Investigating Mercury's Perplexing Poles:

MESSENGER Water-Ice Data Exploration

Teacher Guide

Grade Level: versions for 6-8 and 9-12

Warm-Up: about 45 minutes
Activity: two 45 minutes sessions

Lesson Summary

Students mimic the scientific process that led to the discovery of water ice on Mercury by interacting with actual data from multiple sources, including Earth-based telescope data, data from the NASA Mariner 10 mission in the mid-1970's, and data from the first spacecraft to orbit Mercury, MESSENGER.

Objectives

Students will:

- Appreciate the process of scientific discoveries, especially as they relate to planetary exploration, including:
    - Communicate that scientific discoveries happen over time.
    - Analyze data from multiple sources and instruments to justify conclusions about the presence of water ice on Mercury.
    - Differentiate between the nature and usefulness of data obtained from Earth, from fly-bys, and from orbit.
- Make multi-sensory observations.
- Gather data.
- Demonstrate an understanding of real-life constraints on spacecraft missions.

Essential Questions

- **How do we learn about places that we can't visit?**

Concepts

- There are many ways to study other worlds in the Solar System.
- Space exploration has opened up a whole new area about which to ask questions and seek answers.
- The desire to explore is part of human nature, and it holds its foundation in our past.
- Real-life constraints such as cost, time, and distance determine how much can be learned about another world.

MESSENGER Mission Connection

The MESSENGER spacecraft is one of NASA's Discovery missions. Even with a relatively inexpensive mission, the mission team was able to create an orbiting spacecraft that has told us more about Mercury than we knew from the only previous mission to Mercury (Mariner 10 in the

1970's) and all ground-based observations combined. MESSENGER has unveiled mysteries of Mercury that not only help us to understand this once poorly known planet, but also help scientists learn more about the properties of other planets, including the Earth, and even provide clues to the formation of the Solar System.

Next Generation Science Standards Addressed:

Disciplinary Core Ideas

- ESS1 Earth's Place in the Universe

Science and Engineering Practices

- Practice 1: Asking Questions and Defining Problems
- Practice 6: Constructing Explanations and Designing Solutions
- Practice 7: Engaging in Argument from Evidence
- Practice 8: Obtaining, Evaluating, and Communicating Information

Cross-cutting concepts

1. Patterns
3. Scale, Proportion, and Quantity

Nature of Science

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

Science Overview

Despite the fact that Mercury is the closest planet to our Sun, it has long been postulated that water ice could be stable in cold, permanently shadowed regions of the north and south poles. About 20 years ago, Earth-based observations of Mercury revealed bright spots in radar data, which we call "radar-bright regions". When these data were compared with images from the Mariner 10 spacecraft, which flew by Mercury in the mid-1970's, the radar-bright regions were seen to correspond withimpact craters. One of the major goals for the MESSENGER Mission was to determine the chemical compostion of these polar deposits.

MESSENGER Instruments

The MESSENGER Spacecraft had eight onboard instruments which were carefully chosen to assist in answering the key scientific questions of the mission.

Mercury Dual Imaging System (MDIS)

This instrument consisted of two cameras that mapped landforms, tracked variations in surface spectra and gathered topographic information. A scanning mirror helped point it in whatever direction was chosen. The two instruments enabled MESSENGER to "see" depth much like our two eyes do.

Gamma-Ray and Neutron Spectrometer (GRNS)

This instrument detected gamma rays and neutrons that are emitted by radioactive elements on Mercury's surface, or by surface elements that have been stimulated by cosmic rays. It was used to map the relative abundances of different elements, and helped to determine if there is ice at Mercury's poles, which are never exposed to direct sunlight.

Magnetometer (MAG)

This instrument mapped Mercury's magnetic field, searching for regions of magnetized rocks in the crust.

Mercury Laser Altimeter (MLA)

The Mercury Laser Altimeter contained a laser that sent light to the planet's surface, and a sensor that gathered the laser light after it has been reflected back from the surface. Together they measured the amount of time for light to make a round-trip to the surface and back. Recording variations in this distance produced highly accurate descriptions of Mercury's topography.

Mercury Atmospheric and Surface Composition Spectrometer (MASCS)

This spectrometer was sensitive to light from the infrared to the ultraviolet, and measured the abundances of atmospheric gases, as well as detected minerals on the surface.

Energetic Particle and Plasma Spectrometer (EPPS)

EPPS measured the composition, distribution, and energy of charged particles (electrons and various ions) in Mercury's magnetosphere.

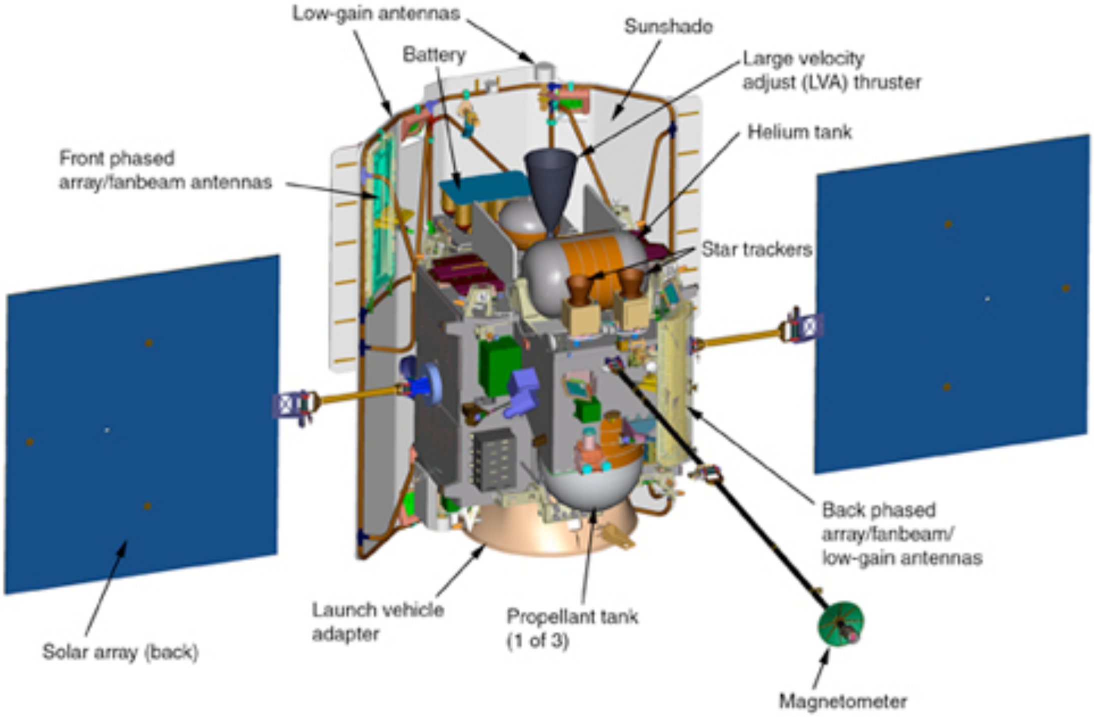
X-Ray Spectrometer (XRS)

