Mars Image Analysis

Grades: 5-12 Prep Time: ~10 Minutes Lesson Time: 3 Hours

WHAT STUDENTS DO: Establish geologic sequences in a Mars image.

Students step into the shoes of real planetary scientists. Using large-format images of Mars, provided by Mars Education at Arizona State University, students reach conclusions about the geology of Mars. Students are tasked with identifying features on the surface of Mars, determining the surface history of the area, calculating the size of features, and developing investigable questions.

NRC CORE & COMPONENT QUESTIONS	INSTRUCTIONAL OBJECTIVES
WHAT IS THE UNIVERSE, AND WHAT IS EARTH'S PLACE IN IT? *NRC Core Question: ESS1: Earth's Place in the Universe*	*Students will be able*
How do people reconstruct and date events in Earth's planetary history? *NRC ESS1.C: The History of the Planet Earth*	**IO1: to reconstruct** geologic events using empirical evidence
Asking Questions and Defining Problems *NRC Practice 1: Science Practices*	

See Section 4.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

1.0 About This Activity

The Mars lessons leverage *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001) (see *Section 4* and *Teacher Guide* at the end of this document). This taxonomy provides a framework to help organize and align learning objectives, activities, and assessments. The taxonomy has two dimensions. The first dimension, cognitive process, provides categories for classifying lesson objectives along a continuum, at increasingly higher levels of thinking; these verbs allow educators to align their instructional objectives and assessments of learning outcomes to an appropriate level in the framework in order to build and support student cognitive processes. The second dimension, knowledge, allows educators to place objectives along a scale from concrete to abstract. By employing Anderson and Krathwohl's (2001) taxonomy, educators can better understand the construction of instructional objectives and learning outcomes in terms of the types of student knowledge and cognitive processes they intend to support. All activities provide a mapping to this taxonomy in the Teacher Guide (at the end of this lesson), which carries additional educator resources. Combined with the aforementioned taxonomy, the lesson design also draws upon Miller, Linn, and Gronlund's (2009) methods for (a) constructing a general, overarching, instructional objective with specific, supporting, and measurable learning outcomes that help assure the instructional objective is met, and (b) appropriately assessing student performance in the intended learning-outcome areas through rubrics and other measures. Construction of rubrics also draws upon Lanz's (2004) guidance, designed to measure science achievement.

How Students Learn: Science in the Classroom (Donovan & Bransford, 2005) advocates the use of a research-based instructional model for improving students' grasp of central science concepts. Based on conceptual-change theory in science education, the 5E Instructional Model (BSCS, 2006) includes five steps for teaching and learning: Engage, Explore, Explain, Elaborate, and Evaluate. The Engage stage is used like a traditional warm-up to pique student curiosity, interest, and other motivation-related behaviors and to assess students' prior knowledge. The Explore step allows students to deepen their understanding and challenges existing preconceptions and misconceptions, offering alternative explanations that help them form new schemata. In Explain, students communicate what they have learned, illustrating initial conceptual change. The Elaborate phase gives students the opportunity to apply their newfound knowledge to novel situations and supports the reinforcement of new schemata or its transfer. Finally, the Evaluate stage serves as a time for students' own formative assessment, as well as for educators' diagnosis of areas of confusion and differentiation of further instruction. This five-part sequence is the organizing tool for the Mars instructional series. The 5E stages can be cyclical and iterative.

2.0 Rationale

Students and teachers alike are often confused or mislead by the textbook version of the scientific method. The process of science is often portrayed as a linear process with a defined beginning and endpoint. For many very young students (K-4), the linear process is a good place to start as they are learning the scientific method; however, for older students, the focus on the iterative process of science begins to develop.

The intent of these lessons is to address the misconceptions of the scientific method and teach a much more accurate representation of the process as a whole. Each segment will provide a rationale section, similar to this one, explaining the intent of the lesson along with possible iterations.

As the classroom facilitator, you have been provided options for how far you intend to take your students into the process of science. You have been provided four paths (Figure 1 & 2); each path with increasing quantities of standards that can be covered. You have the option to complete a full research project, or to focus on specific standards you have been struggling to cover.

All four paths start with Mars Image Analysis, which focuses on developing observation skills by distinguishing between everyday and scientific observations. Additionally, students will find that observations occur throughout the research process.

Figure 1. Pathways

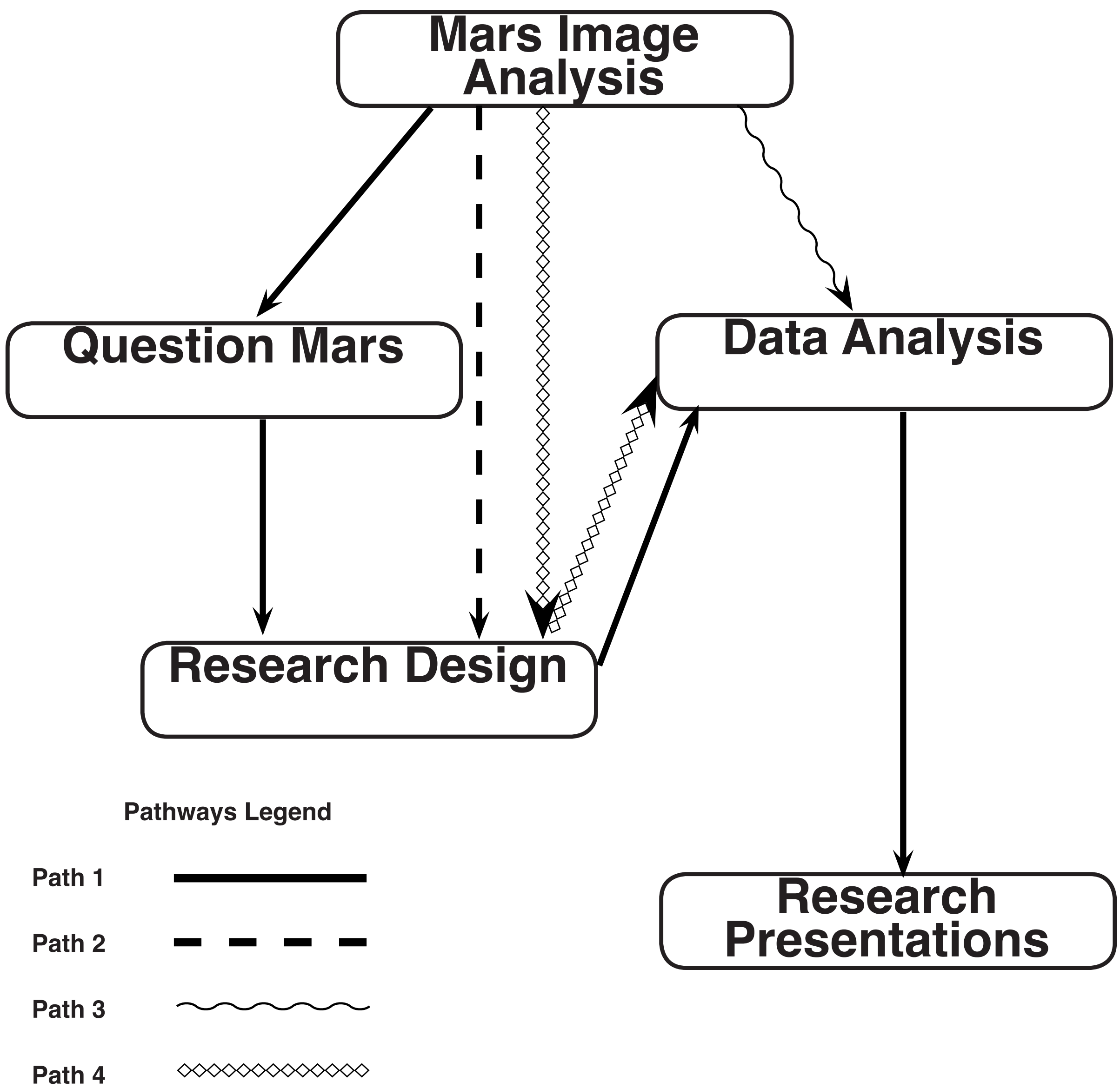


Figure 2. Pathways

Figure 2 - Pathways			
Emphasis	**Lessons in the Path**	**National Standards**	**Est. # of Class periods (45 min segments)**
Path 1: Full scientific process of research	Mars Image Analysis Question Mars Mars Research Design Mars Data Analysis Mars Research Publication	**Science** **Dimension 1: Practices** 1, 2, 3, 4, 5, 6, 7, 8 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C Some types of research: ESS2A, ESS2B, ESS2C, ESS2D	25
Path 2 Developing observation skills and controlled experimental procedures	Mars Image Analysis Mars Research Design	**Science** **Dimension 1: Practices** 2,3 **Dimension 2: Concept** 2, 3, 4 **Dimension 3: ESS** ESS1C	5
Path 3 Developing observation skills, graphing techniques, and graphical interpretation	Mars Image Analysis Mars Data Analysis	**Science** **Dimension 1: Practices** 4, 5, 6 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C	5
Path 4 Developing observation skills, controlled experimental procedures, graphing techniques, and graphical interpretation	Mars Image Analysis Mars Research Design Mars Data Analysis	**Science** **Dimenstion 1: Practices** 2, 3, 4, 5, 6, 7 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C	8

3.0 Materials

Required Materials

Please supply:

• Wet erase marker	- 1 per group
• Ruler	- 1 per group
• Calculator	- 1 per student
• Optional: Computer and Projection System	

Materials Supplied from Mars Education:

• Feature ID Charts	- 1 per group
• THEMIS image	- 1 per group
• MOLA map	- 1 per group
• Optional: Mars Image Analysis PowerPoint Presentation	

Please Print:

From Student Guide:	
(A) What Can You Tell from a Picture?	- 1 per group
(B) Background	- 1 per student
(C) Lesson Background	- 1 per student
(D) Student Data Log	- 1 per student
(K) Making Measurements Notes	- 1 per student
(L) Student Measurement Data Log	- 1 per student
(M) Establishing a Research Topic of Interest	- 1 per student
(N) Background Research	- 1 per student
(P) Example Observation Table	- 1 per student
(Q) Observation Table	- 1 per student
(R) Choosing a Topic for Research	- 1 per student
From Supplemental Materials:	
(E) Sunlight and Shadows	- 1 per group
(F) Determining the Relative Ages of Features	- 1 per group
(G) Crater Classification – Guide	- 1 per group
(H) Relative Age Dating Principles – Guide	- 1 per group
(O) Using THEMIS Website to Make Scientific Observations	- 1 per student
(S) Feature ID Charts	- 1 per group

Optional Materials

Supplemental Materials:

(I) Classifying Craters - 1 per student

(J) Relative Age Dating Principles - 1 per student

(V) Classifying Craters – Sample Answers

(W) Relative Age Dating Principles – Sample Answers

Teacher Guide:

(T) Teacher Resource #1
(U) Teacher Resource #2
(V) Classifying Craters - Sample Answers
(W) Relative Age Dating Principles - Sample Answers
(X) Mars Image Analysis Rubrics
(Y) Alignment of Instructional Objective, Standards, & Learning Outcomes

4.0 Vocabulary

Analyze consider data and results to look for patterns and to compare possible solutions

Classification the assignment of objects to categories based on characteristics

Deposition accumulation of material (such as sediment)

Erosion the process where the surface of earth is worn away by water, glaciers, winds, waves, etc.

Evaluate check the scientific validity or soundness

Everyday Observation the act of noting facts or occurrences that are common characteristics.

Explanations logical descriptions applying scientific information

Geologic History the history of geologic events (such as erosion, deposition, glaciers, volcanism, etc.) of an area

Inference drawing a logical conclusion based on observations and data collection

Scientific Observation the act of noting facts or occurrences that are unique or interesting and can lead to a scientific research question.

Qualitative Observation the act of noting facts or occurrences that are based on physical characteristics or attributes, such as color or texture.

Quantitative Observation the act of noting facts or occurrences that are based on numerical data, such a counting the number of a feature or making measurements of a feature.

Weathering mechanical and chemical processes that cause exposed rock to decompose

5.0 Instructional Objectives, Learning Outcomes, Standards, & Rubrics

Instructional objectives, standards, and learning outcomes are aligned with the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, which serves as a basis for upcoming "Next-generation Science Standards." Current National Science Education Standards (NSES) and other relevant standards are listed for now, but will be updated when the new standards are available.

The following chart provides details on alignment among the core and component NRC questions, instructional objectives, learning outcomes, and educational standards.

- Your **instructional objectives (IO)** for this lesson align with the NRC Framework and education standards.
- You will know that you have achieved these instructional objectives if students demonstrate the related **learning outcomes (LO)**.
- You will know the level to which your students have achieved the learning outcomes by using the suggested **rubrics** (see Teacher Guide at the end of this lesson).

Quick View of Standards Alignment:

The Teacher Guide at the end of this lesson provides full details of standards alignment, rubrics, and the way in which instructional objectives, learning outcomes, 5E activity procedures, and assessments were derived through, and align with, Anderson and Krathwohl's (2001) taxonomy of knowledge and cognitive process types. For convenience, a quick view follows:

WHAT IS THE UNIVERSE, AND WHAT IS EARTH'S PLACE IN IT?

NRC Core Question: ESS1: Earth's Place in the Universe

How do people reconstruct and date events in Earth's planetary history?

