National Aeronautics and
Space Administration

CRATER COMPARISONS

Investigating Impact Craters on Earth and Other Planetary Worlds

TEACHER GUIDE

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Teacher Guide

Goal: This activity is designed to introduce students to the process of science through the completion of a structured mini-research investigation focusing on impact craters on Earth and other planetary worlds in our Solar System.

Aside from providing a meaningful context in which to enable students to gain experience with the process of science (sometimes referred to as the scientific method), this activity helps students learn about geologic processes and how through studying impact craters we can better understand the history of our Solar System.

Objectives: Students will:

1. Identify the causes and formation of impact craters
2. Identify characteristics of impact craters
3. Compare and contrast characteristics of impact craters
4. Infer details about the geologic history of planetary worlds through observations made of crater characteristics and the application of geologic principles
5. Carry out a mini-research investigation by modeling the process of science and completing the following steps:
    1) Asking preliminary questions
    2) Making initial observations
    3) Applying background knowledge
    4) Implementing an experiment design to answer a specific scientific question
    5) Collecting and compiling data
    6) Displaying data
    7) Analyzing and interpreting data
    8) Drawing conclusions and considering potential implications of research

Grade Level: 6 – 8*****
**Grade Level Adaptations:* This activity can also be used with students in grades 5 and 9-12. Students in grades 9-12 should be able to work through the activity more independently than younger grade level students. For younger students it is recommended to check for comprehension of each section as students step through this research process.

Grouping Suggestions: (Note: This activity includes data for 6 planetary worlds)

- Have the class work in groups of 4 or more students.
- Consider having each group focus on a different planetary world **OR** have multiple groups focus on a subset of planetary worlds (i.e. 2 groups focus on Earth, 2 groups focus on Earth's Moon, and 2 groups focus on Mars).

Time Requirements: This activity can be completed in 10-16 class periods. Class periods are based on a 45-minute session. **Class Time Saver** suggestions are provided, where applicable, in the activity procedures section. These suggestions generally include having students complete minimal amounts of independent reading at home.

Below are estimated time requirements for each section of the activity:

- PART 1: OBSERVATIONS AND PRELIMINARY QUESTIONS: ~20 minutes
- PART 2: BACKGROUND INFORMATION ON IMPACT CRATERS: ~1-2 class periods
- PART 3: GEOLOGIC HISTORY PRACTICE SCENARIOS: ~1-2 class periods
- PART 4: INITIAL OBSERVATIONS AND THE BIG PICTURE: ~1 class period
- PART 5: CONTINUING OUR CRATER INVESTIGATION: ~6-10 class periods
- PART 6: EVALUATE: ~20-30 minutes

(Procedures for each part of this activity are included in the ACTIVITY PROCEDURES Section of this guide.)

Materials:

- *CRATER COMPARISONS Student Guide*
- Data Collection Table Handout
- Earth Impact Crater Images (1 set per group) [12 total images]
- Planetary Impact Crater Images (1 set per group)
  NOTE: You can decide to focus on 1 planetary body or multiple planetary bodies, as desired. Image sets provided for this activity include images of **Earth's Moon** [14 total images], **Mars** [12 total images], **Venus** [8 total images]**, Mercury** [11 total images], and **Vesta** (an asteroid) [10 total images].
- Crater Image Metadata Handout
- Crater Comparison Assessment
- Computers (optional)
- Information on planetary worlds being investigated (either through lithographs, books, or posters you may have or through the use of the *Useful Websites* listed on page 5.)

Printing Alternative: As your resources permit, you can download the PDF of the *Crater Comparisons Student Guide* on your student computers and have students fill in answers to questions, save their work, and continue each day without printing anything. This will work with Adobe Reader, which is freely downloadable at http://www.adobe.com/products/reader.html. It is recommended to have students check to make sure their work will save as they begin.

STANDARDS ALIGNMENT
Next Generation Science Standards:
Disciplinary Core Idea

- ESS1C. History of Planet Earth

Science and Engineering Practices

- Practice 1: Asking Questions and Defining Problems
- Practice 3: Planning and Carrying Out Investigations
- Practice 4: Analyzing and Interpreting Data
- Practice 5: Using Mathematics and Computational Thinking
- 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 2. Cause and Effect 3. Scale, Proportion, & Quantity
- 6. Structure and Function 7. Stability and Change

Nature of Science

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural System
- Science is a Human Endeavor
- Science Addresses Questions about the Natural and Material World

NCTM Principles and Standards: Content Standards

- Number and Operations
- Patterns, Functions, and Algebra
- Geometry and Spatial Sense
- Measurement
- Data Analysis, Statistics, and Probability

NCTM Principles and Standards: Process Standards

- Problem Solving
- Reasoning and Proof
- Communication
- Connections
- Representation

Common Core State Standards: Mathematical Practices

- Make sense of problems and persevere in solving them.
- Reason abstractly and quantitatively.
- Construct viable arguments and critiques the reasoning of others.
- Model with mathematics.
- Use appropriate tools strategically.
- Attend to precision.
- Look for and make use of structure.
- Look for and express regularity in repeated reasoning.

Common Core State Standards: Content Standards

- Ratios and Proportional Relationships
- The Number System
- Expressions and Equations
- Functions
- Geometry
- Statistics and Probability

Geography Standards:

- The World In Spatial Terms
- Places and Regions

Technology Standards:

- Basic Operations and Concept
- Social, Ethical, and Human Issues
- Technology Productivity Tools
- Technology Communication Tools
- Technology Research Tools

TEACHER OVERVIEW AND INTRODUCTION:

To effectively prepare the nation's future Science, Technology, Engineering, and Mathematics (STEM) workforce, students in today's classrooms need opportunities to engage in authentic experiences that model skills and practices used by STEM professionals. Relevant, real-world authentic research experiences allow students to behave as scientists as they model the process of science. This enables students to get a true sense of STEM-related professions and also allows them to develop the requisite knowledge, skills, curiosity, and creativity necessary for success in STEM careers. The importance of these skills is evident in the restructuring of science education standards into the Next Generation Science Standards. These standards require K-12 science educators to infuse activities into their standard curriculum that allow students to experience science and engineering practices.

This activity addresses the Next Generation Science Standards while recognizing students potentially lack experience with scientific practices involved in conducting research. This inexperience may lead to challenges facilitating research in the classroom, or lead to a less than successful or incomplete research experience for students. This activity is designed as an entry level research engagement activity that introduces, illustrates, and teaches the skills involved in each step of the scientific research process. Students actively participate in each step of the process of science as they complete a structured comparative planetology research investigation. Students begin the activity by making observations and asking questions about impact craters found on different planetary worlds. As students continue with the activity they gain knowledge in the causes and formation of impact craters and learn to identify characteristics of these features that provide insight into the surface history. Students then make observations of these characteristics as they gather, display, analyze, and interpret data to carry out the structured investigation.

Overarching Goals and Structure of Activity:

- **Parts 1 through 4**: A) Informally introduces students to Steps 1-3 of the process of science; B) Helps lay the foundation to complete the remaining aspects of the investigation.
- **Part 5**: A) Formally introduces the process of science; B) Introduces, illustrates, and guides students through each of the remaining steps involved in the process of science.
- **Part 6:** A) Assesses student mastery of objectives.

By helping students model the process of science using this activity, they can gain experience modeling the skills and practices used by actual scientists and think more critically when conducting a future investigation.

Earth and Planetary Images Used in the Activity

Planetary imagery can vary in many ways. This includes the type of data (visible, radar, elevation, etc.) as well as the size of the features shown in the image. It is useful for students to develop an awareness of these aspects. For this activity, students are not be required to understand the intricate details of these different data sets. Students should focus on the physical characteristics of the surface (the morphology), which is observable in each of the images included in this activity.

A few notes about the images used in this activity:

- Images of craters on Earth were taken by astronauts on the International Space Station (ISS) or Space Shuttle.
- Images of other planetary worlds were mostly taken by robotic spacecraft. (Some images of the surface of the Moon were taken by astronauts.)
- Images of Venus are radar images. Brightly colored features in radar images indicate a rough, rocky surface. Darker colored features indicate smoother areas.
- Some images of Mars were taken with an Infrared Imaging system (THEMIS IR). Brighter versus darker features on an IR image can provide specific information related to temperature and surface characteristics. Students only need to be able to identify physical characteristics or craters observed in images.
- The Mars Orbital Laser Altimeter (MOLA) image of Hellas Planitia on Mars is showing elevation data. Students should note the scale on the bottom of that image.

Addressing the Challenges of Research in the Classroom

Some of the challenges of conducting research in the classroom can be in how to:

- help students formulate an answerable research question during a reasonable amount of class time,
- help students organize their research,
- engage the entire class in the same research activity,
- make sure students will be able to obtain the data they need to successfully complete their research.

This activity addresses these potential challenges by providing structured suggestions and providing all the resources needed to complete this investigation. Aside from the formatted images, this activity also includes the accompanying metadata for each image as well as formatted data collection sheets. The “all-inclusive” nature of this activity allows students to focus on gaining experience in the process of science.

Connection to NASA’s Expedition Earth and Beyond Program

This activity is designed as part of NASA’s Expedition Earth and Beyond (EEAB) program (http://ares.jsc.nasa.gov/education/eeab/). EEAB aims to actively involve students in NASA exploration, discovery, and the process of science. The process of science structure used for this activity is based on the Expedition Earth and Beyond (EEAB) Student Scientist Guidebook. Many of the images used for this activity come from other EEAB activities such as the Blue Marble Matches activity (http://ares.jsc.nasa.gov/education/eeab/blue-marble-matches.html). Images have been reformatted and additional information has been provided specifically to assist students with the research conducted through this activity.