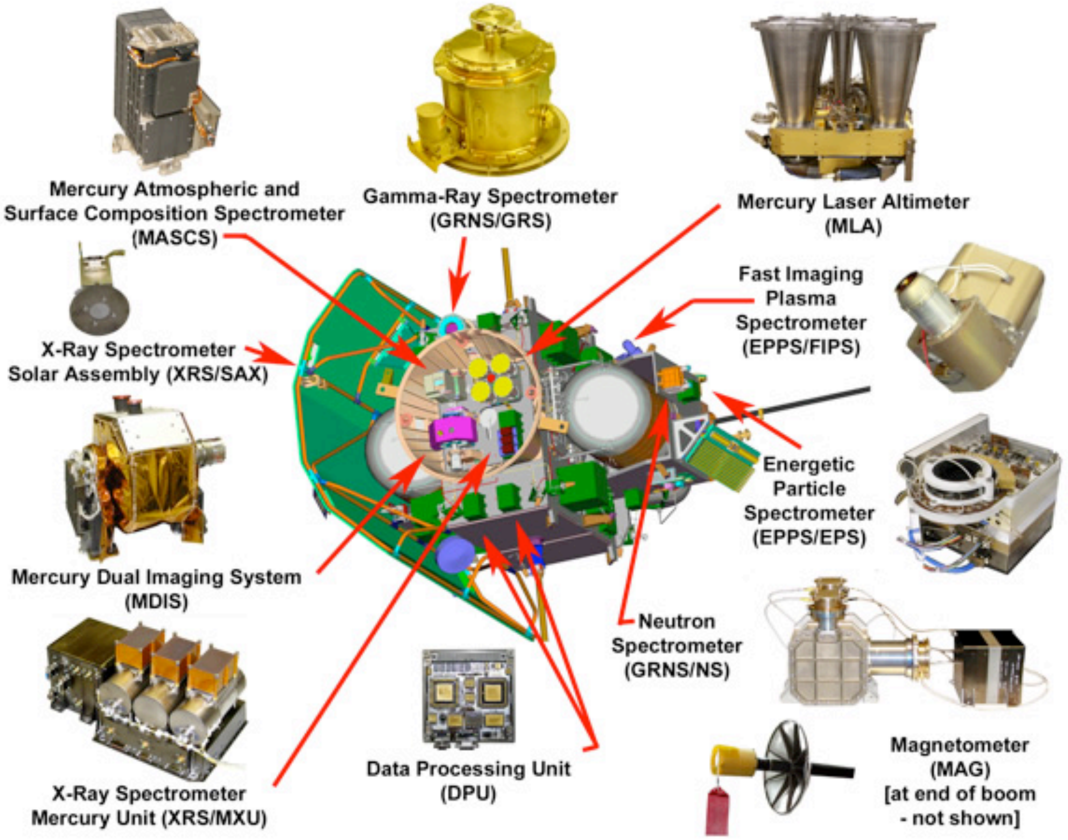
Gamma rays and high energy X-rays from the Sun, striking Mercury's surface, can cause the surface elements to emit low-energy X-rays. XRS detected these emitted X-rays and measured the abundances of various elements in the materials of Mercury's crust.

Radio Science (RS)

RS used the Doppler Effect to measure very slight changes in the spacecraft's velocity as it orbited Mercury. This allowed scientists to study Mercury's mass distribution, including variations in the thickness of its crust.

The following two images show the location of the instruments on the MESSENGER spacecraft.


Low-gain antennas
Sunshade
Battery
Large velocity adjust (LVA) thruster
Helium tank
Front phased array/fanbeam antennas
Star trackers
Back phased array/fanbeam/ low-gain antennas
Launch vehicle adapter
Propellant tank (1 of 3)
Solar array (back)
Magnetometer


Mercury Atmospheric and Surface Composition Spectrometer (MASCS)
Gamma-Ray Spectrometer (GRNS/GRS)
Mercury Laser Altimeter (MLA)
Fast Imaging Plasma Spectrometer (EPPS/FIPS)
X-Ray Spectrometer Solar Assembly (XRS/SAX)
Energetic Particle Spectrometer (EPPS/EPS)
Mercury Dual Imaging System (MDIS)
Neutron Spectrometer (GRNS/NS)
X-Ray Spectrometer Mercury Unit (XRS/MXU)
Data Processing Unit (DPU)
Magnetometer (MAG) [at end of boom - not shown]

Data Layer Description

Information or data can be collected about a planetary body in many different ways. To study Mercury, scientists have used Earth-based optical and radio telescopes, spacecraft flybys and an orbiter.. In this activity students will explore data collected by Arecibo Radio Telescope in Puerto Rico, Mariner 10 and MESSENGER.

In QuickMap, userscan layer different types of data to investigate Mercury. In this case, students will explore data from Mercury's north polar region using the following layers:

Longitude/Latitude Grid: Grid showing key longitude and latitude coordinates. The center of the image is Mercury's north pole.

Mariner 10 Mosaic: The only spacecraft to visit Mercury before MESSENGER was Mariner 10, which flew by the planet three times in 1974 and 1975. This layer shows the portion of the surface of Mercury's Northern Hemisphere imaged by Mariner 10.

Earth-based Radar Data: The Arecibo Radio Telescope in Puerto Rico revealed bright, reflective areas near Mercury's north pole, shown in red in this layer. These areas look similar to radar images of known water ice patches on other planets. How do these bright patches compare with MESSENGER data such as the areas of permanent shadow and the topographically deep craters?

MESSENGER Flybys Mosaic: Before MESSENGER went into orbit around Mercury in March of 2011, it flew past the planet three times in 2008 and 2009. During those flybys, it mapped a large percentage of the planet's surface, including the portion of the North Polar Region shown in this layer.

