Activity One: Choose Your Landing Site

Educator Notes

Learning Objectives

This activity provides Site Information sheets and guiding questions to give students an opportunity to compare and contrast various lunar landing sites for suitability as a potential base camp for humans, considering factors such as geology, resources, communication with Earth, and average surface temperatures to determine the most suitable landing site.

Students will utilize the scientific research process to

- Construct an evidence-based argument about which site is most suitable based on NASA data.
- Convert temperatures from kelvin to Fahrenheit.
- Perform calculations such as surface area and volume in support of their argument.

Investigation Overview

Students are asked to select an appropriate human landing site on the Moon using NASA topographic maps and data. They must consider that different lunar locations will have different resources and conditions. Students must weigh the benefits versus the risks to select the best landing site.

Suggested Pacing

1 to 2 hours

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. *Crosscutting Concepts* • Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between quantities as scales change. • Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. *Science and Engineering Practices* • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.	*Science and Engineering Practices (continued)* • Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. • Engaging in Argument From Evidence: Argumentation is the process by which explanations and solutions are reached. • Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* • Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH.CONTENT.7.G.B.6: Solve real-world and mathematical problems involving area, volume, and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms. (Extension Exercise)	*Content Standards by Domain (continued)* • CCSS.MATH.CONTENT.8.G.C.9: Know the formulas for the volumes of cones, cylinders, and spheres and use them to solve real-world and mathematical problems. (Extension Exercise)

Activity Preparation

The educator should

- Read the introduction and background information, Educator Notes, Lunar Map, five Site Information sheets, and Moon Matrix and Temperature Conversion Worksheet to become familiar with the investigation.
- Print the Site Information sheets for each team (preferably on cardstock paper, or have the sheets laminated).
- Print the Lunar Map for each team (preferably on cardstock paper, or have the sheets laminated).
- Print the Moon Matrix and Math Extension Worksheet for each student.
- Prepare five landing site stations in the room, one station per landing site. Each station should have one Site Information sheet and markers, colored dot stickers, or colored sticky notes for the "Go," "No Go," or "Need More Data" categories (e.g., use a green marker or sticker for "Go," red for "No Go," and yellow for "Need More Data").

Materials

For each team (3 to 5 students):

- Moon and Matrix Temperature Conversion Worksheet for each student
- Full-color Lunar Map of the lunar South Pole with marked landing sites
- Access to a computer or tablet for creation of final presentation or for extension activity using the Moon Trek website at https://trek.nasa.gov/moon/#v=0.1&x=0&y=0&z=1&p=urn%3Aogc%3Adef%3Acrs%3AEPSG%3A%3A104903&d=&locale=&b=moon&e=-269.999994963537%2C-126.91406013260008%2C269.999994963537%2C126.91406013260008

For each lunar landing site station (up to 5):

- Site Information sheets (on cardstock paper)
- Markers, dot stickers, or sticky notes in three different colors

Safety

Ensure students take their time moving between landing site stations to prevent accidents.

Introduce the Investigation

Inform students that they will be selecting an appropriate landing site on the South Pole of the Moon using NASA topographic maps and data. Remind students that each landing site has different types of resources and advantages versus disadvantages. Review the following selection criteria:

Selection Criteria
Students must pick only one landing site located on the lunar South Pole.
Students must weigh the benefits versus the risks of a landing site that contains resources for astronauts.
Students must justify a site where there are sufficient resources.

Facilitate the Investigation

Pose Question

Give students the following scenario:

> You have been told that you are going on a field trip far away from home for the weekend to learn about ecosystems. You know that the place is in a rural area, the weather will be warm, and you will be surrounded by a swamp. What items would you take with you to be comfortable?

Create a graphic organizer with students' responses.

Develop Hypothesis

Explain that astronauts will live in the crew cabin of the human landing system while they are on the Moon's surface.

- Have students think about what they know about the basic needs of humans. What resources will astronauts need to bring with them, and what could they find on the surface?
- Have students look at the Lunar Map with the five predetermined landing sites. Based on the teams' discussion about human needs and resources, they should choose a site they believe will meet most of the needs they have discussed.
- If students are having difficulty formulating a testable hypothesis, provide them with the following prompt: "I predict the best location is going to be ______, because _______."

Plan Investigation

- After setting up stations with the additional information for each of the five landing sites, randomly assign each team to one of the five sites.
- Students will look through the Site Information sheets to make an informed decision about their choice for a suitable landing site.
- Discuss the following priorities that NASA requires of a landing site:
    1. Access to sunlight for long periods of time. The temperature of the Moon drops significantly when in shadow.
    2. Direct view of Earth. This will help prevent communications disturbances.
    3. Surface conditions and slopes that are safe for landing systems and for robotic and astronaut travel.
    4. Access to permanently shadowed regions where water ice and other compounds are located. Astronauts may be able to utilize water ice and resources in the depths of these ancient craters that have been untouched throughout time.

