2005 Lost City Expedition

Lost City Chemistry Detectives

Focus
Chemistry of the Lost City Hydrothermal Field

Grade Level
9-12 (Chemistry/Earth Science)

Focus Question
What chemical reactions account for the appearance and characteristics of the Lost City Hydrothermal Field?

Learning Objectives
Students will be able to compare and contrast the formation processes that produce "black smokers" and the Lost City Hydrothermal Field.

Students will be able to describe the process of serpentinization, and how this process contributes to formation of chimneys at the Lost City Hydrothermal Field.

Students will be able to describe and explain the chemical reactions that produce hydrogen and methane in Lost City hydrothermal vent fluids.

Materials
- ❒ Copies of "Lost City Chemistry Detectives Worksheet," one copy for each student

Audio/Visual Materials
- ❒ (Optional) equipment for viewing online or downloaded video of vent communities

Teaching Time
One or two 45-minute class periods, plus time for student research

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Lost City
Hydrothermal vent
Peridotite
Olivine
Ultramafic
Serpentinization

Background Information
In 1977, scientists in the deep-diving submersible Alvin made the first visit to an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. In the middle of deep, cold ocean waters, they found hot springs and observed black smoke-like clouds billowing from chimneys of rock; and nearby were communities of animals that no one had ever seen before.

These hot springs came to be known as hydrothermal vents, and since that first discovery, more than 200 similar vent fields have been documented in the world's ocean. These systems are formed when seawater flowing through cracks in the seafloor crust enters magma-containing chambers beneath a spreading ridge. Intense heat from the molten rock causes a variety of chemical changes and many substances from the rocks become dissolved in the fluid. The heated fluid becomes less dense, rises upward, and emerges onto the sea floor to form a hydrothermal vent. When the heated fluid is cooled by cold water of the deep ocean, many of the dissolved materials precipitate, creating black clouds and chimneys of rock-like deposits. The hydrothermal fluid emerging from the vents is rich in sulfide, which is used as an energy source by chemosynthetic bacteria to produce essential organic substances. These autotrophic bacteria are the base of a diverse food web that includes large tubeworms (vestimentiferans), clams, mussels, limpets, polychaete worms, shrimp, and crabs.

In 2000, a different sort of vent field was serendipitously discovered on an underwater mountain called the Atlantis Massif near the Mid-Atlantic Ridge. This new field also had hot fluids venting from rocky chimneys. But these chimneys towered as much as 200 feet above the seafloor, much larger than chimneys found in other vent fields. In fact, the vent field was located 15 kilometers away from the spreading axis of the Mid-Atlantic Ridge and the chimneys looked so much like towers and spires of a fantastic city that the new vent field was named "Lost City." And the fluids emerging from the chimneys, as well as the surrounding biological communities, were unlike any other known hydrothermal system. Subsequent investigations have shown that the newly-discovered hydrothermal fields are not formed by seawater reacting with molten magma. Instead, these fields are formed when seawater reacts with solid mantle rocks. These rocks, called peridotites, are formed deep inside the Earth, but a unique type of faulting can bring them close to the seafloor. Cracks in the seafloor can allow seawater to percolate down to the up-lifted peridotites. When this happens, numerous chemical reactions occur between seawater and minerals in the rock (a process called serpentinization). These reactions produce a large amount of heat that causes the fluids to rise and eventually vent at the surface of the seafloor. Mixing between the heated fluids and cold surrounding seawater causes additional reactions that include precipitation of calcium carbonate (limestone), which forms the towering chimneys of Lost City. Because the reactions of seawater with peridotites are essential to these formations, the Lost City is called a "peridotite-hosted ecosystem."

