately as you can.
5. Use a digital camera to take a picture of your model. Does the picture look like the original image?
6. If time allows, continue to improve your model.
7. Reflect on the 3D model your group has created by answering the following questions.

### Questions:

What parts of your model do you feel are most accurate? Be sure to give specific examples and support your examples with evidence from your image and model.

What parts of your model are not accurate? Be sure to give specific examples and support your examples with evidence from your image and model.

How could you make your model more accurate?

What tools or information could help you make a better model?

---

# SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

## Teacher Scoring Guide

**Assignment:** Making a Model Day 1 and Day 2

Student Name(s): \_\_\_\_\_

Date: \_\_\_\_\_

| Performance Indicator   | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Students completed all questions in the assignment.   |   |   |   |   |   |
| All responses were clear, accurate and thorough.  |   |   |   |   |   |
| Students incorporated new information and evidence from what they have learned in their responses.              |   |   |   |   |   |
| Student responses show evidence of thinking critically about their models.                                      |   |   |   |   |   |
| Student responses show evidence of the creation of a protocol for representing specific features in their work. |   |   |   |   |   |
| Student responses show evidence of using information from all available sources.                                |   |   |   |   |   |
| <b>Point Total</b>  |   |   |   |   |   |

**Point total from above:** \_\_\_\_\_ / (24 possible)

**Grading Scale:**

A = 22 - 24 points

B = 19 - 21 points

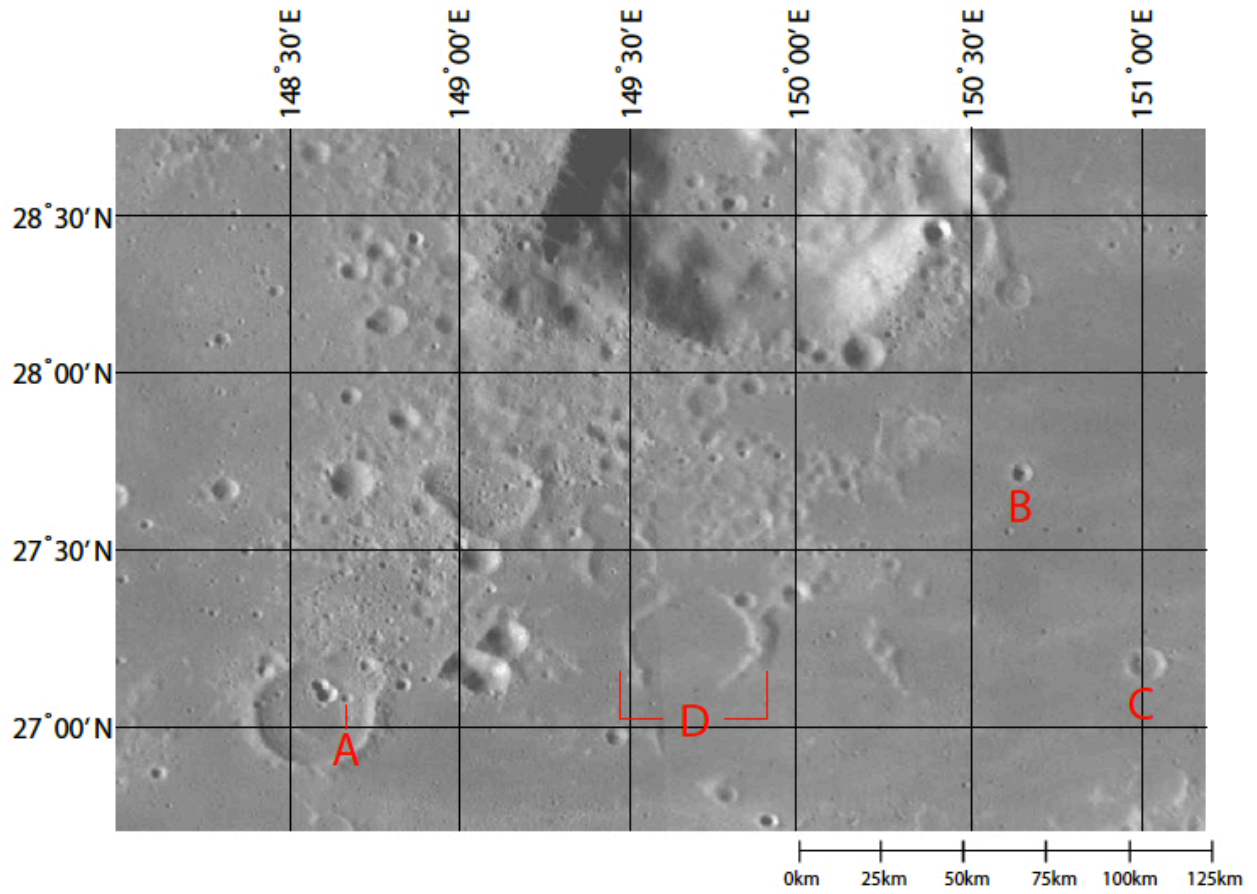
C = 16 - 18 points

D = 13 - 15 points

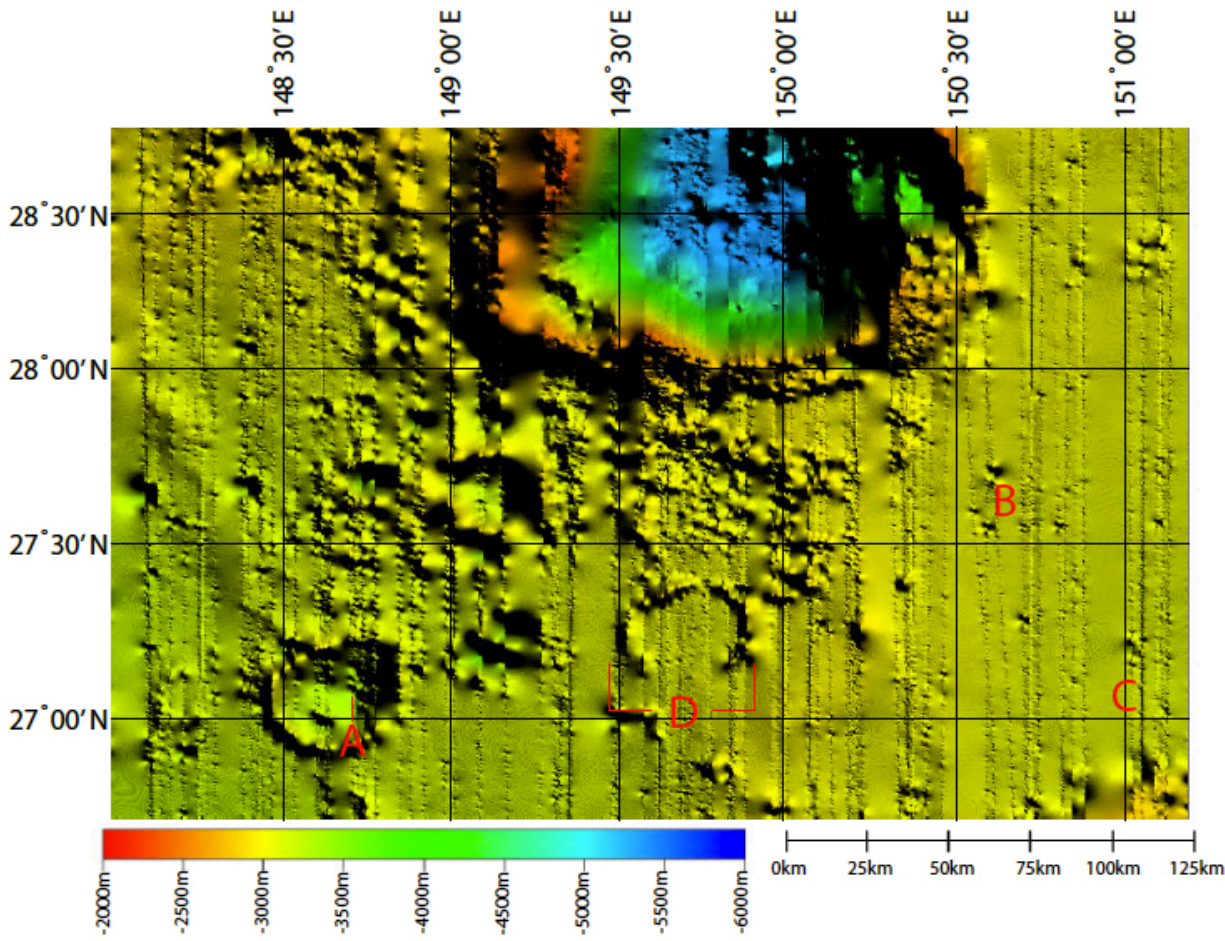
F = 0 - 12 points

**Grade for this Assignment:** \_\_\_\_\_

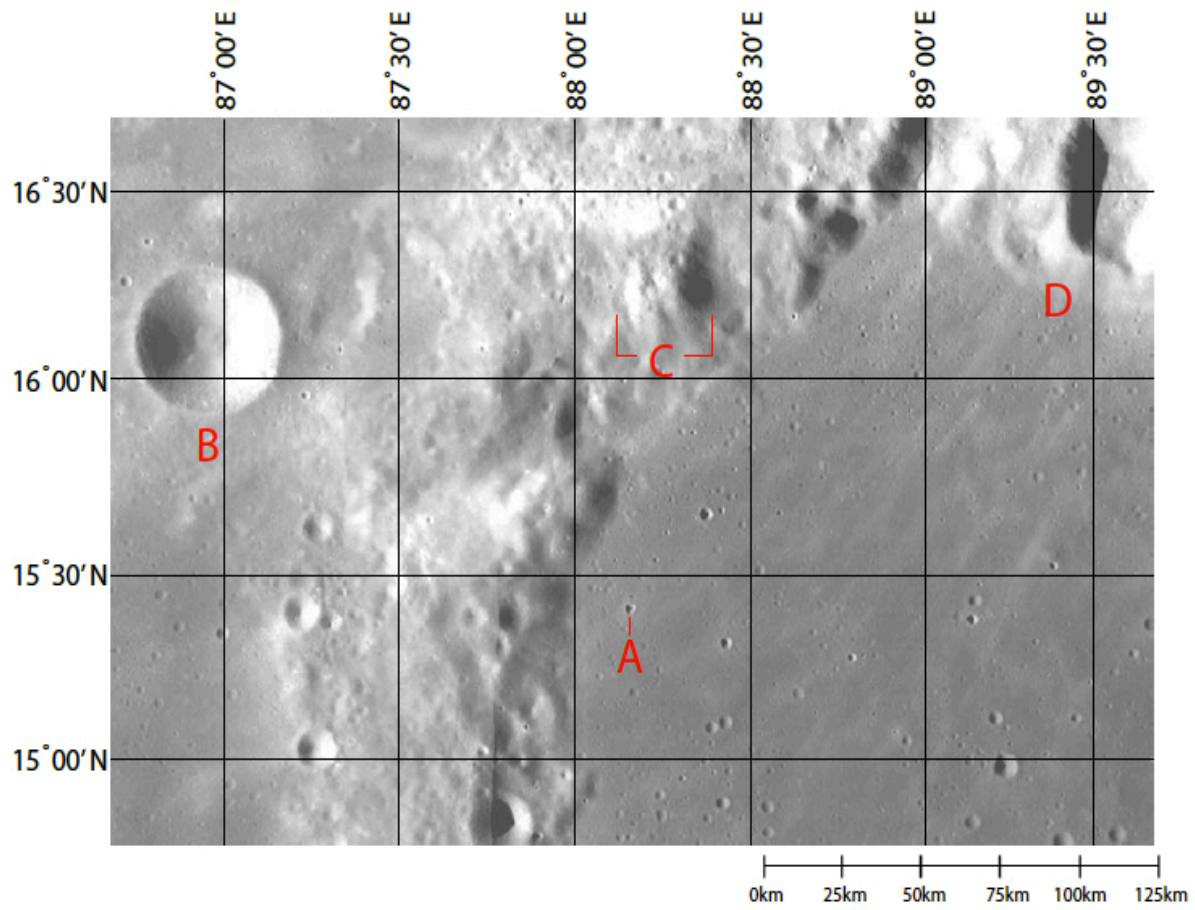
# Moscoviense Region #1



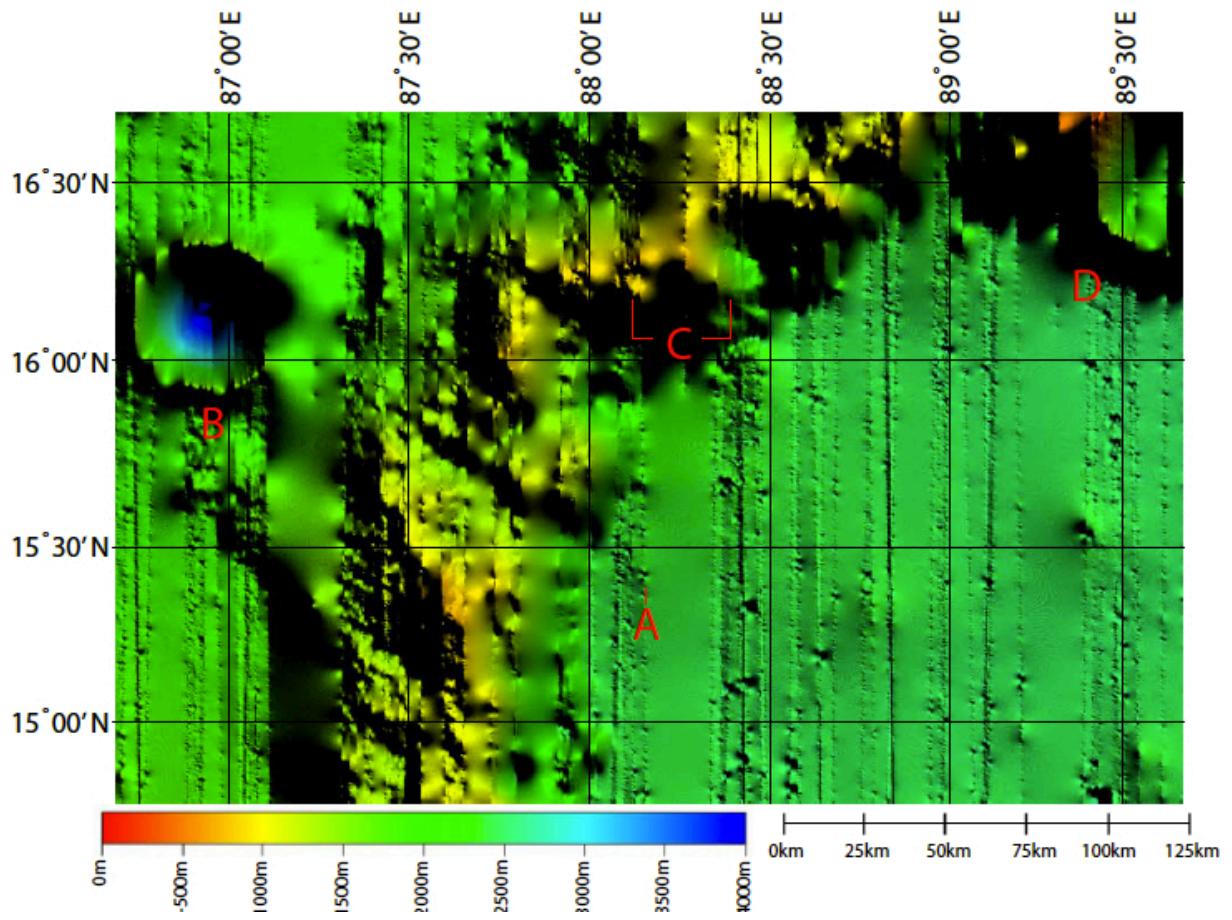
# Moscoviense Region #3



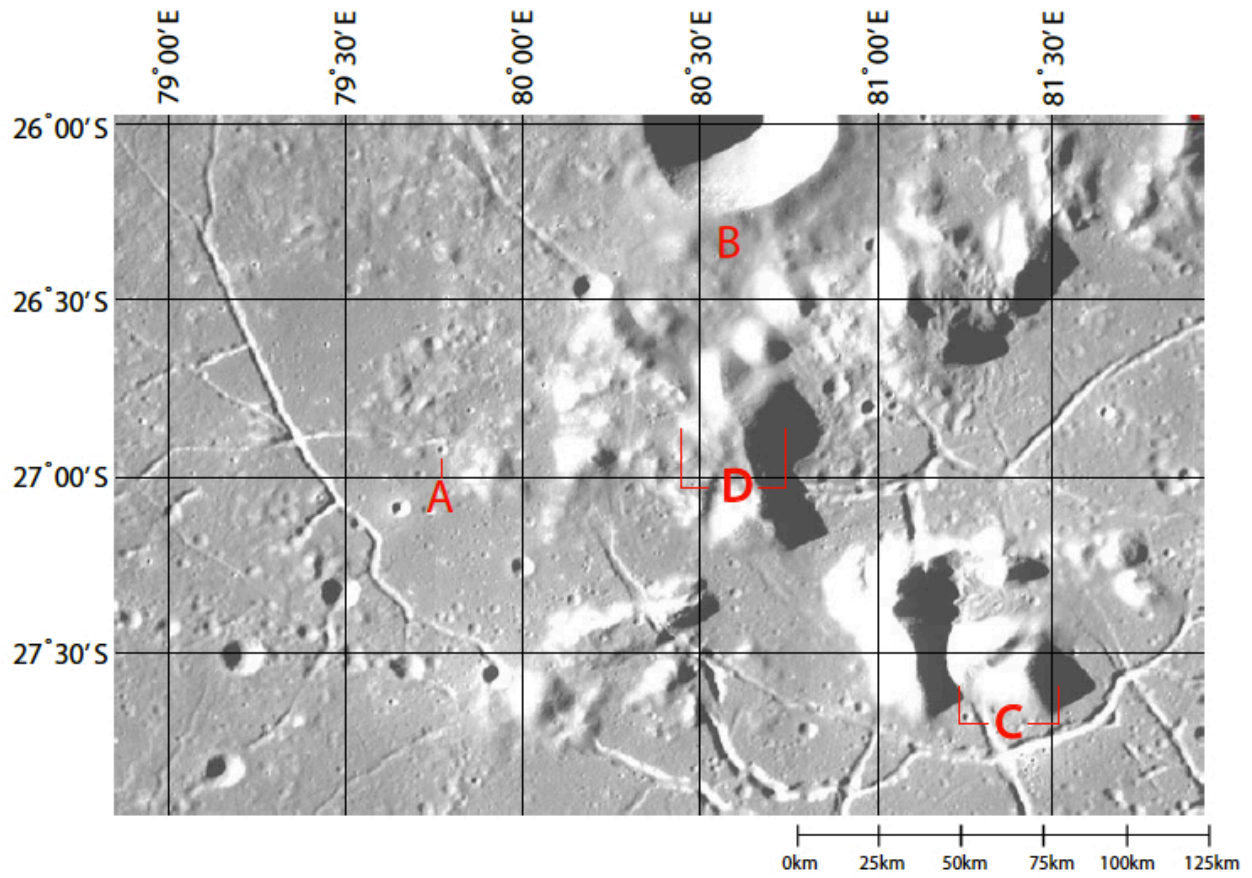
# Goddard Region #1



# Goddard Region #3

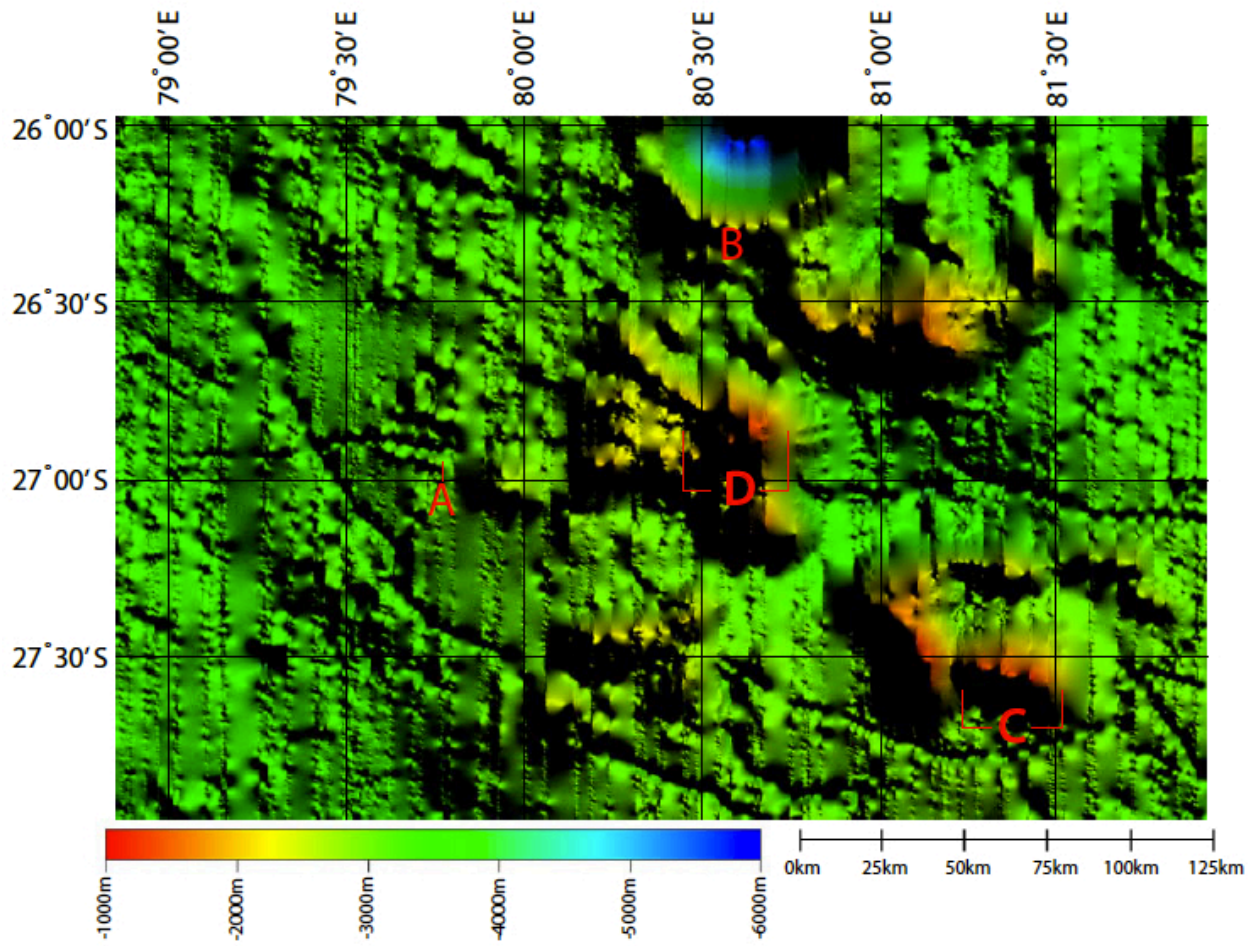


# Humboltanium Region #1

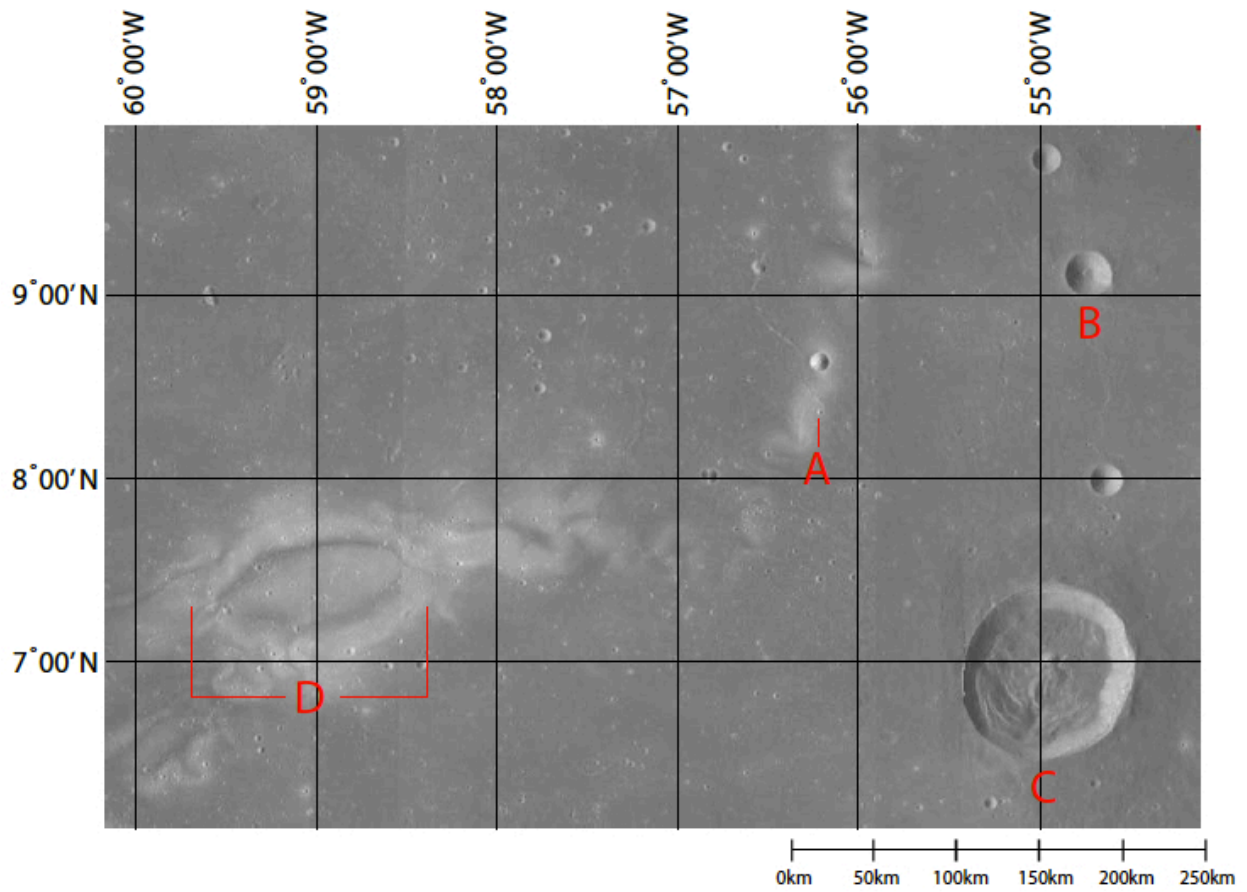




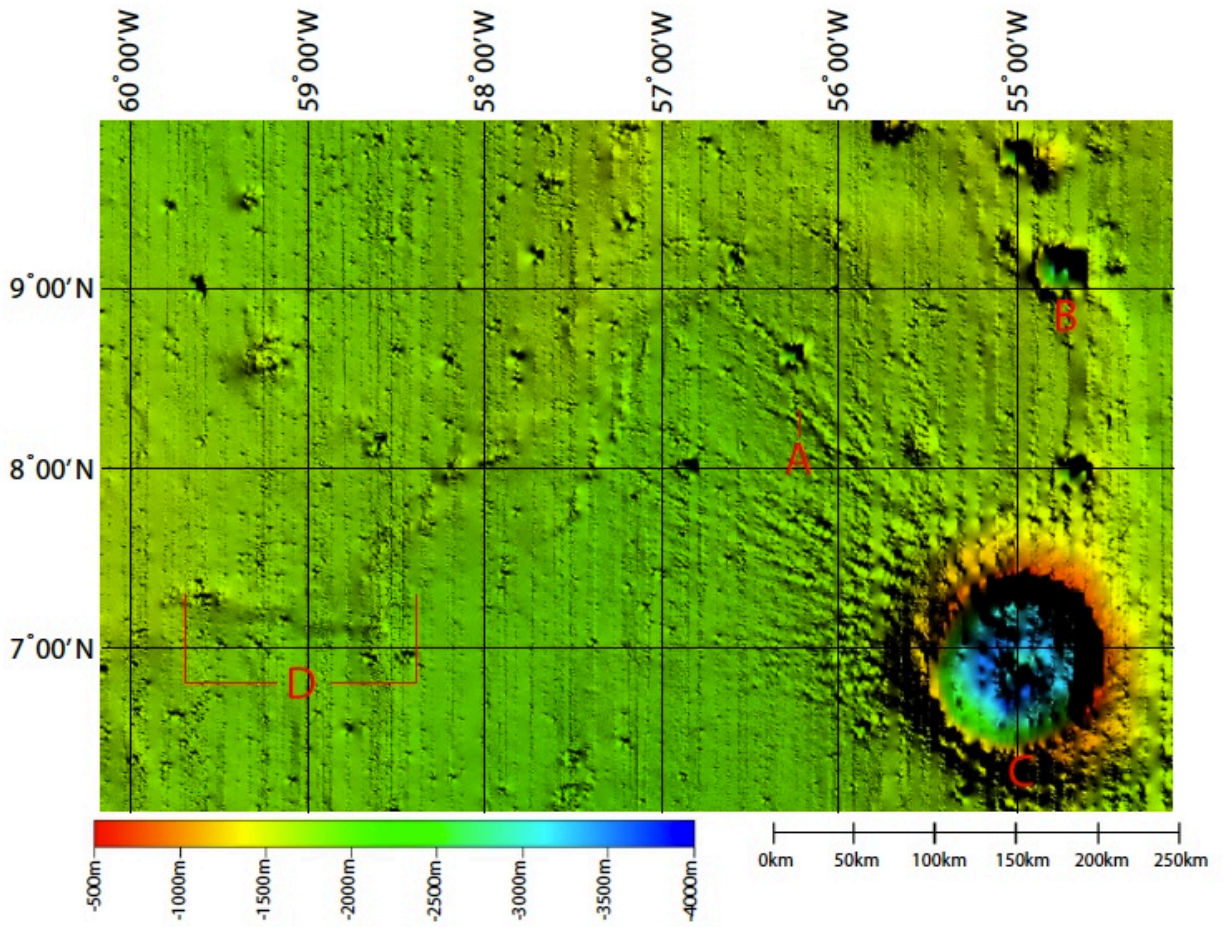
# Humboltanium Region #3



# Reiner Region #1



# Reiner Region #3



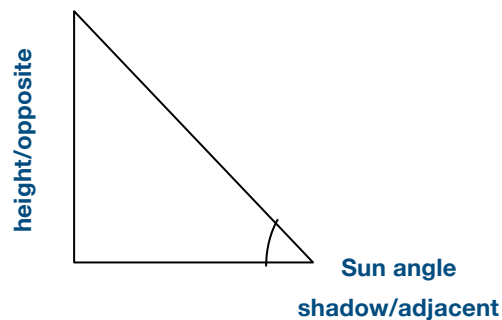
## Assessment:

Review the critiques of the model from Day 1 and 2 looking for the ways that new information was incorporated and evidence that students are thinking critically about their models. Review individual assignments for evidence that the group created some sort of protocol for representing features and used information from all the available sources. See the attached rubric in the supplemental materials section for a suggestion to grading your students' work.

## Extension Activities:

This lesson can include a great deal of geometry. The following concepts can be explored as a part of this lesson or in a math class:

- Triangles with the same angle measures ( $90^\circ$ ,  $70^\circ$ , and  $20^\circ$ , for example) are called similar triangles. They have the same shape even though they may have different side lengths. The lengths of the sides of similar triangles have the same ratios. We can use this ratio to figure out the height of features/ objects based on the length of the shadow.
- For a challenge or for advanced math students, you may choose to introduce the use of sine, cosine, and tangent. In these triangles, we are using the tangent (opposite/ adjacent) of the sun angle to determine the height (opposite).



# Lunar Reconnaissance Orbiter: (LROC)

## Audience

Grades 5-9

## Time Recommended

2-4 Hours

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- a. Identify questions that can be answered through scientific investigations.
- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

Content Standard D (5-8): Earth and Space Science; Earth's History:

- a. The Earth processes we see today, including erosion, movement of lithospheric composition, are similar to those that occurred in the past.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

## MATERIALS

- Lunar Image Analysis Student Data Log
- Lunar Image Analysis Observation Sheets
- Lunar Image Analysis Topic Selection Sheet
- Lunar Reconnaissance Orbiter Camera (LROC) Wide-Angle Camera (WAC) Lunar Orbiter
- Laser Altimeter (LOLA) Topographic Map
- Access to JMARS for Moon  
<http://jmars.asu.edu/download-jmoon>

# Question Moon: An Introduction to the Process of Science

## Learning Objectives:

- Generate a big picture question related to the Moon.
- Generate hypotheses related to lunar geology.
- Generate a research question related to lunar geology.

Overview: In this activity, students step into the shoes of real planetary scientists and experience one of the first steps in the process of science—developing hypotheses and testable research questions. Students will be tasked with using the topic identified in the Lunar Image Analysis activity to establish hypotheses and a question about the surface of the Moon. The purpose of this lesson is for students to use a critical thinking, collaborative approach to scientific research within the field of planetary geology.

## Preparation:

1. All science begins with a question or a hypothesis. Keep in mind that it is a natural part of science to refine or even change your question as your research progresses. The process of science continues with designing an experiment to answer that question and test your hypotheses. For this activity, the focus is on generating a high-quality research question and hypothesis.
2. Students will need the Lunar Image Analysis materials for this lesson and should be grouped in small groups (approximately 3-4) for brainstorming and development of hypotheses and questions.

## Background Information:

### STUDENT SHEET #1:

The intention of this sheet is to help students understand that scientists do not use a contrived process in developing a question and hypothesis, but instead they make observations that guide their hypotheses and their questions. Examples have been provided for students to work with and to establish a model. It would be helpful to have conversations with the students about these examples to ensure they understand the difference between the big picture question, hypothesis, and research question.