NRC ESS1.C: The History of the Planet Earth

Asking Questions and Defining Problems

NRC Practice 1: Science Practices

Instructional Objective *Students will be able*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO1: **to reconstruct** geologic events using empirical evidence	**LO1a. to identify geologic features in a THEMIS image** **LO1b. to sequence geologic features using relative dating principles** **LO1c. to explain how the sequence of geologic features were determined**	**NSES: UNIFYING CONCEPTS & PROCESSES:** **K-12: Evidence, models, and explanations** **NSES (D): EARTH AND SPACE SCIENCE:** **Structure of the Earth System** **Grades 5-8:** D1c, D1d **Earth's History** **Grades 5-8:** D2a **The Origin and Evolution of the Earth System** **Grades 9-12:** D3b, D3c **NSES (E): SCIENCE & TECHNOLOGY** **Evaluate Completed Technological Design or Products** **Grades 5-8:** E1d	***Rubrics in Teacher Guide***

This activity also aligns with:

NRC SCIENCE & ENGINEERING PRACTICES

4) Analyzing & interpreting data
5) Using mathematical and computational thinking
6) Constructing explanations and designing solutions

NRC SCIENCE & ENGINEERING CROSSCUTTING CONCEPTS

2) Cause and effect
4) Systems and system models

AAAS BENCHMARKS FOR SCIENCE LITERACY

1.A The Scientific World View
1.B Scientific Inquiry
4.A The Universe
4.B The Earth
4.C Processes that Shape the Earth
12.C Manipulation and Observation
12.D Communication Skills
12.E Critical-Response Skills

NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS (NCTM)

- Algebra
- Measurement
- Data Analysis and Probability

21ST CENTURY SKILLS

- Critical Thinking and Problem Solving
- Communication
- Collaboration

6.0 Procedure

PREPARATION (~15 minutes)

A. Print materials

B. Organize 1 THEMIS image, 1 MOLA map, 1 set of (S) *Feature ID Charts*, and 1 wet erase marker for each group (face down on table).

STEP 1: ENGAGE (~10 minutes)

What can you tell from a picture?

A. Hand out THEMIS image, (A) *What can you tell from a picture?* sheet

B. Ask students to look at the top image on page 1 of *(A) What can you tell from a picture?*and ask where the arrow is pointing on the map. Ask the students to make observations and share their observations about this area on the image.

C. Next, ask the students to look at the second and third images on (*A) What can you tell from a picture?* (which are zoomed-in versions of this image) in both colorized elevation and black and white infrared imaging. Again, make observations and share them about this area on their image. Do they understand anything different about this area than they did before? Share out with the classroom.

D. Finally, ask the students to look at the final image on (*A) What can you tell from a picture?* - a black and white THEMIS image. This image is further zoomed in for even more detail. One last time, ask them to make observations and share their observations about this area. Do they understand anything different about this area than they did before? Share out with the classroom.

E. At this point, the students should have made many observations. Ask students what information is missing? If we were to attempt to explain why this crater looks so different from other craters, what else would we need to know, observe, or understand to do that? (Students should say they need more observations, find more distinguishing characteristics, possibly a closer image or other types of data.)

F. Point out that images provide the simplest means of exploring another world. We use images of Mars to make observations and identify what other information we need. We zoom in and zoom out to get better detail or more information about our image. We will look at some of these THEMIS images of Mars. Before we do, let's learn a little about THEMIS. Hand out *(B) Background sheet*.

STEP 2: EXPLORE (~60 minutes)

- Print B-L and S in Materials list

Image Analysis

Identify Surface Features

(See Teacher Resource #1 and #2 for an orientation of these materials)

A. Before distributing materials, have students brainstorm analogous features they know exist on Earth that may also exist on Mars. This will help students build knowledge and make connections to previous knowledge throughout the activity.

B. Have students read (*C) Lesson Background* to orient them to the purpose and intent of the lesson.

C. Familiarize and distribute Feature ID Charts, *(E) Sunlight and Shadows Sheet*, and THEMIS images to students.

D. Have students use erasable markers to identify features on laminated THEMIS images using *(S) Feature ID Charts*. Have students initially work with one image.

E. After ~10-15 minutes, have students exchange images they have analyzed so other students can make observations of other images.

   i. End this part of the activity with a discussion of features observed in images from either the PowerPoint slides or paper.

   ii. Ask students to record the identified features into the *(D) Data Log Sheet* and the geologic processes involved in their creation.

Teacher Tip

The observations students will make here are most likely considered "everyday observations." This means they will be simplified to examples such as "There are 30 craters in the image." While this is a true observation, it most likely will not lead to an experimental question. Providing extra time, even when the students appear to be done and off task will allow them to make better observations; however, students may need more content knowledge about the topic they choose before they can make scientific observations. This will be addressed later in the lesson.

Determine the Relative Ages of Features
(See Teacher Resource #2 for an orientation of these materials)

A. Before distributing materials, discuss with students how they may know when one feature is older or younger than another. This will again help students build knowledge and make connections to previous knowledge throughout the activity.

B. Familiarize and distribute *(H) Relative Age Dating Principles Guide* and (*G) Crater Classification Guide* handout to students.

C. Have students use erasable markers to identify relative ages of features on the original image they were working with. Have students at least label the "oldest" and "youngest" feature. Students can then identify relative ages of other features with respect to the oldest/youngest feature.

D. After ~8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of Mars) as part of their discussion.

E. Ask students to go back to their *(D) Student Data Log* and include the order of which the features have occurred in the Relative Age column and the evidence they used to determine this rank in the Evidence column.

Teacher Tip

Supplemental Materials *(I) Classifying Craters* and *(J) Relative Age Dating Principles* have been provided as additional practice sheets to strengthen their understanding of these principles that are often incorporated in National and State standards. Answer Keys can be found in *(V)* and *(W).*

Calculate the Size of Features

A. Using *(K) Student Measurement Notes* **sheet**, have students measure and simply label features using metric units.

B. Review the example of calculating the size of features in THEMIS images with students.

C. Have students determine the *scale factor* of their image.

D. Once students have determined the *scale factor* of their image, make sure they write this somewhere on their image.

E. Have students use the measurements (in centimeters) of the features labeled on their image and make the appropriate calculation (feature measurement X scale factor) to determine the size of each measured feature in kilometers on Mars.

F. Have students write these measurements for each feature into their *(L) Student Measurement Data Log* in the Measurement column.

Teacher Tip

This would be a good time to discuss scale. Have students estimate the size of the classroom in meters, measure the room, then figure out how many of their classroom would fit into one of their features. For example, in a 3-kilometer wide crater, your classroom may fit inside it 200 times!

STEP 3: EXPLAIN (~20 minutes)

Discussion and Sharing

Identify Surface Features:

A. End this part of the activity with a discussion of features observed in images

Determine the Relative Ages of Features:

A. After ~8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of Mars) as part of their discussion.

Calculate the Size of Features:

A. Have students use the measurements (in centimeters) of the features labeled on their image and make the appropriate calculation (feature measurement X scale factor) to determine the size of each measured feature in kilometers on Mars.

B. Have students write this measurement for each feature into their *(L) Student Measurement Data Log* in the Measurement column.

STEP 4: ELABORATE (~15 minutes)

- Print (M-R)

Compare Mars to Earth

A. Have students take their list of geologic features they have identified on Mars and make a list of similar Earth geologic features and their locations.

B. Compare and contrast the geologic features on both planets.

C. Present a hypothesis as to why the geologic features might differ.

Establishing a Research Topic

Materials Needed:

- (N) Background Research
- (O) Using THEMIS Website to Make Scientific Observations
- (P) Example Observation Table
- (Q) Observation Table (2 sheets)
- Index cards (3"x5")
- Markers

A. Have each student find a partner and work together to fill in list #1 on the *(M) Establishing a Research Topic of Interest* sheet. They should spend about 3-5 minutes doing this and can come up with topics from any aspect of Mars exploration or geology that interests them.

B. As a class, the students will need to debate and establish their research topic of interest. Should the class be evenly split on a research topic, they could possibly combine their two top topics by establishing a relationship between the two topics to explore.

C. After the students have established a topic, they will need to do some research about it. The goal is to learn how the feature forms, where they are typically found, if there are similar features on Earth or other planetary bodies and how they are the same or different to feature on Earth or other planetary bodies. Students should become experts on their topic. Photocopy as many *(N) Background Research* sheets as they will need.

D. Students may need help getting started with their research. Here are a couple of sources they can use to learn more about their topic of interest:
    - http://themis.asu.edu/topic
    - http://redplanet.asu.edu/

Making Scientific Observations

A. Using background knowledge on their topic, students will make scientific observations about their selected topic as opposed to everyday observations.

B. Point out that the primary difference between these types of observations is the understanding of the topic. A scientist who understands how craters are formed will notice a crater(s) with a different pattern, shape or possibly different features that are not common to the crater. Simply observing that a crater exists is an everyday observation.

C. Their research will help the students make scientific observations. For example, their observations will improve from "There are 30 craters in the image." to "There are 5 Modified craters, 25 destroyed craters, 10 craters are less than 2km wide, 20 are greater than 2 km wide, all of the modified lack a central peak, etc."

D. Students will use *(O) Using THEMIS Website to Make Scientific Observations, (P) Example Observation Table,* and *(Q) Observation Table.*

Choosing a Final Research Topic

A. Students will complete *(R) Choosing a Topic for Research* and share their most interesting scientific observations from *(Q) Observation Table*. These observations will guide the potential discussion and will allow them to group topics or concepts.

B. It may be helpful to use index cards for topics and scientific observations. They may even find they can incorporate a couple of topics of interest for primary and secondary science. Allow the students to debate and come to a consensus on the final topic for research. This is an opportunity to experience authentic science and debate. Scientists typically do not work individually. They discuss ideas and interesting topics for research with other scientists in the field.

> "Critical thinking is required, whether in developing and refining an idea (an explanation or a design) or in conducting an investigation. The dominant activities in this sphere are argumentation and critique, which often lead to further experiments and observations or to changes in proposed models, explanation, or designs. Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design." (National Research Council Science Framework, pg. 46.)

STEP 5: EVALUATE (~20 minutes)

- Print Rubrics

Evaluate proposed solutions using criteria.

Identify Surface Features

A. Ask students to record the identified features into the *(D) Data Log Sheet* and the geologic processes involved in their creation.

Determine the Relative Ages of Features

A. Ask student to go back to their *(D) Student Data Log* and include the order of which the features have occurred in the Relative Age column and the evidence they used to determine this rank in the Evidence column.

Making Scientific Observations and Establishing a Research Topic

A. For students to make scientific observations instead of everyday observations, they will need to understand a topic very well. To do that, they will need to establish a topic that interests them about Mars and do in-depth research on that topic. Scientific observations lead to testable research questions. A rubric has been provided to evaluate the student's ability to write scientific observations and to actively debate the qualities of a good research topic.

7.0 Extensions

CALCULATING HEIGHTS AND DEPTHS OF FEATURES:
Students can calculate depths and heights of features by dividing the length of a shadow by the tangent of the incidence angle (incidence angle information is provided).

To do this, students would use the following steps:

- Measure the width of the shadow in centimeters.
- Using the calculated scale factor (Part 3 of the *Mars Image Analysis* activity), convert the shadow measurement to kilometers.
- Divide that calculated measurement by the tangent of the incidence angle to compute the depth of the feature being observed.

PARTICIPATING IN THE MARS STUDENT IMAGING PROJECT:
This activity can be used as an introduction to participation in the Mars Student Imaging Project (MSIP). The Mars Student Imaging Project allows students to conduct authentic research about Mars with the opportunity to target a new image from the THEMIS visible camera onboard the Mars Odyssey spacecraft. For more information on the Mars Student Imaging Project, go to http://marsed.asu.edu/msip-home.

ANALYZING OTHER THEMIS IMAGES:
Students can analyze other THEMIS visible images available on the THEMIS website: http://themis.asu.edu.

GETTING INVOLVED IN OTHER MARS-RELATED OPPORTUNITIES:
Students can get involved in activities available on NASA's Be A Martian website: http://beamartian.jpl.nasa.gov/welcome.

8.0 Evaluation/Assessment

Use the *(W) Mars Image Analysis Rubric* as a formative and summative assessment, allowing students to improve their work and learn from mistakes during class. The rubric aligns with the NRC Framework, National Science Education Standards, and the instructional objective(s) and learning outcomes in this lesson.

9.0 References

Anderson, L.W., & Krathwohl (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Longman.

Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Carson Powell, J., Westbrook, A., Landes, N. (2006) *The BSCS 5E instructional model: origins, effectiveness, and applications.* Colorado Springs: BSCS.

Donovan, S. & Bransford, J. D. (2005). *How Students Learn: History, Mathematics, and Science in the Classroom.* Washington, DC: The National Academies Press.

Lantz, H.B. (2004). *Rubrics for Assessing Student Achievement in Science Grades K-12.* Thousand Oaks: Corwin Press.

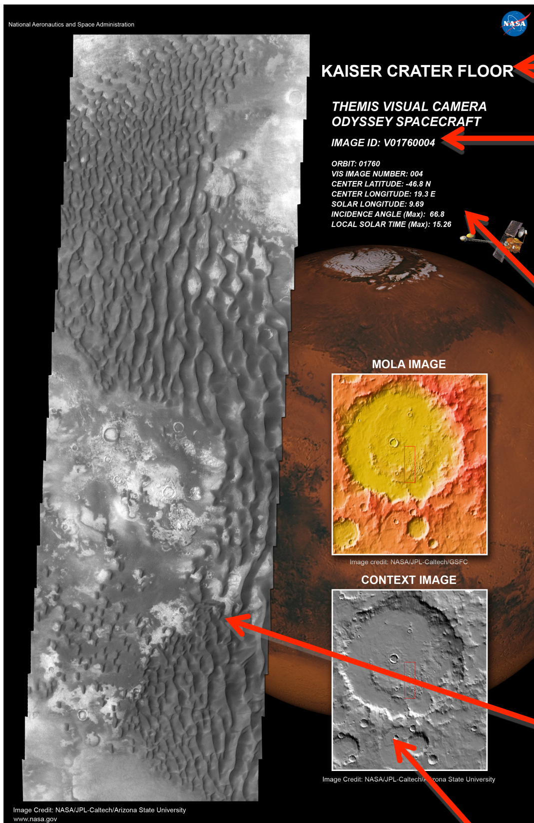
Miller, Linn, & Gronlund. (2009). *Measurement and assessment in teaching*. Upper Saddle River, NJ: Pearson.