In contrast to the abundant biological communities of hydrothermal vents formed by volcanic activity, the Lost City Hydrothermal Field (LCHF) initially appeared to be devoid of living organisms. But when scientists took a closer look at the surface of the chimneys (they actually vacuumed the surface), they found large numbers of tiny shrimps and crabs. Because most of these animals are less than one centimeter in size, transparent or translucent, and tend to hide in small crevices, they were easily overlooked when the LCHF was first discovered. While the total biomass around the LCHF vents appears to be less than at other hydrothermal vents, scientists believe there is just as much diversity (variety of different species). Like previously discovered vent communities, the LCHF ecosystem is based on microorganisms that are able to use chemicals in the vent fluids as an energy source for producing complex organic compounds that are used as food by other species (chemosynthesis). But again, the LCHF differs in that the fluids emerging from the chimneys has very little of the hydrogen sulfide and metals that are typical in hydrothermal fluids of other vent. Instead, LCHF vent fluids contain high concentrations of methane and hydrogen, and these chemicals appear to provide the energy source for chemosynthetic microbes.

In this lesson, students will apply some basic concepts of chemistry to make inferences about the geological and chemical processes that produce hydrothermal vents at Lost City.

Learning Procedure

1. To prepare for this lesson, visit the Lost City expedition's Web pages (http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html; http://www.lostcity.washington.edu/; and http://www.immersionpresents.org) for an overview of the expedition and background essays.

2. Briefly review:
   - The concepts of plate tectonics, being sure that students understand the processes that take place at convergent and divergent boundaries, and why these boundaries are often the site of volcanic activity;
   - The discovery of hydrothermal vents in 1977, the appearance of black smokers, and characteristic pH and temperature of vent fluids; and
   - The discovery of Lost City hydrothermal vents in 2000, contrasting the appearance, pH, and temperature of vent fluids with those found at black smokers.

   You may want to show video clips from some of the sites referenced in Step 1 to supplement this discussion.

3. Provide each student with a "Lost City Chemistry Detectives Worksheet", and tell students that their assignment is to develop inferences about chemical reactions that explain observations at the LCHF, and provide answers to questions on the worksheet. You may want to provide addresses for the Web sites listed in Step 1, or allow students to find these (or similar) resources for themselves.

4. Lead a discussion of students' answers to questions on the worksheet. The following points should be included:

   - Black smokers are formed when seawater enters magma-containing chambers (typcially at a spreading ridge) and is heated to temperatures ranging from 200°C to 400°C. The superheated seawater reacts with basalt, the predominant rock of the oceanic crust. These reactions change the seawater into an acidic fluid with high concentrations of dissolved iron and sulfide minerals. When the fluid emerges from a vent into cold seawater, these minerals precipitate forming the characteristic black "smoke" and metallic chimneys.

   - Hydrothermal vents at Lost City are the result of reactions between seawater and mantle rocks (instead of crustal basalt). These mantle rocks are known as peridotites, and are composed of several minerals of which olivine is the most common. Peridotites are "ultramafic," meaning that they have a very low silica content (less than 45%) and high concentrations (usually greater than 90%) of magnesium and iron. Peridotites are characteristic of the Earth's mantle, and thus are typically well below the crust. Uplifting caused by faulting, however, can raise peridotites to the surface of the crust, where they are likely to be exposed to water. Olivine (and other peridotite minerals) is unstable at temperatures below about 425°C and reacts with seawater to form the mineral serpentine. These changes cause the peridotite rock to become serpentinite rock. The overall process is known as serpentinization:

     Olivine $(Mg, Fe)_2SiO_4$ (magnesium iron silicate)

     reacts with seawater to form

     Serpentine $(Mg,Fe)_3Si_2O_5(OH)_4$ (magnesium iron silicate hydroxide)

     and

     Magnetite Fe_3O_4 (iron oxide)

   - Formation of magnetite involves oxidation of ferrous (Fe^{2+}) iron in olivine to ferric (Fe^{3+})

iron in magnetite. This process consumes oxygen from the fluid, creating reducing conditions that cause hydrogen gas (H_2) to form from reduced hydrogen ions (H^+), and methane (CH_4) to form from reduced carbonate (CO_3^{2-}) or bicarbonate (HCO_3^-) ions.