### STUDENT SHEET #2:

These sheets are provided to give students a guide for their initial questioning. The prompts provided are not the only prompts students can use, but these cover the major types of questions students will ask while making their

observations. These big picture questions are important questions, but are not research questions. These are very broad questions, which require a significant amount of research to answer. In this case, the students will be investigating one small aspect of their big picture question. Give students the opportunity to work together in groups for brainstorming. As a team, the students will need to make calculated decisions, so debate and collaboration will be extremely important.

#### STUDENT SHEET #3:

In this sheet, students will begin developing explanations for their big picture questions. These will eventually be hypotheses, but for now, they will most likely just be ideas. These will be critical in developing high quality research questions and hypotheses. Students will need the opportunity to work in JMARS for Moon ( <http://jmars.asu.edu/download-jmoon> ) in order to check that these explanations have measurable attributes and data is currently available.

#### STUDENT SHEET #4:

Students will use the explanations they have established in the previous sheet to create research questions. These questions will need to be testable and the students will need to establish what exactly will be measured in the experiment (to learn if their explanation is true). A list of possible variables (in a simplified form) have been provided in the lesson, but research questions are not limited to these variables— these are simply a guide to get students moving in the right direction. As a class, they will need to make decisions together, so debate and collaboration will be extremely important. See the assessment section for the rationale on given evaluation criteria.

#### STUDENT SHEET #5:

Now that students have a research question, they can write a formal hypothesis. The “if...then...” statement has been provided as a guide, but is not 100% true in all cases. There is no need to use it if it doesn’t make sense. By the end of this sheet, students should have a final research question and a matching, testable hypothesis. As a class, they will need to make decisions together, so debate and collaboration will be extremely important.

### Procedure:

1. See worksheets for guidance.
2. Provide a set of worksheets for each student



## QUESTION MOON

# An Introduction to the Process of Science

### Objective:

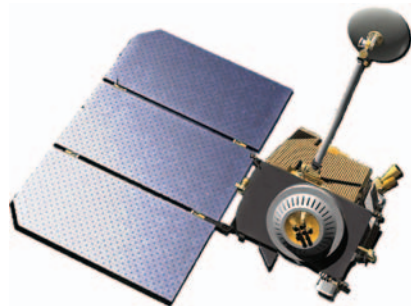
Create a question and hypothesis about the Moon that can be answered using images taken from orbit.

### Student Introduction:

All science begins with a question or an hypothesis. Some people refer to this as the “scientific method”. The scientific method starts from questions or hypotheses we create based on our curiosity. We become curious about scientific observations we make. Professional scientists have questions about the Moon they want to answer because they are curious, and so you will begin by investigating images from Earth’s nearest neighbor. Keep in mind it is a natural part of science to refine or even change your question as you research. The process of science continues with designing an experiment to answer that question and test your hypotheses.

### Your goals through this lesson are:

- Follow your curiosity about the Moon and create research questions and hypotheses
- Evaluate your questions, making sure you have met the criteria for a scientific question
- Realize there are three different types of questions for research based on the branch of science you are conducting your research in.
- Realize that it’s understandable to have “big picture” questions, but scientists (including you) need a specific focus or question to study.
- Recognize that scientists contribute to a greater understanding of the Moon through detailed research.



**In 2009, NASA returned to the Moon by sending a robotic scout called the Lunar Reconnaissance Orbiter (LRO) to gather crucial data on the lunar environment. During its orbital mission, LRO’s seven instruments have been collecting data to find safe future landing sites, locate potential resources for possible human outposts, characterize the radiation environment and test new technology.**



# STUDENT SHEET #1

## Questions and Hypotheses

Did you know often scientists start with a big question in mind before they even have a research question or hypothesis? This often occurs as a result of a very specific, scientific observation, such as the observations you made in the Lunar Image Analysis. These big questions often lead to possible explanations. We call these explanations hypotheses. You may even already have a big question and a hypothesis about your topic! Below you will find a description of what is meant by a “big picture question,” an hypothesis, and a research question.

**Big picture questions** are the initial questions a scientist will ask while making observations. When researchers observe a feature that is interesting or unique, they will often ask themselves “What is that? How did it form? Why does it appear this way? Or why is this different from other examples?” One of these questions will be the guiding question for the remainder of their research or even possibly their career!

**Hypotheses** often result from these “big picture questions.” These are in the form of potential answers or explanations for the observation. There can be many working hypotheses which are an attempt to answer the question. Each hypothesis is specific to the data that will be collected. The hypotheses must be testable and falsifiable. This means an answer can be found and the answer can either support or disprove the hypothesis.

**Research questions** are the best explanations to the big picture questions. Research questions are specific to the data that will be collected. Results from each research question can be pooled together to determine the best answer to the big picture question. Sometimes the hypothesis and research question are considered to be the same.

