Mars for Earthlings
DYNAMIC MARS

All of the instructor *in-class activities* have the Bybee (2006) pedagogical 5E approach, organized into the categories of Engage, Explore, Explain, Elaborate, and Evaluate. However, the actual student activity and homework assignments are not laid out in that specific 5E format in order to be consistent with other inquiry learning activities and homeworks on the SERC platform (Science Education Resource Center hosts our original Mars for Earthlings pages http://serc.carleton.edu/marsforearthlings/index.html). Thus, the 5E format is mainly a guide for instructors to use as they choose.

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For more background on the Mars for Earthlings Concept see:

Chan, M. A., and Kahmann-Robinson, J., 2014, Mars for Earthlings: An Analog Approach to Mars in Undergraduate Education: Astrobiology. v. 14, n. 1, p. 42-49.

All materials given here and on the Mars for Earthlings website
http://serc.carleton.edu/marsforearthlings/index.html

Mars for Earthlings

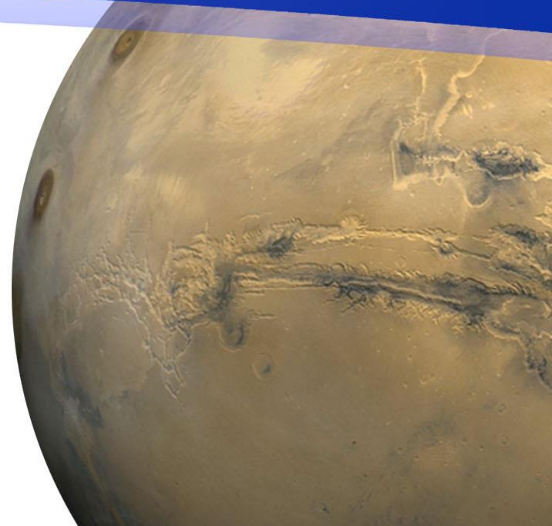
Mars for Earthlings is a set of 23 teaching modules comprised of both in class and homework activities. The modules are intended for use in a lower level geoscience or planetary science undergraduate course, however they can be modified for either introductory or more advanced students. Because undergraduate introductory courses can vary with different aptitudes or teaching philosophies, the modules try to introduce complex topics while allowing room to expand based on choices, background, or expertise of the instructor.

For each module set there is both a student and instructor version. The instructor version comes with an introductory page and the in-class activities are written in the 5E teaching format (see explanation of 5E in the introductory page). The instructor versions of the homework assignments have adjusted language directed to the teacher, but are otherwise formatted similar to the student version. The student version contains all necessary handouts, homeworks, and in-class instructions for the activities, however we suggest that the instructor introduce the activities and guide students through the material. Additionally, in-class activities can be modified to become homework assignments and vice versa.

References:

Bybee, R.W., Buchwald, C. E., Crissman, S., Heil, D. R., Kuerbis, P. J., Matsumoto, C., and Mclnerney, J. D. 1989. Science and technology education for the elementary years: Frameworks for curriculum and instruction. Washington, D.C. *The National Center for Improving Instruction*, 155 p.

Chan, M. A., and Kahmann-Robinson, J., 2014, Mars for Earthlings: An Analog Approach to Mars in Undergraduate Education: Astrobiology. v. 14, n. 1, p. 42-49.



Lesson 1: Welcome to Earth and Mars

Summary

This introduction will expose students to Mars imaging software platforms so that students may become familiar with their navigation and imagery products.

Learning Goals

Students will be able to:

- Navigate and use both Google Mars and JMARS.
- Become familiar with imagery collections available (e.g., HiRISE, CRISM, THEMIS) via the above software programs.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course. The *In-Class Activities* can be easily adapted for homework when desired.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Mars Analogs

Homework/Lab

Homework 1: Google Mars
Homework 2: Exploring Gale Crater
Homework 3: JMARS- Mawrth Vallis "Potential landing site"
Homework 4: Meet the Scientist- Who studies Mars?
Homework 5: Having fun with Mars programs

Teaching Notes and Tips

1. Before assigning Homework 1 or 2 spend some time exploring both Google Mars and JMARS with the students for a "first pass" exposure.

Assessment

- Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Image File: Welcome to Earth and Mars
2. JMARS Website: http://jmars.asu.edu/
3. Google Earth Free download: http://www.google.com/earth/index.html

Mars for Earthlings

In-Class Activity 1
Intro to Mars_MFE
Mars Analogs

Purpose: Observe and rank potential Earth analogs for Mars planetary study.

Preparation:
1. Print off student exercise
2. Use .ppt image file for class

Resources:
Intro to Mars Image File

Engage
What is an analog?
1. What do students think scientists mean by an "earth analog" in the context of studying Mars?
2. As an example, why is the komodo dragon considered an "analog" for a dinosaur?

Explore
Present the following regions as potential analogs for Mars (via Intro to Mars Image File):
- Atacama Desert
- Death Valley, CA
- John Day Formation, Oregon
- Southern Utah
- Antarctic Dry Valleys

Ask students to consider their criterion for whether or not a region is a good analog. Discuss varying criteria as a class and determine the most appropriate definition of a good analog.

Explain
Have students investigate "vital statistics" of Mars via the internet (see Image File examples) such as: ambient temperature ranges, atmospheric composition, mineralogy, depositional environment, the absence of life, water, and geomorphic features.
Other example references: http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html

Elaborate
As students discuss the various regions, have them provide the Earth data/statistics (similar to Mars) of these regions for comparison to Mars.

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Evaluate
Check off how important students think the following factors are in deciding whether this is a good analog to Mars (1-very important, 5-not important)

_________ Environment conditions, setting for deposits

_________ Geomorphic features (landscape expression)

_________ Type of water and its presence or absence

_________ Ambient temperature range

_________ Mineralogy

_________ Type of life, if present (extremophile or not)

_________ Rainfall

_________ Atmospheric composition

Note: it may be difficult for any Earth Analog to satisfy all the conditions of similarity to Mars

Mars for Earthlings

Homework 1
Intro to Mars_MFE
Google Mars

Objective: Observe important features and "divisions" of the surface of Mars.

Introduction: This brief introduction will hone students' observation skills to notice features on the surface of Mars and some of the major natural landscape features.

Getting Started
Use the web version of Google Mars http://www.google.com/mars/
Notice that the map wraps (repeats), so students will want to crop the window so it just shows 1.

Exploring Mars
This initial flat plane projection map has 3 viewing options (upper right). The standard default is ______________________________. Here, the colors represent the scale in units of __________________. The other 2 viewing options are ____________________ and __________________.

Click on Stories. What is the name of the Martian rift zone? _________________________ In the left column window, click on "glossary" and review the terms. A mountain is called ___________________________ and a low plain is called _____________________. A high plain is called __________________________.

Click on Spacecraft. Why do the students think the spacecrafts were mainly in the "middle" of the planet?____

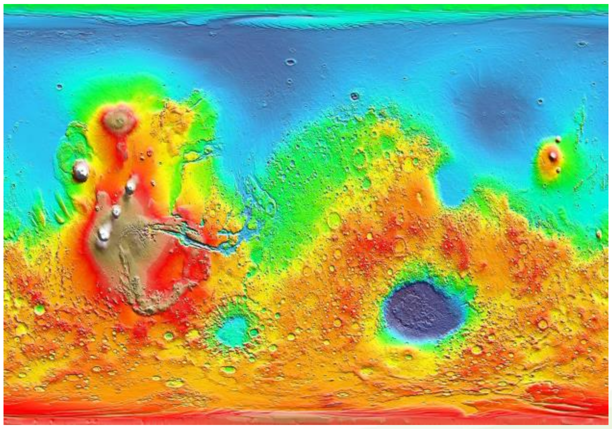
Overall
Just looking at the color patterns & textures, if the students were dividing the planet into 2 parts, how would they be defined and what are their characteristics?

Location Characteristics

1.

2.

Draw the boundary line between the two parts and have the students discuss their answers with one of their classmates (as assigned) and compare thoughts.



Mars for Earthlings

Homework 2
Intro to Mars_MFE
Exploring Gale Crater

Objective: To navigate, learn and utilize the tools offered within Google Mars.

Introduction: In order to accomplish this lab the students will need to download Google Earth 6 (http://www.google.com/earth/index.html). This lab will completely utilize Mars; all answers to questions can found by using the layers provided in the program. Some questions will be straightforward; however others will require students to use their own judgment and intuition.

Intro to Google Mars
Open Google Earth. In the icon list across the top of the window, click on the planet with a single ring button with a small dropdown arrow. The dropdown menu will provide options for Sky, Mars, and Moon. Click on Mars.

Searching the Layers Bar on the left:

1. Click on the drop down arrow for Global Maps.
    a. What map is used (checked/dotted) when Google Mars loaded (consult the Global Maps Layer)?

       What do the colors refer to?

    b. View the other Global Map types. Is there another the students prefer? (Why or why not?)

2. Click on the drop down arrow for Spacecraft Imagery.
    a. How many imaging devices are available?
    b. What are the image devices' names and what spacecraft are they aboard (click on each)?

    c. Which instrument/camera has the best resolution?

3. Make sure *Rovers and Landers* are checked before the students proceed.

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Exploring Curiosity's Landing Site

4. Type Gale Crater into the Search Box (Curiosity's landing site on August 5th, 2012).
   a. Is any imagery available right after it zooms in? Why or why not?

   b. Who is the crater named for and what is his/her nationality?
   c. What is the documented location of the crater?
      i. Center latitude
      ii. Center longitude
   d. What is the diameter size of the crater?

5. Zoom out (exit street view if necessary) until the MOLA colorized elevation map comes into better resolution. The students should see a swath of "***i***'s" in the upper left corner of Gale Crater.
   a. Find the landing site of the Curiosity Rover. It is marked with a flag icon. What was the location of its landing site (use the Google GPS coordinates)?

   b. Click on the Flag icon. What other landing sites were considered for Curiosity?

   c. Why do the students think that the majority of landing sites are crater locations?

6. Activate the HiRISE imagery in the Spacecraft Imagery Layer (red outlined rectangles should appear).
   HiRISE stands for ____
   a. Where are most of the HiRISE images taken?

   b. Why might the majority of images be in this location?

c. View the HiRISE image with the small *pink square box* labeled "Grand Canyon of Gale Crater" ESP_012195_1750 (located S of the landing site, where red line box appears as the students hover the mouse). Can they see the canyon? To download the image:
   i. In the information pane click on *observation information page* in blue (link)
   ii. This will bring up the HiRISE webpage. Scroll down to "Image Products" purple bar
   iii. Choose JPEG→ Grayscale → Map Projected
   iv. Paste the image here as a .jpg or sketch the image. Use an arrow and point to the location of the canyon. Use the space below to explain why this might be of interest to scientists.

7. Go through other images and information provided by Google Mars for Gale Crater. Write a convincing argument in 3-5 sentences on why Gale Crater was chosen as the landing site for MSL Curiosity.

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Homework 3
Intro to Mars_MFE
JMARS- Mawrth Vallis "Potential landing site"

Objective: To navigate, learn and utilize the tools offered within the software JMARS.

Introduction: In order to complete this lab the students need to register and download JMARS:

1. Go to webpage: http://jmars.asu.edu/
2. Click: Create New Account
3. Enter desired account information
4. Click: Request New Account (page should prompt them to check their email for password and further instructions)
5. Check email and click on link (or enter the link into their browser)
6. Click login and change password. The account should last 6 months.
7. Click on "Download JMARS" tab
8. Under section "JMARS Public Downloads" click "Cross-platform Java Webstart Installer"
9. Open installer: When JMARS opens the students will need to enter username and password.

For information about the software and great tutorial videos, go to https://jmars.mars.asu.edu/videotutorials. Make sure to watch Tutorial 1 to gain a brief introduction to the layout and use of the JMARS software. Alternatively, go to the JMARS homepage and explore the options under the "Tour of the JMARS user interface" and "Tour of the JMARS Layers" panels. Have fun exploring Mars and other planetary bodies.

Intro to JMARS
Have students open JMARS using their email/password. JMARS functions very much like the layers in Photoshop or GIS in order to view different image sets.

8. In the Layer Window, choose and press the button "Add New Layer" in the Main tab (other tabs at this point are: MOLA Shaded Relief NE, Lat/Lon Grid).
    a. Add the layer Nomenclature. With this layer open, the students can navigate to any feature on Mars by name.
    b. Activate/Open the Nomenclature tab. Keep all default boxes checked. Select Vallis in the *Selected Landmarks Types* menu.
    c. In the *Navigation* Menu select Vallis for *Landmark Type* and Mawrth Vallis for *Landmark*.
    d. Then press the *Go-To* button below. The software will automatically find and zoom to this location and label it.

e. What are the coordinates of Mawrth Vallis (place cursor/arrow over the red marker; the default color for the marker)?
f. Observe the terrain; have students explain why they think this area was considered as a landing site for MSL Curiosity (they may play around with the Zoom in the upper right of the viewing window, default is always 32).

9. Exploring Mawrth Vallis' relationship to other major Mars geologic/geographic features.

Add a new layer: Choose by Instrument → MOLA → MOLA Shaded relief/Colorized Elevation → View Graphic data. **note, if students are having trouble seeing the labels, move the Nomenclature label to the top of the layer window.

a. How does the colorized data help the students?

b. Where is Mawrth Vallis in relationship to Vallis Marineris (they may need to using the Nomenclature tab to find Vallis Marineris)?

Do they think these features are the same? Why or why not?

c. Where is Mawrth Vallis in relationship to the large expanse of "blue space" in the Martian Northern Hemisphere?

How could the students potentially interpret the 'blue space?' What about Mawrth Vallis?

10. Exploring the mineralogy of Mawrth Vallis.

    There are several methods to explore the mineralogy of the Martian surface in JMARS. We will only explore one. *Note: Make sure you can see the Mawrth Vallis label. If not, drag the Nomenclature layer to the top of the Layer Window.

    Using TES Mineral Maps: Add New Layer → Maps by Instrument → TES Mineral Map → Now select the following maps separately and explain their: spatial coverage, resolution and abundance of that mineral.

    a. TES Hematite

    b. TES Basalt Abundance

    c. TES Carbonate Abundance (Bandfield 2002)

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Homework 4
Intro to Mars_MFE
Meet the Scientist-Who studies Mars?

Directions: Navigate to http://serc.carleton.edu/marsforearthlings/index.html and click on "Meet the Scientist". Answer the following questions:

Watch all the short clips (only 2 mins. each or less) and answer the following questions.

1. How is this group of profiled scientists DIVERSE?

2. Who are the scientists that study Mars? *Choose 5 scientists to profile.*
List the scientists' last name and the institution each scientist is associated with. Describe the goals of their research.

	Name	Institution	Research
a.			
b.			
c.			
d.			
e.			

3. What is interesting and relevant? Have students choose two of their favorite scientists from *Meet the Scientists*.

- What is the most interesting fact (or rumor) they can find when they Google their name?

	Name	Fact
a.		
b.		

- In their opinion, is their research relevant (use a scale from 1-10 with 10 being extremely relevant)? Have them give a brief statement to justify their answer.

	Name	Relevance
a.		
b.		

- Can their research be helpful in other fields? If so give example(s).

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Name Helpful

a.

b.

- If students were an investor/ philanthropist/ government official would they fund the scientist's research? What would they change or applaud in their research?

Name Fact

a.

b.

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Homework 5
Intro to Mars_MFE
Having fun with Mars programs

1. Directions: Navigate to NASA's Eyes on the Solar System http://eyes.nasa.gov/

Explore Mars, and click on the Spacecraft icon.
Name the 3 types/categories of Mars Missions and cite the newest (most recent/current) example of each:

Mars Mission TYPE Newest Example

a. ____: ____

b. ____: ____

c. ____: ____

Click on the Landing Sites icon (top bar on right). Which landing site was closest to the N Pole of Mars? ________________________________

Explore several other planets. Which of the other Non-Mars planets did the students find most interesting? __________________________________

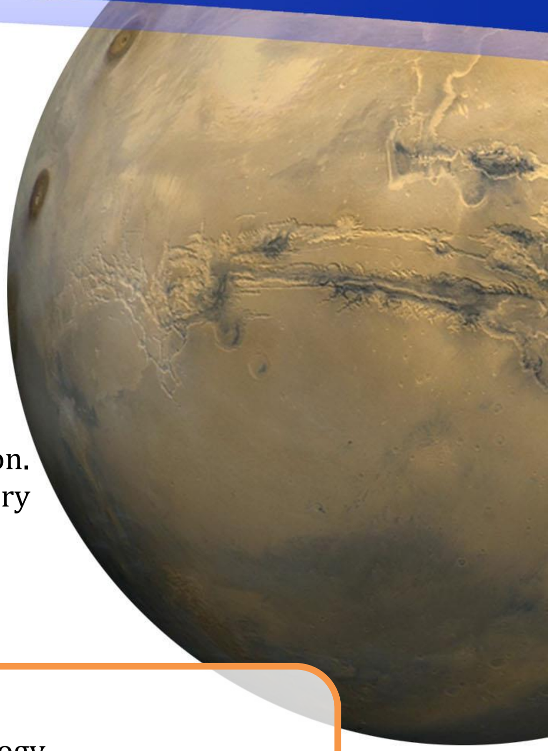
Explain why, what was interesting to the students?:

____
Note: The students can look at the planet in all kinds or orientations.

2. Directions: Navigate to NASA Spacecraft 3D (may work best on mobile, available in app store free download). The students may want to use the Augmented Reality target.

Take a picture of you and the Curiosity rover and email to you

Lesson 2: Planetary Formation: Mars vs. Earth formation and the Case for Pluto



Summary

This learning module and related laboratory exercise exposes students to planetary body classification, and planet differentiation. Students will be able to compare and contrast the formation history of Mars and Earth as well as confidently assess the present classification of the planet Pluto.

Learning Goals

Students will be able to:

- Explain how planets form using JELL-O 1-2-3 as an analogy.
- Engage in a positive interactive debate regarding the classification of Pluto and in written format express their view competently using current scientific theory and resources.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1- Differentiation of Planets & Jell-O 1-2-3

Homework/Lab

Homework 1- Pluto Debate Write-up

Teaching Notes and Tips

1. JELLO 1-2-3 Analogy
    a. Small class size <20: have JELLO ingredients made up and ready for disbursement at end of class.
    b. Large class size >20: have both ingredients and one pre-made JELLO cup for students to analyze and develop an analogy for planet differentiation.

2. Pluto debate
    a. Prior to class assign students to either the Affirmative or Negative team so students have a chance to develop an argument. **<u>OR</u>**
    b. During class, allow students 10-15min to develop an argument

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References and Resources

1. Planetary Differentiation and Planet Comparison Overview:
   http://nineplanets.org/overview.html
2. Jello 1-2-3 recipe: http://gourmetish.blogspot.com/2006/10/jello-1-2-3.html
3. Mars vs. Earth size research: Brandon, Alan 2011. *Nature* 473, 460–461 (26 May 2011)
   doi:10.1038/473460a
4. Pluto and Planetary Body Classification : http://www.iau.org/public/pluto/
5. New Horizon Probe to Pluto NASA Video (see homepage for link) :
   http://www.nasa.gov/mission_pages/newhorizons/main/index.html
6. Kuiper Belt and the Oort Cloud information:
   http://www.nasa.gov/sites/default/files/files/Kuiper_Belt_Lithograph.pdf

Mars for Earthlings

In-Class Activity 1
Planetary Formation MFE
Differentiation of Planets & Jell-O 1-2-3

Engage
To engage students, have a brief discussion on the interior of the Earth using the following explore activity as a preliminary analogy.

Explore
To explore the concept of differentiation, try an activity involving jello.
In Class activity 1 – Jello
Jello 1-2-3 recipe: http://gourmetish.blogspot.com/2006/10/jello-1-2-3.html

Differentiation is the concept of how different constituents of a planetary body separate out as a consequence of their physical or chemical behavior. The planetary body develops into compositionally distinct layers. Can students come up with any other examples of differentiation (e.g., salad dressing oil and water)?

Explain
To further explain how differentiation occurs in planets, have students examine other references, such as:

Planetary Differentiation and Planet Comparison Overview
Mars vs. Earth size research: Brandon, Alan 2011. *Nature* **473**, 460–461 (26 May 2011)
doi:10.1038/473460a

Elaborate
To distinguish planetary classifications, provide the following reading for further information on Pluto.
Pluto and Planetary Body Classification
http://www.iau.org/public/pluto/

Evaluate
The Pluto debate demonstrates the evolution of science as new information becomes available. This is a fundamental component of the Nature of Science. Have a class debate about whether or not Pluto is a planet.

New Horizon Probe to Pluto NASA Video (see homepage for link) :
http://www.nasa.gov/mission_pages/newhorizons/main/index.html

Kuiper Belt and the Oort Cloud information:
http://www.nasa.gov/sites/default/files/files/Kuiper_Belt_Lithograph.pdf

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After the in-class debate, students will write up a short 1 page cited discussion paper on their opinion regarding the classification of Pluto (see link for paper guidelines). Make sure students include and discuss the current planetary classification scheme.

Students will develop an analogy, as a class, between JELL-O 1-2-3 and planetary differentiation.

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Homework 1
Birth of Planets_MFE
The Pluto Debate

Directions:

1. Ask the students to argue in the affirmative or negative for the retention of Pluto's classification as a planet. Utilize facts of Pluto and the IAU Planet Classification system (http://www.iau.org/public/pluto/).
2. Have them write a 1 page, 12pt font, double-spaced summary of their position regarding Pluto's classification as a planet.

Pluto Facts:

1. Pluto is the smallest planet in the Solar System, smaller than Earth's Moon, and half the width of Jupiter's moon, Ganymede.
2. Pluto's journey around the Sun takes 248 Earth years. This means that, since its discovery in 1930, it still has 177 years to go until it has made a complete orbit around the Sun.
3. Pluto's atmosphere is composed of a thin layer of gas containing carbon monoxide, methane, and nitrogen. Its atmospheric pressure has been estimated to be 1/700,000 compared with that of earth.
4. Pluto orbits the Sun on a different plane than the other 8 planets.
5. Pluto has three identified moons. Charon, the largest, is not much bigger than Pluto itself (Pluto is 2,280 kilometers wide, Charon is 1,212 kilometers wide).
6. A day on Pluto is equivalent to Earth's 6 days and 9 hours, meaning that it has the second slowest rotation in the Solar System (after Venus, which takes 243 days to turn on its axis).
7. Pluto's orbit is the more eccentric (more elliptical) than any planets' orbit. It can come closer to the Sun than Neptune, but then go almost two billion kilometers further away from Neptune's orbit.
8. Pluto maximum distance from the Sun – 7.38 billion km (4.6 billion miles).
9. Pluto's minimum distance from Earth – 4.28 billion km (2.7 billion miles).

Kuiper Belt and the Oort Cloud:

1. Have the students familiarize themselves with the Kuiper Belt and the Oort Cloud: http://www.nasa.gov/sites/default/files/files/Kuiper_Belt_Lithograph.pdf

IAU Classification System:

1. A planet is a celestial body that
   a. is in orbit around the Sun,
   b. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
   c. has cleared the neighborhood around its orbit.
2. A "dwarf planet" is a celestial body that
   a. is in orbit around the Sun,

b. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape,
c. has not cleared the neighborhood around its orbit, and
d. is not a satellite.

The New Horizons Probe:

1. Ask the students to explore the mission page for the New Horizons Probe. (http://www.nasa.gov/mission_pages/newhorizons/main/)

2. What new information did they learn about Pluto from this mission? Does this information change their opinion about Pluto's classification? Why or why not?

Lesson 3: Views & Missions in Space

Summary
This learning module compares early and recent missions to Mars as well as familiarizes students with a common instrument used in NASA mission payloads.

Learning Goals

Students will be able to:

- Familiarize themselves with mass spectroscopy, a common instrument aboard NASA missions.
- Compare the Viking and MSL-Curiosity missions in terms of advances in technology.

Context for Use
This learning module is meant for adaptation in an introductory Earth science course and/or planetary science course. Students will only need prior basic knowledge of Mars to understand the significance of sophisticated technology.

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: Measuring "the tiny"
Homework/Lab
Homework 1: Viking vs. MSL-Curiosity

Teaching Notes and Tips

1. *Homework 1* may be used as an *In-Class Activity* if desired.
2. If your institution has a mass spectrometer in-house, schedule a visit for the class to view the instrument. Most lab mass spectrometers are at least 10x's bigger than spectrometers used on rovers and/or satellites orbiting Mars.

Assessment
Each In-Class Activity and Homework set has its own measure of assessment/evaluation.

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References and Resources

1. Image File: Views and Missions in Space
2. Mass Spectrometer YouTube video: http://www.youtube.com/watch?v=_L4U6ImYSj0
3. Viking Mission Documentary: http://www.youtube.com/watch?v=ggjD3i7efKU
4. Curiosity Rover trailer: http://www.youtube.com/watch?v=mNVZ6cJYYcY
5. MSL Curiosity 7 minutes of terror: http://www.youtube.com/watch?v=h2I8AoB1xgU

Mars for Earthlings

In-Class Activity 1
Missions to Mars_MFE
Measuring "the tiny"

Purpose: Determine a method to detect elements of interest (water and/or life-indicating) on Mars and become familiar with mass spectrometer devices on Mars-bound missions.

Preparation:
1. Display a periodic table
2. Bring any type of rock to class
3. Internet connection

Resources:
NASA Mass Spec Video: http://www.youtube.com/watch?v=_L4U6ImYSj0

Engage
Display a picture of the periodic table and ask students the following questions:
1. What are the differences between the elements of C, K, and O?
2. How could you measure their differences strictly from a principle standpoint?
3. As students provide answers, make sure they understand that an element's mass is its most unique feature (charge is not).

Explore (Corresponds with "measuring the tiny" in the student version)
Ask students to brainstorm a method, in teams, that would measure how much of each element was present in the rock you brought to class.
1. Can they turn this method into an instrument? What are the pros and cons/challenges?
2. Could they use this instrument to detect elements on Mars? Why or why not? What are the engineering design challenges?

Explain
Watch the following NASA Mass Spectrometer Video:
http://www.youtube.com/watch?v=_L4U6ImYSj0

Elaborate
Send students on a treasure hunt or provide the specific link where they can do secondary research. Possibly discuss the value of research as a scientific tool. What are the priorities of payloads of various Mars orbiters and rovers? How do the priorities affect whether one could house mass spectrometer instruments?

Possible links include:
Mars Science Laboratory Spectrometer:
http://mars.jpl.nasa.gov/msl/mission/instruments/spectrometers/sam/

Mars for Earthlings

NASA Mass Spectrometry 101:
http://www.nasa.gov/multimedia/podcasting/mass_spectrometer101.html

Evaluate

What elements would NASA like to detect to infer the possibility of extraterrestrial life? After watching the NASA Mass Spectrometer video, ask students how the methods or instruments they brainstormed compare to NASA's methods.

Ask students to describe how Mass Spectrometry works.
Students can watch this video (note the large size of this instrument)
http://www.youtube.com/watch?v=J-wao0O0_qM

Why is it so difficult to get Mass Spectroscopy instruments on NASA robots or probes?

Mars for Earthlings

Homework 1
Views & Missions in Space_MFE
A Mission Comparison

Purpose: Students will explore past exploration of Mars and discuss the increase in sophistication of investigation and resolution of data over century and decadal scales.

Preparation:
Make sure students have Google Earth installed on their computers. Students will need internet access. The videos comprise about 15 minutes of watching time. Parts 1 & 2 might take about 30 minutes each.

Introduction
Space exploration is an iterative process; current exploration builds on the knowledge and technological breakthroughs of past missions, which allows for further improvements to spacecraft and instruments. This process is best illustrated by comparing two wildly successful missions: Viking launched in 1975, and MSL (Mars Science Laboratory) launched in 2011.

Part 1
Watch the following videos then have the students answer the following questions:

- Viking Missions to Mars:
  http://www.youtube.com/watch?v=ggjD3i7efKU
- 7-Minutes of Terror:
  http://www.youtube.com/watch?v=h2I8AoB1xgU
- MSL Curiosity Entry, Descent, Landing:
  http://mars.jpl.nasa.gov/msl/mission/timeline/edl/

1. What are some of the complicating factors with landing spacecraft on the surface of Mars?

2. How is the entry and landing of Viking similar to Curiosity?

3. How does the entry and landing differ?

4. What is the students' favorite component to Curiosity's landing procedure (EDL)?

5. How were the landing sites for Viking 1 and 2 selected? How does this differ for the landing site selection for MSL?

Mars for Earthlings

Part 2

Discuss the increase in resolution and available data

As imaging/data collection capabilities increase, our ability to comprehend geologic features increases. Consider this through the next activity.

Exploration of historic maps available through google earth

1. Open Google Earth
2. Click on the planet icon in the toolbar and select Mars (alternatively, go to top tool bar and click "View" → "Explore" → "Mars") to switch to Google Mars.
3. In the "Layers" panel to the lower left, click on the arrow by "Historic Maps" to expand the layer options and check the circle next to "Giovanni Schiaparelli - 1890" (make sure that the global maps layer circle is unchecked).
   A. What are some general observations regarding this map?

   B. What are the prominent features?

4. Click on "Giovanni Schiaparelli" in the layer options to access information about this map.
   A. How and when did he make this map?

   B. What do the students think the linear features are in this map?

5. Now click on the arrow by "Global Maps" to expand the layer options, and check the circle next to "Viking Color Imagery".
   A. What are the similarities between the historic maps and the global mosaic from spacecraft data?

   B. How do the historic maps differ from the global mosaics?

"Face on Mars"

Go to this website: http://www.msss.com/education/facepage/face.html

1. How does lighting direction influence the appearance of the "Face"?

2. How does the "Face" seem to change when viewed under higher-resolution imagery?

3. Does it still look like a face under higher resolution?

Mars for Earthlings

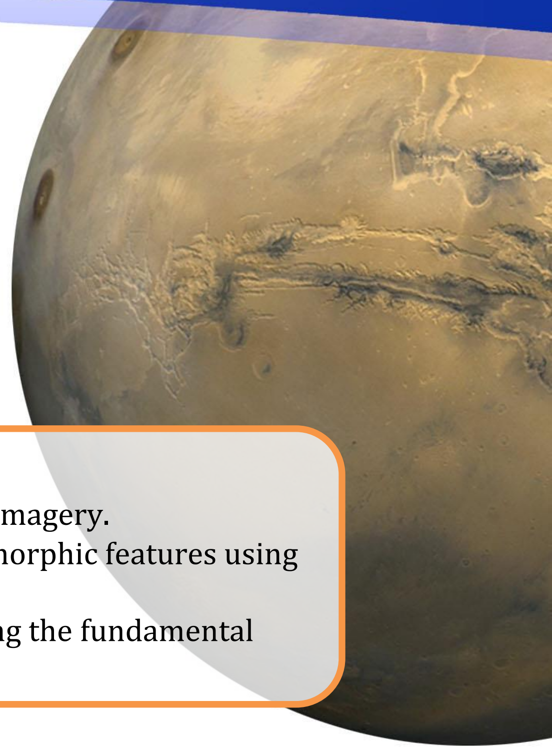
Questions

Based on the discussion of historic global maps and the "Face on Mars", answer the following questions:

1. How does the increase in resolution affect our understanding of geologic landforms?

2. How does this relate to the scientific process in general?

Lesson 4: Remote Sensing Mars



Summary

This learning module and related laboratory exercise exposes students to remote sensing techniques utilized on Mars.