- Serpentinization reactions produce an alkaline fluid that is rich in dissolved calcium. When this fluid vents into cold seawater, calcium ions react with carbonate ions to form aragonite, $CaCO_3$ (calcium carbonate), and magnesium ions react with hydroxide ions to form brucite, $Mg(OH)_2$ (magnesium hydroxide). The LCHF chimneys are formed primarily of aragonite with lesser amounts of brucite. Over time, aragonite converts to calcite ($CaCO_3$); with the same chemical composition as aragonite, but a different—and more stable—crystal structure).

- The serpentinization reactions are exothermic and cause the peridotite rock to expand by as much as 40% as it changes to serpentinite. This expansion causes the rock to shatter, exposing more of the peridotite to water and thus extends the serpentinization reaction. This process also reduces the density of the rock from about 3.3 g/cm^3 to about 2.7 g/cm^3. Reduced density and increased volume due to expansion cause mountains composed of peridotites to become higher.

You may want to point out that serpentinization consumes large amounts of water (as much as 300 kg per cubic meter of rock) which is retained in the oceanic plates. The entire process is reversed when oceanic plates are subducted, and the water is released into the deep lithosphere and re-emerges in volcanic eruptions.

The Bridge Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Habitats," then "Deep Sea" for links to resources about hydrothermal vents.

The "Me" Connection

Have students write a brief essay describing how investigation of areas such as the "Lost City" could prove to be of personal benefit. If students have trouble with this, you may want to remind them that no one had any idea that this area even existed until it was accidentally discovered; what other totally unexpected discoveries might result from further exploration?

Connections to Other Subjects

English/Language Arts, Geography

Evaluation

Written answers to worksheet questions and group discussions provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html to keep up to date with the latest Lost City Expedition discoveries.

2. Have students research and report on areas in which peridotites are uplifted to emerge from the continental crust (in contrast to the oceanic crust, as at Lost City).

Resources

http://oceanexplorer.noaa.gov/explorations/05lostcity/welcome.html – Web site for the 2005 Lost City expedition

http://mineral.galleries.com/minerals/by-name.htm – Web site for the "Mineral Gallery," with information about the structure and chemistry of many minerals and mineral groups

http://www.oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Virtual tour of Magic Mountain, a hydrothermal vent site located on Explorer Ridge in the NE Pacific

Ocean, about 150 miles west of Vancouver Island, British Columbia, Canada.

http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – 3-dimensional structure of a "mid-ocean ridge," where two of the Earth's tectonic plates are spreading apart

http://www.bio.psu.edu/hotvents – Virtual tour of hydrothermal vent communities

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML.ps_vents.html – Links to many other Web sites with information about hydrothermal vents

Corliss, J. B., J. Dymond, L.I. Gordon, J.M. Edmond, R.P. von Herzen, R.D. Ballard, K. Green, D. Williams, A. Bainbridge, K. Crane, and T.H. Andel, 1979. Submarine thermal springs on the Galapagos Rift. Science 203:1073-1083. – Scientific journal article describing the first submersible visit to a hydrothermal vent community

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
- Chemical reactions
- Motions and forces

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

Content Standard E: Science and Technology
- Abilities of technological design

Content Standard G: History and Nature of Science
- Nature of scientific knowledge

For More Information

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

Acknowledgements

This lesson plan was produced by Mel Goodwin, PhD, The Harmony Project, Charleston, SC for the National Oceanic and Atmospheric Administration. If reproducing this lesson, please cite NOAA as the source, and provide the following URL:
http://oceanexplorer.noaa.gov

Lost City Chemistry Detectives Worksheet

"Black smokers" and Lost City hydrothermal vents are both produced by reactions between rocks and seawater, but the vent chimneys and hydrothermal fluids have very different chemistries.

1. What types of rocks are involved in these reactions?

2. How do the reactions that form Lost City hydrothermal vents help explain the presence of methane and hydrogen gas in Lost City vent fluids?

3. How do these reactions help explain the chemical composition of chimneys at the Lost City hydrothermal vents?

4. How might the chemical reactions that produce the Lost City hydrothermal vents contribute to mountain building?

Hint: Your answers should include the following terms:

basalt	serpentine	reducing conditions
peridotite	serpentinite	aragonite
olivine	serpentinization	brucite
ultramafic	magnetite	calcite