### A few sources that might be useful:

<http://www.lroc.asu.edu/lrolive/#loc=video&category=sci&vid=102>

<http://www.lpi.usra.edu/lunar/moon101>

<http://lroc.sese.asu.edu/news/index.php?/categories/2-Featured-Image>

[http://wms.lroc.asu.edu/lroc\\_browse](http://wms.lroc.asu.edu/lroc_browse)

<http://lunar.gsfc.nasa.gov/moonfacts.html>

<http://lunar.gsfc.nasa.gov/faq.html>

<http://nssdc.gsfc.nasa.gov/planetary/factseet/moonfact.html>

[http://www.nasa.gov/multimedia/videogallery/index.html?media\\_id=135568801](http://www.nasa.gov/multimedia/videogallery/index.html?media_id=135568801)

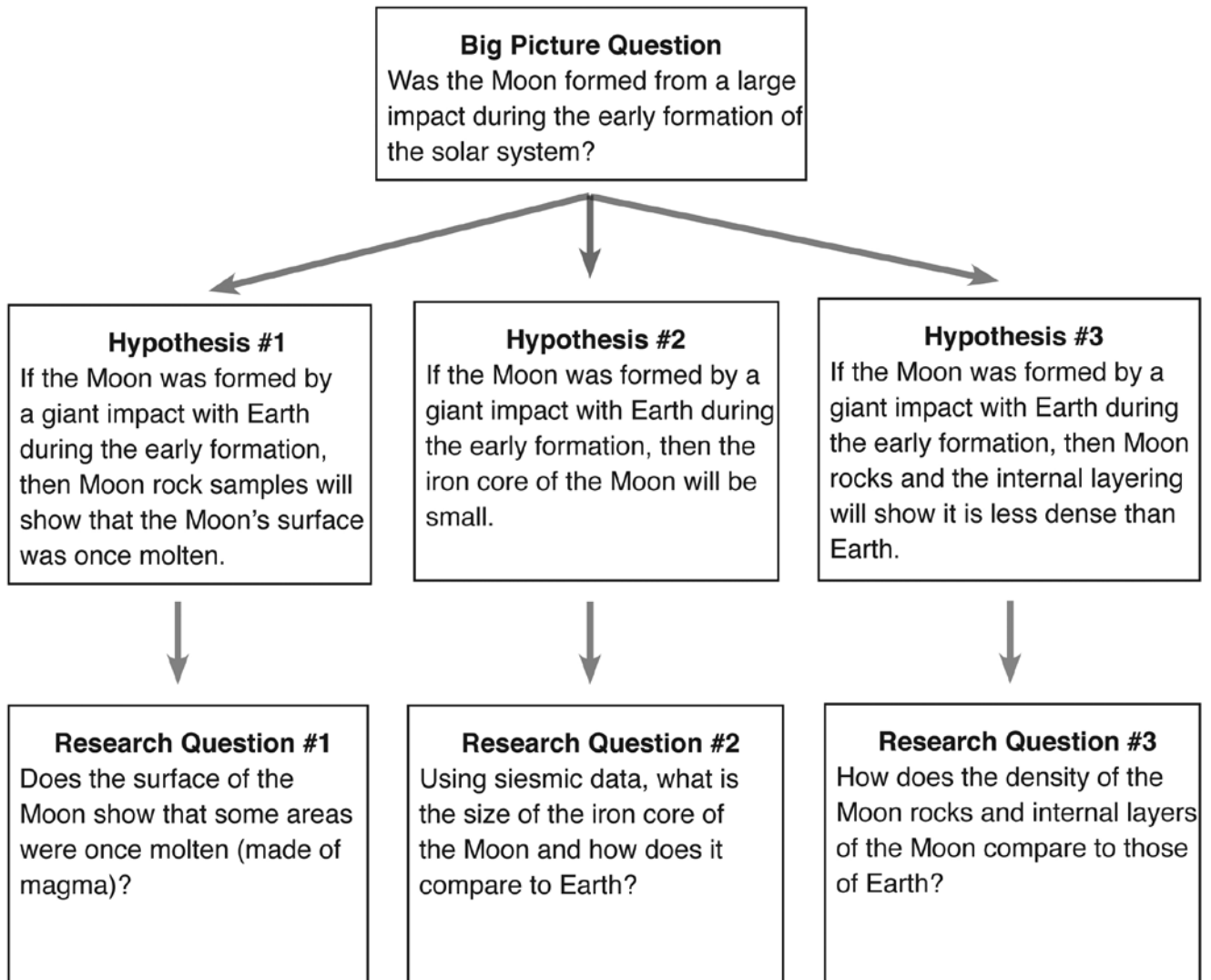




# STUDENT SHEET #1

## Questions and Hypotheses

### Giant Impact Hypothesis Example





## STUDENT SHEET #1

Name \_\_\_\_\_

## Questions and Hypotheses

Below you will find 2 examples of stories from real research regarding the Moon. These examples are stories about how the scientists came up with their questions for research. Read through each of these scenarios. Look for the hypothesis and overall research question. The big picture question has been provided for you. Be prepared to share your findings with the class. Don't forget, sometimes the question may not be written in the form of a question, but more as a statement.

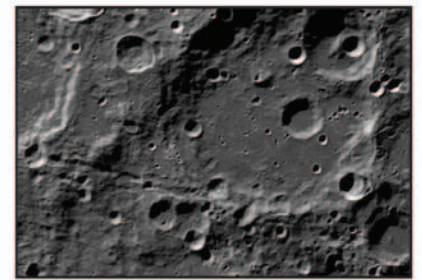
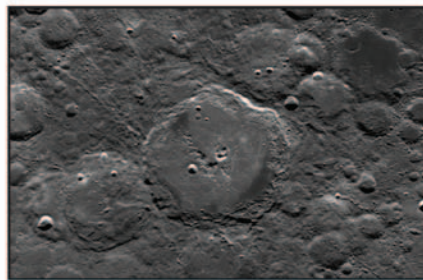
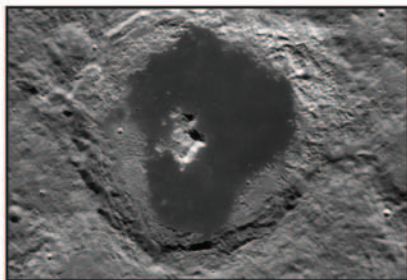
### Craters on the Moon

Prior to the 1940's, scientists were fairly certain that craters on the Moon were formed from volcanic activity. Throughout the 1940's into the 1960's, including the Apollo program, scientists studied these craters to uncover if they were volcanic or made by meteor impacts. Lunar Orbiters and the Apollo missions took pictures of the Moon that showed details not seen through telescopes. The Apollo missions also returned rock samples from the Moon. These samples along with better pictures of the craters showed that the craters were the result of impacts and not related to volcanoes.

**Big Picture Question:** How were craters formed on the Moon?

Hypothesis:

Research Question:



[NASA/GSFC/Arizona State University]



# STUDENT SHEET #1

## Questions and Hypotheses

Name \_\_\_\_\_

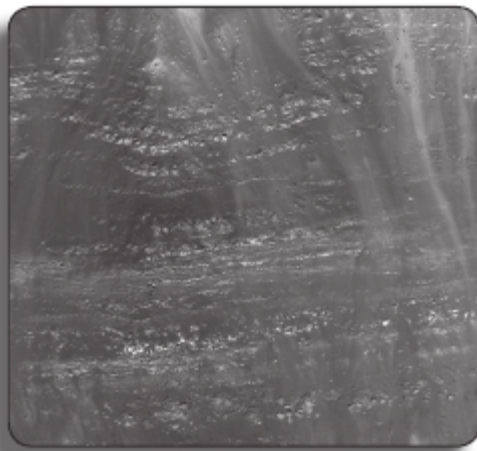
### Maria Layers on the Moon:

Scientists first observed layering in the lunar mare (pronounced mahr-ey) when the Apollo 15 astronauts visited Hadley Rille, a channel carved by lava. More recently, images from the LROC camera have shown layering in the mare in the walls of impact craters. The layers average 10-20 m thick and we only see layers in the craters on the mare, not the highlands. Scientists have debated for years about how the mare formed. Was it from a few, very large eruptions or from numerous smaller eruptions? To begin testing this, researchers have been looking for as many examples of layering to identify the range in thicknesses of the mare layer. They will then compare them to chemical data, lava models, and lava flows on Earth to better understand how the mare lavas formed.

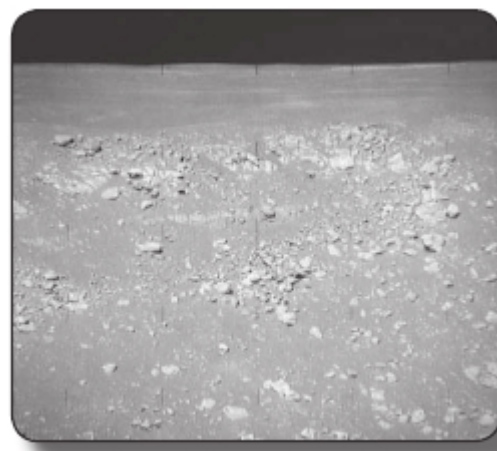
**Big Picture Question:** How did the maria form?

Hypothesis:

Research Question:



LROC image of Euler Crater layers.  
Credit: NASA/GSF/Arizona State University.



Apollo 15 image of Hadley Rille layers.  
Credit: NASA/LPI.



worksheets

## STUDENT SHEET #2

Name \_\_\_\_\_

# Identifying the Big Picture Question

For this activity, you will need the observations and your team chosen topic from the Lunar Image Analysis activity. Review the key observations your team used to pick your topic and discuss with your team what was unique and interesting about these observations. Work in a small group to brainstorm some of the big picture questions about your topic. Question prompts have been provided. You are not limited to the number of times you can use a prompt and may not use all of the provided prompts. Additional space has been provided in case you want to use a prompt more than once.

What is \_\_\_\_\_?

(Should be a specific description of an interesting feature you are unable to identify)

How did \_\_\_\_\_ form?

(Should be a specific feature)

Why does \_\_\_\_\_ appear \_\_\_\_\_?  
\_\_\_\_\_?

(A specific feature and a description of the appearance)

Why is \_\_\_\_\_ different from \_\_\_\_\_?  
\_\_\_\_\_?



## STUDENT SHEET #2

Name \_\_\_\_\_

# Identifying the Big Picture Question

Now that you have a list of possible Big Picture Questions, share your favorite one or two with the team. Explain why you are interested in answering this question and what observations were made that brought you to the question.

### Top two Big Picture Questions to share:

#1:

This question is interesting and important because:

#2:

This question is interesting and important because:



worksheets

# STUDENT SHEET #3

## Identifying the Explanations

Name \_\_\_\_\_

As a team, you will now need to debate which Big Picture Question you would like to use. Once your team has selected a Big Picture Question, record it here:

**Big Picture Question:**

With a big picture question in place, you are ready to start brainstorming possible explanations. Below, create a list of possible answers or explanations to the Big Picture Question. Work with your team to create this list.



## STUDENT SHEET #3

Name \_\_\_\_\_

# Identifying Explanations with Available Tools

Take some time with your team to see if there are tools available to test your explanations. An explanation cannot become a hypothesis if you do not have the appropriate tools available to test it. In this case, you can use the JMARS for the Moon tool (<http://jmars.asu.edu/download-jmoon>) to see what types of data can be collected. Take a few minutes to use the JMARS for the Moon tool and record the layers that might be helpful in research of your topic. Record those layers below and explain what type of data they can help you research. An example has been provided for you.

| JMARS for Moon        | What will be measured or recorded?   |
|-----------------------|--|
| example: Lat/Lon Grid | example: measure distances of features in km or find the latitude/longitude of a feature |
|                       |  |
|                       |  |
|                       |  |
|                       |  |
|                       |  |
|                       |  |
|                       |  |



# STUDENT SHEET #3

## Identifying the Explanations

Name \_\_\_\_\_

With your understanding of what tools you have available, go back to your original brainstorming list and mark the explanations you will be unable to research because you do not have the tools available. From the remaining list, choose two explanations you would like to share with the team as a possible explanation.

#1:

#2:

As a team you will need to debate among all of the possible explanations which is the best. This will be your primary hypothesis. You may pick a second if it is closely related to the primary. We will revisit this hypothesis after writing our research question to ensure it is testable and falsifiable (can prove that it is false).

**Primary Hypothesis (DRAFT):**





## STUDENT SHEET #4

Name \_\_\_\_\_

# Writing a Research Question

In order to write a quality research question, you need to consider the information you need to prove or disprove your explanation (hypothesis). You will need to consider the variables you intend to collect data on. A variable is something that will be measured or observed in an experiment. Below you will find a list to get you started. This list does not contain all of the possible variables, but provides a guide to get you started. Create your own list of variables which are specific to your explanation in the area below.

| Potential Variables |               |                 |               |
|---------------------|---------------|-----------------|---------------|
| Location            | Comparisons   | Characteristics | Measurements  |
| region              | similarities  | shape           | length        |
| distribution        | differences   | type            | diameter      |
| near side/far side  | relationships | texture         | circumference |
| lowlands/highlands  | patterns      | quantity        | height        |



## STUDENT SHEET #4

Name \_\_\_\_\_

# Writing a Research Question

Using your list on the previous page, create at least 2 questions for your research on the Moon. These questions should be related to your topic/ primary hypothesis and be testable. Once you have written your questions, use the Evaluation Criteria in the box below to see if your question qualifies as a testable research question. If you can put a check (✓) in all of the boxes, your question should be good enough for your team to consider for your research.

Question 1:

Question 2:

| Question |   | Evaluation Criteria  |
|----------|---|--|
| 1        | 2 |  |
|          |   | Question can be answered using materials available and in the time allotted.   |
|          |   | Question focusses on specific features that can be observed using the LROC WAC Equatorial Mosaic and JMARS for Moon.                   |
|          |   | Question does not focus on HOW the feature formed.   |
|          |   | Question includes observations or is similar to one of these: Evidence, shape, similarities, differences, relationship, patterns, etc. |
|          |   | Question is not a “why” or “how come.”   |



# STUDENT SHEET #4

## Writing a Research Question

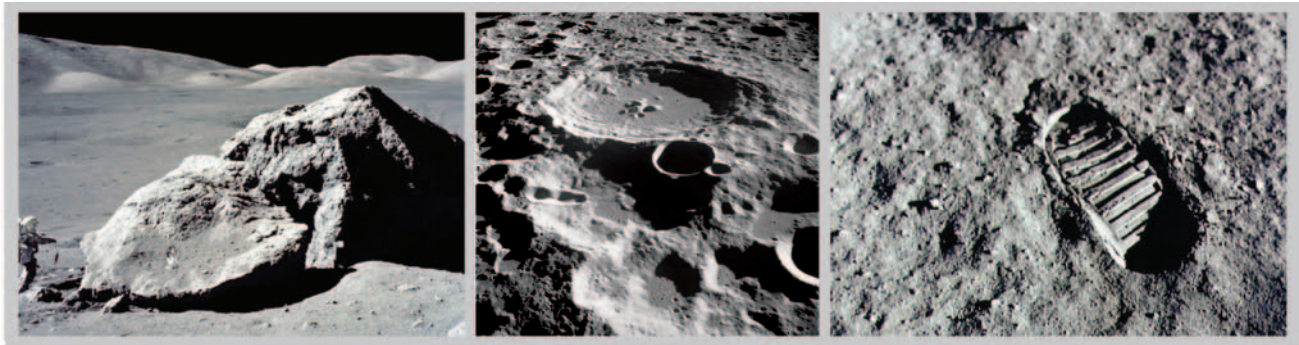
Name \_\_\_\_\_

Share your research questions with your team. As a team, debate which question would be the best potential question for your class to research. Decide which final question is the most interesting and answerable question using LROC images.

Try not to feel “possessive” of your own created question. Your creation and participation in team discussions and decisions will help to select the best and most interesting question to focus on for your research.

Why is this question the best? List the reasons here:

**Final Science Question:**



Credit: NASA



## STUDENT SHEET #5

# Writing a Testable Hypothesis

Name \_\_\_\_\_

Refer to your primary hypothesis written in Student Sheet #3 and your newly written team question. You will need to modify the hypothesis to more accurately reflect the research question your team has chosen. Once you have written your hypothesis, use the Evaluation Criteria in the box below to see if your hypothesis qualifies as a testable and falsifiable hypothesis. If you can put a check (✓) in all of the boxes, your hypothesis should be good enough for your team to consider for your research.

Primary Hypothesis Draft:

Research Question:

Research Hypothesis:

| (✓) | Evaluation Criteria  |
|-----|--|
|     | Hypothesis can be answered using materials available and in the time allotted.   |
|     | Hypothesis focuses on specific features that can be observed using the LROC WAC Equatorial Mosaic and JMARS for Moon.                    |
|     | Results of the experiment could support the hypothesis OR disprove it.   |
|     | Hypothesis includes observations or is similar to one of these: evidence, shape, similarities, differences, relationship, patterns, etc. |
|     | Hypothesis includes an 'If...then...' statement (*note* not always 100% true. This works MOST of the time.)                              |



# STUDENT SHEET #5

## Writing a Testable Hypothesis

Name \_\_\_\_\_

If it meets the criteria, share your hypothesis with your team. As a team, debate which hypothesis would be the best for your class to research. Decide which hypothesis is the most interesting and answerable question using LROC images.

Try not to feel “possessive” of your own created hypothesis. Your creation and participation in the team discussions and decisions will help your team select the best and most interesting hypothesis to focus on for your research.

Why is this hypothesis the best? List the reasons here:

**Final Science Question:**

**Final Science Hypothesis:**

---

## SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Sample Answers:

### STUDENT SHEET #1

## Questions and Hypotheses

Below you will find 2 examples of stories from real research regarding the Moon. These examples are stories about how the scientists came up with their questions for research. Read through each of these scenarios. Look for the hypothesis and overall research question. The big picture question has been provided for you. Be prepared to share your findings with the class. Don't forget, sometimes the question may not be written in the form of a question, but more as a statement.

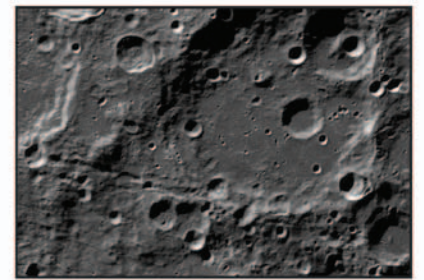
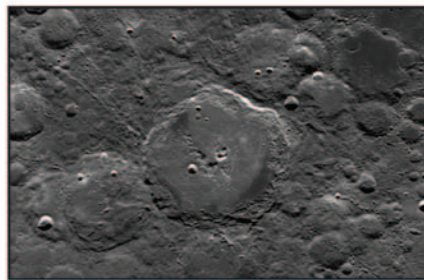
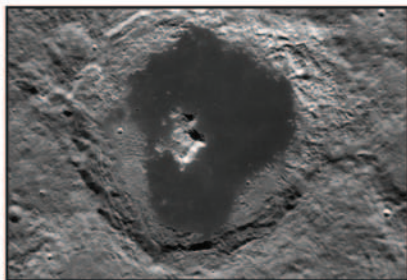
### Craters on the Moon

Prior to the 1940's, scientists were fairly certain that craters on the Moon were formed from volcanic activity. Throughout the 1940's into the 1960's, including the Apollo program, scientists studied these craters to uncover if they were volcanic or made by meteor impacts. Lunar Orbiters and the Apollo missions took pictures of the Moon that showed details not seen through telescopes. The Apollo missions also returned rock samples from the Moon. These samples along with better pictures of the craters showed that the craters were the result of impacts and not related to volcanoes.

**Big Picture Question:** How were craters formed on the Moon?

Hypothesis: **If craters on the Moon were formed by volcanoes, then the rock around the crater will be volcanic.**

Research Question: **Were the craters on the Moon formed from volcanoes or from meteor impacts?**



---

[NASA/GSFC/Arizona State University]

## Sample Answers

# STUDENT SHEET #1

## Questions and Hypotheses

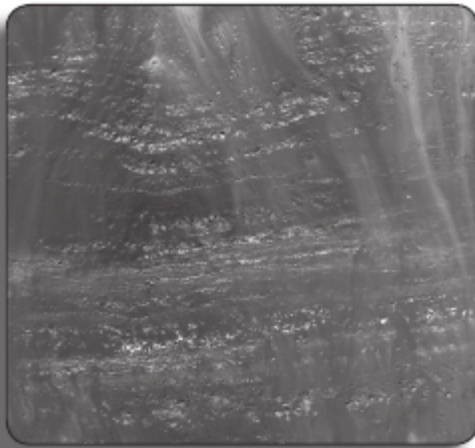
### Maria Layers on the Moon:

Scientists first observed layering in the lunar mare (pronounced mahr-ey) when the Apollo 15 astronauts visited Hadley Rille, a channel carved by lava. More recently, images from the LROC camera have shown layering in the mare in the walls of impact craters. The layers average 10-20 m thick and we only see layers in the craters on the mare, not the highlands. Scientists have debated for years about how the mare formed. Was it from a few, very large eruptions or from numerous smaller eruptions? To begin testing this, researchers have been looking for as many examples of layering to identify the range in thicknesses of the mare layer. They will then compare them to chemical data, lava models, and lava flows on Earth to better understand how the mare lavas formed.

**Big Picture Question:** How did the maria form?

Hypothesis: **The mare were formed from many small eruptions over a long period of time.**

Research Question: **Did the mare on the Moon form from many small eruptions over a long period of time, or from a few, larger eruptions in a short period of time?**



LROC image of Euler Crater layers.  
Credit: NASA/GSF/Arizona State University.



Apollo 15 image of Hadley Rill layers.  
Credit: NASA/LPI.

## Rubric

The following table has been developed to explain the rationale behind the evaluation criteria. The rationale may be helpful in your explanations to students regarding high quality research questions.

| <b>Evaluation Criteria</b>  | <b>Rationale</b>   |
|---|--|
| Question can be answered using materials available and in the time allotted.  | Focus on questions that can be answered using an image. Consider the amount of data that will be necessary to answer the question. For example, global questions are very time consuming and many scientists will spend their career collecting this kind of data. |
| Question focuses on specific features that can be found using the LROC WAC Equatorial Mosaic.                           | Not all questions can be answered by a picture. If students ask a question that would require video or a direct presence to observe, then it is typically not investigable by looking at an image.   |
| Question does not focus on HOW the feature formed.  | These are often the big picture questions we are trying to answer. We want to know if the processes are the same or different from those we see on Earth, therefore we look for evidence (variables) that then tells us how the features are formed.               |
| Question includes one of the following words: evidence, shape, similarities, differences, relationships, patterns, etc. | This is a small list, but covers many of the general terms students could use in their question. These are directly related to evidence they could collect. Students just need to plug the variables in.   |



# Lunar Reconnaissance Orbiter:

## Audience

Grades 6-8

## Time Recommended

1-2 Hours

## AAAS STANDARDS

- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information
- 1C/M1: Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.