Learning Goals

Students will be able to:

- Apply the concepts of scale and context in remote sensing imagery.
- View THEMIS and HiRISE images and interpret major geomorphic features using Google Mars and associated homework activities.
- Understand how MOLA generates its image data by applying the fundamental equations in an experiment.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course. It is advised that the teacher compare Earth-based remote sensing instrumentation for context/reference such as LandSat 7.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Scale and Context
In-Class Activity 2: MOLA simulation

Homework/Lab

Homework 1: Google Mars-Following Opportunity
Homework 2: Mars Image Analysis

Teaching Notes and Tips

1. The *In-Class Activities* can be utilized as homework as well. Students will have a lab-write up associated with the *MOLA simulation*.
2. For a large class size >20 you may either have a separate lab time/class for different sections or demonstrate the lab with the entire class and employ student participation.
3. We advise instructors to compare Earth-based remote sensing packages such as Landsat 7 for context.
4. In preparation for the MOLA simulation *In-Class Activity* instructors must gather a few materials (see the *MOLA simulation* for further clarification).

Assessment

- The *MOLA simulation* Lab write-up will assess the student's understanding of the MOLA instrument and MOLA's utility.
- The *Google Mars* homework will assess whether or not students can successfully navigate the Google Mars software and begin to interpret the data provided by Google Mars.

Sponsored by:
National Aeronautics
and Space Administration
NASA Award (NNX11AH29G)

Mars for Earthlings

References and Resources

1. THEMIS images url: http://themis.asu.edu/
2. LANDSAT 7 images url: http://landsat.gsfc.nasa.gov/images/
3. HiRISE 13 April 2011 YouTube video: http://www.youtube.com/watch?v=-U6-uYDtuSg
4. MRO/HiRISE All HiClips revisited (Feb 2012) YouTube Video: http://www.youtube.com/watch?v=YVDUQjJbjyc
5. MOLA images url: http://mola.gsfc.nasa.gov/index.html
6. Ping-Pong Lab (NASA): http://mola.gsfc.nasa.gov/pingpong.html

Mars for Earthlings

In-Class Activity 1
Remote Sensing Mars_MFE
Scale and Context

Purpose: Recognize the purpose and need for understanding the scale and context of various remote sensing imaging techniques.

Preparation: Print images (or share in .ppt, see *Image File*) without their captions.

Images:

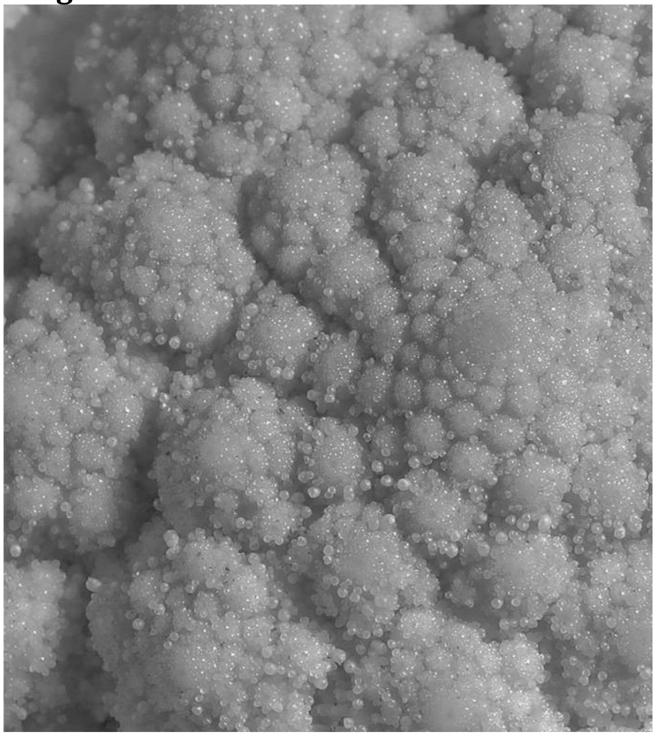


Figure 1: Close-up of broccoli romanesco
Image credit: Petr Kratochvil, public domain.

Context Image

Mars for Earthlings

Context Image

Figure 2: Close-up of a pine cone. **Image credit: Petr Kratochvil, public domain**

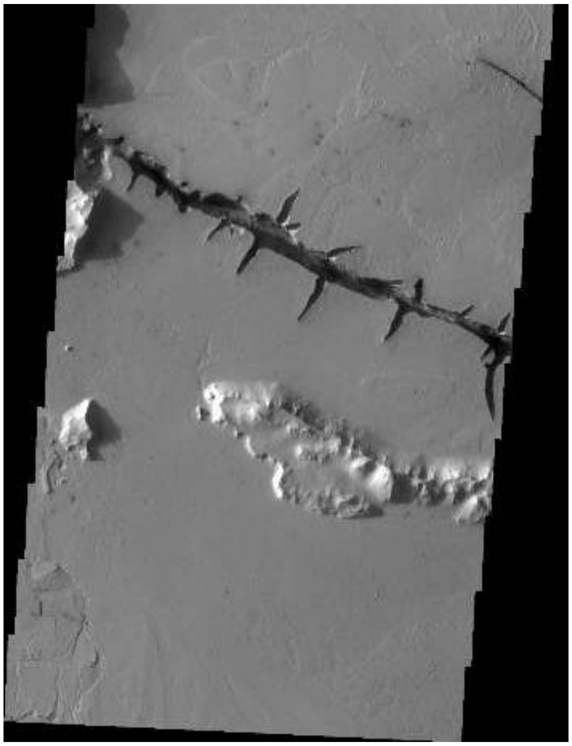


Figure 3 THEMIS Image #V13300013, Image width: 25km; Lat 7.3/Long 161.3. Image credit: NASA/JPL/ASU; Image Source: http://themis.asu.edu/zoom-20050225a

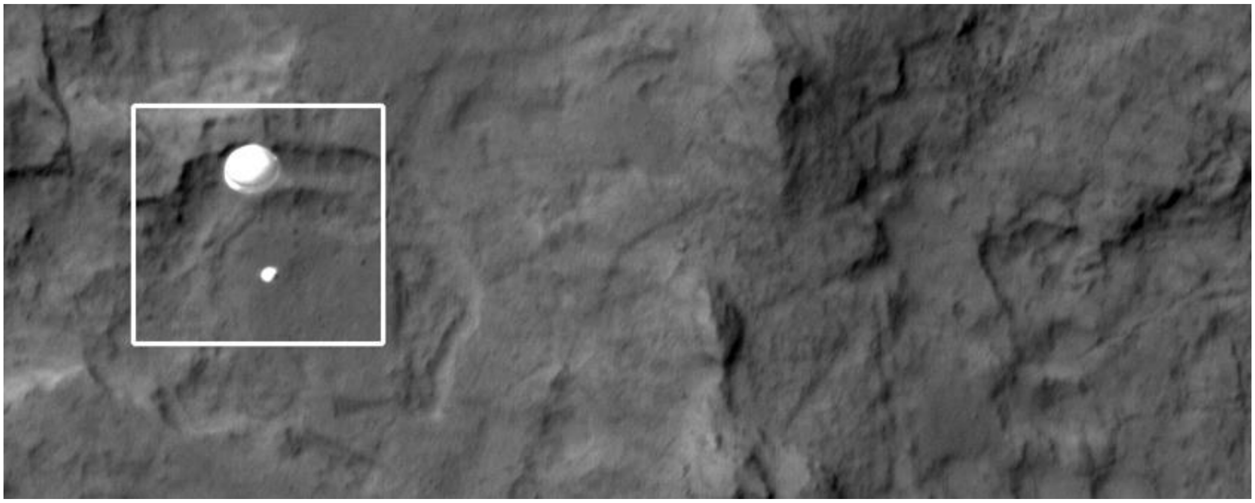


Figure 4: HiRISE image (ESP_028256_9022) of Curiosity descending to the Martian surface acquired August 5, 2012. Scale = 33.6 cm/pixel; Image Source: http://hirise.lpl.arizona.edu/releases/msl-descent.php

Engage

Referring to Figures 1-2 ask students to:

1. Hypothesize what is pictured in Figure 1 & 2.
2. Describe the basis for their hypothesis.
3. List at least (4) ideas for gathering other information that could aid in determining what the image is exactly. Explain their reasoning for their choices.

Explore

Time to apply these terms for images of Mars

1. Have students interpret Figures 1 & 2. Then, define terms of scale and context, and apply knowledge to Mars imagery.
2. Encourage students to interpret Figure 3 & 4. Provide students with the scale and context for the images (given in this version in the image caption).
3. Ask students to discuss whether or not knowing the *scale* and *context* of the images has aided them in interpretation.

Explain

1. Discuss and determine definitions of the terms *scale* and *context*.
2. Reveal the identity of the objects shown in Figure 1 & 2 (knowing what these are given in the image captions, the scales of these are small - cm to mm).
3. Ask students to provide a *scale* and *context* for each image.

Mars for Earthlings

Elaborate

1. Time permitting, have students explore mission websites such as THEMIS (http://themis.asu.edu) or HiRISE (http://hirise.lpl.arizona.edu)
2. Have them choose an image that interests them. What caught their interest? What features do they see?
3. Can they find the scale and context of the image? After knowing the scale and context, does their interpretation of the image change?

Evaluate

1. Evaluate student responses as they interpret the images. Each student should select an image and submit an explanation of the scale and context for evaluation. Do students have a clear understanding of scale and context as indicated by their answers in the ***Elaboration*** section?

Mars for Earthlings

In-Class Activity 2
Remote Sensing_MFE
*MOLA Simulation**

Purpose: Understand how we explore the surface of Mars via remote sensing techniques by performing a ping-pong experiment.

Preparation: This experiment requires some space (like a hallway, or space near a cleared wall in a classroom) and will take some prep time ~ 15 mins., and ~ 20-30 mins. for students to perform the exercise. Some of the data plotting can be done as homework.

Materials Needed:
Masking tape, meter sticks or measuring tape, ping pong balls, stopwatch or watch timer, bricks or blocks that allow ping pong balls to bounce (textbooks are ineffective)

Engage
How do we know what the surface of Mars is like, especially for areas that we have only seen from a distance? Think about how dolphins know the difference between a BB gun pellet and a kernel of corn from 50' (or 16 m away). Could a similar type of detection be used to decipher the surface of Mars?
Ref. http://science.howstuffworks.com/zoology/marine-life/dolphin-disarm-sea-mine1.htm

Explore
Perform a ping-pong experiment.

Procedure:
The students must have at least 2 people in their group (3 per group is preferable).

Step 1:

1. Place 2 strips of tape on the wall, one approximately 2 meters (200 cm) high and the other 45 cm high. Both should be at least 200 cm long and parallel; students will be using these as the points to start and stop the stopwatch.

2. One partner should hold the ping-pong ball between the first finger and thumb next to the higher piece of tape approximately one inch from the wall.

3. One partner, the "timer", should have a stopwatch and have his/her eyes level with the second piece of tape. A third partner, if available, should record the results of each ball drop using the attached data sheet. *Note: Use a spreadsheet for recording and calculating the data.

4. Drop the ball. Start the stop watch as soon as the ball begins to drop.

5. The timer will stop the watch when the ball rebounds and reaches the lower line, i.e. the clock starts when the ball drops and stops when the ball reaches the second piece of tape. Record the time on the data sheet. Repeat this step four more times.

6. Calculate the velocities (V=D/T). The distance (D) is the combination of the height of the high tape plus the height of the low tape. After finding the velocity for each of the trials, find the average velocity of the ping-pong ball. This average will be used later in this lab as the students' baseline for comparing data. Ask the students if for each trial are they measuring an average or instantaneous velocity?

7. Many spacecraft use lasers (light) to determine topography similar to how the students are using a ping pong ball. However there is a potential over-simplification in using a ping pong ball as an analog to a laser. What are the issues? (Hint: Think about velocity vs. acceleration.)

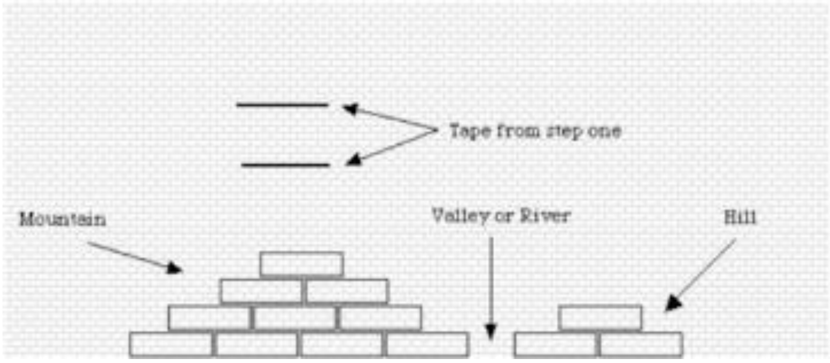
Data Table I (Baseline , datum)

Drop	Distance Ball Traveled	Time (Seconds)	Velocity (distance/time)
1			
2			
3			
4			
5			
		Average Velocity	

Step 2:

Now that the students have found the velocity of the ping-pong ball, they will use this information to plot the topography of a transect along the surface of an imaginary asteroid. They will be creating your own asteroid terrain on the floor against the wall where they just did Step 1.

1. Create the topography model of an asteroid along the wall where the students did Step One. In order to do this, they need to place wooden blocks *against* the wall in a line about 6 feet long. Be sure that they build some hills, mountains, valleys, etc. (see Figure below).



Ping-pong experiment layout diagram.🅭

2. Starting at the beginning of the top piece of tape, place a mark every 20cm. The bottom piece does not need to be marked. Measure and record the topography heights in the far right column of Table II as a check.

3. Again, starting at the 0 cm mark the students made at the beginning of the tape, they will drop the ping-pong ball as they did in Step One, and record the time in Data Table II. Drop the ball every 20cm along the tape until they reach the end. Be sure to be as accurate as possible with the timing.

4. Find the average time for each of the intervals and record it in the data table.

5. Have the students exchange their average time data with another student group (Table II) of just the cm interval, the average time. They will interpret each other's data to see if they can identify the topography of the other group's asteroid.

6. Next, fill in the distance traveled in Table II by multiplying the average velocity from Table I by the average time just calculated at each interval.

7. In Data Table III, take the original distance traveled (height of high tape plus height of low tape, which will be the same for every interval) and fill in the first column of the table.

8. In the second column, take the distance the ball traveled from the column in Table II (last column on right) and copy that information to the 2nd column of Table III. Now, for the last column, simply subtract the 1st column data from the 2nd column data (the difference between the two) to determine the altitude of their modeled topography.

9. Plot the data (with interval/distance on the x-axis and altitude on the y-axis). Connect the dots to create their transect. Does their image match the true topography? If not, explain why it is different.

Data Table II

Interval	Trial 1	Trial 2	Trial 3	Time Average	Distance Ball Traveled = (velocity*average time) (cm)	Known measured height of placed block topography (cm)
0 cm						
20 cm						
40 cm						
60 cm						
80 cm						
100 cm						
120 cm						
140 cm						
160 cm						
180 cm						
200 cm						

---------------- tear here to give Table III to blind student group ----------------
Check their altitude answers with your measured known values in far right column of your Table II.

Data Table III (share with other "blind" student group) Ave Vel. = ___________

*R Interval	Time Average of 3 Trials	Original Distance Ball Traveled (Baseline From Data Table I) {D1}	Distance Ball Traveled = (velocity*average time) (cm) {D2}	Altitude (cm) {D1-D2=Altitude}
0 cm				
20 cm				
40 cm				
60 cm				
80 cm				
100 cm				
120 cm				
140 cm				
160 cm				
180 cm				
200 cm				

Step 3: Optional Plotting and Graphing the Data (if time, check resolution)

Elaborate

Follow-Up Questions:

1. Why is it important to keep the distance between each altimeter measurement consistent?
2. How could we make the topographical profile more accurate?
3. What does the graph look like in the comparison to your model (i.e. the same, inverted etc.)?
4. Which looks more like the model, the graph you generated from the shorter or longer distance between readings (intervals)? Why is this?

Evaluate

Step 4: Expand your thought process

The Laser Rangefinder aboard NEAR sends out a laser beam and "catches" it as it returns from being reflected by the surface of 433 Eros. The instrument records how long it takes the beam to reach the surface and bounce back. The scientists know how *fast* the beam is traveling; therefore, they can calculate how *far* it traveled. By measuring this time and multiplying by the velocity of the beam, they calculate how far the laser has traveled. They must then divide the distance the beam traveled in half.

1. Ask the students why they did not divide in half to find the distance to the object in *their* topography model.

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

1. Why do we not use the term "sea level" for Mars and other planets?

2. The students will now calculate the altitude of the points along their model. To do this subtract the distance the ball traveled at each interval (from Data Table II) from the distance the ball traveled in Step 1 (column B, Data Table I). The number students come up with will be zero or greater. Use Data Table III to do the calculations. The number in column B in this table should be the same for every interval. Remember, it is the baseline altitude and does not change.

*This exercise was adapted from Goddard Space Flight Center:
http://mola.gsfc.nasa.gov/pingpong.html

Mars for Earthlings

In-Class Activity 2

Remote Sensing_ REVISED (*Note: This is a shorter version of the previous activity. Instructors may choose either version depending on time constraints.)

*MOLA Simulation**

Since we ran out of time, we're simplifying the ping pong exercise to just 3 "topographies"- 1) a base datum (floor), 2) a medium level, and 3) the highest level.

For each topography level, the students should have had several timings to ensure that they have a consistent value. Just report the averages here. Transfer data in shade boxes to Data Table III for another group to calculate.

Data Table I (D1 Baseline , datum),

Level	Distance Ball Traveled	Ave. Time (Seconds)	Velocity (distance/time)
Base			

Data Table II

Level	Time Average (secs)	Calculated Distance Ball (cms) Traveled = (velocity*average time)	Your known measured height of placed block topography (cm) (keep as your "answer")
2- med			
3- high			

-------------------------------- *tear here to give Table III to blind student group* --------------------------------

Transfer the data shown by the shade areas so they can make the calculations.

Data Table III (share with other "blind" student group)

Group _______

Give the {D1} Ave Vel. =

*R Interval	Time Average (secs) of "topographies"	Original Distance Ball Traveled (Baseline From Data Table I) {D1}	Distance Ball Traveled = (velocity*average time) (cm) {D2}	Calculated Altitude (cm) {D1-D2=Altitude}
2- med				
3- high				

After students calculate the altitude of the "unknown" topography heights 2 & 3, **check their calculated altitude answers with their measured known values the group had actually measured (their far right column of Table II**).

If the calculated doesn't match the measured values, explain why the results might be so different:

Mars for Earthlings

Part 4

The Laser Rangefinder aboard NEAR sends out a laser beam and "catches" it as it returns from being reflected by the surface of 433 Eros. The instrument records how long it takes the beam to reach the surface and bounce back. The scientists know how *fast* the beam is traveling; therefore, they can calculate how *far* it traveled. By measuring this time and multiplying by the velocity of the beam, they calculate how far the laser has traveled. They must then divide the distance the beam traveled in half.

1. Ask the students why they did not divide in half to find the distance to the object in *their* topography model.

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

1. Why do we not use the term "sea level" for Mars and other planets?

2. The students will now calculate the altitude of the points along their model. To do this subtract the distance the ball traveled at each interval (from Data Table II) from the distance the ball traveled in Step 1 (column B, Data Table I). The number students come up with will be zero or greater. Use Data Table III to do the calculations. The number in column B in this table should be the same for every interval. Remember, it is the baseline altitude and does not change.

*This exercise was adapted from Goddard Space Flight Center:
http://mola.gsfc.nasa.gov/pingpong.html

Mars for Earthlings

Homework 1
Remote Sensing_MFE
Google Mars-Following Opportunity

Objective: The purpose of this homework set is to get you familiar with different types of Mars remote sensing imagery and programs.

Google Mars-Following Opportunity

Directions/Questions:
Download Google Earth if you haven't already:
http://www.google.com/earth/download/ge/agree.html

In the icon list across the top of the window click on the planet with a single ring and a small dropdown arrow. The students should see options for Sky, Mars, and Moon. Click on Mars.

1. Name the 5 types of spacecraft imagery available through Google Mars.
   What do the 5 acronyms stand for?

   a.

   b.

   c.

   d.

   e.

Find Olympus Mons (see if the students can find it without typing the name in the "fly to" box).

2. What is the highest elevation according to Google (find the appropriate *Global Map Layer* in order to determine this information)?

3. In the *Global Maps Layer*, besides the *Visible Imagery*, which imagery gives the students the highest resolution of the volcano? Why is this the case?

Mars for Earthlings

Go to the *Rovers* and *Landers layer*

4. What are the current coordinates of these 3 lander sites?
   Phoenix Lander
   Viking 2 Lander
   Mars 3 Lander

5. Where did MER Opportunity Rover land? (i.e. what crater?)

   What crater did it visit next?

Look at the Burns Cliff panorama photo (camera icon, students may have to click on a couple to figure out the right one).

6. List 2 observations the students can make about the photo (colors, shapes, lineations, etc.)?

   Name 2 other craters the Opportunity rover explored.

   ______________________________, ______________________________

7. Write down two observations about what students see in the bottom/ centers of Victoria Crater. Can students name the features?

8. Using the Traverse Path layer of the MER Opportunity Rover, locate its position on Sol 1685 (sol= Mars day). What annotated feature (labeled named) is it nearest?

Mars for Earthlings

Homework 2
Remote Sensing_MFE
Mars Image Analysis

Directions: View the following THEMIS image and answer the questions about the image. As students view the image, think about how this image might support one or more of NASA's main exploration goals:

1. Determine if life ever existed on Mars
2. Characterize the climate of Mars
3. Characterize the geology of Mars
4. Prepare for future human exploration of Mars

Go to: http://themis.asu.edu/

Questions:
Getting to know THEMIS imagery (click on the "about")

1. In a few sentences explain what THEMIS detects and how it works.

2. Go to THEMIS image: http://themis.asu.edu/node/5765
   What is the title of the THEMIS image?

3. Study the THEMIS image. List at least two features you observe.
   a.

   b.

4. If the sun is illuminating from the left, are the features expressing positive (hill) or negative (valley) relief? If features differ from another (i.e. one has positive relief and the other negative) describe their relief separately.

5. What is the Lat/Long of the center of THEMIS image?
   Lat ____________________________ Long ____________________________

Mars for Earthlings

6. Explain how this image meets or does not meet NASA's exploration goals of Mars.

7. If students were to lead a lander mission to an area located within the image, where would they land and why?

More THEMIS Imagery

8. Go to the THEMIS image gallery by Topic: http://themis.asu.edu/gallery
   Have the students choose an image they like and report the following:
   a. What is the image ID or the image url?
   b. Why did the students choose this image?
   c. Where is the image located?
   d. Near what major Mars geographic region is it located (South/North pole, Victoria Crater, Endurance Crater, Merdiani Planum, Hellas Basin, etc.)? Use the *View this image on Map* link at the bottom of the image data column to see a map view of Mars.
   e. Why might this location be important to science?

9. Navigate to the HiRISE website: http://hirise.lpl.arizona.edu/
    a. Scroll to the bottom of the page (gray box) and click on the link “Science Themes”. Click on the *Aeolian Processes* file of images. Under the main image click “View Images in this Theme.” Find image titled “Dunes in the Western Nereidum Montes.” If students cannot find the image type ESP_013046_1390 into the search box.

    b. Define the term *Aeolian*. (also known as eolian)

    c. Why might an image of *aeolian* processes on Mars be of interest to us on Earth?

    d. Have students sketch what they see below. Label appropriate parts (high and low areas). Can they identify the direction of the wind if North on Mars is up? If so, what direction (cardinal direction) is it?

Lesson 5: Why Matter and Minerals Matter!

Summary
This learning module and related laboratory exercise exposes students to the make-up of minerals and rocks on both Earth and Mars.

Learning Goals

Students will be able to:

- Observe different rock-forming minerals and explain their relationship with water.
- Use CRISM and HiRISE images to identify regions on Mars where aqueous conditions might have been present.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course. Provide students with an introduction to the atom and the periodic table to provide context and a resource to understand mineral formation.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Follow the water with minerals

Homework/Lab

Homework 1: Identifying the clay: Endeavor Crater

Teaching Notes and Tips

1. For *In-Class Activity 1* either (a) print off colored copies for students (b) have hand sample specimens of each mineral for students to observe or (c) use the image file to show students the minerals.
2. For a large class size >20 where you would like to use hand-specimens, have a scope attached to your projector so students may observe "up-close".
3. Become familiar with JMARS software prior to class (loaded on whatever machine you will be using for presentation), especially with viewing CRISM and HiRISE image stamps to discern mineralogy on Mars.
4. Students should have a working understanding of how to navigate and use JMARS prior to completing *Homework 1*.

Assessment

Assessment is imbedded within each *In-Class Activity*.

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National Aeronautics
and Space Administration
NASA Award (NNX11AH29G)

References and Resources

1. Image File: Matter and Minerals
2. CRISM webpage: http://crism-map.jhuapl.edu
3. HiRISE webpage: http://hirise.lpl.arizona.edu

Mars for Earthlings

In-Class Activity 1
Building Blocks: Matter and Minerals_MFE
Follow the Water with Minerals

Purpose
Observe various minerals and identify their connection to water using their chemical formulas and environments of formation.

Preparation
1. Assemble mineral hand samples of: hematite, calcite, gypsum, olivine, feldspar, and kaolinite (or other smectite)
2. If hand samples are not available use the mineral images provided in the module *Image File*

Engage
Show images and/or hand samples of a few of the minerals listed in *Preparation*. Ask students to quickly make a hypothesis as to which minerals indicate aqueous environments.

Explore
- Ask students to indicate whether or not each mineral has an aqueous history of formation/precipitation.
- Once students determine the aqueous history have them connect the mineral to its most probable environment of formation.
- Ask students if they think that these minerals could have multiple environments of formation and why.

Explain
1. As students work to identify, with sound reasoning, which minerals indicate an aqueous environment of formation describe the minerals in terms of their properties and general classification (i.e. sulfates, hardness, cleavage etc.).
2. Provide students a context of the environments of formation (shield volcano, desert playa, hot springs, pluton, altered volcanic tuff, coastal shelf) listed for students to connect each mineral to its most probable environment of formation. Should you desire, you could provide a PowerPoint slideshow of the environments.
3. Encourage students to list their reasoning for their answers.

Elaborate
- Rank the minerals according to what students believe to be their relative abundance on Mars. Highest = most abundant on Mars, Lowest = least abundant on Mars
- Discuss with students their ranking system and their method behind the ranking.
- Share with students a Mars geologic map to give them an idea of the rock types across Mars (see link: http://www.lpi.usra.edu/resources/mars_maps/1083/).

Mars for Earthlings

Evaluate

1. Evaluate student response as they interpret the images.
2. Can students recognize, from the chemical formulas of minerals, which minerals could indicate an aqueous environment? Observe this by their ranking and method of ranking in **Elaborate** and throughout the **Explore** sections.

Mars for Earthlings

Homework 1
Matter and Minerals_MFE
Identifying the Clay: Endeavor Crater

Objective: To further utilize the tools offered within the software JMARS and investigate mineralogies observed at Endeavor Crater.

Introduction: In order to accomplish this lab the students will need to register and download JMARS. By this point, they should be familiar with JMARS software and how to navigate to regions of interest on Mars.

1. Using the Nomenclature Layer, navigate to Endeavor Crater (approx. 354.7705°E, -2.2480°N).
    a. For best viewing results, Zoom to 1024 and center the main screen on the western rim of Endeavor Crater
    b. If the students still have their nomenclature layer turned on, they will see the labeled "Endeavor" to the right of the rim they are exploring

2. Choosing HiRISE stamps to explore Endeavor Crater with the highest resolution possible.
    a. Using the stamps layer choose either HiRISE DTMS or HiRISE full stamps. Make sure the students zoom in close so that when they search for HiRISE stamps hundreds do not try to load. Use the "main view" to limit the search of HiRISE stamps. Choose stamps rendered by ASU.
    b. Compare and contrast the HiRISE DTM images and the HiRISE Full stamps images. Which do the students prefer and why?

    c. Consult the webpage: http://hirise.lpl.arizona.edu/dtm/about.php . After consulting the webpage, which set of imagery would they rather use, DTM or Full stamps? Did their choice change? Why or why not?

    d. Decide which HiRISE imagery the students will choose to display and explore the western crater rim.

Mars for Earthlings

3. Exploring the mineralogy of Endeavor Crater using CRISM
    a. Add the CRISM stamps layer and use a different outline color to differentiate CRISM and HiRISE stamps. To display CRISM stamps, use the “Main View” to set the bounds of the image search.
    b. Provide a rough estimate of the number of CRISM stamps: ____________
    Do they outnumber the HiRISE DTM stamps or full stamps? Why do the students think this is (think of current/past mission objectives)?
    c. Start exploring some of the CRISM stamps intersecting the HiRISE DTM stamps. Choose any stamp and the ASU-rendered images. When using ASU images, use the *color overlay*. ASU provides the students with a number of options. List at least three below (i.e. Ferric Mineralogy):
    d. Find a CRISM stamp that is rendered for phyllosilicates. Where are the phyllosilicates located in the crater (the rim, the rim wall, or the bottom of the crater)? What does this tell them? *Note: the warmer the color the higher content of the respective mineral.
    e. Compare the sulfate CRISM overlays. Are sulfates found in the same region as the phyllosilicates? Why or why not?
    f. Select another crater on Mars that has CRISM stamps available. Compare and contrast the phyllosilicates abundance between the two craters below. Please name the crater and its coordinates for verification.

Lesson 6: Olympus Mons and Igneous Rocks

Summary

This learning module and related laboratory exercise exposes students to volcanic styles, eruptions, igneous rock textures and their evidence in the Martian landscape.

Learning Goals

Students will be able to:

- Differentiate between pahoehoe and a'a lava flows through USGS video and subsequent discussion. Students will then observe Mars imaging of lava flows and hypothesize which lava flow is more likely on Mars.
- Observe a columnar joint experiment using cornstarch, observe the process and discuss its potential formation on Mars. Students will observe columnar jointing on Mars using HiRISE imaging and compare the features to the Columbia River basalts on Earth as an analog.
- Use Google Mars and JMARS software, students will increase their literacy with the software packages as well as recognize and analyze different mineralogies on Mars and the nature of Olympus Mons in comparison to Earth analog volcanoes.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course. Before engaging in the In-Class Activities and/or Homework, students will need to be provided with an overview of igneous rocks (see Teaching Notes and Tips). All In-Class Activities can be adapted to a homework set if desired. Online access is essential for video viewing in association with the In-Class Activities.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Lava flows
In-Class Activity 2: Cornstarch columnar joints

Homework/Lab

Homework 1: Google Olympus Mons
Homework 2: Basalt & JMARS

Teaching Notes and Tips

1. Provide students with a background in the rock cycle, igneous rock textures, volcanic styles, and rates of cooling for *In-Class Activity 1.*

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2. Instructors may choose to develop their own cornstarch experiment by the adaptation of the following published experiment and results: http://www.physics.utoronto.ca/~nonlin/papers_mud.html
3. Make sure students are familiar with both Google Mars and JMARS software. The introduction module "Introduction to Mars and Earth Analogs" provide homework and/or In-Class activities to expose and orient students to the software packages.

Assessment

- One of the goals of MFE is to have students become familiar with Mars imagery and navigating the mission online archives as well as software programs available to explore Mars imagery. The homework assignments, if completed, will provide students with increased competence in navigating both Google Mars and JMARS software.
- Through comparison of various Mars images students will be asked to identify common minerals on Mars, their abundance in terms of geographic location, as well as style of igneous rock formation.

