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2004 Gulf of Alaska Expedition

Iron Bugs

Focus
Influence of microorganisms on geochemical processes

Grade Level
9-12 (Chemistry/Life Science/Earth Science)

Focus Question
How can microbial metabolism affect geochemical processes?

Learning Objectives
Students will be able to describe how microbial metabolism may affect the dissolution of igneous rocks.

Students will be able to define and explain the function of siderophores.

Students will be able to describe at least two ways in which bacteria may utilize iron, and explain why iron availability may limit biological activity even though it is extremely abundant in nature.

Materials
❒ Copies of "Guiding Questions for Investigating Bacteria and Geological Processes," one copy for each student or student group

Audio/Visual Materials
❒ None

Teaching Time
One 45-minute class period, plus time for student research

Seating Arrangement
Classroom style or groups of two to three students

Maximum Number of Students
30

Key Words
Redox reaction
Siderophore
Ligand
Coordination complex
Chemolithotroph

Background Information
Seamounts (also called "guyots") are undersea mountains that are generally thought to be the remains of underwater volcanoes, often with heights of 3,000 m (10,000 ft) or more. There are an estimated 30,000 seamounts in all of the Earth's ocean, but only a few hundred have been visited by explorers, and far fewer have been intensively studied. Volcanoes that can form seamounts are often associated with the movement of the tectonic plates that make up the Earth's crust. Where these plates move apart (for example, along the mid-ocean ridge in the middle of the Atlantic Ocean) a rift is formed, which allows magma (molten rock) to escape from deep within the Earth and harden into solid rock known as basalt. Where tectonic plates come together, one plate may descend beneath the other in a process called subduction, which generates high temperatures and pressures that can lead to explosive volcanic eruptions (such as the Mount St. Helens eruption which resulted from subduction of the Juan de Fuca tectonic plate beneath

the North American tectonic plate). Volcanoes can also be formed at hotspots, which are thought to be natural pipelines to reservoirs of magma in the upper portion of the Earth's mantle.

In the late 1960's, biologists searching for new commercial fishing grounds discovered that seamounts have high biological productivity compared to surrounding ocean waters, and provide habitats for a variety of plant, animal, and microbial species, many of which were previously unknown. Deep-sea corals are often conspicuous, and provide essential habitat for other organisms in seamount ecosystems. These organisms include commercially-important fish species, and seamounts have become a prime fishing location for deep-water trawlers. Unfortunately, commercial fishing activity can severely damage entire bottom communities: trawling is known to have removed 85% of the living cover from some seamounts (Malakoff, 2003). In February 2004, concern for this large-scale destruction of virtually unexplored ecosystems led 1,136 scientists from 69 countries to release a statement calling for governments and the United Nations to protect deep-sea coral and sponge ecosystems.

This same concern has stimulated scientific research on seamounts. Despite increasing awareness of the importance of seamounts, relatively little is known about how seamounts are formed and how they change over time. Better understanding of the geologic processes that form and change seamounts is a primary objective of the Ocean Exploration 2004 Gulf of Alaska Expedition, which will focus on a seamount chain that stretches roughly 900 km from Kodiak Seamount at the Alaskan Trench to Bowie Seamount off of the Queen Charlotte Islands. A key question for scientists on this expedition is how microorganisms change the volcanic rocks that are the foundation of seamounts. While the transformation of igneous rocks to other materials was once believed to involve purely physical and chemical processes, recent research has shown that bacteria are a significant part of many important geochemical reactions.

In this activity, students will research some of the basic biological and chemical concepts involved in the linkage of microbial metabolism and geochemical processes. This activity may be accompanied by a variety of laboratory experiments and/or demonstrations involving redox reactions and ligand chemistry.

Learning Procedure

1. Explain that seamounts are the remains of underwater volcanoes, and that they are islands of productivity compared to the surrounding environment. Tell students that expeditions to seamounts often report many species that are new to science and many that appear to be endemic to a particular group of seamounts.

   You may want to show images of seamount communities from http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html or http://www.mcbi.org/DSC_statement/coral_images.htm, or direct students to these sites. Tell students that one of the major objectives of the Ocean Exploration 2004 Gulf of Alaska Expedition is to investigate how microorganisms change the volcanic rocks that are the foundation of seamounts.

2. Provide each student or student group with a copy of "Guiding Questions for Investigating Bacteria and Geological Processes." Tell students that their assignment is to investigate some of the basic concepts involved in how bacteria may be involved with geochemical processes, and to prepare a written report that contains answers to questions on the worksheet.

3. After students have completed and submitted their reports, lead a discussion of students' research results. The following points should emerge in this discussion:
   - A redox (reduction-oxidation) reaction occurs when one compound receives one or more electrons from another compound. The compound that gains electrons is said to have been "reduced," while the compound that loses elec-

trons is said to have been "oxidized."

