

Exploring Alaska's Seamounts

Rock Eaters of the Gulf of Alaska

FOCUS

Chemosynthetic microbes in basalt rocks

GRADE LEVEL

9-12 (Chemistry, Biology, Earth Science)

FOCUS QUESTION

How can life exist in extreme environments?

LEARNING OBJECTIVES

Students will be able to compare and contrast the processes of photosynthesis and chemosynthesis.

Students will be able to identify and describe sources of energy used by various organisms for chemosynthesis.

Students will be able to predict what chemosynthetic reactions might be possible in selected "extreme" environments.

ADDITIONAL INFORMATION FOR TEACHERS OF DEAF STUDENTS

In addition to the words listed as Key Words, the following words should be part of the list.

Biological Productivity
Habitats
Microbial
Parallel
Tectonic Plates
Mid Ocean Ridge
Magma
Subduction
Eruptions
Photosynthesis
Hydrothermal Vents

Oxidation

Methane

These words are integral to the unit. They are really the material of the lesson. There are no formal signs in American Sign Language for any of these words and many are difficult to lipread. Having the vocabulary list on the board as a reference during the lesson will be extremely helpful. Look in the Resource section for the teacher's guide on plate tectonics and the notes on chemosynthesis. This will be helpful as background information for the teacher.

MATERIALS

- Copies of press releases on the moons of Jupiter and collapse of the Loihi volcano, enough copies for each student or student group

AUDIO/VISUAL MATERIALS

None

TEACHING TIME

One 45-minute class period, two periods if students play the "Sea-Life Connections" game

SEATING ARRANGEMENT

Classroom style or groups of two or three students

MAXIMUM NUMBER OF STUDENTS

24

KEY WORDS

Basalt

Seamount
Chemosynthesis
Archaea
Weathering

BACKGROUND INFORMATION

Seamounts are undersea mountains that rise from the ocean floor, often with heights of 3,000 m (10,000 ft) or more. Compared to the surrounding ocean waters, seamounts have high biological productivity, and provide habitats for a variety of plant, animal, and microbial species. Numerous seamounts have been discovered in the Gulf of Alaska. Many of these seamounts occur in long chains that parallel the west coast of the U.S. and Canada. One of the longest chains, known as the Axial-Cobb-Eikelberg-Patton chain, is being intensively studied by the Ocean Exploration 2002 Gulf of Alaska Expedition.

Seamounts are generally thought to be the remains of underwater volcanoes that can be formed in several ways. Many volcanoes are 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.

When magma emerges into the ocean, it has a temperature of about 1200° C. Because deep ocean water is quite cold, the magma quickly

solidifies into a mixture of minerals and volcanic glass. Scientists have noticed that basalt formations are slowly broken down in a process they call "weathering." For many years, weathering was believed to be a chemical process, but in the last ten years evidence has been discovered that microbial organisms may also be at least partly responsible for the alteration of basalt in the Earth's crust. Microscopic examination of weathered basalts from many locations have shown pits, channels, and other patterns that are unlike chemical weathering. Moreover, these weathered rocks were also found to contain increased amounts of carbon, phosphorus, and nitrogen which are byproducts of biological activity, as well as traces of nucleic acids. No living cells have been discovered in the rocks, but objects have been found in the rocks that resemble cellular structures.

Ocean Exploration 2002 Gulf of Alaska Expedition includes an intensive effort to find living microbes in basalt rocks, experiments to determine whether they receive energy from the rocks, and investigations to determine whether basalts of different age have different microbe communities.

LEARNING PROCEDURE

1. Explain that seamounts are the remains of underwater volcanoes, and describe the general process of underwater volcano formation. You may need to review the concept of plate tectonics, if students are unfamiliar with the relevant terms. Describe the evidence that suggests that microbial life may inhabit seamount basalt and be at least partially responsible for weathering observed in these rocks. Discuss with the students how such organisms might be able to survive, leading to the concept of chemosynthesis. Contrast chemosynthesis with photosynthesis: in both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Point

out that there are a variety of chemical reactions that can provide this kind of energy—the bacteria that are the base of the food chain around hydrothermal vents appear to obtain energy for chemosynthesis from the oxidation of hydrogen sulfide to sulfur:

$\text{CO}_2 + 4\text{H}_2\text{S} + \text{O}_2 > \text{CH}_2\text{O} + 4\text{S} + 3\text{H}_2\text{O}$
(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water). Visit <http://oceanexplorer.noaa.gov> for more information and activities on hydrothermal vent communities.