Benefits of Extending Research in the Classroom

The Expedition Earth and Beyond Program encourages teachers to have their students expand on this *Crater Comparison* research investigation or initiate their own unique investigation. Through these extensions of research in the classroom, students have the opportunity to benefit from two unique and powerful resources:

- **Access to a mentor:** Students expanding on this research or initiating a new research investigation have the opportunity to work with a mentor. Mentors are STEM professionals who can provide helpful tips and input to students as they progress through their research.
- **Requesting new imagery of Earth from astronauts on the ISS:** To support student research, student teams can request new imagery of Earth to be obtained by astronauts on the International Space Station (ISS) through the Crew Earth Observation (CEO) team at the NASA Johnson Space Center. Image requests can be submitted online at: http://eol.jsc.nasa.gov/RequestNewImagery/EEAB.htm

Useful Websites:

- Expedition Earth and Beyond Program: http://ares.jsc.nasa.gov/education/eeab/
- Gateway to Astronaut Photography of Earth: http://eol.jsc.nasa.gov
- Planetary Photojournal: http://photojournal.jpl.nasa.gov
- Earth Impact Database: http://www.passc.net/EarthImpactDatabase/index.html
- Google Earth, Moon, and Mars: http://earth.google.com; http://www.google.com/moon/ http://www.google.com/mars/ [Other maps may be available.]
- Solar System Exploration: http://solarsystem.nasa.gov/planets/
- Exploring the Planets: http://nasm.si.edu/etp
- Impact Cratering: http://www.lpi.usra.edu/education/explore/shaping_the_planets/impact_cratering.shtml

Extensions:

Suggested extensions for this activity include (but are not limited to) having students:

1. Submit a Data Request for new imagery of craters on Earth to be taken from the ISS. Students can request imagery of:
   a. Craters they have already observed (but perhaps want to make additional observations of through the use of new imagery.)
   b. Other craters on Earth. To find other craters on Earth students can:
      - Look at the complete list of Earth Impact craters available on the Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html). (Note: This database provides information such as the location of impact craters on Earth, their estimated ages, diameters, and access to different types of imagery/data to observe these craters.)
      - Look for astronaut imagery of other impact craters on the Gateway to Astronaut Imagery of Earth (http://eol.jsc.nasa.gov). There are numerous ways to search for imagery. Students may want to use the location information obtained from the Earth Impact Database to do a search using the Google Map tool on this website (http://eol.jsc.nasa.gov/). Astronaut imagery of some craters may not exist. This can help justify a request for new imagery.

2. Design and complete their own unique crater-related investigation. This might entail formulating a new research question, hypothesis, and experiment design.
3. Design their own unique investigation on a topic of their choosing, using this investigation as a model.
4. Design a human or robotic mission to visit one of these planetary worlds.
5. Create scaled clay models of the different impact craters observed. This provides an additional way to display data and provides a tactile way to reinforce information learned about impact craters.

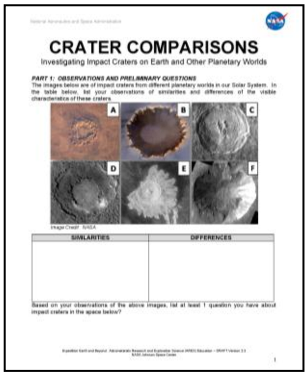
5-E Model of Inquiry: This activity is designed using the 5-E model of inquiry. This model of instruction is based on a constructive approach to learning where students learn by building or constructing new ideas by comparing new experiences to existing frameworks of knowledge. The 5-E model of instruction breaks this approach into 5 phases:

5-E Phase	**General Description**	**Crater Comparison Activity**
Engage	Teachers engage students using an activity, image, or discussion to focus students' thinking on the learning outcomes of an activity.	Students observe images and list similarities and differences of visible characteristics of impact craters. (Part 1)
Explore	Students actively explore and make discoveries using hands-on materials. Students develop concepts, processes, and skills to establish an understanding of content.	Students read background information about craters and geologic principles and develop the skills to help them establish an understanding of content through practice exercises. (Parts 2, 3, and 4)
Explain	Students communicate and explain concepts they have been exploring. Students use formal language and vocabulary associated with content.	Students use formal language and vocabulary associated with content in logged observations, data displays, analysis and interpretation of data and as they share (explain) their findings with the class. (Part 5: Steps 4, 5, 6, and 7 of the process of science)
Elaborate	Students extend conceptual understandings to new problems or experiences. Students reinforce and develop a deeper understanding of concepts and skills.	Students apply knowledge acquired to draw conclusions about impact craters on Earth and other planetary worlds and consider the potential implications in the "What Does It All Mean" section of the *Student Guide*. (Part 5: Step 8 of the process of science.)
Evaluate	Teachers and students assess new knowledge and understanding of key concepts.	Students complete the Crater Comparison Assessment. (Part 6: Assessment)

ACTIVITY PROCEDURES:

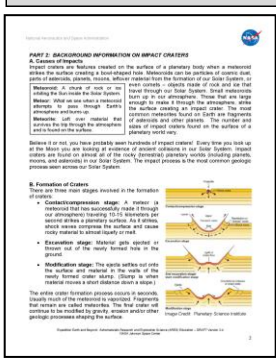
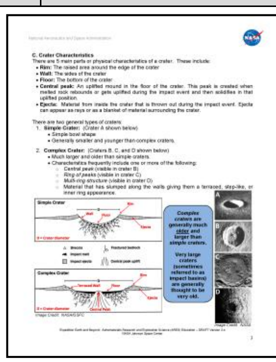
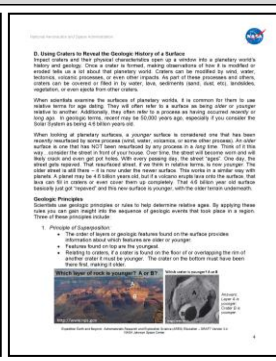
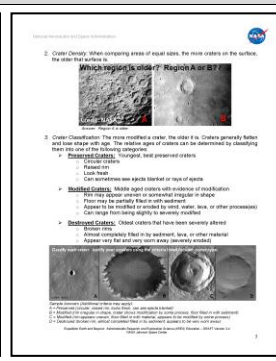
This set of activity procedures is provided as a suggested guide for the *Crater Comparisons* classroom activity. Estimated time frames for each section are provided but can vary depending on your level of students and time you feel is necessary for classroom discussions.

PART 1: OBSERVATIONS AND PRELIMINARY QUESTIONS (<u>E</u>ngage)	
Main Goal(s):	*A) Engage students by having them make observations of impact craters from different planetary worlds in our Solar System;* *B) Have students formulate an initial question;* *C) Assess student prior knowledge.*
Estimated Time:	*~20 minutes*
Class Time Saver:	*No recommendations*
Materials Needed:	• *Student Guide page 1*



1. Divide the class into groups consisting of ~4 students.
2. Give students ~12-15 minutes to list their observations of the set of images provided. Students should list similarities and differences of the visible characteristics.
3. As students list their observations, informally asses their prior knowledge. Be cognizant of any student misconceptions.
4. Ask students to list a question they have about impact craters (based on their observations) at the bottom of the page.
5. Begin a class discussion acknowledging student observations. If you detected any misconceptions, bring those up as potential discussion points. Revisit these items at the end of the activity.
6. Briefly discuss student questions, validating that all questions are good questions. Indicate the importance of considering how to answer a posed question.

PART 2: BACKGROUND INFORMATION ON IMPACT CRATERS (<u>E</u>xplore)	
Main Goal(s):	*Have students gain background information about impact craters and geologic principles used to reveal the geologic history of a surface.*
Estimated Time:	*~1-2 class periods*
Class Time Saver:	*Have students read pages 2-5 at home. Provide summary questions to help students pull out important information.*
Materials Needed:	• *Student Guide pages 2-5*

BACKGROUND INFORMATION: The *Background Information* section is divided into four sub-sections of information. Assign a section (A through D) to different groups of students so they can become responsible to share the information they read with the rest of the class. Students should be prepared to give a summary of the information they have read. The questions listed below may help students pull out important summary information. Alternatively, you may want to ask students to independently read each section (in class or for homework) and answer the questions provided below. Sections and summary questions include:

A) Causes of Impacts
   - How are impact craters created?
   - What is the difference between a meteoroid, meteor, and meteorite?
   - Where do we find impact craters?
   - What is the most common process seen across the Solar System?

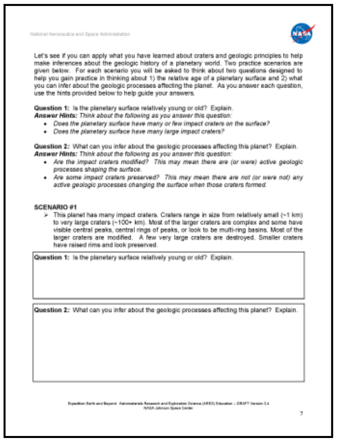
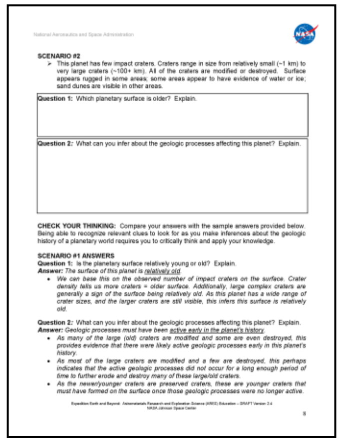
B) Formation of Craters
   - Briefly describe the following stages of crater formation:
     - Contact/Compression Stage
     - Excavation Stage
     - Modification Stage
   - Once a crater is formed, what forces or processes can modify the crater?
   - How long does the crater formation process take?

C) Crater Characteristics
   - Identify the 5 main parts or physical characteristics of a crater.
   - Describe at least two differences between a simple crater and complex crater. (NOTE: Make sure students include that complex craters are generally larger and older than simple craters)
   - Describe how a central peak forms.