## NSES STANDARDS

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

Content Standard F (5-8): Science and Technology in Society:

- e. Science and technology have advanced through contributions of many different people, in different cultures, at different times in history.

Content Standard G (5-8): History and Nature of Science:

- c. In historical perspective, science has been practiced by different individuals in different cultures.

## MATERIALS

- Computers or Computer Lab
- Timeline Student Worksheet (attached)
- Research Support Sheet (attached)
- Drawing Tools
- Tape

# Lunar Exploration Timeline:

## Learning Objectives:

- Students will be able to discuss past missions and make a visual connection between them.
- Students will understand that individual missions build on each other to contribute to lunar exploration as a whole.

Students will understand the history of the space exploration as a whole and learn about major events in the history of lunar exploration. They will be introduced to previous and current moon missions and explore the accomplishments of each.

## Preparation:

Prior to starting this lesson, you may need to reserve time in the computer lab or allow access to computers in the classroom. As an optional pre-lesson activity you could ask students to create a list of events in space history. You may choose to have them research this topic, list events they remember or have heard about, or interview friends/family members about the topics. Review the Student Research Support document to be familiar with the resources you will be leading the students to and helpful strategies for student research.

## Procedure:

1. Investigate what your class knows about space exploration history. Students could use notes they took as preparation for this activity. What missions or programs are they familiar with? What space explorers can they name and what do they know about them?
2. Break class into groups of 3-4 students and assign each group a mission or program that contributed to lunar exploration. Give each group a timeline worksheet to fill out with mission program start and end dates, goals, accomplishments, destination, and fun facts. Students should also add imagery of the spacecraft, astronauts, badges or any other significant images by drawing images based on information from the mission sheets. If available, students can also cut and past images onto the mission sheets. Give students at least 30 minutes to complete their own research into that mission or program.
3. When students are finished, they should work together as a class to form a timeline in chronological order. The timeline worksheets can be attached end to end to create the physical timeline on a wall in the classroom. Each group should report on the program/mission they investigated. You should spend approximately 15 minutes reporting out.

4. For approximately 15 minutes, discuss the following as a class: What have we learned thus far from space exploration? What have we accomplished solely with moon missions? How did the achievements of early missions contribute to the success of later missions? How could we build off of what we have learned from the past missions?

### Assessment:

Review each group's timeline worksheets for completeness and accuracy. Student presentations should convey all, important information in a way that is easy for the class to understand. As a class, students should be able to work together to construct the full timeline.

### TEACHER SCORING GUIDE

**Assignment:** Timeline Activity

Student Name(s): \_\_\_\_\_

Date: \_\_\_\_\_

| Performance Indicator  | 0 | 1 | 2 | 3 | 4 |
|--|---|---|---|---|---|
| Students completed all sections of the worksheet.  |   |   |   |   |   |
| Students' work shows evidence that care was taken when completed                                 |   |   |   |   |   |
| All information presented is accurate.   |   |   |   |   |   |
| Students convey all the important information in a way that is easy for the class to understand. |   |   |   |   |   |
| Students have a sense for where their mission fits into the overall timeline.                    |   |   |   |   |   |
| <b>Point Total</b>   |   |   |   |   |   |

**Point total from above:** \_\_\_\_\_ / (20 possible)

**Grading Scale:**

A = 18 - 20 points

B = 16 - 17 points


C = 14 - 15 points

D = 12 - 13 points

F = 0 - 11 points

**Grade for this Assignment:** \_\_\_\_\_

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

|                                      |                        |  |
|--------------------------------------|------------------------|--|
| <p><b>Start Date</b></p>             | <p><b>End Date</b></p> | <p><b>Mission or Program Name</b></p>  |
| <p><b>Mission/Program Images</b></p> |                        | <p><b>Country</b></p>  |
|                                      |                        | <p><b>Mission/Program Goals (check if met)</b></p>   |
|                                      |                        | <p><b>Fun Facts</b></p>  |

# Student Research Support

## TEACHER NOTE:

Students should be encouraged to do their own research to develop 21st century skills involving the evaluation of information and the use of technology. The following sites are approved and relevant sites for the information required in the activity. If you allow more advanced students to use sites other than those listed please take time to evaluate the relevance and validity of those sites and communicate the importance of doing that to your students.

## APPROVED SITES AND LUNAR MISSIONS/PROGRAMS:

<http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Target&Target=Moon&Era=Present>

## OVERVIEW OF LUNAR MISSIONS

### Past Programs and Missions

- Pioneer Program and missions
- Luna Program and missions
- Ranger Program and mission
- Surveyor Program and missions
- Lunar Orbiter Program and missions
- Explorer Program and missions
- Apollo Program and missions
- Lunar Prospector
- Hiten-Hagamoro
- Kaguya
- Chang'e 1
- Chandrayaan-1
- Clementine
- SMART -1
- LCROSS
- ARTEMIS

### Present Programs and Missions

- LRO (Lunar Reconnaissance Orbiter)
- Chang'e 2
- GRAIL

### Future Programs and Missions

- LADEE

**More detailed information about each of these missions can be found on their specific mission sites (including images).** Search for those here: <http://www.nasa.gov/missions/index.html>

## OTHER APPROVED SITES:

### **Japan Aerospace Exploration Agency**

[http://www.jaxa.jp/projects/sat/index\\_e.html](http://www.jaxa.jp/projects/sat/index_e.html)

Selene/Kaguya

[http://www.jaxa.jp/projects/sat/selene/index\\_e.html](http://www.jaxa.jp/projects/sat/selene/index_e.html)

Hiten Muses-A

<http://www.isas.jaxa.jp/e/enterp/missions/hiten.shtml>

### **European Space Agency**

<http://www.esa.int/export/esaCP/index.html>

SMART -1

<http://www.esa.int/export/SPECIALS/SMART-1/index.html>

## STRATEGIES FOR SUCCESSFUL AND EFFICIENT STUDENT RESEARCH

1. If possible get support from the school librarian or media specialist who may be specifically trained in facilitating this type of student research.
2. Have different students in each group be responsible for a piece of the required information and then they can collaborate to make sure it all comes together cohesively for the presentation.
3. Remind students to look for what's special or unique about their topic and how it might relate to other topics in a meaningful way.
4. Insist that students should not copy word for word what's on the site, but evaluate what information is needed and what information they feel confident communicating to others in their own words.
5. Allow students different options of how to collect the information. Some students like to print out everything and then select the important information others like to select the important information electronically and then print only what's relevant.
6. Remind students to stay on topic. This kind of autonomy can be difficult for some students and they may need multiple reminders of the task at hand.
7. Give students periodic time checks. The students will be more able to assess what they have accomplished and can decide how to best use the remaining time with the computers.

## Extension Activities:

Add other historical events to the timeline to create a context for the lunar missions.

# Lunar Reconnaissance Orbiter: (Mini-RF)

## Audience

Grades 6-8

## Time Recommended

1-2 Hours Pre-Lab activities; 1-2 hours Lab activities

## AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.
- 12D/M10: Understand oral, written, or visual presentations that incorporate circle charts, bar and line graphs, two-way data tables, diagrams, and symbols.

## NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations.

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

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigation, inquiry, and analysis.

## MATERIALS

- Pre-lab worksheets (included)
- Lab worksheets (included)
- Set of Clementine images (included)
- Corresponding Mini-RF data (included)
- Dry erase markers
- Clear overhead transparencies
- Lunar Landforms Definitions with Associated Images sheet (included)
  - » NOTE: When printing images, be sure to print as high of a resolution as possible

# Mini-RF: Using Radar to Search the Darkness

## Learning Objectives:

- Using Mini-RF data, participants will learn how the Mini-RF can identify lunar surface features that are permanently shadowed, or lack any visible evidence of surface morphology.

## Preparation:

See procedure section for specific details regarding each activity.

## Background Information:

An instrument onboard the Lunar Reconnaissance Orbiter (LRO) called Mini-RF is searching for something special. People have been gazing and wondering about the Moon for millennia, but it still holds many mysteries. Until recently, we haven't been able to see into places such as permanently shadowed craters on the lunar surface. Mini-RF is helping scientists look into regions never before seen to make new discoveries about our Moon.

One of the things scientists are searching for is water. While the samples of lunar rock that were returned by Apollo were dry, there is evidence that water ice may exist inside impact craters near the cold lunar poles. This water ice would have been delivered to the Moon, over billions of years, by multiple impacts of comets and asteroids.

It is theorized that the interiors of permanently-shadowed craters near the poles are so cold that any water molecule entering would be unable to escape. Mini-RF will use radar to "look" inside these craters to search for any ice present. These ice deposits could be a valuable resource for a future human outpost, since such exploration is expensive.

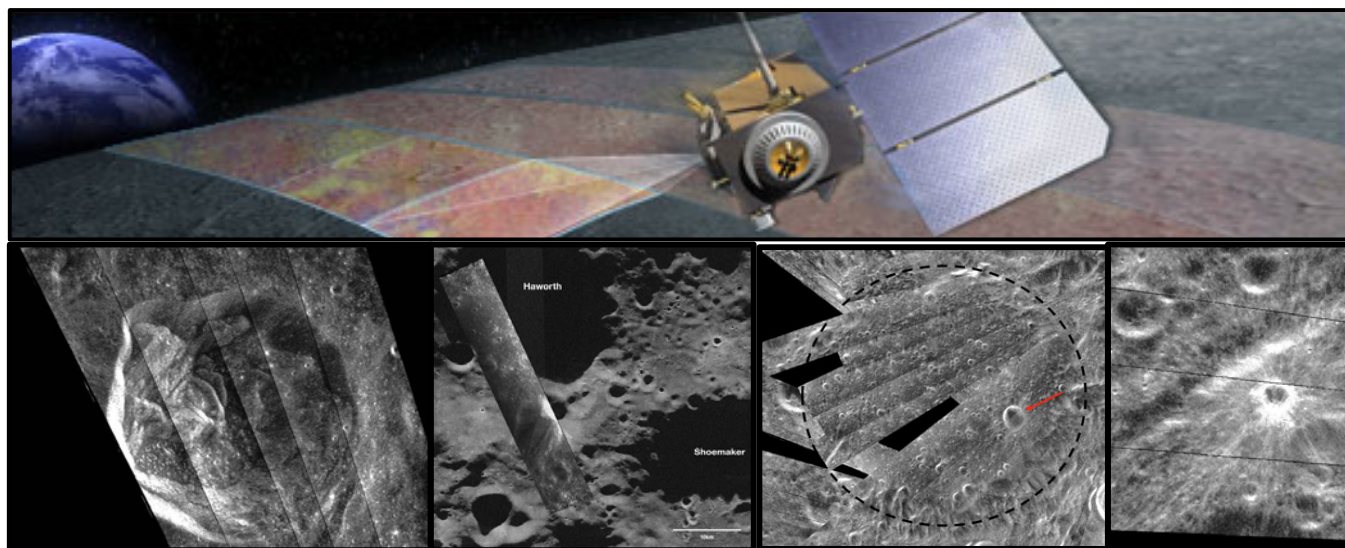
Over the years, several missions have done their part in searching for water on the Moon:

1. The EPOXI mission (<http://epoxi.umd.edu>): During its journey to the Tempel 1 comet, the Deep Impact spacecraft focused its instruments on the Moon in June 2009, where it revealed evidence for the presence of water on the lunar surface.
2. Chandrayaan-1 (M3) mission (<http://m3.jpl.nasa.gov>): The Moon Mineralogy Mapper (M3) is one of two instruments contributed by NASA to India's first mission to the Moon, Chandrayaan-1. M3, a state-of-the-art imaging spectrometer, has provided the first mineralogical map of the lunar surface at high spatial and spectral resolution. By analyzing the data, scientists are determining the composition of the surface of the Moon. Data collected indicated molecules of water in trace amounts.

3. Apollo sample return discoveries: In rock samples that were returned from the Moon during the Apollo missions, scientists found trace amounts of water.
4. LCROSS: ( [http://www.nasa.gov/mission\\_pages/LCROSS/main/index.html](http://www.nasa.gov/mission_pages/LCROSS/main/index.html) ) The impact plumes of the Lunar Crater Observation and Sensing. LCROSS and its Centaur rocket stage in Cabeus crater near the south pole of the Moon on Oct 9, 2009 showed the spectral signature of hydroxyl, a key indicator that water ice is present in the floor of the crater.

The discovery of water ice on the Moon has enormous implications for a permanent human return to the Moon. Water ice is made up of hydrogen and oxygen, two elements vital to human life and space operations. Lunar ice can be mined and dissociated into hydrogen and oxygen by electric power provided by solar panels deployed in nearby illuminated areas or a nuclear generator. This hydrogen and oxygen on the Moon is a prime rocket fuel, giving us the ability to refuel rockets at a lunar “filling station” and making transport to and from the Moon more economical by at least a factor of ten. Additionally, the water from lunar polar ice and oxygen generated from the ice could support a permanent facility or outpost on the Moon. The discovery of this material, rare on the Moon but so vital to human life and operations in space, will make our expansion into the solar system easier while reaffirming the immense value of our own Moon as the stepping stone into the universe.

Mini-RF also allows scientists to gain more information about the surface and subsurface of the Moon, including the far side we never see from Earth. Mini-RF also allows scientists to get a better feel for surface properties and the composition of the Moon, essentially bridging the gap between past research and current technologies.



## Procedure:

See each student lesson located in the worksheets section for the corresponding procedure. There are pre-lab and lab worksheets to choose from related to the Mini-RF.

## PRE-LAB ACTIVITIES: How We Use Radar to See

Name \_\_\_\_\_

We're used to seeing images of Earth or the Moon or any planetary body using ordinary cameras that see things the same way our eyes do: with visible light provided by the Sun or by a flash. But radar uses microwaves (energy with a longer wavelength than light) which also reflects off the surface being imaged. But, because it uses energy in a region of the electromagnetic spectrum that has longer wavelengths, it can do things that ordinary cameras can't: radar can show features that we can't see with our eyes.

### Pre-Lab Activity Part 1 – Seeing Through the Smoke

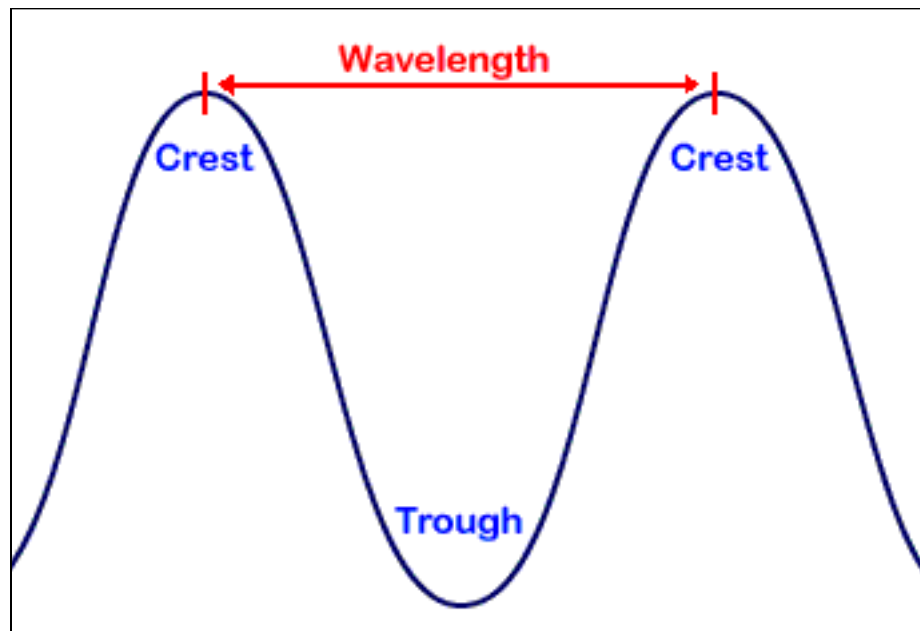
To give you an idea of how this works, let's look at a few images taken from space using radar.



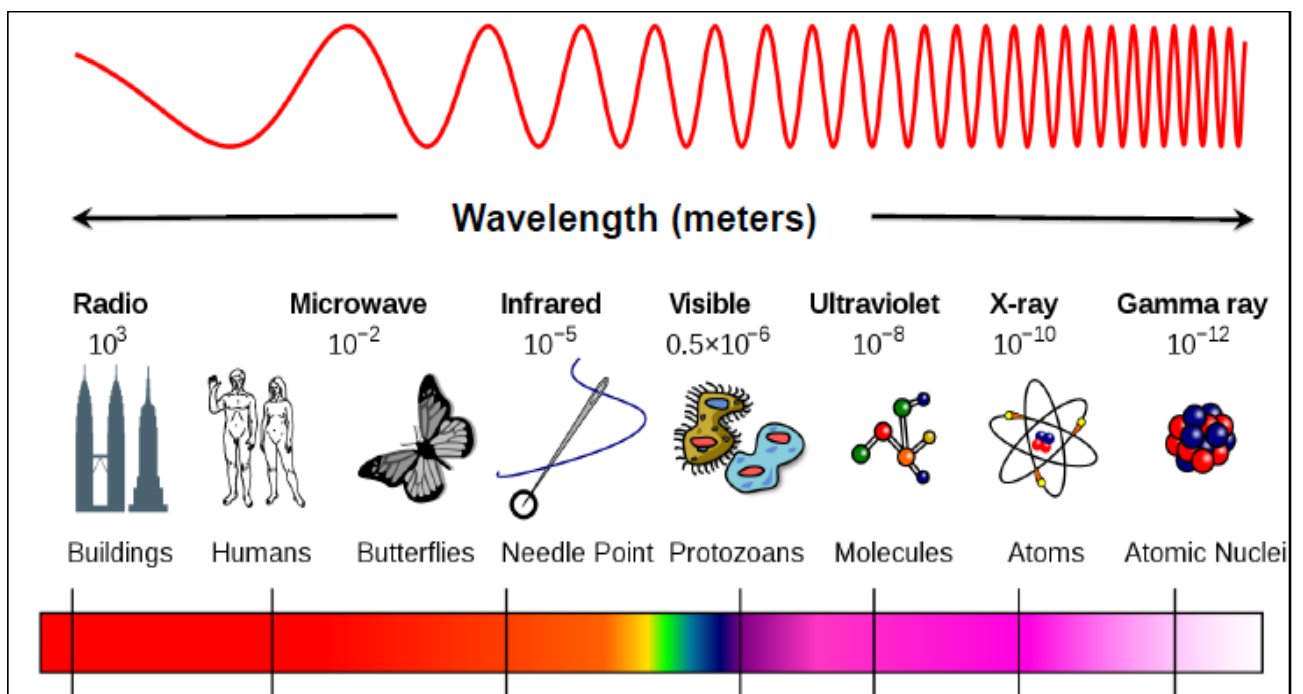
These side-by-side images of the same volcanic eruption show the differences between optical imaging and radar imaging. On the left is a photograph taken by space shuttle astronauts as the shuttle Endeavor passed over the eruption of Kliuchevskoi volcano in Kamchatka, Russia. On the right is the radar image acquired by the SIR-C/X-SAR radar instrument. In the photograph, the ash plume is emerging from a vent on the north flank of Kliuchevskoi. In this view, the volcano is partially hidden by the ash plume and its shadow. The radar image shows how radar can see through the ash and smoke to reveal the contours of the land underneath.



So, how does radar “see” through the smoke and haze? It all has to do with wavelength. As energy radiates out from a source, it travels in a wave. All radiation can be described in terms of energy or what we can also call wavelength. Wavelength is the distance from one wave crest to the next wave crest:



The range of all possible wavelengths is called the electromagnetic spectrum:





Our eyes can only detect radiation from a very small portion of the electromagnetic spectrum (from about 400-700 nanometers). Because visible light has such a small wavelength, it has a tendency to bounce off every object, including smoke particles and water droplets in a cloud. By the time it is transmitted through the smoke or rain, it has been scattered too much. Radar on the other hand has such a longer wavelength compared to visible light, it doesn't reflect or bounce around water droplets or smoke particles. Thus, radio waves can enter and exit the clouds relatively undistorted, allowing scientists to see through them.