National Academies Press. (1996, January 1). *National science education standards*. Retrieved February 7, 2011 from http://www.nap.edu/catalog.php?record_id=4962

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

The Partnership for 21st Century Skills (2011). *A framework for 21st century learning.* Retrieved March 15, 2012 from http://www.p21.org/

(T) Teacher Resource #1 (1 of 2)



THEMIS visible images are ~18 km wide.

Title: Names the general region where the image is located on Mars.

Image ID: Includes the orbit # in which the image was taken (first 5 digits) followed by a 3 digit number that indicates the count of the visible images that were taken during that orbit.

Center Latitude and Center Longitude: Exact location of this image on a map of Mars.
Incidence Angle: Angle of the Sun when the image was taken. This would be used if the students wanted to measure depth or heights of features using the sun or incidence angle.
Orbit: Orbit in which the image was acquired.
Mars Solar Time: Time (on Mars) when the image was taken.

THEMIS Image: The long, rectangular image consisting of 18-19 framelets. Framelets are angled due to the rotation of the planet beneath the camera as it takes photos.

Context Image: Shows the surrounding area where the THEMIS image was taken. The THEMIS image "stamp" is the rectangular box in the center of the context image.

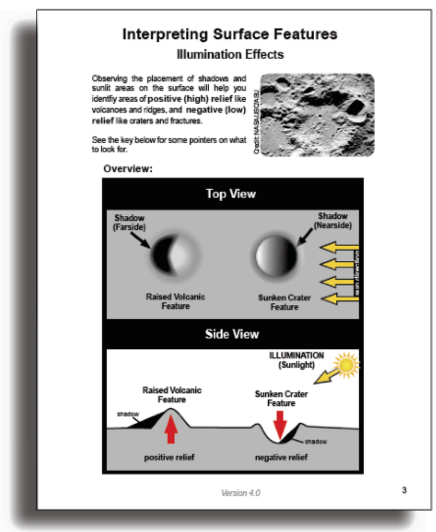
NOTE: With THEMIS visible images, the sunlight is coming from the left. A feature with a shadow on the left is carved into the surface. (Example: an impact crater will have the shadow on the left.)

(T) Teacher Resource #1 (2 of 2)

Additional Details:

- **Image ID #:** Allows you to view this image on the THEMIS viewer website (http://viewer.mars.asu.edu/#start)
- **Mars Solar Time:** Time is based on a 24-hour clock and uses percentages of hours rather than minutes. For example, if an image was taken at 15.75, it would be 3pm and 75% of an hour, or 3:45pm. If an image was taken at 16.2, the time would be 4pm and 20% of an hour or 4:12pm.
- **Context Image:** Shows a Mars Orbiter Laser Altimeter (MOLA) shaded relief map. This is not a photograph but is considered an "artificial image" that uses data acquired by the MOLA instrument to provide a black and white context showing elevation differences.

SUNLIGHT AND SHADOWS

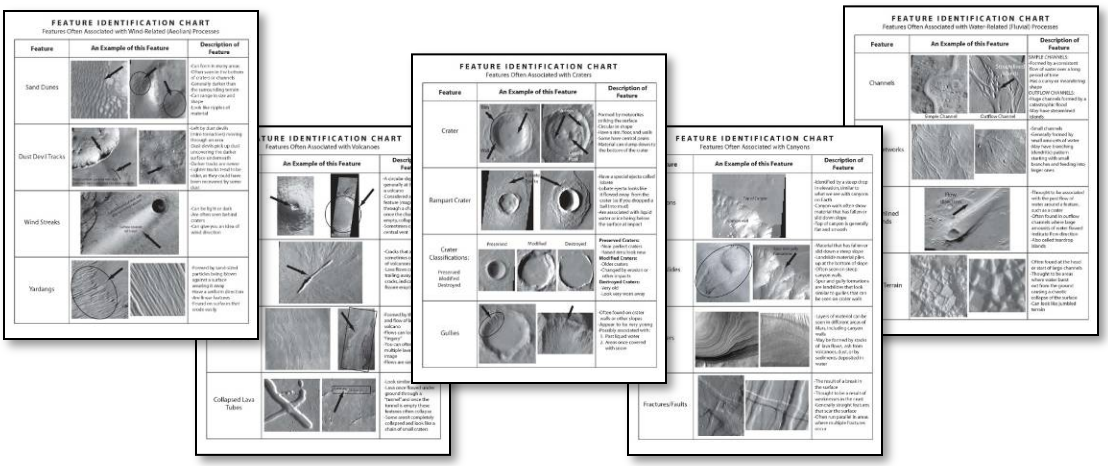


The Sunlight and Shadows sheet will help students to identify features in their LROC WAC Mosaic by orienting them to how shadowing is used to identify a raised or carved feature. Some students may need additional practice with this concept using concrete materials such as a cup and flashlight. Have students discover how the lighting works with the cup turned right-side up and up-side down.

(U) Teacher Resource #2

FEATURE IDENTIFICATION CHARTS

marsed.asu.edu/files/msip_resources/FeatureIDCharts.pdf

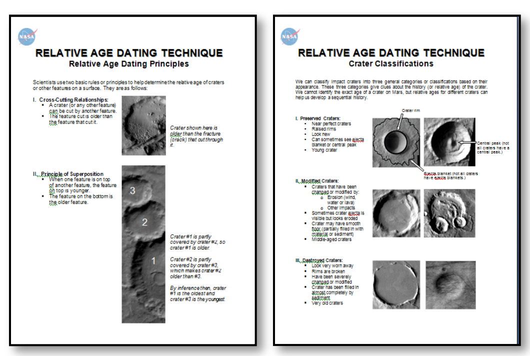


The Feature ID Charts will help students learn the names of different geologic features on Mars. They also provide information on how features form. The information at the top of each chart indicates what geologic process the listed features are associated with. There are 5 total charts that focus on features associated with *canyons*, *craters*, *wind*, *water*, and *volcanoes*. There are many other features students may observe in images that are not included on these charts. Encourage students to share other features they may know.

RELATIVE AGE DATING TECHNIQUE HANDOUTS

marsed.asu.edu/files/msip_resources/RelativeAgeDatingTechniqueHandout.pdf

One additional tool students will use for this activity are the **Relative Age Dating Technique** handouts. These two pages will help students identify what features are older or younger, which will help them better understand the geologic history of the surface.



(X) Teacher Resource. Mars Image Analysis Rubric (1 of 4)

You will know the level to which your students have achieved the **Learning Outcomes**, and thus the **Instructional Objective(s)**, by using the suggested **Rubrics** below.

Instructional Objective 1: to reconstruct geologic events using empirical evidence

Related Standard(s) (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
UNIFYING CONCEPTS & PROCESSES

Grades K-12: Evidence, models, and explanations
Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems. Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.

Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements. Different terms, such as “hypothesis,” “model,” “law,” “principle,” “theory,” and “paradigm” are used to describe various types of scientific explanations.

As students develop and as they understand more science concepts and processes, their explanations should become more sophisticated. That is, their scientific explanations should more frequently include a rich scientific knowledge base, evidence of logic, higher levels of analysis, greater tolerance of criticism and uncertainty, and a clearer demonstration of the relationship between logic, evidence, and current knowledge.

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

National Science Education Standards (NSES)
(D) Earth and Space Science: Structure of the Earth System

Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and depositions of sediment, while destructive forces include weathering and erosion (Grades 5-8: D1c).

(X) Teacher Resource. Mars Image Analysis Rubric (2 of 4)

Some changes in the solid earth can be describes as the "rock cycle." Old rocks at the Earth's surface weather, forming sediments that are buried, then compacted, heated, and often recrystallized into new rock. Eventually, those new rocks may be brought to the surface by the forces that drive plate motions, and the rock cycle continues (Grades 5-8: D1d).

National Science Education Standards (NSES)
(D) Earth and Space Science: Earth's History
The earth process we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet (Grades 5-8: D2a).

National Science Education Standards (NSES)
(D) Earth and Space Science: The Origin and Evolution of the Earth System
Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed (Grades 9-12: D3b).
Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years (Grades 9-12: D3c).

National Science Education Standards (NSES)
(E) Science and Technology: Abilities of Technological Design
Evaluate a Product or Design. Students should use criteria relevant to the original purpose or need, consider a variety of factors that might affect acceptability and suitability for intended users or beneficiaries, and develop measures of quality with respect to such criteria and factors; they should also suggest improvements and, for their own products, try proposed modifications. (Grades 5-8: E1d)

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a. to identify geologic features in a THEMIS image	Geologic features identifications are logical and supported by evidenced	Geologic features are logical and somewhat supported by evidence	Geologic features are reasonably logical and somewhat supported by evidence	Geologic features are illogical and/or not supported by evidence

(X) Teacher Resource. Mars Image Analysis Rubric (3 of 4)

Related Standards (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
(A) Science as Inquiry: Abilities Necessary to Do Scientific Inquiry
Identify questions that can be answered through scientific investigations (Grades 5-8: A1a).
Think critically and logically to make the relationship between evidence and explanations (Grades 5-8: A1e).

Identify questions and concepts that guide scientific investigation (Grades 9-12: A1a)
Formulate and revise scientific explanations and models using logic and evidence (Grades 9-12: A1d)

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1b: to sequence geologic features using relative dating principles	Geologic sequences are logical and supported by evidenced	Geologic sequences are logical and somewhat supported by evidence	Geologic sequences are reasonably logical and somewhat supported by evidence	Geologic sequences are illogical and/or not supported by evidence

(X) Teacher Resource. Mars Image Analysis Rubric (4 of 4)

National Science Education Standards (NSES)
(A) Science as Inquiry: Abilities Necessary to Do Scientific Inquiry
Think critically and logically to make the relationship between evidence and explanations (Grades 5-8: A1e).
Formulate and revise scientific explanations and models using logic and evidence (Grades 9-12: A1d).

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

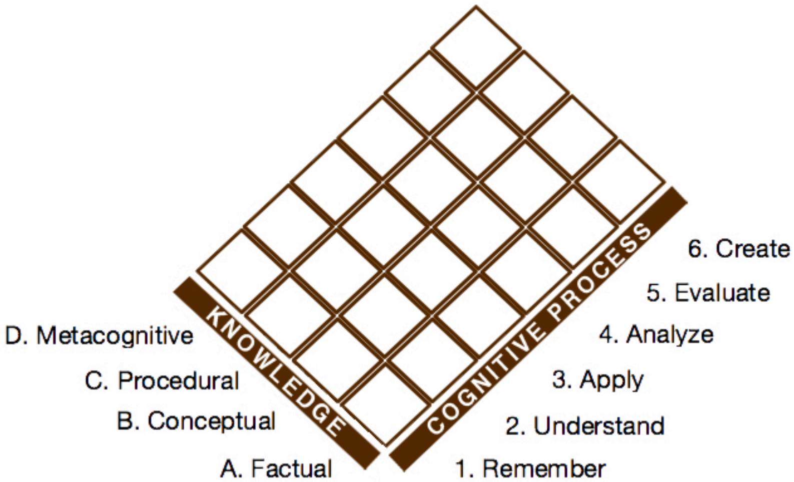
National Science Education Standards (NSES)
(D) Earth and Space Science: Structure of the Earth System
Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and depositions of sediment, while destructive forces include weathering and erosion (Grades 5-8: D1c).
Some changes in the solid earth can be describes as the "rock cycle." Old rocks at the Earth's surface weather, forming sediments that are buried, then compacted, heated, and often recrystallized into new rock. Eventually, those new rocks may be brought to the surface by the forces that drive plate motions, and the rock cycle continues (Grades 5-8: D1d).

National Science Education Standards (NSES)
(D) Earth and Space Science: Earth's History
The earth process we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet (Grades 5-8: D2a).

National Science Education Standards (NSES)
(D) Earth and Space Science: The Origin and Evolution of the Earth System
Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed (Grades 9-12: D3b).
Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years (Grades 9-12: D3c).

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1c **to explain how the sequence of geologic features were determined**	Geologic sequences are logical and supported by evidenced	Geologic sequences are logical and somewhat supported by evidence	Geologic sequences are reasonably logical and somewhat supported by evidence	Geologic sequences are illogical and/or not supported by evidence

(Y) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (1 of 3)



This lesson adapts Anderson and Krathwohl's (2001) taxonomy, which has two domains: Knowledge and Cognitive Process, each with types and subtypes (listed below). Verbs for objectives and outcomes in this lesson align with the suggested knowledge and cognitive process area and are mapped on the next page(s). Activity procedures and assessments are designed to support the target knowledge/cognitive process.