Mars for Earthlings

References and Resources

1. Image file: Igneous Rocks and Volcanics
2. Rock Cycle Background: http://www.classzone.com/books/earth_science/terc/content/investigations/es0602/es0602page02.cfm
3. Columnar Joint Experiment Video: www.youtube.com/watch?v=CJWfneKdv08
4. Columnar Joint Article: http://www.sciencedaily.com/releases/2008/12/081216104325.htm
5. Columnar Jointing in Columbia River Gorge Oregon: http://www.youtube.com/watch?v=WLGXmJZ_KIU
6. Mars columnar jointing discovery by HIRISE in Geology: http://geology.gsapubs.org/content/37/2/171/F1.expansion.html
7. HIRIES columnar jointing image: http://www.nasa.gov/mission_pages/MRO/multimedia/mro20090225.html
8. Pahoehoe lava flow video: http://www.youtube.com/watch?v=qTTLYx4Xo2k&feature=related
9. A'a lava flow video: http://www.youtube.com/watch?v=bWswq8PmRII
10. Basalt on Mars (Hawaii): http://www.psrd.hawaii.edu/May09/Mars.Basaltic.Crust.html
11. Athabasca Spiral lava flows: Discovery news article: http://www.space.com/15446-mars-lava-volcanoes.html
    Image source: http://www.space.com/15446-mars-lava-volcanoes.html
12. Mars Plagioclase mineralogy animation: http://www.youtube.com/watch?v=FRU0cHb31JM

Mars for Earthlings

In-Class Activity 1
Olympus Mons_MFE
Lava Flows

Purpose: Recognize a pahoehoe vs. a'a lava flow through video, explain why the flows differ, and hypothesize which flow might be more common on Mars.

Resources:
-Pahoehoe lava flow video:
http://www.youtube.com/watch?v=qTTLYx4Xo2k&feature=related
-A'a lava flow video: http://www.youtube.com/watch?v=bWswq8PmRII
-Mars lava coils: Discovery news article: http://www.space.com/15446-mars-lava-volcanoes.html

Engage

1. Have students watch both the pahoehoe and a'a video (see **Resources** above in this *In-Class Activity*). As they are watching, have them record their observations of each flow and how they differ.
2. Discuss student observations of these Earth examples and make corrections where necessary.

Explore

1. Ask students which lava flow, both or neither, would be more common to Mars. Encourage students to substantiate their answers.
2. Following discussion of the above present Figure 1 and ask what type of lava flow is most likely to have formed the below spiral feature (see Image File for higher resolution and original image size):

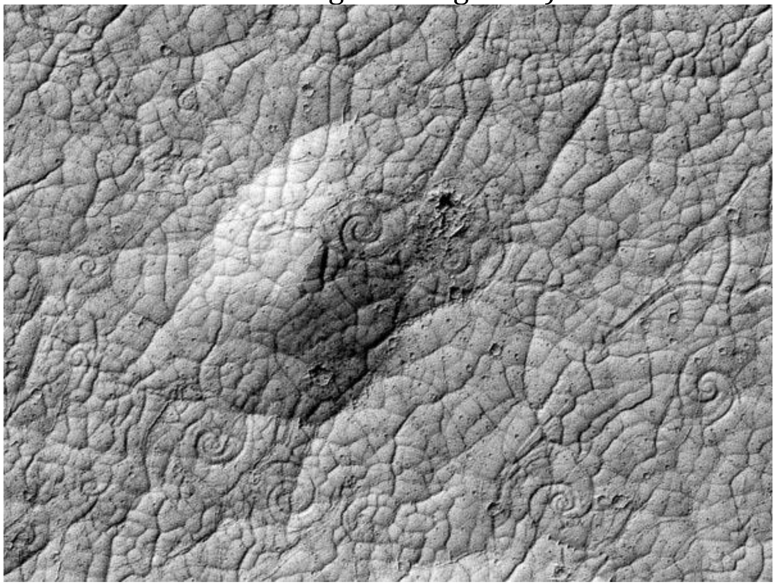

Figure 1: Spirals in Athabasca Valles, Credit: NASA/JPL/University of Arizona, Spirals are 16-98 ft wide. Image source: http://www.space.com/15446-mars-lava-volcanoes.html

Explain

Divide the class into 2 teams (one pahoehoe, the other a'a) and give them the basic physical characteristics of the two lava types. Their job is to research (e.g. on the Internet) what causes the different physical properties (WHY the two types of lava are different). They should explain how different fluid properties such as viscosity, and crystal and gas bubble content affects their type of flow. Each team can give a short presentation of their lava. Examples and definitions, followed by the processes they should investigate.

Pahoehoe lava- is basaltic lava that has a smooth, billowy, undulating, or ropy surface. These surface features are due to the movement of very fluid lava under a congealing surface crust. A pahoehoe flow typically advances as a series of small lobes and toes that continually break out from a cooled crust. It also forms lava tubes where the minimal heat loss maintains low viscosity. The surface texture of pahoehoe flows varies widely, displaying all kinds of bizarre shapes often referred to as lava sculpture. With increasing distance from the source, pahoehoe flows may change into a'a flows in response to heat loss and consequent increase in viscosity. Pahoehoe lavas typically have a temperature of 1100 to 1200 °C.

A'a lava- The loose, broken, and sharp, spiny surface of an a'a flow makes hiking difficult and slow. The clinkery surface actually covers a massive dense core, which is the most active part of the flow. As pasty lava in the core travels downslope, the clinkers are carried along at the surface. At the leading edge of an a'a flow, however, these cooled fragments tumble down the steep front and are buried by the advancing flow. This produces a layer of lava fragments both at the bottom and top of an a'a flow. A'a lavas typically erupt at temperatures of 1000 to 1100 °C.

Accretionary lava balls as large as 3 meters (10 feet) are common on a'a flows. A'a is usually of higher viscosity than pahoehoe. Pahoehoe can turn into a'a if it becomes turbulent from meeting impediments or steep slopes.

Mars for Earthlings

Elaborate

Of the below rocks pictured:

1. Which are most likely to have formed by igneous processes on Earth?
2. Which by igneous processes on Mars?
3. Make sure students explain their choices in discussion. (Hide caption from students) **The .ppt image file does not have descriptions.

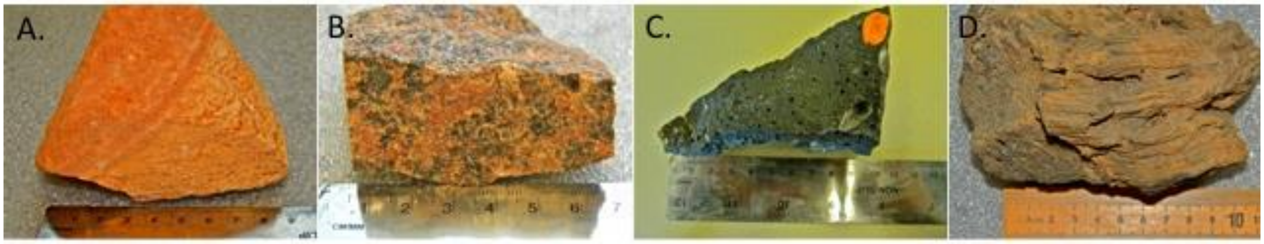

Figure 2: A. Sandstone, B. Potassium Feldspar Granite, C. Basalt, D. Oxidized Basalt

Evaluate

Consider the Spirals in Athabasca Valles (Figure 1). Which rock(s) in Figure 2 would students expect to find in Athabasca Valles? Why?

Mars for Earthlings

In-Class Activity 2
Olympus Mons_MFE
Columnar jointing on Mars

Purpose: Become familiar with the formation, the processes, of columnar jointing and its apparent formation on Mars.

Engage
Study Figure 1 (a) below. A. In a few sentences, have the students write down their hypotheses for how these features form. B. Are there any other features in their daily life or on Earth that have similar characteristics?

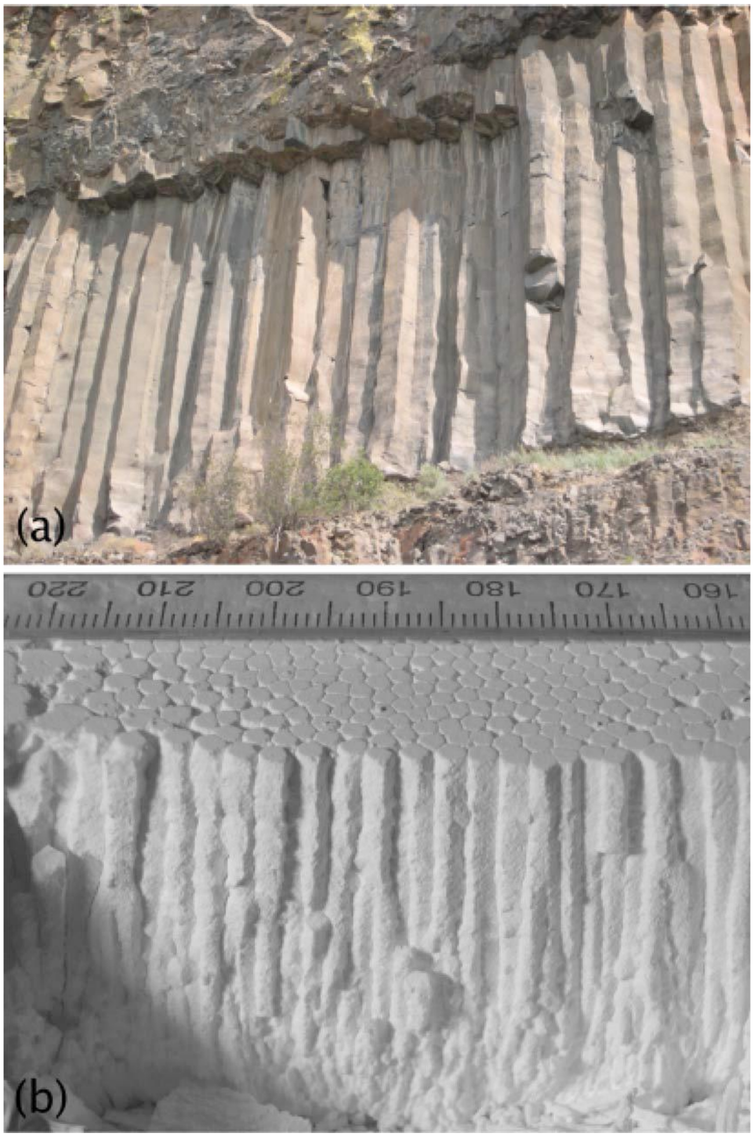

Figure 1: Columnar jointing in (a) basalt of the Columbia Plateau near Banks Lake ~95 cm average diameter, and (b) in desiccated corn starch. (Image Credit: Gohering L., Morris, S.W., and Lin, Z., 2006. Experimental investigation of the scaling of columnar joints. PHYSICAL REVIEW E 74, 036115, p. 1-12.)

Explore
Read the following article or view the following cornstarch experiment video used to illustrate columnar jointing (Figure 1 (b) is a still from the experiment). Consult the explanation under the video window.
Video: www.youtube.com/watch?v=CJWfneKdv08
Article: http://www.sciencedaily.com/releases/2008/12/081216104325.htm

1. Is there perfect similarity between the "real" columnar joints of the Columbia River basalts and the experiment? Why or why not?

2. How do the fractures/cracks form? Are they widening, re-forming through time, or starting new fractures?

3. What might enhance the cracks?

4. How could the students foresee such features forming on Mars?

Explain
Columnar jointing forms in lava flows, sills, dikes, ignimbrites (ashflow tuffs), and shallow intrusions of all compositions. Most columns are straight with parallel sides (colonnade) and diameters from a few centimeters to 3 m. Some columns are curved and vary in width (entablature). Columns can reach heights of 30 m. The columns form due to stress as the lava cools (Mallet, 1875; Iddings, 1886, 1909; Spry, 1962). The lava contracts as it cools, forming cracks. Once the crack develops it continues to grow. The growth is perpendicular to the surface of the flow. Entablature is probably the result of cooling caused by fresh lava being covered by water. The flood basalts probably damned rivers. When the rivers returned the water seeped down the cracks in the cooling lava and caused rapid cooling from the surface downward (Long and Wood, 1986). The division of colonnade and entablature is the result of slow cooling from the base upward and rapid cooling from the top downward.

Website reference:
http://volcano.oregonstate.edu/education/facts/col_joint.html

Mars for Earthlings

Elaborate

View the following discovery, in 2009, on Mars and have the students answer the following questions: http://geology.gsapubs.org/content/37/2/171/F1.expansion.html

1. Referring to the image, about how wide are the columns? (Pay attention to the horizontal scale bar)

2. What does this image tell you about igneous rocks and their history on Mars?

Evaluate

Students should understand how columnar joints form and should be able to identify columnar joints on Mars.

Figure 2 below is the original image of columnar jointing captured on Mars using the HiRISE camera for the above discovery. Using arrows, point to where you think the columnar joints are exposed in this terrain.

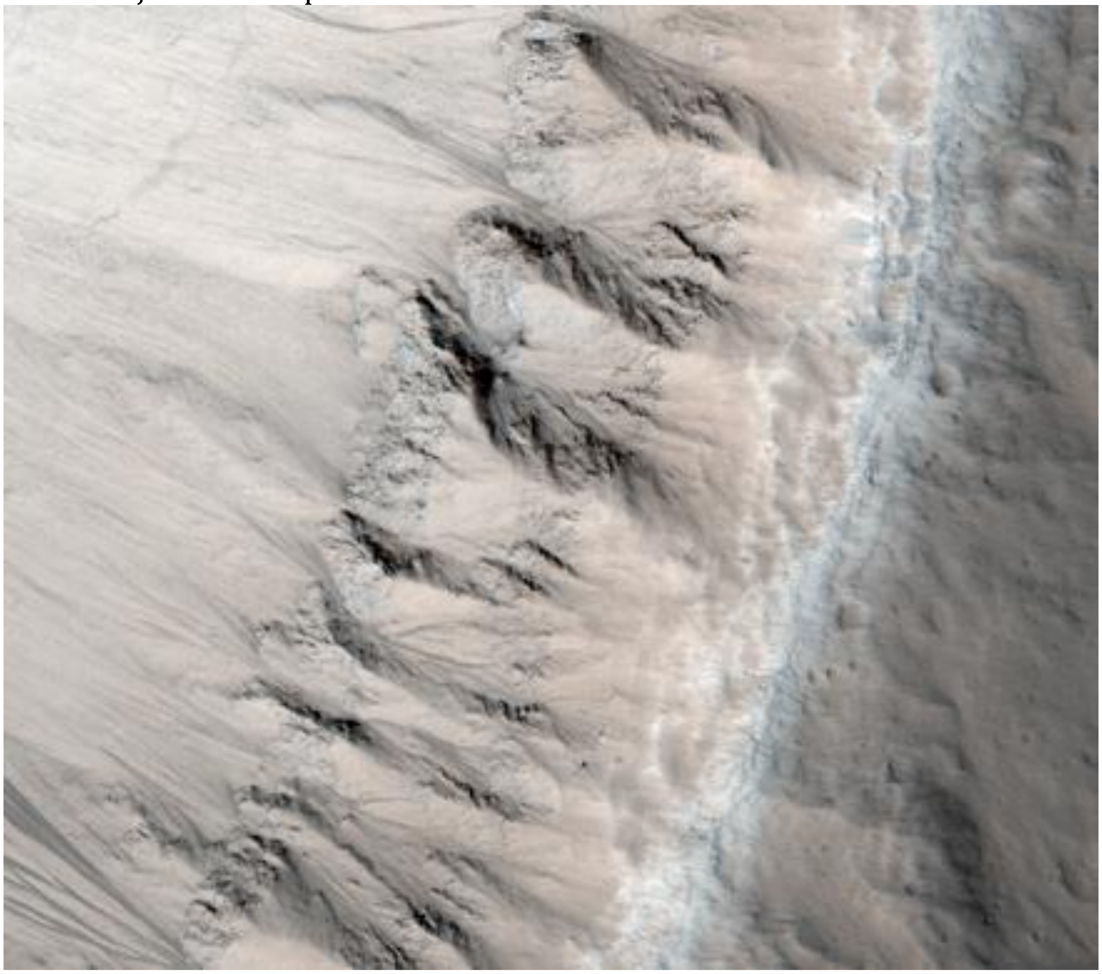

Figure 2: http://hirise.lpl.arizona.edu/PSP_005917_2020 (Image Credit: NASA/HiRISE)

Mars for Earthlings

References:

Goehring, L., et al., 2008, Nonequilibrium scale selection mechanism for columnar jointing, PNAS, V. 106, p. 387

Goehring, L. and Morris, S.W., 2008, Scaling of columnar joints in basalt, JGR-Solid Earth, v. 113, pp. B10203

Iddings, J.P., 1886, Columnar structure in the igneous rocks of orange Mtn., N.J.: American Journal of Science, v. 131, p. 321-330.

Iddings, J.P., 1909, Igneous Rocks: Wiley, New York.

Long, P.E., and Wood, B.J., 1986, Structures, textures, and cooling histories of Columbia River basalt flows: Geol. Soc. America Bull., v. 97, p. 1144-1155.

Mallet, R., 1875, Origin and mechanism of production of prismatic (or Columnar) structure in basalt: Phil. Mag. v. 4, p. 122-135 and 201-226.

Milazzo et al., 2009 Discovery of Columnar Jointing on Mars; *Geology* 2009;37;171-174 doi:10.1130/G25187A.1

Spry, A., 1962, The origin of columnar jointing, particularly in basalt flows: Journal of the Australian Geological Society, v. 8, p. 192-216.

Mars for Earthlings

Homework 1
Igneous Rocks & Volcanics_MFE
Google Olympus Mons

Purpose: Explore Olympus Mons using the Google Mars platform through HiRISE imagery and Colorized Terrain maps.

Preparation: Download Google Earth 6
http://www.google.com/earth/download/ge/agree.html

Directions/Questions:

Navigate to Olympus Mons

1. Open Google Mars (click on the planet with a ring)
2. Turn on the Global Maps Layer *Colorized Terrain*
3. Navigate to Olympus Mons- the tallest point on Mars
    a. What is the elevation of Olympus Mons?
4. Activate the *HIRISE Image layer* under the Spacecraft Image Layer Folder

Analyze Olympus Mons Images

5. Zoom in to the top of the Olympus Mons Caldera
    a. Find image PSP_004821_1985 from HIRISE [near the Hiker icon]
    b. Have the students sketch what they see in the image below.

    c. What might they be seeing? Consider the context image of the Colorized Terrain map and have them list their observations.

6. Find image PSP_004531_1990: NW flank of Olympus Mons (note the compass in the upper right ~ 15-18km elevation, 18.56N 224.28E)
    a. Have the students sketch what they see in the image below.

b. Can they make some interpretations about what they are observing?

Comparing Olympus Mons and Earth Analogs

7. Of the volcanic styles (mafic vs. felsic), which volcanic type fits Olympus Mons the best? Have students explain their choice and why Olympus Mons cannot be classified as the other choices.

8. If they wanted to be sure about their volcano classification, what additional data would they need to confirm their choice in #7?

9. What volcano on Earth serves as the best comparison to Olympus Mons (the students may need to do some outside research to answer this question adequately)?

Mars for Earthlings

Homework 2
Igneous Rocks & Volcanics_MFE
Basalt & JMARS

Discussion/Questions

1. The following are common igneous/mafic rock forming minerals. For each mineral, list its chemical formula:
   a. Olivine

   b. Pyroxene

   c. Amphibole

   d. Biotite

   e. Plagioclase (anorthite)

2. Compare the chemical formulas and their elements to the element abundance list for Mars below. Which minerals do the students think will be more common on Mars? Have the students explain their choices below next to the list.
   1. oxygen
   2. silicon
   3. iron
   4. magnesium
   5. calcium
   6. aluminium
   7. sodium
   8. potassium
   9. chloride

3. Open JMARS. Using the *Nomenclature* layer, zoom to Valles Marineris to gain a geographical bearing. Add and compare the following layers (Add New Layer → Maps by Instrument →TES Mineral Maps): Basalt Abundance, Plagioclase Abundance (Bandfield, 2002), any olivine abundance map, and Carbonate Abundance. Warmer colors denote greater abundance.
   a. Which map has the most coverage? Why might this be? What complications might arise from collecting this type of data? Could anything distort the data?

b. Where does the abundance of Plagioclase generally increase on the surface of Mars? Use geographical points of references or lat/long to explain.

c. Compare the following animation for plagioclase abundance on Mars to the JMARS mineral map. Which perspective do the students prefer? http://www.youtube.com/watch?v=FRU0cHb31JM

d. Are they surprised about the abundance of plagioclase on Mars in comparison to other minerals? Why or why not?

Lesson 7: Life Hosting Rocks

Summary
This learning module and related laboratory exercise exposes students to the types of lithologies on Earth that host life and the sedimentary processes that formed them.

Learning Goals

Students will be able to:

- Recognize and identify sedimentary rocks on Earth and Mars.
- Identify sedimentary structures that provide clues as to the environment of formation (i.e. mud cracks, cross-bedding etc.).
- Observe the expansion of clays and explain why water influences clay-rich rocks at the molecular level.

Context for Use
This learning module is meant for adaptation in an introductory earth science course and/or planetary science course. Students need a prior knowledge of minerals before going through this module. Provide an understanding of grain sorting and sedimentary structures resulting from varying energy in the system (i.e. low energy = laminations; cross-bedding = higher energy system).

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: Swelling Rocks
In-Class Activity 2: *Understanding Albedo*
Homework/Lab
Homework 1: The Energy of Rocks

Teaching Notes and Tips

1. The *In-Class Activities* can be utilized as homework as well. The activity is designed as such that students can effectively complete the activity at home.

Assessment

- Each *In-Class Activity* and *Homework* has its own method of assessment.

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Mars for Earthlings

References and Resources

1. Image file: Life-Hosting Rocks
2. Swelling clay-rich soil demonstration: http://www.youtube.com/watch?v=ACpuYED9WkU
3. Ripple-formation video: http://www.youtube.com/watch?v=zRGuMddjRGg&list=PL17AFB4B8AB3DCCF7
4. Laminar-flow video: http://www.youtube.com/watch?v=W3YZ5veN_Bg

Mars for Earthlings

In-Class Activity 1
Life-Hosting Rocks_MFE
Swelling Rocks

Purpose: Explain why clay soils expand and discern where clays might be present on Mars.

Engage
Expanding Soil - Observe the class demonstration or video [http://www.youtube.com/watch?v=ACpuYED9WkU] and answer the following questions.

1. According to the demo/video, why does the soil expand?

2. How does the bulk density change? What does this change indicate?

Explore
The molecular level- Utilize the diagram below to help students understand how clays are made up of stacked layers. (Figure 1) Students should answer the following questions.

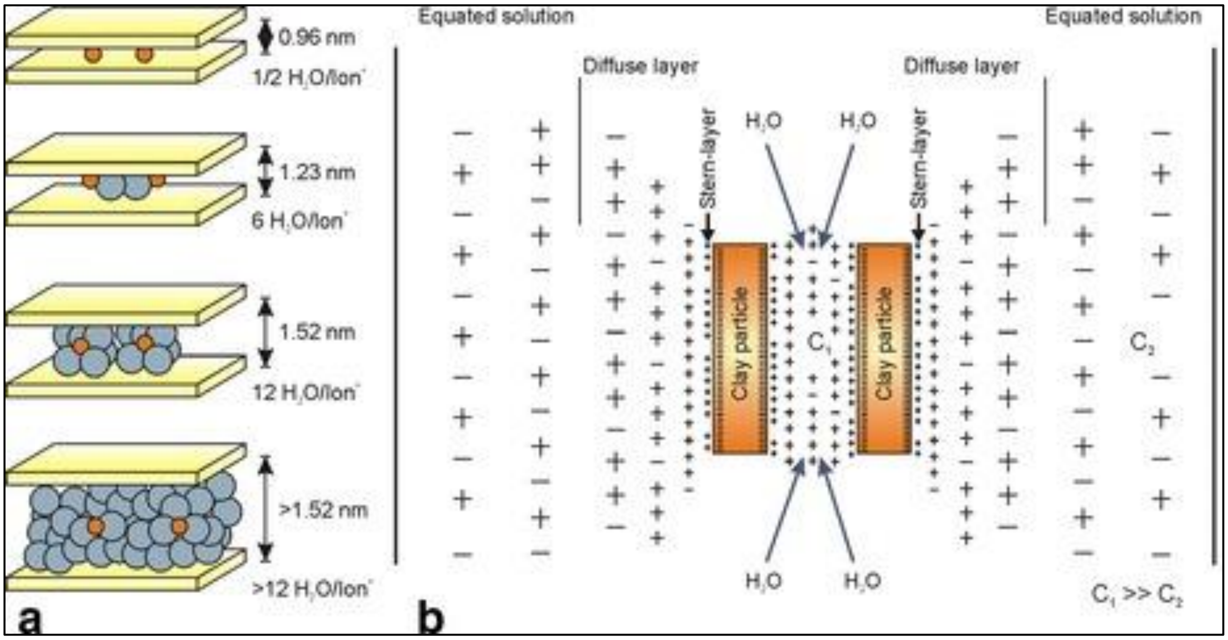


Figure 1: Butt et al., 2003

1. In Fig. 1a, how are the water molecules influencing the structure?

2. Why do the students think the water attracts to the clay rather than the sand of the sandy loam (consult Fig. 1b)?

Mars for Earthlings

Explain

Share the following information about clays with students:

- Clays are expandable due to their layer charge. The higher the layer charge (for example montmorillonite or bentonite) the more the clay will expand.
- The interlayer (the charged layer) attracts water molecules allowing for the clay to expand
- Clays are commonly formed in pedogenic, hydrothermal, or acid lake environments on Earth.

Elaborate

3. Given the students understanding of clays now, if clays [$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2(H_2O)_{10}$] are observed on Mars….what does this mean?

Evaluate

4. Where might students look to find clays on Mars (what kind of features)? *Hint: consider their environment of formation, do we have evidence for their presence on Mars?

Mars for Earthlings

In-Class Activity 2
Life Hosting Rocks_MFE
Understanding Albedo

Purpose: Recognize sedimentary rocks on both Earth and Mars using the albedo effect.

Resources:
1. Last Chance Canyon, Guadalupe Mountains, NM image in Image file: Life-Hosting Rocks
2. Interactive Earth Surface Albedo Map (NASA-CERES): http://www-surf.larc.nasa.gov/surf/pages/bbalb.html
3. Earth surface types map (NASA-CERES): http://www-surf.larc.nasa.gov/surf/pages/sce_type.html
4. Global albedo map of Mars: http://www.mars.asu.edu/data/tes_albedo/large/tes_albedo_label.png
5. Global albedo map of Earth: http://eoimages.gsfc.nasa.gov/images/imagerecords/60000/60636/modis_albedo.jpg

Engage
Present the following along with an image of Last Chance Canyon, New Mexico (see Image file: Life-Hosting Rocks):

Scenario: The students are planning to hike Last Chance Canyon in the Guadalupe Mountains National Park. It is arid, no winds, and about 95°F. If they had the following options for attire which would they choose and why:
- Sleeveless cotton medium blue colored shirt
- White long-sleeve cotton shirt
- Black long-sleeve cotton shirt

Discuss student response and their reasoning.

Explore
1. Use the interactive Earth Surface Albedo Map and Earth surface types map (produced by NASA-CERES in **Resources**) and ask students which surface types correspond to the highest albedo.
2. Probe students as to why some "surfaces" have a higher albedo than others (i.e. ice, ocean, desert, forest cover, grassland, etc.)
3. Display hand samples of sandstone, andesite, and basalt (or use the Image file: Life-Hosting Rocks). Ask students to rank the samples according to their albedo effect.

4. If students were to picture an albedo map of Mars, do they think the surface would be as variable as Earth? How do the students think that, overall, the albedo of Mars would compare to that of Earth?
5. After the students have discussed these questions, compare the global albedo maps of Earth and Mars (in **Resources** above).

Explain

Explain the terms 'reflectance' and 'albedo' using the definitions below. Relate them to the discussion in the **Engage** section.

- Reflectance- Reflectance is a surface's ability to reflect light and is a property of the material.
- Albedo- Albedo is the measure of the percentage of solar energy reflected by a surface, typically that of a planet or moon. It is expressed as the ratio of light reflected by a surface to the total incident light and ranges in value from 0 to 1 (i.e., albedo comprises multidirectional, diffuse reflections all combined).

This youtube video can help explain albedo and how it is related to global warming: http://www.youtube.com/watch?v=QgzggbEQ2MY

Elaborate

Use the TES Dust Cover Index layer in JMARS to account for the fact that volcanic regions such as the Tharsis bulge appear to have high reflectivity. While much of the terrain is actually basaltic in composition, dust cover gives the illusion of a highly reflective surface.

Explore TES imagery in JMARS and understand albedo.

1. Add the MOLA colorized elevation map for use as context if desired.
2. Add New Layer → Maps By Instrument → TES → TES-Albedo → View graphic data
3. Zoom to a window (2 or 4) that allows the students to differentiate familiar terrain. They can change the transparency of the TES-Albedo map to see the underlying MOLA colorized map to find major geographic regions of interest.
4. Discuss with the students the results of the albedo map. Is anything surprising to them (i.e. Why do basalt/volcanic regions have high reflectivity? See **Explanation**)? What could distort the results?
5. Do students find that albedo maps to be a good indicator of lithology?

Mars for Earthlings

Evaluate

Go to the Kepler: Light Grapher web page:
http://kepler.nasa.gov/education/ModelsandSimulations/lightgrapher/

Using the Light Grapher software and a webcam, measure the amount of light reflected by basalt vs sandstone. This can be done by the following steps:

1. Go to the Kepler: Light Grapher web page and click on “Run LightGrapher”.
2. Hold the basalt rock in the camera field of view within the circle of LightGrapher.
3. Make sure that the data capture time is set at 30 seconds then click on “Capture Data”. This will begin measuring the amount of light reflected by the basalt.
4. Keep the basalt in the field of view for ~15 seconds then switch to the sandstone for the next 15 seconds. Make sure that the measurement distance for each rock is the same.
5. This will generate a graph that shows the light detected over the 30 second interval.
6. See how students can correlate this activity with albedo as an analogy.
7. You may use other objects with varying color/reflectivity.

To instructors: This is the type of approach you could use. An example of results obtained from this procedure can be found below as well as in the module Image File

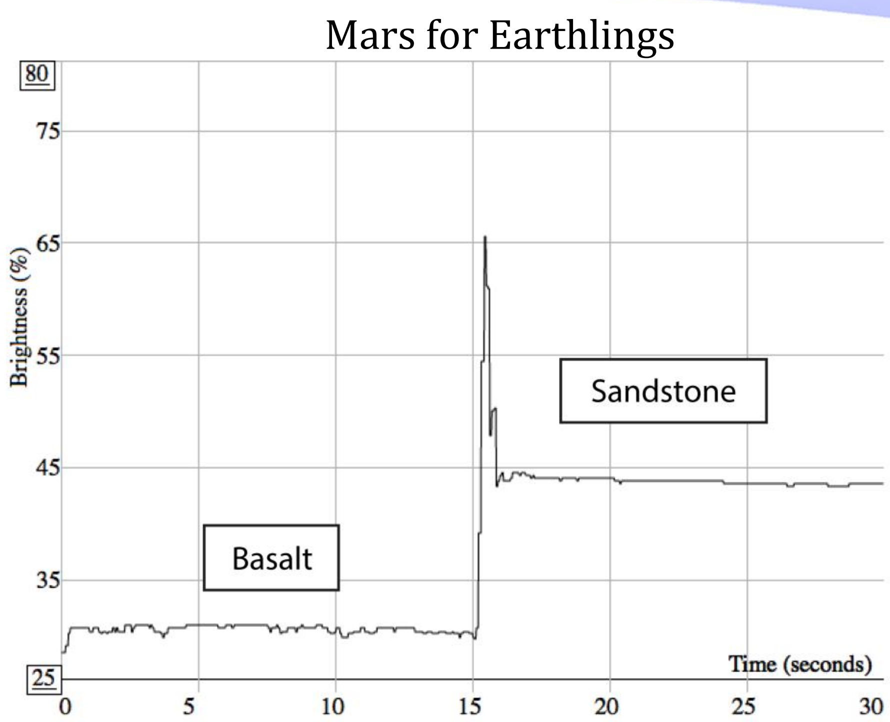


Figure 1. Top left: Vesicular basalt from the Hell's Half Acre Lava Field, Snake River Plain, Idaho; top right: sandstone from the Jurassic Nugget Formation exposed along the Grandeur Peak trail, near Salt Lake City, Utah; bottom: brightness graph generated from 'Kepler: Light Grapher' showing the difference in reflectivity of the basalt and sandstone. The bright peak at ~15 seconds is the change from basalt to sandstone (no rock in field of view).
Images: C. Duncan, University of Utah.