Assemble Data

- Using the Moon Matrix and Temperature Conversions Worksheet, each student will record pertinent data from all five sites that will aid in making an informed decision about the most suitable landing site. Students will then discuss their individual findings in their teams.
- Before giving students the Temperature Conversions Worksheet, a concept review of negative numbers may be necessary.
- Ask student teams to rotate through all five landing stations and look through the Site Information sheets.

Analyze and Document Conclusions

- After each team visits and records data from all five of the landing stations, have students discuss their findings and determine which landing site their team agrees is the most suitable.
- Students should compare their final decision with their original hypothesis.
- Each team should mark their chosen site on the Lunar Map and defend their selection by answering the question posed on the Moon Matrix handout.

Share With Students

Brain Booster

The pressure suits worn by the Apollo astronauts greatly restricted their mobility while working on the Moon, including their ability to bend over. To aid the astronauts, special tools were designed to allow them to collect rocks and soil samples to take back to Earth for study. These sample collection sites were carefully planned out prior to the start of each mission as well. Artemis astronauts will wear new spacesuits designed for greater mobility and enhanced communications. Explore the Apollo photo gallery for images of lunar excavation tools and check out NASA's Suit Up page for more about the Artemis Generation spacesuit.

Learn more:
https://www.flickr.com/photos/projectapolloarchive/albums
https://www.nasa.gov/suitup

On Location

Take a field trip to the Moon! Explore human landing sites, robotic missions, geography, and more with this interactive website. Investigate the Moon with your students and learn about other valuable resources, the current phase and temperature of the Moon, and much more.

Learn more:
https://moon.nasa.gov/

Present Findings

Student teams can present their findings and conclusions to the whole group in a variety of ways, depending on the amount of time remaining. Suggestions include a debate, a question-and-answer session, or travel advertisements. Regardless of the format, presentations should be made using computer software or video. Ensure that whatever method is chosen for the discussion, students defend their choices using hard data and logical reasoning.

- What are the advantages/disadvantages of the site you have chosen?
- What resources are available to the astronauts at your landing site?
- Did you obey all the selection criteria for this activity?
- How did your calculations inform your decision?
- Was your final decision the same as your prediction?
- Do you have enough supporting evidence that NASA would agree with the site your team has chosen?
- How would you generate a rating system to make sure that the site picked will ensure success for the mission?

Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions and Differentiations

- Using the Moon Trek application (see References), guide students to generate a three-dimensional (3D) profile of their landing site and create a model to be printed on a 3D printer.
- Conduct a lesson on creating topographical maps. https://spaceplace.nasa.gov/topomap-clay/en/
- Use the Math Extension Worksheet for an increased emphasis on math.
- Print directions to help students who may need additional structure for this activity.

Reference

Mission Moon Activity
https://www.lpi.usra.edu/education/explore/LRO/activities/mission_moon/

Resource

Moon Trek Website
https://trek.nasa.gov/moon/#v=0.1&x=0&y=0&z=1&p=urn%3Aogc%3Adef%3Acrs%3AEPSG%3A%3A104903&d=&locale=&b=moon&e=-224.99999580294752%2C-106.52343551295796%2C224.99999580294752%2C106.52343551295796

Activity One: Choose Your Landing Site

Student Handout

Your Investigation

You will select an appropriate landing site for astronauts on the South Pole of the Moon by using NASA topographic maps and data to compare resources and conditions at five locations for a potential base camp for humans.

Selection Criteria
You must pick only one landing site located on the lunar South Pole.
You must weigh the benefits versus the risks of a landing site that contains resources for astronauts.
You must justify a site where there are sufficient resources.

Pose Question

NASA is exploring the South Pole region of the Moon.

- What resources would astronauts living on the Moon need to survive? Use what you know about basic human needs to defend your answers.

Develop Hypothesis

Astronauts will live in the crew cabin of the human landing system while they are on the Moon's surface.

- Look at the Lunar Map, which shows five predetermined landing sites on the lunar South Pole. Based on your team's discussion about human needs and resources, choose a site your team believes will meet most of the needs you have discussed.
- Having access to persistently shadowed areas and regions of extremely cold temperatures of the Moon is very important for scientific exploration.
- If you are having difficulty formulating a hypothesis, you can use the following prompt: "I predict the best location is going to be ______, because _______."

Plan Investigation

You will randomly be assigned to begin at one of the five landing stations. You will use the Site Information sheets and the Moon Matrix sheet to help you make an informed decision about your hypothesis after visiting all five landing stations.

- There are a few priorities that NASA requires of a landing site:
    1. Access to sunlight for long periods of time
    2. Direct view of Earth to help with communications
    3. Surface conditions and slopes that are safe for landing systems and for robotic and astronaut travel
    4. Access to permanently shadowed regions where water ice and other compounds are thought to be located

Fun Fact

The Lunar Flashlight is the first CubeSat that will reach the Moon using green propulsion, which is less toxic and more efficient than traditional fuels. This very small spacecraft will be launched on the Space Launch System as part of the Artemis I mission. The Lunar Flashlight will map the lunar South Pole for volatiles, like water ice and other compounds, and will use lasers to look for water ice.