Knowledge	Cognitive Process
A. Factual **Aa:** Knowledge of Terminology **Ab:** Knowledge of Specific Details & Elements **B. Conceptual** **Ba:** Knowledge of classifications and categories **Bb:** Knowledge of principles and generalizations **Bc:** Knowledge of theories, models, and structures **C. Procedural** **Ca:** Knowledge of subject-specific skills and algorithms **Cb:** Knowledge of subject-specific techniques and methods **Cc:** Knowledge of criteria for determining when to use appropriate procedures **D. Metacognitive** **Da:** Strategic Knowledge **Db:** Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge **Dc:** Self-knowledge	**1. Remember** **1.1** Recognizing (Identifying) **1.2** Recalling (Retrieving) **2. Understand** **2.1** Interpreting (Clarifying, Paraphrasing, Representing, Translating) **2.2** Exemplifying (Illustrating, Instantiating) **2.3** Classifying (Categorizing, Subsuming) **2.4** Summarizing (Abstracting, Generalizing) **2.5** Inferring (Concluding, Extrapolating, Interpolating, Predicting) **2.6** Comparing (Contrasting, Mapping, Matching **2.7** Explaining (Constructing models) **3. Apply** **3.1** Executing (Carrying out) **3.2** Implementing (Using) **4. Analyze** **4.1** Differentiating (Discriminating, distinguishing, focusing, selecting) **4.2** Organizing (Finding coherence, integrating, outlining, parsing, structuring) **4.3** Attributing (Deconstructing) **5. Evaluate** **5.1** Checking (Coordinating, Detecting, Monitoring, Testing) **5.2** Critiquing (Judging) **6. Create** **6.1** Generating (Hypothesizing) **6.2** Planning (Designing) **6.3** Producing (Constructing)

(Y) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (2 of 3)

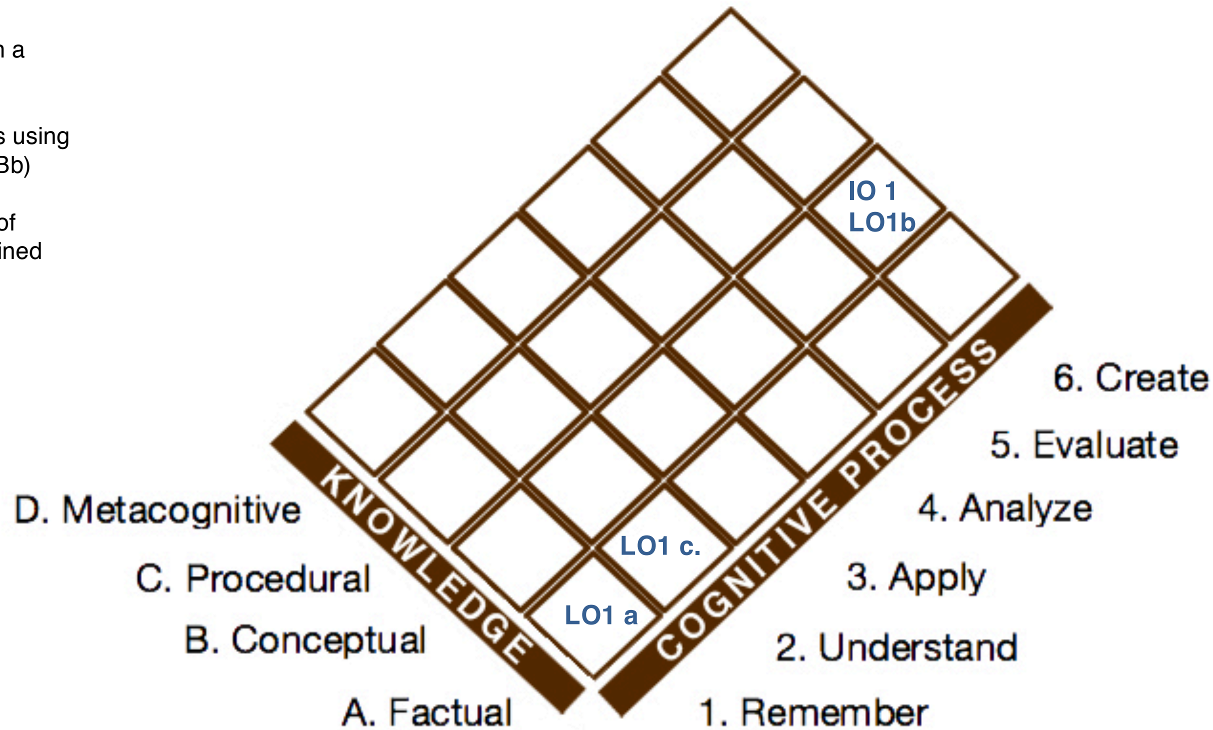
The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Pedagogically, it is important to ensure that objectives and outcomes are written to match the knowledge and cognitive process students are intended to acquire.

IO1: to reconstruct geologic events using empirical evidence (6.3; Bb)

LO1a. to identify geologic features in a THEMIS image (1.1; Ab)

LO1b. to sequence geologic features using relative dating principles (6.3; Bb)

LO1c. to explain how the sequence of geologic features were determined (2.7; Ab)



(Y) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (3 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Below are the knowledge and cognitive process types students are intended to acquire per the instructional objective(s) and learning outcomes written for this lesson. The specific, scaffolded 5E steps in this lesson (see 5.0 Procedures) and the formative assessments (worksheets in the Student Guide and rubrics in the Teacher Guide) are written to support those objective(s) and learning outcomes. Refer to (X, 1 of 3) for the full list of categories in the taxonomy from which the following were selected. The prior page (X, 2 of 3) provides a visual description of the placement of learning outcomes that enable the overall instructional objective(s) to be met.

At the end of the lesson, students will be able

IO1: **to reconstruct** geologic events
- 6.3: to produce
- Bb: principles and generalizations

To meet that instructional objective, students will demonstrate the abilities:

LO1a: **to identify** geologic features in a THEMIS image
- 1.1: to identify
- Ab: specific details and elements

LO1b: **to sequence** geologic features using relative dating principles
- 6.3: to construct
- Bb: principles and generalizations

LO1c: **to explain** how the sequence of geologic features were determined
- 2.7: to explain
- Ab: specific details and elements

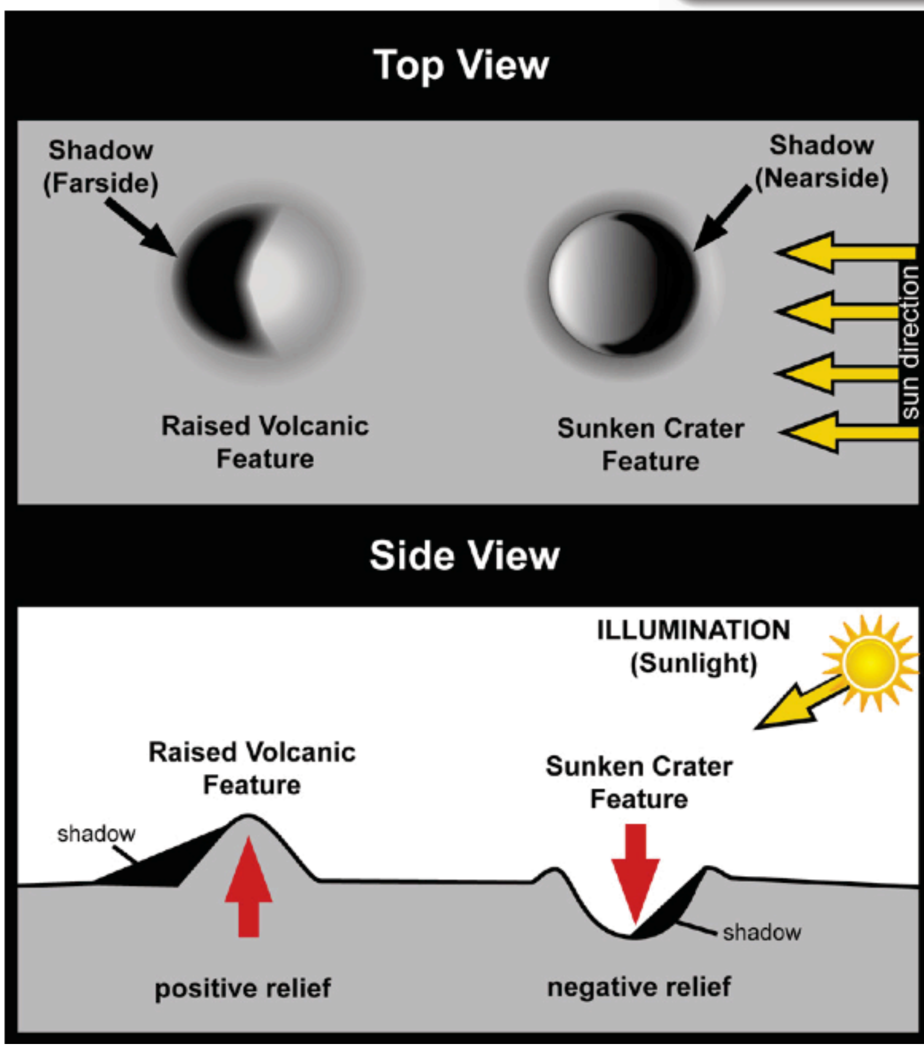
(E) Sunlight and Shadows

Observing the position of shadows and sunlit areas on Mars surface will help you identfiy areas of **positive (high) relief** like volcanoes and ridges, and **negative (low) relief** like craters and fractures.

See the key below for some pointers on what to look for as you start working with Mars images.

When the Sun is low in the horizon, light strikes the surface at low angles making long shadows. This geometry enhances surface features (image at right).

Image Credit: NASA/JPL-Caltech/Arizona State University



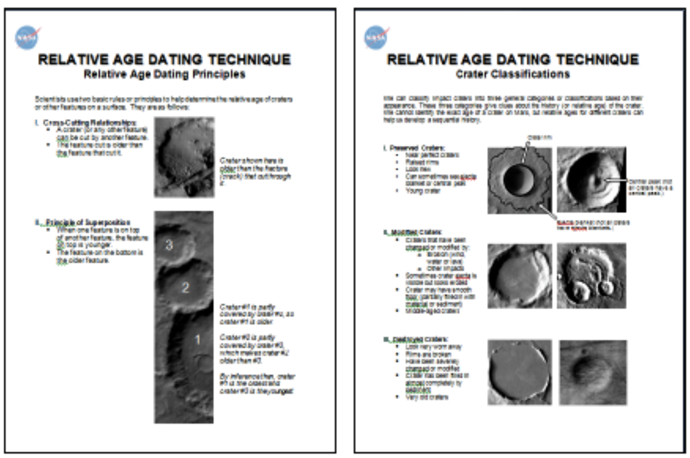
See Section 5.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

(F) Determining the Relative Ages of Features

In this part of the activity, you will continue to analyze images of Mars. Now you will think about the history of the area by using relative-age-dating techniques. Commonly used age-dating techniques are:

- **Crater classifications:** Preserved, Modified, and Destroyed; and,
- **Relative Age Dating Principles:** Principal of Superposition and Crosscutting Relationships.

Use the **Relative Age Dating Technique handout** (sample below) as a tool to help you determine the relative ages of features on your images of Mars. Be ready to discuss what has happened (the geologic history) in your area of Mars.

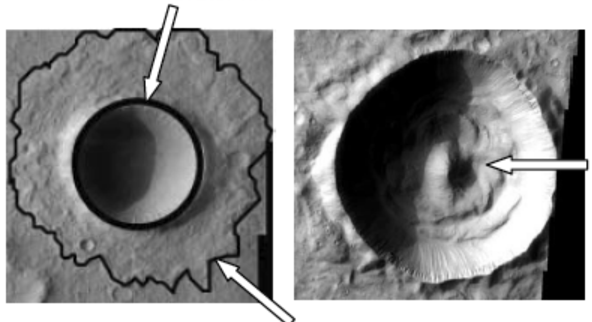


RELATIVE AGE DATING TECHNIQUES

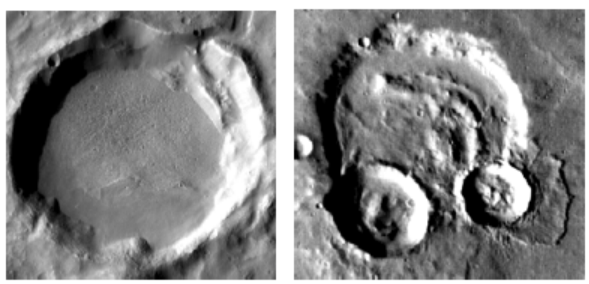
(G) Crater Classification Guide

We can classify impact craters into three general categories or classifications based on their appearance. These three categories give clues about the history (or relative age) of the crater. We cannot identify the exact age of a crater on Mars, but relative ages for different craters can help us develop a sequential history.

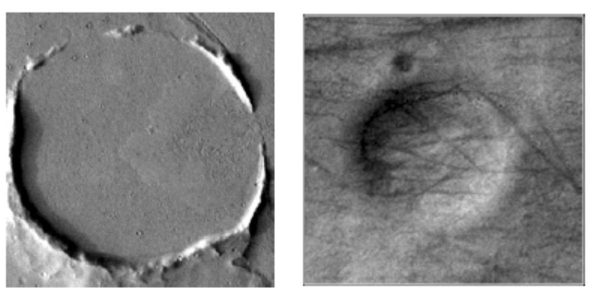
I. Preserved Craters:
- Near perfect craters
- Raised rims
- Look new
- Can sometimes see ejecta blanket or central peak
- Young crater



II. Modified Craters:
- Craters that have been changed or modified by:
  - o Erosion (wind, water or lava)
  - o Other impacts
- Sometimes crater ejecta is visible but looks eroded
- Crater may have smooth floor (partially filled in with material or sediment)
- Middle-aged craters



III. Destroyed Craters:
- Look very worn away
- Rims are broken
- Have been severely changed or modified
- Crater has been filled in almost completely by sediment
- Very old craters

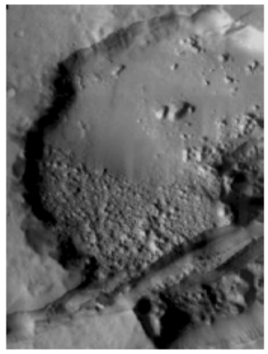


(H) Relative Age Dating Principles Guide

Scientists use two basic rules or principles to help determine the relative age of craters or other features on a surface. They are as follows:

I. Cross-Cutting Relationships:

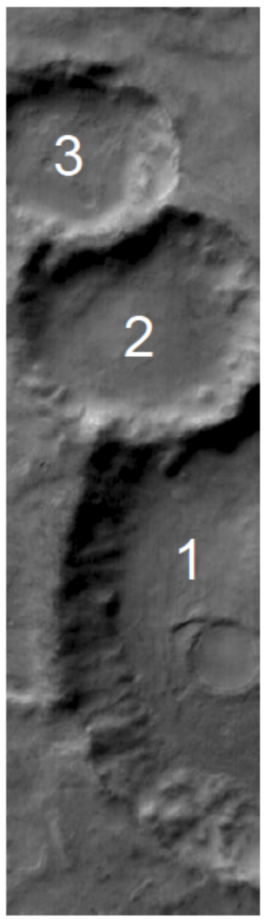
- A crater (or any other feature) can be cut by another feature.
- The feature cut is older than the feature that cut it.