D) Using Craters to Reveal the Geologic History of a Surface
   - What types of processes can modify, cover, or fill in a crater?
   - Describe what is meant by an *older* versus *younger* surface.
   - Briefly describe the following geologic principles or rules:
     - Principle of Superposition
     - Crater Density
     - Crater Classifications

As you discuss section D, be sure to review questions (practice exercises) included within the descriptions of the three geologic principles. Even though the answers are provided, reinforce to students the importance of justifying, explaining, and supporting answers with evidence. In science, this is oftentimes more important "the answer". It is not uncommon for scientists to disagree on "answers". The most convincing way to justify a given point of view is through specific evidence that helps support your thinking.

PART 3: GEOLOGIC HISTORY PRACTICE SCENARIOS (**E**xplore)	
Main Goal(s):	*Have students practice applying the knowledge they have learned about impact craters and geologic principles.*
Estimated Time:	*~1-2 class periods*
Class Time Saver:	*Have students read pages 6-9 at home. Students could also complete the two Practice Geologic Scenarios independently. Be sure to discuss in class as these scenarios directly relate to the research students will complete as part of this activity.*
Materials Needed:	• *Student Guide pages 6-9*


Read over the information provided on page 6 together as a class. This leads students into completing the practice scenarios provided in this section. These scenarios directly relate to the research students will complete as part of this activity. The two different scenarios are provided to help illustrate how students can apply the geologic principles they have learned to make inferences about planetary surfaces. Students are asked to answer two questions related to 1) the relative age of a planetary surface and also 2) what the information provided allows them to infer about the geologic processes affecting the planet. The following hints are provided to help students learn how to apply the background knowledge they have read towards answering these types of questions.

Question 1: Is the planetary surface relatively young or old? Explain.
Answer Hints: *Think about the following as you answer this question:*

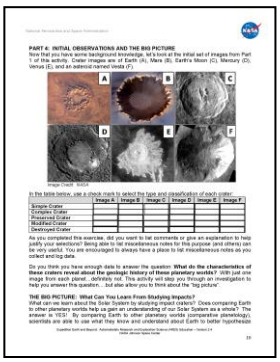
- *Does the planetary surface have many or few impact craters on the surface? (Crater density tells us the more crater on the surface, the older the surface is.)*
- *Does the planetary surface have many large impact craters? (Large impact craters are generally old craters.)*

Question 2*:* What can you infer about the geologic processes affecting this planet? Explain.
Answer Hints: *Think about the following as you answer this question:*

- *Are the impact craters modified? This may mean there are (or were) active geologic processes shaping the surface.*
- *Are some impact craters preserved? This may mean there are not (or were not) any active geologic processes changing the surface when those craters formed.*

Answers to these scenarios are provided so students can check their thinking. Discuss the scenarios and answers with students to ensure their understanding. Again, justification of their thought process is key. This section ends by planting the seed so students can think about other big picture questions related to studying impacts and these planetary worlds.

PART 4: INITIAL OBSERVATIONS AND THE BIG PICTURE (**E**xplore)	
Main Goal(s):	*A) Briefly experience and reflect on logging specific observations;* *B) Think about the "big picture" and the relevance of studying impact craters.*
Estimated Time:	*~1 class period*
Class Time Saver:	*If you run out of time reading the information on the bottom of page 10 and 11, have students read this information for homework.*
Materials Needed:	• *Student Guide pages 10-11*




INITIAL OBSERVATIONS: Now that students have some background knowledge, have them log initial observations related to specific characteristics visible in the crater images into the table provided. After students log their observations, ask them the following questions:

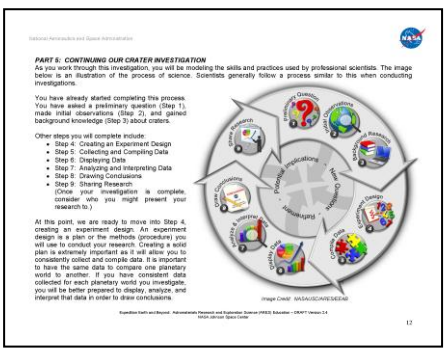
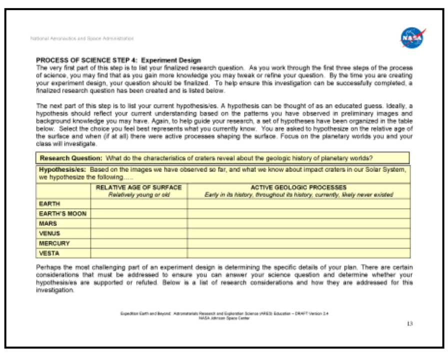
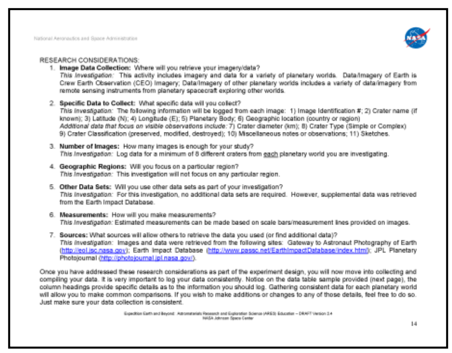
a) Did you want to make comments about some of the observations you were logging as opposed to just putting in a check mark? (Hopefully students will say yes to this, reinforcing the idea that sometimes it is important to include miscellaneous notes as part of logging your observations.)
b) Can you now answer the following question: **What do the characteristics of these craters reveal about the geologic history of these planetary worlds?** Students should realize that they cannot answer this question with one data point. This should also lead into the idea that they will be conducting an investigation to help them answer this question as well as think about the "big picture" and the relevance of studying impacts.

THE BIG PICTURE: What Can You Learn From Studying Impacts?

- As a class (or for homework), read over the information provided to help reinforce the relevance of studying impact craters.
- Students should leave this section thinking about the implications (the "big picture") of how studying impact craters will allow them to: 1) better understand the history of our Solar System, 2) make predictions about potential future impacts, and 3) better understand factors that may influence future robotic or even human exploration of other worlds.

PART 5: CONTINUING OUR CRATER INVESTIGATION Steps 4-8 of the Process of Science (Explain and Elaborate)	
Main Goal(s):	Introduce, illustrate, and provide guided experience with the steps involved in the process of science.
Estimated Time:	*~6-10 class periods [NOTE: Each step of the process of science included in Part 5 (Steps 4 – 8) is explained below. Each explanation includes a breakdown of materials needed and an estimated time for the completion of that step.]*
Class Time Saver:	*Individual recommendations for steps 4-8 of the process of science are included in the descriptions provided below.*
Materials Needed: *Listed handouts are available at the end of this Guide.* *Image resources are available as a separate file.*	• *Student Guide pages 12-25* • *Data Collection Table Handout* • *Earth Impact Crater Images (1 set per group)* • *Planetary Impact Crater Images (1 set per group) [NOTE: You can decide to focus on 1 planetary body or multiple planetary bodies, as desired. Image sets provided for this activity include images of Earth's Moon, Mars, Vesta, Mercury, and Venus.]* • *Crater Image Metadata Handout*

STEP 4: EXPERIMENT DESIGN	
Main Goal(s):	*Finalize the research question, hypotheses, and develop a research plan.*
Estimated Time:	*~1 class period*
Class Time Saver:	*If necessary, have students read page 14 for homework.*
Materials Needed:	• *Student Guide pages 12-14*

OVERVIEW OF THE PROCESS OF SCIENCE:

Let students know that as scientists conduct investigations, they follow what we call the process of science. The graphic on page 12 of the *Student Guide* shows an illustration of that process. Tell students they have already completed Steps 1–3 of this process. Step 1 included their Preliminary Question about impact craters based on their initial observations. Step 3 included their gain of background knowledge about impact craters. Step 2 enabled them to make a set of structured initial and more informed observations about the impact craters and geologic principles. This part of the activity will introduce, illustrate, and guide students through

Steps 4 – 8 including: Experiment Design (Step 4), Collecting and Compiling Data (Step 5), Displaying Data (Step 6), Analyzing and Interpreting Data (Step 7), and Drawing Conclusions (Step 8). Though it is not a formal part of this activity, Sharing Research (Step 9) is an important part of the process of science. We encourage you to have your students present their research to an administrator, school board, parents, or other suitable audiences.

Although students may notice the steps shown in the process of science illustration are numbered from 1 – 9, make sure they are aware that it is very common for scientists to move back and forth among these steps. This is what makes this process a very iterative process. For example, scientists oftentimes refine their research question as they make initial observations and gain more knowledge about the feature and process they may be investigating. However, once that final research question is defined, a plan needs to be put in place in order to answer that question with supporting evidence. This plan, called the Experiment Design, is part of Step 4 of the process of science. Establishing a research question and developing an appropriate experiment design are critical aspects of any research investigation.

PROCESS OF SCIENCE STEP 4: EXPERIMENT DESIGN:

1. QUESTION AND HYPOTHESIS: Let students know that defining an experiment design can be challenging, especially if you have little experience defining a research plan. For starters, students should become familiar with the research question and come up with their hypothesis/es. The hypothesis structure for this activity is designed to have students formulate a hypothesis related to the relative age of a planetary surface and also a hypothesis about when (if at all) there were active geologic processes shaping that surface. Students should focus on whichever planetary worlds the class will focus on as a whole. Students should base their hypotheses on what they may already know or observations they have previously made of craters. Too often students believe a hypothesis is just a guess. They should realize that a hypothesis is an educated guess based on what they may already know or what they have observed. The additional research they do, along with specific data they collect, will allow them to determine if their original hypotheses are supported or refuted.

Research Question: What do the characteristics of craters reveal about the geologic history of planetary worlds?

Hypothesis/es: Based on the images we have observed so far, and what we know about impact craters in our Solar System, we hypothesize the following…..

