2006 Exploring Ancient Coral Gardens

No Escape

(adapted from The Mountains in the Sea 2003 Expedition)

Focus

Fate of benthic invertebrate larvae in the vicinity of seamounts

Grade Level

9-12 (Earth Science)

Focus Question

Are floating larvae retained in the vicinity of seamounts by patterns of water circulation?

Learning Objectives

Students will be able to field data to evaluate an hypothesis about the influence of a water circulation cell on the retention of benthic invertebrate larvae in the vicinity of a seamount.

Students will be able to describe some potential advantages and disadvantages to species whose larvae are retained in the vicinity of seamounts where the larvae are produced.

Students will be able to describe the consequences of partial or total larval retention on the biological evolution of species producing these larvae.

Materials

❒ "Three-dimensional Diagram of Mean Flows in the Fieberling Guyot Circulation Cell" and "Topographic Map of Fieberling Guyot," copied onto an overhead transparency

❒ "Abundance of Hydroids Colonizing Settlement Plates Around Fieberling Guyot," one copy for each student group

❒ "Settlement Plate Data Summary Sheets," one copy for each student group

Audio/Visual Materials

Overhead projector

Teaching Time

One 45-minute class periods

Seating Arrangement

Groups of approximately four students

Maximum Number of Students

30

Key Words

Seamount
Biodiversity
Endemic
Circulation cell
Hydroid
Settlement plate
Plankton tow

Background Information

Seamounts are undersea mountains formed by volcanic processes, either as isolated peaks or as chains that may be thousands of miles long 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 many species of plant, animal, and microbial organisms. Recently, increasing attention is being directed toward deep water coral species found on seamounts. In contrast to shallow-water coral reefs, deep-sea coral communities are virtually unknown to the general public and have received much less scientific study. Yet, deep-water coral ecosystems may have a diversity of species comparable to that of corals reefs in shallow waters. Because many seamount species are endemic (that is, they are found nowhere else), these ecosystems may be a unique feature of seamounts, and are likely to be important for several reasons. First, because of their high biological productivity, these communities are directly associated with important commercial fisheries. Moreover, deep-sea corals have been identified as promising sources for new drugs to treat cancer and other diseases, as well as natural pesticides and nutritional substances. Recent discoveries suggesting that some corals may be hundreds of years old means that these organisms can provide important records of past climactic conditions in the deep ocean. Apart from these potential benefits, deep-sea corals are part of our world heritage—the environment we hand down from one generation to the next.

Despite their importance, there is growing concern about the impact of human activities on these ecosystems. Commercial fisheries, particularly fisheries that use trawling gear, cause severe damage to seamount habitats. Scientists at the First International Symposium on Deep Sea Corals (August, 2000), warned that more than half of the world's deep-sea coral reefs have been destroyed. Ironically, some scientists believe that destruction of deep-sea corals by bottom trawlers is responsible for the decline of major fisheries such as cod.

In addition to impacts from fisheries, deep-sea coral communities can also be damaged by oil and mineral exploration, ocean dumping, and unregulated collecting. Other impacts may result from efforts to mitigate increasing levels of atmospheric carbon dioxide. One proposed mitigation is to sequester large quantities of the gas in the deep ocean, either by injecting liquid carbon dioxide into deep ocean areas where it would form a stable layer on the sea floor or by dropping torpedo-shaped blocks of solid carbon dioxide through the water column to eventually penetrate deep into benthic sediments. While the actual impacts are not known, some scientists speculate that since coral skeletons are made of calcium carbonate, their growth would probably decrease if more carbon dioxide were dissolved in the ocean.

The Davidson Seamount, located about 75 miles southwest of Monterey, CA, was the first geological feature to be described as a "seamount" in 1933. The now-extinct volcanoes that formed this and other nearby seamounts were different from typical ocean volcanoes. While the typical undersea volcano is steep-sided, with a flat top and a crater, seamounts in the Davidson vicinity are formed of parallel ridges topped by a series of knobs. These observations suggest that the ridges were formed by many small eruptions that occurred 3 to 5 million years apart. Typical undersea volcanoes are formed by more violent eruptions that gush out lava more frequently over several hundred thousand years.