Crater shown here is older than the fracture (crack) that cut through it.

II. Principle of Superposition

- When one feature is on top of another feature, the feature on top is younger.
- The feature on the bottom is the older feature.



Crater #1 is partly covered by crater #2, so crater #1 is older.

Crater #2 is partly covered by crater #3, which makes crater #2 older than #3.

By inference then, crater #1 is the oldest and crater #3 is the youngest.

(I) Classifying Craters

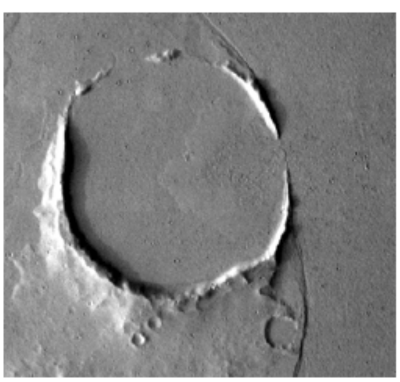
NAME:________________________________

Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

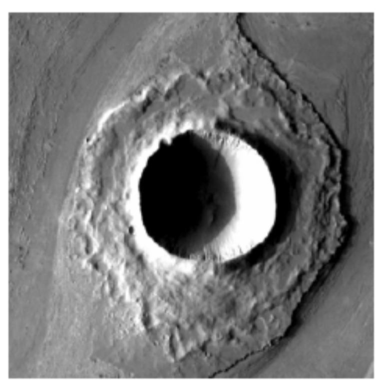
CRATER IMAGE	CRATER CLASSIFICATION (Preserved, Modified, or Destroyed)	EXPLAIN YOUR REASON
Crater A		
Crater B		
Crater C		
Crater D		

Crater A

Crater B



Crater C

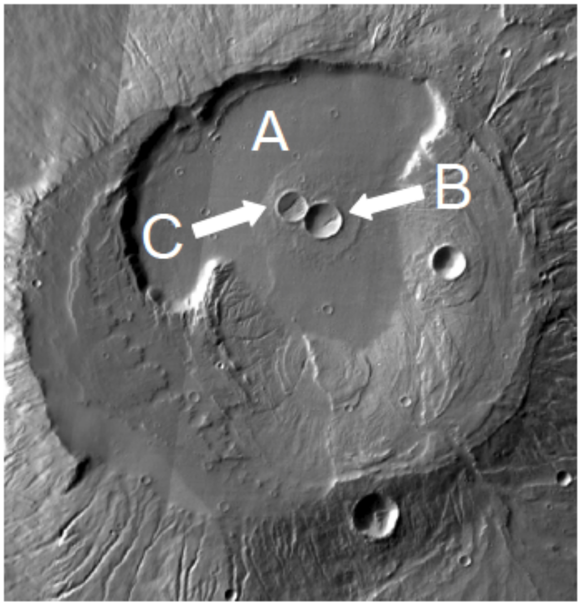


Crater D

(J) Relative Age Dating Principles

NAME:________________________________

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



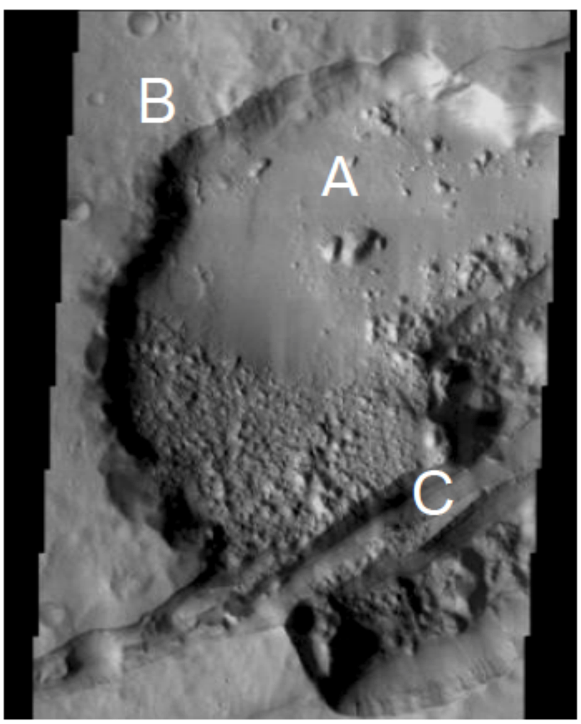
Oldest Feature: _______

Younger Feature: _______

Youngest Feature: _______

Please explain your answers:

Which principle(s) did you use to choose your answer?
____



Oldest Feature: _______

Younger Feature: _______

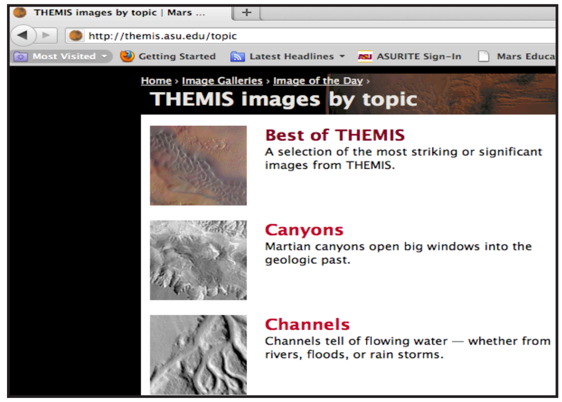
Youngest Feature: _______

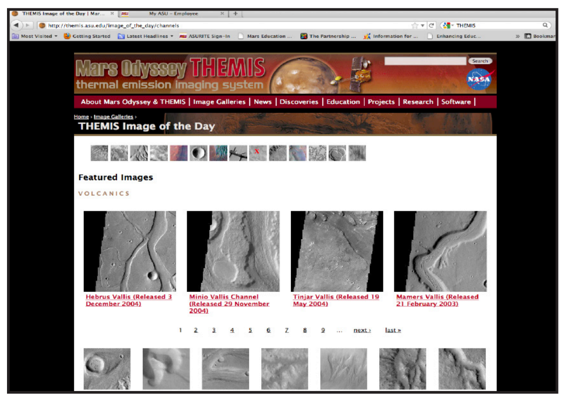
Please explain your answers:

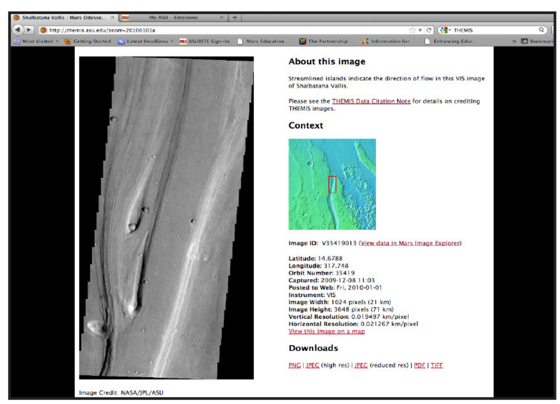
Which principle(s) did you use to choose your answer?
____

(O) Using THEMIS Website to Make Scientific Observations

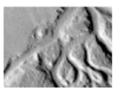
This activity will focus on THEMIS images that show details of many of the geologic features seen on the Mars surface. In this exercise, you will look at THEMIS images and log specific information about each image you observe. Here's what to do:







1. Go to the http://themis.asu.edu/topic website and click on the thumbnail (small square showing a part of a THEMIS image) of the topic your group will research:

   
   Channels
   Channels tell of flowing water — whether from rivers, floods, or rain storms.

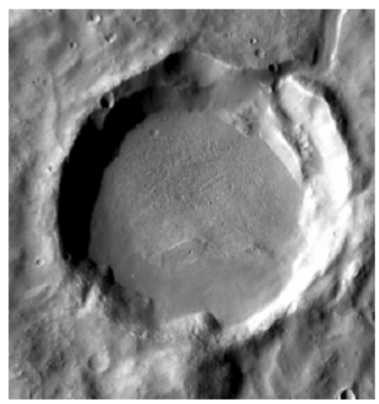
2. Click on any of the thumbnails to see a THEMIS image of Mars related to your topic:
   a. There are four large thumbnails at the top of the page.
   b. Below the top six thumbnails are more thumbnails of additional images.
   c. There are generally multiple pages of image thumbnails to choose from.
3. Click on a thumbnail to see a specific THEMIS image, context images showing the area where the image is located on Mars, and general information about the image.
   a. You can get an enlarged view of the THEMIS or context images by clicking on the image.
   b. Some images will have an Image ID #. To get more information on this image click on the "View data in Mars Image Explorer".
      i. This will open a new window showing the Image ID # and image information. Images that are not yet released will not have this link.

(V) Classifying Craters – Sample Answers

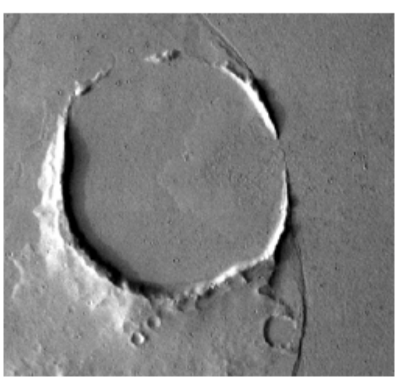
Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

CRATER IMAGE	CRATER CLASSIFICATION (Preserved, Modified, or Destroyed)	EXPLAIN YOUR REASON
Crater A	***Preserved***	***Can see ejecta blanket clearly; has central peak; crater looks new***
Crater B	***Modified***	***Rim is broken by other impacts and a landslide; other small impacts are seen on the floor***
Crater C	***Destroyed***	***Rim are broken; crater appears to be almost completely filled in***
Crater D	***Preserved***	***Can see ejecta blanket; rim looks nearly perfect; crater looks new***

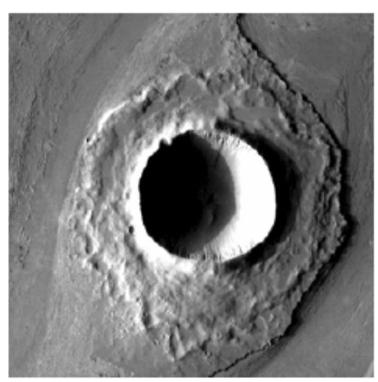
Crater A



Crater B



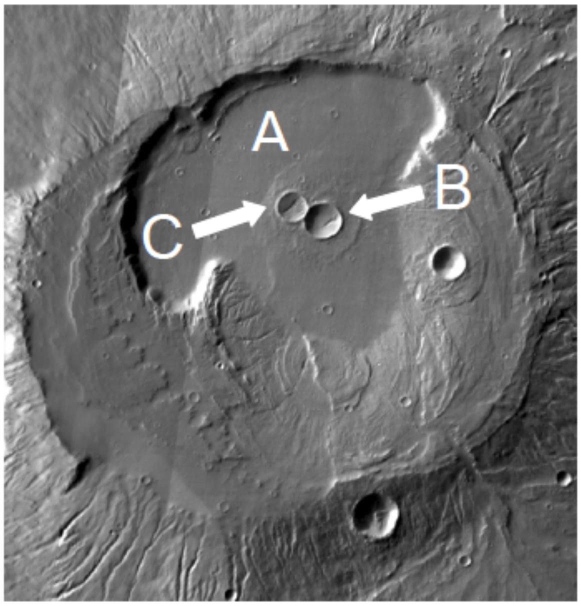
Crater C



Crater D

(W) Relative Age Dating Principles – Sample Answers

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



Oldest Feature: ___*A*___

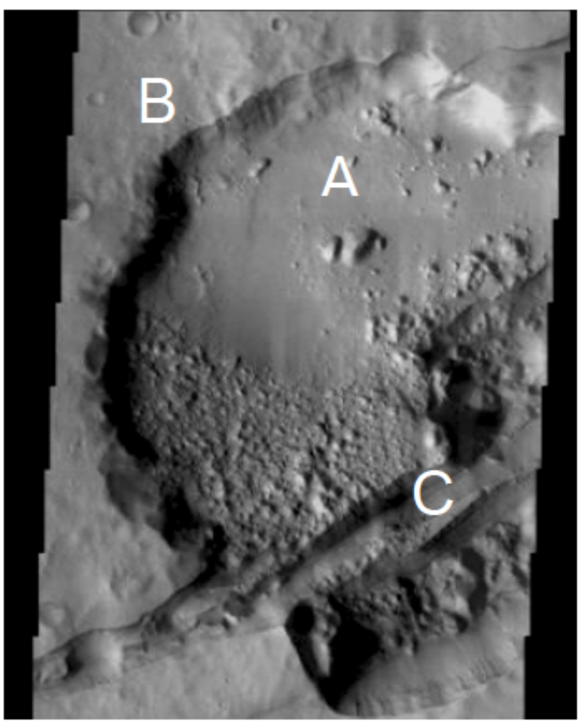
Younger Feature: ___*B*___

Youngest Feature: ___*C*___

Please explain your answers:

Crater C is on top of the ejecta blanket of Crater B so it is the youngest. Crater B and C are on top of the Crater A so Crater A is the oldest.