	RELATIVE AGE OF SURFACE *Relatively young or old*	**ACTIVE GEOLOGIC PROCESSES** *Early in its history; throughout its history; currently; likely never existed*
EARTH		
EARTH'S MOON		
MARS		
VENUS		
MERCURY		
VESTA		

Table from Student Guide showing research question and suggested hypothesis/es. Feel free to have students make adjustments to how they write their hypotheses. Hypotheses, however, should address relative age of a surface and existence of active geologic processes.

2. EXPERIMENT DESIGN: The plan or experiment design for any research investigation is driven by the research question and hypotheses. This drives the data that will be collected in order to draw conclusions. Review the information listed that needs to be considered in order to complete this investigation. These seven items basically parallel important considerations for any type of research investigation. They include:

1) ***Image Data Collection:*** It is important to know where you will retrieve your data. In this activity, the data (images) have already been organized so students can focus on logging metadata and observations. Finding useful image data can sometimes be very time consuming.

2) ***Specific Data to Collect:*** Students need to think about the specific data they will collect and log from every image observed. It is important to be as consistent (and detailed) as possible with data collection. It can be challenging for students to determine what data to collect, especially if they have little experience conducting research. The data students will collect for this investigation is aligned with the question being posed.

3) ***Number of Images*****:** Students should consider the number of images or data points they would like to collect. The more data collected, the more evidence they will have to support their conclusions. For this activity students are recommended to log information for at least 8 different craters for each planetary world being studied. This is a minimal amount of data, but enables students to gain experience in the process without being overwhelmed. Students may find that the number of images they use for their research could be considered a limitation -- which is an aspect of research they will be asked to consider later in the activity.

4) ***Geographic Region:*** Students should think about whether they will focus on a specific geographic region. Since there is no one specific region in which we find impact craters on Earth, this investigation will not focus on any particular region.

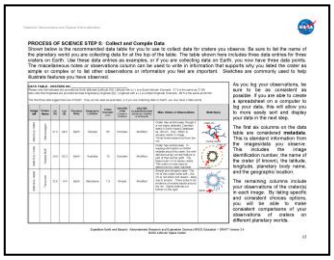
5) ***Other Data Sets:*** It is important for students to consider if other data sets are necessary to complete their investigation. In this investigation, aside from the imagery provided, no additional data sets are required. However, supplemental data was retrieved from the Earth Impact Database.

6) ***Measurements*****:** If students plan to include measurements in their research, they should be able to indicate how they will obtain those measurements. In this activity either a scale bar or measurement reference line has been included on each available image.

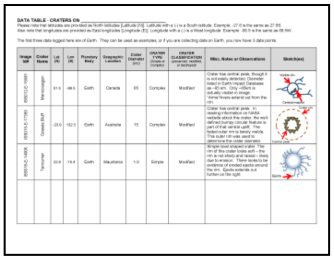
7) ***Sources:*** Students should list the sources of their data retrieval. This enables others to make observations of the same images included in the research, or look for additional data.

There is certainly a lot to think about when designing a research investigation. For this investigation, the information has been structured and provided to help students gain experience in this aspect of their research. By discussing this information with students, they can reflect on and be better prepared to critically think about these important considerations if they were to design a future research investigation.

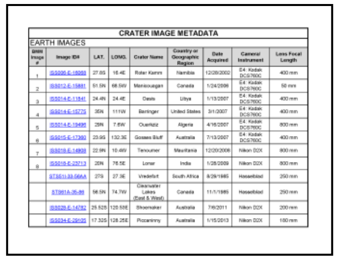
STEP 5: COLLECT AND COMPILE DATA	
Main Goal(s):	*Enable students to gain experience collecting data.*
Estimated Time:	*~1-2 class periods*
Class Time Saver:	*No recommendations.*
Materials Needed: *Extra data collection sheets and crater image metadata are available at the end of this Guide.*	• *Student Guide pages 15* • *Hard copy (and/or spreadsheet of) data collection sheets* • *Crater Image Metadata* • *Images of impact craters (8-14 images per planetary body)* • *Access to computers (optional)*



Student Guide page 15



Data Collection Sheet



Metadata (1 page for each world)

Sample Image of Earth

(Not shown: Sample thumbnail image of Mars, Earth's Moon, Mercury, Venus, and Asteroid Vesta.

1. GETTING ORGANIZED: This step in the process of science will give students experience collecting and compiling data. It is strongly recommended that you have your students create a spreadsheet (Excel or Google spreadsheet for example) to input their data. This will allow them to more easily sort the data, which will be useful as they later display their data. If you have access to computers, assign 1-2 students within the group to take on the responsibility of compiling the data from the rest of the group into the spreadsheet. SUGGESTION: While some students are logging data on hard copy data collection sheets, have your designated "excel" students input the data into a computer spreadsheet. The end result will be a complete master data table in both hard copy and electronic format.

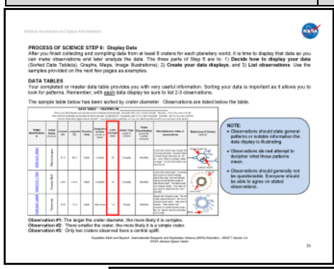
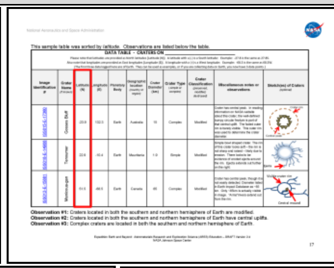
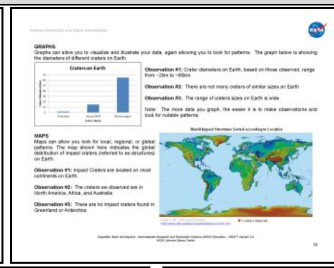
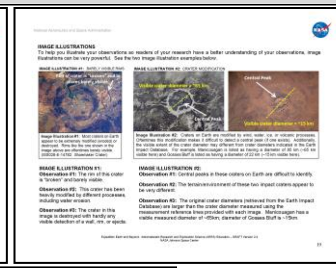
This investigation enables students to compare their findings from studying craters on Earth with craters on other worlds. One way to approach this is to have different groups of students focus on different planetary worlds. If you have 6 groups of students, 1 group can focus on Earth, while the others focus on Earth's Moon, Mars, Vesta, Mercury, and/or Venus. Alternatively, you may want to focus on a few of these planetary worlds and would therefore assign multiple groups to the same planetary world.

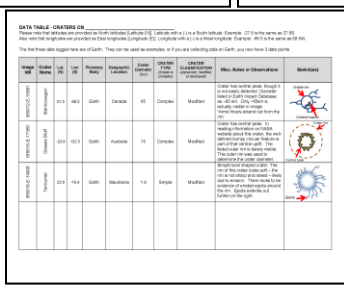
2. COLLECTING DATA:

- Provide student groups with the following:
  - Planetary images of the specific world they will focus on
  - Crater Image Metadata Handout (for the specific world they will focus on)
  - Hard copy data collection sheets

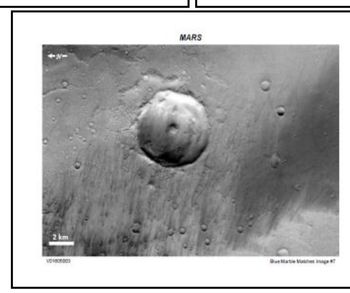
Students should aim to collect data on at least 8 different impact craters found in images of their planetary world. Make sure students log data consistently.

STEP 6: DISPLAY DATA	
Main Goal(s):	*Enable students to gain experience creating data displays and listing observations of those displays.*
Estimated Time:	*~1-2 class periods*
Class Time Saver:	*No recommendations.*
Materials Needed: *Extra data collection sheets and crater image metadata are available at the end of this Guide.*	• *Student Guide pages 16-19* • *Hard copy (and/or spreadsheet of) data collection sheets* • *Images of impact craters (8-14 images per planetary body)* • *Butcher paper (optional) and markers or colored pencils*


Data Collection Sheet

Sample Image of Earth



Sample Image of Mars

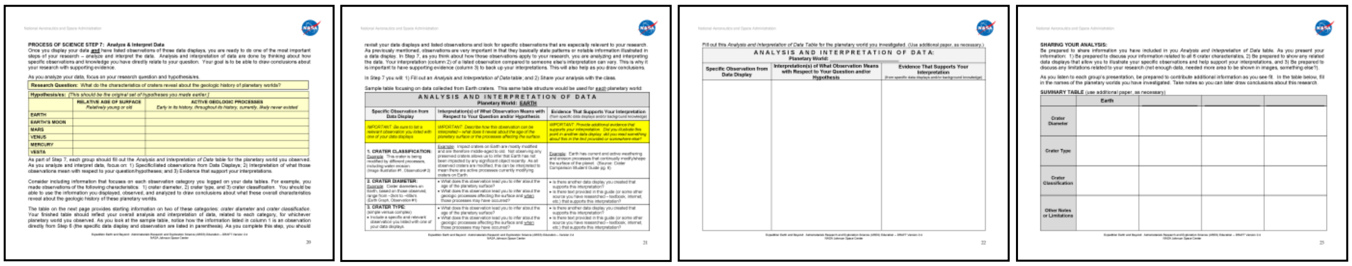
(Not shown: Sample thumbnail image of Earth's Moon, Asteroid Vesta, Mercury, and Venus)

Depending on the level of your students and how much guidance you feel they need, have them read over the PROCESS OF SCIENCE STEP 6: Data Display section in the *Student Guide* (pages 16 – 19). Each group will need to:

- ***Decide how to display their data*****:** There are 4 suggested data display options: 1) Sorted data tables, 2) Graphs; 3) Maps; 4) Image Illustrations.
- ***Create those data displays:*** Students within each group should divide up how they want to organize themselves to create those data displays.
- ***List observations of each data display:*** As students finish any data display, they should list 2-3 observations of what the data are showing. Remind students that observations state general patterns or trends. They do not attempt to decipher what those patterns mean.