Although it was the first recognized seamount and is relatively near the U.S. coast, the Davidson Seamount is still 99.98% unexplored. In 2002, a NOAA-funded expedition to the Seamount found a wide variety of organisms, including extensive deep-water coral communities. Among many intriguing discoveries were observations of animals that had never been seen live before, as well as indications that some coral species may be several hundred years old (visit http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html and http://montereybay.noaa.gov/reports/2002/eco/ocean.html for more information about the 2002 Expedition).

The 2006 Exploring Ancient Coral Gardens Expedition is focussed on learning more about deep-sea corals at Davidson Seamount, with four general goals:

- to understand why deep-sea corals live where

they do on the seamount;
- to determine the age and growth patterns of the bamboo coral;
- to improve the species list and taxonomy of corals from the seamount; and
- to share the exciting experience with the public through television and the Internet.

Seamounts are good places to look for new species because they are relatively isolated from each other and from other marine habitats. This means that seamounts can vary greatly in their biodiversity (the number of different species present) and can also have a high degree of endemism. A key factor that affects biodiversity and endemism is the reproductive strategy used by benthic seamount species. Most benthic marine invertebrates produce free-swimming or floating planktonic larvae that can be carried for many miles by ocean currents until the larvae settle to the bottom and change (metamorphose) into juvenile animals that usually resemble adults of the species. A longer larval phase allows for greater dispersal, and gives the species a wider geographic range.

On the other hand, species with shorter larval stages do not have the advantage of broad dispersal, but are able to remain in favorable local environments. Some species do not have a free larval stage, but brood their larvae inside the adult animal or in egg cases until metamorphosis. Other forces may tend to keep larvae from drifting away. Seamounts are often exposed to strong, steady ocean currents. When these currents impinge on a seamount, they cause an upwelling of deep cold water. This cold water has a higher density than surrounding water and tends to sink. This combination of water movements can cause an eddy to form that is known as a Taylor column. Taylor columns may remain over seamounts for several weeks, and can effectively trap larvae that would otherwise be carried away.

A key factor in protecting seamount communities is to understand the reproductive strategies used by benthic seamount species. If these species are able to keep their offspring nearby, protecting selected seamounts could be an effective way to improve populations of corals and other species on those seamounts that may have been damaged by human activities or natural events. But if the larvae produced on a protected seamount were actually carried far away from the protected area, protecting only a few seamounts might not produce major improvements to benthic communities on these seamounts.

The question of reproductive strategy is fundamental to protecting and managing seamount resources. This lesson builds on results of studies described in the "Round and Round" lesson plan (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf). These studies showed that currents in the vicinity of one seamount formed a circulation cell that might tend to keep free-floating larvae in the vicinity of the seamount. This lesson is based on studies that were undertaken to test this hypothesis of larval retention by seamount-generated water flows.

Learning Procedure

1. To prepare for this lesson, read the introductory essays for the 2006 Exploring Ancient Coral Gardens Expedition at http://oceanexplorer.noaa.gov/explorations/06davidson/welcome.html, and review the NOAA Learning Object on deep-sea corals at http://www.learningdemo.com/noaa/. Explain that while seamounts have not been extensively explored, 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. Briefly describe reproduction used by many benthic invertebrates that results in the production of larvae.

3. If students have completed the "Round and Round" lesson, remind them of the circulation cell diagrammed in "Three-dimensional

Diagram of Mean Flows in the Fieberling Guyot Circulation Cell." Students should understand that this model suggests that larvae might be retained in a pancake-shaped region centered directly over the seamount center, extending vertically several hundred meters, and horizontally at least 7 km (possibly as far as 40 km). Proceed to Step #4.

If students have not completed the "Round and Round" lesson, show them "Topographic Map of Fieberling Guyot" and say that a year-long study of currents on and around the seamount used current meters were located at the center of the seamount (C), two on the rim of the seamount (R1 and R2), two on the slope (or "flank") of the seamount (F1 and F2), and two on the seabottom plain roughly 25 km from the base of the seamount (B1 and B2). The study found that water near the surface of the seamount moves outward from its center. Near the rim and flank of the seamount, water begins to move upward (toward the surface) and inward (back toward the center of the seamount). Over the center of the seamount and about 50 m above the seamount surface, water circulation is strongly downward, and is carried back toward the seamount surface. As the object moves through this vertical circulation cycle, it also moves in a generally clockwise direction. At stations B1 and B2, currents are weak with no definite circulation pattern. Show students "Three-dimensional Diagram of Mean Flows in the Fieberling Guyot Circulation Cell," and briefly discuss how this circulation pattern might affect free-floating larvae. Students should understand that this model suggests that larvae might be retained in a pancake-shaped region centered directly over the seamount center, extending vertically several hundred meters, and horizontally at least 7 km (possibly as far as 40 km).