Mars for Earthlings

Homework 1
Life-Hosting Rocks_MFE
The Energy of Rocks

Purpose: Recognize the energy of the environment by its sedimentary structures.

Corn Syrup and Water Experiments
Watch the following videos:

- Flume Experiment: http://www.youtube.com/watch?v=zRGuMddjRGg&list=PL17AFB4B8AB3DCCF7
- Corn-Syrup Experiment: http://www.youtube.com/watch?v=W3YZ5veN_Bg

1. As the students watch the videos, compare/contrast the following parameters:

Parameter	Corn Syrup	Water
Velocity of flow		
Type of structures formed		
High or low energy environment		

The dynamics of sedimentary environments

2. Compare the following environments of deposition according to the following parameters: [Have the students write their answers a-c to the right of the image]
   a. Processes at work
   b. Strength of weathering and/or erosion
   c. Preservation potential of life

Figure 2: Cathedral Cove; Channel Islands National Park, CA. Image: nps.gov

Mars for Earthlings

Figure 3: White Sands National Monument, NM. Image: nps.gov

Sedimentary structures/textures on Mars

3. Similar to Question #3, annotate to the right of each image of Mars below:
    a. What structures do the students see?
    b. What is a likely environment of formation?
    c. Was the environment high or low energy in your opinion?

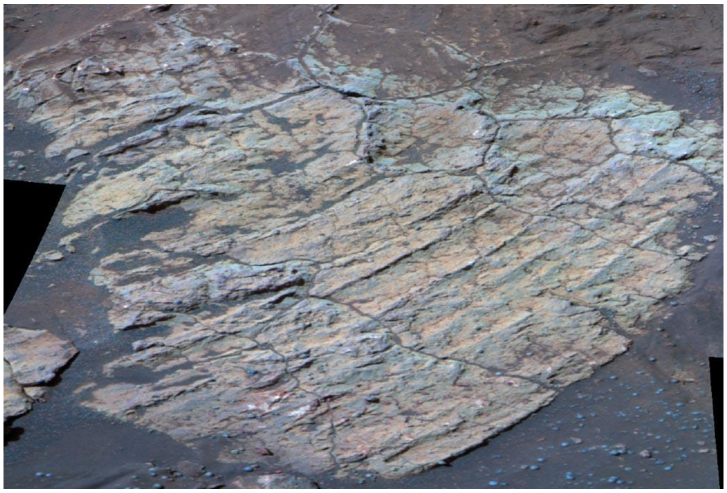


Figure 4: "Escher" rock in Endurance Crater investigated by Opportunity rover; Image Credit: NASA/JPL

Mars for Earthlings

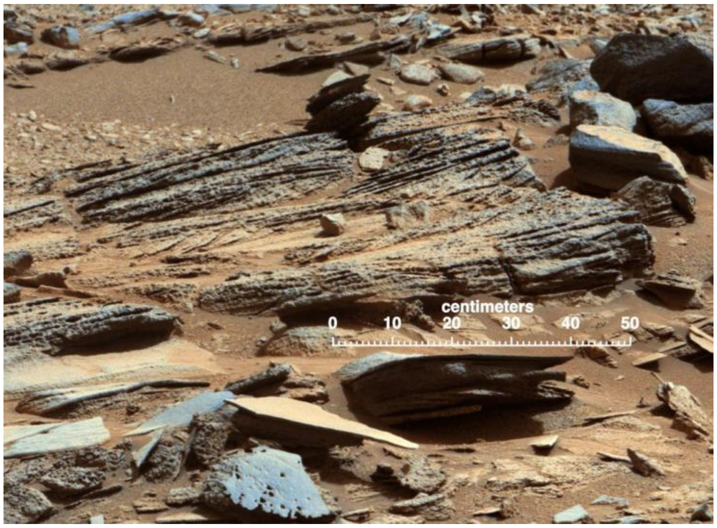
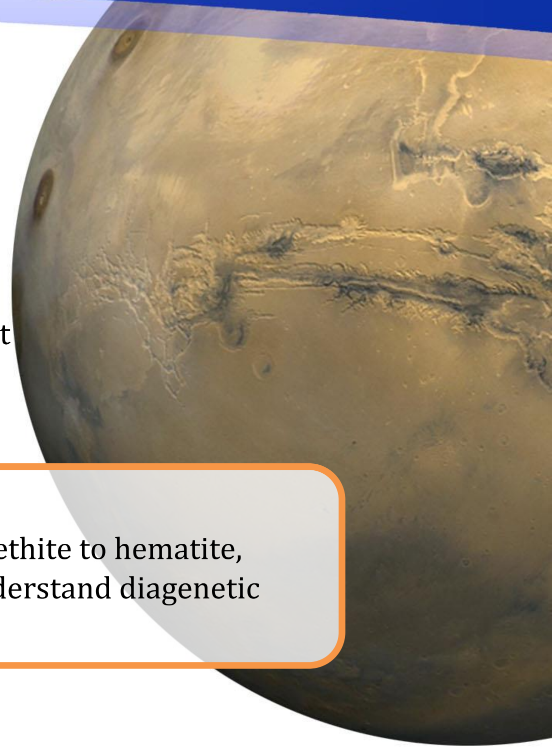


Figure 5: "Shaler" outcrop at Gale Crater investigated by MSL Curiosity rover; Image Credit: NASA/JPL-Caltech/MSSS

Lesson 8: Rock Evolution & Change



Summary
Students will be exposed to the processes of metamorphism and diagenesis on Earth and determine which processes are dominant on Mars. Are diagenetic processes on Earth mirrored on Mars?

Learning Goals

Students will be able to:

- Observe and understand the diagenetic alteration of goethite to hematite,
- Test different variables through experimentation to understand diagenetic environment thresholds of alteration.

Context for Use:
This module is meant for adaptation in an earth science course where sedimentary rock lithology and processes of formation are already familiar to students.

Background materials for rock types and classification include:
http://www.youtube.com/watch?v=pg_jKJFbA2A (This is a classification using a cooking kitchen analogy)

Description and Teaching Materials
In-Class Activity:

In-Class Activity 1: Cooking Rocks - Did the experiment work? - After the students have tried the homework (they may need several days to complete it), a later follow-up activity includes discussing whether the experiment worked for people and why/why not?

Homework/Lab

Homework 1: Cooking Rocks- Diagenesis

Teaching Notes and Tips

- In Homework 1: students will need samples of southern Utah picturestone.

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Image File: Rock Evolution and Change
2. Potential picturestone vendor- Kanab, UT: http://www.westernhills.com/index.html?shopper=cb6311c803426cebbc922d135f10e356
3. Rainbow Bridge Image: http://nature.nps.gov/geology/geologic_wonders/images/rainbow.jpg
4. Gold stone Image: http://rayerminerals.homestead.com/Verkoop_mineralen_6.html#
5. Published paper on the exercise: Chan, M. A., and Kahmann-Robinson, J., 2015, Cooking Rocks: Teaching About Diagenesis on Earth and Mars. Journal of Geoscience Education v. 63, p. 57-65.

Mars for Earthlings

In-Class Activity 1
How Rocks Change on Mars_MFE
Cooking Rocks: Did the experiment work?

Preparation: In this case students should do the homework before this activity. The students will need several days to do the homework at home. For this activity, make sure students have completed their "Cooking Rocks" homework.

Engage

What do the students think?

1. What holds sand grains together in a sandstone?
2. How does the cementing mineral form?
3. Can some of these minerals change?
4. Do similar minerals occur on Mars?
5. What might happen when you "cook" a rock with minerals containing water?

Have students think about the fact that minerals can change under certain conditions. For example: graphite and diamond are c-based minerals.

Movie showing conversion of synthetic diamonds to graphite
http://www.youtube.com/watch?v=7L7BV3IBfFA

For the homework experiment:
Observe the following experimental results (left side examples are "before" and right side examples are "after"). Why are they different colors?

Credit: Marjorie Chan

Explore

1. Do the students consider their experiment successful? Why or why not?

2. If any failures or issues presented themselves, why did they occur? How could the students mitigate them?

Explain

1. As students discuss their experiment, particularly the results, explain what success in experimentation really means. Success isn't always equated to "the test worked". Sometimes there is much to be learned in what may appear as failure.
2. If students experienced "failure" help them to determine the parameters that can be changed, or ascertain from the students what they think prevented them from a successful experiment.

Mars for Earthlings

Elaborate

1. Have students in their own words, define the term diagenesis:

2. How do goethite and hematite differ?

3. How did “cooking” the rock facilitate a change in mineral composition?

4. Would adding water into/onto the “after” sample change the mineralogy? Why or why not?

Evaluate

1. Are there diagenetic minerals on Mars? Why would one be more common than another?

2. What is the origin of the hematite in the Thermal Emission Spectroscopy (TES) imagery?

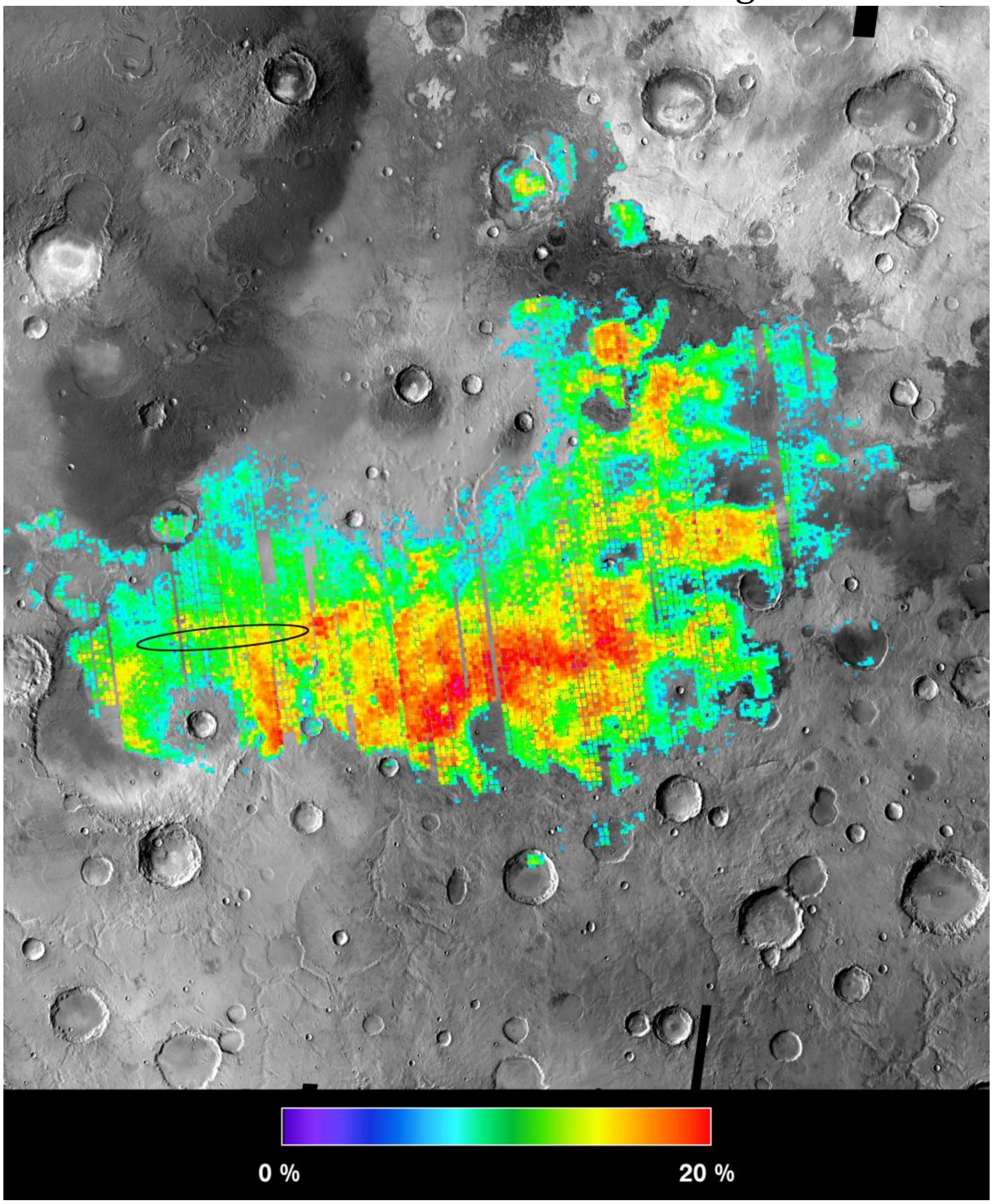


Figure 1: Meridiani Planum; Image credit: NASA/JPL/Arizona State University.

Image from: http://www.nasa.gov/mission_pages/mgs/20061121-imagesb.html

Note: On the relative abundance bar at the bottom, hematite abundances range from 5 % (blue) to 20 % (red). Hematite often forms in the presence of liquid water.

Mars for Earthlings

Homework 1
Rock Evolution & Change_MFE
Cooking Rocks: Diagenesis

Objective: Observe and understand how iron oxide minerals are affected by diagenesis on Earth and apply this thinking to diagenesis and iron oxide minerals (e.g., hematite) on Mars. (*Note: Homework 1 must be completed before portions of In-class Activity 1).

Materials Needed: Rock sample, oven access, digital camera.
*Note: This assignment may take up to a few hours.

Experiment Steps:
1. Read through all steps and the instructions for your report.
2. Have students get their piece of “Kanab Picturestone” rock. Make note of its color, size, and any other identifying features. The rock is an ancient (Triassic) porous sandstone that has liesegang bands (iron –oxide mineral bands), a record of past fluids that moved through the rock during its burial history.
3. Carefully document all steps and experiment conditions.
4. Take a “before” picture with a ruler for scale.
5. Decide on an experiment to test how goethite (FeOOH) can transform to hematite (Fe_2O_3). In general the change can occur at temperatures of about 400 degrees F (~ 204 degrees C) in a normal oven for about an hour or more. Experiment with some different conditions (e.g., students may want to vary the time, and/or temperature). If they have access to a chemistry hotplate, they could try the experiment on it as well.
6. Be sure to have students use some aluminum foil or something underneath the sample as they heat their sample so sand grains don’t get all over their oven, and/or it can protect their container if they are using one. ***<u>If using a microwave, do not use foil</u>***!
7. Leave the rock in the oven to cool before attempting to remove it!
8. Take an “after” picture with a ruler for scale (same position, conditions as step 4).

Safety:
Observe safety and caution at all steps (e.g., use safety goggles, and use insulated gloves/potholders). If the rock contains water, it is possible something could pop so it is advisable to have some aluminum foil around it loosely, and let it cool before trying to examine it. Be sure students keep track of the sample in the oven so they do not forget it and leave it unattended.

Experiment Follow-up:
1. What is the dominant change students observe (before vs. after experiment)?

2. Have students explain their reasoning for the dominant change they observe.

3. Explain the relevance of the experiment to understanding Earth processes and why this might help us understand similar mineralogies on Mars (e.g., hematite "blueberries" at Meridiani Planum, Mars).

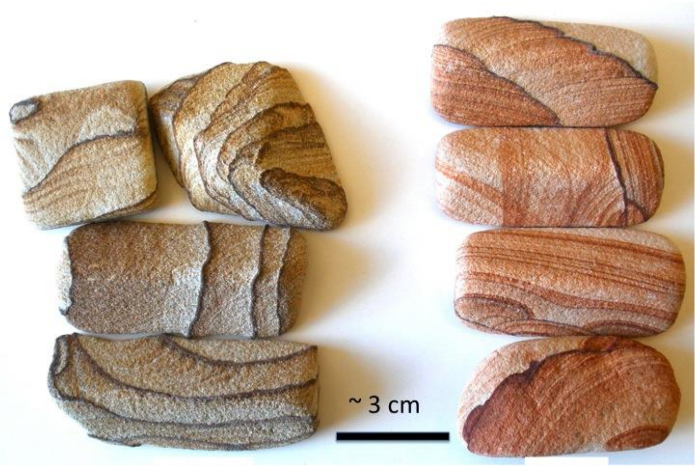
4. What are the limitations of this experiment (scale, time) and why are Earth examples not perfect analogs to Mars (e.g., what are some of the differences between Earth and Mars sandstones or chemistry)?

5. If any failures or issues presented themselves, why did they occur? How could students mitigate them?

Write a Report

1. Type a short, 1 to 2-page report with the student's name, and titled sections that have: A. Purpose, B. Hypothesis, C. Methods, D. Analysis, Results, and E. Conclusion and Relevance to Mars.
2. The report should include a before and after picture of your sample in the same position and location with a consistent scale (show a ruler or similar measuring tool to indicate scale when taking photos). This can go on a separate page.
   a. Label the pictures and include appropriate explanatory photo captions.
   b. Make sure the students document the actual conditions (temperature of oven, duration of time sample spent in oven, etc.) of the experiment and any other unusual circumstances.

Sample below from: Triassic Chinle Formation (Shinarump Member), (samples available from www.westernhills.com), Kanab UT. Image: M. Chan, University of Utah.



BEFORE AFTER

Mars for Earthlings

Advanced Questions:

1. Are the mineralogic changes detectable analytically besides by just the coloration visible to the eye? To better understand mineralogic changes, students can do XRD or Vnir spectroscopy to identify the minerals before and after.
2. How long would it take to get hematite on Mars, did it form quickly or slowly? See ref. Elwood Madden, M.E. et al. 2009, How long was Meridiani Planum wet? Applying a jarosite stopwatch to determine the duration of aqueous diagenesis: Geology v. 37, p. 6350638. geology.gsapubs.org/content/37/7/635.full.pdf
3. How would coarse crystalline hematite form on Mars? See ref. Madden, A. S., et al. 2010, Low-temperature mechanism for formation of coarse crystalline hematite through nanoparticle aggregation: EPSL v. 298, p 377-384. http://www.sciencedirect.com/science/article/pii/S0012821X10005248
4. Would temperature or salinity affect the hematite formation rates? See ref. Elwood Madden, M.E. et al. 2012, Jarosite dissolution rates and nanoscale mineralogy: Geochemica et Cosmochimica Acta 91 p. 306 - 321.

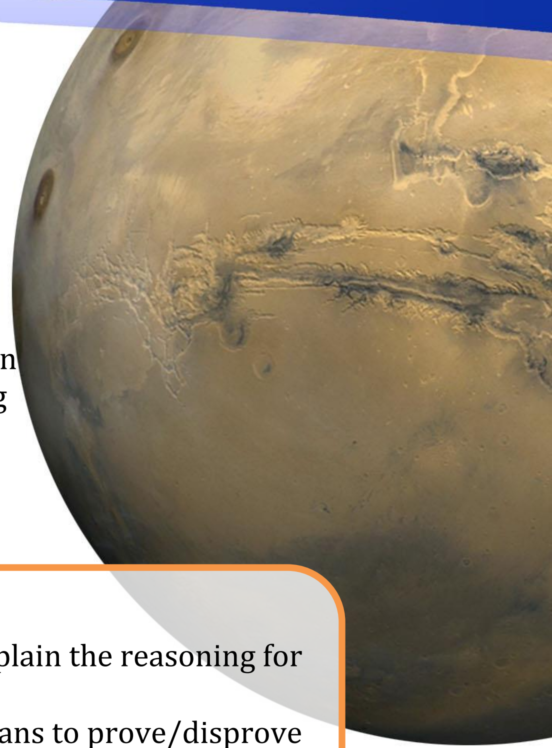
References for further elaboration ("advanced questions" in Elaboration section):

1. Elwood Madden, M.E. et al. 2009. How long was Meridiani Planum wet? Applying a jarosite stopwatch to determine the duration of aqueous diagenesis: Geology 37: 635-638. geology.gsapubs.org/content/37/7/635.full.pdf
2. Madden, A. S., et al. 2010. Low-temperature mechanism for formation of coarse crystalline hematite through nanoparticle aggregation: EPSL 298:377-384. http://www.sciencedirect.com/science/article/pii/S0012821X10005248
3. Elwood Madden, M.E. et al. 2012. Jarosite dissolution rates and nanoscale mineralogy: Geochemica et Cosmochimica Acta 91:306-321.
4. Fraeman, A. A., et al. 2013. A hematite-bearing layer in Gale Crater, Mars: Mapping and implications for past aqueous conditions. Geology 41:1103-1106.

XRD analysis

Whole-rock X-ray diffraction (XRD) analyses were performed on "before" and "after" pieces sandstone examples to compare the mineralogy signatures. These analyses were conducted in the XRD laboratory at the Energy & Geoscience Institute at the University of Utah, using a Bruker D8 Advance X-ray diffractometer. Phase quantification using the Reitveld method was performed using TOPAS software, developed by Bruker. The principle of the Reitveld method is that the intensities calculated from a model of the crystalline structure are fit to the observed X-ray powder pattern by a least squares refinement. This is done by varying the parameters of the crystal structures and of the peak profiles to minimize the difference between observed and calculated powder patterns. Because the whole powder pattern is taken into consideration, problems of peak overlap are minimized and accurate quantitative analyses can be obtained. The following operating parameters were used when analyzing the powdered samples: Cu-K-α radiation at 40 kV and 40 mA, $0.02^{o}2\theta$ step size, and 0.6 seconds per step. Bulk samples were examined 4 to $65^{o}2\theta$. The instrument is equipped with a detector (lynx eye) that collects data over 2.6 mm, rather than at a point, greatly increasing the X-ray counts collected, and decreasing acquisition time; a rotating sample stage which increases the mineral grain orientations encountered by the incident electron beam; and an automated sample changer capable of holding up to 90 samples. Each sample was ground in a micronizing mill. The samples was then rolled approximately 50 times to randomly orient the mineral grains before being scanned. The results reveal that upon heating, the mineral goethite (before value of ~ 7.0 wt % goethite) alters to hematite (after value of ~ 3.5 wt % hematite).

Lesson 9: Active Interior and Crustal Change



Summary
Students will become familiar with the theory of plate tectonics on Earth and evaluate the possibility of plate tectonics on Mars using the evidence (continental puzzle, faunal correlation, magnetic reversals etc.) utilized on Earth to support plate tectonic theory.

Learning Goals

Students will be able to:

- Identify Earth's geographic and magnetic North and explain the reasoning for their positions.
- Evaluate the use of magnetic reversals on Mars as a means to prove/disprove plate tectonic activity on Mars
- Compare and contrast Valles Marineris and Earth's Grand Canyon
- Find and analyze data using Google Earth and Google Mars software.

Context for Use
Students need a background in basic rock classification in order to be successful in this exercise as well as a general knowledge of the geography of Mars. Make sure students are familiar with navigation in Google Earth and Google Mars software. They should be able to access imagery and use the layers in the programs. Before assigning Homework 1 provide some instruction on faulting and fault types.

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: Plate tectonics & The Magnetic Reversals
Homework/Lab
Homework 1: Valles Marineris vs. The Grand Canyon

Teaching Notes and Tips

1. If appropriate use the JPL Valles Marineris "fly-by" to introduce Valles Marineris to your class (see **References and Resources**)
2. For *In-Class Activity 1* you may provide copies to each student for them to fill-in and follow along or simply run through the exercise with the students. We maintain student attention better if students have their own copy and are required to turn in the activity for class participation points.

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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References and Resources

1. Image File: Active Interior & Crustal Change
2. General Grand Canyon info: http://www.nps.gov/grca/index.htm
3. Valles Mariners animated "fly-by" courtesy of JPL: http://www.youtube.com/watch?v=JUbQM47QXwQ
4. Earth's Magnetic Field references: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html
5. NASA Geomagnetism reference: http://image.gsfc.nasa.gov/poetry/magnetism/magnetism.html
6. Connerney, J., 2005. Tectonic implications of Mars crustal magnetism. PNAS 102(42): 14970–14975; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1250232/
7. Fault Classification reference: http://www.opensha.org/glossary-hangingFootWall

Mars for Earthlings

In-Class Activity 1
The Active Interior and Crustal Change
Plate Tectonics & The Magnetic Field

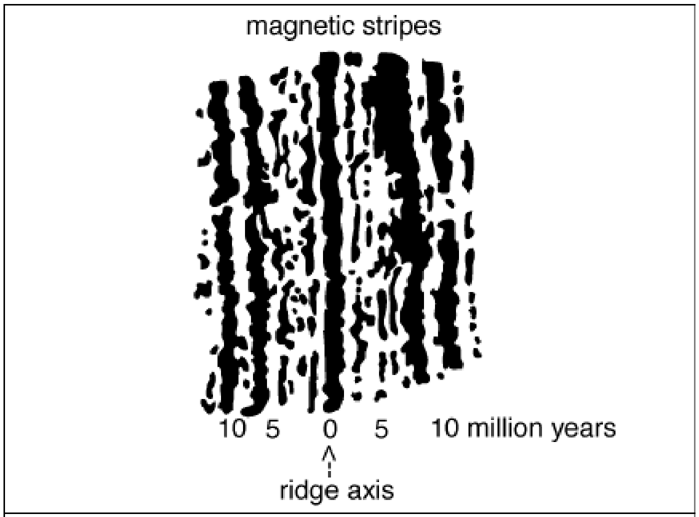
Preparation

1. Discuss and review the "puzzle" evidence of continental drift and plate tectonics. See examples of government sites such as:
   http://volcanoes.usgs.gov/about/edu/dynamicplanet/wegener/

   http://pubs.usgs.gov/gip/dynamic/dynamic.html

2. Other evidence such as fossil correlation and magnetic reversals on Earth may be discussed prior to this activity.
3. **Reference:** Connerney et al. (2005) Tectonic implications of Mars crustal magnetism: Proc Natl Acad Sci USA 102(42), p. 14970–14975, available online at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1250232/

Materials Needed:
Compasses and labeled magnets (positive-negative) to meet the size of the class.



Pattern created by magnetic stripes along the Mid-Atlantic Ridge south of Iceland.

Figure 1: Source: http://www.london-oratory.org/chemistry_folder/Revision/Earth&Rocks/New/student%20workbook%202.htm

Engage

Have students observe the following image (Figure 1) and explain that the banding is associated with normal and negative polarity reversals in Earth's Magnetic Field as recorded by basaltic rocks at the Mid-Atlantic Ridge. Note the "ridge axis of the Mid-Atlantic Ridge" in the image. This is used as evidence for continental drift.

Ask students the following:

Mars for Earthlings

1. What is a polarity reversal?

2. How is this image proof that the Earth's crust is moving?

3. Why are the rocks recording a reversal/change in polarity?

Explore

In order to understand the previous section, explore the following link and use it to help answer questions 1-3 (http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html):

1. What creates the Earth's magnetic field?

2. What is the Dynamo effect?

3. What benefits does a magnetic field provide?

4. Describe the crustal magnetism of Mars at Meridiani Terra (Figure 3). Do you see any banding? If so, what is the orientation?

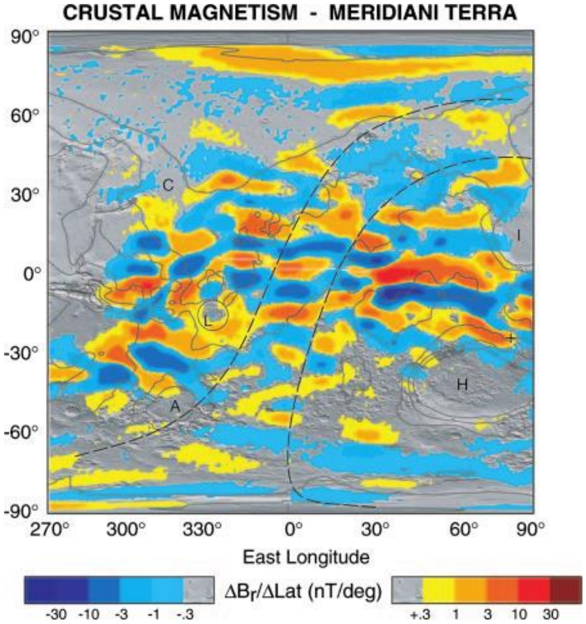


Figure 2: Crustal magnetism at Meridiani Terra Mars. Warmer colors are positive anomalies (Connerney, 2005).

Explain

1. The Earth itself is a magnet due to the convection of Earth's inner core causing electrical currents and a resulting electromagnetic field.
2. The South Pole of the Earth's magnet is in the geographical North because it attracts the North Pole of the suspended magnet and vice versa. Thus, there is a magnetic S-pole near the geographical North, and a magnetic N-pole near the geographical South. The positions of the Earth's magnetic poles are not well defined on the globe; they are spread over an area. The axis of Earth's magnet and the geographical axis do not coincide. The axis of the Earth's magnetic field is inclined at an angle of about 15° with the geographical axis. Due to this a freely suspended magnet makes an angle of about 15°with the geographical axis and points only approximately in the North-South directions at a place. In other words, a freely suspended magnet does not show exact geographical South and North because the magnetic axis and geographical axis of the Earth do not coincide.

Elaborate

Different stations on Earth are recording the changes in the electromagnetic field on Earth. One such station is found in Sweden.

Mars for Earthlings

1. Navigate to the following website: http://www.irf.se/Observatory/?link[Magnetometers]=Data/
2. Ask students to note the legend and discuss the “description” tab
3. Ask students observe the “real time” data of the EM field ask them to postulate reasons for why there is activity in the data.

Evaluate

In a class discussion environment, ask the class if Mars has a magnetic field and what studies in the future could reveal new discoveries about the potential for Mars to have had a magnetic field in the past?

Mars for Earthlings

Homework 1
The Active Interior and Valles Marineris
Valles Marineris vs. The Grand Canyon

Preparation

- Have access to Google Earth and Google Mars

Comparing dimensions
Using Google Earth and Google Mars, compare the length of Valles Marineris (VM) to the Grand Canyon (GC) using the ruler tool [button with a ruler on it in top task bar].

1. Valles Marineris (take the longest axis measurement you can) ______________ mi

2. The Grand Canyon (start: Marble Falls, AZ; end: beginning of Lake Mead) _________ mi

3. How do their lengths compare? Find a comparable landmass on Earth that would be close to the length of Valles Marineris.

Depth of the Canyons
Using Google Mars, find Candor Chasma and make sure the colorized terrain map (layer in Global Maps) is visible.