Images from MESSENGER: Click on a dot to display a featured image of that region and to learn more about the region. Once selected, you can click on the link at the bottom of the "Feature Info" window to visit the MESSENGER website, where you can browse additional Featured Images. MESSENGER's Mercury Dual Imaging System (MDIS) cameras captured these images.

Features on Mercury: Displays the location, name and additional information for surface features (craters, mountains, valleys and others) and albedo features (bright, reflective areas) approved by the International Astronomical Union (IAU).

- Albedo Feature: Geographic area distinguished by the amount of reflected light
- Catena, catenae: Chain of craters
- Crater, craters: A circular depression
- Dorsum, dorsa: Ridge
- Fossa, fossae: Long, narrow depression
- Mons, montes: Mountain
- Planitia, planitiae: Low plain
- Rupe, rupes: Scarp
- Vallis, valles: Valley

Permanently Shadowed Areas: At Mercury's north pole, the low angle of the sun, elevation of surface features and depth of craters result in areas that are in perpetual shadow, as shown by the dark blue areas in this layer.

Mercury Temperature Map: Map of the maximum surface temperature reached over a two-year period over the north polar region of Mercury. This map comes from a computer model that calculates the surface and subsurface temperatures based on Mercury's topography, surface materials, and solar illumination. At the equator of Mercury some areas reach maximum temperatures of 700 K (800° F), whereas regions in permanent shadow and in some of the high-latitude craters shown here temperatures can drop below 50 K (-370° F). In the craters with poleward-facing slopes on which the annual maximum temperature is less than 100 K (-280° F) water ice is thermally stable over billion-year timescales.

Neutron Counts: When a very fast-moving proton known as a cosmic ray hits the surface of Mercury, neutrons are emitted from near-surface materials. Abundant hydrogen atoms (as in water ice) stop these neutrons and prevent them from escaping into space. Therefore, when the Neutron Spectrometer (NS) instrument aboard MESSENGER detects a decrease in neutrons, we attribute it to more hydrogen (and, by inference, water ice) present on the planet's surface. This layer shows an average of the neutron count rate over the polar region, where the blue areas represent a low neutron count and thus more hydrogen (likely in the form of water ice).

Topographic Relief Map: Topography of Mercury's north polar region in shaded relief and color-coded by elevation. Notice the interior of the large dark blue crater at about 4 o'clock (60°E) is more than 5 km below what we would call "sea level" on Earth or the topographic datum of Mercury. This layer is technically called the Northern Hemisphere Digital Elevation Model (DEM) and was derived from the MESSENGER Laser Altimeter (MLA).

Mercury's Surface Image: This image is a complete surface map of Mercury's north polar region produced using the MESSENGER's Mercury Dual Imaging System (MDIS) during more than 1,000 orbits around the planet.

Warm-up and Pre-Assessment (45 minutes)

Materials

Teacher Materials for planets -- make 5 spheres that are identical.

Make planets from several different materials with other interesting materials on the surface – examples below.

- Play-dough (multi colored spheres) or plastic balls, modeling clay, Styrofoam© balls, or rounded fruit (grapefruit, oranges, etc.)
- Various small parts to add to the play-dough/clay planets planets—at least 5 of each (marbles, beads, etc.)
- Cloves, vinegar, or mild scents like peppermint
- Glue (if needed)

- Black paper or cardboard to obscure some of the planets
- Copies of "The Planet Perspective" Data Sheets (1 per student)

Display materials

- Towel (Black or dark blue to put under and drape over planets – helps the planets stand)
- Tall stool or stack of boxes to display planets for observations – arranged for fly-by and orbits.

Make Planets – Planets may be made days in advance; store in plastic bags to keep from drying out.

- Keep the planets covered until students are ready to observe
- Make 5 multi-colored clay or play-dough balls or choose an object such as a plastic ball or fruit (orange, grapefruit, etc) that allows for multi-sensory observations.
- To make the objects interesting to observe, add color and texture to the planets by embedding beads, aquarium rocks, twigs, whole cloves, scents, yarn, clear flat glass from flower vase (looks like water), or very small stickers (butterfly stickers simulate possible life on a strange planet.)
- Place some of these materials discreetly so that they are not obvious upon brief or distant inspection.
- Make landform features -- some suggestions for features are:
  - Create clouds by using cotton
  - Make polar ice caps with white clay or play-dough
  - Carve channels or rivers
  - Make impact craters

Assemble viewing tubes - one per team

- Make or gather tubes for observing – paper towel cardboard is best, rolled and taped paper works
- Place cellophane on one end of each tube and secure with a rubber band (Blue cellophane can be hard to find and is optional.)

Set-up

- Choose appropriate location for the planets – consider that the students will observe the planets from a distance, then pass by (fly-by), then orbit the planet area. Planets may be in different room – so observers are the only ones going on each mission to bring back data.
- Place the planets on a tall stool or stack of boxes (use table or desk if necessary – not preferred.) A tray on top of a tall waste basket works. Place moon near one planet. Make sure the observers will be able to see the planets.
- Cover the objects with a towel before students arrive.
- Seat students in working teams of 3-4 students. Seat the teams as far away from the planets as possible. The planets could be in a hall or other room.
- Give each team one observing tube.
- Distribute Data Sheets for each team.

The Planet Perspective:

NASA Impact of Discovery Workshop adaption 2016
NASA JSC ARES Education adaptation 2009
ASU Mars K-12 Education Program 6/99
Adapted from NASA Education Brief "EB-112: How to Explore a Planet" 5/93

In this activity students will observe play-dough "planets" from various perspectives and with specific controls on those perspectives to try to replicate what we learn about a distant body from Earth-based observatories, fly-by missions, orbiters, landers, and finally sample return missions.

Brief students on their task: To explore a strange new planet(s) asking questions and taking and reporting data like a science team. They will work as a science mission team. Let teams know that they are seated in their own Mission Control area.

For each mission, team members who are not the current Mission Observer will face away from the planet display -- they are in Mission Control waiting to receive data from the Observer. Only the Observer on each mission gathers the data and takes it back to the team. The team members will rotate responsibilities with each student taking a different role for each mission. Use the viewers when observing the planet from a distance and for the fly-by. Other techniques or technology may be used for the orbiter mission (camera or ruler, etc.) Encourage use of all senses -- except taste.