Visible light contains a range of wavelengths, but with radar we often measure one very specific wavelength. Just think of how differently things would look if you could only see yellow. Your eyes would only detect how brightly an object scattered yellow, so the reflection's intensity, not the color, is what would give you new and useful information.

Similarly, radar antennae are often made to detect how brightly objects reflect one particular wavelength. Since there are no other "colors" (wavelengths) to mix in, we really only care about the backscatter's intensity and therefore scientists will often use grayscale when showing surface features.

Look at both images of the volcano. What are three features you can see in the radar image, that are hidden in the visible image?



Name \_\_\_\_\_

## How Radar Unmasks a Surface

### Pre-Lab Activity Part 2— Revealing Ancient Rivers

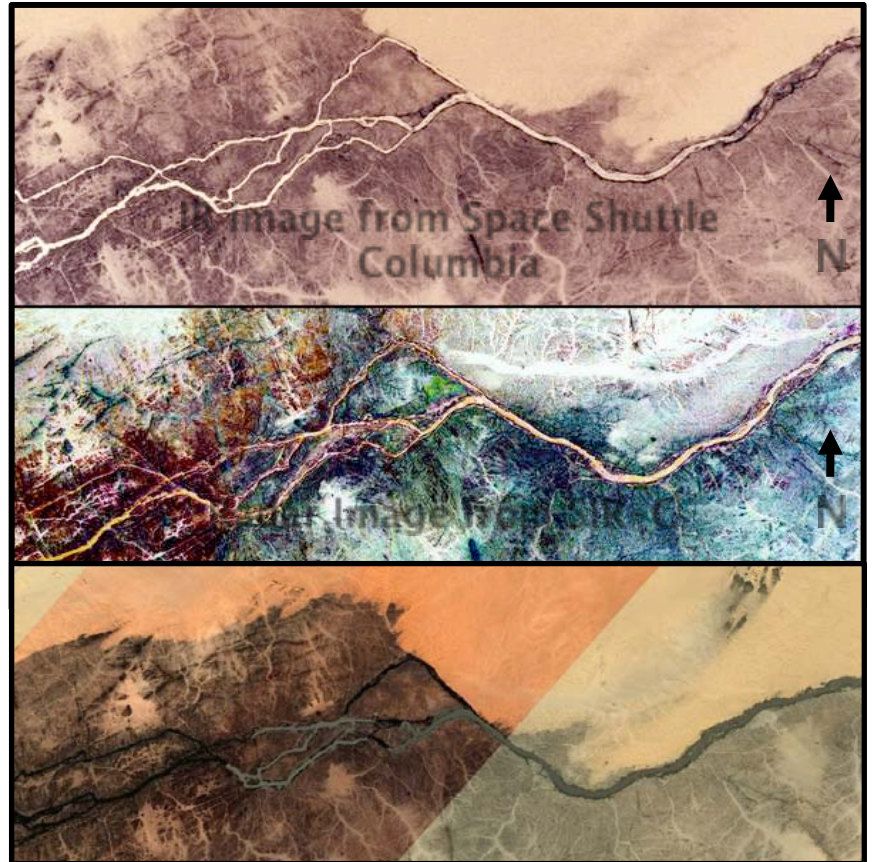
These are three views of parts of the Nile River, near the Fourth Cataract in Sudan, Africa. The top image is a photograph taken with color infrared (IR) film from space shuttle Columbia in November 1995.

The middle is a radar image that was acquired by the Spaceborne Imaging Radar C/X-Band and Synthetic Aperture Radar (SIR-C/X-SAR) aboard space shuttle Endeavour in April 1994.

The third image is a visible image from Google Earth from 2010. The thick, white band in the top right of the radar image is an ancient channel of the Nile that is now buried under layers of sand. This channel cannot be seen in either the IR photograph or the visible image. Its existence was not known before the radar image was processed.

The area to the left in all the images shows how the Nile is forced to flow through a

chaotic set of fractures that causes the river to break up into smaller channels. Because radar can penetrate below the surface of the sand to a certain depth, scientists can see where the river used to be and where it is today. Scientists estimate that probably sometime between 10,000 and 1 million years ago, the Nile was forced to abandon its bed and take up a new course to the south. (<http://www.jpl.nasa.gov/news/releases/96/sirnile.html>) The radar images have allowed scientists to develop new theories to explain the origin of the “Great Bend” of Nile in Sudan, where the river takes a broad turn to the southwest before resuming its northward course to the Mediterranean Sea. As you can see, radar allows scientists to uncover features they would never have seen before, and gave them a new tool to understand the complexities of this feature. Mini-RF does the same thing for scientists, allowing them to peer into areas that are either completely hidden by ejecta from a crater or peer into the darkness of a shadowed crater.



## Student Exercises

1. How could we use what we learn from this above image to help establish agricultural areas along the Nile? Using the radar images, how could scientists track future changes to the path of the Nile?
2. List ways that radar images from space can give us information needed to help manage and solve environmental issues on the Earth and possible landing sites on the Moon.

Earth:

Moon

## Using Radar to “see” the Moon—Intro

As we have seen in previous images, radar allows scientists to view areas of a planet that are covered by the ground, foliage, and even clouds. If radar allows scientists to see hidden objects, then it can be used to peer into dark, unlit regions as well. This is where the Mini-RF instrument comes in. Mini-RF not only allows scientists to see dark regions, but it allows scientists to view hidden features, which are typically hidden from view.

Images from the Mini-RF instrument, (a lightweight, Synthetic Aperture Radar or SAR), show the floors of permanently shadowed polar craters on the Moon that aren't visible from Earth. With the data acquired from the poles, scientists are looking for evidence of water ice. With the data they acquire from non-polar regions, they are looking at ejecta patterns, tectonic features and compositional effects of impact craters on the surface of the Moon.

Look at the image to the left, which was taken of an area near the south pole of the Moon. Several areas at the south pole never see sunlight and are permanently shadowed, like Haworth crater. The long rectangle in the middle is a Mini-RF radar image placed over the top of a larger Moon surface image that was taken from an Earth-based telescopic image. The Mini-RF image, taken in 2009, reveals a part of the shadowed crater never seen before. This type of imaging (using radar) helps scientists explore these permanently shadowed regions.

In this image, bright areas represent surface roughness or slopes pointing toward the spacecraft. The data strip covers an area approximately 50 kilometers (31 miles) by 18 kilometers (11 miles).

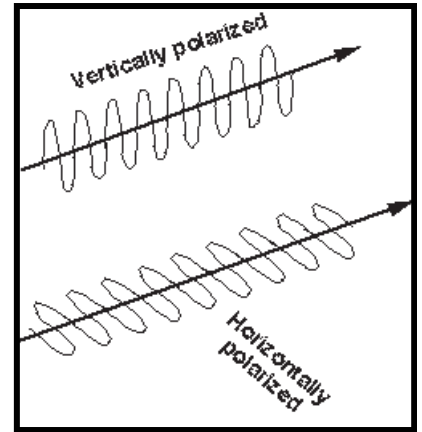
Once Mini-RF takes images of the surface of the Moon, the image can then be overlaid onto a visible image, which may then reveal areas which are completely obscured to the human eye.



## Polarization

As mentioned previously energy travels in waves. Visible light for example travels at all angles as it moves. This movement is in many different directions, but we can isolate certain movements compared to other movements (i.e. vertical versus horizontal movement). Polarization is the phenomenon in which waves of light or other radiation are restricted in a certain direction. Think of a rope that you pull through a picket fence. If you hold one end of the rope and someone holds the other end, and you move it up and down like a wave, the wave can travel right through the vertical pickets. But, if you try to make a wave side to side, only some waves may get through, while others are blocked. This is an example of polarization.

As you can see in the example to the right, vertically polarized waves travel in a vertical fashion, where as horizontal waves travel horizontally.

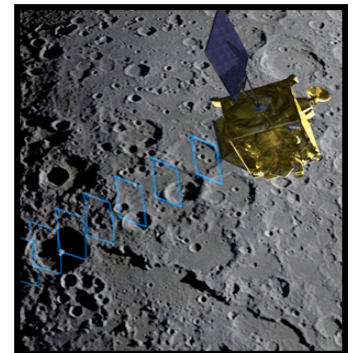


## What Does This Have To Do With Radar?

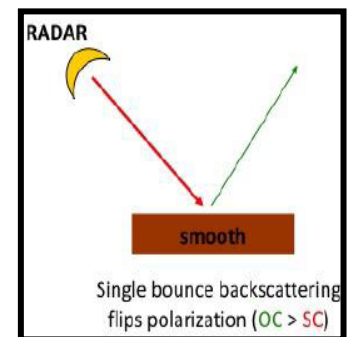
Mini-RF sends pulses of radar that are polarized. It transmits radar signals to the surface of the Moon and oscillates in a circle as it goes along (like a slinky or a spring). Typical planetary surfaces reverse the polarization during the reflection of radio waves, so that normal echoes from Mini-RF are right, circular polarized (this measurement is called the Circular Polarization Ratio or CPR).

## Let's detail how Mini-RF analyzes a signal:

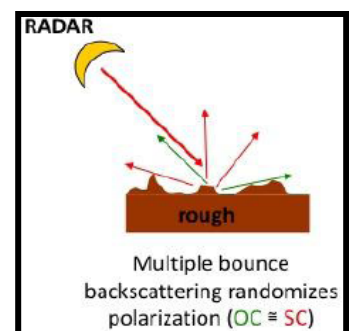
**Step 1:** When Mini-RF sends the radar signal down to the surface (it is spinning in a certain direction— i.e. left circular, or counter clockwise). When the light hits the surface, it bounces off and some reflects back to the instrument. Think of it like a bicycle reflector spinning and reflecting light back.



**Step 2a:** If the signal from the surface of a planet returns spinning in the opposite direction of the sent signal, then the signal is said to have opposite polarization. This indicates that the surface is smooth. In Mini-RF images, these smooth areas would appear dark. Scientists use the abbreviation “OC” to mean the polarization returning from the surface is opposite polarization compared to when it left the instrument. “SC” means it returns as the same polarization.



**Step 2b:** The signal returned from the lunar surface is called the radar “backscatter”. When the surface is rough, the signal is scattered in many different directions, including back towards the radar receiver. In Mini-RF images, these rough areas would appear bright. When the surface is smooth, the signal is primarily scattered in one direction, away from the radar receiver. In Mini-RF images, these smooth areas would appear dark.





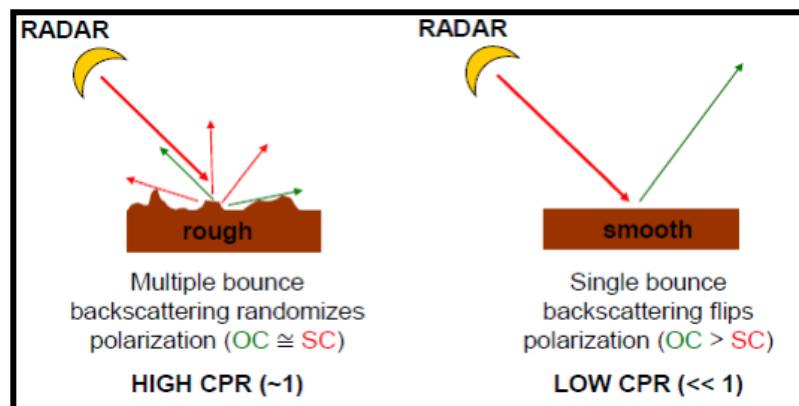
The radar signal is transmitted with a certain polarization (you can think of the radar wave as spinning through space in a clockwise direction). This polarization – the “same-sense” that was transmitted – is flipped when it bounces off a surface, and takes on the “opposite-sense” polarization (a wave that is spinning through space in a counter-clockwise direction). On a rough surface, the signal will bounce several times before returning to the receiver. This “randomizes” the polarization that is received by the radar, so the signal is roughly equal parts, or “same-sense” and “opposite-sense.” On a smooth surface, the signal will generally bounce only once, producing a return with mostly “opposite” polarization. When you compare the ratio of “same-sense” polarization to “opposite-sense” polarization, it will therefore be high for rough surfaces, and low for smooth surfaces.

### CPR: Circular Polarization Ratio

Once scientists have determined the polarization of the signal, they can then measure how much a signal has been reflected back to the spacecraft, or how much of it has been scattered, putting these numbers into a ratio called a circular polarization ratio, or CPR.

If there is more “opposite sense—OC” than “same sense—SC” of a polarized signal reflected back to the spacecraft, then the surface is said to have a “low CPR” or low Circular Polarization Ratio. In science terms, this means a surface is smooth. Here is the ratio: **CPR = SC/OC**

If the OC and SC are very similar (meaning the surface equally reflects back the same signal and opposite signal) then it is said to have a “high CPR” or high Circular Polarization Ratio. Again, in science terms, this means the surface is rough, and should be looked at more closely. A high CPR could mean the area is a rough, rocky terrain, or it could mean there may be ice causing the light to scatter. Using the empty box below, create a “reference box” similar to the one you see here:



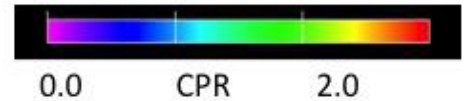
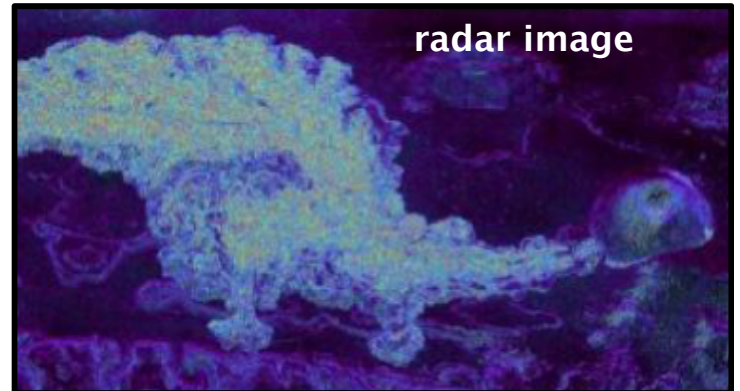
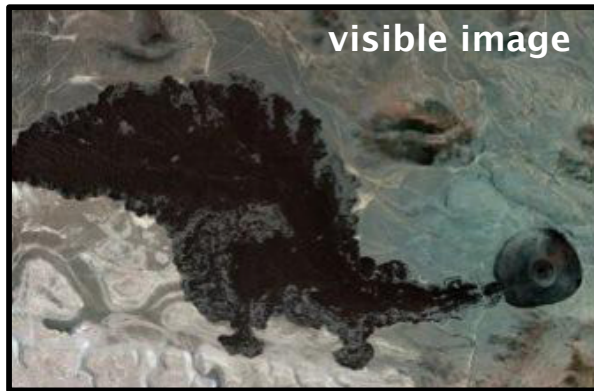
### Student “Reference Box”

Name \_\_\_\_\_

# Difference Between Radar and Visible Light

## Pre-Lab Activity Part 3—Image Analysis

Take a look at the color radar image below. This is an image that was taken of a volcano in northern Arizona. Compare the visible image with the radar image on the right.



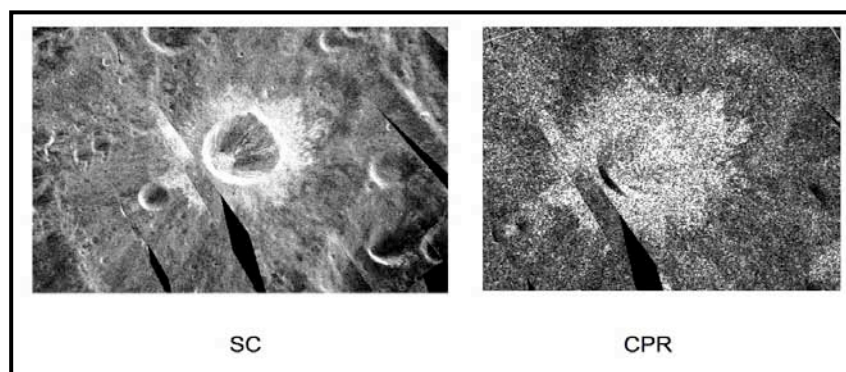
1. What do you notice about the difference between the two images?
2. Next, take a look at the color bar. From what you understand about High CPR (rough areas) and Low CPR (smooth areas), what is the one thing you can determine about the brightly colored area in the radar image?
3. Could you tell in the visible image if the dark region is smooth or rough? Why or why not?
4. What does water ice look like to radar? How can we tell if it might be there? When scientists compare the high CPR images, (indicating a rough surface) with images that are visually smooth, then something else must be present. A likely possibility of water ice!

Additionally, when scientists compare the Mini-RF images with terrain that is known to be older or younger, this helps the scientists know whether there is a strong possibility of water ice there. “Newer” craters are more likely to be blocky and rough, whereas “older” craters are more worn, so we expect them to be smooth. If we find an older crater with a high CPR (normally indicating a rough surface) that indicates there is a good chance ice is there.

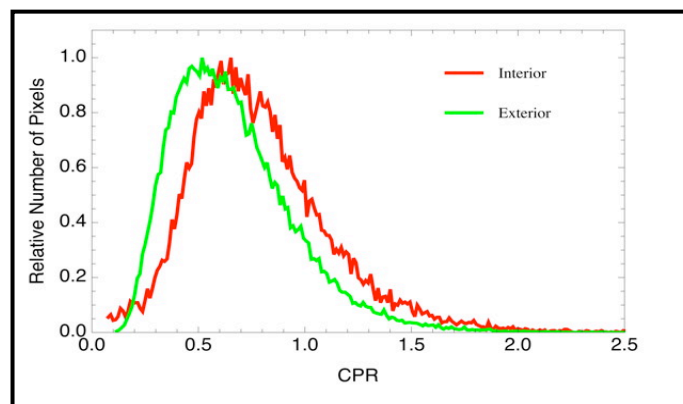
### What does water on the Moon look like?

The images below (all radar images) show how scientists search for evidence of water on the Moon. This first image shows no signs of water, simply rough areas on the Moon. How can we tell?

First, let’s take a look at the image. In the two images below, one is labeled “SC” (same sense) and the other is “CPR” (Circular Polarization Ratio). Remember, bright areas indicate a rough surface. The SC image indicates the brighter areas that would indicate to scientists that those areas are rough. Now, look at the “CPR” image. When scientists compare both images, we see that the SC and CPR images show very similar patterns of white, which indicates that we are looking at ejected material onto the surface after the impact.