Which principle(s) did you use to choose your answer?
____*Principle of Superposition*____



Oldest Feature: ___*B*___

Younger Feature: ___*A*___

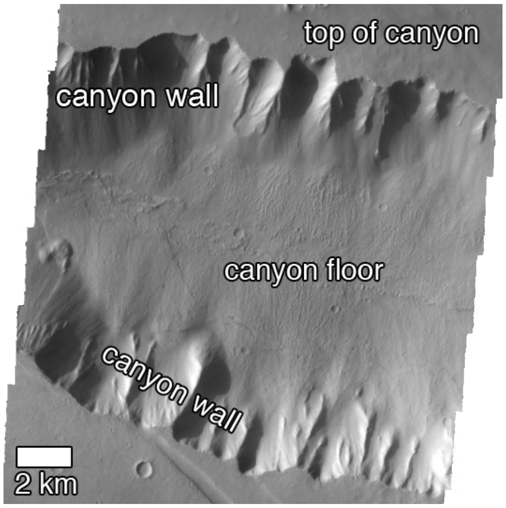
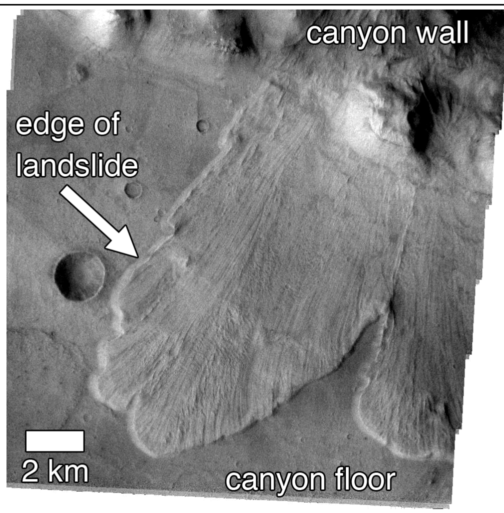
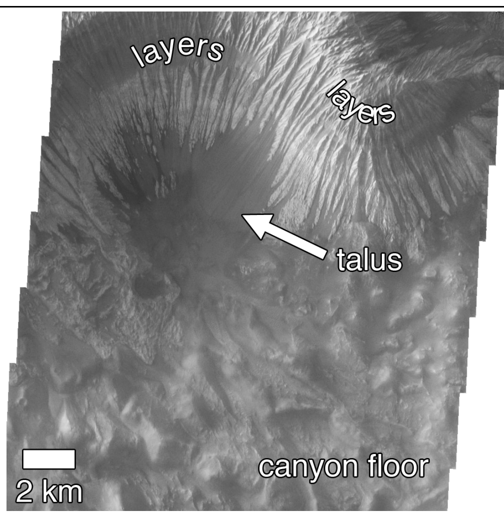
Youngest Feature: ___*C*___

Please explain your answers:

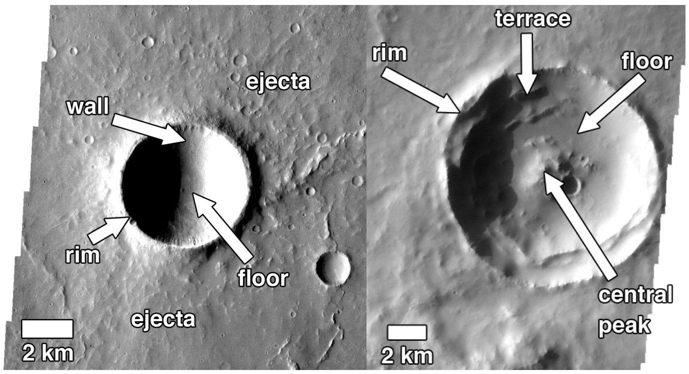
Feature C is on top of Feature A so it is younger than Feature A. Feature C is also cutting Feature A, so that also provides evidence that it is younger. Feature A is on top of Feature B, so A is younger than B. Feature B is on the bottom of both features, so it is the oldest.

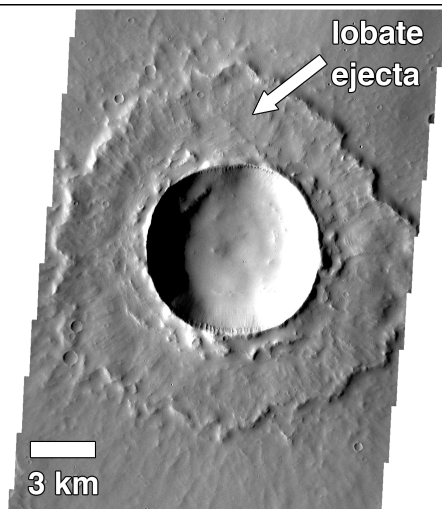
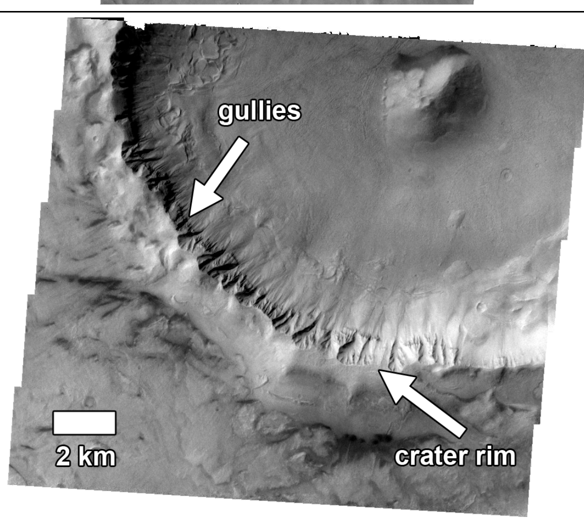
Which principle(s) did you use to choose your answer?
*Cross Cutting and Superposition*

(S) Feature ID Charts – Canyons

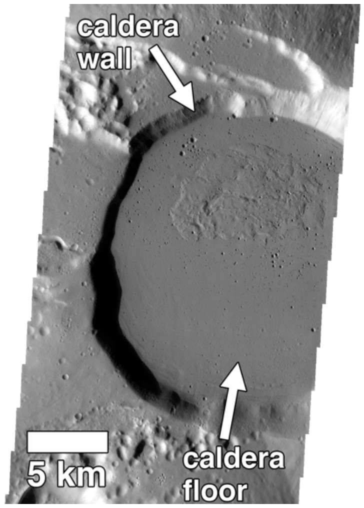
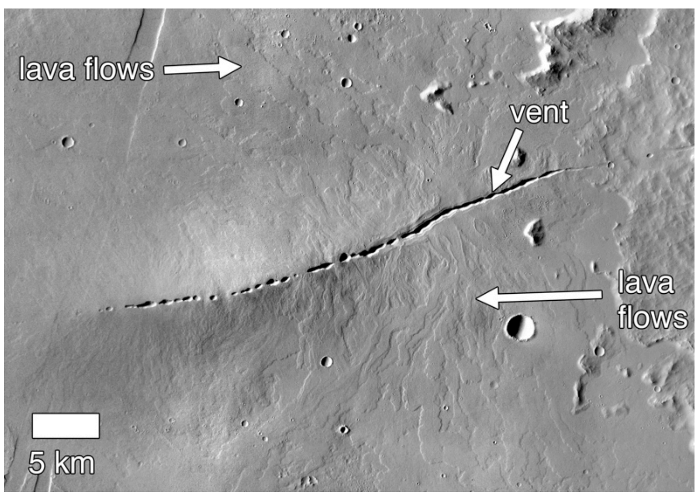
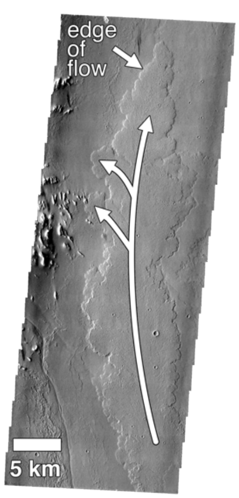
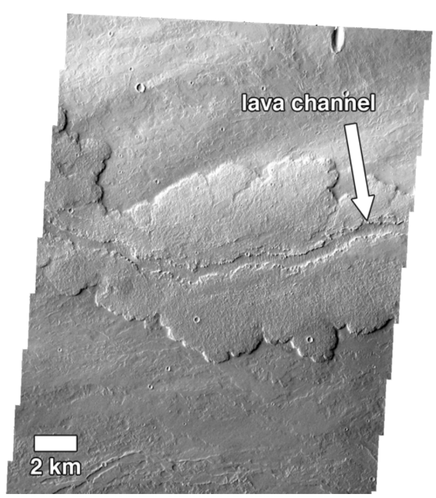
Feature	Example	Description
Canyon		• Identified by a steep drop in elevation, similar to what is seen with canyons on Earth • Canyon walls often have been eroded, forming spurs and gullies • Top of canyon is generally flat and smooth
Landslide		• Material that has slid down the canyon wall • Often has linear (long and straight) grooves parallel to the direction of flow (white arrows on flow) • Lobate edges look like fingers or tongues
Layers		• May be found in canyon walls • Contain a record of previous conditions • Thickness may indicate relative deposition time or deposition rate • Talus (material that has fallen down slope) collects at the base of the canyon wall and in gullies

(S) Feature ID Charts – Craters

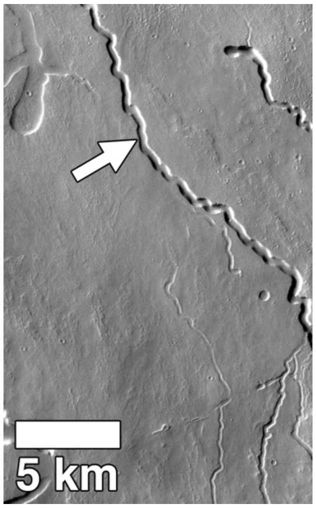
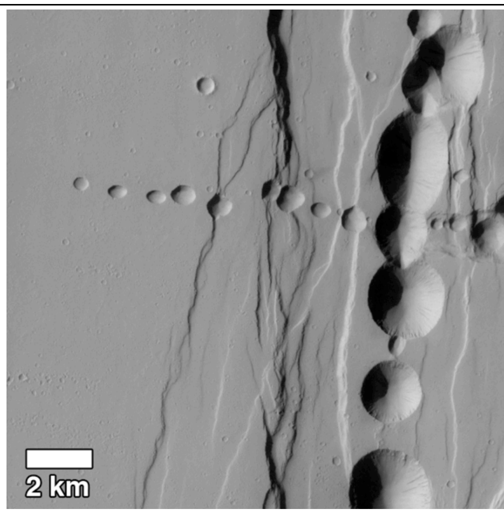
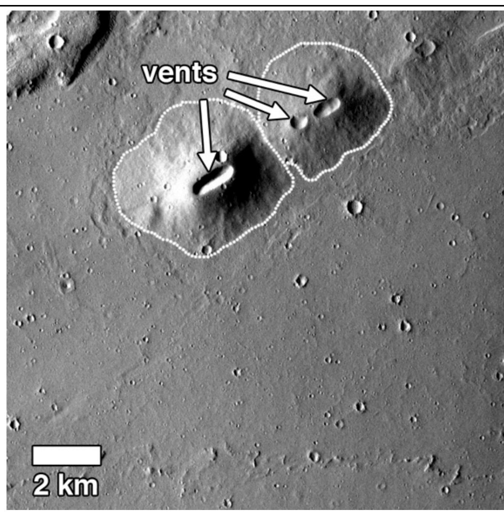
<table>
<tr><th>Feature</th><th>Example</th><th>Description</th></tr>
<tr><td>Simple & Complex Crater</td><td>

simple complex</td><td>• Formed by objects striking the surface
• Usually circular in shape
• Have a rim, floor, and walls
• Smaller (simple) craters have a bowl shape while larger (complex) may have a central peak and terraced walls</td></tr>
<tr><td>Rampart Crater</td><td>
</td><td>• May form around both simple and complex craters
• Have a special ejecta called lobate
• Ejecta looks like it flowed away from the crater
• Are associated with liquid water or ice being below the surface</td></tr>
<tr><td>Gullies</td><td>
</td><td>• Often found on crater walls or other steep slopes
• Appear to be young
• May be formed by liquid water or dry avalanches</td></tr>
</table>

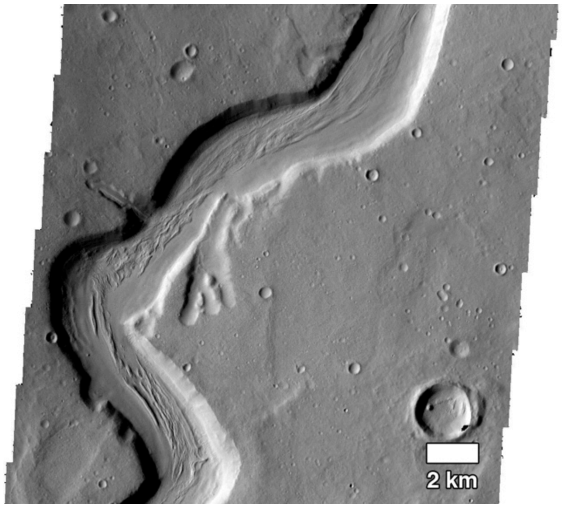
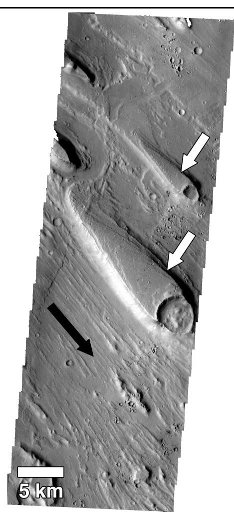
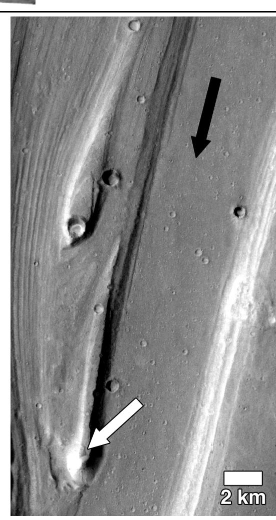
(S) Feature ID Charts – Volcanoes

Feature	Example	Description
Caldera		• A circular depression near the summit (top) of a volcano (some volcanoes have multiple calderas) • Likely form from collapse (after magma erupted, the top of the volcano collapses into empty magma chamber) • Sometimes called a central vent
Fissures		• Cracks in the crust where lava erupts, usually found near volcanoes • Multiple lava flows are seen trailing away from the crack • Highest point is at the vent with lavas sloping away from the vent
Lava Flows	 	• Formed by the eruption of magma (liquid rock) at the surface • "Fingers" point in direction of flow (white arrows in left image) • Often multiple flows in an image • May have a central lava channel