Learn more: https://www.jpl.nasa.gov/cubesat/missions/lunar_flashlight.php

Career Corner

Adriana Ocampo is a scientist at NASA Headquarters. Adriana was born in Colombia and raised in Argentina, and her family moved to the United States when she was 14. As a planetary geologist, Adriana studies how planets, moons, and asteroids form and evolve over time. She started her career by volunteering at the Jet Propulsion Laboratory after her junior year of high school. Her current job allows her to work on many NASA missions.

Adriana Ocampo

Learn more: https://solarsystem.nasa.gov/people/1780/adriana-ocampo/

Assemble Data

- Using the Moon Matrix and Temperature Conversions Worksheet, you will record data from each of the five stations that will aid you in making an informed decision about the most suitable landing site.
- The Temperature Conversions Worksheet will allow you to convert temperatures from kelvin to Fahrenheit.
- You will rotate through all five landing stations and look through the Site Information sheets for data.
- You will mark the landing site as “Go,” “No Go,” or “Need More Data” using the colored dots or markers provided.

Analyze and Document Conclusions

- Explain to your team the details you have found about the different landing sites.
- Defend the landing site you have chosen based on the data you have gathered from each station.
- Decide as a team what landing site you will pick. Mark the site on your Lunar Map and list the reasons why the team selected this site.
- Compare your final decision with your original hypothesis.

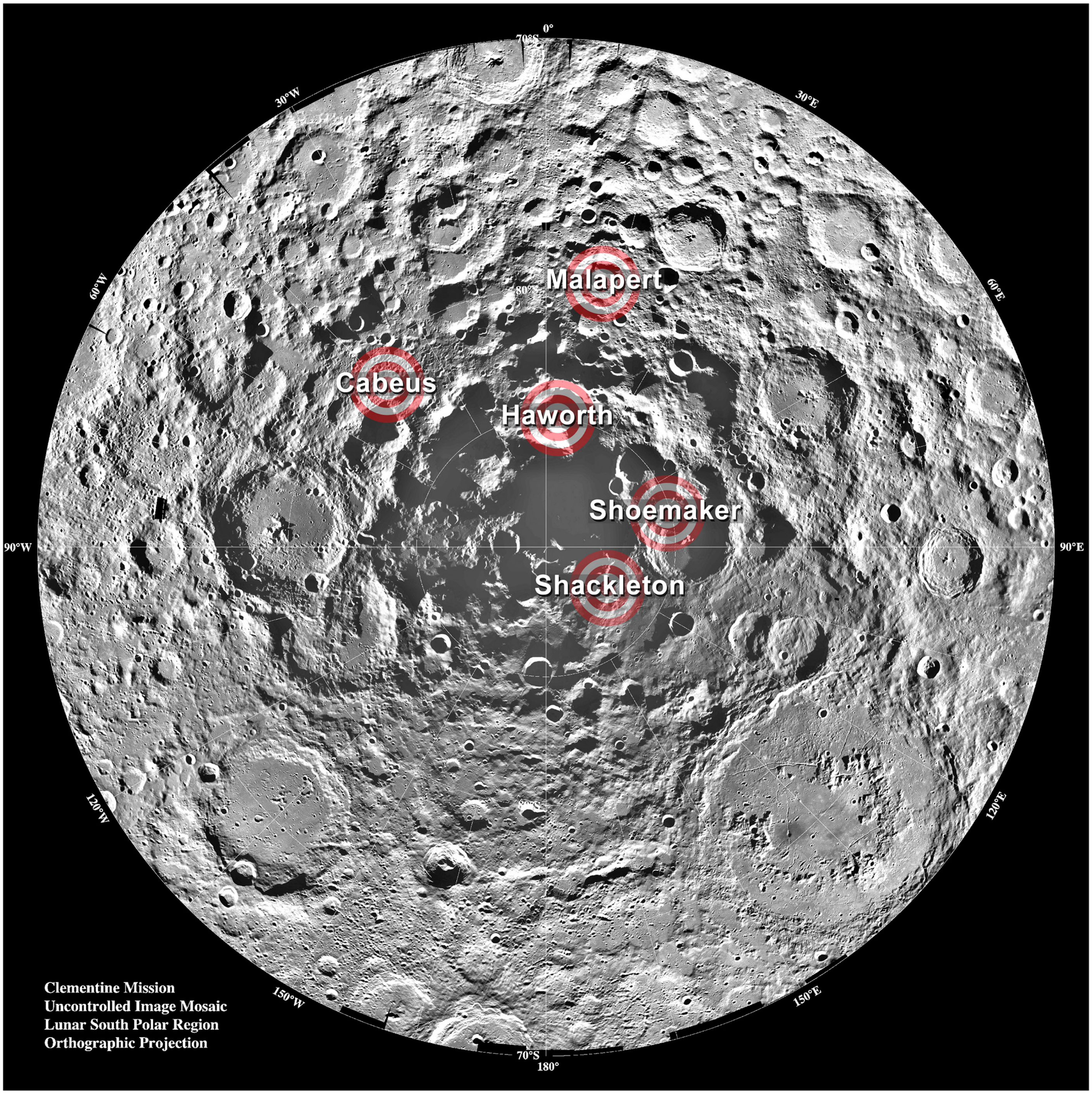
Present Findings

You have been provided instructions for presenting your findings. As you present why you chose your landing site, be sure to answer the following questions:

- What are the advantages/disadvantages of the site you have chosen?
- What resources are available to astronauts at your landing site?
- Did you obey all the selection criteria for this activity?
- How did your calculations inform your decision?
- Was your final decision the same as your prediction?
- Do you have enough supporting evidence that NASA would agree with the site your team has chosen?
- How would you generate a rating system to make sure that the site picked will ensure success for the mission?