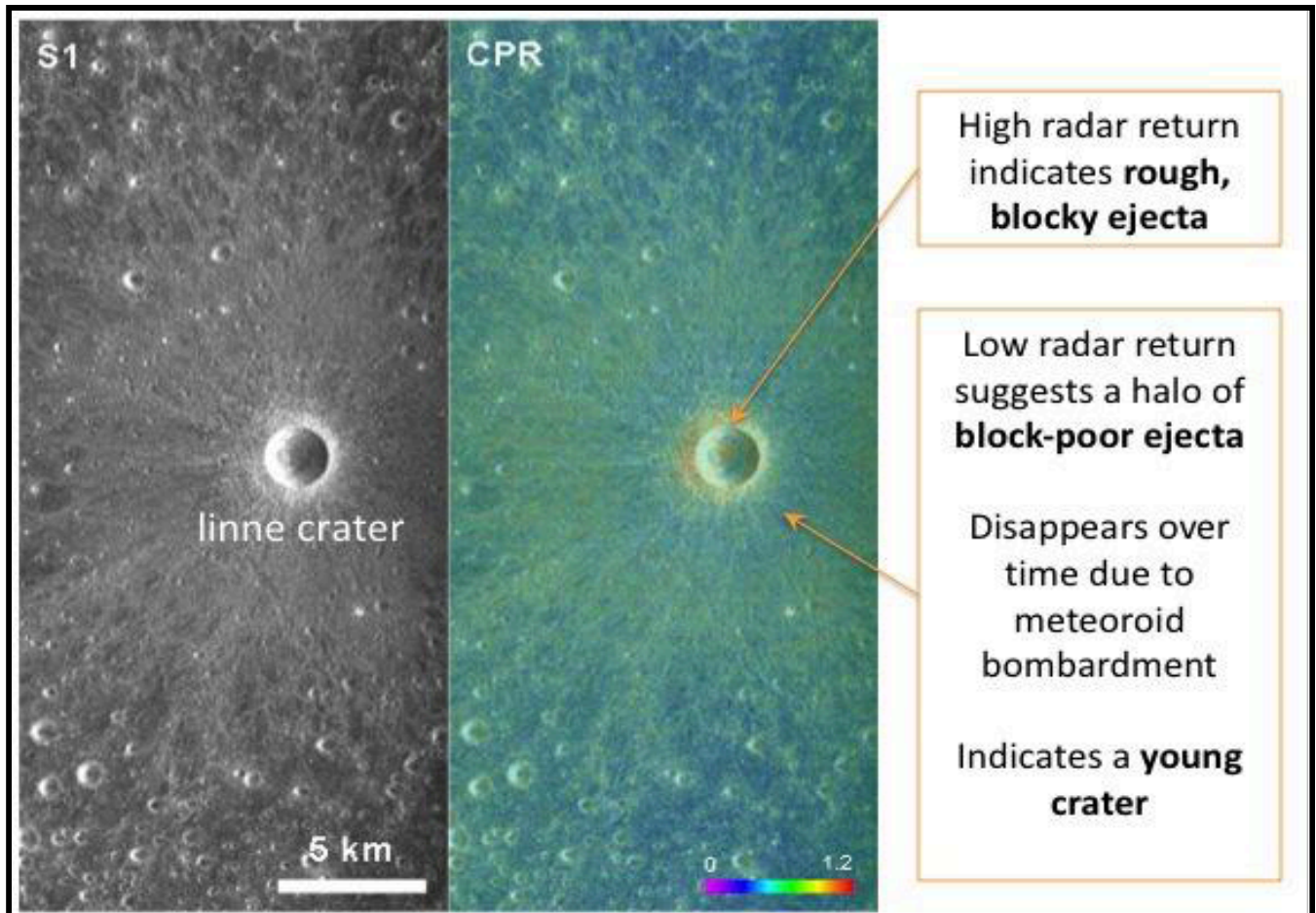
Next, scientists can take the data from Mini-RF and graph it as seen below with the red and green lines. They compare the high CPR values (or white in the image) inside and outside the crater rim. The red line is the interior of the crater and the green line is the exterior of the crater. By graphing the data, they can see the values both inside and outside the crater are almost the same. Graphically speaking, the white in the images indicates a rough, rocky surface.





Here is another comparison of radar images. The false-color helps scientists determine the level of CPR in the image on the right.

In the image to the left, you can see similar correlation between image on the left and the high CPR readings around the outside of the crater. This indicates a rough surface. Other details are also provided to show how scientists can analyze even more information when looking at CPR data.



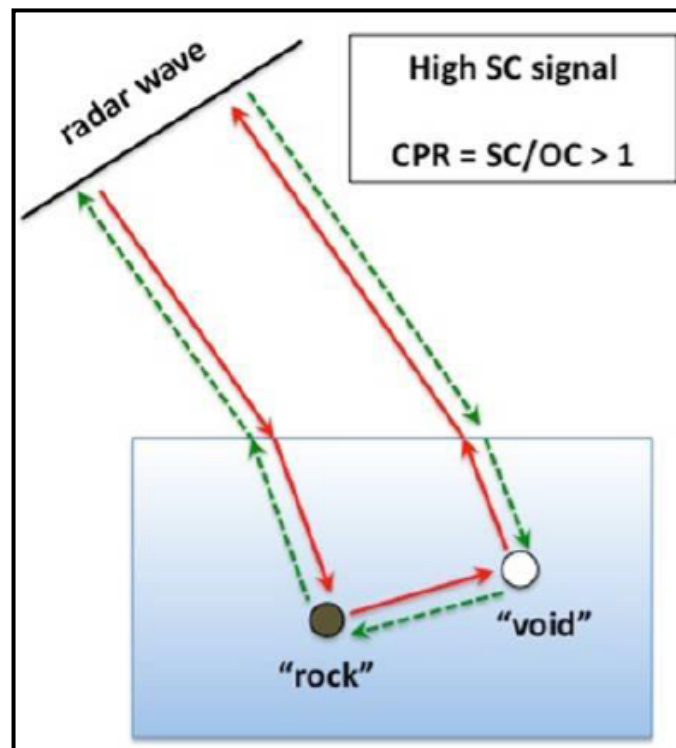
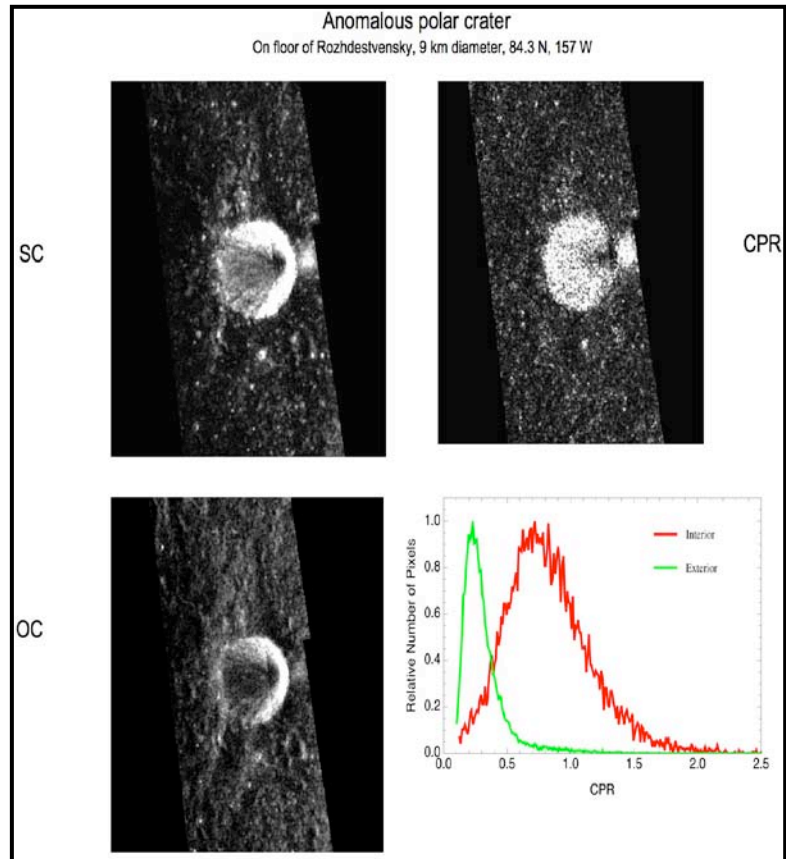
The picture to the right shows a crater on the floor of Rozhdestvensky near the north pole of the Moon. This feature shows high CPR within the crater rim but low CPR outside, suggesting that roughness, which occurs throughout a fresh crater, is not the cause of the elevated CPR.

How do scientists know the high CPR levels inside the crater might indicate ice?

First of all, this feature's interior is in permanent sun shadow. Because this area is in permanent shadow, the sun never shines on the dark areas of the crater, and doesn't ever heat the surface.

Secondly, when scientists compare the values the CPR readings, they can clearly see that interior points (red line) have higher CPR values than those outside the crater rim (green line). When they see that the CPR readings indicate that the crater floor is rougher inside the crater than on the outside, this could indicate something else that is causing the reading other than blocky terrain.

In ice (as seen in the image below), two radar signals will follow the same path in opposite direction. These signals add to produce very bright radar returns. Unlike normal radar returns, these signals maintain the original polarization of the radar wave, leading to large same sense (SC) returns, and high circular polarization ratios (CPR).



## LAB ACTIVITY PART 1

# Comparing Visible and Radar images

### Materials:

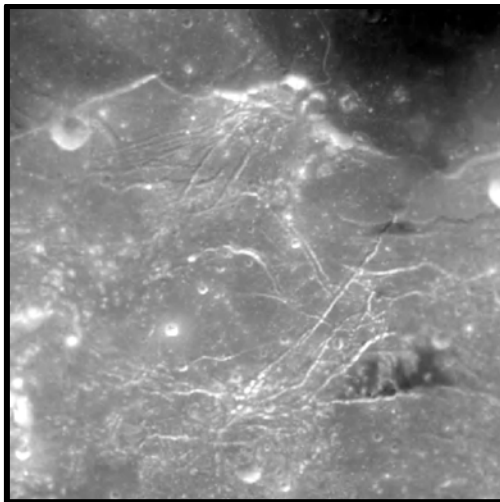
- Visible images of the surface of the Moon
- Mini-RF image strips taken of the same region
- Dry erase markers
- Clean overhead transparencies

### Procedure:

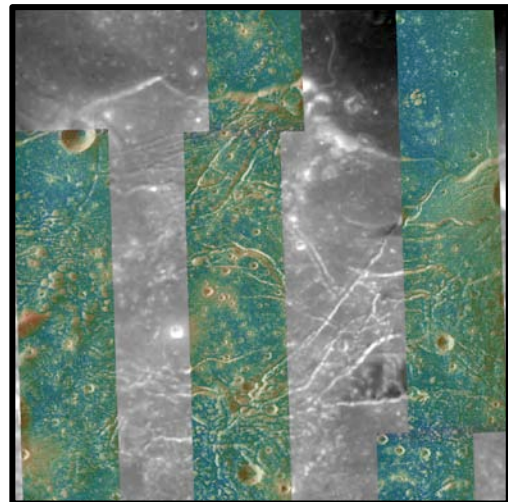
Dark areas on the surface of the Moon can indicate different things. Not only does radar help us peer into permanently shadowed areas on the Moon, it also helps us analyze other features.

By analyzing the Mini-RF image and overlaying that on a visible image of the Moon, scientists can gain a better understanding of what is happening on the surface of the Moon that visible images may not otherwise reveal.

Let's take a look at the example images provided (use the larger **Orientele Basin** images for better resolution):



Clementine mosaic of Orientele Basin



Clementine mosaic of Orientele Basin with Mini-RF overlay

Notice the color in the image on the right. This color enhancement allows scientists to see the different features with more clarity than just simply looking at a black and white image. The blues are low CPR and reds are high. Remember: high CPR suggests a 'rough' surface.

So, let's review (refer to the information above): how do scientists figure out what is high CPR and what is low CPR?



## LAB ACTIVITY PART 2

# Analysis of Orientale

Name \_\_\_\_\_

### Materials:

- Dry erase markers
- “Context for Orientale Basin” image (see supplemental materials section)
- “Orientale Basin image with Mini-RF data” image (see supplemental materials section)
- Clear overhead transparency
- Tape (blue painter’s tape works well)
- Lunar Landforms and Associated Images sheets (see supplemental materials section)

### Procedure:

1. Now, let’s do some analysis: taking note of the color, list three surface features you can see with the Mini-RF overlay image that you can’t see in the black and white Clementine image:
  - a.
  - b.
  - c.
2. Next, place a clean overhead transparency over the image “Orientale Basin with Mini-RF Data”. Tape the corners so the transparency doesn’t move.
3. Using the dry-erase markers, make notes on the image that show geologic features (lava tubes, craters, maria, lava flows, etc. Also note areas of high CPR, low CPR, and what that could indicate).
4. Using the information you noted on the image, list what you think the geologic history might have been in this area:



## LAB ACTIVITY PART 3

Name \_\_\_\_\_

# Analysis of additional images (optional: Humboldt Crater)

In this activity, you will practice techniques learned in Activity 2 by analyzing additional lunar surface images. You will be using the image “Humboldt Crater”. Identify features and try to determine the geologic history of the areas using your new analysis skills.

## Materials:

- Dry-erase markers
- “Context for Humboldt Crater” image (see supplemental materials section)
- “Clementine Mosaic—Humboldt Crater” image (see supplemental materials section)
- “Clementine Mosaic with Mini-RF data overlay” image (see supplemental materials section)
- “Mini-RF data Magnified—Humboldt” (see supplemental materials section)
- Clear overhead transparency
- Tape (blue painter’s tape works well but something else will suffice)
- Lunar Landforms and Associated Images sheets (see supplemental materials section)

## Procedure:

1. Similar to what you did in the previous activity, list 3 surface features you can see with the Mini-RF overlay image that you can’t see in the black and white Clementine image.
  - a.
  - b.
  - c.
2. Next, place a clean overhead transparency over the image “Clementine Mosaic with Mini-RF data overlay”. Tape the corners with clear tape so the transparency doesn’t move.
3. Using dry-erase markers, make notes on the image that show geologic features (lava tubes, craters, maria, lava flows, etc). Also, note areas of high CPR, low CPR and what that could indicate.
4. Next, using the 2 images “Mini-RF data Magnified—Humboldt”, try to match the part of the Mini-RF data strip these images came from.



worksheet

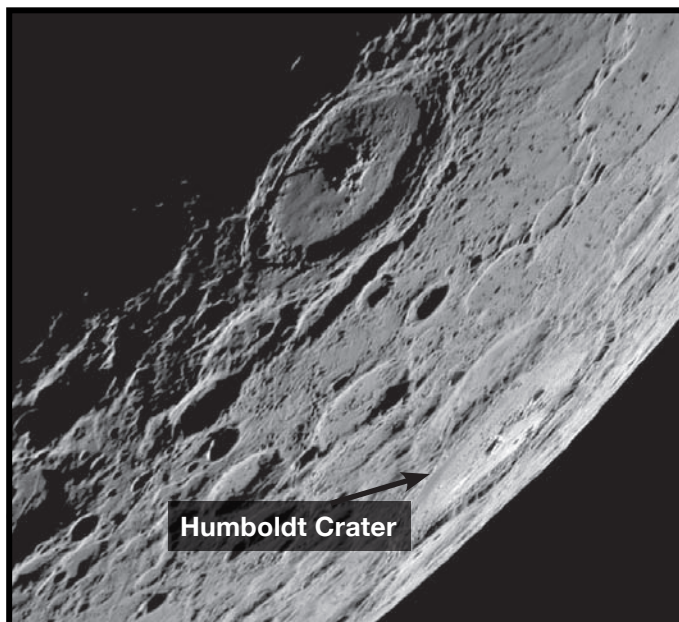
5. Once you have identified the location, list three distinct geologic features you can see within these magnified images:
  - a.
  - b.
  - c.
  
6. Using the information you noted on the image, list what you think the geologic history might have been in this area:

## LAB ACTIVITY PART 3

# Image Descriptions

### Orientele Basin Description:

It is over 3 billion years old, about 965 kilometers (600 miles) across and was formed by the impact of an asteroid sized object. The collision caused ripples in the lunar crust resulting in the three concentric circular features visible in this 1967 photograph made by NASA's Lunar Orbiter 4. Molten lava from the Moon's interior flooded the impact site through the fractured crust creating a mare. Dark, smooth regions on the Moon are called mare (Latin for sea), because early astronomers thought these areas might be oceans.



### Humboldt Crater Description:

Humboldt is a large lunar crater that is located near the eastern limb of the Moon. Due to foreshortening, this formation has an extremely oblong appearance. The actual shape of the crater is an irregular circle, with a significant indentation along the southeastern rim where the prominent crater Barnard intrudes. The rim of Humboldt is low, worn, and irregular in outline. The central peak forms a range on the crater floor. The floor surface contains a network of clefts forming a pattern of radial spokes and concentric arcs. There are also some dark patches located northwest, and southeast. There is a chain of craters as long as the crater is wide. This formation is designated



## LAB ACTIVITY PART 4

Name \_\_\_\_\_

## Image comparisons: looking for water

In this activity, you will be making comparisons between permanently shadowed areas and areas that are exposed to sunlight during part of the Moon's rotation.

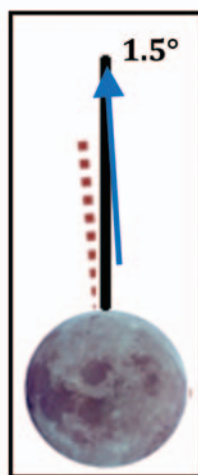
**Materials:**

- Worksheets that show 2 different images: the lunar south pole, and a sunlit area of the Moon (on next page).

**Background Information:**

The Moon is a unique environment because it has no atmosphere. As a result, the Moon is a relatively dry and hostile environment. During the daytime on the Moon, the temperatures can soar to  $123^{\circ}\text{C}$ , and at night can dip as low as  $-233^{\circ}\text{C}$ . Water freezes at  $0^{\circ}\text{C}$  and boils at  $100^{\circ}\text{C}$ , so as you can see, this environment makes it difficult for water to remain on the surface for any length of time.

The only way water could be found in such a barren environment would be if it were sheltered from the elements. Make a list of the places you might find water on the Moon:



Like other planetary bodies in the solar system, the Moon has an axis. The Moon also rotates on this axis; however its axial tilt is much different than Earth's. Earth has an axial tilt of  $23^{\circ}$  while the Moon only has an axial tilt of  $1.5^{\circ}$ . Because the Earth is tilted at such an angle, we experience seasons and both the North and South poles receive direct sunlight at least for part of the year. This causes the poles to expand and contract with the changing of the seasons.

The Moon on the other hand rotates almost straight up and down, meaning it hardly has any axial tilt. Because of this, parts of the poles have never seen the light of day! This creates an interesting environment. In a place that experiences  $350^{\circ}$  temperature differences between night and day, the lunar poles remain VERY cold.



Now that you have made a list of the areas that may provide an environment for water, let's compare a couple of images of the surface of the moon that could help identify locations for finding water.

Compare the two images below. What is the same and what is different?

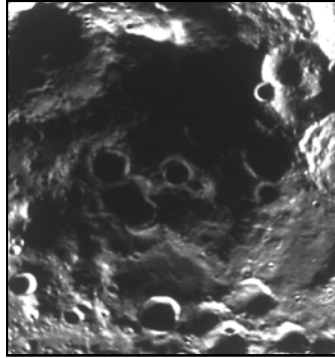


Image 1 — south pole

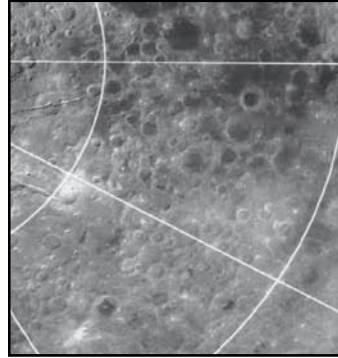


Image 2 — sunlit area

**Same:**

**Different:**



## LAB ACTIVITY PART 5

# Looking for Water

Name \_\_\_\_\_

Next, we will test your skills on being able to find “anomalous” craters at the north pole of the Moon.

### Materials:

- Red and Blue dry erase markers
- “Mini-SAR CPR map” image (see supplemental materials section)
- “Clementine Mosaic North Pole” image (see supplemental materials section)
- Clear overhead transparency
- Tape (blue painter’s tape works well)
- Lunar Landforms and Associated Images sheets (see supplemental materials section)

### Procedure:

1. Similar to what you did in the previous activity, compare the two images “Mini-SAR CPR map” image and the “Clementine Mosaic North Pole” image.
2. List three surface features you can see in the Mini-SAR image that you can’t see in the black and white mosaic image (pay no attention to the circles or arrows in the Mini-SAR image).
  - a.
  - b.
  - c.
3. Next, place a clean overhead transparency over the image “Mini-SAR CPR map” and one over the “Clementine Mosaic North Pole” image. Tape the corners with clear tape so the transparency doesn’t move.
4. Notice that in the “Mini-SAR CPR map” image, numerous craters are circled and some have arrows pointing to them.
5. Compare this image with the “Clementine Mosaic North Pole” image.
6. Identify five circles in the “Mini-SAR CPR map” and match them with the craters in the “Clementine Mosaic North Pole” image.
7. On the “Mini-SAR CPR map” use a blue dry erase marker to indicate “different” or “anomalous” craters, or craters that should look rough (white) but show up on the visible image as “smooth”, and use a red dry marker to indicate craters that don’t show any unusual pattern.

(continued on next page)



# worksheet

8. Of the five craters you chose, describe what you found and your reasons:

## Assessment:

As you have seen, utilizing radar data helps scientists to view hidden areas of the surface of a planet. Discuss with students:

- What are some additional ways planetary scientists might use radar imagery with the analysis of a planet?
- Are there other disciplines in science (biology, meteorology, oceanography, etc.) that can utilize radar images? In what ways?
- In your own words, can you define what is meant by high CPR and low CPR?