4. What is the diameter of Candor Chasma (click on the dot/name)? _____________ mi

5. Is Candor Chasma longer or shorter than the Grand Canyon?

6. How deep is Candor Chasma (use the colorized terrain map and/or ruler tool)? Take 3 measurements trying to find the deepest points. Provide the average.

   a. ______________ mi

   b. ______________ mi

   c. ______________ mi

   d. ______________ average mi

7. Just west of Candor Chasma (orient N to be North) is a HiRISE image ESP_014286_1735. Go to the observation information page to view the image in

greater detail. What kind of faults might be forming the ridges? Have students give their reasoning. (Hint: Basin and Range Province of the United States)

8. Sketch an image of how the fault students named in #7 works (Show the hanging wall and foot wall with relative motion. For help determining hanging wall and foot wall see: http://www.opensha.org/glossary-hangingFootWall):

Go back to Google Earth and find the Grand Canyon

9. How deep is the Grand Canyon? Take 3 measurements trying to find the deepest points. Provide the average. Use the ruler tool (students may need to adjust their viewpoint in Google Earth to see depth).

    a. _______________ mi

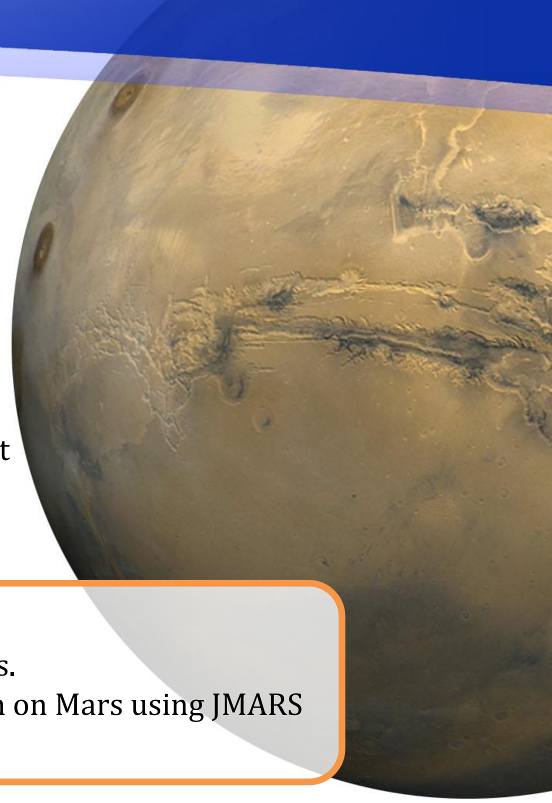
    b. _______________ mi

    c. _______________ mi

    d. _______________ average mi

10. Can students observe any evidence of faulting in the Grand Canyon (spend some time viewing the entire canyon in Google Earth)? If so, what do they observe?

11. Which canyon is deeper? Provide at least 2 reasons for why one canyon might be longer and deeper than the other.



Lesson 10: Meteorites and Impact Craters

Summary

A learning module for incorporation in to Earth science courses that exposes students to the formation of impact craters and what differentiates a meteorite from other rocks on Earth.

Learning Goals

Students will be able to:
- Practice identifying meteorites vs. Earth rock specimens.
- Attempt crater counting and accurately age-date terrain on Mars using JMARS software.

Context for Use

Prior exposure to rock & mineral classification is advisable, although not necessary to be successful in these exercises. In addition discuss relative and absolute dating techniques on Earth prior to these activities.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Is it a Meteorite?

Homework/Lab

Homework 1: Crater Counting

Teaching Notes and Tips

1. It will take at least an hour of prep time to become familiar with the crater count material in order to teach the crater counting method. It is recommended that during the class meeting when you assign Homework 1 that you provide a quick tutorial of crater counting and how to use the tools in JMARS.
2. For *In-Class Activity 1* you may provide samples of the required rocks/meteorites or use the images provided in the *Image File*.

Assessment

Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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References and Resources

1. Image File: Meteorites and Impact Craters
2. Criteria to identify a meteorite via NASA/DAWN mission interactive: http://dawn.jpl.nasa.gov/meteorite/experiment.asp
3. Background on determining the age of surfaces on Mars: http://www.msss.com/http/ps/age2.html
4. JMARS crater counting tutorial: http://jmars.asu.edu/crater-counting-layer

Mars for Earthlings

In Class Activity 1
Meteorite and Impact Craters_MFE
Is it a meteorite?

Purpose: Discover the criteria by which meteorites are identified.

Engage
Is it a Meteorite?
Have the students observe the rocks. Have them mark Yes or No for whether or not they think the rock is a meteorite. Also note if the rock is: igneous, metamorphic, or sedimentary.

	Yes	No	Lithology
Rock A			
Rock B			
Rock C			
Rock D			

What criterion/criteria do the students use to identify whether or not a rock is a meteorite? Have them explain below:

Explain
Criteria to identify a meteorite in hand sample (NASA DAWN Mission: http://dawn.jpl.nasa.gov/meteorite/experiment.asp). Does the specimen have:
1. Presence of a fusion crust?
2. Presence of shiny metals?
3. Presence of regmaglyps (thumbprints)?
4. Attracted to a magnet?
5. Density greater than a typical Earth rock?
6. Presence of chondrules?

Go through these criteria as the discussion with the students would indicate in **Engage**. Ultimately, chemical analyses will be crucial to positive identification.

Explain
Read about meteorite vs. meteor-wrongs. Have students vote on what website they think gives the best presentation (and/or give some alternate sites). Possible websites to use are below.
http://meteorite-identification.com/
http://www.littlewolf.us/meteoriteormeteorwrong.html
http://www.meteorites-for-sale.com/meteorite-identification/meteor-right-wrong.html

Mars for Earthlings

Elaborate
Discuss how many meteorites are from Mars. Is the number single digits, tens, hundreds, or thousands? Have students guess, and then they can check their guess at this website.
http://www2.jpl.nasa.gov/snc/

What criteria do we use to tell if a meteorite is from Mars?
http://www.imca.cc/mars/martian-meteorites.htm

Evaluate
What happens when a meteorite hits a planetary surface? How big will the crater be?
Observe the below meteor crater in Arizona measuring: 0.737 mi (1.19 km) in diameter, 570 ft (170m) deep

1. Did scientists find any of the meteorite (students may need to do some outside research)?

2. What factors influence the size of the crater? List at least 5 below.

Figure 1: Photograph by David Roddy, United States Geological Survey.

Calculate your own crater size!

1. Using the below link, have the students calculate the size of 3 craters that will form when they change varying parameters. Record the parameters and results below. Have them consider #2 as they change their parameters.
http://www.lpl.arizona.edu/tekton/crater_c.html (*Note: Make sure they calculated at least 2 craters and varied the inputs.)

2. What parameter was the most influential in the size of a crater?

Google Mars & Craters

3. Using Google Earth find the region Mawrth Valles (22.43_N 343.03_E) in the Mars navigation. Using the ruler tool try and determine the average diameter of craters in the region. Write the average below.

4. What might this say about the ages of these craters compared to other regions? Is it more like the area to the South or to the North?

Testing your skills

Which image below is a meteorite, Figure 2 or Figure 3? List your criteria.

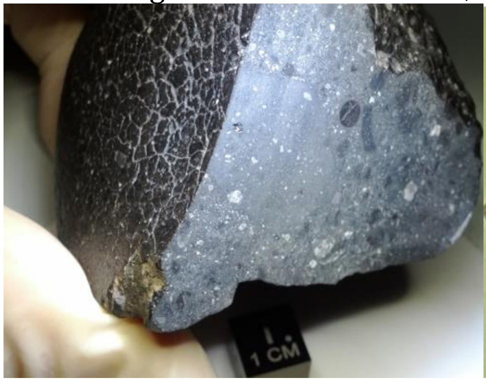

Figure 2. Image credit: http://www.nasa.gov/mission_pages/mars/news/mars20130103.html

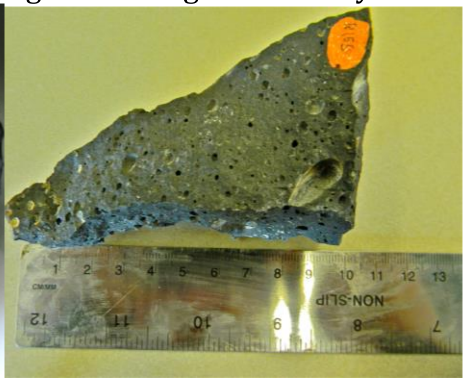

Figure 3. Image credit: Levi Huish, University of Utah

Mars for Earthlings

Homework 1
Ages and Times of Earth & Mars
Crater Counting

Background:
In reference to: http://www.msss.com/http/ps/age2.html (**NOTE: This map is centered at a different location than the map below in question 4, so you need to be sure to match up appropriate geographic locations).

1. We often use radiometric dating to determine the age of Earth's rocks. Is this technique applicable on Mars? What would be the challenges of preforming this technique on Mars?

2. What is the general assumption of age relative to the overall appearance of craters?

3. How can we roughly divide the history of crater formation into three periods, from oldest to newest?

4. Using the map of Mars below, sketch the basic boundaries of the three Mars Epochs that are based on crater counts (Labels: Noachian, Hesperian, Amazonian)

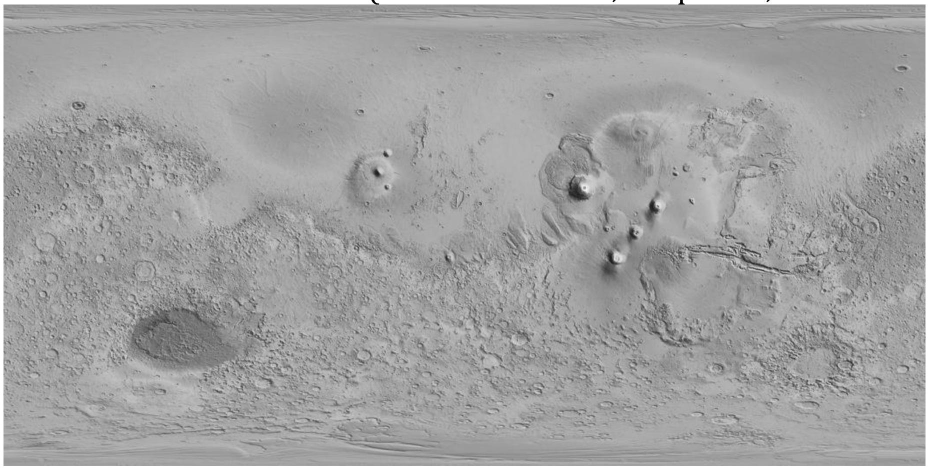

Figure 1 MOLA colorized elevation map in grayscale.

Mars for Earthlings

Crater Counting:
Review this tutorial in order to use the Crater Counting layer in JMARS:
http://jmars.asu.edu/crater-counting-layer

5. Measure the diameter of as many craters you can using JMARS *Crater Counting* layer. Choose craters that are roughly the same size. Use a 128 zoom OR larger (to give you at least 30 or more craters) and fill in the average crater diameter and # of craters you measured. If the students can separate out sizes, do so. Use the measure tool located in the tool bar at the top of the window to measure the x and y dimensions of the area they're counting in, then calculate area by Area = x*y.

Region	**Size 1:**		**Size 2:**		**Size 3:**	
	Ave diameter ***(X-axis), #***	**#/ area =** ***plot on Y-axis***	**Ave diameter** ***(X-axis), #***	**#/ area =** ***plot on Y-axis***	**Ave diameter** ***(X-axis), #***	**#/ area =** ***plot on Y-axis***
Amenthes Rupes Area =	**Dia:** **X=**		**Dia:** **X=**		**Dia:** **X=**	
Vichada Valles Area=	**Dia:** **X=**		**Dia:** **X=**		**Dia:** **X=**	
Mawrth Valles Area=	**Dia:** **X=**		**Dia:** **X=**		**Dia:** **X=**	
Astapus Colles Area=	**Dia:** **X=**		**Dia:** **X=**		**Dia:** **X=**	

Mars for Earthlings

6. Use the isochron diagram on the following page to determine the age of the terrain. Have students PLOT their points on Figure 2. To scale the Y-axis correctly: use proportions and be sure to square the area they investigated.
   Example: 20 counted craters, diameter 4km in a 200km by 200km counted area- $20/(200)^2 = 0.0005$ which gives you a y-axis value of 10^{-5}
   Use the diameter of 4km that they measured for the x-axis and plot.
   Does their age coincide with the sketch they made in #4?

   Amenthes Rupes- Epoch: ____________________

   Vichada Valles- Epoch: ____________________

   Mawrth Valles- Epoch: ____________________

   Astapus Colles- Epoch: ____________________

7. What are the difficulties the students faced in crater counting on Mars? Do they feel like it is too "averaged" and some terrains are not accounted for? Why or why not?

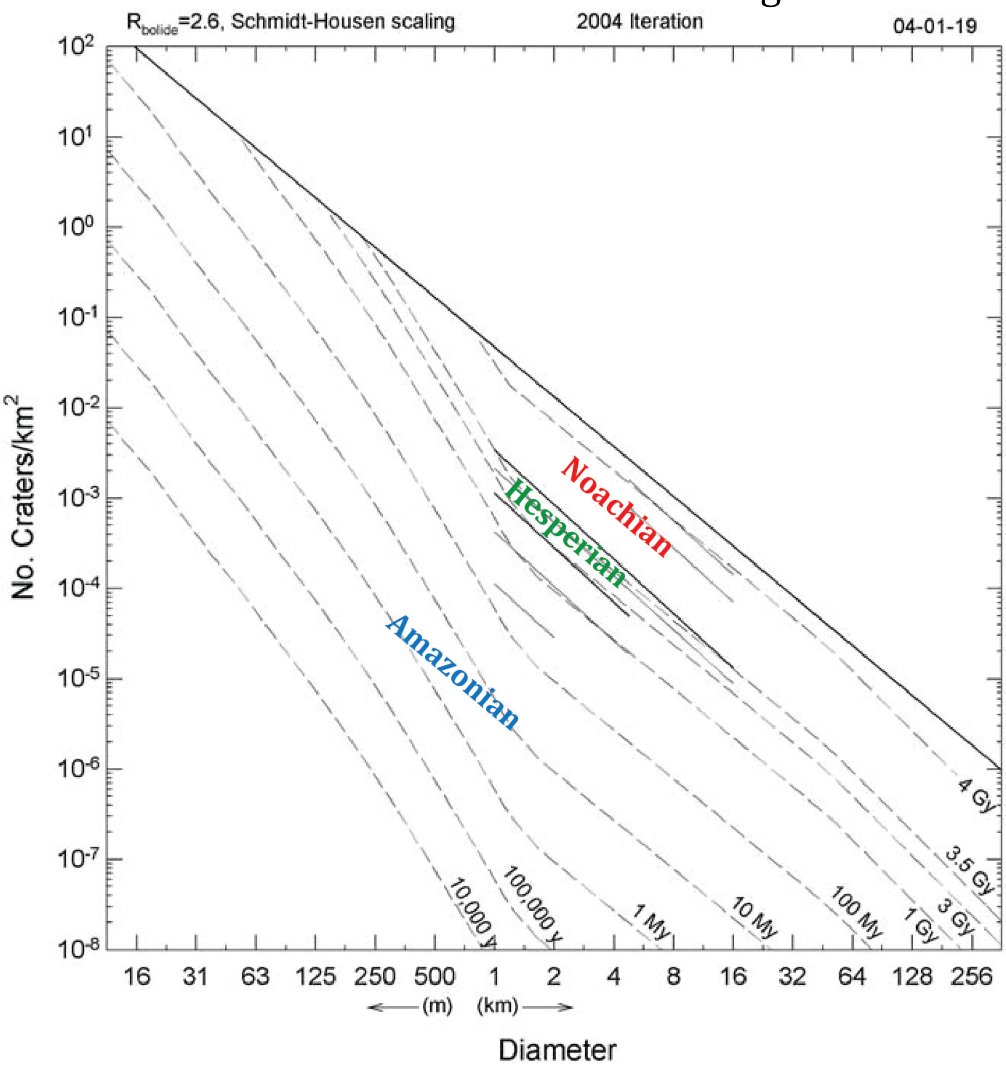

Figure 2. Final 2004 iteration of Martian crater-count isochron diagram. Upper solid line marks saturation equilibrium. Heavier short solid lines (1 km < *D* < 16 km) mark divisions of Amazonian, Hesperian, and Noachian eras; lighter nearby solid lines mark subdivisions of eras all based on definitions by Tanaka (1986). Uncertainties on isochron positions are estimated at a factor ~ 2, larger at the smallest *D*. 100 m (total uncertainties in final model ages, derived from fits at a wide range in *D*, including uncertainties in counts, are estimated a factor ~ 3).

Figure source: http://www.psi.edu/sites/default/files/imported/research/isochrons/mc8/fig6.jpg

Lesson 11: Age & Times of Mars vs. Earth

Summary
This learning module discusses the geologic history of the Earth, the principles scientists use to define the Earth's geologic history, and relative dating techniques.

Learning Goals

Students will be able to:

- Use principles of relative dating to interpret block diagrams, Earth outcrops, and Mars imagery.
- Compare the geologic history of Earth and Mars.
  Compare examples
  http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA16098 &
  http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA16099

Context for Use
Make sure students have a basic understanding of lithologies in addition to the method of crater counting for dating and interpreting the ages of Martian terrain.

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: A Timescale Comparison
Homework/Lab
Homework 1: It's All Relative

Teaching Notes and Tips

1. Expose students to Crater Counting such that students realize the geologic timescale of Mars and that dating of the Mars surface is based upon crater counting.
2. For *Homework 1* make sure students have a basic knowledge of lithology in order to interpret unconformities.
3. Depending on class size, if possible, make copies of the geologic maps for students to use during *In-Class Activity 1*. If class sizes are larger than 30, include these maps in a course packet. Overhead projection of the maps may not be sufficient to engage fully in the activity.
4. *Homework 1* can be adapted for an in-class activity as desired.

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Image File: Age and Times of Mars vs. Earth
2. YouTube video of the Noachian period on Mars (artist interpretation): http://www.youtube.com/watch?v=JfYIvkTQ2pc
3. Simplified geologic map of the state of Utah: http://geology.utah.gov/maps/geomap/postcards/pdf/utgeo_postcd.pdf
4. Geologic maps of Mars: http://www.lpi.usra.edu/resources/mars_maps/1083/index.html http://pubs.usgs.gov/sim/3292/

Mars for Earthlings

In-Class Activity 1
Age & Times of Mars vs. Earth_MFE
A timescale comparison

Preparation

1. Using either the image file provided in the Age & Times of Mars vs. Earth learning module or images of your own, display the geologic timescales of Mars and Earth.
2. Have copies of both Utah geologic maps and Mars geologic maps available for students to use. See Resources & References in Age & Times of Mars vs. Earth.

Engage

Compare the geologic timescales of Earth vs. Mars and ask students the following questions:

1. What differences do the students observe in the timescales?
2. What do they think is responsible for those differences?

Explore

Have students view the following YouTube video about the Noachian period of Mars (an artist's rendition/animation of the period):
http://www.youtube.com/watch?v=JfYIvkTQ2pc

1. What do students notice about the early period of Mars?
2. How similar/dissimilar is it from Earth?

Explain

1. Due to Earth's diverse processes and its location in the habitability zone, Earth's geologic history is diverse and varied with respect to Mars.
   Note: The **habitable zone** (a.k.a. the **Goldilocks zone)** is the region around a star where planetary bodies with sufficient atmospheric pressure can support liquid water at their surface. The Kepler project specifically looks for habitable planets.
   http://www.nasa.gov/mission_pages/kepler/main/index.html#.UjJMMbwZ9ho
2. Earth's geologic history is largely defined by its faunal/fossil record, whereas Mars cannot be dated by such a method.

3. Mars geologic history is defined by the amount and size of craters per unit area (see *Crater Counting In-Class Activity* in learning module **Meteorites & Impact Craters**).

Elaborate

Geologic Map of Earth

View a geologic Map of the state of Utah on Earth:
http://geology.utah.gov/maps/geomap/postcards/pdf/utgeo_postcd.pdf
Note: this map is simplified

1. What is the scale of the map?

   How many degrees of latitude and longitude does the map cover?

2. Roughly how many colors are used on the map and what do they represent?

3. How old is the oldest terrain in Utah? (give "age name" and years)

   Why is there so little of this terrain?

Geologic Map of Mars

View a geologic Map of Mars:
http://www.lpi.usra.edu/resources/mars_maps/1083/index.html

1. What is the scale of the map (ratio)?

   How many degrees of latitude and longitude does the map cover?

2. What does the color scale indicate on the map and how does this differ from the Utah map?

3. How old is the oldest terrain according to the map? (give "age name")

   If this is hard to discern, why is this?

Mars for Earthlings

4. Now look at the latest map of Mars (click on map sheet) at:
http://pubs.usgs.gov/sim/3292/
Name 3 ways in which it is different from the earlier map of Mars that you looked at? (hint look at the abstract)

a.

b.

c.

Evaluate

1. Consider the difference between Mars and Earth. Ask the students why only a geologic map of Utah (and then N. America) was provided to them.

   What is the potential difficulty in providing them a geologic map of the entire Earth?

2. Notice how the shapes and geometries of colored units on Mars vs. colored units on Earth. Cite 3 ways in which the mapped geologic features of Mars are distinctive or different from Earth (comment on the implication of the processes that are different):

   a.

   b.

   c.

Mars for Earthlings

Homework 1
Age & Times of Mars vs. Earth_MFE
It's All Relative

Objective: Apply relative dating laws to interpret block diagrams, Earth road cuts, and Mars imagery.

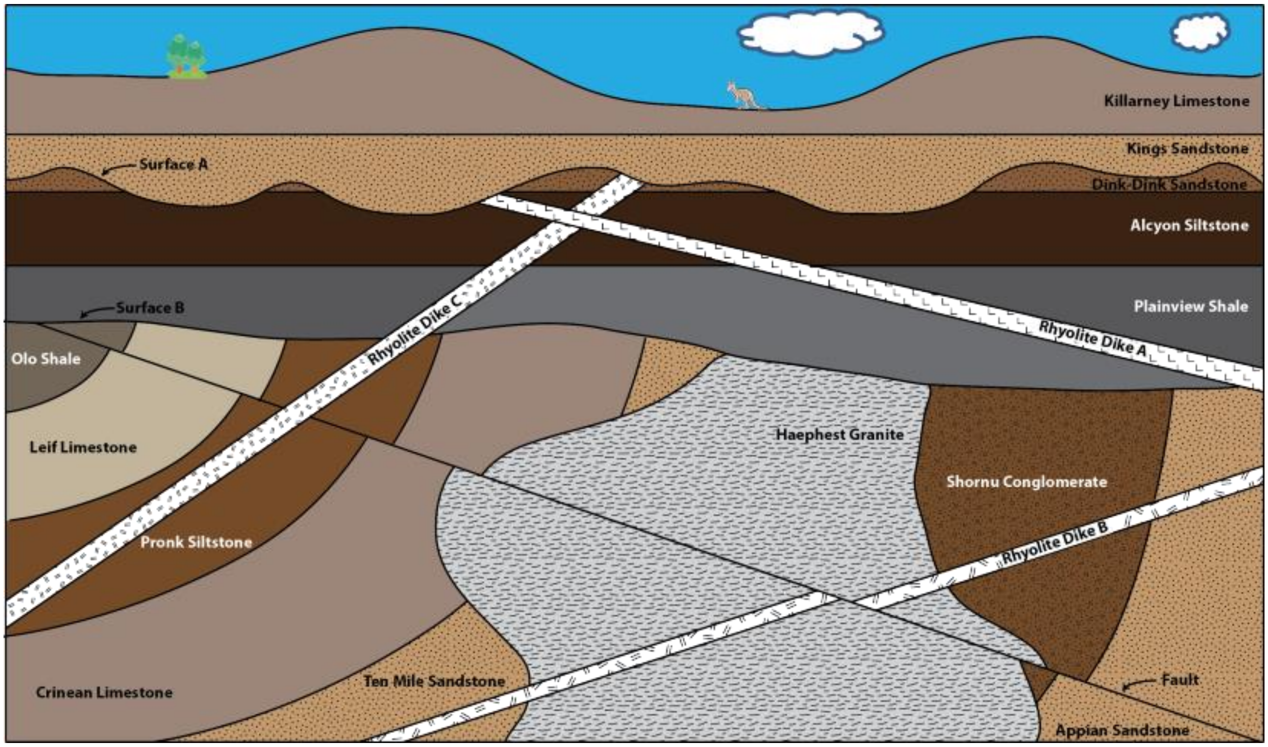

Figure 1 Block diagram. Source: http://fractalplanet.wordpress.com/2013/02/11/relative-dating-activity/

1. How many unconformities (erosional breaks) are present in the image? Name each kind and explain your reasoning.

2. What law did the students use to determine the relative ages of the Ten Mile Sandstone and Appian Sandstone?

3. List the order of geologic events by name from *oldest to youngest* below (i.e. Surface A, Rhyolite Dike C, Ten Mile Sandstone etc.):

Road Cuts on Earth

Navigate to the website: http://www.gigapan.com/gigapans/104247 to view the Moab Fault Zone in Utah.

4. How many faults do the students observe?
5. How many geologic units do they see? What criteria are they using to differentiate their geologic units?
6. What principle of relative dating is most useful for interpreting this image?
7. Are there any unconformities? If so, how many and what type?

Mars for Earthlings

Tractus Catena on the south of Alba Mons

Below (Figure 2) is an image taken by THEMIS of a fracture zone on Mars. Observe the image and answer the following questions:

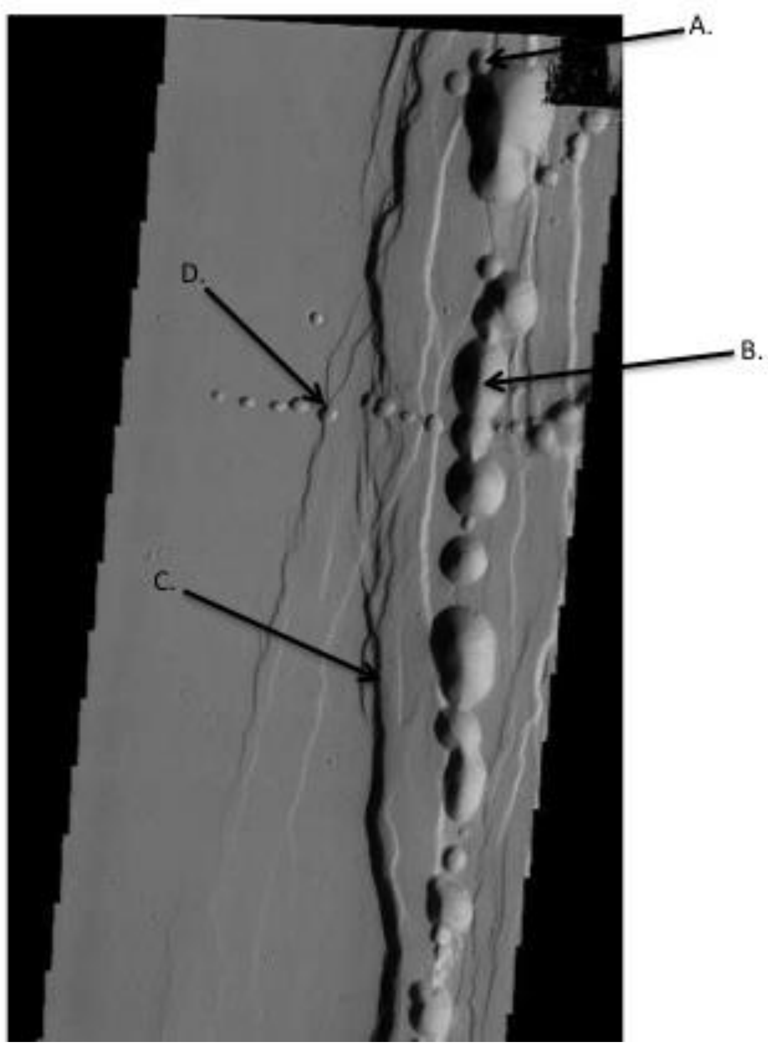

Figure 2 Tractus Catena on the south of Alba Mons, Mars. Themis image; Image Credit: NASA/JPL/ASU. Source: http://themis.asu.edu/node/5918

8. Order the geologic events (A-D) from *oldest to youngest*. Make sure the students note the entire image as you make their decisions.

9. What makes this image difficult to interpret?

10. What law(s)/principles of relative dating did they use to interpret the image?

11. If they are already familiar with tectonics, are features B and D likely related to extension or compression? Have students justify their answers.

Lesson 12: Surface Sculpting Waters on Mars

Summary

This learning module and related laboratory exercise exposes students to surface water erosion due to rivers and deltas and their evidence on the Martian landscape. Students will use modern analogs to assess the hypothesis that both rivers and deltas existed on Mars.

Learning Goals

Students will be able to:

- Demonstrate comprehension of fluvial styles and processes as well as delta formation through comparison of Earth-analog environments and Mars imaging.
- Gain experience with contour maps on both Earth & Mars.

Context for Use

This learning module is meant for adaptation in an introductory Earth science course and/or planetary science course. If you desire to use the *In-Class Activity 1: Stream Table and Mars*, provide exposure to fluvial processes and styles prior to the activity.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Carving Mars: Rivers

In-Class Activity 2: Eberswalde Delta Mars

Homework/Lab

Homework 1: Mars Fluvial Channels: Contour Maps

Teaching Notes and Tips

1. If you have access to a stream table conduct the “Stream Table and Mars” *In-Class Activity* in the stream table lab.
2. For larger classes (>20 students) in the “Stream Table and Mars” *In-Class Activity* use the video link provided in References and Resources and ask for volunteers to sketch out fluvial events on the board for others to explain and discuss. Encourage all students to participate and turn in their sketches for a participation grade.
3. All images required for activities/homework are available in the References and Resources in PowerPoint format.
4. Acquire red/blue glasses to view HIRISE red-blue anaglyph images.

Assessment

Each *In-Class Activity* and *Homework* has its own measure of Assessment.

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NASA Award (NNX11AH29G)

References and Resources

1. Image File: Surface Sculpting Waters
2. Stream Table: meandering river- http://www.youtube.com/watch?v=YsQ7hW2fAEs&feature=related
3. Boggs, S., 2001. Principles of Sedimentology and Stratigraphy, 3rd ed. Prentice Hall, ISBN: 0-13-099696-3, 726p.
4. Mars Global Surveyor image & Video of Martian delta: http://www.nasa.gov/multimedia/imagegallery/image_feature_98.html
5. Red-blue glass anaglyph glasses example from Amazon: http://www.amazon.com/Red-Blue-Anaglyphic-Glasses-Paper/dp/B002MXP42W
6. Ehlmann B., et al. 2008. Clay minerals in delta deposits and organic preservation potential on Mars, Nature Geoscience, doi:10.1038/ngeo207.
7. Bhattacharya, J., and Giosan, L., 2003. Wave-influenced deltas: geomorphological implications for facies reconstruction, Sedimentology, v. 50, p. 187-210.
8. Water flows on Mars presented by Alfred McEwen (choose the video under "Possible Water Flows on Mars": http://mars.jpl.nasa.gov/mro/multimedia/videoarchive/

Mars for Earthlings

In-Class Activity 1
Surface Water_MFE
Carving Mars: Rivers

Purpose: Observe the formation of fluvial channels, the effects associated with varying water velocity and changing base/level gradient, and the evidence for fluvial/alluvial environments on Mars.

Preparation:

1. Acquire red/blue glasses to view HIRISE red-blue anaglyph images (http://www.amazon.com/Red-Blue-Anaglyphic-Glasses-Paper/dp/B002MXP42W).
2. Expose students to fluvial styles and fluvial processes (meandering vs. braided channels, base level fluctuation, changing stream gradient etc.) on Earth and how they are formed ***prior to*** conducting this *In-Class Activity*.

Resources:

1. Stream Table by Davidson Geology: meandering river- http://www.youtube.com/watch?v=YsQ7hW2fAEs&feature=related
2. Eberswalde Delta-HIRISE: (context) http://hirise.lpl.arizona.edu/PSP_001534_1560 Image: http://hirise.lpl.arizona.edu/images/2007/details/cut/Eberswalde-delta-3x.jpg
3. MOLA global map: http://www.google.com/mars/
4. Meander Scar Image Source: ftp://eol.jsc.nasa.gov/EFS_highres_ISS022_ISS022-E-19513.JPG
5. Water flows on Mars (choose the video under "Possible Water Flows on Mars"): http://mars.jpl.nasa.gov/mro/multimedia/videoarchive/

Engage
Watch the following video: https://www.youtube.com/watch?v=E6sWiPAu708

As the students watch the video, have them answer the following:

a. Where is the river fastest?

b. Where do sandbars form?

c. Why does the river form sinuous bends?