Similarly, chemosynthetic organisms that inhabit hot springs, in temperatures exceeding 100° C, obtain energy from the oxidation of hydrogen gas:

$\text{CO}_2 + 3\text{H}_2 + \text{S} > \text{CH}_2\text{O} + \text{H}_2\text{S} + \text{H}_2\text{O}$
(carbon dioxide plus hydrogen plus sulfur yields organic matter, hydrogen sulfide, and water).

Of particular interest to the Gulf of Alaska Expedition, are chemosynthesizers discovered in deep drill holes into Columbia River basalts. These organisms, 1500 m below the surface, oxidize iron in the rocks to produce hydrogen gas, which is then combined with carbon dioxide to produce methane:

$2\text{FeO} (\text{rocks}) + \text{H}_2\text{O} > \text{Fe}_2\text{O}_3 + \text{H}_2$, and
 $4\text{H}_2 + \text{CO}_2 > \text{CH}_4 + 2\text{H}_2\text{O}$

Explain that the point is that there are a variety of ways organisms can survive (and thrive) in environments that to us are “extreme,” hostile, and unliveable. Many chemosynthesizers belong to a group of organisms called Archaea, because they appear to be most “primitive” in their DNA and RNA, and that these types of organisms may be similar to early forms of life on earth. In fact, many scientists suspect that hydrothermal vents and/or underwater volcanoes may be where life on Earth actually began. It is intriguing to note

that the cell-like shapes and inclusions found in volcanic glass by researchers on the Gulf of Alaska Expedition are quite similar to the shapes of known Archaea.

2. Discuss the implications of rock-eating bacteria to the question of early life on Earth and the possibility of life on other planets. Provide students or student groups with copies of press releases on Jupiter’s moons and underwater volcano Loihi. Have each student or student group hypothesize what chemosynthetic reactions might be taking place in these environments, what other chemicals would be necessary for these reactions, and what other types of organisms might co-exist in these environments by using the chemosynthesizers as the base of a food chain. You may want to have students play the “Sea-Life Connections” game (<http://www.mims.logan.k12.ut.us/science/ESSeaConnect.html>) if they are not familiar with the concept of food chains.

THE BRIDGE CONNECTION

www.vims.edu/bridge

THE “ME” CONNECTION

Have students write a first-hand account of life in an extreme environment, and the adaptations they use to make it possible to survive in this environment.

CONNECTIONS TO OTHER SUBJECTS

English/Language Arts, Biology, Geography, Physics

EVALUATION

Have each student or student group submit a written report detailing the chemosynthetic reactions they postulate for their extreme environment(s), and describing the types of living communities that might be supported by chemosynthesizers using these reactions.

EXTENSIONS

Have students visit <http://oceanexplorer.noaa.gov>

to keep up to date with the latest Gulf of Alaska Expedition discoveries.

RESOURCES

<http://oceanexplorer.noaa.gov> – Follow the Gulf of Alaska Expedition daily as documentaries and discoveries are posted each day for your classroom use. A wealth of information can also be found at this site.

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

<http://volcano.und.nodak.edu/vwdocs/vwlessons.atg.html> – teacher's guide on plate tectonics, hot spots, and volcanoes

<http://www.ethomas.web.wesleyan.edu/scie639/sci639syl.htm>
– detailed lecture notes on chemosynthesis, early life on Earth, and evolution

<http://www.sciencegems.com> – science education resources

<http://www-sci.lib.uci.edu/HSG/Ref.html> – references on just about everything

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Chemical reactions
- Interactions of energy and matter

Content Standard C: Life Science

- Biological Evolution

Content Standard D: Earth and Space Science

- Origin and evolution of the earth system

FOR MORE INFORMATION

Paula Keener-Chavis, National Education
Coordinator/Marine Biologist
NOAA Office of Exploration
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818
843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Student Handout

PRESS RELEASE

(from <http://www.jpl.nasa.gov/galileo/news2.html>)