Lunar Map

Directions: Mark your chosen lunar outpost location. On the Moon Matrix sheet, list the reasons why your team selected this site.



Site Information: Cabeus

Water and Other Resources

- Contains volatile compounds such as methane, ammonia, and hydrogen gas
- Metals such as sodium, mercury, and silver can also be found here

Topography

- Flat floor with gentle slopes and an absence of large boulders
- Significant areas of permanent shadows
- Diameter: 100 km
- Depth: 4 km
- Shadowed area: 900 km^2

Temperature

- Extremely cold temperatures that range from 41 to 50 K

General Science

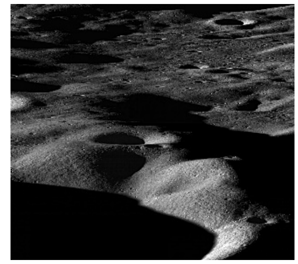
- Concentrations of hydrogen detected by NASA's Lunar Prospector spacecraft
- 5.6 percent of the total mass inside Cabeus is water ice
- Centaur rocket impact site for the Lunar CRater Observation and Sensing Satellite (LCROSS) experiment

Illumination

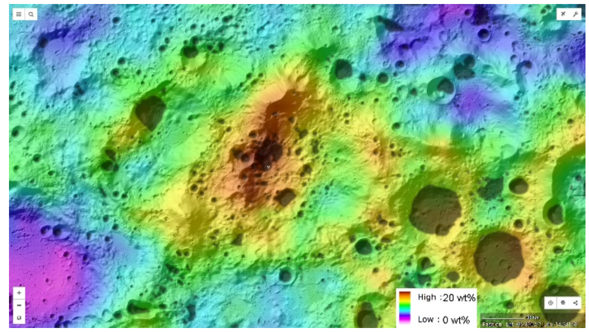
- Cabeus is illuminated 1/4 of the Moon's day

Special Considerations

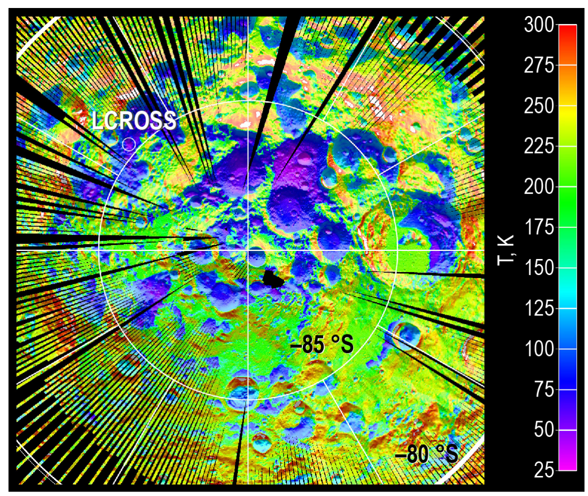
- A significant portion of the crater's floor is permanently shadowed
- Crater contains water ice and dry ice (frozen carbon dioxide)
- Can be seen from Earth
- The compounds that exist in the crater are the same as those in icy comets



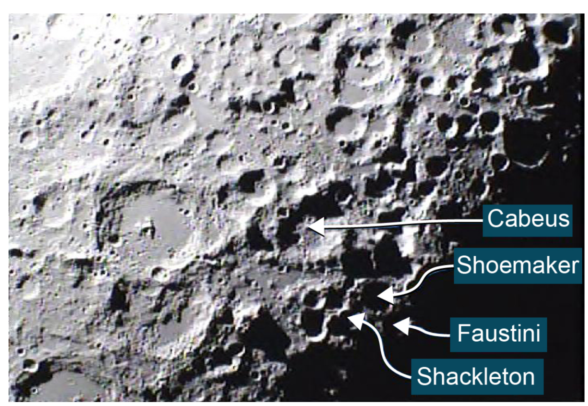
Lunar Reconnaissance Orbiter image of the northern rim of Cabeus. (NASA)



Cabeus region showing the highest concentrations of hydrogen depicted in orange. (NASA)

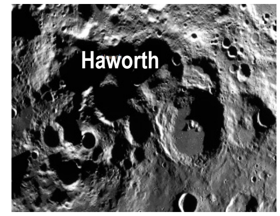


Temperature map of lunar South Pole showing impact site of Centaur rocket for Lunar CRater Observation and Sensing Satellite (LCROSS) experiment. (NASA)



