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.

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

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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):

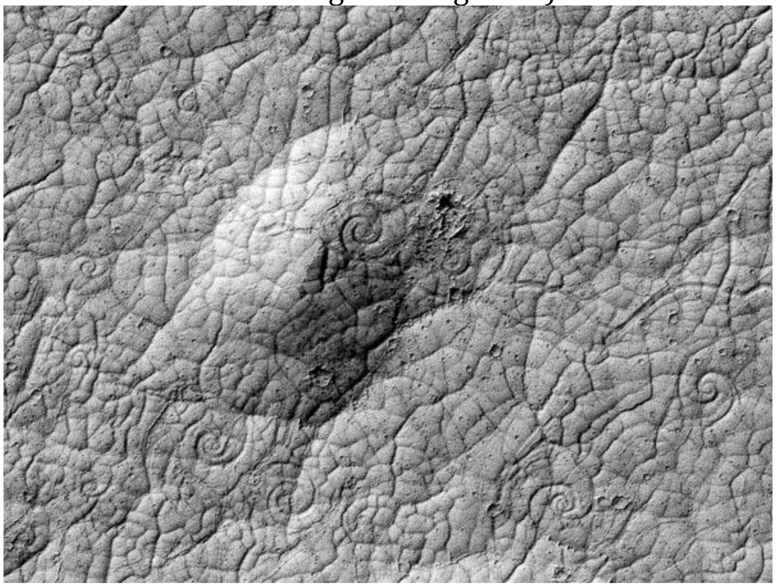

Figure 1: Spirals in Athabasca Valles, Credit: NASA/JPL/University of Arizona, Spirals are 16-98 ft wide. Image source: http://www.space.com/15446-mars-lava-volcanoes.html

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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.

<u>Pahoehoe lava</u>- 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.

<u>A'a lava</u>- 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.

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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.

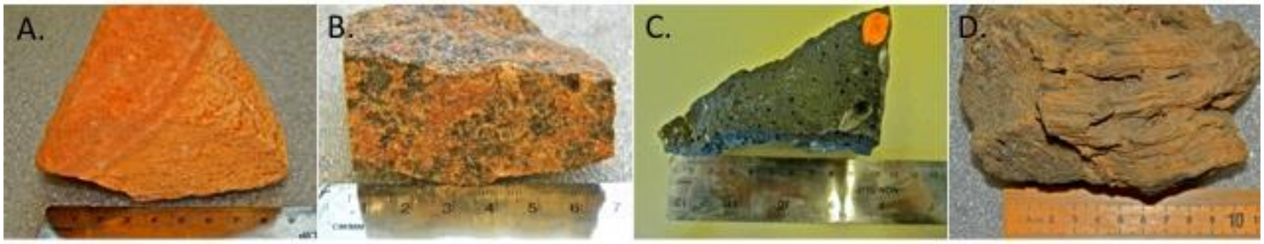

Figure 2: A. Sandstone, B. Potassium Feldspar Granite, C. Basalt, D. Oxidized Basalt

Evaluate

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

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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?