1. Create 5 planets using 5 spherical objects of the same kind and size, e.g. 5 oranges, 5 baseballs, 5 apples, etc. Decorate each of the spherical objects identically using play-dough, beads, marbles, dimples for craters, white at the poles, and various other materials you have on hand. **Make sure they all LOOK THE SAME**. Place one spherical object at each station. Directions for each station is available on the student data sheet

2. Upon entering the room, have each student take a "Planet Perspectives" student data sheet. Have them proceed through the stations, recording their observations on the data sheet in the spaces provided as they go.
   STATION 1: Please observe from the location indicated, and you can't lean in for a better view here!
   - What can you observe about your planet from here? (What data can you collect?)
   - What science question(s) do you have about the planet you are observing?
   - How might you get more information or data about your planet?
   - What are the pros and cons of using this type of exploration?

3. Proceed to the next station until all stations and questions have been completed.

4. Stations setup and procedure around the room as follows:
   a. Station 1: *Earth Based*: Place a planet on a table, which is covered by a towel. Choose an observation spot that is far away from planet. Uncover the planet for approximately 10-15 seconds. Have the students look only through the observation tube (telescope) to view the distant planet. If blue cellophane is available, have students complete this station twice. Once with the blue cellophane on, representing the Earth's atmosphere.

The molecules in the atmosphere inhibit really good observations Then again with it off, as if from a telescope above the atmosphere. Recover the planet. Have the students record their observations in their "Planet Perspectives" student data sheet." At this point, the observations will be visual and will include color, shape, texture, and position. Ask Teams to discuss the questions they have about the planets that could be explored in future missions to the planet. Records the questions the team would like to explore.

b. Station 2: *Flyby*: Place a planet on a table that is against the wall, which is covered by a towel. Place tape on the floor or chairs around the table so, the students can't walk to the sides of the table; they can only view the planet from one side. Make sure there is a different observer from each team. Remove the towel halfway, exposing only half of the planet that is facing the observer. Using the observation tube again, the observer will walk past the planet while looking through just the observation tube. Allow for approximately 15 seconds to observe. Replace the towel after the observation. Have the students return to their teams to record their observations in their "Planet Perspectives" student data sheet." Discuss what was observed and what questions the team would like to explore.

c. Station 3: *Orbiter*: Place a planet in center of round table (or chairs/tape on floor around square/rectangular table to make it circular…or maybe it is an elliptical orbit!) Have each team choose a different Mission Observer. Remove the towel completely. Using the telescope tube, each Observer will walk around the planet twice. Have all observers go around the planet in the same direction. Replace the towel over the planets. Observers should go back to their teams to share the data. Remind students to record observations in their data sheets. Have the teams discuss the observations.

d. Station 4: *Lander*: Place a planet on table and with access from all sides so users can make very close observation of the planet. Ask each team to designate the next Mission Observer and to make sure that the observer knows the specific planet to observe and the questions that the team wants answered with the Lander Mission. Observer will need a toothpick or small paper flag to designate the Team Landing Site. Remove the towel completely. Have each observer walk around the planet twice. Keep all observers going the same direction. Remind observers that they are looking to designate the very best landing site where the next mission will take a sample. Remember to focus on an area no bigger than a quarter. Observers should go back to their teams to share the data. Remind students to record observations in their data sheets. Have the teams discuss the observations.

e. Station 5: *Sample return*: Place a planet on table and with access from all sides so users can grab a small piece of something from the planet (bead, clove, clear flat marble, white from poles, etc.). Ask each team to designate the next Mission Observer and to make sure that the observer knows the specific spot on the planet where the Team Sample will be taken. Before going and taking a sample have the teams discuss sampling methods – a small pinch of material or a small drill core of material would be appropriate – other ideas may work too – just be sure they do not take a really large fist full of planet. Observers should go back to their teams to share the sample. Remind students to record observations in their data sheets. Have the teams discuss the observations and analysis.

5. When all observations are complete, students may discuss findings to answer the questions in PART II of their data sheet.

Activity Questions –Main Activity

- Could there be water ice at the poles of Mercury?
- Is there enough supporting data available to make a conclusion about water ice at Mercury's poles without sending a lander?

Core Experience

Now it is your turn to mimic the scientific process, in which data from various instruments have helped to answer one of the questions guiding this mission: *What are the unusual materials at Mercury's poles?*

Materials

Water Ice Data Exploration Activity:

- Access to computers or tablets and the internet (students can work in pairs if necessary)
- Copies of "Investigating Mercury's Perplexing Poles" student worksheet(1 per student)

Procedures (two 45 minute periods)

Water Ice Data Exploration - Investigating Mercury's Perplexing Poles: Scientists commonly compare data from different instruments to better understand the target of their observations. Just like scientists, students will be using the actual data from a variety of different missions and instruments. Each of the data layers provides information about Mercury's north pole. Combining the different data layers will help students interpret the data and form their conclusions.

1. Explain to students that they will be exploring data from the first spacecraft to orbit the planet Mercury, MESSENGER. Distribute copies of the "Investigating Mercury's Perplexing Poles" student worksheet, one per student. Students may work independently or with teacher guidance.

2. You may wish to guide students through an introduction to the Water Ice Data Exploration QuickMap tool. Note that there is a tutorial available if you wish to have students watch that instead, which is accessible by clicking on the "?" at the bottom center of the QuickMap Tool. Allow about 5-10 minutes for students to explore the QuickMap Tool.

    Locate where the Mercury Layers are Ask the students to add and remove different layers by checking the boxes. In almost every layer, the students have the option to adjust the opacity of the data.

    Next ask the students to add the Mariner 10 Mosaic data and Topographic Relief Map data. Encourage the students to adjust the opacity for both layers to allow them to observe possible correlations between layers. Ask the students to share their observations.

Using the plus (+) and minus (-) symbols, the students are able to zoom in and out to view Mercury's surface in detail. Ask the students to share their observations. What information about the image changes?

3. Uncheck all the data layers except the Mercury North Pole Longitude/Latitude Grid layer and the Mercury's Surface Image.

   Mariner 10 spacecraft provided the first close up look of Mercury. It flew by the planet three times between 1974 and 1975. Mariner 10 imaged 45% of the planet. The following composite, images of the north polar region, were captured: Mariner 10 flyby images.

   Add the Mariner 10 Mosaic layer by clicking on the appropriate data layer box.

4. **Ask students to share their observations** and answer Questions 1-5 on the student worksheet.