Mars for Earthlings

Explore

1. Have students observe the Davidson Geology stream table experiment: http://www.youtube.com/watch?v=YsQ7hW2fAEs&feature=related
    a. Students should sketch and label the timestamp associated with the following fluvial events:
        i. Formation of a cut bank
        ii. Formation of a point bar
        iii. Stream avulsion
        iv. Formation of multiple channels (at least more than 1)

    b. For each of the sketches have students describe why they occurred.
        i. Cut bank
        ii. Point Bar
        iii. Stream Avulsion
        iv. Multiple channels

    c. As students progress through the Exploration portion of the exercise discuss the terms and concepts:
        i. Cut bank
        ii. Point Bar
        iii. Meandering vs. braided

2. Explore the HIRSE anaglyph image, using red-blue glasses (blue filter over right eye), of the Eberswalde region of Mars: http://hirise.lpl.arizona.edu/images/2007/details/cut/Eberswalde-delta-3x.jpg
    a. Ask the students if any of their stream table sketches are similar to what they observe on Mars? Which one, if any?
    b. Explain the circumstances in which this surface geomorphology on Mars might have formed.

Explain

1. Students can use Google Earth to show continental areas on Earth (e.g. look in high mountainous areas) where multi-stacked channel styles are prevalent. Do the same for braided vs. meandering styles. In doing so, discuss the following concepts:
    a. Channel gradient
    b. Sediment input

Elaborate

Make a Mars global map available for students to view digitally or hardcopy: http://www.google.com/mars/

1. Consider the landscape of Mars. In what regions, could water have flowed as braided channels? Ask students to label a map or directly point out their response.
2. Would meandering or braided fluvial styles be more common on Mars? How does this differ from Earth, or does it?

Evaluate

1. In reference to figure 1 ask:
    a. Where would it be safe to build a house?
    b. Where is deposition occurring? What about erosion?
2. When students see the scars, ask the class:
    a. What does this tell you about the meanders?
    b. Can the students discern which meanders are older and which are younger?
    c. Did they observe similar geomorphology on Mars?

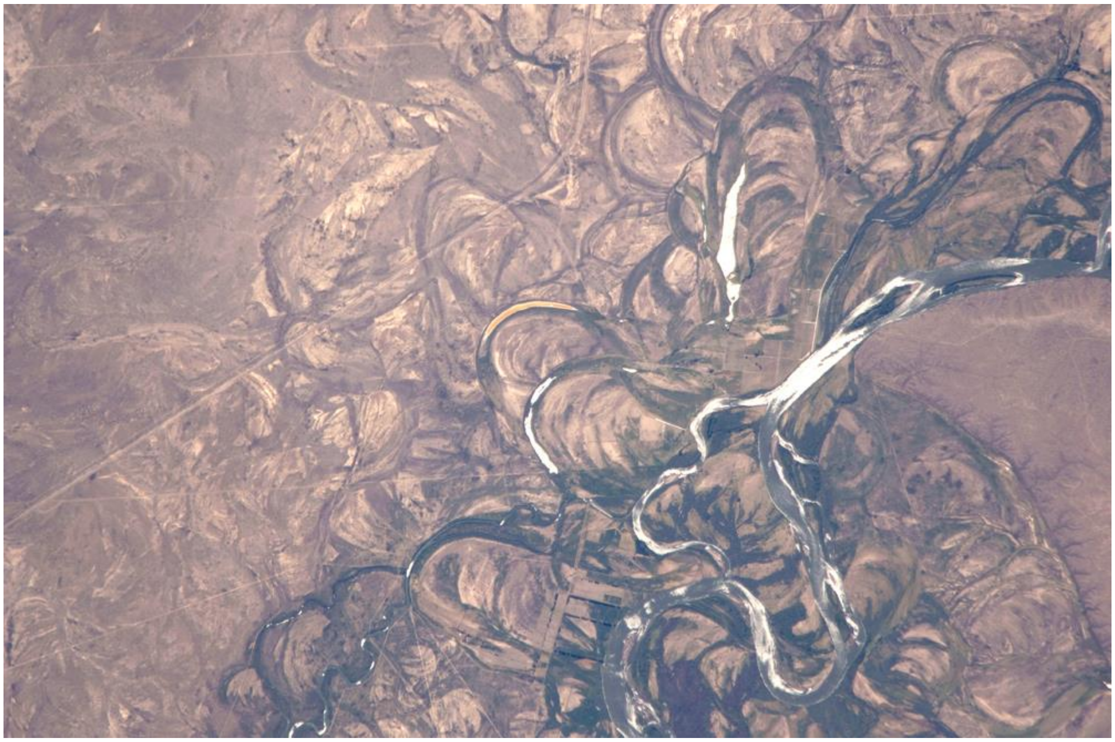

Figure 1: RIO NEGRO, COLONEL JOSEFA AREA, FLOOD PLAIN
Center Point Latitude: -39.8 Center Point Longitude: -65.4
Credit NASA. (Image Source: ftp://eol.jsc.nasa.gov/EFS_highres_ISS022_ISS022-E-19513.JPG. ISS/NASA)

Mars for Earthlings

In-Class Activity 2
Surface Water_MFE
Eberswalde Delta Mars

Purpose: Become acquainted with deltas on Earth and apply the principles of delta-formation to Mars images. Students will be able to create an informed hypothesis as to whether or not deltas are present on Mars.

Preparation

1. Acquaint students with delta formation previous to this exercise or as a simultaneous component to your teaching.
2. Research and present deltas found here on Earth to serve as analog comparisons. The **Engagement** section will provide an opportunity, albeit small, for students to see an analog.

Engage

1. Ask students the following question to start off the activity: When you hear the word “delta” what do you think of?
    a. List ideas on board
    b. Discuss each one as it applies
2. To test current understanding share with them the following images and have them identify which is a “delta” (see the Image file in **References and Resources** for images).
    a. Horseshoe Bend Colorado
    b. Lake Powell
    c. Amazon Delta
    d. Congo River

Explore

1. View the following video from NASA.gov- click on the “+ View Video” link in blue: http://www.nasa.gov/multimedia/imagegallery/image_feature_98.html

2. As students view the video, ask them to write down the evidence cited by scientists that this is a delta on Mars.

3. Ask students to compare and contrast their Mars findings with Earth-based observations of the following deltas: Mississippi River and Colorado River (dry).
    a. You may use a similar Table Format provided in this learning module if you plan to have students turn in their observations as a result of this *In-Class Activity*
    b. See the Image file in **References and Resources** for images.

Mars for Earthlings

Delta	Overall Geometry	What body is/was it emptying into? Evidence?
Eberswalde Crater, Mars		
Mississippi River, Earth		

Explain

1. As students complete the **Explore** activity, discuss concepts such as delta *lobe switching* and the *forces creating different delta geometries* (bird's foot vs. cuspate).
2. As appropriate share the tripartite classification (consult Bhattacharya & Giosan, 2003 **References and Resources**) of deltas and which would be more applicable on Mars (Ehlmann et al., 2008 **References and Resources**), if any.

Elaborate

1. Search and discover other deltas on Earth via Google Image search or the like (HINT: search major river systems). Have students determine which delta on Earth is most similar to Eberswalde Delta on Mars. Are any a good match? Ask students to explain why or why not.
2. Ask students how they might conduct "tests" on Mars to determine whether or not a delta exists? (Hint: remember that deltas form where sediment is dispersed into a standing body or former standing body of water.)

Evaluate

1. If you use this activity as homework, have students submit the chart and associated questions and assess their answers.
2. If you use the Elaboration section, the tests students come up with should indicate their grasp of delta processes.

Mars for Earthlings

Homework 1
Surface Water_MFE
Mars Fluvial Channels: Contour Maps

Purpose: Become familiar with contour maps and learn how to read them. Observe fluvial incised-channels on a contour map of Earth and compare to a contour map of Mars, and make predictions of potential fluvial activity on Mars.

Preparation:
1. If not uploaded to the students' Google Earth application, load the USGS topographic maps layer to Google Earth using the following website and link: http://www.gelib.com/ng-topo.htm
2. Open the Mars contour map found here: http://pubs.usgs.gov/imap/i2782/i2782_sh2.pdf

Directions/Questions:
Earth Fluvial Channels
1. Open Google Earth:
   a. Have the students get their bearings on Earth by centering their map/viewer on the following coordinates:38°27'N, 109°41'W, near Pyramid Butte, UT.

   b. What is the major river in the area?

   c. Find Dripping Spring (southeast of Pyramid Butte). What is the flow direction from Dripping Spring to the nearby major river?

      How do the contour lines indicate the flow direction? Sketch an example below of what the contour lines look like in relationship to the stream:

   d. If the students were to hike from Pyramid Butte to the nearby campground in the northeast, would they be hiking uphill or downhill? Have them explain their reasoning.

e. Follow the meanders of the major river channel. How are the contours drawn near the river? Do they follow the river? Cross the river? Explain the reason why the contours are drawn that way.

f. Using the ruler tool, estimate the distance in miles from Pyramid Butte to Musselman Arch to the southwest.

g. Zoom in on the Goosenecks of the major river. Zoom in enough to see the annotated hand-drawn sand bars of the river. Explain the origin of the sand bars and whether or not you could hike out of the Goosenecks easily.

h. Is the white area where the words "Goosenecks" are written an area of relief or a depression? Have students explain their reasoning.

Mars Fluvial Channels

2. Using the Mars contour map, find Valles Marineris. Look northeast of Valles Marineris, around the 330E/30W longitude line and the Martian equator.
   a. What features stand out/are enhanced by the contour data (mountains, rivers, craters etc.)?

   b. Are there any areas that are similar to a fluvial channel? If so, screen capture an image and paste here or have the students sketch what they see as evidence of a fluvial channel.

Lesson 13: The Water Underneath: Groundwater

Summary

A learning module for incorporation in to Earth science courses that exposes students to the influence of groundwater and on the surface of Mars.

Learning Goals

Students will be able to:

- See how water movement underground produces surface expressions
- Simulate and observe catastrophic flow behavior

Context for Use

This lab and associated discussion will likely take the entire class meeting to finish. Prior exposure to concepts of the zone of saturation (saturated, water-filled pores), water table, and permeability is advisable although not necessary to be successful in the lab.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Water Underneath: Mars Groundwater

Catastrophic Flow Experiment (see Reference below)

Teaching Notes and Tips

1. We encourage instructors to have their own template for having students write up the lab experiment (this makes it easier to grade and find the student answers).
2. This experiment works well for small groups of students (3-4). For large classes >20, one could also simply provide a demonstration and ask students for their hypothesis and what they believe will result from the experiment.
3. Some researchers propose that many of the deep channels and canyons found on Mars might be the result of catastrophic flow from groundwater seepage.

Assessment

Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

Student Homework 1 Version on Catastrophic Flow:

You may want to develop your own homework on Catastrophic Flow, and use a website like this to see if students can detect catastrophic flow on Mars.

http://www.nasa.gov/mission_pages/MRO/news/mro20130120.html#.UkBtIFMgrnh

Mars for Earthlings

In-Class Activity 1
The Water Underneath: Mars Groundwater
Catastrophic Flow Experiment
Adapted from J. Weller Cochise College, AZ (2008)

Purpose: To conduct a small benchtop experiment to understand the surface expressions of groundwater springs, sapping, and gullies.

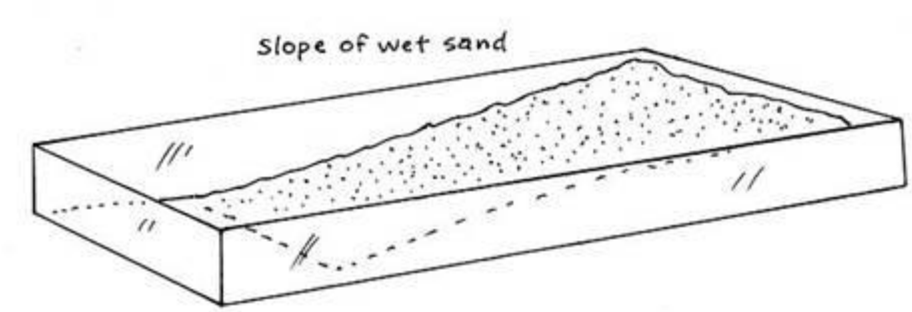
Preparation: This can be a bit messy, so it is good to have an area where there are sinks and clean up facilities.

1. Acquire some large plastic tub containers and fill them with loose sand to create a mini sandbox. (a 1.5-2 feet long and 1-1.5 feet wide tub works well, but larger sizes can also be used)
2. Have a supply of plastic ziplock bags (could try both quart and gallon size dependent on the size of the plastic tub and the amount of sand.

Engage
Have students look up groundwater sapping images of Mars (e.g., Noachis Terra) on the internet and examples on Earth.

Explore (Experiment)
Using the sandbox let's try to see if we can duplicate some of the features seen in the Martian photographs.

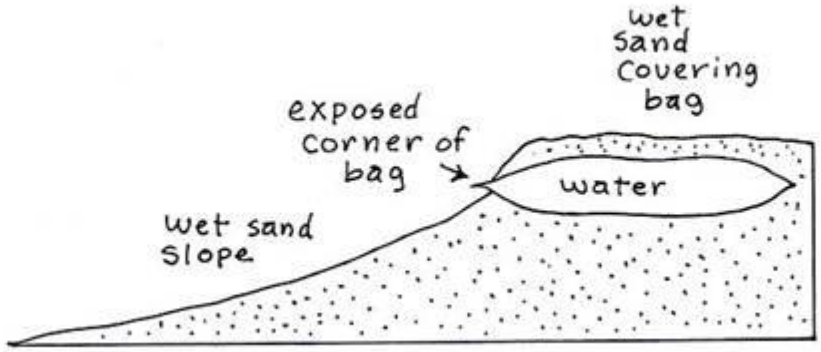
1. First, fill a gallon-size zip-lock plastic bag with water. Try not to leave any air in the bag.
2. Next, create a long low slope of wet sand in the sandbox.



Credit: J. Weller/Cochise College, AZ (2008)

3. At the top of the slope bury the plastic bag of water so that one corner of the bag slightly sticks out of the slope.

Mars for Earthlings



Credit: J. Weller/Cochise College, AZ (2008)

4. Cover the bag with about one inch of wet sand. The water in the bag sloshes around; so smooth the surface above the bag so that there are no cracks at the surface.
5. Dust the slope with a very thin layer of dark dirt. This will help show the flow channel better.
6. With a pair of good scissors, quickly cut off about one inch of the exposed corner of the water-filled plastic bag, setting off the flood and collapse.

Explain

1. Would the rate of water outflow change the surface expression? Why or why not?

2. Consider a liquid with higher viscosity then water (e.g. molasses), that might be used in the bag. Would the surface expression change?

3. This hypothesis is considered by many Mars researchers to be the cause of extensive deep channels and canyons present on the surface of Mars. Does groundwater sapping seem plausible as a formation mechanism for channels on Mars? Can it account for channeling as large and deep as Valles Marineris? Why or why not?

Mars for Earthlings

Elaborate
Direct students to look at more detailed simulations of erosion and sapping to further explain channel systems on Mars.

Possible resources:
http://erode.evsc.virginia.edu/marssap.htm

Evaluate
Researchers propose that gullies and channels might be formed by the groundwater sapping. However, there could be more recent dry flows within the same channels. See this HiRISE flyover video: http://www.youtube.com/watch?v=mgzl3l9bS_g

Lesson 14: Mars Water World

Summary

It is hypothesized that an ocean might have existed on Mars. Students will learn what sedimentary structures and landforms in ancient, Earth, marine environments look like and the processes that formed them. From this Earth-analog approach students will observe Mars imagery and determine whether or not a Mars ocean might have existed in the distant past.

Learning Goals

Students will be able to:

- Identify spits on Mars and Earth and understand their formation.
- Recognize and identify carbonate rocks and the reasons for a lack of carbonates on Mars.
- Critically analyze press releases of Mars discoveries and determine what other data, if any, is needed to make the scientific findings valid.

Context for Use

This learning module is meant for adaptation in an introductory Earth science course and/or planetary science course. The *In-Class Activities* can be easily adapted for homework when desired.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Spits on Mars
In-Class Activity 2: Where is the carbonate on Mars?

Homework/Lab

Homework 1: Mars Ocean Press Release

Teaching Notes and Tips

1. *In-Class Activity 2:* for classes >20 students we recommend passing around several specimens of carbonate rocks and/or use an overhead microscope system for the classroom so students can observe the texture and make observations of the carbonate rocks without a hand specimen.
2. *Homework 1*: You may need to exchange the press release articles for more current articles depending on the year in which you use this material.
3. You will often integrate the Explanation and Exploration sections of the In-Class Activities. Interact with the students as they "explore" and help them define terms/principles.

Assessment

Each In-Class Activity and/or Homework has its own measure of Assessment.

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Mars for Earthlings

Resources

1. Image File: Water World.
2. Spit Formation in the UK and longshore drift: http://www.youtube.com/watch?v=Fe9YBuK_qEo&feature=endscreen&NR=1
3. Lake Bonneville video: http://www.youtube.com/watch?v=0SJDOluY4OI
4. NASA Video "Keeping up with Carbon": http://www.youtube.com/watch?v=FgEZpX3n5mo
5. Beachy Head geology: http://www.discoveringfossils.co.uk/beachy_head_fossils.htm

Mars for Earthlings

In-Class Activity 1
Water World_MFE
Spits on Mars

Purpose:
- Understand the concept of longshore drift and the geomorphic features it creates/develops.
- Search for and identify sand spits/tombolos on Mars

Preparation:
1. Have an Internet connection in classroom.
2. Prepare MOLA colorized elevation maps if desired (see *Exploration*)

Resources:
Spit Formation in the UK and longshore drift:
http://www.youtube.com/watch?v=Fe9YBuK_qEo&feature=endscreen&NR=1

Engage
Have students view the following video of Spit Formation in the UK and consider the following questions:
http://www.youtube.com/watch?v=Fe9YBuK_qEo&feature=endscreen&NR=1

1. On the beach, where would the coarsest of grain sizes be deposited (nearest the ocean or nearer the land; proximal/distal)?
2. What determines the location of particular grain sizes?
3. What governs the growth of a spit?

Explore
Using a MOLA colorized elevation map, have students do the following (students may come up to the screen and point, or students can annotate a map):
1. Mark or point to areas on Mars where spits could be present.
2. How did they make their decisions?
3. If longshore drift was present in the students' chosen regions, what direction is the longshore drift heading?

Explain
Longshore drift- caused by wave and current action. It is the primary method of sediment transport along the beach. The direction of this motion is always parallel to the beach face. This USGS website gives a description of longshore motion parallel to the beach face.
http://geomaps.wr.usgs.gov/parks/sea/beach3.html

Here is another short movie on longshore drift, but it does not explain that the return flow back to the ocean takes a pathway directly perpendicular to the shoreface (the shortest distance back under the influence of gravity).
http://www.youtube.com/watch?v=rCpZYlPqn6E

Mars for Earthlings

Elaborate

1. What do deposits of longshore drifts look like in cross-section? **Note: Have students hypothesize or draw a stratigraphic section. Provide guidance for the stratigraphic section.*
2. What determines the size of grains that are deposited?

Evaluate

1. Students should be able to understand and use geomorphological evidence to determine if any area had a prolonged shoreline during a period in its history (This understanding will be utilized in subsequent activities).

Mars for Earthlings

In-Class Activity 2
Water World_MFE
Where is the carbonate on Mars?

Purpose: Expose students to the carbon cycle on Earth and how carbonate rocks are created. Students will develop a line of evidence or explanation for the reasons why carbonate rocks are not abundant on Mars.

Preparation

1. Depending on your mode of delivery (in class versus perhaps a homework setting), load the Image File .ppt for the class and make sure you have an Internet connection to view the associated videos.
2. Find 3 specimens of carbonate rocks (micrite, coquina, grainstone/packstone, or chalk) or use *Image File* to show 3 specimens of carbonate rocks.
3. Have JMARS available to view carbonate minerals maps of Mars, as well as MOLA maps for geographic context.

Engage

Have students observe 3 different carbonate rocks and ask the following:

1. What are the similarities between these rocks?
2. Where might these rocks have been deposited or formed? What is the students' evidence?

Explore

Forming carbonate rocks on Earth

1. Have students brainstorm how carbonate rocks are formed. Write their ideas on the board.
2. Watch the following NASA video entitled "Keeping up with Carbon": http://www.youtube.com/watch?v=FgEZpX3n5mo
    a. How does the student's "formation" history compare/contrast with the video?
    b. What elements of the video's content exist/do not exist on Mars?

Carbonate rocks on Mars

1. Bring up JMARS maps of carbonate rocks for students to view the extent (or lack thereof) of carbonate rocks.
2. Where are the carbonate minerals most common?

Explain

Carbonates – a class of sedimentary rocks composed primarily of carbonate minerals ranging from calcite to dolomite.

Elaborate

Mars for Earthlings

Assign to students:
Consider the biosphere, lithosphere, and current atmospheric conditions of Mars at present, when responding to the following questions:

1. What would students need to change about Mars today for Mars to be conducive to carbonate development?

   *Note: Answers can be elaborately crazy, i.e. put petroleum-powered cars on Mars and create vast amounts of CO2 emissions or if possible move Mars closer to the sun so that it isn't so cold….etc.

Evaluate
Present the following image of Mars (for a full resolution image see the *Image File* for this module) and ask students the following questions:

In this hypothetical situation (although *real* imagery)

1. Where might the students find carbonates?
2. On what information did the students base their answers?

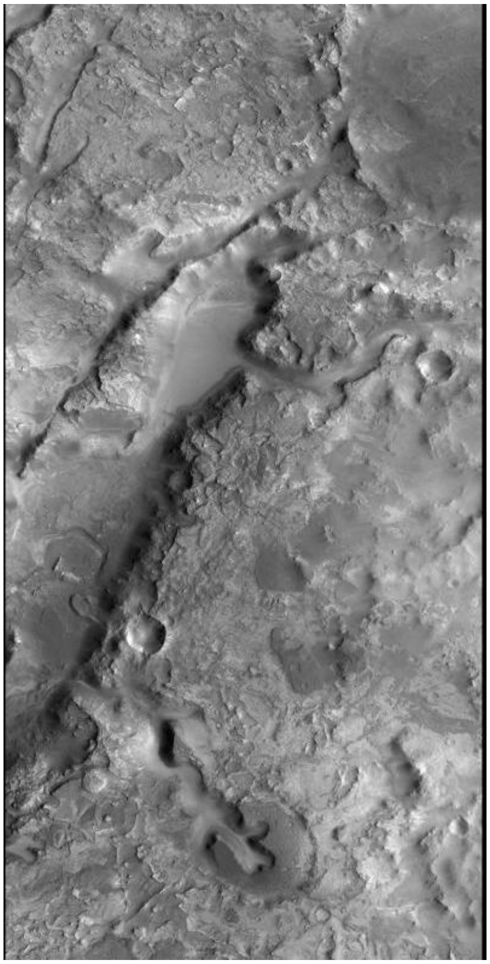

Figure 1: Nili Fossae Region Imaged by CTX, Image Credit: ASU/Malin Space Science Systems

Mars for Earthlings

Homework 1
Water World_MFE
Mars Ocean Press Release

Purpose:
Critically assess the validity of media-released discoveries of Mars; in this case, a Mars ocean.

Directions/Questions:
Navigate to the following press release by CU-Boulder in June 2010:
http://www.colorado.edu/news/releases/2010/06/13/new-cu-boulder-study-indicates-ancient-ocean-may-have-covered-one-third

1. What evidence does the article use to support an ancient Mars ocean?

2. In what geologic age of Mars' history would oceans most likely have existed? (Noachian, Hesperian or Amazonian) *Note: The students may need to do some outside research to answer this question.

3. What evidence would convince them that an ocean existed on Mars that this press release did not address?

4. How would they improve the press release overall?

5. Contrast the Science Daily press-release with CU-Boulder's press release. Do they differ? If so, how?http://www.sciencedaily.com/releases/2010/06/100613181245.htm

6. Find a more recent article on the potential Mars Ocean. Summarize the major points. Has scientists' thinking on the topic changed?

Evaluate:
After students turn in this assignment, have students discuss these answers in class, time permitting. It is important for students to discern fact (clear observations) from fiction (interpretations from incomplete evidence or wishful thinking) and recognize a properly-executed scientific inquiry.

Lesson 15: Ice Ages & Climate Dynamics

Summary
Discuss the causes of ice ages on Earth and determine if Mars experiences similar climate dynamics as Earth.

Learning Goals

Students will be able to:

- Observe ice ages through time and provide explanations for icehouse/greenhouse periods.
- Determine if Mars goes through similar Earth climate changes
- Distinguish between different drivers of climate change at different scales
- Form an informed opinion regarding global warming

Context for Use
It is advisable that students are familiar with basic lithology and mineralogy to be successful in these activities and homework sets. This learning module may be utilized in any course where global warming and climate change are discussed.

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: Ice Ages through time
Homework/Lab
Homework 1: Ice on Mars

Teaching Notes and Tips

1. Infuse data from http://climate.nasa.gov/ Students can make graphs of change over time, focus on a specific region, compare Arctic and Antarctic, etc.
   They can also compare Earth's poles to Mars poles OR evidence of ice on both planets
2. It is advisable that students understand that Mars can change its axial tilt prior to completing *Homework 1*. This will enable students to properly evaluate the effect of Milankovitch cycles on Mars' climate.

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Paleogeography through time YouTube video:
   http://www.youtube.com/watch?v=Q2dAmLnR3tA
2. Ice age references: http://www.pbs.org/wgbh/nova/earth/cause-ice-age.html
   http://geology.utah.gov/surveynotes/gladasked/gladice_ages.htm
3. Ted Talk 2009 on James Balog: https://www.youtube.com/watch?v=DjeIpjhAqsM
4. Extreme Ice Survey website: http://extremeicesurvey.org
5. Milankovitch cycle information:
   http://www.indiana.edu/~geol105/images/gaia_chapter_4/milankovitch.htm
6. Mars Orbital Parameter reference: : http://phoenix.lpl.arizona.edu/mars172.php#1
7. SERC webpage: http://serc.carleton.edu/climatechange/index.html

Mars for Earthlings

In-Class Activity 1
Ice Ages_MFE
Ice Ages Through Time

Purpose:
Students should:
- Understand that climate changes over time
- Hypothesize the causes of ice ages on Earth and extrapolate those causes to Mars

Engage
Watch Earth's Paleogeography through time:
http://www.youtube.com/watch?v=Q2dAmLnR3tA

Explore
The correlation between continent distribution and ice:
Ask students the following questions and discuss responses as they watch the YouTube video in *Engage*.

1. At what Earth age (ages) was there the greatest extent of ice cover towards the South/Southern Pole?

   At what Earth age (ages) was there the greatest extent of ice cover towards the North/Northern Pole?

Explain
Share the following with students:

Ice ages are periods of low temperature when glacial ice develops in continental and polar ice sheets and alpine glaciers. In Earth's geologic record, large-scale ice ages are related to climate, sea level, tectonics (plate configurations and positions), and Earth orbital parameters. Fluctuations in the amount of insolation (incoming solar radiation) are the cause of high frequency changes in Earth's climate during the Quaternary.

This PBS video is one way to visually help explain ice ages.
http://www.pbs.org/wgbh/nova/earth/cause-ice-age.html

Another reference page is:
http://geology.utah.gov/surveynotes/gladasked/gladice_ages.htm

Mars for Earthlings

This video shows a simulation of solar insolation and climate feedback relationships for the last 100,000 years.
http://www.youtube.com/watch?v=WoAvpTdqrfw

Elaborate

Part 1: Extreme Ice Survey
Watch this 21 min. Ted Talk 2009 movie on James Balog: Time-lapse proof of extreme ice loss: https://www.youtube.com/watch?v=DjeIpjhAqsM

Ask student the following questions:

What is he trying to do and show?

How does he power his equipment?

What is his photography showing?

1. Why do glaciers matter? See extremeicesurvey.org/why-do-glaciers-matter/
 Give 3 reasons:
 a.
 b.
 c.

Part 2: Milankovitch Cycles and Glaciation

1. What are Milankovitch cycles and how do they affect glaciation? (For help use: http://www.indiana.edu/~geol105/images/gaia_chapter_4/milankovitch.htm)

2. What are some major differences between the Milankovitch cycles of both Mars and Earth? (For help use: http://phoenix.lpl.arizona.edu/mars172.php#1)

3. How might those differences affect climate changes on Mars compared to Earth especially related to ice ages?

Evaluate: Mars and Ice Ages

1. Ask students whether they think Mars experienced ice ages as well. What is their reasoning?

2. Why or how would the orbital parameters of Mars affect potential ice ages?

Mars for Earthlings

Homework 1
Ice Ages_MFE
Ice on Mars

Objective: Find and understand terrains on Mars that contain or harbor ice.

Activity/Assignment:

1. Research regions on Mars that have been identified to have fretted terrain.

Hint: Fretted terrain is most common in northern Arabia, between latitudes 30°N and 50°N and longitudes 270°W and 360°W. Two good examples of fretted terrain are Deuteronilus Mensae and Protonilus Mensae.

2. Using JMARS, search for and capture images of the following:
    a. Fretted terrain
    b. Softened terrain
    c. Lobate morphologies
    d. Make note of the following for each captured image:
        i. Lat/Long,
        ii. Zoom increment
        iii. Map used for each image captured (THEMIS, MOLA etc.)

What the students turn in:

3. Have students compile their findings into a .ppt presentation (Have them print out their slide presentation with speaker notes where they've indicated any important info)
    a. Label all features.
    b. For JMARS images, label the feature, Lat/Long, Zoom increment, and Map on each slide (with the image).
    c. Use the "speaker notes" to further elaborate on their findings.
    d. They should have at least 3 slides
        i. Slide 1: fretted terrain
        ii. Slide 2: softened terrain
        iii. Slide 3: lobate morphology

Lesson 16: Weathering and Soils

Summary

This module is aimed at helping students understand the patterns and drivers of weathering and the formation of soils on Earth and Mars.

Learning Goals

Students will be able to:

- Differentiate, in photos, between mechanical and chemical weathering processes on Mars & Earth
- Discern, in hand sample, weathered vs. non/lesser weathered material
- Recognize and discern a soil and define soil-forming factors
- Critique the presence of "soil" observations on Mars

Context for Use

It is advisable that students are familiar with basic lithology and mineralogy to be successful in these activities and homework sets.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Break a Rock! (need rocks, hammers, and handlenses)

In-Class Activity 2: Is it a Soil?

Homework/Lab

Homework 1: Chemical vs. Mechanical

Teaching Notes and Tips

1. Depending on class size, samples for every student would be advisable to proceed with In-Class Activity 1. With classes size >20 or more students, simply provide a demonstration and have students record the methods and outcomes of what they are observing
2. For In-Class Activity 1 conduct the exercise in a lab environment and/or outside

Assessment

Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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NASA

Mars for Earthlings

References and Resources:

1. Image File: Weathering and Soils
2. This NASA webpage has a search function for many images related to weathering.
   http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA12994
   e.g., the word "soil" will pull up images of both Earth and Mars
3. Mars "blueberries" spherules NASA announcement:
   http://www.nasa.gov/mission_pages/mer/multimedia/pia16139.html

Mars for Earthlings

In-Class Activity 1
Weathering & Patterned Ground_MFE
Break a Rock!

Purpose:
Determine how the physical breakdown of rocks leads to increased rates of weathering and erosion.

Preparation:
Depending on class size the following is need for each student or team of students:

1. Rock hammers
2. Rocks (Geodes would be nice! Otherwise a rock with a weathering rind is good.)
3. Hand lens if possible, but not necessary

Engage
Use the rock hammer and rock provided by your instructor. Break the rock in such a manner that the students can see "the middle" of the rock.