## Extension Activities:

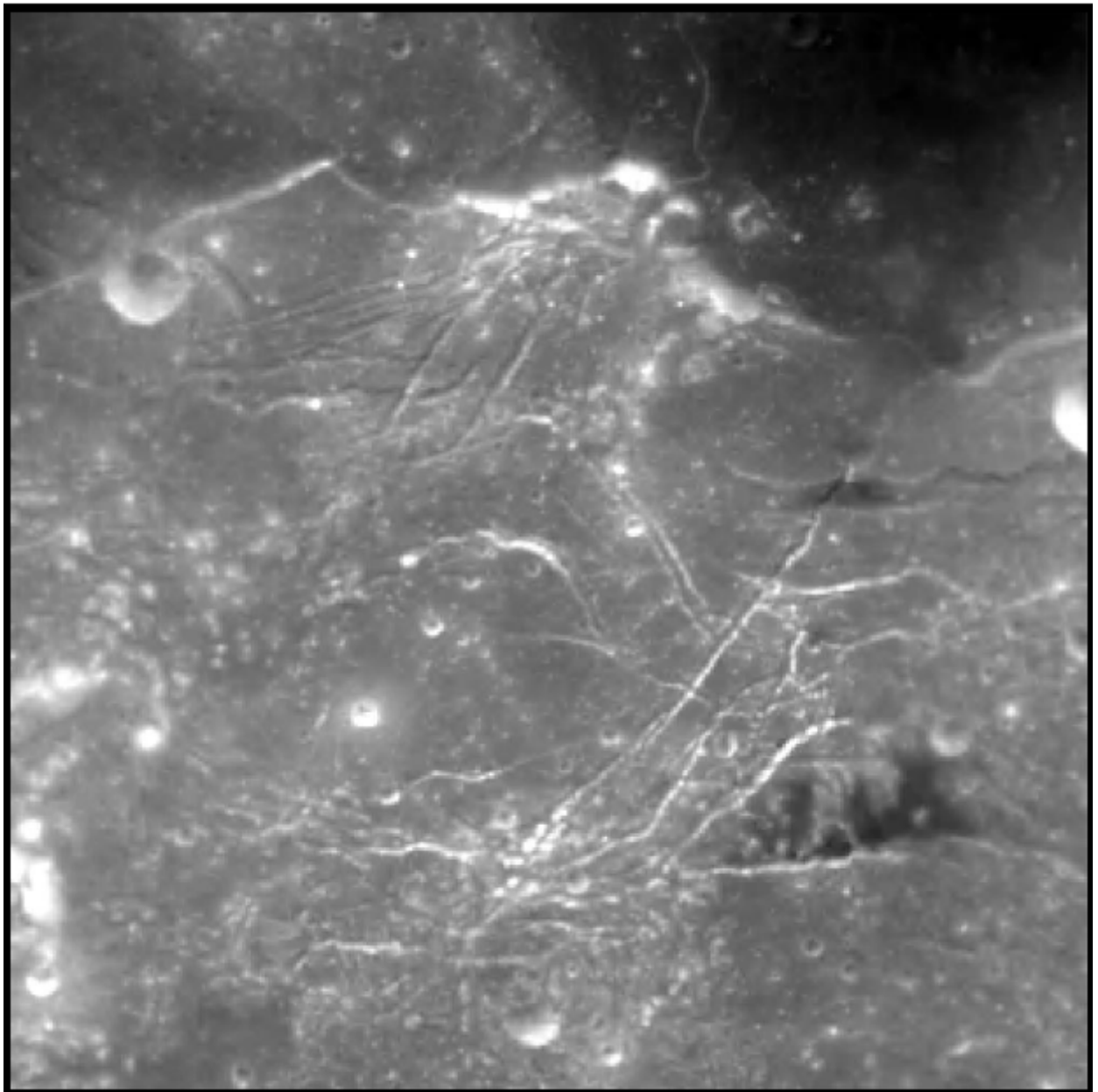
Use Google Earth or Google Maps in conjunction with NASA's "Visible Earth" ( <http://visibleearth.nasa.gov/> ) website to conduct additional analyses of images. Once on the "Visible Earth" website, follow the steps below to find radar images:

- Go to "sensor".
- Scroll down to the bottom and select "SIR-C/X-SAR." This will give you a list of the images that were taken using SIR-C radar imaging instrument. Have students identify where this image was taken, then locate it via Google Earth or Google Maps. Have the students compare both images and make notes as to what they can see or not see comparing radar and visible images of the same location.

---

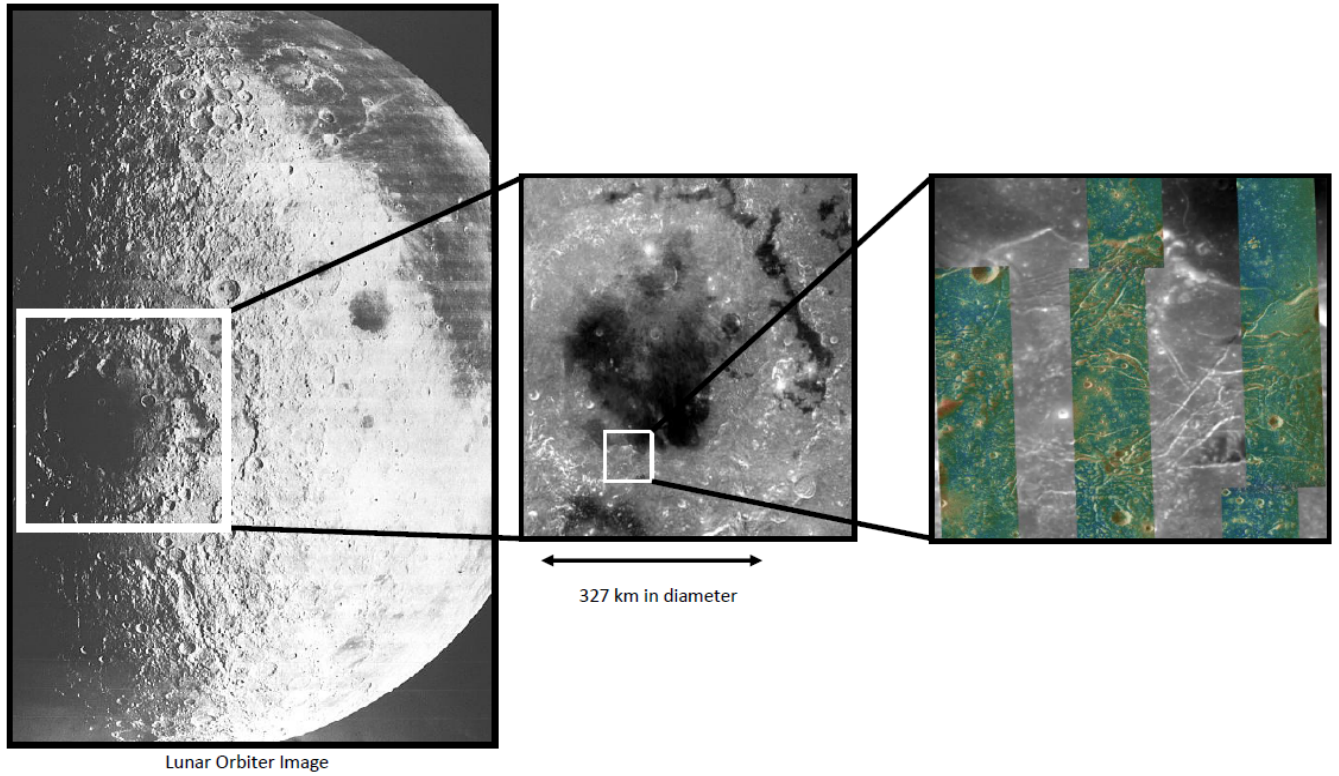
SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Oriente Basin

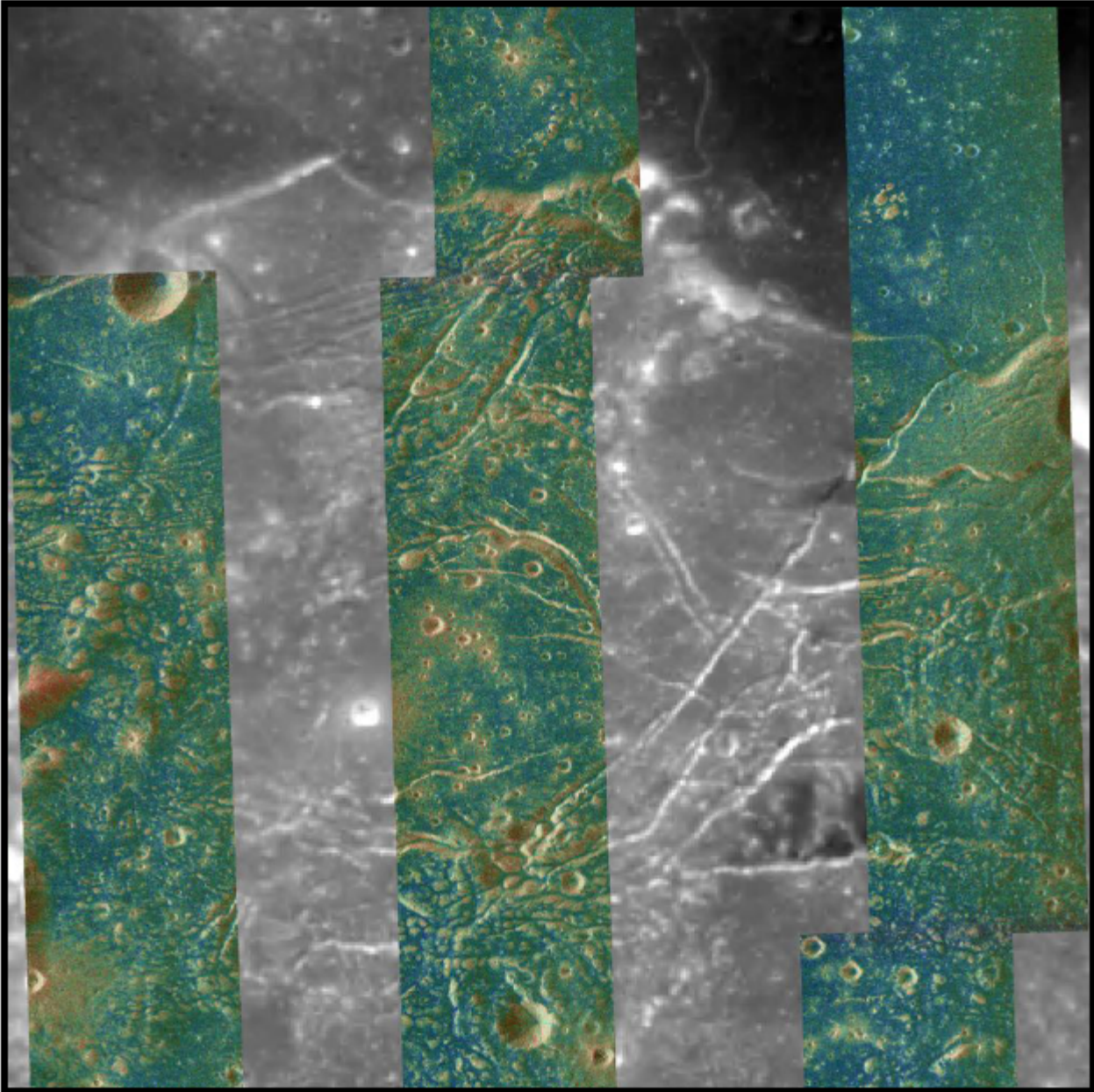


## Context for Orientale Basin

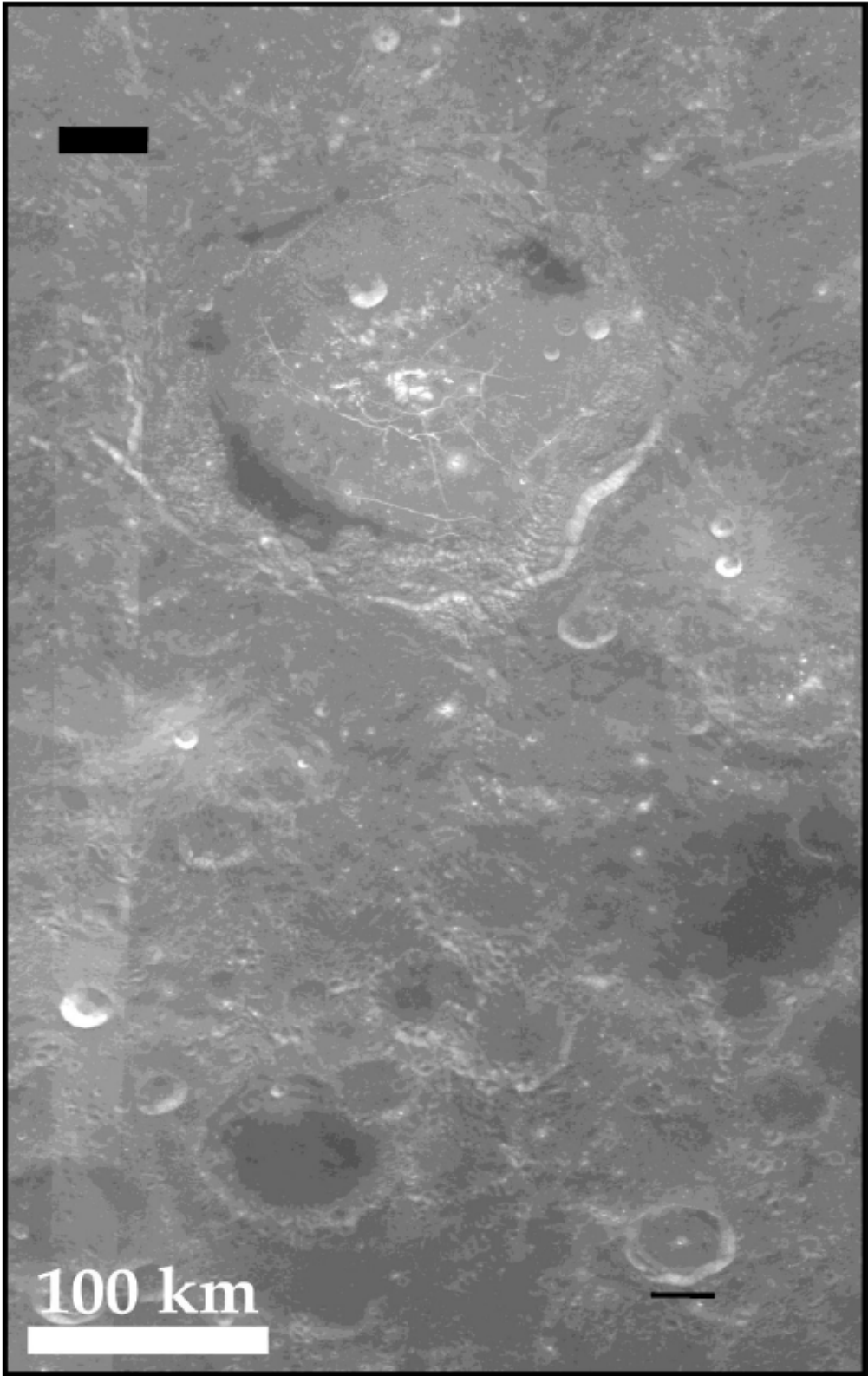
Like a target ring bull's-eye, the Mare Orientale is one of the most striking large-scale lunar features. Located on the Moon's extreme western edge, this impact basin is unfortunately difficult to see from an earthbound perspective.