Lunar CRater Observation and Sensing Satellite (LCROSS) visible light camera from altitude of approximately 770 km. (NASA)

Site Information: Haworth



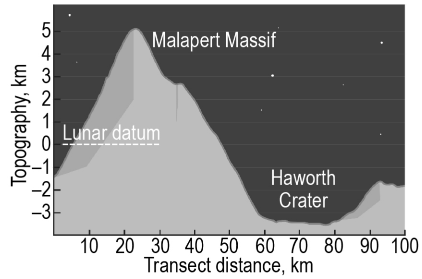
Moon Trek image of Haworth. (NASA)

Water and Other Resources

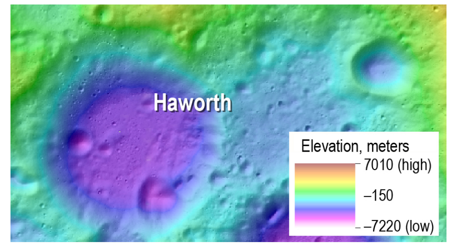
- Water-equivalent hydrogen is 0.15 percent

Topography

- Diameter: 52 km
- Lunar mountains are called *massifs*. There is a massif named Mons Malapert right next to Haworth. The elevation difference between them is close to the height of Mt. Everest!



Topography shows a change in elevation that exceeds 8 km. (NASA)



Elevation of Haworth in meters. (Lunar and Planetary Institute, Houston, Texas)

Temperature

- Extremely cold temperatures that rarely exceed 40 K

General Science

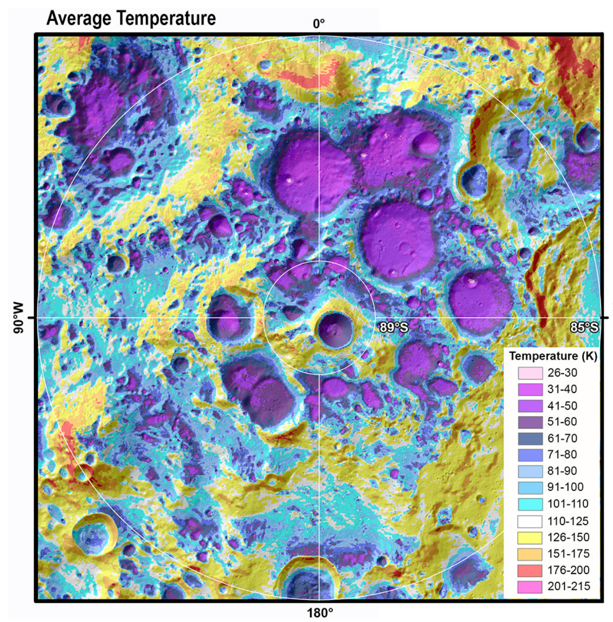
- Low hydrogen content
- Large areas of crater are permanently shadowed
- The only way this crater has been explored is by orbital imaging radar

Illumination

- Nearly always in permanent shadow; not visible from Earth

Special Considerations

- This crater has a large amount of surface frost.
- The map below shows the slope of various craters, including Haworth.



Average temperature of the Haworth crater area in kelvin (K). (Lunar and Planetary Institute, Houston, Texas)

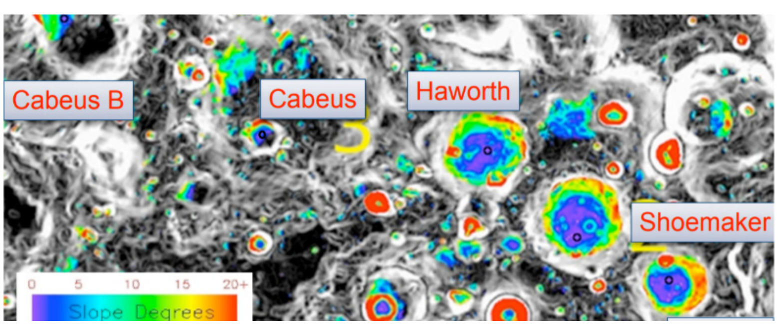
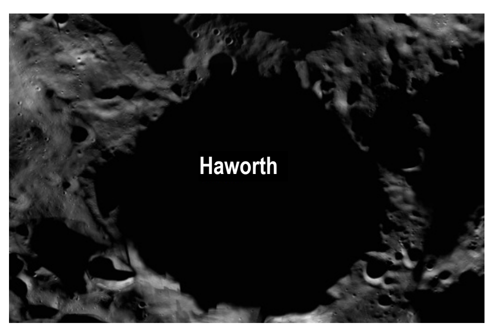


Image showing degrees of slope of Haworth and other craters. (NASA)



Closeup image of Haworth from Moon Trek application. (NASA)

Site Information: Mons Malapert

Lunar South Pole visualization using Lunar Reconnaissance Orbiter data. (NASA)