Explore
Have students make a sketch in each circle below of the outside vs. inside of the rock (respectively). Students should note color changes, sizes of crystals, any mottling etc. Be as observant as possible. Also, they provide some sort of scale to understand the relative sizes of sketches.

Outside
Scale:

Inside
Scale:

Mars for Earthlings

Mechanical vs. Chemical Weathering

Consider the sketches, do students see evidence for mechanical weathering and/or chemical weathering? Please list them.

Explain

- The rates of weathering depend on a number of factors, from climate to grain size of the weathered lithology. Help students to recognize these different factors and perhaps what is most influential.
- Have students try to recognize weathered vs. non-weathered material and how it appears in hand sample.

Elaborate

1. Do you think smaller features will experience higher rates of weathering? Why or why not? What determines the "rate"?

2. Considering Figure 1, would the concept "the smaller the better" apply here? Why or why not? Note the scale in the caption.

3. Have students find an internet image of the weathered accumulations of these "blueberries" from other Opportunity explorations and explain what that that means about how an outcrop would erode over time.

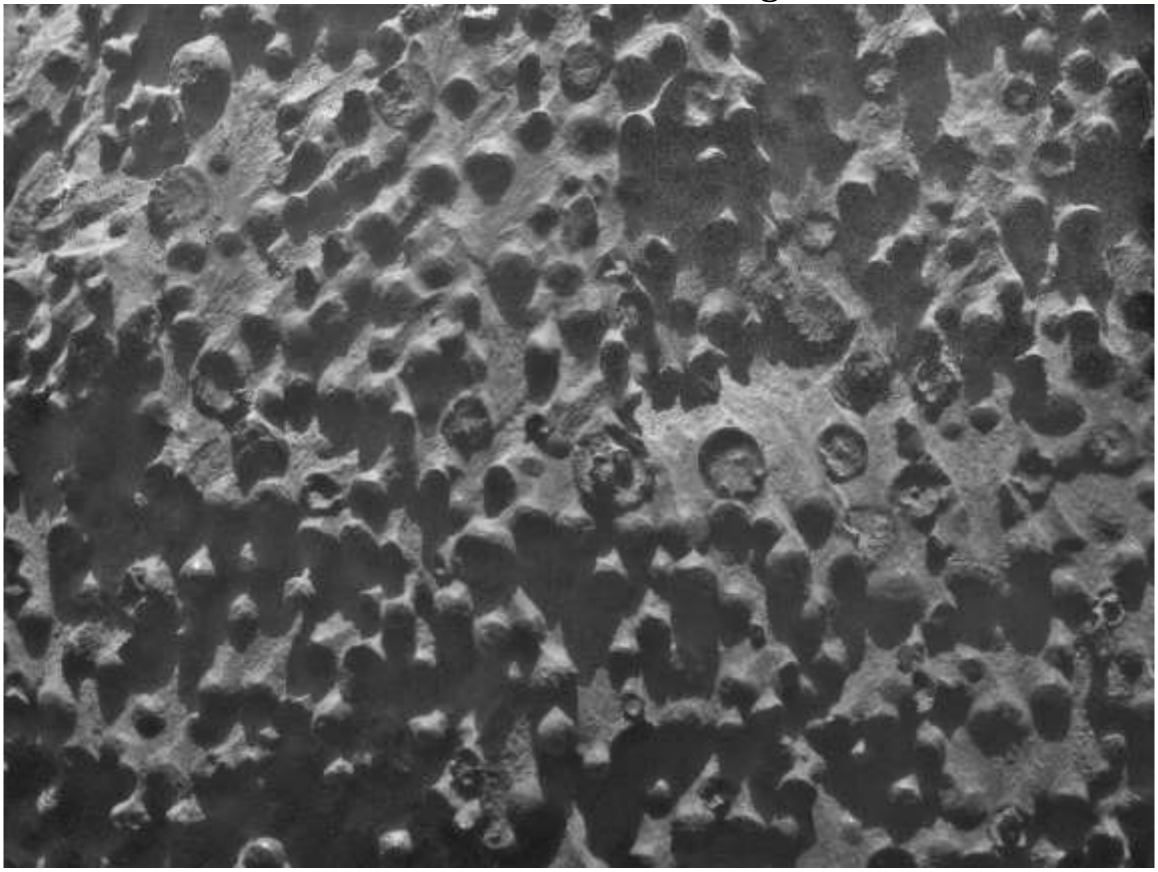


Figure 1: Image taken by rover Opportunity at Endeavor Crater: The view covers an area about 2.4 inches (6 centimeters) across, at an outcrop called "Kirkwood" in the Cape York segment of the western rim of Endeavour Crater. The individual spherules are up to about one-eighth inch (3 millimeters) in diameter. Image Credit: NASA/JPL-Caltech/Cornell Univ./ USGS/Modesto Junior College.

Evaluate

Ask students to list the most important factors in the rate of weathering (name 3 factors).

1.

2.

3.

Mars for Earthlings

In-Class Activity 2
Weathering & Soils_MFE
Soils on Mars?

Purpose: Identify Earth soil horizons and extrapolate what characteristics of soil would be observable on Mars.

Engage
Study Figure 1 below.

1. Does this picture represent a complete soil profile? If not, what horizons are present?

2. What criterion are the students using to define a soil?

Figure 2: A Russian Chernozem (Mollisols in most cases) and the landscape NW of Kursk, in the Kursk Oblast, Russia. Source: http://web.utk.edu/~ammonst/research.html

3. Brainstorm at least (4) factors that create and form soil on Earth.
    a. Factor 1:
    b. Factor 2:
    c. Factor 3:
    d. Factor 4:

4. Are all factors of equal influence (explain why/why not)?

5. After discussing the soil forming factors, determine which factors exist and/or have the greatest influence on Mars. List and describe below.

Explore
Identifying Soil Horizons
In Figure 2 draw lines and/or labels at horizon boundaries. Indicate if any layers are not present.
O Horizon- thick organic-rich layer
A Horizon- relatively thin organic layer with rooting
E Horizon- leached layer (not always present)
B Horizon- mineral layer
C Horizon- parent material

Figure 3: Image Credit: NRCS Soils

1. What characteristics of this profile might the students observe on Mars? Can they observe it remotely? What do they think gives the yellow layer its color?

Mars for Earthlings

Explain

- The 5 soil-forming factors are: (1) parent materials (2) time (3) biota (4) topography and (5) climate
- In order for a soil to be *classified* as a soil it must have evidence of life and/or plant material
- With regard to general soil horizons: the O-horizon must have a thick layer of organic matter, an A-horizon typically has an abundance of roots and some organic matter, an E-horizon is a leached horizon (of most base-forming cations), the B-horizon is a mineral layer where minerals accumulate, the C-horizon has some characteristics of pedogenesis but still may show structures of the parent material such as bedding, the R-horizon *is* the parent material.

Elaborate

Observe Figure 3 from Mars at Mawrth Vallis, one of the landing site considerations of MSL Curiosity (captured via JMARS):

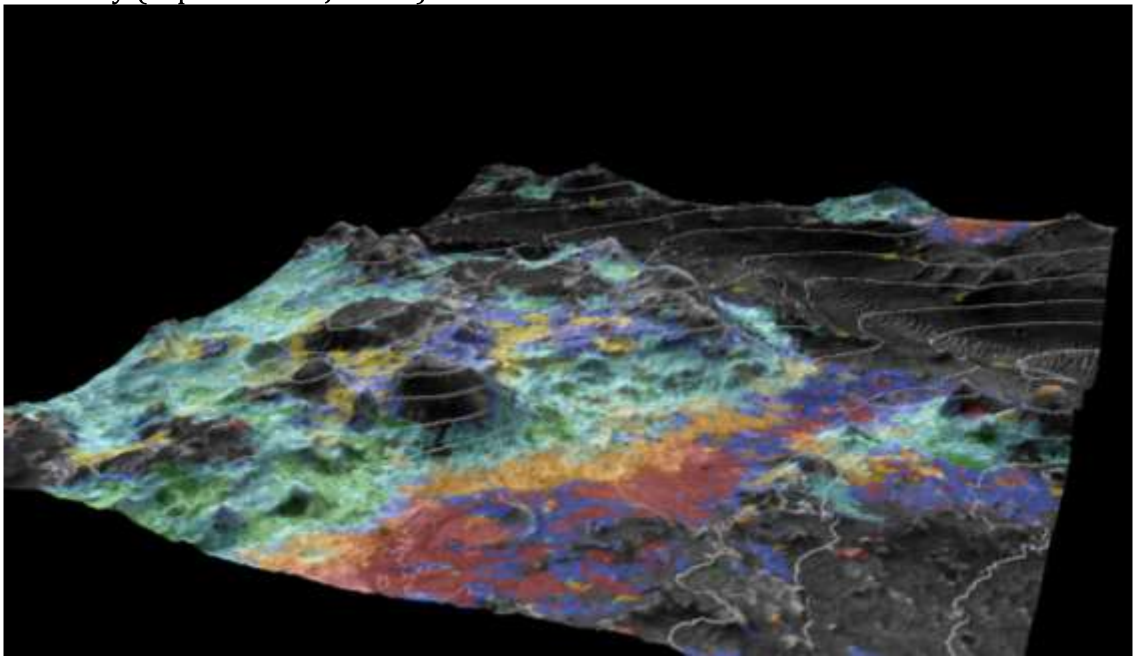


Figure 4: Mawrth Vallis CRISM image overlain on HiRISE imagery. Image Courtesy of Briony Horgan, ASU. Scale of image ~ several km across.

1. What do you observe in this image?
2. Do changes in color follow any discernable pattern?

Evaluation

1. How would students recognize soils on Mars? What would be their criteria?

Mars for Earthlings

Homework 1
Weathering and Soils_MFE
Chemical vs. Mechanical

Introduction: This exercise will focus on the students' ability to identify weathering processes/features on Earth and on Mars. The last part of this exercise will involve using Google Mars to recognize weathering features through high-resolution images.

PART I—Weathering of Earth

For the following 4 images, determine whether they are the result of mechanical or chemical weathering, and identify the specific process that formed the weathering feature.

Sandstone
Australia
Humid continental

Image 1 (Image Source: http://commons.wikimedia.org/wiki/File:Cracked_boulder_DMCR.jpg, "Devil's Marbles" Author: Prince Roy)

Mars for Earthlings

Sandstone
Oregon,
Coastal/temperate

Image 2 (Image Source: http://www.earthscienceworld.org/images/search/results.html?Category=&Continent=&ImageID=hhrhsr#null Photographer: Marli Miller, University of Oregon)

Sandstone
Anza-Borrego Desert State Park, California,
Semi-arid/rain shadow

Image 3 (Image Credit: Michael Szoenyi/Science Photo Library; http://www.sciencephoto.com/media/173681/enlarge)

Granite
Enchanted Rock,
Texas
Humid Subtropical

Image 4 (Image Source http://en.wikipedia.org/wiki/File:GeologicalExfoliationOfGraniteRock.jpg)

PART II—Weathering of Mars

For the following images, identify whether the features are caused by mechanical or chemical weathering and answer the additional questions for each image.

Image 5

1. What are 3 likely processes causing the pits in the rock in the image below?
2. What does the pitting process mean for the type of environment that could have existed on Mars?
3. Name 3 geographic areas on Earth that would work as an analog to this rock.

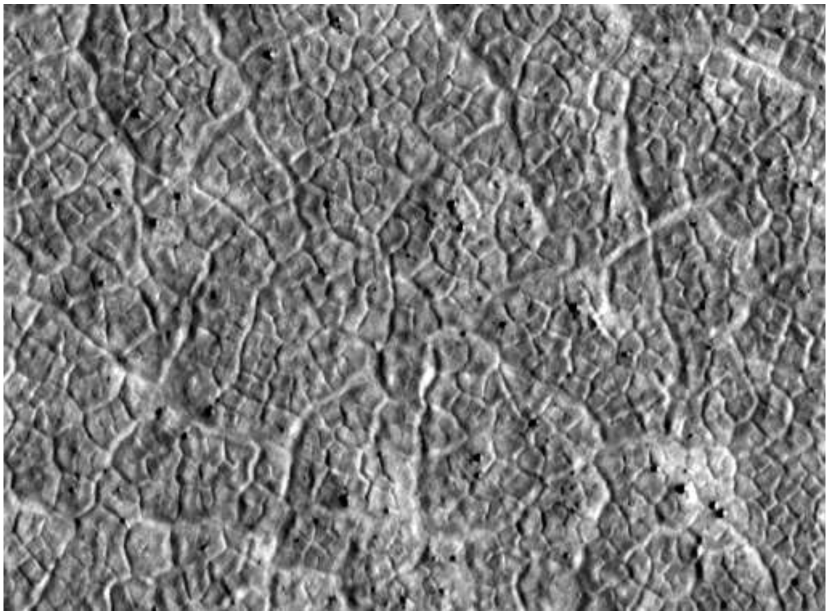
Volcanic rock
Ares Valles region,
Pathfinder landing site

Image 5 (Image Source: http://science.ksc.nasa.gov/mars/mpf/stereo-arc.html)

Mars for Earthlings

Image 6

1. What feature is shown below?
2. What are 3 processes/influences that can cause these features?



Likely sand-siltstone
Near North Pole

Image 6 (Image Source: http://web.pdx.edu/~pdx06058/Planetary_Research.html)

Image 7

1. This is a false-color image of the surrounding area around the Sojourner Rover. What is the red tone on the Martian surface and what does that mean?

2. Which direction is the wind coming from (This does not have to do with weathering)?

Volcanic rock (Yogi rock)
Ares Valles region
Pathfinder Lander location

Image 7 (Image Source: http://nssdc.gsfc.nasa.gov/planetary/marspath_images_2.html)

Image 8

1. What is the nickname given to the little balls scattered in the image below?

2. What are they? How are they formed and what does that mean for surface processes in the Martian past?

3. What weathers faster: the host rock or the little balls scattered on the surface? Give some reasons to support your answer.

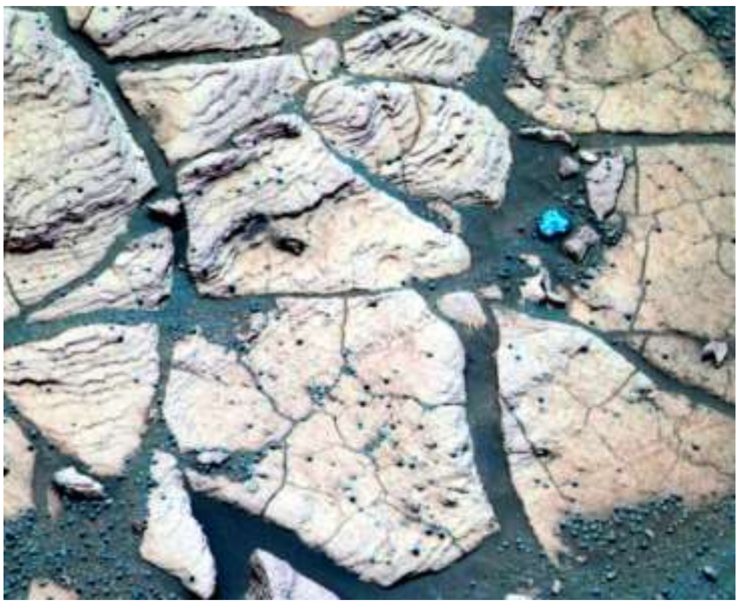


Photo by MER Opportunity Rover At rock outcrop "Shoemaker's Patio"

Image 8 (Image Credit: NASA/JPL; Source: http://photojournal.jpl.nasa.gov/catalog/PIA05584)

PART III—Google Mars

1) The images in questions 1 and 3 were taken by the Mars Pathfinder Lander.
    a. Where is the lander located (lat/long)?
    b. Go into the "presidential" panorama and describe the image and features.
    c. It landed in Ares Valles. Describe the area in terms of the geomorphic features and why it presently looks this way.

2) The image in question 2 was taken by the HiRISE camera aboard the Mars Reconnaissance Orbiter. The coordinates are approximately 71° 38' N and 145° 20' E.
    a. What kind of environment would create a surface like this? Is this process continuing today on Mars? Is it continuing on Earth?

3) The MER Opportunity rover took the image 8. Go to the following website:

Mars for Earthlings

http://mars.nasa.gov/mer/home/

Click on Multimedia

- Click on images
- Go to All Raw images for the Opportunity Rover
- Next go down to Science Cameras/Panoramic Camera and scroll down to Sol 109, Click "View Selected Images"
- Scroll down and explore images 8-20 under Sub-Frame EDR (not numbered)

a. Determine why it took so many images of the same spot on the surface.

b. Record the Sol from the latest image (go back one page). How does this Sol compare to the expected life of the mission?

c. Go back to Google Mars and determine approximately where the rover was when it took these pictures, both geographically and lat/long.

d. Go to the panoramic, "Crater of Clues" and have the students briefly describe what they see, both around the rim of the crater as well as within the crater.

Lesson 17: Vast Deserts on Mars

Summary

Using a Sandbox experiment and Google Earth students will study the formation of dunes and relate their observations to Mars dune field imagery.

Learning Goals

Students will be able to:

- Identify wind current directions on Earth and Mars
- Explain the formation of certain dune morphologies.
- Use Google Earth to identify changing paleocurrent direction, bounding surfaces, and their potential to be observed/preserved on Mars.

Context for Use

This learning module is meant for integrating the Martian wind into terrestrial analysis. The *In-Class Activities* can be easily adapted for homework when desired.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: Sandbox Dunes
In-Class Activity 2: Martian Ventifacts

Homework/Lab

Homework 1: "Bounding" Through Dunes

Teaching Notes and Tips

1. For larger classes (>20 students) you can either create your own Sandbox Dune demonstration or use the Video demonstration (see Resources).
2. In Homework 1: students will need a clear understanding of how dunes and dune processes are recorded in the rock record (marching away from you, toward you, paleocurrent direction etc.).
3. You will often integrate the Explain and Explore sections of the In-Class Activities. Interact with the students as they "explore" and help them define terms/principles (Ex: Sandbox Dunes).

Assessment

Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Image file: Vast Deserts on Mars
2. Antarctica Ventifacts
3. Sand Box Dune Video: http://serc.carleton.edu/details/files/44290.html
4. Grotzinger, J.P. et al., 2005. Stratigraphy and sedimentology of a dry to wet eolian depositional system, Burns formation, Meridiani Planum, Mars. Earth & Planetary Science Letters, v. 240, p.11-72.
5. Burns Formation PanCam Sol 288 Image Source: http://marsrover.nasa.gov/gallery/all/1/p/288/1P153752565ESF37MIP2544L7M1.HTML

Mars for Earthlings

In-Class Activity 1
Vast Deserts_MFE
Sand Box Dunes

Purpose: Understand the processes that form sand dunes on Mars and Earth.

Preparation:
1. Build your own Sandbox or download the video of MFE's sandbox demonstration from **References and Resources** of this module for use in the classroom.

Resources:
1. For full resolution images in this *In Class Activity* use the PowerPoint image file (.pptx) for this module located in **References and Resources**.
2. Sandbox video: http://serc.carleton.edu/details/files/44290.html
3. HiRISE Dune Image Source: http://hirise.lpl.arizona.edu/ESP_012202_1390
4. THEMIS Dune Image Source: http://themis.asu.edu/node/5758
5. Mars Global MOLA map: http://mola.gsfc.nasa.gov/images/mercat_med.jpg

Engage
Encourage discussion from students using the following questions:
1. If you were to travel into a valley and see the rocks shown in Figure 1:
    a. What processes are at work in the valley?
    b. What grain sizes are left?
    c. What happened to the rest of the grains?

Figure 1: Death Valley ventifacts; *Photo by Marjorie Chan*

Explore
1. Take the students through a Sandbox demonstration (via video or http://serc.carleton.edu/details/files/44290.html from Mars for Earthlings website, or your own sandbox)
    a. Vary sediment input
    b. Vary wind speed

c. Vary surface area or focus of wind source
d. If possible incorporate varying wind directions to achieve multi-directional dune morphologies

2. Watch the sandbox demonstration and answer the following
   a. How does the surface change?
   b. Which side of the dunes are the steepest? Why?
   c. What happens when the angle becomes too steep? What do we call that angle?
   d. What is the steep side of the dune called?
   e. How does the slip face change through time?
3. View Mars Images
   a. Present students the following Mars Images (see **Resources** in this activity). Indicate where these areas are found on Mars using Google Mars or the annotated image in the Image File for this module).
      i. HiRISE: ESP_012202_1390 Dunes in the Western Nereidum Montes (38.6S, 44W)
      ii. THEMIS: V43323004 Terra Sirenum (39.7S, 150W) is the location of this image. The unnamed crater has dunes on its floor (students will likely have to zoom-in on the image).
   b. Have students discuss the following
      i. What is the prevailing wind direction in each image?
      ii. Are the dunes multi-directional? If so, how can the students tell?
      iii. Is there more than one dune shape/morphology (barchans, transverse, longitudinal, parabolic etc.)? If so, what are they?

Explain

1. As students complete their observations in **Explore** discuss the following terminology in light of their sketches and observations *before they interpret Mars* images.
   a. Angle of Repose
   b. Slip face
   c. Saltation
   d. Deflation and Abrasion
   e. Dune Morphologies (barchans, transverse, longitudinal, parabolic etc.)
2. If possible, have students label these terms in their sketches after they are finished sketching.

Elaborate

Referring to the Mars Images utilized in **Explore**, encourage students to interpret the following about the eolian system:

1. What is the sediment supply like (abundant, sparse)? Have students explain their answer.

2. According to your knowledge of the geography of Mars and its regions, what might be the source of the sediment (Supply students a copy of a Mars MOLA or project the global MOLA map)?

Evaluate

1. Peer evaluation
    a. In both the Exploration and Elaboration activities, try having students write their answers on cards and pass them to their neighbors
    b. Have their peers agree or disagree with their findings. Given time, have them discuss their findings.
2. The labeling activity in **Explain** will help instructors determine whether or not students comprehend the terms and their use.

Mars for Earthlings

In-Class Activity 2
Vast Deserts_MFE
Martian Ventifacts

Purpose: Explore the existence and formation processes of ventifacts.

Preparation
Depending on your mode of delivery (in class versus a homework setting), load the Image File .ppt for the class and make sure you have an Internet connection to view the associated videos.

Resources:

1. Mojave Desert Ventifact Video: http://www.youtube.com/watch?v=OOqOm3KgGMw&feature=endscreen
2. Mars ventifact images: http://www.psi.edu/pgwg/images/jul09image.html

Engage
Have students observe the large ventifact in Death Valley (see Image File, Photo by Marjorie Chan)

1. What formation seems odd to the students? Have they seen anything like it? Why is there only one?
2. Ask students to hypothesize how this might have formed.

Figure 1: Death Valley Photo, credit: Marjorie Chan

Explore
Ask students to view the following video and answer the following questions. Start a discussion with your students.
http://www.youtube.com/watch?v=OOqOm3KgGMw&feature=endscreen

Mars for Earthlings

1. What do the students look for in order to determine if a rock or feature is a ventifact?

2. How can they discern which direction the wind was/is blowing?

3. What causes the reddish-orange coloration?

Explain

Definition: Ventifact- A rock that has been shaped or polished by the sandblasting effect of wind-blown sand

Elaborate

Here are what might be considered ventifacts on Mars:
http://www.psi.edu/sites/default/files/imported/pgwg/images/VentFig4.jpg

1. Bring up images on the screen or provide laminated copies upon which students can make annotations
2. Ask students to label the wind direction on each: A thru G.
3. Discuss with students the preservation potential of these eolian reworked deposits.
    a. Is the preservation potential higher on Mars or Earth? Have the students explain their reasoning via images where possible.

Evaluate

1. Do the students believe that these are indeed ventifacts? Why or why not? Which images are the best examples of true ventifacts? Which images are more dubious?
2. Discuss student ideas and their understanding of ventifact formation and their indicators for wind current direction.

Mars for Earthlings

Homework 1
Vast Deserts_MFE
"Bounding" through Dunes

Purpose:
- Recognize bounding surfaces in Google Earth imagery and their meaning in the geologic record.
- Understand why bounding surfaces are or are not recognized on Mars.

Preparation:
Make sure the students have Google Earth downloaded on their computer to accomplish this exercise. http://www.google.com/earth/download/ge/agree.html

Questions:
Checkerboard Mesa, Zion National Park UT
1. Open Google Earth (load the free program if necessary).
2. Navigate to 37°13'30.75"N 112°52'54.13"W and orient the window looking Southwest. See image below* for orientation of the viewing window.

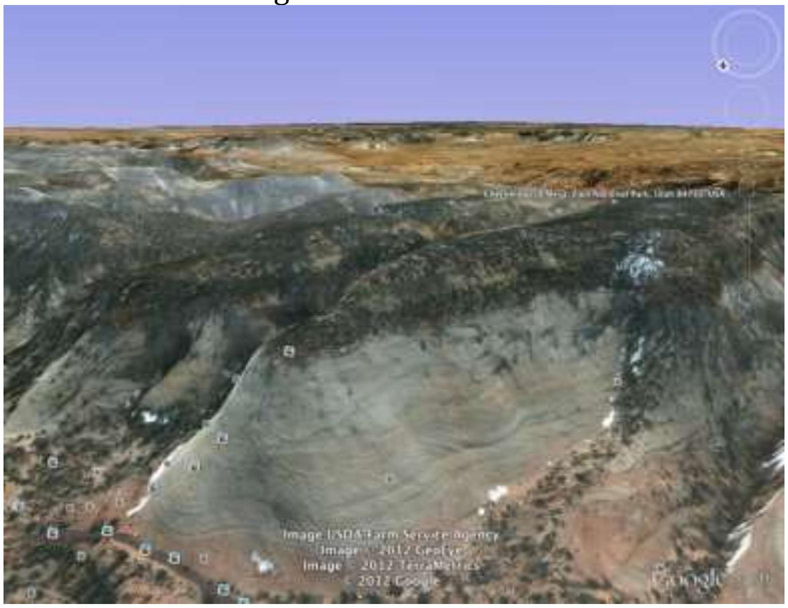

Figure 1 Image captured through Google Earth

Have the students capture their own .jpg and insert their image into a PowerPoint file.
*the image in this exercise is not zoomed in or large enough for their PowerPoint slide

3. In PowerPoint, have students annotate their image with the following:
    a. Paleocurrent direction- red arrows
    b. Bounding surfaces- green lines
    c. Dunes are "marching towards you" – blue triangles
    d. Dune are "marching away from you"…in any direction – orange triangles

4. On another slide, answer the following questions
   a. What do the bounding surfaces represent?
   b. What created the sinusoid (sine wave) morphology of the beds?

Burns formation, Meridiani Planum Mars

5. Insert the following Burns formation image into a slide and do the following:

Figure 2 Left Panoramic Camera Non-linearized Sub-frame EDR acquired on Sol 288 of Opportunity's mission to Meridiani Planum at approximately 13:10:16 Mars local solar time, camera commanded to use Filter 7 (432 nm). NASA/JPL/Cornell

   a. Follow the same instructions for labeling as for Checkerboard Mesa above (answers to the following questions should be given in a separate slide).
   b. What are the main differences between Checkerboard Mesa and the Burns Formation outcrop? Cite at least 3.
   c. Do the students think the Burns Formation was formed in an eolian environment? Why or why not?
   d. In the below photos, how is the colorized imagery helpful? What do they observe in Image C of Figure 3? Why do some layers “look different”?

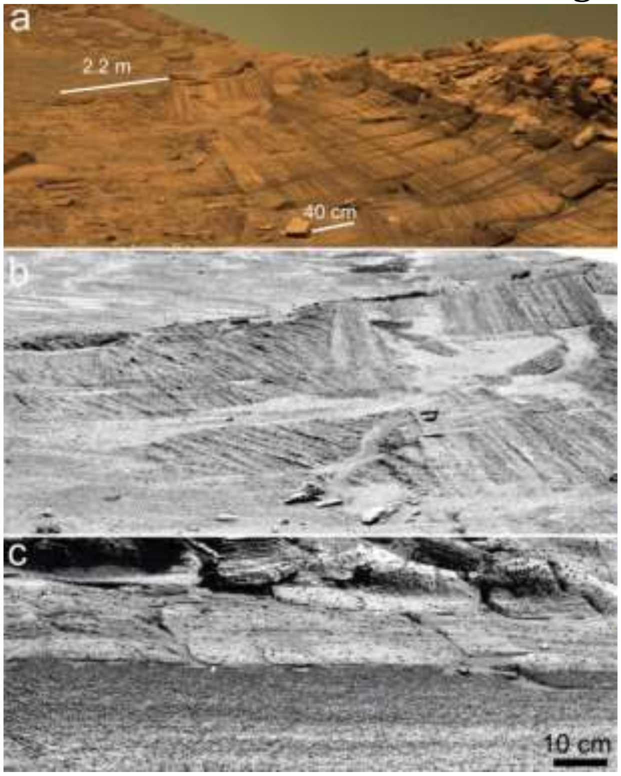

Figure 3: Burns Formation stratigraphy (Grotzinger et al., 2005).

Lesson 18: Origin of Life

Summary
This module explores various hypotheses concerning the origins of life on planet Earth and their plausibility when applied to Mars.

Learning Goals

Students will be able to:

- Explain the conditions of the Miller-Urey Experiment.
- Define "life" and the requirements for life.
- Determine if the Miller-Urey Experiment has applicability on Mars.

Context for Use
This module is meant for adaptation in an Earth science course, particularly a segment discussing Pre-Cambrian/Hadean environmental conditions on Earth. Biology instructors are also encouraged to adapt this material.

Description and Teaching Materials

In-Class Activity 1: Miller-Urey Experiment

In-Class Activity 2: Mars Life through the Lens of MSL Curiosity

Teaching Notes and Tips

1. Encourage a discussion about the requirements for life and what "life" means in the In-Class Activity
2. Have students determine the viability of the Miller-Urey Experiment as a theory for the origin of life.

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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References and Resources

Miller-Urey Experiment YouTube Video: http://www.youtube.com/watch?v=iahBQolXQH8

Mars for Earthlings

In-Class Activity 1
The Origin of Life
Miller-Urey Experiment

Preparation
Have an Internet connection to view the associated video

Engage
Questions for students:

1. Have the students in their own words, define "life":

2. List some requirements for life?

Explain

1. Students can debate the different definitions of life. A general definition of life is as follows: an organismic state characterized by capacity for metabolism, growth, reaction to stimuli, and reproduction.
2. Requirements for life are: chemical building blocks, energy, and a liquid medium.
3. Most researchers would general agree that life requires water; hence NASA's campaign "Follow the Water".
4. Energy does not need to be sourced from photosynthesis (e.g. chemosynthesis).

Explore
View the following YouTube animation of the Miller-Urey Experiment:
http://www.youtube.com/watch?v=iahBQolXQH8

1. Describe at least 4 conditions of the experiment.

2. What was "applied" after the gases travelled through the horizontal tube?

3. Was O2 gas an important component of the experiment? Why or why not?

4. Did the experiment accurately represent a scale model of early Earth? Did they set up the conditions of early Earth properly?

Mars for Earthlings

Elaborate

1. Would this experiment be applicable to early Mars?

2. How would the students modify the experiment to represent what might have occurred on Mars?

3. Visit NASA's NAI-Astrobiology website and explore the various "headlines." https://astrobiology.nasa.gov/nai/ List at least 2 ongoing investigations that have applicability to researching the "origin of life."

4. Read "About NAI" on the website. Are investigations into the origin of life a NAI focus? Why or why not?

Students could also consider exploring a planet in a habitable zone and compare it to Earth and Mars using data from the Kepler mission. See upcoming news featuring NASA's Kepler Mission.