5. Next, add the Earth-based Radar Data (Arecibo Radar Image) by checking the data layer box.

   In the early 1990's, radio astronomers from the Arecibo Observatory, Puerto Rico, observed unusually radar-bright patches at the poles of Mercury. The radar-bright materials in these patches have radar characteristics that are best matched elsewhere in the solar system by water ice. Many of these patches appear to correspond to the location of impact craters. NOTE: YOU SHOULD ALLOW YOUR STUDENTS TO DISCOVER THIS FOR THEMSELVES! NO PROBLEM IF THEY DON'T DISCOVER THIS RIGHT AWAY! Data layer is available here: radar-bright materials shown in red. See Figure 1.

6. **Allow students to share their observations**, and then answer Question 6.

7. Uncheck Earth-based Radar Data layer leaving Longitude/Latitude Grid and composite Mariner 10 Mosaic layer.

8. Next check the MESSENGER Flyby Mosaic data layer.

9. **Allow students to share their observations** then answer questions 7 and 8.

During the 6.5-year journey from Earth to enter into orbit around Mercury, the MESSENGER spacecraft flew past Mercury 3 times. During these flybys the spacecraft was near the equator, so only some of the North Polar Region was imaged: Mariner 10 and MESSENGER flyby images.

10. Add the Earth-based Radar Data layer. See Figure 2.

    TIP: Have the students change the opacity of the Arecibo layer so that students can see the relative positions of geographical features and the radar-bright patches. **Ask for student comments** then ask them to answer Question 9.

On March 18, 2011, MESSENGER became the first spacecraft to orbit Mercury! With that remarkable feat came mountains of data, including imaging coverage of 100% of the planet: MESSENGER orbital images.

11. Uncheck the Earth-based Radar Data layer. The students should have the Mariner 10 and MESSENGER flyby mosaic data layers checked. Next add the Mercury's Surface Image data layer by clicking the check box. Ask students compare the data layers that occurred prior to orbit to that afterwards. Have them share what they observe (clarity of images, amount of surface imaged, appearance of surface). **Allow students to share their observations** then answer Question 10.

12. Uncheck all layers except the Mercury's Surface Image.

13. Check the Earth-based Radar Data layer to add to the Mercury's Surface Image layer. TIP: have the students change the opacity of the Arecibo layer so that students can see the relative positions of geographical features and the radar-bright patches. **Allow students to share their observations** then answer Question 11.

    Along with spectacular images of Mercury, MESSENGER collected data from several other instruments, including the Mercury Laser Altimeter (MLA). Using a laser pulse, the MLA instrument mapped the surface of Mercury, producing a topographic map: MLA topography data.

14. Add the Topography Relief Map data layer by checking the appropriate data layer box. TIP: Have the students change the opacity on the layers so that students can see how the data in each layer relates to the data in the other layers. You also might change the order of the layers. **Lead a discussion of student observations** then ask them to answer Question 12.

15. Organize your students into small groups to discuss Questions 13-16 for about 10 minutes, and then write their answers (answers can be decided by the group or written individually).

16. Add the following layers, one at a time: Permanently Shadowed Areas, Mercury Temperature Map, and Neutron Counts. (See Figure 3 as an example)

17. Ask a representative from each group to share the answer to each question with the whole class. Lead a class discussion about the data and its possible interpretation and implications.

18. Allow students to re-write their answers to Questions 13-16 if they wish to do so in Questions 17-20.

Part II – Measuring Craters

19. Using the Line Path tool, located by clicking on the wrench in the upper right corner, students will be measuring the diameter of three of the six craters on the list. After selecting the Line Path tool, click on the edge of a crater to start measuring. Remind the students that when measuring the diameter of the crater, they will need their line to go through the middle of the crater to the other side, creating a straight line. Double click to end the measurement and view

the results.

Two distances will be found in the results, cartographic and geodetic distance. The cartographic distance is measured on a two-dimensional map projection. The geodetic distance is measured over the surface of Mercury. Students should report their cartographic distance in the table on the student worksheet.

Students should take three different diameter measurements of each crater. Each time they take a diameter measurement, they will also be able to determine the lowest point along the line path. Both measurements should be recorded on the table. Students should then find the average diameter and depth.

20. Next, students will compare their measurements with the officially recorded measurements. Double click on the crater name to display about each crater. Record the official crater diameter on the student worksheet.

    Compare the official recorded crater diameter with the calculated average crater diameter, to determine the percentage difference.

21. Next, discuss what may have contributed to a percentage difference over 10%.

Discussion & Reflection

Lead a class discussion about the data and its possible interpretation and implications, with questions such as:

- What were the difficulties in completing this assignment? Can you relate these difficulties to real-world constraints? How does this relate to what scientists and engineers experience when designing a real mission?
- What is the difference in the nature and type of information provided by each of the layers?
- Is information from **all** of the layers necessary or sufficient to support the conclusion that water ice exists at Mercury's poles?
- Where do errors in measurement come from?

Teaching Tips

- Remind the students of the importance of using evidence to support an argument.

Assessment Criteria

Assess how well students appreciate the process of scientific discoveries, especially as they relate to planetary exploration, including:

- Articulate that scientific discoveries happen over time.
- Analyze data from multiple sources and instruments to make conclusions.
- Differentiate between the type of data obtained from Earth, from fly-by, and from orbit.

Additional Resources

Video of MESSENGER team members Nancy Chabot and Alice Berman discussing how to use the transparency overlays and how the compilation of data leads to new discoveries: http://www.youtube.com/watch?v=Dz3tkBD4lfs?rel=0.

The corresponding slides to this presentation can be found at: http://dawn.jpl.nasa.gov/discovery/pdfs/MSNG_workshop2.pdf.