Water and Other Resources

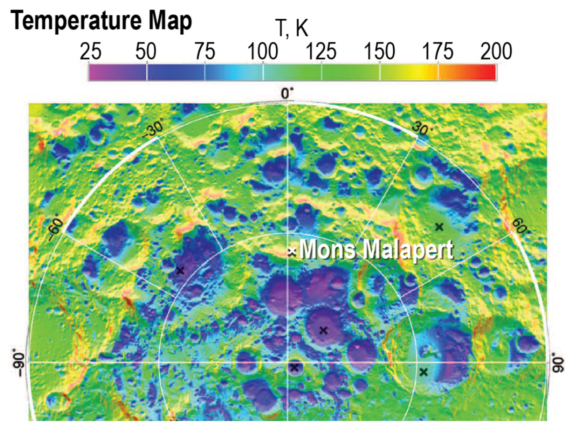
- Enriched iron content
- High hydrogen concentrations

Topography

- A 5-km-high mountain with a long, flat plain at its base
- Slope range is from 6° to 30°

Temperature

- Average temperature is 175 K



Average temperature (T) for Mons Malapert in kelvin (K). (NASA)

General Science

- Located near other permanently shadowed regions
- Located on rim of South Pole–Aitken basin, Moon's largest impact basin (diameter = 2,500 km); several craters in this basin may contain deposits of water ice

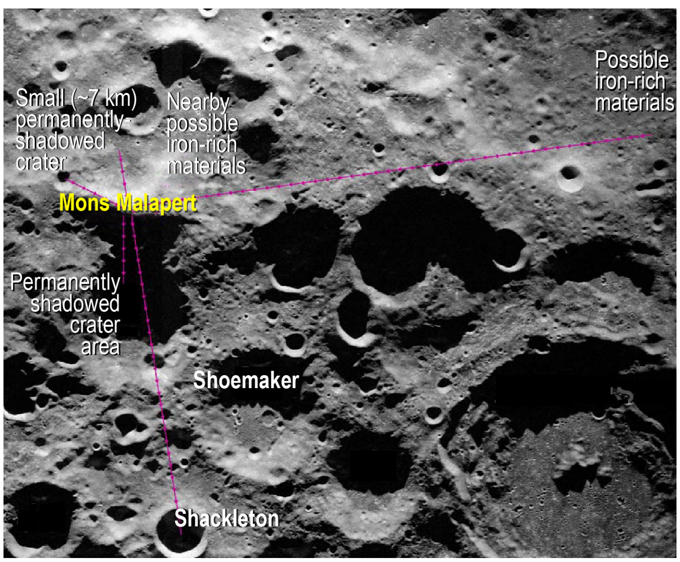


Image of region surrounding Mons Malapert. (NASA)

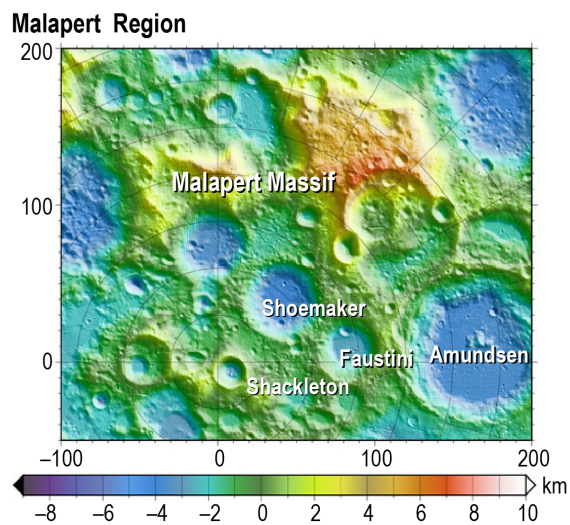


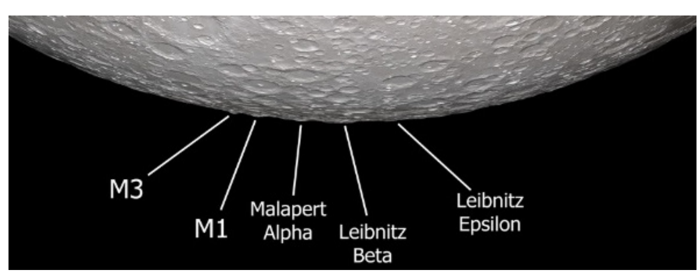
Image depicting elevation of the Malapert region. (NASA)

Illumination

- Receives full or partial sunlight 93 percent of the lunar year

Special Considerations

- Nearby craters like Shackleton
- Mons Malapert can be seen from Earth
- Exceptional visibility of Earth from peak



Five peaks near the lunar South Pole, visible in silhouette. (NASA)

Site Information: Shackleton

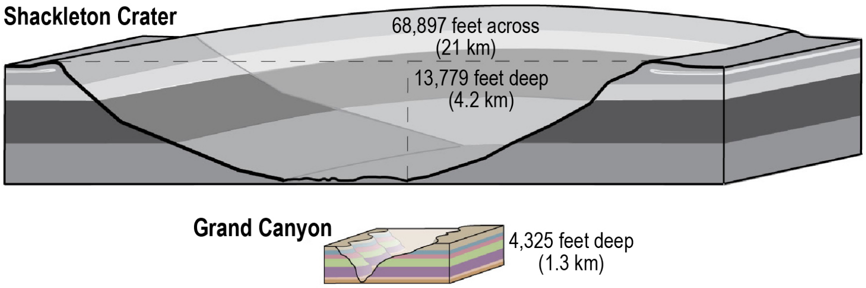
Visualization of Shackleton in natural color. (NASA)