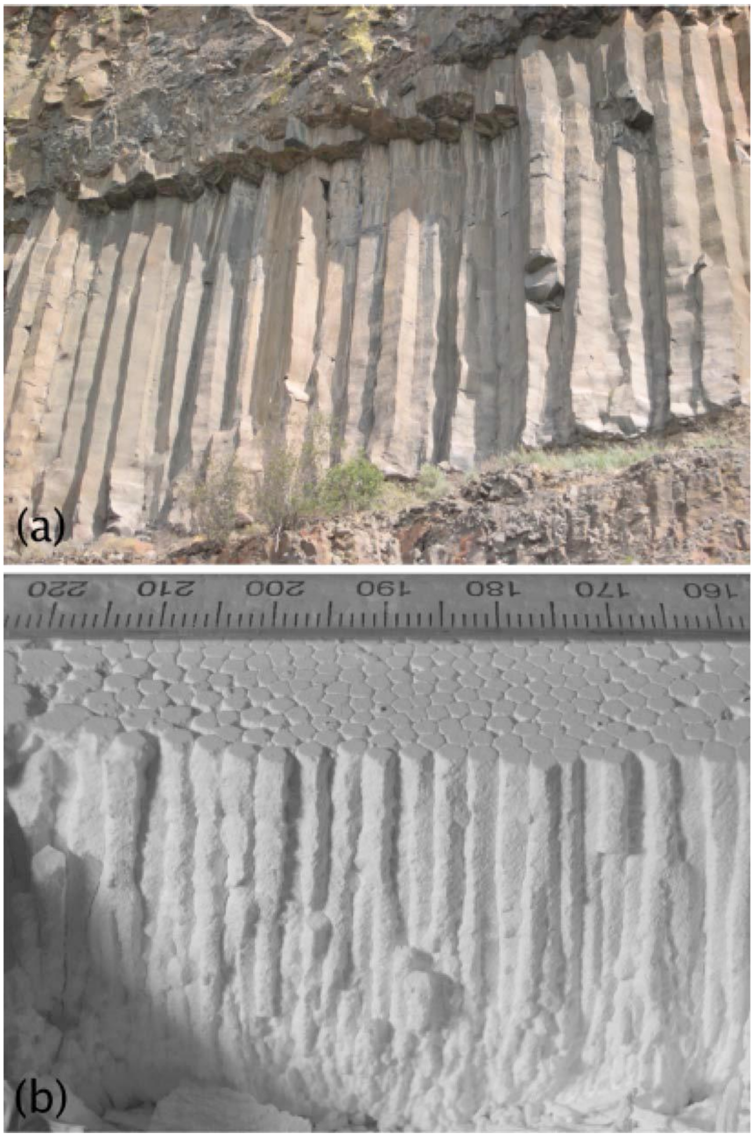

Figure 1: Columnar jointing in (a) basalt of the Columbia Plateau near Banks Lake ~95 cm average diameter, and (b) in desiccated corn starch. (Image Credit: Gohering L., Morris, S.W., and Lin, Z., 2006. Experimental investigation of the scaling of columnar joints. PHYSICAL REVIEW E 74, 036115, p. 1-12.)

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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

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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.

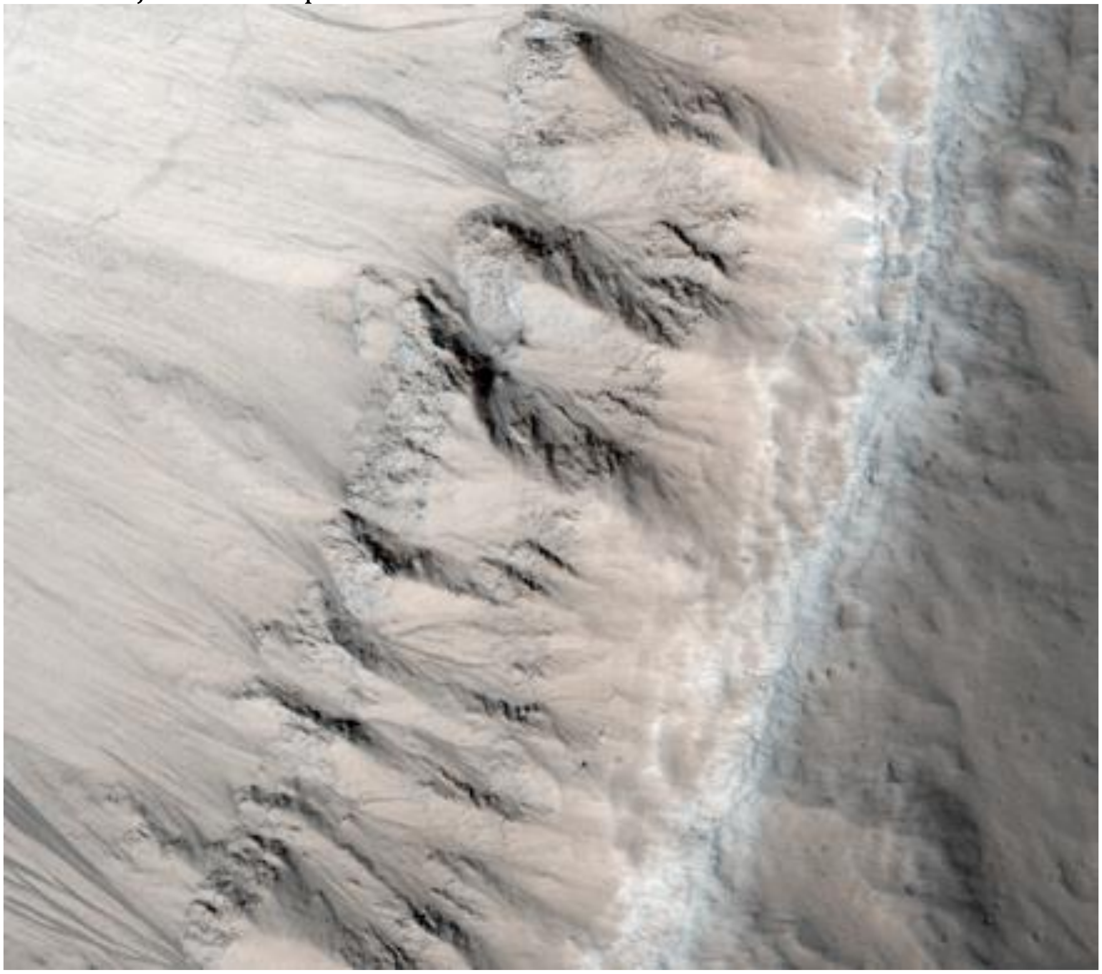

Figure 2: http://hirise.lpl.arizona.edu/PSP_005917_2020 (Image Credit: NASA/HiRISE)

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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.

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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.

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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)?

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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?