Students should use the examples provided in the *Student Guide* for guidance and/or data display options they may want to consider. Have students create data displays on butcher paper or on 8 ½ X 11" paper. Remind students to list 2-3 observations with each data display.

STEP 7: ANALYZE & INTERPRET DATA	
Main Goal(s):	*Enable students to gain experience analyzing and interpreting data.*
Estimated Time:	*~2-3 class periods*
Class Time Saver:	*No recommendations.*
Materials Needed:	• *Student Guide pages 20-23* • *Student created data displays and listed observations*



Step 7, the analysis and interpretation of data, is one of the most important aspects of any research investigation. It can also be a challenging step for many students.

For starters, students should revisit the research question and the original hypotheses they listed in Step 4 of this process. As they analyze the data, their analysis should focus and directly relate to these aspects of their research. To complete this step, students will: 1) fill out an *Analysis and Interpretation of Data* table and 2) share their analysis with the class.

1. COMPLETING THE ANALYSIS & INTERPRETATION OF DATA TABLE: The *Analysis & Interpretation of Data* Table provided should help students organize their thoughts. As students analyze and interpret data, it is important that they focus on:

- ***Column 1: Specific observations from Data Displays:*** Students should list previously written observations (from Step 6) that they feel are especially relevant to the research question/hypotheses. To help reinforce that they are listing previously made observations, the sample information listed includes the data display name and observation # in parenthesis after each listed observation in column 1.

- ***Column 2: Interpretation of What Observation Means with Respect to Your Question and/or Hypothesis:*** Students should state or explain how they think the listed observation connects and applies to their question and/or hypotheses. Specifically, students should describe what their listed observation allows them to infer about the age of the planetary surface or the processes affecting the surface.

These first two columns are similar to *IF….THEN….* statements. ***IF***….*name a specific observation*….***THAN***….*describe what that might mean with respect to the research.*

- ***Column 3: Evidence That Support Your Interpretation:*** Students should list additional evidence that supports their interpretation. Supporting evidence could be from another data display they created and/or background knowledge they may have learned that supports this interpretation.

To help students complete this table, it is suggested that they aim to include information related to crater diameter, crater type, and crater classifications.

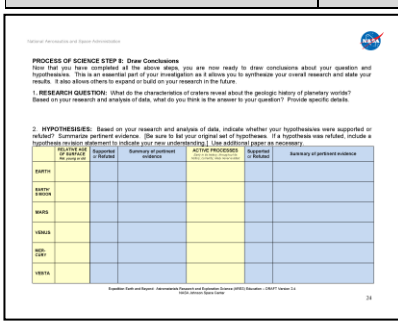
2. SHARING FINDINGS

As students will have put together data and information from different planetary worlds, each group should briefly present this information to the rest of the class. Each group of students should be prepared to share information they have included in the *Analysis and Interpretation of Data* table. As students present their information they should:

1. Be prepared to discuss information related to crater diameter, crater type, and crater classification.
2. Be prepared to show any related data displays that allow them to illustrate their specific observations and help support their interpretations.
3. Be prepared to discuss any limitations related to their research. This may include aspects such as needing more data to better complete the research, needing more area to be visible in images to better detect possible ejecta blankets, etc. Acknowledging limitations of research is an important consideration for any researcher.

As students listen to each group's presentation, they should contribute additional information as they see fit. Students should also take notes as other groups present. This will help them draw conclusions. A summary table for notes is provided on page 23 of the *Student Guide.*

STEP 8: DRAW CONCLUSIONS	
Main Goal(s):	A) Enable students to gain experience drawing conclusions about their research including answering their science question and indicating whether their original hypotheses were supported or refuted; B) Have students think about how their investigation of impact craters is related to the "big picture".
Estimated Time:	*~1-2 class periods*
Class Time Saver:	*No recommendations.*
Materials Needed:	• *Student Guide pages 24-25*



PROCESS OF SCIENCE STEP 8: Draw Conclusions

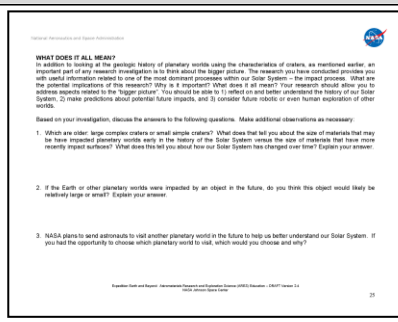
Now that you have completed all the above steps, you are now ready to draw conclusions about your question and hypothesis/es. This is an essential part of your investigation as it allows you to synthesize your overall research and state your results. It also allows others to expand or build on your research in the future.

1. **RESEARCH QUESTION:** What do the characteristics of craters reveal about the geologic history of planetary worlds? Based on your research and analysis of data, what do you think is the answer to your question? Provide specific details.

2. **HYPOTHESIS/ES:** Based on your research and analysis of data, indicate whether your hypothesis/es were supported or refuted? Summarize pertinent evidence. [Be sure to list your original set of hypotheses. If a hypothesis was refuted, include a hypothesis revision statement to indicate your new understanding.] Use additional paper as necessary.

	RELATIVE AGE OF SURFACE	Supported or Refuted	Summary of pertinent evidence	ACTIVE PROCESSES	Supported or Refuted	Summary of pertinent evidence
EARTH						
EARTH'S MOON						
MARS						
VENUS						
MER-CURY						
VESTA						

24



WHAT DOES IT ALL MEAN?

In addition to looking at the geologic history of planetary worlds using the characteristics of craters, as mentioned earlier, an important part of any research investigation is to think about the bigger picture. The research you have conducted provides you with useful information related to one of the most dominant processes within our Solar System – the impact process. What are the potential implications of this research? Why is it important? What does it all mean? Your research should allow you to address aspects related to the "bigger picture". You should be able to 1) reflect on and better understand the history of our Solar System, 2) make predictions about potential future impacts, and 3) consider future robotic or even human exploration of other worlds.

Based on your investigation, discuss the answers to the following questions. Make additional observations as necessary:

1. Which are older: large complex craters or small simple craters? What does that tell you about the size of materials that may be have impacted planetary worlds early in the history of the Solar System versus the size of materials that have more recently impact surfaces? What does this tell you about how our Solar System has changed over time? Explain your answer.

2. If the Earth or other planetary worlds were impacted by an object in the future, do you think this object would likely be relatively large or small? Explain your answer.

3. NASA plans to send astronauts to visit another planetary world in the future to help us better understand our Solar System. If you had the opportunity to choose which planetary world to visit, which would you choose and why?

25

DRAW CONCLUSIONS: Based on information presented and shared, students should be able to provide an answer to the research question as well as indicate whether their initial hypotheses were supported or refuted.

When answering the research question, students should frame their answer to indicate what the characteristics of craters can reveal about the geologic history of a planetary world. Students should briefly explain how specific crater characteristics allow them to determine if the surface is relatively young or old and when (if at all) the planetary world had active processes. NOTE: Information related to a specific planetary world should be included in the hypothesis/es section.

***RESEARCH QUESTION & SAMPLE ANSWER**:*

What do the characteristics of craters reveal about the geologic history of planetary worlds? *Characteristics of craters can help reveal whether a planetary surface is relatively young or old and approximately when that planetary surface may have had active geologic processes. Specific characteristics that enable you to do this include the sizes and classifications of craters. For example, a planetary world with many craters, including relatively large craters is likely old. If the craters are modified or destroyed, this can lead you to infer the planetary world had active processes at some point in its history. Finding preserved craters on a planetary surface may indicate that active geologic processes modifying the surface of that world no longer existed when those impact craters were formed.*

HYPOTHESIS/ES: Answers will vary. Students should indicate whether their original hypotheses were supported or refuted AND should include a brief summary of pertinent evidence. Additionally, if a hypothesis was refuted, students should include a HYPOTHESIS REVISION statement indicating their new understanding. See sample answers in the table below.

	RELATIVE AGE OF SURFACE *Rel. young or old*	**Supported or Refuted**	**Summary of pertinent evidence**	**ACTIVE PROCESSES** *Early in its history, throughout its history, currently, likely never existed*	**Supported or Refuted**	**Summary of pertinent evidence**
EARTH	*relatively young*	*Supported*	*-relatively few craters -variety of crater sizes, some large but most relatively small*	*currently*	*Supported*	*-most of the craters are modified or destroyed illustrating Earth has active processes modifying these craters.*
EARTH'S MOON	*relatively old*	*Supported*	*-lots of craters -large number of both large and small craters*	*likely never existed*	*refuted*	*-older larger craters are modified or destroyed. -smaller craters preserved -**HYPOTHESIS REVISION:** geologic process active relatively early in the Moon's history.*
MARS	*relatively old*	*Somewhat refuted:*	*-lots of craters -large number of both large and small craters -some areas are relatively young and others relatively old -**HYPOTHESIS REVISION:** relative age is "middle-aged"*	*likely never existed*	*refuted*	*-older larger craters are modified or destroyed. -some small craters are preserved but others are modified -planet appears to have processes that may be currently active – especially wind -**HYPOTHESIS REVISION:** geologic processes active throughout Mars' history; some are currently active.*
VENUS						
MER-CURY						
VESTA						

PLANETARY COMPARISONS: *If you decide to discuss comparisons among these planetary worlds, students should note that they have observed surface areas of varying sizes so they cannot make a one to one comparison of these planetary worlds. They can however, make a few general statements. These may include the following:*

- *All planetary surfaces studied are "older" than the surface of the Earth. This is supported as Earth has fewer craters compared to the number of craters observed (overall) on the surface of other worlds. Additionally, as Earth has active geologic processes (i.e. wind, water, volcanics, tectonics) modifying its surface. The currently active processes keep "resurfacing" the Earth, keeping its surface relatively young in comparison to other worlds.*