4. Show students "Topographic Map of Fieberling Guyot." Tell students that the purpose of this study was to test the hypothesis that larvae from benthic invertebrates on the seamount will accumulate in a region that corresponds to the extent of the circulation cell. Two techniques were used to sample larvae around Fieberling Guyot to test this hypothesis. The first technique was to sample larvae with plankton nets towed from a research vessel at various depths. This technique allows scientists to identify the locations in which larvae are most likely to be found. A disadvantage is that samples are taken over a very short time span, so if larvae of some benthic animals may not be found if those animals produce their larvae at times other than those sampled.

The second technique was to sample larvae by providing artificial surfaces onto which larvae might settle and grow. After the artificial surfaces have been in place for the desired period of time (usually several months or more), they are retrieved and the attached animals are identified and counted. The advantage of this method is that larvae are sampled over a long period of time. A disadvantage is that larvae of some species may prefer other substrates and fail to attach to the artificial surfaces. In this study, plastic plates were attached to mooring lines located at the seamount center (C and RF), rim (R1, R2, and SPR), flank (F1 and F2), and seabottom (B1 and B2). The plates were attached so that they could rotate freely around the mooring line and orient themselves parallel to the current flow. Four plates, each 23 cm x 28 cm, were attached at depths of about 500 m and 1500 m. At the RF and SPR sites, plates were attached 1 m, 5 m, 10 m, 20 m, and 40 m above the bottom to obtain additional information on larval abundances near the seamount surface. Three moorings were used at each of the RF and SPR sites, and the plates were retrieved after six months. Plates at the other sites were retrieved after one year.

5. Tell students that results from plankton tows showed that the most abundant larvae belonged to the same taxonomic groups that are abundant on the seamount surface: cnidarians, polychaetes, and gastropods. The plankton tows did not, however, contain larvae from taxonomic groups that are abundant in deepsea sediments (other types of polychaetes, tanaids, bivalves, and isopods). The scientists concluded from these data that larvae in the plankton tows came from benthic animals living on the seamount.

6. Provide each student group with a copy of "Abundance of Hydroids Colonizing Settlement Plates Around Fieberling Guyot" and "Settlement Plate Data Summary Sheet." Tell students that rough weather during recovery of the plates damaged, and may have dislodged, some of the attached organisms. One species of hydroid, however, had very strong attachments and investigators were able to count and identify this species.

   Have each student group fill in the Data Summary Sheet using information from "Abundance of Hydroids Colonizing Settlement Plates Around Fieberling Guyot." Each rectangle on the Data Summary Sheet corresponds to a particular depth and sampling station. Students should shade each rectangle to indicate the number of hydroids recovered from that location. Point out that the scale for stations RF and SPR is different from that used for other stations because settlement plates at stations RF and SPR were intended to sample larvae close to the bottom, while plates at the other stations were intended to reveal differences in larval abundance at deep (about 1500 m) and shallower (300 m – 750 m) locations.

7. Lead a discussion about the summarized data. Students should recognize that hydroid colonization occurred at all but one of the sampling stations, and that colonization was limited to a depth range of 450 – 500 m. These observations are consistent with the hypothesis that larvae from benthic invertebrates on the seamount accumulate in a pancake-shaped region that corresponds to the extent of the circulation cell.

   Students should also recognize that data from stations RF and SPR indicate that hydroid colonization decreases with increasing distance from the bottom. Ask students to speculate on why this might be the case. Some suggestions are that larvae may be attracted to areas that are close to adult populations of the same species, since these areas would have suitable conditions for the species. Another possibility is that differences in water flow conditions close to the surface (such as drag from bottom features that would decrease current flow) cause larvae to accumulate. The vertical distribution of hydroids found at these sites is consistent with the primary hypothesis, but is not predicted by the hypothesis. The investigators are not sure why this distribution occurred.

   Ask students to speculate on the implications of larval retention to seamount ecosystems and species. Students should recognize that if the larvae of benthic seamount species tend to be retained on one or a few specific seamounts, then those species will have reduced exchange of genetic material with other populations of their species. If populations are completly isolated, then they may evolve into new species. This is probably fairly rare, since most seamounts occur in chains. Water circulation around these chains is primarily influenced by the topography of the entire chain.