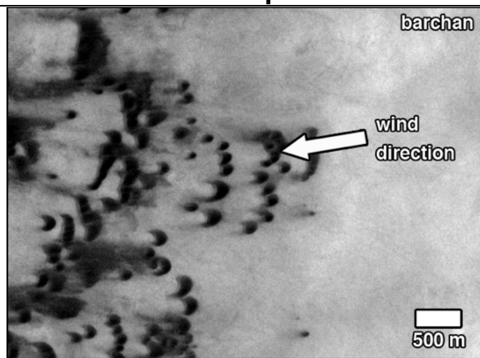
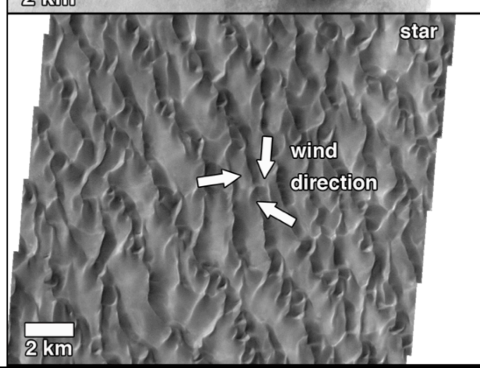
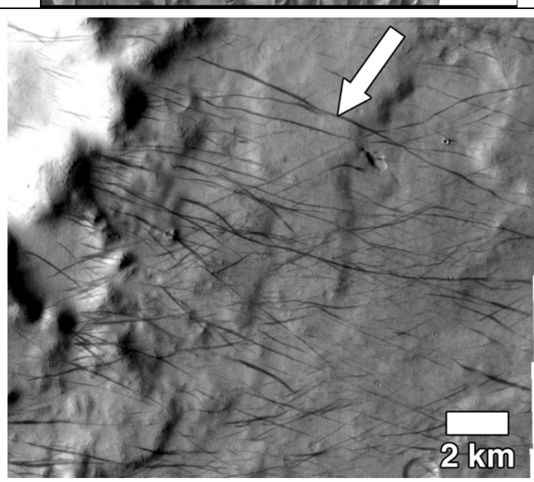
(S) Feature ID Charts – Volcanoes

Feature	Example	Description
Collapsed Lava Tubes		• Look similar to water channels but are more "squiggly" • Lava once flowed under ground through a tunnel and the roof collapsed into the empty tunnel • Often see multiple collapsed lava tubes in one image
Pit Chains		• Sometimes form over empty lava tubes • May form over faults (cracks in the surface) related to volcanism • Pits in a chain usually have similar diameters
Low Shield		• Small volcanoes that usually have central depression (vent) • Often found in fields or clusters • Not found in the Southern Highlands • May have smooth sides or radial (pointing away from the center) lava flows

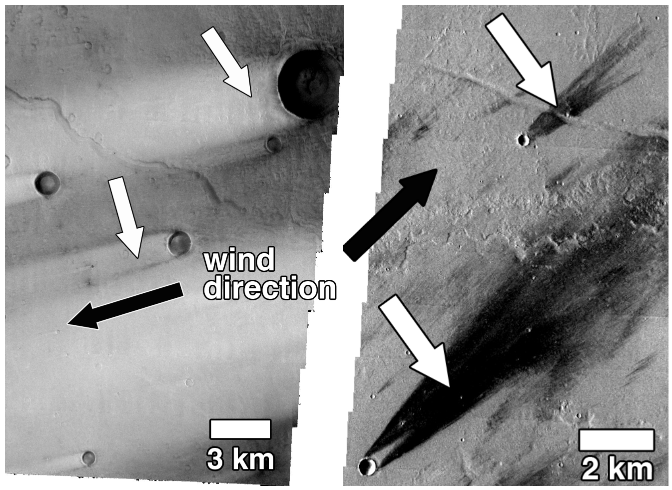
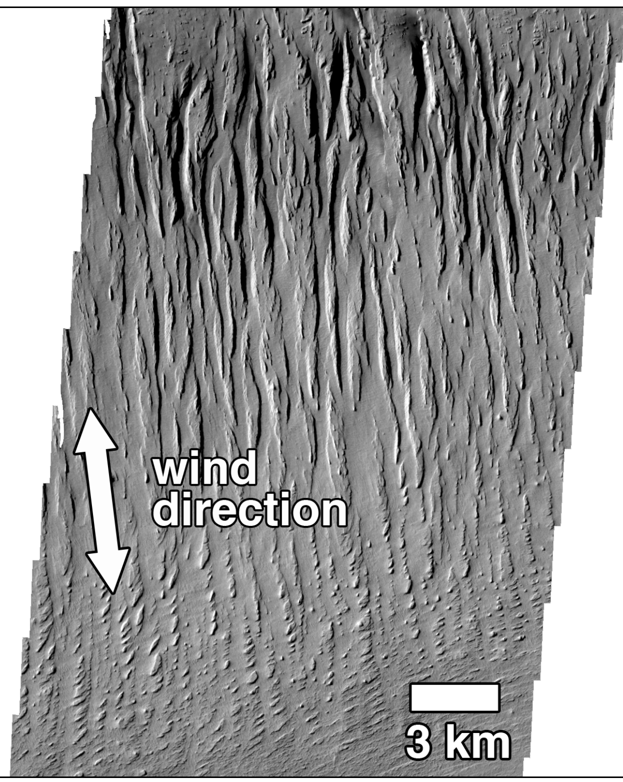
(S) Feature ID Charts – Water-Related (Fluvial) Processes

Feature	Example	Description
Simple Channels		• Likely formed by consistent flow of water over a long period of time • Has a meandering (curvy) shape
Chaotic Terrain		• Often found at the head (start) of large channels and looks chaotic (jumbled) • May have formed where water burst from the ground due to volcanic heating of subsurface ice or groundwater • Surface then collapsed into voids (holes) where the ice/water was
Streamlined Islands	 	• Thought to form by water flowing around a crater (left and right image) or ridge (right image) • Usually found in larger channels and indicate flow direction (black arrows) • Have a teardrop shape

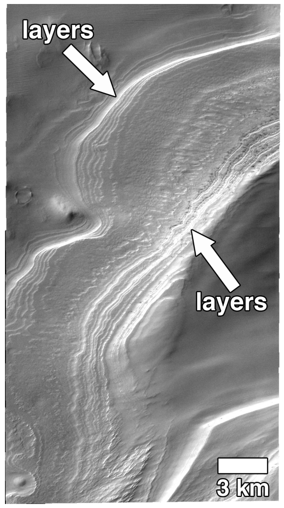
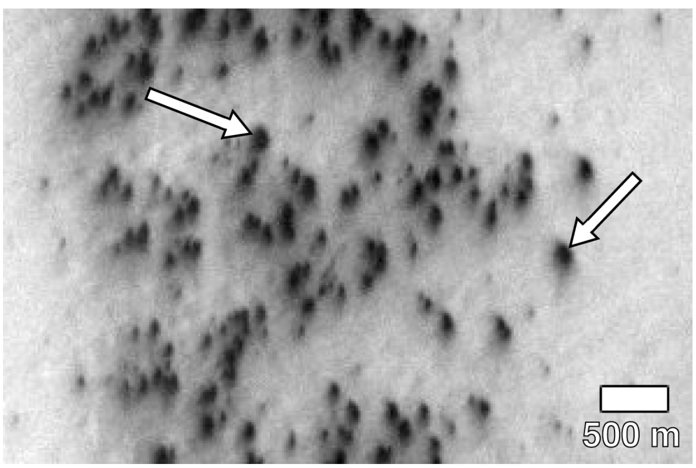
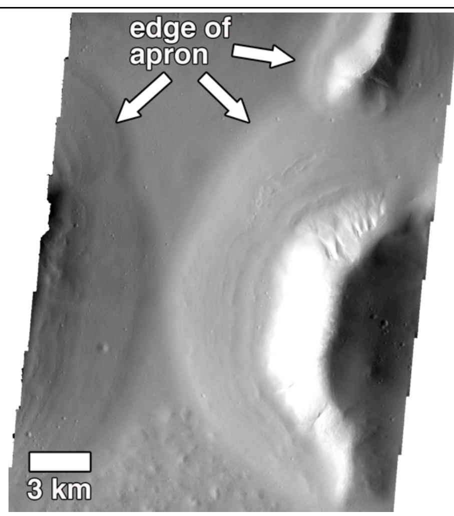
(S) Feature ID Charts – Wind-Related (Aeolian) Processes

Feature	Example	Description
Sand Dunes	  	• Form in windy areas and are usually darker than surrounding terrain (surface) • Show direction of wind when they formed (may be old and found in currently calm areas) • Barchan dunes have a crescent shape where the ends point in the wind direction • Transverse dunes around found in fields and one side (upwind side) is wider than the downwind side • Star dunes form where the wind blows in more than two directions
Dust Devil Tracks		• Dust devils pick up bright dust, exposing darker surface underneath • Darker tracks are usually younger and get lighter as dust slowly covers the track • Can help identify wind direction

(S) Feature ID Charts – Wind-Related (Aeolian) Processes

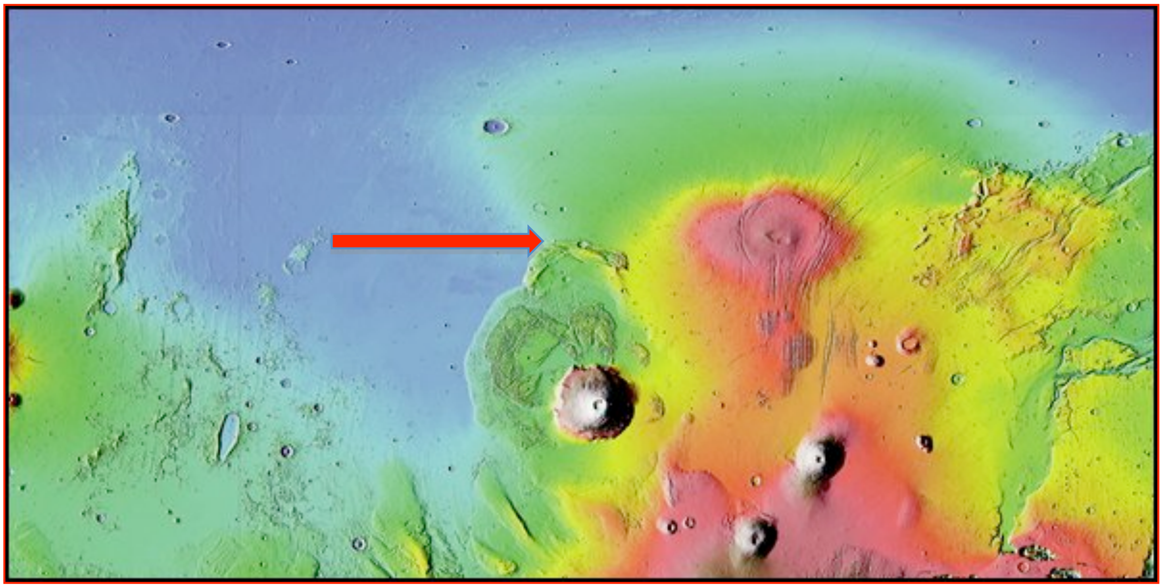
Feature	Example	Description
Wind Streaks		• Can be light (left image) or dark (right image) • Often form behind craters or ridges • Light streaks are thought to form by deposition (deposit) of dust • Dark streaks are thought to from by erosion (removal) of surface material • Indicate prevailing wind direction (black arrows)
Yardangs		• Erosional feature formed by sand-sized particles being blown against a surface • Have a uniform direction • Are linear (straight and long) features • Found on surfaces that erode easily

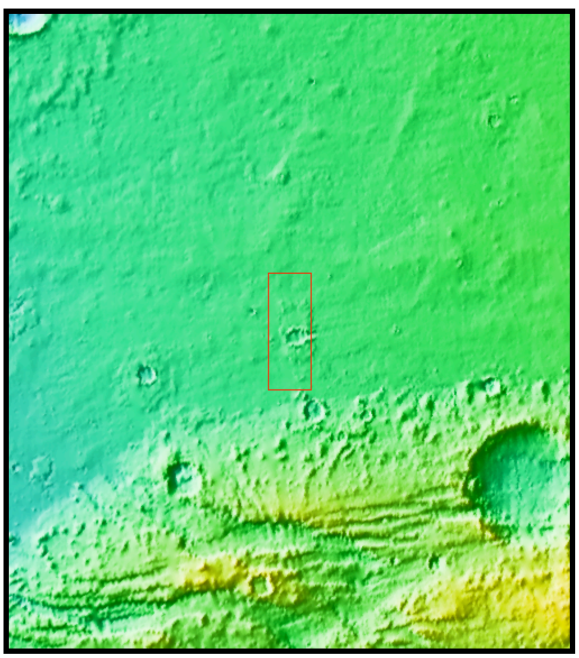
(S) Feature ID Charts – Ice

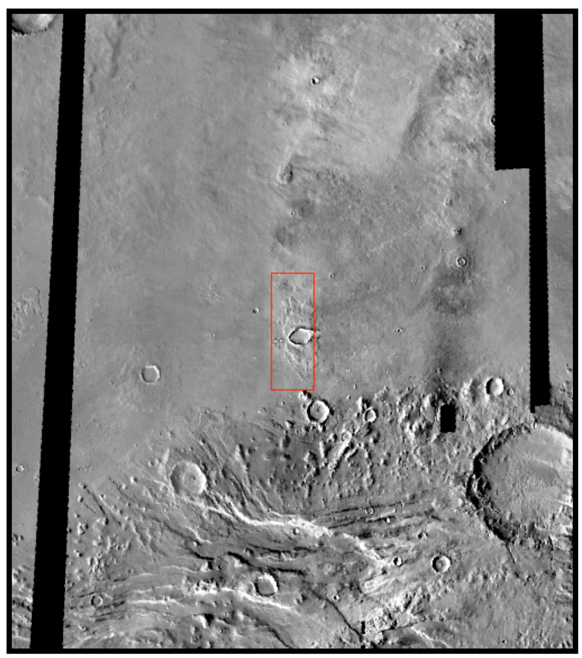
Feature	Example	Description
Polar Ice Caps		• Found at the north and south pole • Layers represent changing conditions (seasonal or longer) • Stacked layers of dusty or sandy ice
Polar Spots		• Only found near the south polar ice cap • Form seasonally (same time of the year) and may be caused by geysers (jets) of carbon-dioxide gas carrying sand • Wind can blow the sand, leaving streaks which show wind direction
Lobate Debris Apron		• Found in low to mid latitudes around plateaus and ridges • Composed (made) of water ice and rocks (rock glaciers) • Can flow up to 15 km away from the base • Appear to be young features (very few impact craters on the surface)

(A) What can you tell from a picture? (1 of 2)

NAME:________________________________







See Section 5.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

(A) What can you tell from a picture? (2 of 2)

(B) Background

How do scientists understand and interpret the surface features of Mars from orbit and determine if a proposed landing site will meet the mission's science goals? The distance to Mars varies between 80 and 240 million kilometers (50 – 150 million miles). The planet is therefore studied using remote sensing techniques. As part of the science studies from the *Mars Global Surveyor* and *Mars Odyssey* missions, images from these spacecraft have provided valuable information that has been used to understand the surface of Mars in the context of finding and evaluating possible landing sites. The images from these orbiters have also given scientists a better understanding of the past geologic history and the present conditions on Mars. The geological processes that occur on Mars are similar to those that occur on Earth. Comparative planetology, especially between Earth and Mars, is widely used by scientists currently researching Mars. As you work through this activity, think about what you know about Earth to help you better understand the processes on Mars.

