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2005 Lost City Expedition

Strange Bugs

Focus
Archaea of the Lost City Hydrothermal Field

Grade Level
9-12 (Biology/Chemistry)

Focus Question
What is the role of Archaea in biological communities at the Lost City Hydrothermal Field?

Learning Objectives
Students will be able to define "lipid biomarkers," and explain what the presence of certain biomarkers signifies.

Students will be able to describe Archaea, and explain why these organisms are often considered to be unusual.

Students will be able to compare and contrast Archaea with bacteria and eukaryotes.

Students will be able to define methanogen and methanotroph, and explain the relevance of these terms to Archaea.

Students will be able to discuss the potential significance of Archaea at the Lost City Hydrothermal Field.

Materials
- ❒ Copies of "Strange Bugs Worksheet," one copy for each student or student group

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 if students are working individually, or groups of two to four students

Maximum Number of Students
30

Key Words
Lost City
Hydrothermal field
Archaea
Methanogen
Methanotroph
Chemoautotroph

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 vents. 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 investigate what may be the strangest and most fascinating of these microbes: the archaea, whose specialty is living in some of the most extreme environments on Earth.

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.

   You may also want to review background information on lipid biomarkers and archaea at http://exobiology.arc.nasa.gov/ssx/biomarkerlab/index.html and http://www.ucmp.berkeley.edu/archaea/archaea.htm. The National Research Council publication, "Chemical Reference Materials: Setting the Standards for Ocean Science" also has a good discussion of lipid biomarkers (available as a free PDF download from: http://www.nap.edu/catalog/10476.html).

2. Briefly review:
   (a) 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 sites of volcanic activity; and
   (b) Hydrothermal vents, cold seeps, and the Lost City Hydrothermal Field emphasizing distinctions between the characteristics and origin of vented fluids. Point out that each of these habitats is associated with distinct living communities, and that they are all based on chemoautotrophic organisms that are able to thrive in conditions that would be lethal for most species and are also able to use substances in vent fluids as energy sources for the synthesis of essential compounds needed by living organisms.

3. This lesson may be undertaken as an individual student activity or by small groups of 2 - 4 students. Because the assignment requires significant student research and potentially novel concepts, the group approach provides an opportunity to distribute the work effort and for students to help each other master these concepts.

   Provide each student or student group with a copy of "Strange Bugs Worksheet" and say that their assignment is to prepare a brief report containing answers to questions on the worksheet. Encourage students to use diagrams where these would clarify their answers. You may also want to provide addresses to the resources referenced above as a starting point for student research.

4. Lead a discussion of students' answers to worksheet questions. The following points should be included:
   - Lipid biomarkers are lipid molecules that are found only in specific groups of organisms. Detection of these molecules signifies the presence of their corresponding organisms. Since lipids are major constituents of all living cells and include a wide range of biomolecules there are many potential biomarkers. Since some of these molecules can remain almost intact for billions of years, lipid biomarkers can be used to detect the presence of various groups of organisms in the fossil record.

   - Large quantities of ether-linked lipids and lesser quantities of hopanoids in extracts from crushed samples of carbonate chimneys suggest the presence of large numbers of archaea and lesser numbers of prokaryotic organisms (bacteria).

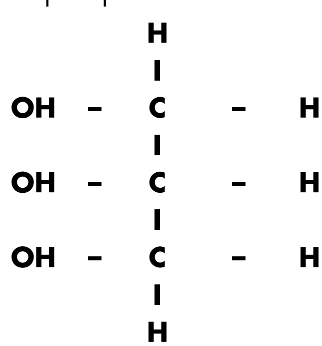
   - Archaea are microorganisms that superficially resemble bacteria, in that they are prokaryotic (they have no nucleus or internal cell membranes). But archaeal DNA is so profoundly different from other organisms that it merits classifying Archaea as an entirely separate group. Life on Earth is now classified into three "domains:" Bacteria, Eukaryota, and Archaea.

- Archaea are often considered to be unusual because many of them are "extremophiles;" that is, they prefer environmental conditions that would be considered extreme for most organisms. These environments include deep sea hydrothermal vents where temperatures are well above 100 degrees Centigrade, extremely alkaline or acid waters, extremely saline waters, and even petroleum deposits deep underground. But Archaea are not confined to "extreme" environments; they are found in many other locations, including marshes, soils, and among the plankton of the open ocean. They are also found in the digestive tracts of many animals including humans (but are not known to cause human disease).

  Archaea are also unusual in that most archaeal DNA is completely different from that of bacteria and eukaryotes. Sometimes this is referred to as "junk" DNA; but the truth is we just don't know what it does.

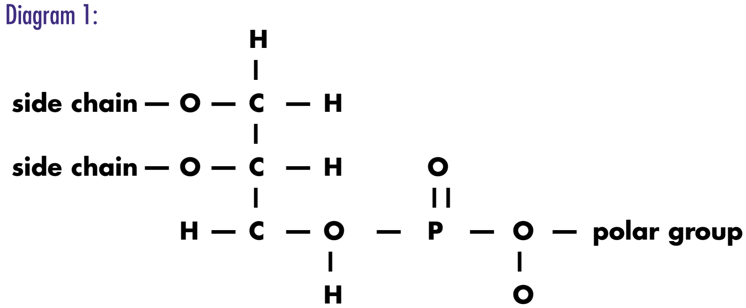
- Key structures of archaeal cells are chemically distinct from bacteria and eukaryotes. In particular, archaeal cell membranes are distinct in four ways.