   Students may wonder whether data from only one species are sufficient to draw general conclusions about the behavior of the larvae of many species. This is a legitimate concern, and is a good opportunity to point out that it is usually impossible to absolutely prove a hypothesis, since it only takes one exception to show that a hypothesis is not always valid. In fact, many other species were also recovered from the settlement plates at stations RF and SPR, including ciliates, anemones, other hydroids, serpulid polychaetes, and ascidians. These species were not included in the analyses, however, to maintain consistency with analyses of data from other stations.

The Bridge Connection

www.vims.edu/bridge/ –Click on "Ocean Science Topics." In the "Ocean Science Topics" menu, click on "Physics."

The "Me" Connection

Ask students whether they think additional investigations are needed of the hypothesis presented in Step #3, and if so, what measurements or experiments should be undertaken.

Connections to Other Subjects

Earth Science; Physics

Assessment

Develop a rubric for grading students' performance in completing Step #5. This could include accuracy, attention to instructions, and appearance of the final summary sheet. Have students prepare individual written interpretations of their data summaries (Step #6) prior to the group discussion.

Extensions

Log on to http://oceanexplorer.noaa.gov to keep up to date with the latest Davidson Seamount Expedition discoveries, and to find out what researchers are learning about deep-water hard-bottom communities.

Resources

NOAA Learning Objects

http://www.learningdemo.com/noaa/ – Click on the link to "Lesson 3 – Deep-Sea Corals" for an interactive multimedia presentation on deep-sea corals, as well as Learning Activities and additional information on global impacts and deep-sea coral communities.

Other Relevant Lesson Plans from the Ocean Exploration Program

Cool Corals (http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf; (7 pages, 476k)

Focus: Biology and ecology of *Lophelia* corals (Life Science)

Students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

What's the Difference? (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_difference.pdf; (15 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Identification of biological communities from survey data (Life Science)

Students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

Round and Round (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf; (11 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Circulation cells in the vicinity of seamounts (Earth Science)

Students will be able to interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation, hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae, and describe the importance of measurements to verify theoretical predictions.

A Tough Neighborhood (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_toughhood.pdf; (4 pages, 244k) (from The Charleston Bump 2003 Expedition)

Focus: Adaptations of benthic organisms to deep water, hard substrates, and strong currents (Life Science)

Students will be able to describe at least three attributes of the deep ocean physical environment that are radically different from ocean habitats near the sea surface and explain at least three morphological or physiological adaptations that allow organisms to survive in the physical environment of the deep ocean. Students will also be able to identify at least three organisms with adaptations to the deep ocean environment that are found (or may be found) on the Charleston Bump.

Keep It Complex! (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_complex.pdf; (5 pages, 272k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of habitat complexity on biological diversity (Life Science)

Students will be able to describe the significance of complexity in benthic habitats to organisms that live in these habitats and will describe at least three attributes of benthic habitats that can increase the physical complexity of these habitats. Students will also be able to give examples of organisms that increase the structural complexity of their communities and infer and explain relationships between species diversity and habitat complexity in benthic communities.

Eddies, Gyres, and Drowning Machines (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_eddies.pdf; (5 pages, 256k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of bottom topography on currents (Physical Science/Earth Science)

Students will be able to describe at least three types of effects that physical obstructions may have on water flowing past the obstructions, explain at least three ways in which current flow can be significant to benthic organisms, and explain how physical obstructions to current flow can create hazardous swimming conditions.

Top to Bottom (http://oceanexplorer.noaa.gov/explorations/05stepstones/background/education/ss_2005_topbottom.pdf; (7 pages, 348k) (from the North Atlantic Stepping Stones 2005 Expedition)

Focus (Earth Science/Life Science) - Impacts of climate change on biological communities of the deep ocean

Students will be able to describe thermohaline circulation, explain how climate change might affect thermohaline circulation, and identify the time scale over which such effects might take place. Students will also be able to explain how warmer temperatures might affect wind-driven surface currents and how these effects might impact biological communities of the deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

Designing Tools for Ocean Exploration (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_designingtools.pdf; (13 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Ocean Exploration

Students will understand the complexity of ocean exploration; students will understand the technological applications and capabilities required for ocean exploration; students will understand the importance of teamwork in scientific research projects; students will develop abilities necessary to do scientific inquiry.