- *Some planetary worlds have evidence of active processes (especially Mars), however, based on the number of impact craters on the surface of these other worlds and the modification of the craters observed, these worlds "today" do not have the same level of active processes we currently see on Earth. In focusing on the planetary worlds being studied in this activity, after Earth, the surface of Mars or Venus may be the youngest of the other planetary worlds.*

- *Potential "oldest" planetary surfaces could be interpreted to be Earth's Moon or Mercury. Using what they have learned about crater density, images of these worlds include numerous craters, which is why their surfaces would be considered older than Earth, Mars, or Venus. Additionally, Earth's Moon and Mercury have numerous large craters. Vesta could potentially be considered as having an "older" planetary surface – especially compared to Earth, Mars, or Venus.*

SUPPLEMENTAL INFORMATION YOU MAY FIND USEFUL:

- *The surface of Mars is thought to have been altered by water, wind, and volcanic processes, some of which may be still active (wind).*
- *The surface of Venus does not show evidence of modification by water, but there is some evidence of wind processes (although that evidence may not be visible in the images included in this activity. Volcanism, however, plays a large role that likely continues to the present.*
- *Images of Earth's Moon provide evidence of volcanic processes which likely occurred early in its history. This is observed by the larger craters on the Moon that have been filled in most likely by lava. (Volcanic and Impact processes have been the two dominant processes that have shaped the surface of the Moon.)*
- *Younger craters on the Moon are much more preserved and do not show evidence of being filled in by lava or modified by any active processes. This supports that volcanic activity occurred early in the Moon's history and that there are no active processes that have changed these smaller younger craters since they formed.*
- *The craters on Mercury appear to be similar to those on the Moon although it does not appear as though they have been modified as much by volcanic activity.*
- *Images of Vesta show evidence of some sort of active processes affecting the surface and modifying craters although it is not completely understood, in many cases, what those processes may be.*
- *Many of the images of craters on Venus clearly show visible ejecta blankets and central peaks. Images show potential evidence of erosion though it is not clear, in some cases, what those erosional processes may include. Venus is thought to have been influenced by volcanic processes. As some crater ejecta blankets do not completely surround the crater rim, perhaps they were eroded by volcanic processes. One alternative explanation of these incomplete ejecta blankets may be related to the angle in which the meteor that created the crater impacted the surface. Students can discuss and debate possible explanations.*

B. WHAT DOES IT ALL MEAN? It is important for students to now think about the potential implications of this research, why it is important, and what it all means. Have students read over the information on page 25 of the *Student Guide* and discuss the answers to the questions posed in their groups. After student groups have had the opportunity to discuss the questions, discuss as a class.

1. Which do you think are older: large complex craters or small simple craters? What does that tell you about the size of materials that may be have impacted planetary worlds early in the history of the Solar System versus the size of materials that have more recently impact surfaces? What does this tell you about how our Solar System has changed over time? Explain your answer.

NOTE: Students may not have some of the background knowledge to discuss concepts such as accretion (mentioned in the sample answer below). You may want to discuss this (or other concepts related to the formation of the Solar System) if you feel it is appropriate for your grade level of students.

Large complex craters are older than small simple craters. This tells us that early in the history of the Solar System although there were both large and small materials impacting planetary surfaces, there were a greater number of "large" pieces of materials impacting planetary surfaces compared to what we see today. As the Solar System evolved, fewer and fewer large fragments were "floating around" in the Solar System as they potentially coalesced/accreted and became part of the planetary worlds we see today. Older smaller craters have likely been resurfaced, but the larger craters are still visible today. Younger craters seen on planetary surfaces today are generally smaller than those that formed early in the planet's history.

2. If the Earth or other planetary worlds were to be impacted by an object in the future, do you think this object would likely be relatively large or small? Explain your answer.

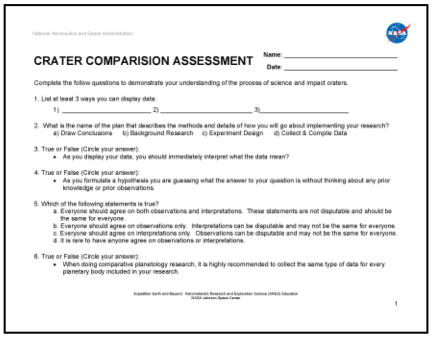
Based on the previous question, students should answer this indicating that objects would be relatively small. We do see meteors in our night sky, which are small grains of dust or rocky material attempting to make it through our atmosphere before they burn up. Students may reference other newsworthy events such as the object that entered Earth's atmosphere in Russia (Spring 2013). Although this impactor caused some damage in the local area, relatively speaking, this object was not thought to be a large object.

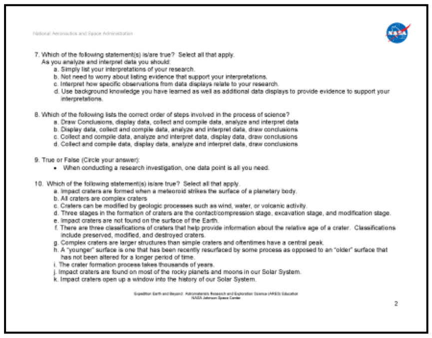
Students may also bring up the idea of the Earth being struck by a "large" asteroid. There are scientists who track the orbits of what are called Near Earth Objects (NEOs). Some of these objects may come close to the Earth in the future but assure students that scientists have no evidence to believe Earth is on a collision course with any potentially hazardous objects. Students may think of or ask about the impact that is thought to have wiped out the dinosaurs. Assure students that impacts such as this are uncommon and with instruments and detection capabilities scientists have today, we would be able to detect any incoming hazardous object with enough time to consider how to help mitigate any danger.

3. NASA plans to send astronauts to visit another planetary world in the future to help us better understand our Solar System. If you had the opportunity to choose which planetary world to visit, which would you choose and why?

Student answers will vary.

PART 6: EVALUATE	
Main Goal(s):	*Evaluate student mastery of objectives*
Estimated Time:	*~20-30 minutes*
Class Time Saver:	*No recommendations.*
Materials Needed:	• *Crater Comparison Assessment*

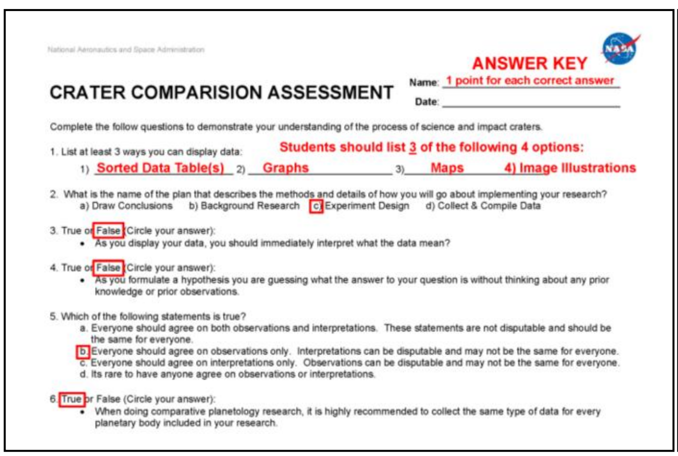

CRATER COMPARISION ASSESSMENT



The *Crater Comparison Assessment* focuses on the steps involved in the process of science and information related to impact craters. Each question and correct answer is worth 1 point. The grading rubric is as follows:

- 18-20 points: A
- 15-17 points: B
- 12-14 points: C
- 9-11 points: D
- Below 9 points: F

Answer key is below: (1 point per correct answer)


National Aeronautics and Space Administration

ANSWER KEY

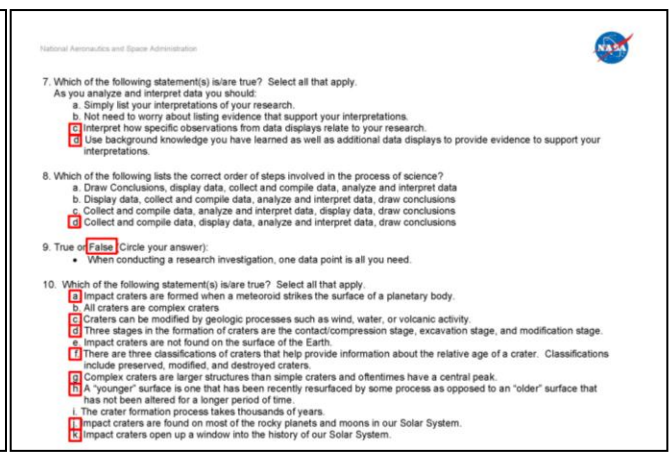
CRATER COMPARISION ASSESSMENT

Name: 1 point for each correct answer

Date:

Complete the follow questions to demonstrate your understanding of the process of science and impact craters.

1. List at least 3 ways you can display data: Students should list 3 of the following 4 options:
   1) Sorted Data Table(s) 2) Graphs 3) Maps 4) Image Illustrations
2. What is the name of the plan that describes the methods and details of how you will go about implementing your research?
   a) Draw Conclusions b) Background Research c) Experiment Design d) Collect & Compile Data
3. True or False (Circle your answer):
   - As you display your data, you should immediately interpret what the data mean?
4. True or False (Circle your answer):
   - As you formulate a hypothesis you are guessing what the answer to your question is without thinking about any prior knowledge or prior observations.
5. Which of the following statements is true?
   a. Everyone should agree on both observations and interpretations. These statements are not disputable and should be the same for everyone.
   b. Everyone should agree on observations only. Interpretations can be disputable and may not be the same for everyone.
   c. Everyone should agree on interpretations only. Observations can be disputable and may not be the same for everyone.
   d. Its rare to have anyone agree on observations or interpretations.
6. True or False (Circle your answer):
   - When doing comparative planetology research, it is highly recommended to collect the same type of data for every planetary body included in your research.