Evaluate

1. When students consider the present and/or past environment of Mars, could they find all the requirements for life?

Mars for Earthlings

In-Class Activity 2
Origin of Life?
Mars life: through the lens of Curiosity

Purpose: Students will become familiar with the mission of Curiosity as it pertains to finding life on other planets.

Preparation:

- Internet access in the classroom
- Students need to be somewhat familiar with the mineralogy of Mars to be successful in this activity (olivine, phyllosilicates, sulfates etc.).

Resources:

- Mars Curiosity Habitability Mission video: http://www.youtube.com/watch?v=oHLbXTOaw7w&feature=relmfu

Engage
Have students view the following video from NASA regarding the mission of MSL Curiosity: http://www.youtube.com/watch?v=oHLbXTOaw7w&feature=relmfu

Explore
As students watch the video have them be ready to answer and discuss the following questions:

1. What type of "life" are scientists looking for?
2. Can instruments on the MSL Rover Curiosity detect life?
3. What compound is associated with all life?
4. What element is necessary for life?
5. Why would the layering of rocks at Gale Crater be of interest? What might that layering imply?

Explain
Students should define habitability, extinct life, and extant life. They should understand that the "life" on Mars may be very small and primitive if scientists are lucky enough to find and detect it.

Here is a short recommended reading on habitability of Mars: http://www.space.com/19928-mars-habitable-life-possible.html

Mars for Earthlings

Elaborate

Detecting Life: Ask the students the following question.

1. Does Curiosity have any instruments that can directly test for life?

Evaluate

Promote discussions about the challenges NASA faces now and in the future as they continue the search for life. To spark discussion use the following question:

1. What are some of the challenges related to directly testing for life?

Lesson 19: Extremophiles

Summary
This learning module and related laboratory exercise exposes students to extremophiles, their habitats, and the potential to find habitable environments on Mars.

Learning Goals

Students will be able to:

- Understand the environment in which the *Tardigrade* can survive.
- Explore hydrothermal environments on Earth and Mars.

Context for Use

This learning module is meant for adaptation in an introductory earth science course and/or planetary science course.

Description and Teaching Materials

In-Class Activity

In-Class Activity 1: *Tardigrades: Living extremely*

Homework

Homework 1: *Sea Monkey Experiment*

Homework 2: *The Color of Temperature*

Teaching Notes and Tips

1. Students must be familiar with Mars environments of deposition, surface processes and climate.
2. To be successful in Homework 2 students need to have exposure and instruction in making contour maps.

Assessment

Each *In-Class Activity* and *Homework* has its own measure of Assessment.

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Mars for Earthlings

References and Resources

1. Image File: Extremophiles
2. Gale Crater Habitability via Curiosity: http://www.youtube.com/watch?v=oHLbXTOaw7w&feature=relmfu
3. Tardigrades video from SciShow on YouTube: http://www.youtube.com/watch?v=6H0E77TdYnY&continue_action=r7OE3bLJMHT8fAwevwnX9Oh_0zzl6Ajt2P3129QN588gcYR6MkEN_obkOAtaq5MUvFV4Yiq09ljbJDp8wedzPE1U417RionrJuPdT2CAALc=
4. Additional Tardigrade link: http://serc.carleton.edu/microbelife/topics/tardigrade/index.html

Mars for Earthlings

In-Class Activity 1
Extremophiles 1_MFE
Tardigrades: Living extremely

Purpose: Become acquainted with the Tardigrade ("water bear") extremophile, its living conditions, and importance of its scientific study.

Preparation:
Have Internet access in your classroom.

Resources:
1. Tardigrade YouTube video: http://www.youtube.com/watch?v=6H0E77TdYnY&continue_action=r7OE3bLJMHT8fAwevwnX9Oh_0zzl6Ajt2P3129QN588gcYR6MkEN_obkOAtaq5MUvFV4Yiq09ljbJDp8wedzPE1U417RionrJuPdT2CAALc=
2. SERC definition of Extremophiles: http://serc.carleton.edu/microbelife/extreme/extremophiles.html

Engage
Watch the following You Tube Tardigrade video from the SciShow:
http://www.youtube.com/watch?v=6H0E77TdYnY&continue_action=r7OE3bLJMHT8fAwevwnX9Oh_0zzl6Ajt2P3129QN588gcYR6MkEN_obkOAtaq5MUvFV4Yiq09ljbJDp8wedzPE1U417RionrJuPdT2CAALc=

As students watch the video have them answer the following questions:
1. What is a *Tardigrade*?
2. What type of environments can *Tardigrade* live in?
3. What is its importance to science?

Explore
Have students briefly "explore" other extremophiles and answer a few questions about their characteristics and report back to the class.

Explain
As students discuss *Tardigrade* and the type of environment in which it can survive, share the following terms related to types of extremophiles. Ask students to classify *Tardigrade in one of these groups:*
1. Acidophile- high pH
2. Alkaliphile- low pH
3. Anaerobe- no need for oxygen
4. Endolith- lives inside rocks
5. Halophile- requires salt
6. Piezophile/Barophile- requires high pressures
7. Thermophile- lives in 40°C or higher
8. Xerophile- limited water supply
9. Psychrophile- lives in 15°C or lower

Mars for Earthlings

Elaborate

Where could Tardigrade live on Mars?

1. Display a global Map of Mars so that all regions can be viewed (see Image File: Extremophiles)
2. Where could *Tardigrade* potentially live on Mars?
3. Is studying *Tardigrade*, and other organisms like it useful to space research? Why or why not?

Have students identify which extremophiles could live on Mars.

Also, possibly consider where they live on Earth for comparison.

Evaluate

Ask students what other Extremophiles classifications (see above) could be present on Mars and give a short presentation on a type of extremophile other than Tardigrade.

Mars for Earthlings

Homework 1
Extremophiles 1_MFE
Sea Monkey Experiment (courtesy of Brain Hynek, University of Colorado-Boulder)

Starting thinking: What is an extremophile?

Resources:
On brine shrimp (see materials needed on these sites)

- http://wildlife.utah.gov/gsl/
- http://www.youtube.com/watch?v=kUN61qJtp6s (tutorial on raising brine shrimp)

On extremophiles

- http://www.spiritus-temporis.com/extremophile/types-of-extremophiles.html
- http://www.daviddarling.info/encyclopedia/E/extremophile.html
- Example: Deinococcus radiodurans can withstand 1,500,000 “rads”. 500 rads can kill humans!

Introduction:
Sea monkey eggs (like Great Salt Lake brine shrimp) reportedly can survive dormant for > 20,000 years without water. They breathe through their feet and are born with 1 eye but develop 2 more. They are ideal for testing life’s response to extreme conditions since they can survive (or remain dormant) in a wide variety of conditions (pH of 2-10, high salinity, various radiation environs, range of temperatures, etc.).

Experiment - Project Assignment:

1. Design a scientific experiment to examine some kind of extreme conditions (without destruction) on the revival and/or survival of dormant life forms (the brine shrimp eggs). The students might bake the eggs, drown them in their favorite soda, soak them in acidic lemon juice, or subject them to other extreme conditions or combinations!
2. Carry out a scientific experiment following the scientific method. Record all condition information of time, methods, amounts, solutions etc.
3. After this we will do a “blind test” and your sea monkey eggs will be given to someone else to raise (so the students are not tempted to bias the experiment).
4. Have students meet with the group that attempted to hatch their eggs. Discuss the results in terms of their hypothesis.
5. In a clear and concise write up of their experiment, discuss the results in the broader terms of astrobiology.

In-Class Discussion
Discuss the design of the students’ experiment and outcomes with the class following the submission of their assignment.

Limits of the Brine Shrimp
Were there any conditions too extreme for the brine shrimp?

Mars for Earthlings

Homework 2
Extremophiles_MFE
The Color of Temperature

Objective: Identify why an environment is considered "extreme" and draw inferences about life based upon the attributes/characteristics of these environments.

Extremophiles in Hot Water
Watch the following YouTube video created by GNC Science and answer the following questions: http://www.youtube.com/watch?v=VU-A6Sx7k-U

1. Why is this environment extreme? List characteristics of the environment that would classify this environment as extreme.

2. Given the list of characteristics you provided in #1, name the types of extremophiles that could exist there [refer to the list of extremophiles provided].

3. The colors of the hot spring have meaning. What do the colors represent? Which colors represent warmer water and, conversely, cooler water?

Yellowstone: An Earth case study
The photograph (Figure 1), taken in Yellowstone National Park, is a hot spring with outflow channels (hydrothermal environment, similar to above).

4. Determine how many colors the students observe and assign a hypothetical temperature range to each color.

Mars for Earthlings

5. Using their temperature ranges, outline the area of each temperature range (at least three but no more than six) to create a temperature map of the photograph provided (this will look similar to a contour map). They students may use trace paper over the image to represent the changes they see in color.

Figure 1: A hot spring in Yellowstone National Park (Image Credit: nps.gov Source: http://earthobservatory.nasa.gov/Features/Zircon/zircon3.php)

Have the students draw their map below (be sure to have them annotate their outlines):

Mars for Earthlings

Holden Crater, Mars
Holden Crater, a potential landing site for MSL Curiosity, is thought to have hydrothermal deposits similar to the Earth environments above. Below in Figure 2 is an example of the terrain provided by HiRISE.

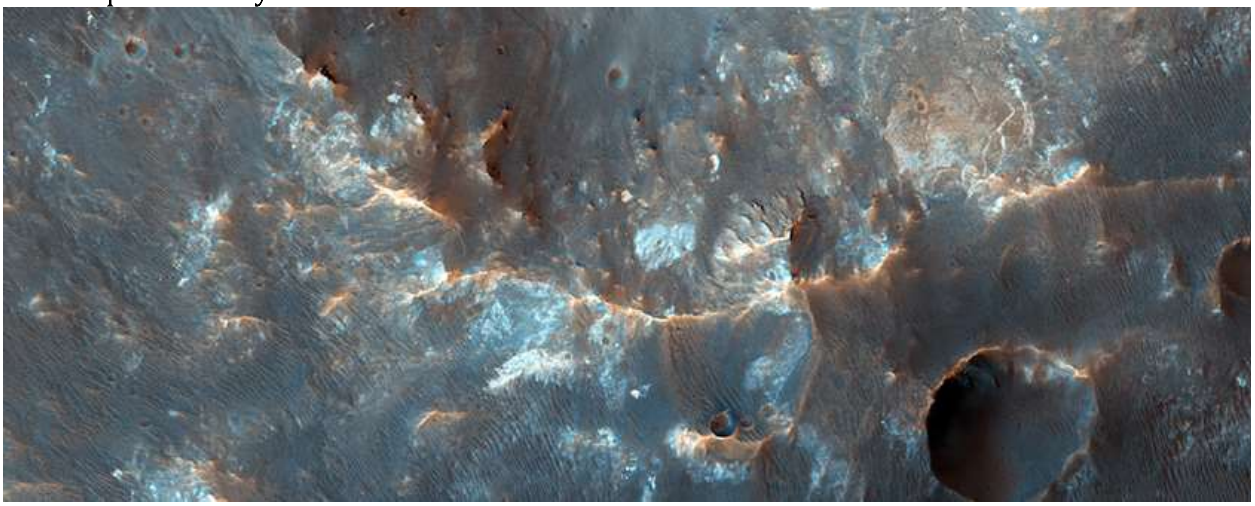

Figure 1: The Western Wall of Holden Crater, HiRISE Image ESP_021946_1535; (Image Credit: NASA/JPL/Univ of Arizona)

1. What do the students think the colors represent in the HiRISE image?

2. Using JMARS, capture one CRISM image that would infer a hydrothermal environment and paste below. Hints: (1) Review navigation in JMARS if necessary and investigate the crater walls/rims. (2) Think about what mineral assemblages would suggest a hydrothermal environment.

Lesson 20: ET in the Universe

Summary
This learning module and related in-class activity is meant to expose students to the SETI program.

Learning Goals

Students will be able to:

- Explain SETI protocols and their ethical implications

Context for Use
This module is to be utilized at the end of a full-term of Mars-related topics in conjunction with Earth science processes. Given its unique topic, however, this activity can be adapted for any course at any time.

Description and Teaching Materials
In-Class Activity

In-Class Activity 1: *Calling Earth*

Teaching Notes and Tips

- The *In-class Activity* can be easily modified to be used as a homework assignment.

Assessment
Each *In-Class Activity* and *Homework* has its own measure of Assessment.

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Mars for Earthlings

References and Resources

1. SETI protocols: http://www.seti.org/post-detection.html

Mars for Earthlings

In-Class Activity 1
ET in the Universe_MFE
Calling Earth

Purpose: Learn the mission of SETI (Search for Extraterrestrial Intelligence) and their protocols.

Engage
Have students begin to think about what they would do if they made contact with extraterrestrial life

Explore
The student is an astrophysicist, if he or she hears what he or she thinks to be communication from outside the solar system, what protocol would he or she follow to make a conclusive determination? Come up with at least 5 steps.

1. ____
2. ____
3. ____
4. ____
5. ____

Explain

- SETI protocols: http://www.seti.org/post-detection.html

Elaborate

1. After students have determined a conclusive ET signal, what steps would they take to inform the world (list them in order of what they would do first)?
2. Have the students compare their above steps to what SETI has published as their protocol (http://www.seti.org/post-detection.html) for ET detection. How do they differ?
3. What ethical implications are involved if such an occurrence were to happen?

An additional activity could involve having students look up protocols for sample return missions from Mars. Should we worry about contaminating Earth with samples from Mars? How should scientists handle this issue and what precautions should be followed?

Evaluate
What are the steps designated by SETI to take in the case of receiving an ET signal?

Lesson 21: Missions Outside Our Solar System: Kepler

Summary
This learning module is meant for adaptation into any course wishing to introduce students to planets outside Earth's solar system. Students will learn about the 'habitable zone' and apply techniques used to find planets outside our solar system.

Learning Goals

Students will be able to:

- Identify and explain the "habitable zone"
- Explain and apply the planet transit technique of detecting planets outside our solar system in the Kepler Mission.
- Utilize software programs such as Planet Hunters and the Kepler Exoplanet Transit Hunt sponsored/created by NASA missions.

Context for Use
This learning module can be used in any course of instruction where instructors would like to introduce students to planets outside our solar system and the concept of the habitability zone.

Description and Teaching Materials
In-Class Activity
In-Class Activity 1: Seeing like Kepler
Homework/Lab
Homework 1: Light Grapher
Homework 2: Planet Hunters!

Teaching Notes and Tips

1. Purchase or order an orrery device in order to use *In-Class Activity 1* Seeing Like Kepler in your course
2. All Homework sets can be adapted for the classroom if desired.
3. Before students are assigned *Homework 1* "Light Grapher" provide a demonstration of how the software works and explain to students that they will need a webcam in order to do the homework
4. Create a planethunters.org account so you can demonstrate how the website interacts with the user in the *Homework 2* "Planet Hunters".

Assessment
Methods of assessment are within each individual *In-Class Activity* and *Homework*.

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Mars for Earthlings

References and Resources

1. Kepler Exoplanet Transit Hunt computer interaction: http://kepler.nasa.gov/multimedia/Interactives/keplerFlashAdvDiscovery/#
2. Orrery suggestions for building: http://kepler.nasa.gov/education/ModelsandSimulations/LegoOrrery/
3. Planet Hunters: http://www.planethunters.org

Mars for Earthlings

In-Class Activity 1
Missions Outside our Solar System_MFE
Seeing like Kepler

Purpose: Understand how Kepler locates planets outside our solar system.

Preparation:
1. Purchase or make an orrery (model planet system)
2. Have Internet access in the classroom

Resources:
1. Orrery suggestions for building: http://kepler.nasa.gov/education/ModelsandSimulations/LegoOrrery/
2. Kepler Mission: http://kepler.nasa.gov
3. Kepler Exoplanet Transit Hunt: http://kepler.nasa.gov/multimedia/Interactives/keplerFlashAdvDiscovery/

Engage
Show students a model planet system (orrery) and ask students how they might be able to detect the planet orbiting its sun if it is thousands of light years away.

Explore
Ask students what problems might they encounter in trying to detect a planet orbiting a star.
- The star is far brighter than the planet and a scientist can't see it because planets are not as bright
- The planet is too small for detection

Have students interact with the online Kepler Exoplanet Transit Hunt simulation: http://kepler.nasa.gov/multimedia/Interactives/keplerFlashAdvDiscovery/?CFID=9187896&CFTOKEN=28729865

Students will:
1. Choose and record the star system they are observing.

2. Manually record and make calculations throughout the simulation. Record calculations below:

3. At the end of the simulation, what kind of planet did the students find? The programs offers an "artist's rendition" of the planet surface....what does it look like?

4. Determine if their star system has a planet in the habitable zone. Explain the reasoning for why the planet is or is not in the habitable zone.

Explain

Transit method of detecting planets (http://www.nasa.gov/mission_pages/kepler/multimedia/images/kepler-transit-graph.html):

When a planet crosses in front of its star as viewed by an observer, the event is called a transit. Transits by terrestrial planets produce a small change in a star's brightness of about 1/10,000 (100 parts per million, ppm), lasting for 2 to 16 hours. This change must be absolutely periodic if it is caused by a planet. In addition, all transits produced by the same planet must be of the same change in brightness and last the same amount of time, thus providing a highly repeatable signal and robust detection method. Credit: NASA

Elaborate

Have students brainstorm

1. A detection method for determining an exoplanet
2. Criterion for the "habitable" zone (size of star, proximity of orbiting planet, size of planet etc.)

Evaluate

1. From students experience in the Kepler simulation what is the *habitable zone* and how does it relate to Earth? What criterion makes a zone "habitable"?

2. Ask students to explain the "transit method" of detecting planets.

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Homework 1
Detecting Planets_MFE
Light Grapher

Directions

1. Go to: http://kepler.nasa.gov/education/ModelsandSimulations/lightgrapher/

2. Read over the webpage for context.

3. Briefly describe the principle(s) being used in order to locate planets.

4. Read through the directions and hints.

5. Run the program at least 3 different times. For each iteration, change the parameters by trying different methods of interaction with the camera, objects, sizes of objects, spacing of objects from camera, light source, etc. Report each iteration as follows as in the example below.

   Ex:
   Iteration #1
   Parameters Used:
   Outcomes (describe the graph and cut/paste the captured images)**:**

6. From their different iterations, what did the students learn about the objects? Did the size, color, transparency, or opacity matter?

7. Consider the planet Mars (typically red-tones) and a planet like Neptune (lighter blue colors). If students were to pass it in front of the webcam which planet would yield a greater change in light? Have students explain your reasoning.

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Homework 2
Missions Outside our Solar System_MFE
Planet Hunters

Join Planet Hunters

1. Navigate to: http://www.planethunters.org. Register, and begin planet hunting by following the online tutorial.
2. What method is *PlanetHunters* using to detect planets?

3. What role do the students play? Will people use their findings? Why or why not?

Classifying the star

4. What types of stars might they encounter? How do the students discern the differences with the data provided? Draw examples of each star and the data they provide.

5. Draw below what a planet transit looks like below. From the students' observations, have most of the stars had a planet transiting? What does this tell them? Would it be possible for a star to have a planet but have an apparent transit?

Lesson 22: The Issues and Future of Space Exploration

Summary
This learning module and related exercises will expose students the issues of space exploration and the other NASA-partnering agencies and institutions as well as private companies engaged in space-related technology. Students address socio-scientific issues and apply the nature of science to real-world decisions regarding human space flight.

Learning Goals

Students will be able to:

- Become aware of NASA partnering agencies and private companies engaged in space-related technology
- Design a mission and experience the panel review/decision process.

Context for Use
This particular module does not apply to any Earth analog approaches, but rather exposes students to the philosophy and ethics of privatized vs. government-funded research programs. Students practice with the realities of a cutting a budget in preparation for the Mission to Mars project.

Description and Teaching Materials
In-Class Activity

In-Class Activity 1: Manned-Space Flight: Is it needed?
In-Class Activity 2: Space flight going private

Homework/Lab

Homework 1: Cut A Budget: An Ethical Debate

Teaching Notes and Tips

1. *Homework 1* should be given prior to the Mission to Mars project due date to give students experience.
2. Become aware of the issues yourself before engaging in a discussion with students regarding privatization.

Assessment
Each *In-Class Activity* and *Homework* has its own measure of Assessment.

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References and Resources

- Mission to Mars Rubric
- Space X Press Release

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In-Class Activity 1
Space Issues_MFE
Manned Space-Flight: Is it needed?

Purpose: Discuss the issues surrounding manned-space flight and the future of space flight.

Preparation:
- Disseminate copies of news articles and/or NASA goals for students to discuss in groups or…
- Summarize points of each article in a PowerPoint presentation for discussion.

Resources:
- News Article (find a recent article such as): http://www.science20.com/brinstorming/near_future_manned_spaceflight-93648
- NASA Human Space Flight Goals: http://www.nasa.gov/pdf/626738main_HEOMD2012Goals.pdf
- NASA roadmap for Astrobiology: https://astrobiology.nasa.gov/roadmap/
- Space-X CEO Interview: *http://www.youtube.com/watch?v=IiPJsI8pl8Q&feature=related*

Engage
Engage students by asking what they think about space flight. Should the U.S. be involved in space exploration? What is the benefit? Should we do more than we are doing? What are the ethical questions? What is their knowledge about NASA missions?

Then Poll students on whether or not manned-space flight is a good idea
1. What is the reason for their choice?
2. What is the history of space flight? (utilize NASA interactive timelines on the history of spaceflight such as those below):
   http://nssdc.gsfc.nasa.gov/planetary/chronology.html
   http://history.nasa.gov/timeline.html
   http://www.nasa.gov/missions/timeline/

Explore
Manned-Space Flight Discussion in the News
1. "The Near Future of Manned Space Flight"
   http://www.science20.com/brinstorming/near_future_manned_spaceflight-93648
2. Discuss the article and what the future might or should be.

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Explain

1. Review NASA Human Space Flight Goals: http://www.nasa.gov/pdf/626738main_HEOMD2012Goals.pdf
2. Review NASA roadmap for Astrobiology: https://astrobiology.nasa.gov/roadmap/
    a. What points do students believe are important?
    b. What aspects did they not expect?

Elaborate

Space X Plans to put man on Mars in 10 years

- Interview with the CEO of Space-X (start interview at Time- 13:00-15:30) *http://www.youtube.com/watch?v=IiPJsI8pl8Q&feature=related*
- Discuss what students think of this venture.

Evaluate

Statement to a Congressman/woman

Ask students to prepare a 2-page statement to a Congressman/woman recommending or declining space flight using NASA published goals and/or other publicly announced space flight goals.

a. Have students identify a real and acting member of Congress and write a letter/statement accordingly.
b. Students must cite publications that support their recommendation.
c. Review student recommendations to Congress for understanding of current NASA goals.

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In-Class Activity 2
Space Issues_MFE
Space Flight going Private

Purpose: Become aware of private companies pursuing space flight and their role with our outside of NASA's Mission directorate (government vs. private funding).

Preparation
Be ready to facilitate a discussion and have talking points outlined. Suggested questions are below.

Engage
Dragon docking with the ISS
Present students the following video of Space X's Dragon spacecraft docking with the ISS:
http://www.youtube.com/watch?v=QwDCWTqNceQ&feature=player_embedded

a. Ask students what is significant about this event
b. Ask students what they think of this venture

Explore
Lead a discussion of Privatization vs. Government-funded research in Space

1. What is the history of privatization?
2. What are the pros and cons of private companies taking over the space program?
3. Share the Space X video of their award to continue on manned-space flight
    a. Video: http://www.youtube.com/watch?v=MZJk4CrxctQ&feature=youtu.be
    b. If the students had the money, would they buy a seat? Why or why not?
4. The Space X reusable Space Craft: http://www.youtube.com/watch?v=sSF81yjVbJE&feature=related
    a. Why is the Space X craft remarkable?

Explain
Compare NASA's budget with other federal government agencies and/or privately funded corporations using the following website:
http://www.richardb.us/nasa.html#table1

Elaborate
Space X's Mars Business Model
http://www.youtube.com/watch?v=4fS1FxBq64A&feature=relmfu

1. What do the students think of *Space X's* Mars Business Model?

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Evaluate

In a Group setting:

1. Decide as a group if privatization is a good route to pursue for space research and flight.
2. Groups should be ready to defend their position.

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Homework 1
Future Mars Missions & Societal Issues_MFE
Cut a Budget: An ethical debate?

Objective: Critique the viewpoint of a proponent of increased NASA funding and cut a theoretical mission budget to fit NASA cut backs.

A Viewpoint on NASA funding
Watch the following YouTube video, narrated by Neil deGrasse Tyson, concerning the national budget and NASA. Neil deGrasse Tyson is an astrophysicist and director of the Hayden Planetarium.
Video: http://www.youtube.com/watch?v=Fl07UfRkPas&feature=youtu.be

1. Do you agree with any of Neil deGrasse Tyson's points?

2. Similarly, do you disagree with any of his points?

3. Do you find Dr. Tyson's line of argument flawed? If so, why?

A Proposed Budget
Below is a proposed hypothetical NASA budget with all budget elements compliant with NASA documentation:
http://www.hq.nasa.gov/office/procurement/nraguidebook/proposer2013.pdf

4. Scrutinize the budget and make a 30% cut to your budget. NASA will approve this mission if you can cut your budget by 30%. For reference on what each budget item means see the above .pdf url link. (1) Show and justify all changes you make to achieve the 30% cut. (2) Attach an extra sheet of paper for justification if necessary. (3) Add items you think are necessary.

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Proposed Budget
(Sample, direct costs)

Mission: Orbit Europa

Duration: 4 years

Category	**Sub-Category (#)**	**Cost per Unit**	**Cost Total (4 years)**
Direct Labor	PI- Scientist (1) (1FTE)	$112,000	$448,000
	Co-I Scientist (3) (1/2 FTE))	$55,000	$660,000
	Co-I Engineer (5) (1FTE)	$95,000	$1,900,000
	Co-I Educator (1) (1/2 FTE)	$40,000	$160,000
	Post-Docs (3)	$48,000	$576,000
	Graduate Students (7)	$24,000	$672,000
	Undergraduate Students (3)	$3,000	$36,000
Other Labor	Consultant- Science (2)	$15,000	$120,000
	Consultant- Education (1)	$10,000	$40,000
Equipment	Orbiter (includes thermal, power, navigation, launch vehicle, etc)	$425,000,000	$425,000,000
	Cameras (1)	$31,000,000	$31,000,000
	Spectrometer (1)	$17,600,000	$17,600,000
	Website development	$40,000	$80,000
Supplies	Publications	$2,000	$10,000
	Software	$20,000	$20,000
	Computer Stations	$50,000	$50,000
Travel	LPSC Meeting Registration	$100	$800
	AGU Meeting Registration	$350	$2,800
	AAAS Meeting Registration	$400	$3,200
	Per Diems ($40/day /person)	$320	$10,240
	Airfare (roundtrip/person)	$600	$4,800
	Lodging (night/person)	$140	$4,480
	Transportation (trip/person)	$40	$960
Facilities/Administration	Imaging lab (yearly)	$15,000	$60,000
	Imaging rendering lab (yearly)	$15,000	$60,000
		Mission Total	$478,519,280

Lesson 23: Project Mission to Mars

Summary
This is a collection of documents to prepare and evaluate students for their Project: Mission to Mars.

Learning Goals

Students will be able to:

- practice creating a mission budget
- define mission objectives, supporting science, and background research to substantiate a mission.
- present a mission project presentation before a review board.
- identify mission personnel currently active in NASA / Astrobiology related studies.

Context for Use

This module exposes students to the realities of creating and seeking funding for a mission to Mars in a presentation format. Students use knowledge gained throughout *Mars for Earthlings* to support their work. This lesson serves as a culminating activity which requires understanding of the Martian surface via Earth analog concepts.

Description and Teaching Materials

- Mission Grading Rubric
- Mission Progress Sheets
- Mission Team Evaluation

Teaching Notes and Tips

1. For the review panel, ask other outside teachers/instructors to join the panel so students do not necessarily recognize their reviewers. TA's could be used as well.
2. Students will be most successful in this project after several weeks of interpreting Mars data and relating Earth analog concepts.
3. Encourage students to refer to the "Meet the Scientists" videos for potential personnel.

Assessment

See the Mission Grading Rubric

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References and Resources

Students participate in virtual projects and activities:
http://mars.jpl.nasa.gov/participate/students/
Mars Exploration Program Analysis Group (MEPAG):
http://mepag.jpl.nasa.gov/reports/MEPAG%20Goals_Document_2012_v7_2014-09-24.pdf

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Mission to Mars Project

Outline

Example Progress Sheet-1 (To ensure that students don't wait until the last minute to attempt a project, it helps to have an early progress check to make sure they are on track. Students will enjoy having a team name that gives them a little sense of competition.)

Directions: Complete and submit an outline of your Mission to Mars Project
Develop a 3-tier outline in the following format:

Major topic

   a. Who is responsible for this section in your group
      i. Team Member
   b. Content
      i. Relate general information
   c. Images you will use

1. Use the Mission to Mars Project grading rubric (following this) to determine the minimum amount of slides needed. You must cover every section in your presentation. Each section will be a "Major Topic" in your outline. You may of course include more slides when necessary. Sections are listed below for clarity:

   a. Mission Objectives
   b. Mission Team
   c. Background
   d. Scientific Merit
   e. Budget
   f. Education & Outreach
   g. Citations

2. In addition to the outline include at least (4) images, referenced and cited, you plan to use. You may insert the images where covered in your outline or you may simply append the images to the document. Make sure you use figure captions.

3. For your ***Budget*** slide make sure you include the amount you are planning on spending and a general break down of the expenditures.

Team Name: ____________________

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EXAMPLE FINAL PROJECT PARTICIPATION SHEET (Not all students actively participate in the project like they should, so this is a mechanism to help determine who has done the work, and allows students to judge their peers on the project.)

For each name, including your own, give your estimated percentage of effort (out of team 100%) you think each person put in (note: if there are 5 people & it was all equal, everyone would be at 20%)

Your Name ____ % Effort ________

Your Final Project Name ____

Your fellow teammates' names:

A. ________________________ %Effort _____ B. _______________________ %Effort _____

C. ________________________ %Effort _____ D. _______________________ %Effort _____

Your Team ROLE: ____

What did your task efforts include (what work did YOU personally do for the project)?

Examples could be: investigated Curiosity instrumentation to determine the necessary instruments for your mission; investigated potential landing sites; writing up a percentage of the final project report, putting together a percentage of the PowerPoint presentation, etc.

Estimate the # of hours you actually spent performing the different tasks.

____ Hours______________

____ Hours______________

____ Hours______________

____ Hours______________

____ Hours______________

____ Hours______________

____ Hours______________

TOTAL HOURS ____________

Grade you think you deserve for this final project ____________

Explain why ____

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Mission to Mars Project Rubric (Example of how you'll be graded)

Team Name: ______________________ Reviewer: ________________________

Task (% possible)	Strengths	Weaknesses	%
Mission Team (10) • role of each member • (2) current NASA engineers/scientists • Partner Agency			
Presentation Clarity (5) • Images in focus • Font is clear			
Presentation Delivery (5) • Questions answered appropriately • Within time limit/clear			
Mission Objectives (5) • Location of mission • Clear purposes			
Background (10) • Previous related missions • Previous scientific work			
Scientific Merit (30) • Justification for Mission • Science to be accomplished • Innovation			
Budget (10) • Elements outlined • Source of funding			
Education & Outreach (10) • Citizen science plan • Education plan			
Citations (15) • References slide • Captioned/credited images			

Panel Decision: Please Circle one **Total Percent ____________**

Fail Passed w/Major Improv Passed w/Minor Improv Passed/Implement