Figure 1

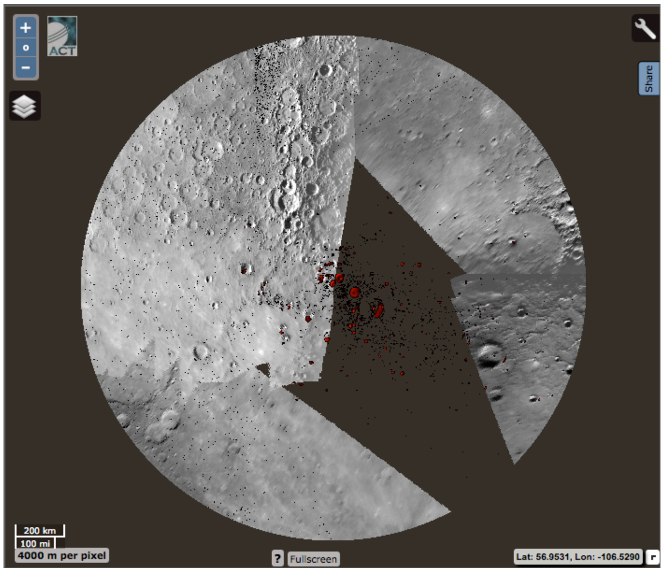


Figure 2

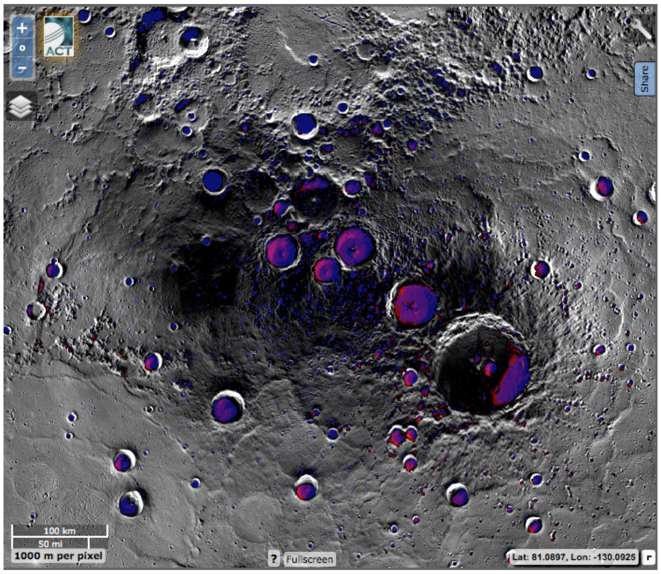


Figure 3

Investigating Mercury's Perplexing Poles

MESSENGER Water-Ice Data Exploration – *Student Worksheet*

Your mission: Answer the question, "*What are the unusual materials at Mercury's poles?*" To help you answer this question, you must think like a scientist and analyze actual data collected by a telescope on Earth, a spacecraft that flew past the planet in the mid-1970's, and a spacecraft that orbited Mercury. As you explore data from these different sources and different instruments, think about what you can learn from each set of data by itself and also what you can learn when you compare the data.

Your guide: To help you examine and compare these different data sets collected over a period of 40 years, you will use the MESSENGER Water-Ice Data Exploration QuickMap: http://messenger.jhuapl.edu/Learn/water_ice_data.html .

1. Begin your exploration with a brief tutorial, accessible by clicking on the "?" at the bottom center of the QuickMap screen.

2. Describe the surface of Mercury that is visible in the Mariner 10 composite image. Does it remind you of the surface of any other Solar System body? If so, which one, and why?

   ____

   ____

   ____

3. How do you think Mercury's surface came to look this way?

   ____

   ____

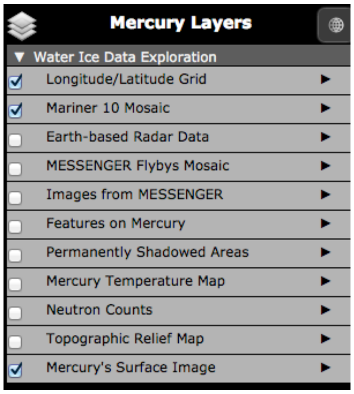
   ____

4. Estimate the percentage of the North Polar Region, ≥ 65º N, that was imaged during the Mariner 10 flyby.

   ____

5. Estimate the percentage of the North Pole, ≥ 85º N, that was imaged during the Mariner 10 flybys.

   ____



Mercury Layers

▼ Water Ice Data Exploration

- ☑ Longitude/Latitude Grid ▶
- ☑ Mariner 10 Mosaic ▶
- ☐ Earth-based Radar Data ▶
- ☐ MESSENGER Flybys Mosaic ▶
- ☐ Images from MESSENGER ▶
- ☐ Features on Mercury ▶
- ☐ Permanently Shadowed Areas ▶
- ☐ Mercury Temperature Map ▶
- ☐ Neutron Counts ▶
- ☐ Topographic Relief Map ▶
- ☑ Mercury's Surface Image ▶

6. Does the distribution of the radar-bright patches seem to follow any pattern? Describe any pattern that you see.

7. After MESSENGER's fly-bys of Mercury, how much of the surface still remained to be imaged?

8. Compare and contrast the images of Mercury's surface obtained by Mariner 10 and MESSENGER as the crafts flew by the planet.

9. In your answer to Question 5, you may have described a pattern for the distribution of radar-bright patches observed from Arecibo on Earth in 1989. Do you still see the same pattern? If you did not see a pattern before, do you see one now and what is it? (hint: look for associations between the different layers of data)

10. Describe the differences between the layer containing the MESSENGER Flyby Mosaic data and the Mercury's Surface Image.

11. When you overlay the Earth-based Radar Data with Mercury's Surface Image, do you see a pattern for the distribution of the radar-bright patches? Describe what you observe.

12. In what ways do these three data sets (Earth-based radar, topography, detailed surface image) relate to each other?

13. Do you think that this data is sufficient to conclude that there is water ice on Mercury at its poles? If so, why? If not, why not?

14. What other evidence would be helpful to confirm that there is water ice at Mercury's poles?

15. Mercury is the closest planet to the Sun. How could it be possible for water ice to be stable anywhere on its surface?

16. How does the additional layers support or oppose your answer to number 15?

Rewrite of numbers 13-16, if applicable

17. Do you think that this data is sufficient to conclude that there is water ice on Mercury at its poles? If so, why? If not, why not?

18. What other evidence would be helpful to confirm that there is water ice at Mercury's poles?

19. Mercury is the closest planet to the Sun. How could it be possible for water ice to be stable anywhere on its surface?

20. How does the additional layers support or oppose your answer to number 15?

Part II – Measuring Craters

21. Crater measurements. Choose three of the following craters to measure their diameter and depth.

- Mendelssohn
- Prokofiev
- Tolkien
- Fuller
- Goethe
- Chesterton

Crater Name:			
Diameter Measurement 1			
Diameter Measurement 2			
Diameter Measurement 3			
Average Diameter			
Depth Measurement 1			
Depth Measurement 2			
Depth Measurement 3			
Average Depth			

22. Using your average diameter, calculate the percent error in your measurements of the craters.

$$\text{Percent Error} = \frac{|\text{Approximate Value - Exact Value}|}{|\text{Exact Value}|} \times 100\%$$

To locate the actual crater diameters, double click on the crater names in QuickMap. The pop-up screen will provide the necessary information.