National Aeronautics and Space Administration

7. Which of the following statement(s) is/are true? Select all that apply.
   As you analyze and interpret data you should:
   a. Simply list your interpretations of your research.
   b. Not need to worry about listing evidence that support your interpretations.
   c. Interpret how specific observations from data displays relate to your research.
   d. Use background knowledge you have learned as well as additional data displays to provide evidence to support your interpretations.
8. Which of the following lists the correct order of steps involved in the process of science?
   a. Draw Conclusions, display data, collect and compile data, analyze and interpret data
   b. Display data, collect and compile data, analyze and interpret data, draw conclusions
   c. Collect and compile data, analyze and interpret data, display data, draw conclusions
   d. Collect and compile data, display data, analyze and interpret data, draw conclusions
9. True or False (Circle your answer):
   - When conducting a research investigation, one data point is all you need.
10. Which of the following statement(s) is/are true? Select all that apply.
    a. Impact craters are formed when a meteoroid strikes the surface of a planetary body.
    b. All craters are complex craters
    c. Craters can be modified by geologic processes such as wind, water, or volcanic activity.
    d. Three stages in the formation of craters are the contact/compression stage, excavation stage, and modification stage.
    e. Impact craters are not found on the surface of the Earth.
    f. There are three classifications of craters that help provide information about the relative age of a crater. Classifications include preserved, modified, and destroyed craters.
    g. Complex craters are larger structures than simple craters and oftentimes have a central peak.
    h. A "younger" surface is one that has been recently resurfaced by some process as opposed to an "older" surface that has not been altered for a longer period of time.
    i. The crater formation process takes thousands of years.
    j. Impact craters are found on most of the rocky planets and moons in our Solar System.
    k. Impact craters open up a window into the history of our Solar System.

1. Students should list any 3 of the following options: 1) Sorted Data Table(s), 2) Graphs, 3) Maps, 4) Image Illustrations

2. C	3. False	4. False	5. B	6. True
7. C & D	8. D	9. False	10. A, C, D, F, G, H, J, K	

SUGGESTED OVERALL GRADING RUBRIC: As this activity will have students working in groups to complete the mini-research investigation, the following rubric can be used as the grading rubric for each step of the process of science (NOTE: Steps 1-4 are not called out separately as those steps are accomplished as a guided introduction completed as a class).

Share this grading rubric with students at the start of the activity so they will understand how they will be graded on this activity.

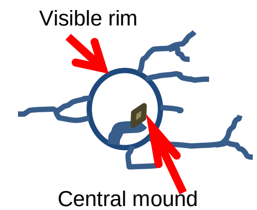
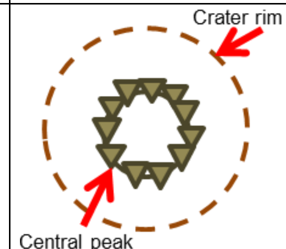
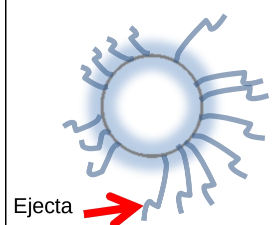
- **90-100%:**
  - **Engagement (E):** Clearly engaged in all parts of this step(s) of the process of science. Excellent participation in group and/or class discussions.
  - **Task Completion (TC):** Demonstrated a complete understanding of this aspect of the process of science.
- **80 – 89%:**
  - **Engagement (E):** Highly engaged in most parts of this step(s) of the process of science. Good participation in group and/or class discussions.
  - **Task Completion (TC):** Demonstrated a good understanding of this aspect of the process of science.
- **70 – 79%:**
  - **Engagement (E):** Somewhat engaged in most parts of this step(s) of the process of science. Limited participation in group and/or class discussions.
  - **Task Completion (TC):** Demonstrated limited understanding of this aspect of the process of science.
- **60 – 69%:**
  - **Engagement (E):** Poorly engaged in all parts of this step(s) of the process of science. Poor participation in group and/or class discussions.
  - **Task Completion (TC):** Demonstrated a poor understanding of this aspect of the process of science.
- **Below 60%:**
  - **Engagement (E):** Little to no engagement in this step(s) of the process of science. Little to no participation in group and/or class discussions.
  - **Task Completion (TC):** Demonstrated little to no understanding of this aspect of the process of science.

Student Name:												
	Steps 1–4		**Step 5**		**Step 6**		**Step 7**		**Step 8**		**Potential Implications**	
	E	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**
90-100%												
80-89%												
70-79%												
60-69%												
Below 60%												

DATA TABLE - CRATERS ON ________________________________

Please note that latitudes are provided as North latitudes [Latitude (N)]. Latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. Longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

The first three data logged here are of Earth. They can be used as examples, or if you are collecting data on Earth, you now have 3 data points.

Image Id#	**Crater Name**	**Lat. (N)**	**Lon (E)**	**Planetary Body**	**Geographic Location**	**Crater Diameter** *(km)*	**CRATER TYPE** *(Simple or Complex)*	**CRATER CLASSIFICATION** *(preserved, modified, or destroyed)*	**Misc. Notes or Observations**	**Sketch(es)**
ISS012-E-15881	Manicouagan	51.5	-68.5	Earth	Canada	65	Complex	Modified	Crater has central peak, though it is not easily detected. Diameter listed in Earth Impact Database as ~85 km. Only ~65km is actually visible in image. "Arms"/rivers extend out from the rim.	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	15	Complex	Modified	Crater has central peak. In reading information on NASA website about this crater, the well-defined bumpy circular feature is part of that central uplift. The faded outer rim is barely visible. This outer rim was used to determine the crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	Simple	Modified	Simple bowl shaped crater. The rim of this crater looks soft – the rim is not sharp and raised – likely due to erosion. There looks to be evidence of eroded ejecta around the rim. Ejecta extends out further on the right.	

DATA TABLE - CRATERS ON ___________________________________

Please note that latitudes are provided as North latitudes [Latitude (N)]. Latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. Longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Id#	Crater Name	Lat. (N)	Lon (E)	Planetary Body	Geographic Location	Crater Diameter *(km)*	CRATER TYPE *(Simple or Complex)*	CRATER CLASSIFICATION *(preserved, modified, or destroyed)*	Misc. Notes or Observations	Sketch(es)

CRATER IMAGE METADATA

EARTH IMAGES

BMM Image #	Image ID#	LAT.	LONG.	Crater Name	Country or Geographic Region	Date Acquired	Camera/ Instrument	Lens Focal Length
1	ISS006-E-16068	27.8S	16.4E	Roter Kamm	Namibia	12/28/2002	E4: Kodak DCS760C	400 mm
2	ISS012-E-15881	51.5N	68.5W	Manicouagan	Canada	1/24/2006	E4: Kodak DCS760C	50 mm
3	ISS014-E-11841	24.4N	24.4E	Oasis	Libya	1/13/2007	E4: Kodak DCS760C	400 mm
4	ISS014-E-15775	35N	111W	Barringer	United States	3/1/2007	E4: Kodak DCS760C	400 mm
5	ISS014-E-19496	29N	7.6W	Ouarkziz	Algeria	4/16/2007	E4: Kodak DCS760C	800 mm
6	ISS015-E-17360	23.9S	132.3E	Gosses Bluff	Australia	7/13/2007	E4: Kodak DCS760C	400 mm
7	ISS018-E-14908	22.9N	10.4W	Tenoumer	Mauritania	12/20/2008	Nikon D2X	800 mm
8	ISS018-E-23713	20N	76.5E	Lonar	India	1/28/2009	Nikon D2X	800 mm
	STS51I-33-56AA	27S	27.3E	Vredefort	South Africa	8/29/1985	Hasselblad	250 mm
	STS61A-35-86	56.5N	74.7W	Clearwater Lakes (East & West)	Canada	11/1/1985	Hasselblad	250 mm
	ISS028-E-14782	25.52S	120.53E	Shoemaker	Australia	7/6/2011	Nikon D2X	200 mm
	ISS034-E-29105	17.32S	128.25E	Piccaninny	Australia	1/15/2013	Nikon D2X	180 mm

CRATER IMAGE METADATA

MARS IMAGES

BMM Image #	Image ID#	LAT.	LONG.	Crater Name	Geographic Region	*Date or Approx. YR Acquired	Camera/ Instrument	Mission Name
	PIA14290	5.4S	137.8E	Gale	Aeolis Mensae	2000's	THEMIS IR	Odyssey
	THEMIS IR MOSAIC	14.5S	175.4E	Gusev	Aeolis Quadrangle	2000's	THEMIS IR	Odyssey
	Colorized MOLA	42S	67E	Hellas Basin	Hellas Planitia	2000's	Mars Orbiter Laser Altimeter (MOLA)	Global Surveyor
	Viking Orbiter Mosaic	26.5S	33.9W	Holden	Margaritifer Sinus	1970's	Visual Imaging Subsystem	Viking
2	V05055010	31.3N	19.1E	unnamed	Northern Arabia	2/3/2003	THEMIS VIS	Odyssey
5	V11030007	20.7N	125.9E	unnamed	Elysium Planitia	6/9/2004	THEMIS VIS	Odyssey
7	V01605003	14.7S	174.7E	unnamed	within Gusev Crater	4/25/2002	THEMIS VIS	Odyssey
10	V18317011	0.3N	155.5E	unnamed	Elysium Planitia	2000's	THEMIS VIS	Odyssey
12	MOC2-1225a	24S	33W	unnamed	Margaritifer Terra	2000's	Mars Obiter Camera	Global Surveyor
13	ESP_013954_1780	2.1S	354.5E	Victoria	Meridiani Planum	7/18/2009	HiRise	Mars Reconnaisance Orbiter (MRO)
14	V01695013	0.04N	71.9E	unnamed	Syrtis Major	6/6/2002	THEMIS VIS	Odyssey
16	THEMIS IR MOSAIC	42S	92W	unnamed	Thaumasia Highlands (Warrego Vallis)	2000's	THEMIS IR	Odyssey