Photo Courtesy of NASA's Jet Propulsion Laboratory

For this activity, you will be using images taken with the Thermal Emission Imaging System (THEMIS) camera on-board Mars Odyssey Spacecraft orbiter (pictured above). THEMIS has taken hundreds of thousands of images of Mars that are available on the internet at http://themis.asu.edu.

THEMIS (pictured right) is a two-in-one camera system:

- Visible Imaging System
  - Shows the morphology or shape of the surface
- Infrared Imaging System
  - Can tell us the temperature of the surface (daytime and nighttime)
  - Provides information about what materials on the surface are made of
  - Daytime infrared images can also show the morphology or shape of the surface in much the same way visible images do.

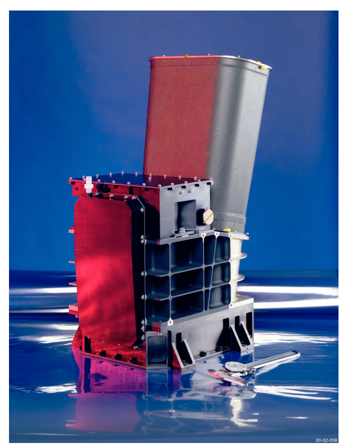


Photo Courtesy of NASA's Jet Propulsion Laboratory

(C) Lesson Background

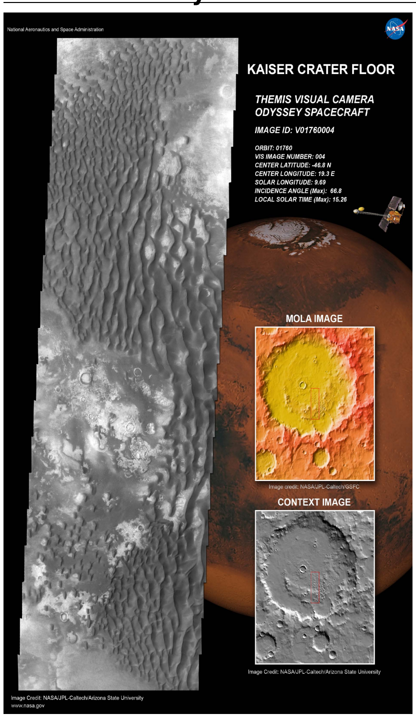
<u>Essential Question</u>: How do people reconstruct and date events in Earth's planetary history?

For this activity, you will be placed in the role of scientists. You will complete four different tasks as part of a guided investigation and introduction to the Mars Thermal Emission Imaging System (THEMIS) camera images. Your investigation will include:

1. Discovering what geologic features can be identified on the surface of Mars;
2. Determining the surface history of an area;
3. Calculating the size of observed features in images; and
4. Developing scientific observations.

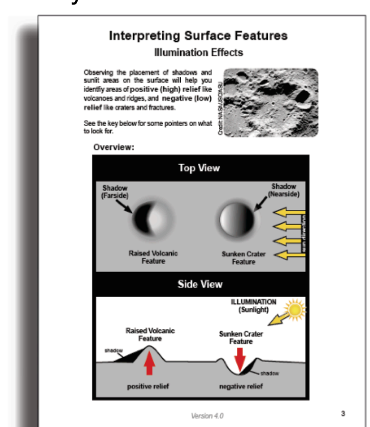
Throughout this activity, you will be completing a **Student Data Log**. A variety of tools are available to help you in this activity. Your teacher will help orient you to each of these throughout the activity.

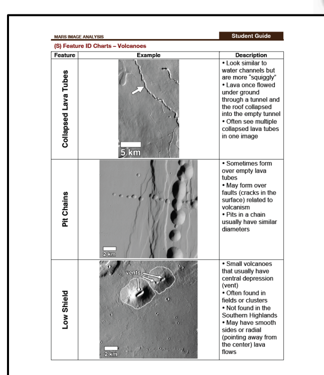
Part 1: Identify Surface Features:

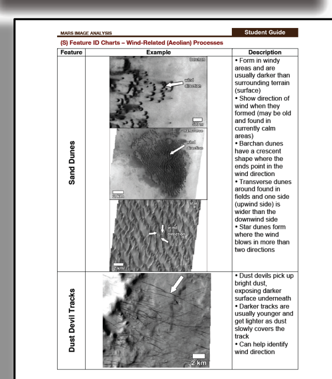


SAMPLE THEMIS IMAGE AND CONTEXT IMAGE

For this activity, you will analyze images of Mars provided by your teacher. As you observe images, be sure to use the **Feature ID Charts** to help you identify and label features with a wet erase marker. Your teacher will explain the materials and information you have available for this part of the activity and when to fill information into the **Student Data Log**. Here you will see a sample of the **THEMIS image** and **Feature ID Charts** you will be using.







(D) Student Data Log

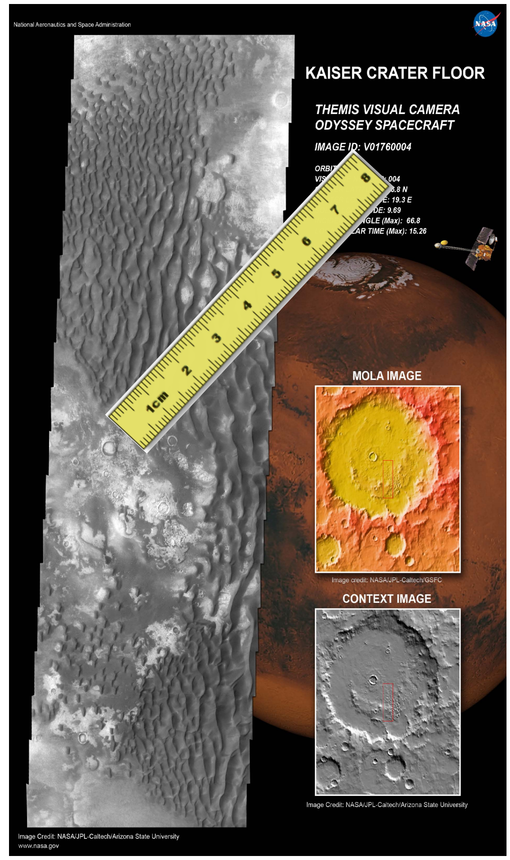
NAME:______________________________

Use this table to order the major (most noticeable) features according to their relative ages. The oldest feature should be numbered 1, next oldest 2, 3, 4, 5, to the youngest number 6.

Feature Name		Age Rank	Describe How Feature Formed
	Oldest ↑		
	↓		
	Youngest		

Write out a short "history" of the major events that took place in your area. Use the relative age of the features that you listed in your table.

(K) Making Measurements Notes



Example:

1. **Determine the *scale factor* for your image:**
   A. Measure the distance across in centimeters: **21 cm**
   B. Divide to figure out the scale of your image:

      18 km = _**21**___cm

      18 km / _**21**__ cm = **0.86** km/cm)

      ***Scale Factor*: 1cm = 0.86 km**

2. **Multiply the size of any feature measured in centimeters by the scale factor:**

   Example: Width of channel = _**2**__cm

   _**2**__ cm X **0.86** km **=** _**1.72**_ **km**

   Width of channel = 1.72 km

**Use this page section to calculate the scale factor of your THEMIS image:
Determine the *scale factor* for ***your image***:

A. Measure the distance across in centimeters: __________cm

B. Divide to figure out the scale of your image:

18 km = ___________cm

18 km / ___________ cm = _____________km/cm)

***Scale Factor*: 1cm =** ________________**km** (Include this scale factor on your image)

**Remember, as you measure features on your image in centimeters, you will multiply that measurement by your *scale factor*. Be sure to list the *scale factor* on your image as well as the sizes of features you calculate.

Record the feature measurements into your Student Data Log sheet.

See Section 5.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

(L) Student Measurement Data Log

NAME:______________________________

Use this table to record your feature measurements.

Step 1: Measure the distance across in centimeters: __________cm

Step 2: Divide to figure out the scale of your image:

18 km = __________cm

18 km / __________ cm = ____________km/cm)

***Scale Factor*: 1cm = _______________km** (write this number in the column title "Scale Factor")

Feature Name	Feature Measurement X	Scale Factor	= Feature Actual Size

(M) Establishing a Research Topic of Interest

NAME:______________________________

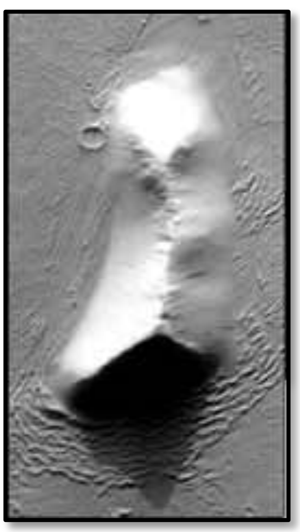
Use the next page as a guide for completing your background research. Remember, your goal is to become an expert on your topic.

1. Within your group, brainstorm four **general topic** that can be studied about Mars. For example; volcanism, cratering, water, human exploration, etc. These can be whatever interests you and your group.

   ______________________________ ______________________________

   ______________________________ ______________________________

2. As a class, vote on the topic that is most interesting for your research. Your class topic for research is: ____



Why Background Research?

Knowing a lot about your topic will help you make better observations. Better observations make better research questions.

Many of your THEMIS image observations are everyday observations. Everyday observations are very general. These observations are good, but we want to learn more about Mars. We need to look for features that are important to scientists.

Important observations make great research questions. Great research questions help scientists understand Mars and its history.

Examples:

Everyday observation:

There are many craters in the image.

Scientific observation:

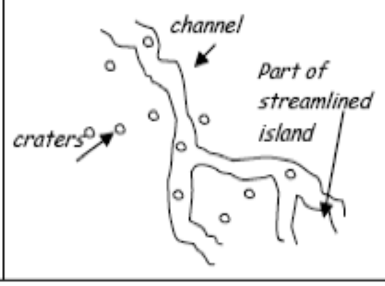
There are 20 craters in the image that are over 10km wide.
25 craters are destroyed craters.
There are 34 craters in the rocky areas, but only 2 in the flat areas.
Not all of the craters with central peak have rough walls.

(N) Background Research

NAME:______________________________

Citation (Source):		
How was the feature formed?	What are are they typically found on the Mars?	How are they similar or different from what can be found on Earth or other planetary bodies (planets/ moons?)
Drawing:	Drawing:	Drawing:

(P) Example Observation Table

Surface/Geologic Feature(s) Observed & Image ID #	Sketch of Surface/Geologic Feature(s)	Specific Observations of Surface/Geologic Feature(s)
Channel with craters **Image ID #:** V11030007		*-Channel does not seem very wide* *-Can see streamlined islands* *-Small craters both on the outside and inside of channel* *-All craters in image seem to be about the same size*

Make scientific observations:

1. Fill out the following two observation tables.
2. Be as detailed as possible as you enter the data in the tables. Remember, your goal is to make Scientific Observations, not Everyday Observations. Use your completed Background Research for details (such as usual features) on your topic.
3. Think about the surface features that you are observing - what interests you?
4. Work with people on your team to find other areas on Mars that have features you are interested in.

Credit: NASA

(Q) Observation Table (1 of 2)

NAME:________________________________

Making Observations of THEMIS Images

Surface Geologic Features Observed & Image ID #	Sketch of Surface Geologic Features	Text Description of Surface Features (use bullets)
Image ID #:		
Image ID #:		
Image ID #:		
Image ID #:		

(Q) Observation Table (2 of 2)

NAME:________________________________

Making Observations of THEMIS Images

Surface Geologic Features Observed & Image ID #	Sketch of Surface Geologic Features	Text Description of Surface Features (use bullets)
Image ID #:		
Image ID #:		
Image ID #:		
Image ID #:		

(R) Choosing a Topic for Research

NAME:_______________________________

1. Review your scientific observations from the Observation Table. Choose two observations you found most interesting during your online research. These are observations you would like to share with the class and could turn into an interesting research project. Record them below.

Observation #1	Observation #2

2. After a class discussion about interesting scientific observations, list six major relevant categories within your topic – or features that the class can choose to study about Mars. For example, with volcanism think about related surface features such as lava flows, eruptions, volcanoes, ash and rock deposits. Once you have created the list, as a team debate and select your topic and relevant category.

_______________________________ _______________________________

_______________________________ _______________________________

_______________________________ _______________________________

3. List the topic your group will research: _______________________________