  The basic "building block" for cell membranes is the phospholipid. The "backbone" of a phospholipid is a molecule of glycerol:



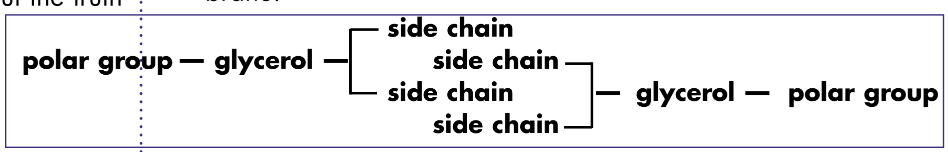
with two side chains attached at one end and a phosphate group coupled to one of various polar groups at the other end:

Diagram 1:



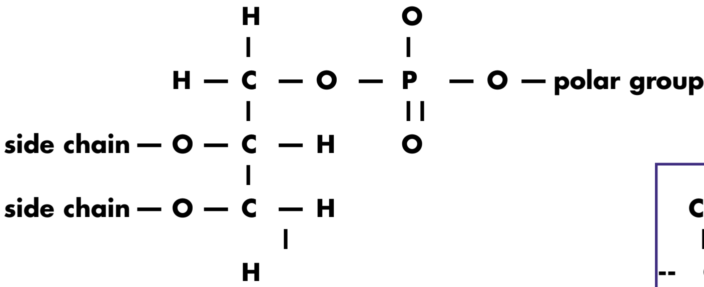
To simplify things, we can diagram this arrangement as

When multiple phospholipids are put together to form a cell membrane, they form a double layer with the side chains sandwiched in the middle and the glycerol and phosphate components oriented toward either side of the membrane:

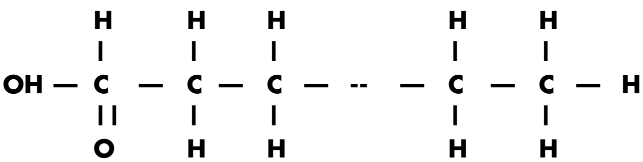


This arrangement provides a chemical barrier around the cell and helps regulate substances that move in and out of the cell's interior (note that cell membranes also contain proteins and carbohydrates; the phospholipids are just the foundation).

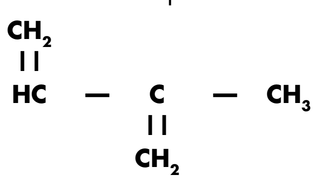
The first way that archaeal cell membranes differ from those of bacteria and eukaryotes is that the glycerol in archaeal phospholipids is a stereoisomer (mirror image) of the glycerol found in cell membranes of other domains. So instead of the arrangement shown in Diagram 1, which is typical of bacteria and eukaryotes, phospholipids of archaea would be diagrammed as:



The second way that archaeal cell membranes are different is that the side chains in phospholipids of bacteria and eukaryotes are fatty acids, which are long unbranched chains, usually of 16 to 18 carbon atoms with a carboxyl group at one end:



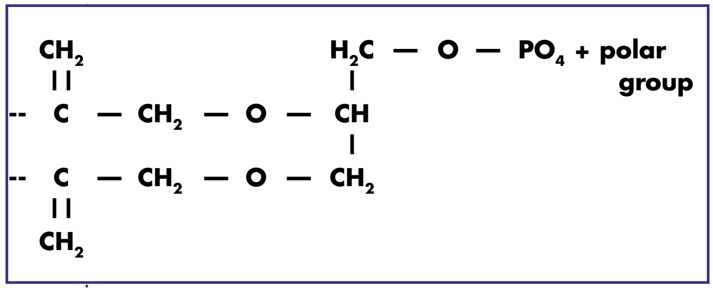
Phospholipid side chains in archaea, however, are not fatty acids, but instead are 20-carbon chains built from isoprene:



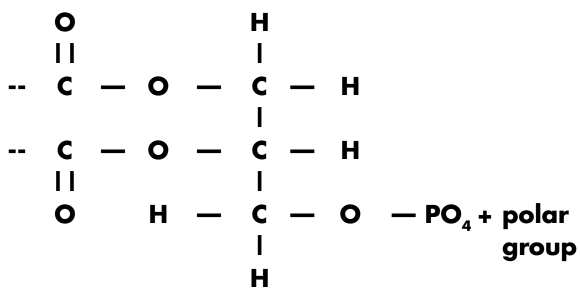
Isoprene molecules can be joined in many ways, and are used to make many synthetic products (including vitamin A, synthetic rubber, and steroid hormones) and are the most common hydrocarbon in the human body.