*Estimated date/year based on mission time frame

CRATER IMAGE METADATA

EARTH'S MOON

BMM Image #	Image ID#	LAT.	LONG.	Crater Name	Geographic Region	*Date or Approx. YR Acquired	Camera/ Instrument	Mission Name
	Clementine Mosaic	75S	132.4E	Schrodinger	near south lunar pole on far side of Moon	1990's	UVVIS camera	Clementine
	PIA14023	19.4S	95W	Orientale	western border of the Moon's nearside and farside	2010's	Wide Angle Camera (WAC)	Lunar Reconnaisance Orbiter (LRO)
	M104584833CE	43.4S	11.1W	Tycho	southern lunar highlands	2010's	WAC	LRO
	LROC WAC Mosaic	23.7N	47.4W	Aristarchus	Oceanus Procellarium	2010's	WAC	LRO
	LROC WAC Mosaic	9.62N	20.1W	Copernicus	Oceanus Procellarium	2010's	WAC	LRO
	AS17-151-23260	9.62N	20.1W	Copernicus	Oceanus Procellarium	December 1972	Hasselblad	Apollo 17
1	AS12-50-7438	1N	15.2W	unnamed	Mare Insularum	November 1969	Hasselblad	Apollo 12
2	AS12_h_50_7431	5.7S	2.1W	Herschel	Sinus Medii	November 1969	Hasselblad	Apollo 12
3	AS16-0692	11.4S	26.4E	Theophilus	Kant Plateau	April 1972	Metric Mapping	Apollo 16
4	L05-H105	25.5N	2.8E	Hadley C	Mare Imbrium	8/14/1967	Medium Resolution Camera	Lunar Orbiter
5	AS15-1010	25.8N	21.0W	Lambert	Mare Imbrium	1971	Metric Mapping	Apollo 15
6	AS15-M-0424	27N	9W	Feuillee and Beer	Mare Imbrium	7/31/1971	Metric Mapping	Apollo 15
7	AS15-2606	25.5N	44.1W	Prinz (Center) [Aristarchus (bright crater/upper right)]	Oceanus Procellarium	Aug.1971	Metric Mapping	Apollo 15
8	AS15-2083	29N	45.6W	Krieger and Van Biesbroeck	Oceanus Procellarium	1971	Metric Mapping	Apollo 15

*Estimated date/year based on mission time frame

CRATER IMAGE METADATA

MERCURY

BMM Image #	Image ID#	LAT.	LONG.	Crater Name	Geographic Region	*Date or Approx. YR Acquired	Camera/ Instrument	Mission Name
1	PIA12163	**dnf	**dnf	unnamed	**dnf	10/6/2008	Narrow Angle Camera (NAC)	MESSENGER
2	PIA12068	**dnf	**dnf	unnamed	**dnf	10/6/2008	NAC	MESSENGER
3	PIA12049	33.2S	271.8W	Rembrandt Basin	Rembrandt Basin	10/6/2008	NAC	MESSENGER
4	PIA11355	11S	31.5W	Kuiper	Kuiper quadrangle	10/6/2008	NAC	MESSENGER
5	PIA12368	**dnf	**dnf	unnamed	**dnf	9/29/2009	NAC	MESSENGER
6	PIA12054	**dnf	**dnf	unnamed	**dnf	10/6/2008	NAC	MESSENGER
7	PIA12370	**dnf	**dnf	unnamed	**dnf	9/29/2009	NAC	MESSENGER
8	PIA12116	15.2N	48.1W	Lermontov	Kuiper quadrangle	10/6/2008	NAC	MESSENGER
	MESSENGER MOSAIC	18S*	308E*	Renoir	**dnf	2010's	Wide Angle Camera (WAC)	MESSENGER
	575089	28.3S	146.9E	Pahinui	**dnf	7/31/2011	NAC	MESSENGER
	1566240	44.13S	251.5E	Michelangelo	**dnf	3/26/2012	NAC	MESSENGER

*Approximation

**dnf = data not found

CRATER IMAGE METADATA

VENUS

BMM Image #	Image ID#	LAT.	LONG.	Crater Name	Geographic Region	*Date or Approx. YR Acquired	Camera/ Instrument	Mission Name
4	PIA00086	27S	339W	unnamed	Lavinia	Sept. 1990	Imaging Radar	Magellan
6	PIA00466	15N	5E	unnamed	Eistla Region	1990's	Imaging Radar	Magellan
7	PIA00239	20.3N	331.8E	Aurelia (proposed name)	Guinevere Planitia	1990's	Imaging Radar	Magellan
	PIA00479	74.6N	177.3E	Dickinson	NE Atalanta Region	1990's	Imaging Radar	Magellan
	PIA00463	27.4N	337.5E	Barton	East of Guinevere Planitia	Sept. 1990	Imaging Radar	Magellan
	PIA00148	12.5N	57.4E	Mead	North of Aphrodite Terra	11/12/1990	Imaging Radar	Magellan
	PIA00100	29.9N	282.9E	unnamed	Beta Regio	1990's	Imaging Radar	Magellan
	PIA00480	30S	204E	Isabella	East of Dali Chasma	1990's	Imaging Radar	Magellan

*Estimated date/year based on mission time frame

CRATER IMAGE METADATA

VESTA

BMM Image #	Image ID#	*LAT.	*LONG.	Crater Name	Geographic Region	Date Acquired	Camera/ Instrument	Mission Name
	PIA15239	39S	155E	Laelia	Sextila Quadrangle	1/8/2012	Framing Camera	Dawn
	PIA15598	39S	155E	Sextilia (upper right), Laelia (lower left)	Sextila Quadrangle	10/2/2011	Framing Camera	Dawn
	PIA15649	**dnf	**dnf	Octavia	Marcia Quadrangle	10/14/2011	Framing Camera	Dawn
	PIA16491	**dnf	**dnf	Fonteia	Rheasilvia Quadrangle	2/7/2012	Framing Camera	Dawn
	PIA16489	11S	224E	Cornelia	Numisia Quadrangle	1/11/2012	Framing Camera	Dawn
	PIA15235	34S	295E	Canuleia	Urbinia Quadrangle	10/25/2011	Framing Camera	Dawn
	PIA15324	63S	77E	unnamed	Pinaria Quadrangle	8/29/2011	Framing Camera	Dawn
	IOTD-127	5.9S	248.2E	Numisia	Numisia Quadrangle	10/21/2011	Framing Camera	Dawn
	IOTD-174	26S	220E	Vibidia	Tuccia Quadrangle	10/21/2011	Framing Camera	Dawn
	IOTD-128	6.5S	307.8E	Oppia	Oppia Quadrangle	10/11/2011	Framing Camera	Dawn

*Approximate location

**dnf = data not found

CRATER COMPARISION ASSESSMENT

Name: ______________________________

Date: ______________________________

Complete the follow questions to demonstrate your understanding of the process of science and impact craters.

1. List at least 3 ways you can display data:

1) ________________________ 2) ________________________ 3)________________________

2. What is the name of the plan that describes the methods and details of how you will go about implementing your research?

a) Draw Conclusions b) Background Research c) Experiment Design d) Collect & Compile Data

3. True or False (Circle your answer):

- As you display your data, you should immediately interpret what the data mean?

4. True or False (Circle your answer):

- As you formulate a hypothesis you are guessing what the answer to your question is without thinking about any prior knowledge or prior observations.

5. Which of the following statements is true?

a. Everyone should agree on both observations and interpretations. These statements are not disputable and should be the same for everyone.
b. Everyone should agree on observations only. Interpretations can be disputable and may not be the same for everyone.
c. Everyone should agree on interpretations only. Observations can be disputable and may not be the same for everyone.
d. It is rare to have anyone agree on observations or interpretations.

6. True or False (Circle your answer):

- When doing comparative planetology research, it is highly recommended to collect the same type of data for every planetary body included in your research.

7. Which of the following statement(s) is/are true? Select all that apply.
   As you analyze and interpret data you should:
   a. Simply list your interpretations of your research.
   b. Not need to worry about listing evidence that support your interpretations.
   c. Interpret how specific observations from data displays relate to your research.
   d. Use background knowledge you have learned as well as additional data displays to provide evidence to support your interpretations.

8. Which of the following lists the correct order of steps involved in the process of science?
   a. Draw Conclusions, display data, collect and compile data, analyze and interpret data
   b. Display data, collect and compile data, analyze and interpret data, draw conclusions
   c. Collect and compile data, analyze and interpret data, display data, draw conclusions
   d. Collect and compile data, display data, analyze and interpret data, draw conclusions

9. True or False (Circle your answer):
   - When conducting a research investigation, one data point is all you need.

10. Which of the following statement(s) is/are true? Select all that apply.
    a. Impact craters are formed when a meteoroid strikes the surface of a planetary body.
    b. All craters are complex craters
    c. Craters can be modified by geologic processes such as wind, water, or volcanic activity.
    d. Three stages in the formation of craters are the contact/compression stage, excavation stage, and modification stage.
    e. Impact craters are not found on the surface of the Earth.
    f. There are three classifications of craters that help provide information about the relative age of a crater. Classifications include preserved, modified, and destroyed craters.
    g. Complex craters are larger structures than simple craters and oftentimes have a central peak.
    h. A “younger” surface is one that has been recently resurfaced by some process as opposed to an “older” surface that has not been altered for a longer period of time.
    i. The crater formation process takes thousands of years.
    j. Impact craters are found on most of the rocky planets and moons in our Solar System.
    k. Impact craters open up a window into the history of our Solar System.