Crater Name:			
Actual Diameter			
Percent Error			

23. Explain the source(s) of your error.

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Answer Key – The Planet Perspective

Student Worksheet 1
1) – 3) Answers will vary. The main goal of the activity is to have the students understand the differences in what kind of information can be gathered with the different mission types, and appreciate the amount of planning that is required for the different missions.

4) Answers will vary. Some possibilities are included below:

Planet Perspective – Station 1: Earth-based observations
Pros:
- The lowest cost (unless the telescope is large or space-based, but even then the cost per observation is probably lower than for a spacecraft mission traveling to the target.)
- Can easily change instruments that are mounted on the telescope.
- Can easily point the telescope to observe many interesting targets.
- Can collect large amounts of data over long periods of time.
- Can be operated easier than the other mission types.

Cons:
- Observations limited: cannot provide detailed information on small-scale features.
- Observational problems due to the Earth's atmosphere (not for space telescopes.)
- Observational problems due to light pollution from cities (not for space telescopes.)
- If only one side of the target can be seen from the Earth, only that side can be observed (for example, the Moon.)
- Can only observe the target at night (unless observing the Sun or using radio waves.)
- Cannot observe in bad weather.

Planet Perspective – Station 2: Flyby
Pros:
- Can observe more details of the world than Earth-based observations.
- Can observe the target all the time during approach and departure.
- Can observe the target with several instruments simultaneously.
- Can observe several targets (for example, a planet and its moons; or fly by several planets), if mission is so designed.

Cons:
- Costs more than most Earth-based observations.
- Cannot repair or replace instruments.
- Observation time and area observed is limited by the amount of time that the spacecraft spends near the target.
- Spacecraft and its instruments must be controlled at least part of the time through computer programs stored onboard the spacecraft.
- Since data must be stored onboard the spacecraft, and sent to the Earth at a specified time, there are limitations to the amount of data that can be returned.
- Communications become more difficult the farther the spacecraft is from the Earth.

Planet Perspective – Station 3: Orbiter
Pros:
- Can observe more details of a target for a longer period of time than a flyby mission.

- Can observe more of the (if not the entire) target
- Can observe global and regional changes on the target's surface and atmosphere over time.
- Can observe the target with several instruments simultaneously.

Cons:

- Costs more than a flyby mission or observations from the Earth.
- Cannot repair or replace instruments.
- Needs more propellant than a flyby mission.
- More hazardous than a flyby mission.
- Communications with the Earth may be more difficult if the spacecraft is behind the target during part of its orbit.
- May need to perform orbit correction maneuvers to remain in orbit around the target.
- Spacecraft and its instruments must be controlled at least part of the time through computer programs stored onboard the spacecraft.
- Needs more complicated computer programs than a flyby mission.

Planet Perspective – Station 4: Lander

Pros:

- Can observe more details of a portion of the target than the other mission types.
- Can observe changes on the surface of the world or its atmosphere in more detail (but only around the landing area.)
- Can observe the area around the landing site with several instruments simultaneously.
- If the lander is movable (e.g., it includes a rover), it can provide detailed observations on several interesting surface features that are within driving distance.
- Can investigate the rocks, and the soil in detail, for example through sample analysis.
- Can perform experiments to see if there are living beings present.
- Can record seismic events (e.g., moonquakes or marsquakes.)

Cons:

- Costs more than the other mission types.
- Cannot repair or replace instruments.
- Needs more propellant than a flyby mission (but maybe not more than an orbiter mission.)
- More hazardous than the other mission types.
- Communications are more difficult because data must be sent from the lander to the Earth (often via an orbiting spacecraft.)
- Communications with the Earth may be more difficult when the lander or the orbiter that acts as a communications relay is behind the target.
- Since data must be stored onboard the spacecraft, and sent to the Earth at specific times, there are limitations to the amount of data that can be returned.
- Spacecraft and its instruments must be controlled through computer programs stored onboard the spacecraft for at least part of the time.
- Needs more complicated computer programs than the other mission types.

Planet Perspective – Station 5: Sample Return

Pros:

- Can observe more details of a portion of the target than the other mission types.

- Can observe changes on the surface of the world or its atmosphere in more detail (but only around the landing area.)
- Can observe the area around the landing site with several instruments simultaneously.
- Can return material so experiments can be performed determine the composition of the material and to see if there are living beings present.
- Can investigate the rocks, and the soil in detail, for example through sample analysis.
- .

Cons:

- Costs more than the other mission types.
- Cannot repair or replace instruments.
- Needs more propellant than a flyby mission
- More hazardous than the other mission types.
- Precise location for sample retrieval must be determined.
- Communications are more difficult because data must be sent from the sample return/lander to the Earth (often via an orbiting spacecraft.)
- Communications with the Earth may be more difficult when the sample return/lander or the orbiter that acts as a communications relay is behind the target.
- Since data must be stored onboard the spacecraft, and sent to the Earth at specific times, there are limitations to the amount of data that can be returned.
- Spacecraft and its instruments must be controlled through computer programs stored onboard the spacecraft for at least part of the time.
- Needs more complicated computer programs than the other mission types.

Teacher's Key

Investigating Mercury's Perplexing Poles

MESSENGER Water-Ice Data Exploration – *Student Worksheet*

Your mission: Answer the question, "*What are the unusual materials at Mercury's poles?"* To help you answer this question, you must think like a scientist and analyze actual data collected by a telescope on Earth, a spacecraft that flew past the planet in the mid-1970's, and a spacecraft that orbited Mercury. As you explore data from these different sources and different instruments, think about what you can learn from each set of data by itself and also what you can learn when you compare the data.

Your guide: To help you examine and compare these different data sets collected over a period of 40 years, you will use the MESSENGER Water-Ice Data Exploration QuickMap: http://messenger.jhuapl.edu/Learn/water_ice_data.html .

1. Begin your exploration with a brief tutorial, accessible by clicking on the "?" at the bottom center of the QuickMap screen.

2. Describe the surface of Mercury that is visible in the Mariner 10 composite image. Does it remind you of the surface of any other Solar System body? If so, which one, and why?