The branching side chains of the isoprene "building block" are the third distinctive feature of archaeal cell membranes. These branches give archaeal cell membranes some interesting properties, including the ability to form carbon rings within the membrane structure. These rings are believed to provide structural stability to the membranes, since such rings are more common in species that tolerate high temperatures.

The fourth distinctive feature of archaeal cell membranes is that the side chains are joined to the glycerol portion of the phospholipid by an ether bond:



while the fatty acid side chains in bacterial and eukaryotic phospholipids are joined with ester bonds:



This also gives the archaeal phospholipid different chemical properties than the membrane lipids of other organisms.

- Methanogens are organisms that produce methane from other chemicals.
- Methanotrophs are organisms that consume methane.
- Archaea can be methanogens as well as methanotrophs. While it is not clear that an single species of Archaea may produce methane as well as consume it, there is some evidence that this may happen. Studies at LCHF indicate that Archaea are actively producing methane, probably from hydrogen, and possibly in association with sulfate-reducing bacteria.

- The abundance of Archaea at the Lost City Hydrothermal Field suggests that these organisms may be the primary chemoautotrophs in the associated biological community, and as such provide the primary source of nutrition for many other organisms present. Just how they do this, and how much methane is produced by Archaea compared to that produced by inorganic processes are two of the many questions that remain to be answered by further exploration.

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 Archaea might be personally important or significant.

Connections to Other Subjects

English/Language Arts, Chemistry, Earth Science

Evaluation

Students reports prepared in response to worksheet questions provide opportunities for assessment.

Extensions

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

Resources

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

D. S. Kelley, J. A. Karson, G. L. Fruh-Green, D. R. Yoerger, T. M. Shank, D. A. Butterfield, J. M. Hayes, M. O. Schrenk, E. J. Olson, G. Proskurowski, M. Jakuba, A. Bradley, B. Larson, K. Ludwig, D. Glickson,K. Buckman, A. S. Bradley, W. J. Brazelton, K. Roe, M. J. Elend, R. E. Summons, and S. P. Sylva. 2005. A Serpentinite-Hosted Ecosystem: The Lost City Hydrothermal Field. Science 307:1428-1434.

Committee on Reference Materials for Ocean Science, National Research Council. 2002. Chemical Reference Materials: Setting the Standards for Ocean Science. (available as a free PDF download from: http://www.nap.edu/catalog/10476.html)

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

Tunnicliffe, V., 1992. Hydrothermal-vent communities of the deep sea. American Scientist 80: 336-349.

National Science Education Standards

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

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

Content Standard D: Earth and Space Science
- Geochemical cycles

Content Standard E: Science and Technology
- Understandings about science and technology

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

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

For More Information

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http://oceanexplorer.noaa.gov

Strange Bugs Worksheet

1. What are lipid biomarkers?

2. Previous expeditions to the Lost City Hydrothermal Field found large quantities of ether-linked lipids and lesser quantities of hopanoids in extracts from crushed samples of carbonate chimneys. What do these observations suggest (see Table 1)?

3. What are Archaea?

4. Why are Archaea often considered to be unusual?

5. How are Archaea different from bacteria and eukaryotes?

6. What are methanogens?

7. What are methanotrophs?

8. Are Archaea methanogens or methanotrophs?

9. What is the potential significance of Archaea at the Lost City Hydrothermal Field?

Strange Bugs Worksheet
Table 1
Examples of Microbial Biomarkers and Potential Source Organisms

(source: Committee on Reference Materials for Ocean Science, National Research Council; see "Resources")

Biomarker	Potential Source Organism(s)
Tetrapyrroles	
Divinyl chlorophylls a and b	*Prochlorococcus spp.*
Monovinyl chlorophyll b	Chlorophytes, prasinophytes
Chlorophylls c1, c2 and c3	Chromophyte microalgae
Bacteriochlorophyll a	Anoxygenic photosynthetic bacteria
Carotenoids	
Peridinin	Dinoflagellates
Fucoxanthin	Diatoms
19'-butanoyloxyfucoxanthin	Pelagophytes
19'-hexanoyloxyfucoxanthin	Haptophytes
Alloxanthin	Cryptophytes
Prasinoxanthin	Prasinophytes
Lutein	Chlorophytes
Zeaxanthin	Cyanobacteria, chlorophytes
C20 isoprenoids	
Phytol	Photoautotrophs
All trans-retinal	Proteobacteria
Ether-linked lipids	Archaea
Sterols	
Dinosterol	Dinoflagellates
24-methylcholesta-5,22E-dien-3,-ol	Diatoms, Haptophytes
24-methylcholesta-5,24(28)-dien-3 ,-ol	Diatoms
24-methyl cholest-5-en-3,-ol	Chlorophytes
Hopanoids	
Diploptene, hopanoic acids	Prokaryotes, including cyanobacteria
Lipopolysaccharides (LPS)	Gram-negative bacteria
Polar lipid fatty acids	
Branched-chain C15 and C17 acids	Bacteria, especially *Bacillus spp.*
Peptidoglycan	
D-amino acids	Bacteria, mainly gram-positive strains