

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.

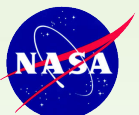
Assessment

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

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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.



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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?



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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.

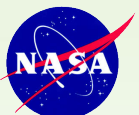
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Elaborate

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?



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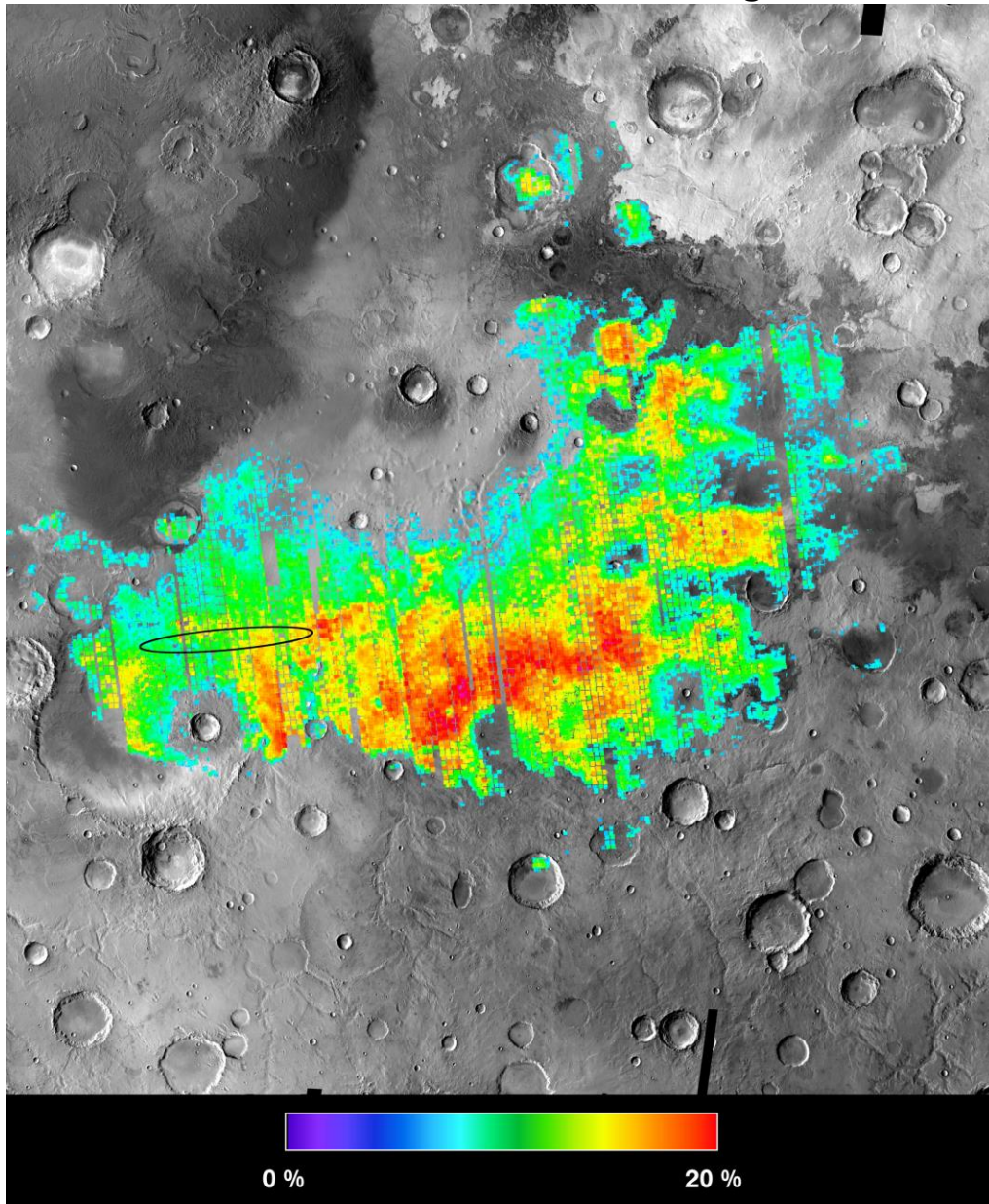


Figure 1: Meridiani Planum; Image credit: NASA/JPL/Arizona State University.

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.

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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. **If using a microwave, do not use foil!**
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.



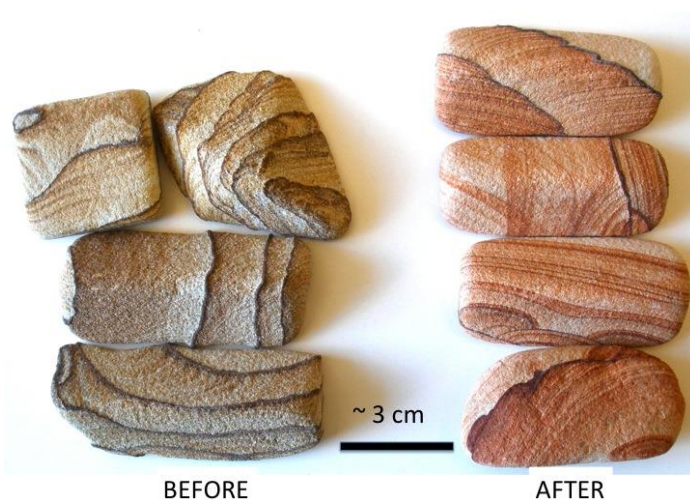
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3. Explain the relevance of the experiment to understanding Earth processes and why this might help us understand similar mineralogies on Mars (e.g., hematite “blueberries” at Meridiani Planum, Mars).
4. What are the limitations of this experiment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



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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. 635-638. 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: *Geochimica 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: *Geochimica 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, $0.02^\circ 2\theta$ step size, and 0.6 seconds per step. Bulk samples were examined 4 to $65^\circ 2\theta$. 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



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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).