Clementine Mosaic of Orientale Basin with Mini-RF Overlay

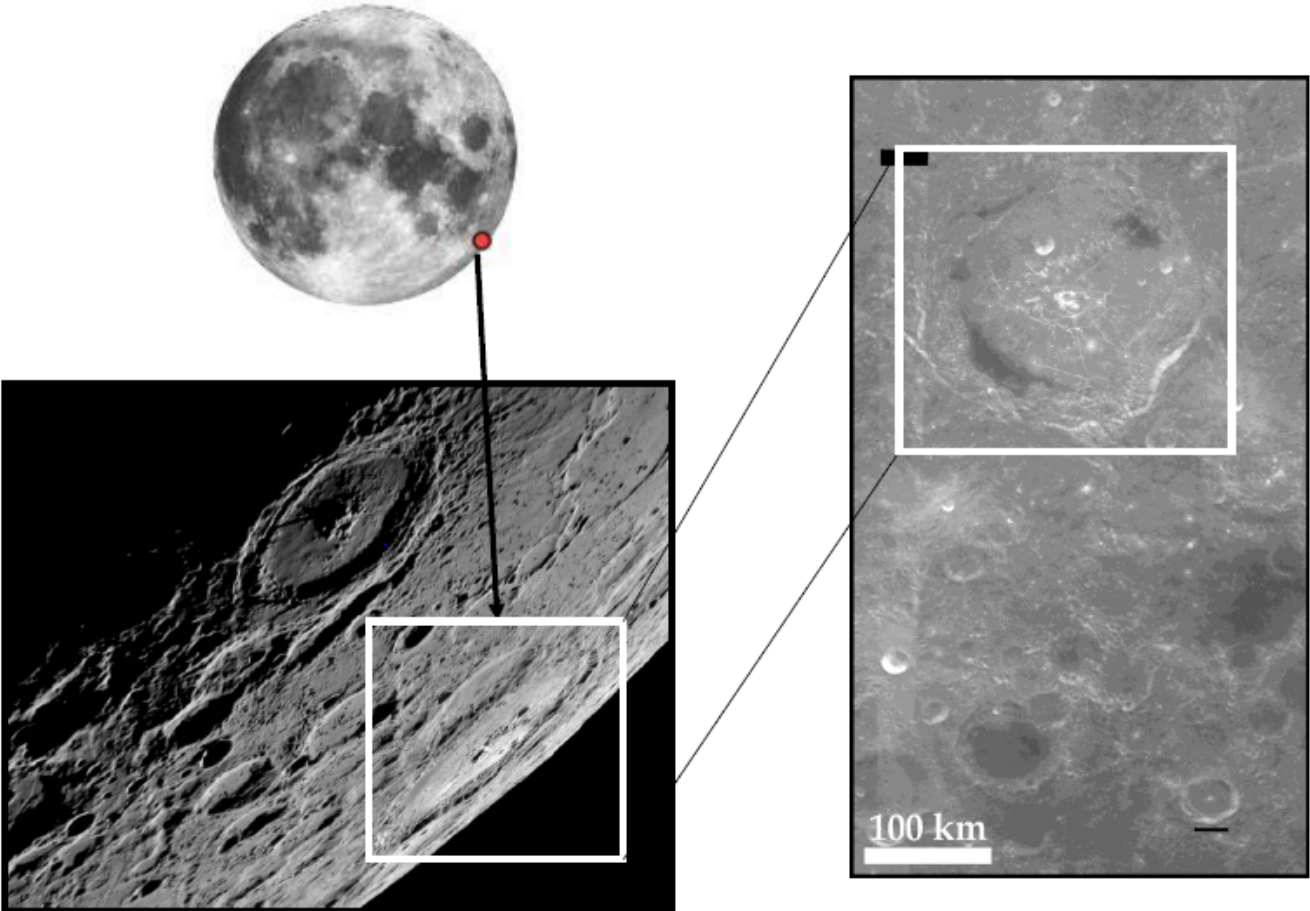


Clementine Mosaic—Humboldt Crater

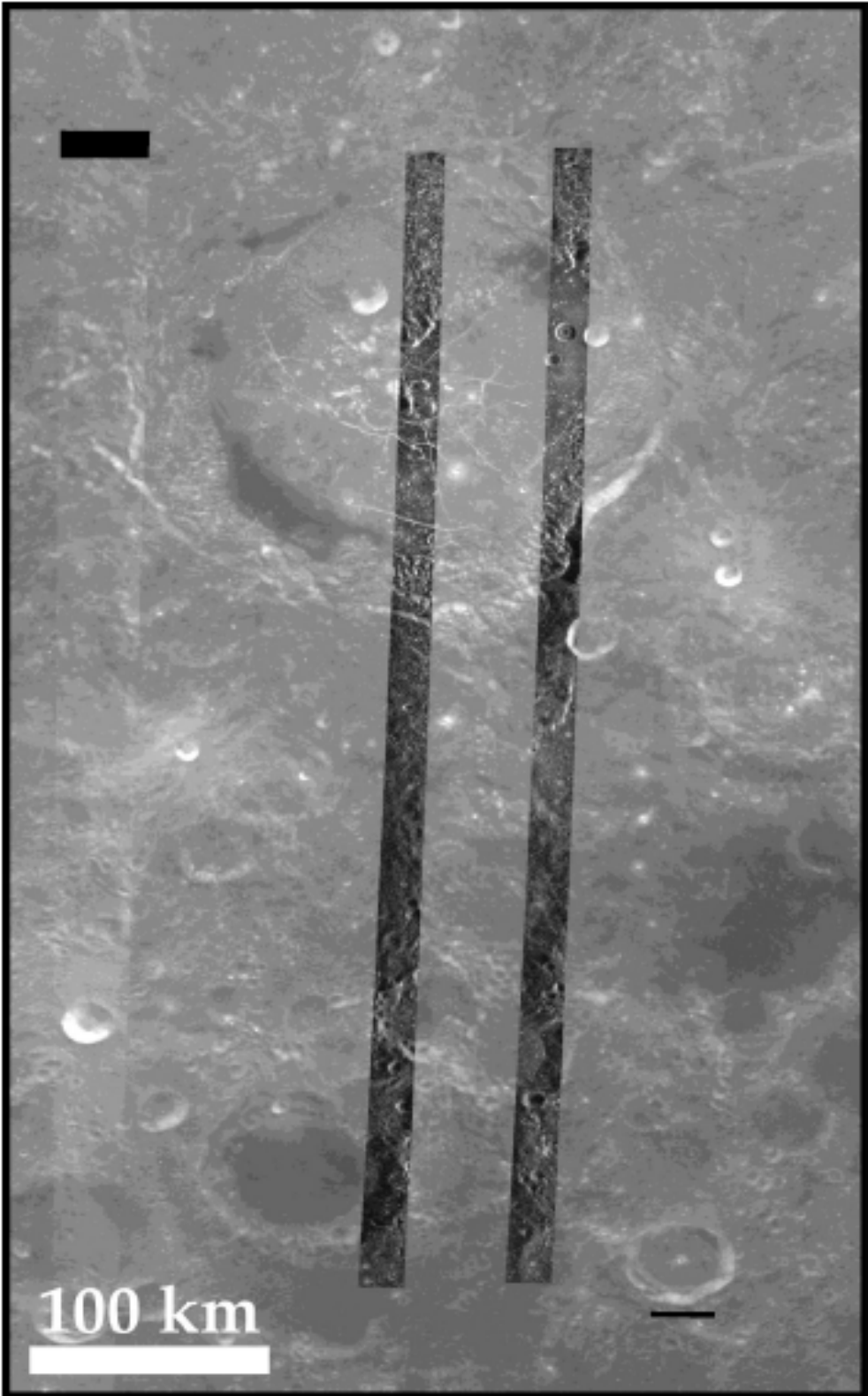




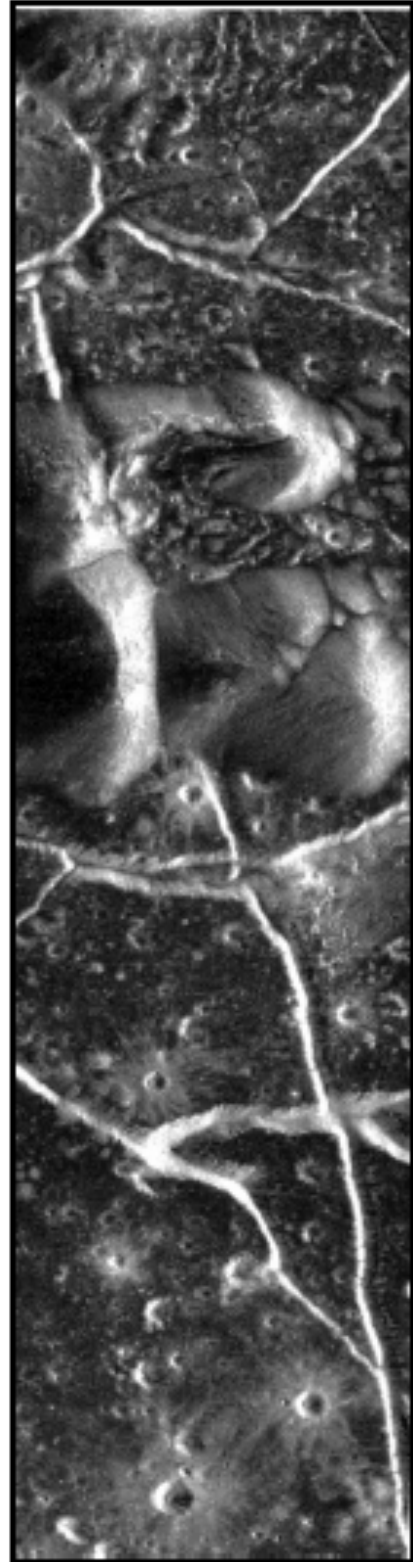
Context for Humboldt Crater



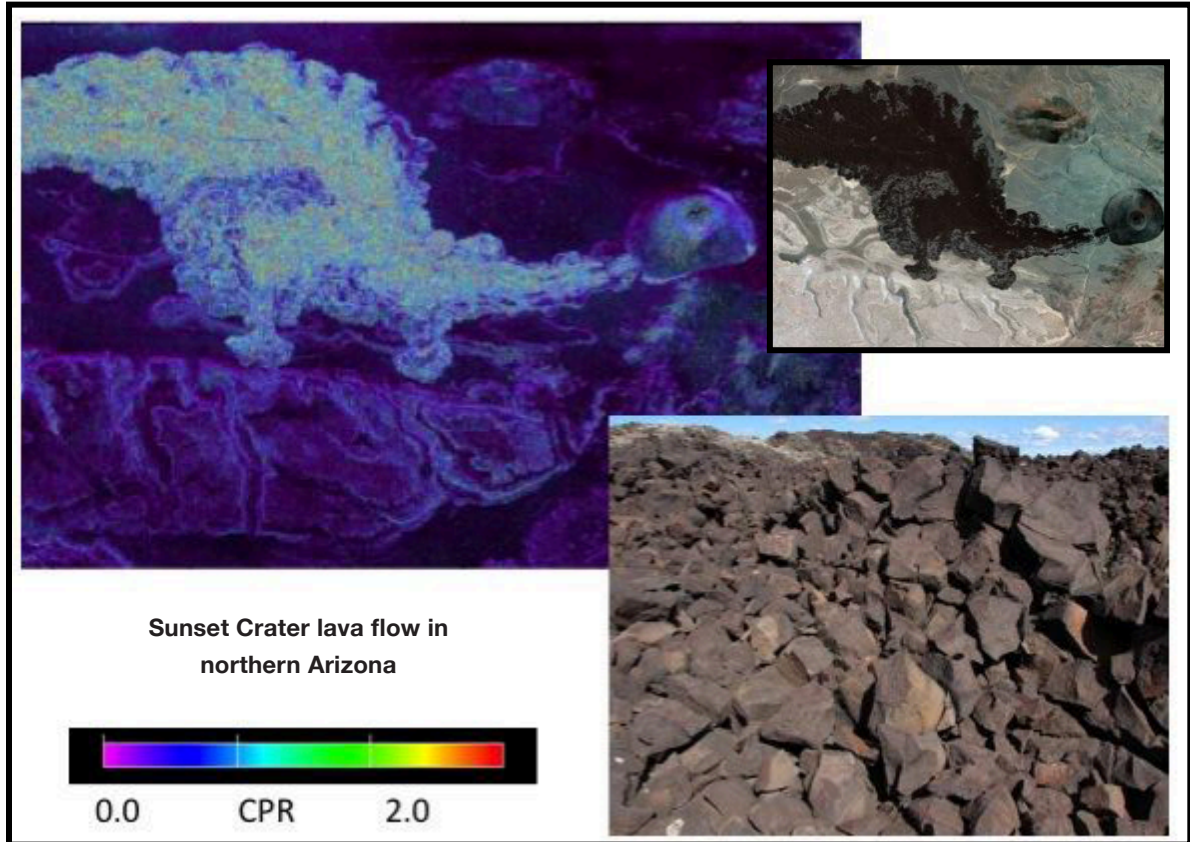
Clementine Mosaic with Min-RF overlay—Humboldt Crater



Mini-RF data Magnified—Humboldt Crater



## Image Interpretation



The image above shows a visible image on the right, and a false-color radar image to the left. False-color simply means that scientists have to add color to the data in the image so they can understand what the information is telling them.

It is difficult to tell in the visible image if the dark area is rough or smooth. But, using radar, we can see using the colored CPR bar at the bottom the surface is fairly rough. We can also confirm this in the close-up image of the same region in the lower right. This is a good example of remote sensing, a technique in which scientists, much like detectives, use satellite images in combination with surface images to piece together clues about a region without actually visiting the site.

## Lunar Landforms Information Sheet

Use this sheet to identify the different types of features found on the Moon:

**Central Crater Uplift:** mountain in the center of large (greater than 40 kilometer in diameter) impact craters.

**Cinder Cone:** a low, broad, dark, cone-shaped hill formed by an explosive volcanic eruption.

**Crater Ejecta:** material thrown out from and deposited around an impact crater.

**Dome:** a low, circular, rounded hill, which is suspected to be a volcanic landform.

**Highlands:** the highlands appear as bright areas of the Moon. The highlands are comprised of countless overlapping craters (ranging from 1 meter to over 1000 meters) that formed when meteorites crashed into the Moon.

**Impact Crater:** a roughly circular hole created when something, such as a meteorite, struck the Moon's surface.

**Lava Flow:** a break out of magma from underground onto the surface.

**Maria:** areas that formed when lava flows filled in low places. The low places are mostly inside huge basins, which were formed by large meteor impacts. The maria cover 16% of the Moon's surface.

**Multi-Ringed Basin:** huge impact crater surrounded by circular mountain chains.

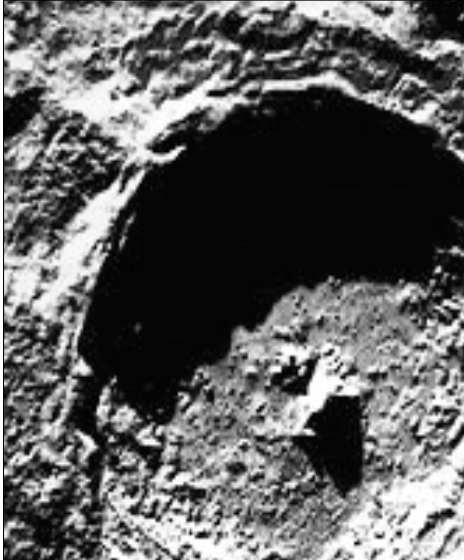
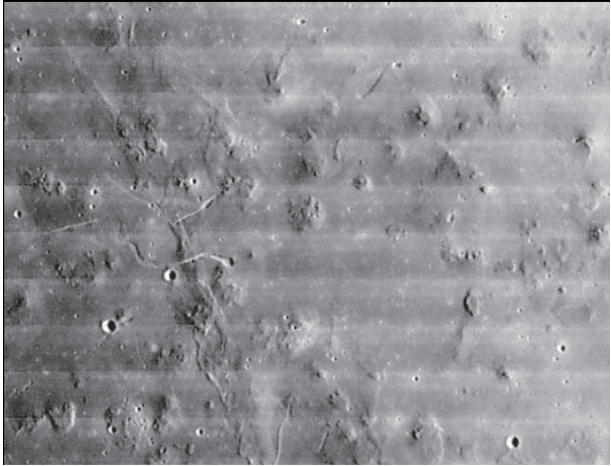
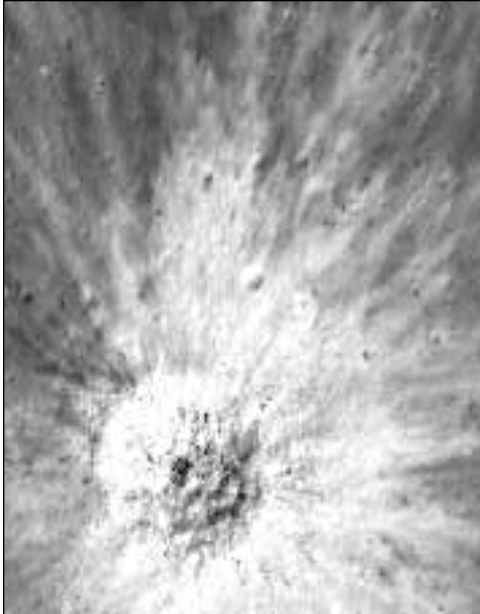
**Ray:** bright streak of material blasted out from an impact crater.

**Rille:** a channel in the lunar maria formed by an open lava channel or a collapsed lava tube.

**Terraced Crater Walls:** steep walls of an impact crater with "stair steps" created by slumping due to gravity and landslides.

**Wrinkle Ridge:** a long, narrow, wrinkly, hilly section in the maria.

## Lunar Landform Definitions and Associated Images

| Definition   | Picture example  |
|--|--|
| <p><b>Central crater uplift:</b><br/>Mountain in the center of large (greater than 40 kilometer in diameter) impact craters.</p> |    |
| <p><b>Cinder cone:</b><br/>A low, broad, dark, cone-shaped hill formed by an explosive volcanic eruption.</p>                    |   |
| <p><b>Crater ejecta:</b><br/>Material thrown out from and deposited around an impact crater.</p>                                 |  |

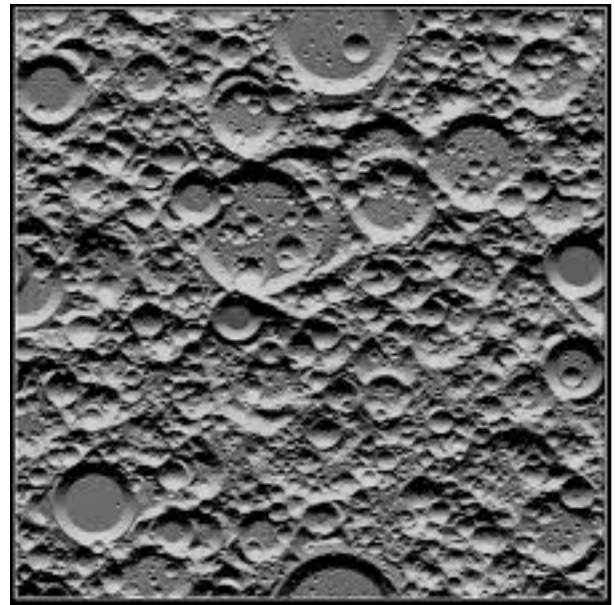
**Dome:**

A low, circular, rounded hill which is suspected to be a volcanic landform.



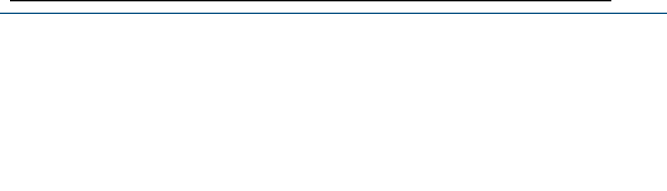
**Highlands:**

The highlands appear as bright areas of the Moon. The highlands are comprised of countless overlapping craters that formed when an impactor crashed into the Moon.



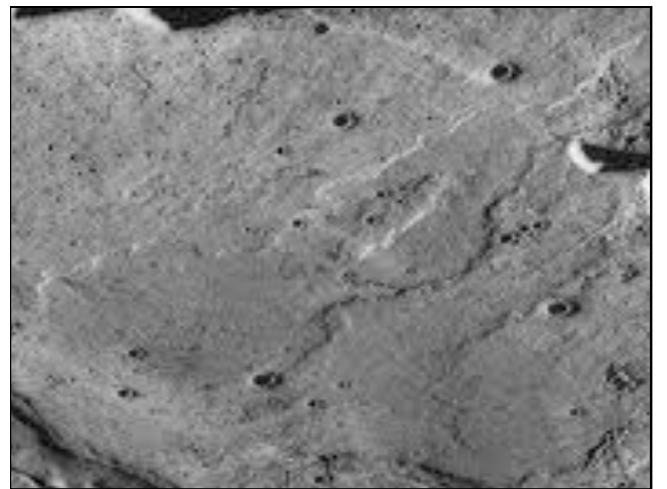
**Impact crater:**

A roughly circular hole created when something, such as a meteorite, struck the Moon's surface.



**Lava flow:**

A break out of magma from underground onto the surface.



**Maria:**

Areas that formed when lava flows filled in low places. The low places are mostly inside huge basins which were formed by large meteor impacts. The maria covers 16% of the Moon's surface.



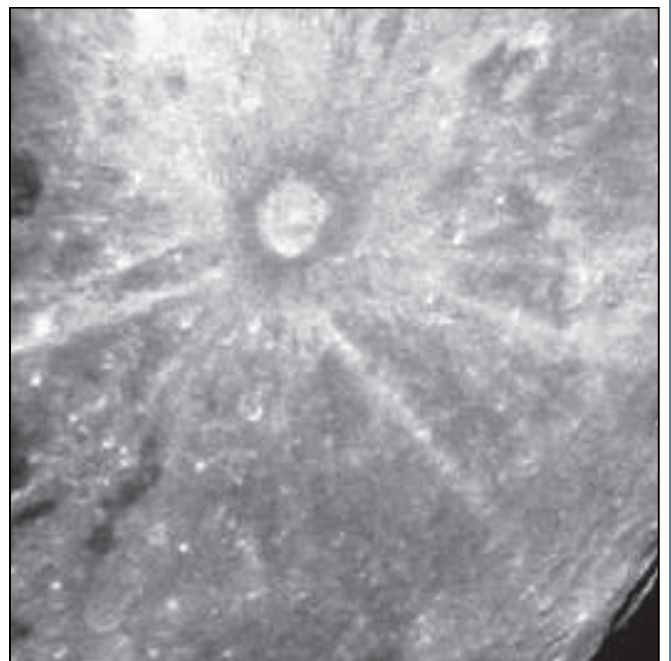
**Multi-ringed basin:**

Huge impact crater surrounded by circular mountain chains.



**Ray:**

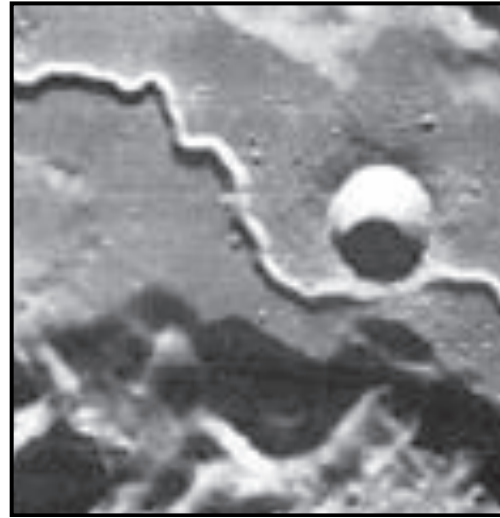
Bright streak of material blasted out from an impact crater.





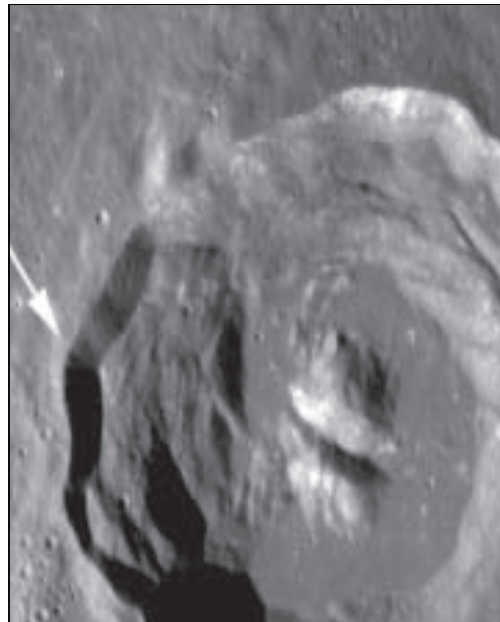
**Rille:**

A channel in the lunar maria formed by an open lava channel or a collapsed lava tube.



**Terraced crater walls:**

Steep walls of an impact crater with “stair steps” created by slumping due to gravity and landslides.



**Wrinkle ridge:**

A long, narrow, wrinkly, hilly section in the maria.



# Mini-SAR CPR map