Living in Extreme Environments (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_extremeenv.pdf; (12 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Biological Sampling Methods (Biological Science)

In this activity, students will understand the use of four methods commonly used by scientists to sample populations; students will understand how to gather, record, and analyze data from a scientific investigation; students will begin to think about what organisms need in order to survive; students will understand the concept of interdependence of organisms.

Mystery of the Alaskan Seamounts (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/mystery9_12.pdf; (9 pages, 132k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Earth Science - Formation of seamounts in the Axial-Cobb-Eikelberg-Patton chain, Gulf of Alaska
Students will be able to describe the processes that form seamounts, learn how isotope ratios can be used to determine the age of volcanic rock, and interpret basalt rock age data from seamounts in the Gulf of Alaska to investigate a hypothesis for the origin of these seamounts.

Are You Related? (http://oceanexplorer.noaa.gov/explorations/05deepcorals/background/edu/media/05deepcorals_related.pdf; (11 pages, 465k) (from the Florida Coast Deep Corals 2005 Expedition)

Focus: Molecular genetics of deepwater corals (Life Science)

Students will define "microsatellite markers" and explain how they may be used to identify different populations and species, explain two definitions of "species," and describe processes that result in speciation. Students will also use microsatellite data to make inferences about populations of deep sea corals.

How Does Your (Coral) Garden Grow? (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf; (6 pages, 456k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Growth rate estimates based on isotope ratios (Life Science/Chemistry)

Students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

Gellin (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf; (4 pages,

372k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)
Focus: DNA analysis

Students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Breaking Away (Or Not . . .) (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/breaking9_12.pdf; (5 pages, 96k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Life Science - Reproductive/developmental strategies of some benthic seamount species

Students will be able to compare and contrast common reproductive strategies used by benthic invertebrates, describe the most common reproductive strategies among benthic invertebrates on a seamount and explain why these strategies are appropriate to seamount conditions. Students will also describe how certain reproductive strategies favor survival of species on seamounts and what changes on seamounts might favor other strategies, and discuss the implications of reproductive strategy to the conservation and protection of seamount communities.

Other Links and Resources

Brink, K. H. 1995. *Tidal and lower frequency currents above Fieberling Guyot.* J. of Geophysical Research, 100:10,817-10,832; and Mullineaux, L. S. and S. W. Mills. 1997. A test of the larval retention hypothesis in seamount-generated flows. Deep-Sea Research 44:745-770. The journal articles on which this activity is based.

http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html – Daily logs, photos, video clips, and backgrounds essays on the 2002 Davidson Seamount Expedition

http://montereybay.noaa.gov/reports/2002/eco/ocean.html – Web page from the Monterey Bay National Marine Sanctuary describing the 2002 exploration of the Davidson Seamount

http://www.mbari.org/ghgases/ – Web page from the Monterey Bay Aquarium Research Institute describing MBARI's work on the Ocean Chemistry of Greenhouse Gases, including work on the potential effects of ocean sequestration of carbon dioxide

http://seamounts.edsc.edu/main.html — Web site sponsored by the National Science Foundation

Pickrell, J. 2004. Trawlers Destroying Deep-Sea Reefs, Scientists Say. National Geographic News. http://news.nationalgeographic.com/news/2004/02/0219_040219_seacorals.html

http://www.mcbi.org/Current_Magazine/Current_Magazine.htm – A special issue of Current: the Journal of Marine Education on deep-sea corals.

Morgan, L. E. 2005. What are deep-sea corals? Current 21(4):2-4; available online at http://www.mcbi.org/Current_Magazine/What_are_DSC.pdf

Reed, J. K. and S. W. Ross. 2005. Deep-water reefs off the southeastern U.S.: Recent discoveries and research. Current 21(4): 33-37; available online at http://www.mcbi.org/Current_Magazine/Southeastern_US.pdf

Frame, C. and H. Gillelan. 2005. Threats to deep-sea corals and their conservation in U.S. waters. Current 21(4):46-47; available online at http://www.mcbi.org/Current_Magazine/Threats_Conservation.pdf

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://www.oceana.org/uploads/oceana_coral_report.pdf — Background on deep-water coral reefs

http://www.oceanicresearch.org/ – The Oceanic Research Group Web site; lots of photos, but note that they are very explicit about their copyrights; check out "Cnidarians: Simple but Deadly Animals!" by Jonathan Bird, which provides an easy introduction designed for classroom use

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

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

- Motion and forces

Content Standard C: Life Science

- Biological evolution
- Matter, energy and organization in living systems
- Behavior

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard G: History and Nature of Science

- Nature of scientific knowledge

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

- *Fundamental Concept b.* An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates.
- *Fundamental Concept h.* Although the ocean is large, it is finite and resources are limited.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

- *Fundamental Concept c.* Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
- *Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
- *Fundamental Concept e.* The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
- *Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

- *Fundamental Concept b.* From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
- *Fundamental Concept c.* The ocean is a source of inspiration, recreation, rejuvenation

and discovery. It is also an important element in the heritage of many cultures.