   You can see many craters and smooth areas. There also appears to be some squiggly lines on the surface. The surface looks gray and white in color. The image looks a little grainy or blurry.

   It does have similar features to that of the Moon. Some students may say Mars with respect to the cratered and smooth area.

3. How do you think Mercury's surface came to look this way?

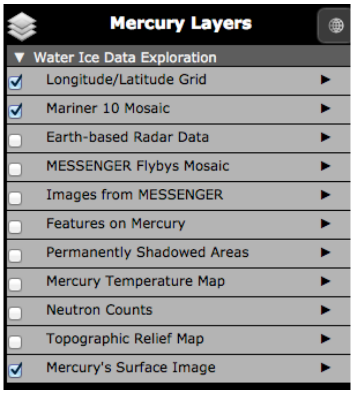
   Meteors or asteroids impacting the surface would create the craters. The smooth areas are caused my lava flow. The color of the surface may be do to the material of the surface.

4. Estimate the percentage of the North Polar Region, ≥ 65º N, that was imaged during the Mariner 10 flyby.

   ~35% These are estimations. A range from 33% to 40% would be acceptable.

5. Estimate the percentage of the North Pole, ≥ 85º N, that was imaged during the Mariner 10 flybys.

   ~ 43% These are estimations. A range from 40% to 45% would be acceptable.



Mercury Layers

▼ Water Ice Data Exploration

- ☑ Longitude/Latitude Grid ▶
- ☑ Mariner 10 Mosaic ▶
- ☐ Earth-based Radar Data ▶
- ☐ MESSENGER Flybys Mosaic ▶
- ☐ Images from MESSENGER ▶
- ☐ Features on Mercury ▶
- ☐ Permanently Shadowed Areas ▶
- ☐ Mercury Temperature Map ▶
- ☐ Neutron Counts ▶
- ☐ Topographic Relief Map ▶
- ☑ Mercury's Surface Image ▶

6. Does the distribution of the radar-bright patches seem to follow any pattern? Describe any pattern that you see.

   Circular in shape with a majority found at >80° N. There are some found in craters need the North Pole.

7. After MESSENGER's fly-bys of Mercury, how much of the surface still remained to be imaged?

   ~20 % - 25%

8. Compare and contrast the images of Mercury's surface obtained by Mariner 10 and MESSENGER as the crafts flew by the planet.

   Images from the Flyby are blurrier than from Mariner 10. The craters are less defined and appear to be smudges. There appears to be more smoother areas and less craters in general.

9. In your answer to Question 5, you may have described a pattern for the distribution of radar-bright patches observed from Arecibo on Earth in 1989. Do you still see the same pattern? If you did not see a pattern before, do you see one now and what is it? (hint: look for associations between the different layers of data)

   The pattern is still the same as in the Mariner 10 image. None of the radar bright patches appear to overlap the Flyby data.

10. Describe the differences between the layer containing the MESSENGER Flyby Mosaic data and the Mercury's Surface Image.

    Clarity of images, amount of surface imaged, appearance of surface.

11. When you overlay the Earth-based Radar Data with Mercury's Surface Image, do you see a pattern for the distribution of the radar-bright patches? Describe what you observe.

    Yes, there appears to be a pattern. The radar-bright patches appear to correlate with craters. These craters appear to be very dark. A majority of them are clustered near the North Pole of Mercury.

12. In what ways do these three data sets (Earth-based radar, topography, detailed surface image) relate to each other?

    The radar-bright areas appear to be in craters that are deeper than some of the other craters in the area

13. Do you think that this data is sufficient to conclude that there is water ice on Mercury at its poles? If so, why? If not, why not?

    The data is not sufficient to conclude that there is water ice on Mercury. One still does not know the composition of the radar-bright patches, temperature of the craters, or if the craters get sunlight that would cause the water ice to sublimate.

14. What other evidence would be helpful to confirm that there is water ice at Mercury's poles?

    Does the Sun illuminate the inside of the craters? What is the composition of the radar-bright material found in the craters near the North Pole. What is the temperature of inside the craters?

15. Mercury is the closest planet to the Sun. How could it be possible for water ice to be stable anywhere on its surface?

    If the craters at the poles were permanently shadowed regions, then the interior portion of the crater would never be illuminated by the Sun or heat up. As a result, there would not be any sublimation.

16. How does the additional layers support or oppose your answer to number 15?

    The extra data layers provide the following information:

    - The luminosity of the interior portion of the craters - (Permanently Shadowed Areas). The inside of these craters remain in shadow.
    - The temperature inside the craters remains low, so there is no sublimation. (Mercury Temperature Map)
    - The decrease in the detection of neutrons allows scientists to infer water ice. (Neutron Count)

    Rewrite of numbers 13-15, if applicable

17. Do you think that this data is sufficient to conclude that there is water ice on Mercury at its poles? If so, why? If not, why not?

    ____

    ____

    ____

18. What other evidence would be helpful to confirm that there is water ice at Mercury's poles?

    ____

    ____

    ____

19. Mercury is the closest planet to the Sun. How could it be possible for water ice to be stable anywhere on its surface?

20. How does the additional layers support or oppose your answer to number 14?

Part II – Measuring Craters

21. Crater measurements. Choose three of the following craters to measure their diameter and depth.

- Mendelssohn
- Prokofiev
- Tolkien
- Fuller
- Goethe
- Chesterton

Crater Name:	Mendelssohn	Prokofiev	Tolkien	Fuller	Goethe	Chesterton
Actual Diameter	291.06 km	112 km	50 km	26.97 km	308.97 km	37.23 km
Possible range of Depth	-2450 km to -2550 km	-4460 km to –5350 km	-3580km to -3660	-4190km to -4220km	-2850km to -2920km	-3500km to -3730km

Depths will vary depending on where the measurement is taken.

22. Using your average diameter, calculate the percent error in your measurements of the craters.

$$\text{Percent Error} = \frac{|\text{Approximate Value - Exact Value}|}{|\text{Exact Value}|} \times 100\%$$

To locate the actual crater diameters, double click on the crater names in QuickMap. The pop-up screen will provide the necessary information.

Crater Name:			
Actual Diameter			
Percent Error			

23. Explain the source(s) of your error.

Possible sources of error:

- The way that in which the students measured the crater diameter.
- Not being able to see the whole crater, so estimations are made.
- Crater is not completely circular.
- Did not measure through the center of the crater.