New Jupiter Findings: Oxygen at Callisto's Surface, Sulfur Dioxide Sources At Io

Office of Public Relations
University of Colorado-Boulder
354 Willard Administrative Center
Campus Box 9
Boulder, Colorado 80309-0009
(303) 492-6431

Contact: Charles Barth, (303) 492-7502
Charles Hord, 492-7923
Amanda Hendrix, 492-8573
Jim Scott, 492-3114

Dec. 10, 1997

NEW JUPITER FINDINGS: OXYGEN AT CALLISTO'S SURFACE, SULFUR DIOXIDE SOURCES AT IO

New data from a University of Colorado at Boulder instrument on board the Galileo spacecraft now at Jupiter indicates one of its four large moons, Callisto, has oxygen on its surface and another, Io, continues to emit hot volcanic gases.

Charles Barth, a senior researcher at the Laboratory for Atmospheric and Space Physics and a member of the CU science team that designed and built the ultraviolet spectrometer flying on Galileo, said hydrogen atoms escaping from Callisto implies the Mercury-sized moon has oxygen locked up in its ice and rocks. In 1996 the CU Galileo team detected evidence of oxygen on the surface of Callisto's neighboring moon, Ganymede.

On Ganymede, the UV spectrometer data from Galileo indicated hydrogen atoms were being knocked off the icy surface by charged particles emanating from Jupiter's plasma torus, a massive, doughnut-shaped ring surrounding the planet, said Barth. Because hydrogen atoms are lighter than oxygen atoms, the hydrogen floated out of the atmosphere and into space, leaving the oxygen behind.

But on Callisto, the furthest of the four large moons from Jupiter, it appears that sunlight striking its rock-hard ice is the primary mechanism for separating the hydrogen and oxygen atoms, he said.

Callisto, roughly 3,000 miles in diameter, is the most heavily cratered moon in the solar system. Callisto is the third largest moon in the solar system behind Ganymede and Titan, the dominant moon of Saturn.

"Because it is further away from Jupiter, Callisto does not interact as strongly as Ganymede with the charged particles in the planet's atmosphere," said Barth. "Instead, we believe it is the ultraviolet solar radiation that is knocking the hydrogen atoms out of the ice on Callisto." The surface of Ganymede is thought to contain about 50 percent ice, while the

ice on the surface of Callisto is thought to comprise less than 20 percent of the planet's surface, said Barth, a professor in the astrophysical and planetary sciences department and former director of LASP.

The CU team, which also has been monitoring sulfur dioxide emissions from Io during recent Galileo fly-bys, discovered that the gases are the result of both active volcanoes and the sublimation of frost on Io's surface. The analysis of the Io data, led by LASP Research Associate Amanda Hendrix, indicates the volcanic activity on Io is extremely variable. The researchers, who made 10 observations of Io volcanoes with the UV spectrometer, found that the thickness of Io's sulfur dioxide atmosphere varied with both time and location over the past year, said Hendrix. Any water present on Io probably disappeared billions of years ago when the volcanic activity commenced.

Launched in 1989 aboard the space shuttle Atlantis, the Galileo spacecraft arrived at Jupiter orbit in December 1995. The Galileo spacecraft is managed for NASA by the Jet Propulsion Laboratory of the California Institute of Technology.

Barth and Hendrix presented the CU-Boulder Galileo results at the fall meeting of the American Geophysical Union in San Francisco Dec. 8 to Dec. 12.

Other LASP researchers on the Galileo UV spectrometer science team led by principal investigator Charles Hord include Ian Stewart, Wayne Pryor, Bill McClintock and Karen Simmons. The team also includes scientists from JPL and the University of Arizona.

Data is being sent from the spacecraft to Deep Space Network antennas located in Goldstone, Calif., Madrid, Spain, and Canberra, Australia. Information from the CU spectrometers is sent on to JPL, then forwarded over data lines to LASP's Space Technology Building in the CU Research Park. The incoming information will be analyzed by faculty and students.

While the original mission goals of Galileo have been accomplished, the instruments will continue to gather data, said Barth. Two primary targets in the next two years will be the continuing search for a possible ocean under the icy surface of the moon, Europa, and additional observations of Io's violent volcanoes.