- *Fundamental Concept e.* Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
- *Fundamental Concept g.* Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

- *Fundamental Concept a.* The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
- *Fundamental Concept b.* Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
- *Fundamental Concept c.* Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.
- *Fundamental Concept d.* New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
- *Fundamental Concept f.* Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

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

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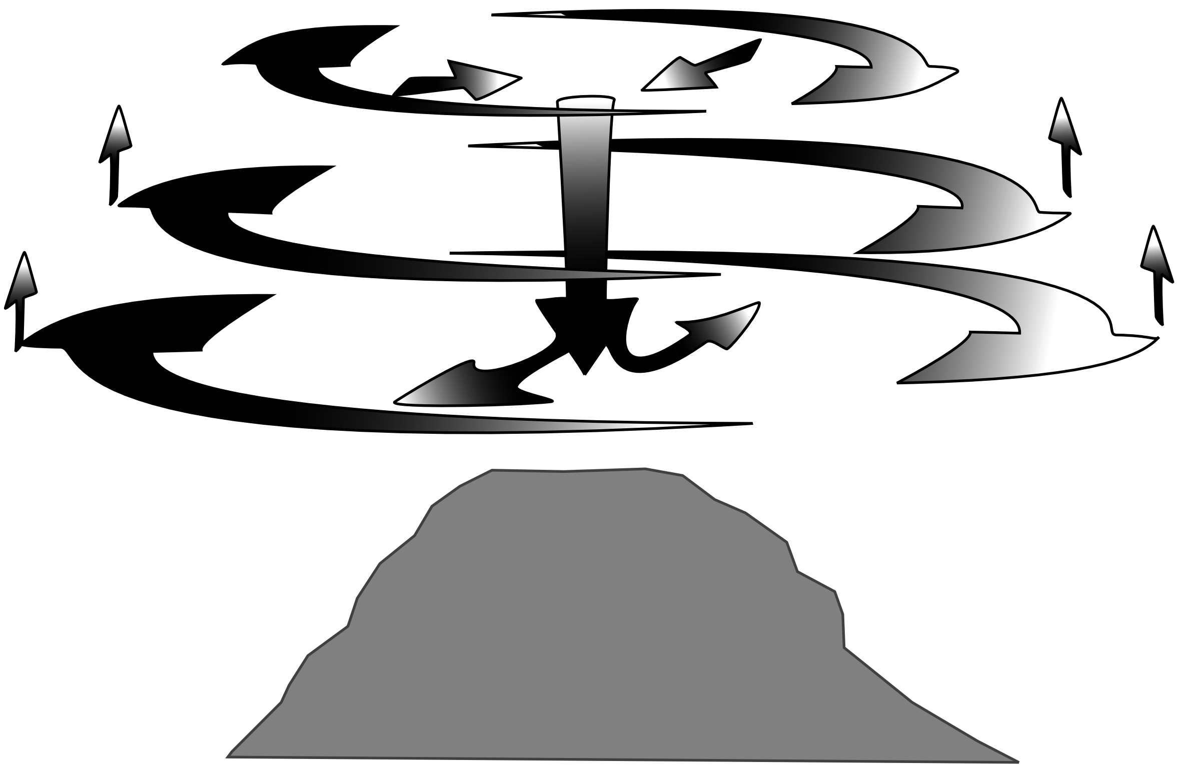
Student Handout