Water and Other Resources

- Floors of the crater are considerably brighter than surrounding craters, indicating small amounts of reflective ice
- Up to 22 percent of the floor may be ice

Topography

- In near darkness most of the year
- Rim of the crater spans 21 km across
- Interior measures over 4 km to the floor and remains in permanent shadow
- Elevated ridges



Shackleton crater versus the Grand Canyon. (Lunar and Planetary Institute, Houston, Texas)

Temperature

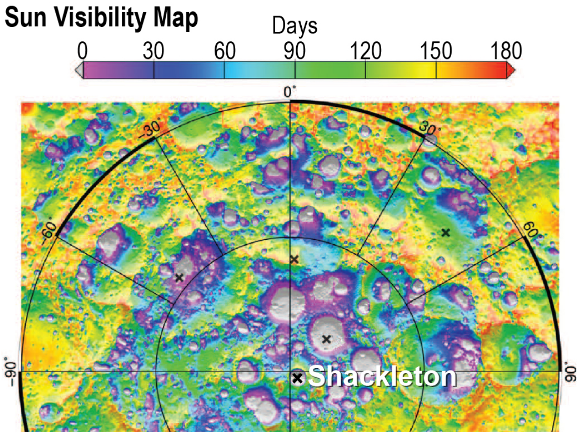
- Relatively high temperatures (80 to 110 K)

General Science

- Explain why the walls of the crater are brighter than the floor.
- The crater is a cold trap that may have collected and stored volatile compounds.

Illumination

- Craters walls are illuminated.
- Rim receives sunlight for half the year.
- Some areas are illuminated 90 percent of the time.
- No areas are permanently illuminated.



Sun visibility map depicting number of days the Sun is visible for the Shackleton crater. (NASA)

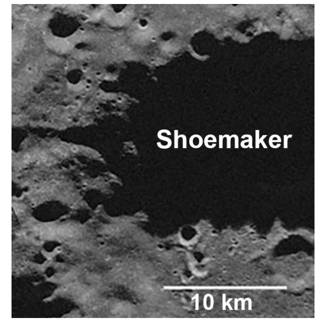
Special Considerations

- Crater walls are too steep for rovers
- Remains relatively unchanged since it was formed 3 billion years ago
- No direct visibility to Earth
- Areas near Shackleton crater are bathed in sunlight

Site Information: Shoemaker

Water and Other Resources

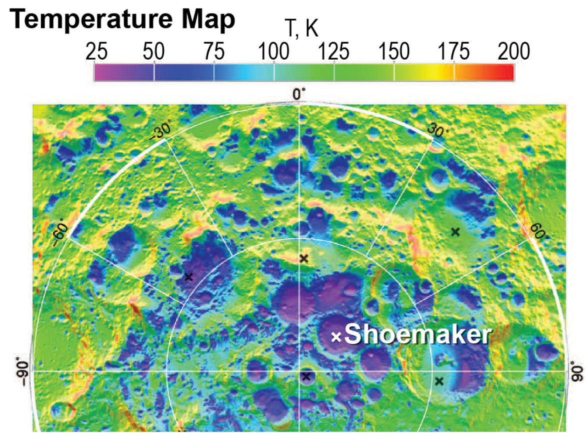
- High abundance of hydrogen
- Water-equivalent hydrogen is 0.15 percent
- Floor of the crater shows no evidence of ice



Portion of Shoemaker crater. (NASA)

Topography

- Diameter: 51 km
- Located between Faustini crater and an unnamed crater
- Intact rim with numerous craters
- Highlands terrain



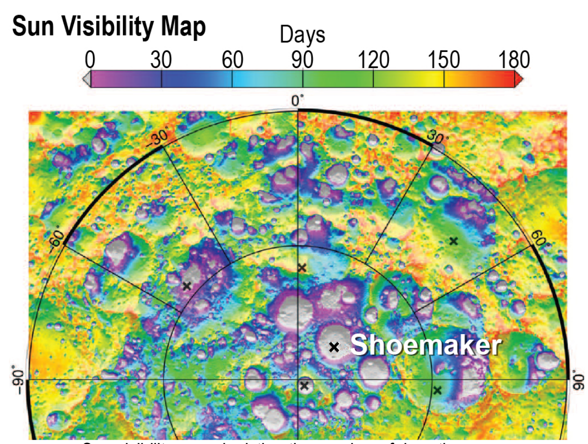
Average temperature (T) for Shoemaker crater in kelvin (K). (NASA)

Temperature

- Below 95 K
- Floor forms a cold trap

General Science

- Topographic line of sight to Earth: 0.56 km
- 1999 Lunar Prospector mission crashed into Shoemaker to release trapped water vapor, but none was detected