- A siderophore is a compound having a low molecular mass and a high affinity for ferric iron. There are almost 500 known siderophores that have widely varying chemical structures. Siderophores are organic ligands.

- Ligands are molecules that contain at least one pair of electrons that can bond to a metal atom or ion by coordinate covalent bonds. This type of bonding is different from a normal covalent bond in which each atom supplies one electron.

- A coordination complex is the product of a coordinate covalent bond. There are many biologically-important coordination complexes, including hemoglobin (a coordination complex of iron), vitamin B_{12} (a coordination complex of cobalt), and chlorophyll (a coordination complex of magnesium).

- Iron is a component of many important compounds in living organisms, and nearly all microorganisms require iron for growth. In addition, some archea (known as chemolithotrophs) are able to obtain energy by reducing iron molecules.

- Iron is abundant in nature, particularly in igneous rocks. But most of this iron is not in a chemical form that can be directly utilized by living organisms. In many environments, available iron is only about one-tenth of the amount required by microorganisms. Some organisms produce chelating compounds that have a high affinity for iron and are thus able to increase its availability to the organisms.

- Evidence of iron-utilizing bacteria has been found at the Axial Volcano on the Juan de Fuca Ridge, and the Loihi Seamount (Hawaii), among others.

- One hypothesis that explains the observations at a newly-formed volcano is: Hematite is composed of Fe^{3+} oxide. The bacterium *Gallionella ferruginea* is capable of reducing ferric (Fe^{3+}) iron to ferrous (Fe^{2+}) iron. The Fe^{2+} oxides may be hypothesized to be the result of bacterial reduction.

- Metals and radionucleides attached to iron in soils could be immobilized or changed into less hazardous forms iron-reducing bacteria.

4. You may want to follow this activity with one or more demonstrations or experiments related to redox reactions or ligands. Numerous examples can be found at http://www.cci.unl.edu/Chemistry/DoChem/DoChem.html

The BRIDGE Connection

www.vims.edu/bridge/geology.html

The "Me" Connection

Have students write a short essay on how chemolithotrophs might be potentially important to their own lives.

Connections to Other Subjects

English/Language Arts, Biology, Geography, Physics

Evaluation

Written reports prepared in Step 2 provide opportunities for assessment.

Extensions

Have students visit http://oceanexplorer.noaa.gov to find out more about the 2004 Gulf of Alaska Expedition and about opportunities for real-time interaction with scientists on current Ocean Exploration expeditions.

Resources

http://www.cci.unl.edu/Chemistry/DoChem/DoChem.html
– National Science Foundation's "Doing Chemistry" project Web page

http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/link.htm – Web site with many links to chemistry demonstrations and experiments

http://ridge.coas.oregonstate.edu/rkeller/seamounts.html – Background on seamount exploration and research in the Gulf of Alaska

http://www.ethomas.web.wesleyan.edu/scie639/sci639syl.h – Notes on chemosynthesis, early life on Earth, and evolution

http://www.terranature.org/deepsea_coral.htm – Article about scientists' call for protection of deep-sea coral ecosystems

http://www.terranature.org/trawlingScientists_ban.htm – Text of Scientists' Statement on Protecting the World's Deep-sea Coral and Sponge Ecosystems

Malakoff, D. 2003. Deep-sea mountaineering. Science 301:1034-1037. – Article on seamounts and deep-sea coral communities

http://www.mcbi.org/DSC_statement/coral_images.htm – Images on the Marine Conservation Biology Institute's Web page

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer photograph gallery

http://oceanica.cofc.edu/activities.htm – Project Oceanica Web site, with a variety of resources on ocean exploration topics

http://www.earthref.org/databases/SC/main.htm – Digital archive of seamount maps

http://seamounts.sdsc.edu/ – Compendium of seamount-related research

National Science Education Standards

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Structure of atoms
- Chemical reactions

Content Standard C: Life Science
- The cell
- Matter, energy, and organization in living systems

Content Standard D: Earth and Space Science
- Energy in the earth system
- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives
- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

For More Information

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Student Handout

Guiding Questions for Investigating Bacteria and Geological Processes

What happens in a "redox reaction?"

What is a siderophore?

What is a ligand?

What is a coordination complex?

What are two ways in which bacteria may use iron?

What is a chemolithotroph?

Why do organisms need siderophores?

Have iron-metabolizing bacteria been found at any active marine volcanoes?

Scientists investigating geological deposits in the vicinity of a newly-formed volcano found large quantities of hematite. A year later, they found large quantities of Fe^{2+} oxides and bacteria belonging to the species *Gallionella ferruginea*. Provide an hypothesis that accounts for these observations.

How might bacteria be useful in cleaning up sites contaminated with nuclear waste or other hazardous metals?