Three-dimensional Diagram of Mean Flows in the Fieberling Guyot Circulation Cell

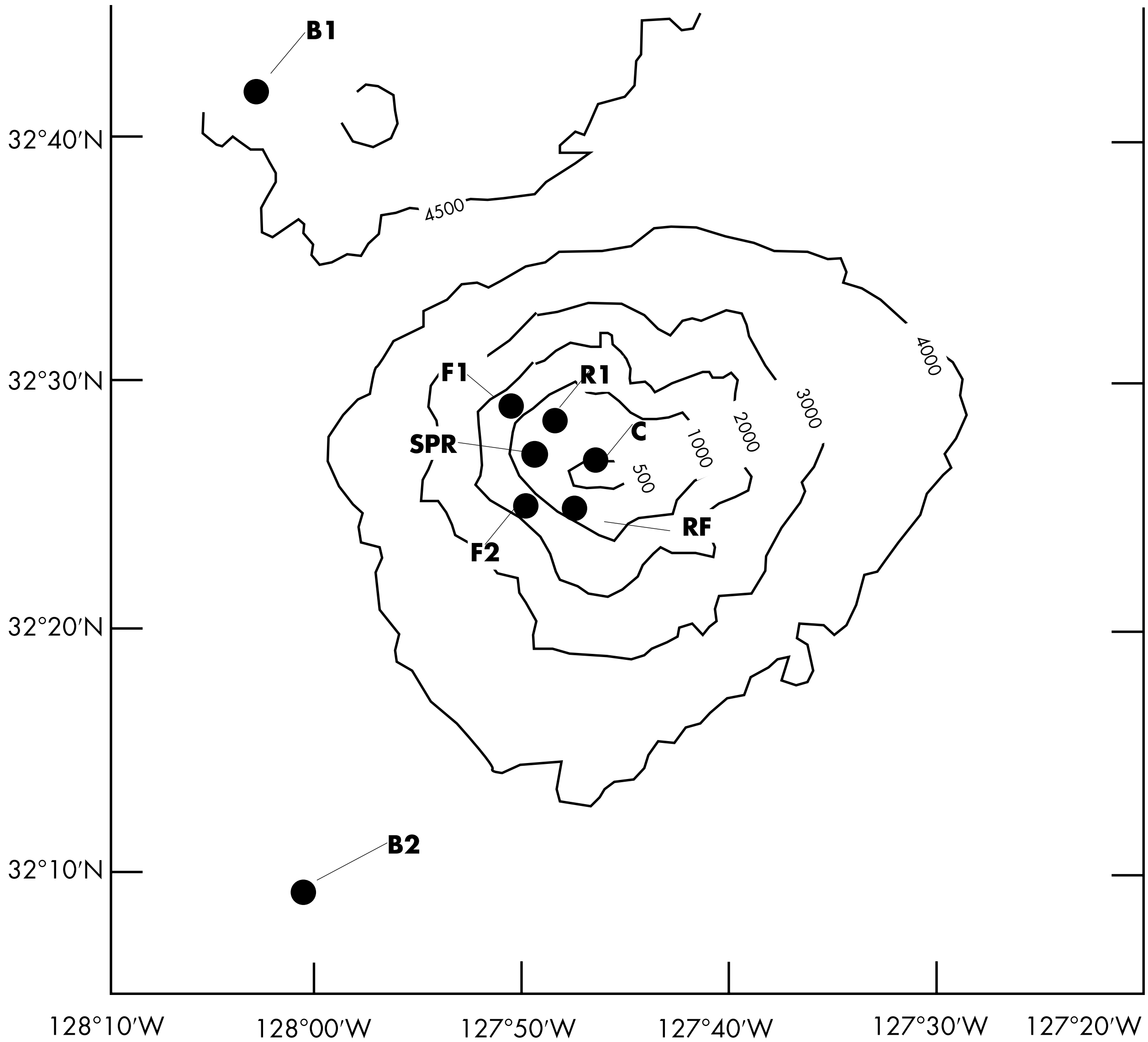
(redrawn from Mullineaux and Mills, 1997)



Student Handout

Topographic Map of Fieberling Guyot

Depths in meters
(redrawn from Mullineaux and Mills, 1997)