Student Handout

PRESS RELEASE

(from: <http://www.publicaffairs.noaa.gov/pr96/oct96/noaa96-69.html>)
NOAA 96-69

Contact: Dane Konop
10/4/96

IMMEDIATE RELEASE

SCIENTISTS OBSERVE COLLAPSED DOME OF UNDERSEA VOLCANO LOIHI

The recent collapse of the lava dome of the underwater volcano Loihi off Hawaii has created a murky crater a half mile across and a thousand feet deep, and given scientists in a research mini-sub a close-up look at the ongoing birth of the next Hawaiian island, according to researchers just back from the site.

The research expedition aboard the RV Ka'imikai-o-Kanaloa (Hawaiian for "investigator god of the sea"), which began Sept. 25 and is continuing off the big island of Hawaii through Oct. 12, is sponsored by the Commerce Department's National Oceanic and Atmospheric Administration and led by Alexander Malahoff, director of the Hawaii Undersea Research Laboratory at the University of Hawaii.

"This was a Mount St. Helen-sized' volcanic event. Pele's Dome, an area on the southern rim of the volcano that previously had been considered very stable, has simply vanished into a giant pit, which we have named the Pele's Pit Crater.' What we learn from this event will have profound implications for virtually everything we now know about undersea volcanism--including the effects of volcanic carbon dioxide emissions on climate, the possible generation of tsunamis that could strike coastal areas, and the impacts on the microscopic organisms that live in and near sea floor vents," Malahoff said.

In a series of six dives into the volcano aboard the research submersible Pisces V, the NOAA-funded university scientists witnessed dramatic evidence of the impact of swarms of sea floor earthquakes that have struck Loihi since mid-July, including the collapse of giant lava rock formations, continuing subsea tremors and landslides, and the creation of new vents spewing a mix of superheated water, dissolved minerals and massive mats of chemosynthetic bacteria that limited the scientists' visibility to a meter or less.

Researchers operating from "K-o-K" also produced a new sonar map of the volcano and used Pisces V to photograph the new topography and hydrothermal venting there, sample seawater in and near the vents to measure concentrations of bacteria and minerals, install sea floor pressure monitoring devices that would signal further collapses of the sea floor, and identify locations to safely position other measuring devices for long-term monitoring.

The whole summit of the volcano, about 3,000 feet below sea surface, has collapsed, shaken by swarms of sea floor earthquakes and the withdrawal of magma within the volcano, said Malahoff, who made the first three of six dives into Loihi in Pisces V September 25-27. "A four to five square-mile

area of the sea floor is completely devastated, strewn with bus-sized volcanic boulders, some so precariously perched that we had to be careful not to bump them with the sub. Compared to what I've observed here in past dives, perhaps 325 million cubic yards of volcanic rock slid into the volcano," he said.

"The currents are very tricky there. Water is flowing down into this newly formed pit on the northern end, where it percolates through the volcano, mixes with minerals and bacterial matter, then rushes out over a lip on the western edge of the volcano. We had to be careful in the sub not to get sucked down by the inflow on the north side of the volcano and buoyed up by the outflow on the western rim.

"The southern face of the volcano is the most active area now, but the whole volcano is very unstable. We think the landscape is still changing since vents that we had found in an earlier dive are no longer there. The northern end appears intact—for now," Malahoff said.

The water in the volcano is very turbid, with visibility down to about a meter in most places, clouded by a combination of dissolved minerals in the water and huge floating mats of chemosynthetic bacteria. The bacteria, which feed on dissolved nutrients, have immediately begun colonizing the new hydrothermal vents, according to University of Hawaii biologist James Cowen, who also dove into Loihi, as did his assistant Charles Holoway, on Sept. 28 and Sept. 30, respectively. Both collected samples of the chemosynthetic bacteria, which can be indicators of the type of inorganic material ejected from the vents, for follow-up studies in their laboratory.

University of Hawaii seismologist Fred Duennebier dove into the less active northern end of Loihi Sept. 29. The topography there appeared unaffected, with huge lava columns still standing. Duennebier will return to Loihi this winter to establish a permanent undersea geological observatory on the volcano to monitor future volcanic activity.

Submersible pilots Terry Kirby and Allen Wright of the Hawaii Undersea Research Laboratory operated the three-person Pisces V on all dives.