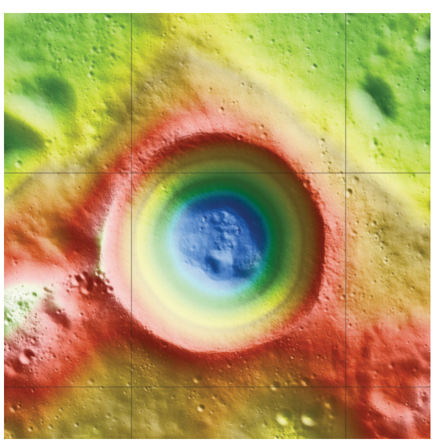
Sun visibility map depicting the number of days the Sun is visible for the Shoemaker crater. (NASA)

Illumination

- Floor is kept in total darkness from the Sun
- Shadowed area: 1,175 km^2

Special Considerations

- Inner walls highly eroded due to erosion
- Floor of Shoemaker is flat



Elevation map of Shackleton crater with blue indicating lowest area and red/white indicating highest. (NASA/Zuber, M.T. et al.)

Moon Matrix and Temperature Conversions Worksheet

Moon Matrix

Directions: For each landing site, complete the Moon Matrix below. As a team, determine whether the landing site is acceptable (Mission Go), unacceptable (Mission No Go), or cannot be determined based on the information (Need More Data).

	Cabeus	Haworth	Shoemaker	Mons Malapert	Shackleton
Water and Other Resources					
Topography					
***Temperature, °F**					
Illumination					
Science					
Special Considerations					
Mission Go, Mission No Go, or Need More Data					

**You will need to convert the temperatures from kelvin to Fahrenheit using the Temperature Conversions Worksheet below.*

As you examine the Site Information sheets, think about the following questions:

- What benefits might large shadowed regions inside a crater have for an astronaut? Could there be any disadvantages?
- Why would the amount of sunlight an area receives on the Moon be an important factor when determining a good landing site for astronauts?
- Think about the topography of each site. What are the advantages and disadvantages for an astronaut?
- What benefits might a highlands terrain have for an astronaut? Could there be any disadvantages?

Which landing site has your team selected and why?

____

____

____

Temperature Conversions Worksheet

Directions: As you examine temperatures for your landing sites, you will notice that each temperature is in kelvin (K). Convert the temperatures from kelvin to Fahrenheit.

Step 1: Use the conversion equation below to aid you in your conversion.

$$F = (K - 273.14) \times 9/5 + 32$$

Step 2: For each landing site, convert the temperature from kelvin to Fahrenheit.

Landing Site	kelvin, K	Fahrenheit, °F
Cabeus		
Haworth		
Shoemaker		
Mons Malapert		
Shackleton		

Math Extension Worksheet

Directions: If you have picked a landing site that is a crater,* you need to estimate the volume of nearby ice sources using the following equations and information.

Crater	Diameter, km	Surface area occupied by surface water ice, percent	Volume of water ice, km^3
Haworth	51.4	5.4	
Shoemaker	51.8	7.0	
Cabeus	100.6	1.1	
Shackleton	20.9	7.3	
Example Crater	**20**	**3.0**	**0.00942**

* Remember that Mons Malapert is a mountain (massif), not a crater.

Step 1: Using the formula below, find the area of each crater (in km^2) in the table above.

$Area_{crater} = \pi r^2$

Example $Area_{crater}$

Hint: You are given the diameter of the crater, so you must find the radius.

Radius: r = ½ (20 km)
= 10 km

$Area_{crater}$ = 3.14 (10 km)^2
= 3.14 (100 km^2)
= 314 km^2

Step 2: Calculate the surface area of ice (in km^2).

$Surface\ Area_{ice}$ = Area of the crater × percentage of surface area occupied by surface water ice

Example $Surface\ Area_{ice}$

Hint: You must first convert the percentage of surface area occupied by surface water ice into a decimal.

Percentage: 3% = 3/100 = 0.03

$Surface\ Area_{ice}$ = 314 km^2 × 0.03
= 9.42 km^2

Step 3: Calculate the volume of ice (in km^3).

$Volume_{ice}$ = Surface area of ice × thickness of ice*

*Assume the thickness of ice is a constant of 1 m.

Example $Volume_{ice}$

Hint: You must first convert the thickness of the ice from meters to kilometers.

$Thickness_{ice}$ = 1 m × (1 km/1,000 m) ←unit conversion
= 0.001 km

$Volume_{ice}$ = 9.42 km^2 × 0.001 km
= 0.00942 km^3

Optional Exercise

On board the International Space Station, astronauts are limited to 11 liters (L) of water per day. Now that you have calculated an estimate of the volume of ice in the crater, use the conversion below to determine how many days' worth of water your landing site would provide for one astronaut on the Moon.

$$1 \text{ m}^3 = 1{,}000 \text{ L}$$

Hint: You must first convert your calculations for volume from km^3 to m^3. (1 km^3 = 100,000,000 m^3)

In the example above: 0.00942 km^3 = 9,420,000 m^3 = 9.42 million m^3