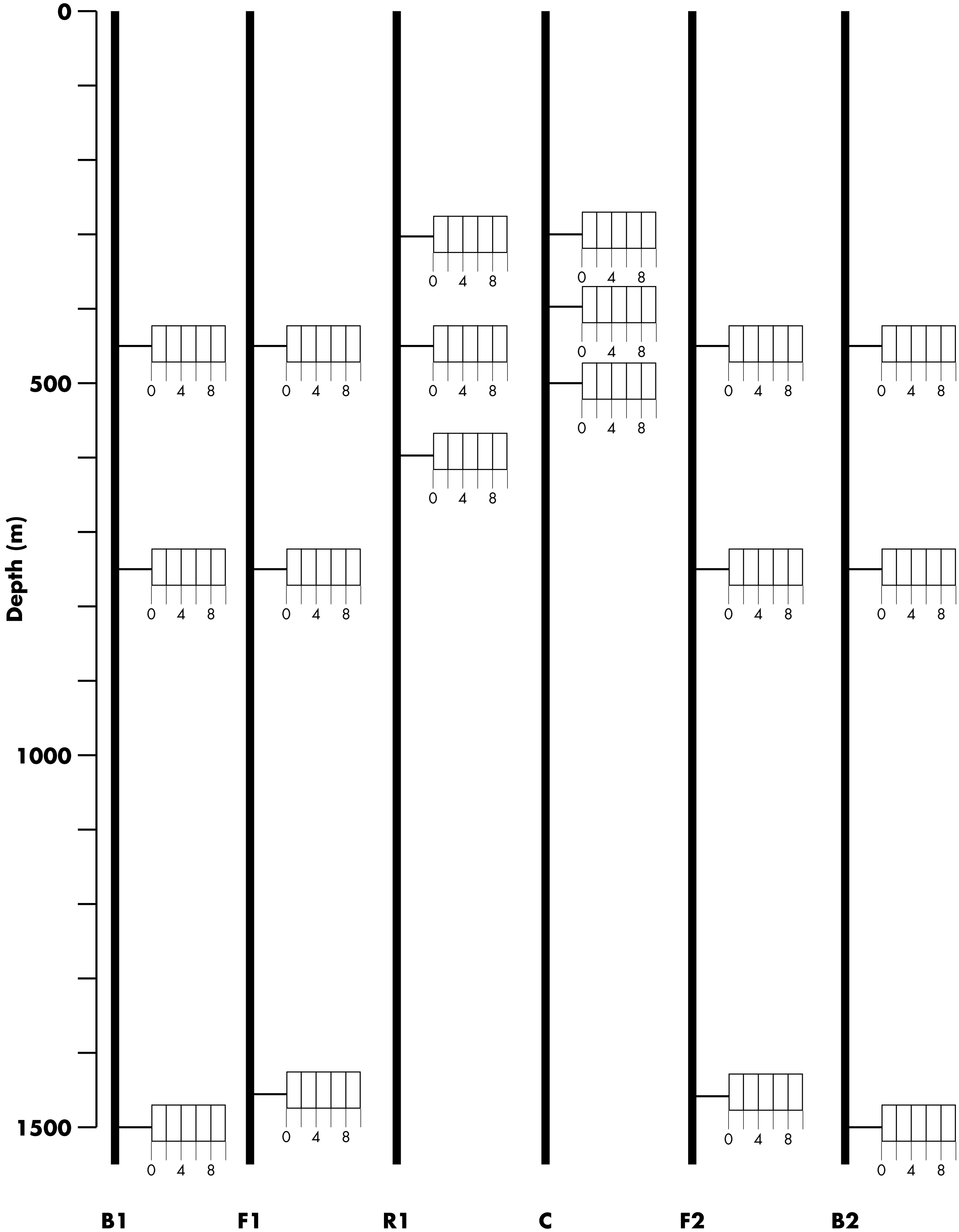
Student Handout

Abundance of Hydroids Colonizing Settlement Plates Around Fieberling Guyot

Location	Depth (m)	Distance Above Bottom (m)	Hydroids (number of individuals)
C	300	215	0
C	400	115	0
C	500	15	4
RF1	450	40	2
RF1	470	20	0
RF1	480	10	2
RF1	485	5	6
RF1	489	1	12
RF2	450	40	0
RF2	470	20	0
RF2	480	10	0
RF2	485	5	4
RF2	489	1	14
RF3	450	40	0
RF3	470	20	0
RF3	480	10	0
RF3	485	5	2
RF3	489	1	6
R1	300	286	0
R1	450	136	2
R1	550	36	6
SPR1	598	40	0
SPR1	618	20	2
SPR1	628	10	2
SPR1	633	5	8
SPR1	637	1	10

Student Handout

Settlement Plate Data Summary Sheet for Locations C, R1, F1, F2, B1, B2



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Settlement Plate Data Summary Sheet for Locations RF1, RF2, RF3, SPR1, SPR2, SPR3