Mountains in the Sea Exploration

Round and Round

Focus
Circulation cells in the vicinity of seamounts

Grade Level
9-12 (Earth Science)

Focus Question
Are there unusual patterns of water circulation in the vicinity of seamounts?

Learning Objectives
Students will be able to interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation.

Students will be able to hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae.

Students will be able to describe the importance of measurements to verify theoretical predictions.

Materials
- ❒ "Topographic Map of Fieberling Guyot" and "Current Modeling Setup;" one copy for each student group, or one copy on an overhead transparency
- ❒ "Data Table for Mean Direction and Velocity of Currents Above Fieberling Guyot;" one copy for each student group
- ❒ "Current Arrows" and "Radial Direction" arrows, copied onto card stock; 21 "Current Arrows," 11 "Radial Direction" arrows
- ❒ Enlarged copy of "Three-dimensional Diagram of Mean Flows in the Fieberling Guyot Circulation Cell," or upload this page of the pdf file to an interactive white board or other display system

Audio/Visual Materials
Interactive white board or other display system

Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of approximately four students

Maximum Number of Students
30

Key Words
Seamount
Biodiversity
Endemic
Circulation cell
Current meter

Background Information
Seamounts are undersea mountains formed by volcanic processes, either as isolated peaks or as chains that may be thousands of miles long. In the Atlantic Ocean, the New England Seamounts form a chain of more than 30 peaks that begins near the coast of New England and extends 1,600 km to the southeast. Some of the peaks are more than 4,000 m above the deep-sea floor — similar to the heights of major peaks in the Alps. A guyot is a seamount, more than 200 m

deep, with a flattened top caused by weathering and wave action that took place when the top of the volcano was at or above sea level. Compared to the surrounding ocean waters, seamounts have high biological productivity, and provide habitats for a variety of plant, animal, and microbial species.

Bear Seamount is the closest of the New England Seamounts to the coast of the United States, and rises from a depth of 2,000 - 3,000 m to a summit that is 1,100 m below the sea surface. Previous investigations have found numerous invertebrates, including cephalopods, crustaceans, and more than a hundred other species in 10 different phyla. These investigations also found more than 100 species of fishes, some of which are commercially important. Several species discovered at Bear Seamount were previously unknown to science.

Unfortunately, seamount habitats are easily damaged by commercial trawl fishing. At the First International Symposium on Deep Sea Corals (August, 2000), scientists warned that more than half of the world's deep-sea coral reefs have been destroyed, and some believe that destruction of deep-sea corals by bottom trawlers is responsible for the decline of major fisheries, such as cod. Seamounts are important for other reasons in addition to commercial fisheries. Because the biological communities of seamounts have not been well-studied, these communities are likely to contain significant numbers of species that are not yet known to science. Some of these species may provide drugs that can directly benefit human beings.

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 (endemic species are species that are only found around seamounts). 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 takes place. 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, and is one of the focal points of the Ocean Exploration 2003 Mountains in the Sea Expedition. Though there have been many theoretical studies of what water movements might occur around seamounts, there have been few actual measurements that can show what is really happening. In this activity, students will analyze actual measurements of currents around a seamount in the North Pacific Ocean. As often happens, the results are different than the scientists expected, showing the importance of direct observations to improve our knowledge of how nature really works.

Learning Procedure

1. Prepare wood dowel assemblies as shown in "Current Modeling Setup."

2. Explain that seamounts are the remains of underwater volcanoes, and that they are islands of productivity compared to the surrounding environment.

   Although 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. Describe the major reproductive strategies found among benthic invertebrates, and explain that this activity is intended to help understand which strategies are actually used on one seamount.

3. Show students "Topographic Map of Fieberling Guyot." Tell students that the purpose of this study was to make direct measurements of currents at various points on and around the seamount over a one-year period to discover how water actually moves around these undersea mountains. Explain that these measurements were made with current meters attached to a cable that was anchored to the bottom at one end, and suspended by a buoy at the other end.

   Several meters were located at various depths along each cable so that water motion could be studied at intervals throughout the water column. Each cable with its attached current meters is called an array.

   Each current meter is capable of recording water movement in three directions, similar to the x-, y-, and z- axes of a three-dimensional graph. These directions are
   - Radial - the direction of water movement relative to the center of the seamount (that is, toward or away from the center of the seamount);
   - Azimuthal - the direction of water movement relative to a fixed horizontal reference point (in nautical navigation, the azimuthal reference point is true north); and
   - Vertical - the up-down direction of movement in the water column.

   Point out the locations of the seven arrays to be used in our analysis: One 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). Be sure students recognize that this seamount rises from a depth of 4,000 m to 500 m at its summit; equivalent to a terrestrial mountain of over 11,000 ft.

4. Tell students that we are going to model the results of a year's worth of measurements by the current monitoring arrays. Arrange the seven wood dowel assemblies as diagrammed in "Current Modeling Setup." Be sure students understand that the scale of this model is distorted to make it workable in a typical classroom:

- If the model were arranged to a uniform horizontal scale, the dowel assemblies representing arrays B1 and B2 would actually be 400 cm from the other arrays;
- The vertical scale of our model (1 cm = 10 m) is not the same as the horizontal scale (1 cm = 100 m); and
- We are only modeling the depth interval between 400 m and 1,000 m (if the dowels were long enough to represent the entire water column (about 4,500 m depth), they would have to be 450 cm long)

5. Provide each group of students with a copy of "Data Table for Mean Direction and Velocity of Currents Above Fieberling Guyot." Assign one or more arrays (C, R1, R2, F1, F2, B1, or B2) to each group. Give each group one "Current Arrow" and one smaller "Radial Direction" arrow for each depth station included in their array(s). Point out that each arrow will provide six types of data:
   - Direction of current flow in the radial direction (toward or away from the center of the seamount);
   - Relative strength of current flow in the radial direction;
   - Direction of current flow in the azimuthal direction (relative to true north);
   - Relative strength of current flow in the azimuthal direction;
   - Direction of current flow in the vertical direction (up = toward the surface, down = toward the bottom); and
   - Relative strength of current flow in the vertical direction.

6. Have students prepare a current arrow for each depth station included in their array(s) as follows:

a. Color the "Azimuthal Direction" segment of the current arrow red if the current velocity is greater than 5; yellow if the current velocity is between 2 and 5; and white if the current velocity is less than 2.

b. Color the "Radial Direction" arrow using the same scheme as in 6a. If Radial Current velocity is zero, write "0" in the center segment of the Current Arrow with a black marker.

c. Color the "Vertical Direction" segment of the Current Arrow using the same scheme as in 6a. Using a black marker, label the tail segment "Up" or "Down" indicated in the Data Table. If Vertical Current velocity is zero, write "0" in the tail segment of the Current Arrow with a black marker.

d. Have students punch a hole in each "Current Arrow" and "Radial Direction" arrow as indicated.

7. Have students place "Current Arrows" and "Radial Direction" arrows onto the wood dowel representing the location of their monitoring array(s). Starting with the deepest current meter location, place the appropriate "Current Arrow" over the dowel. Using the taped "North Arrow," students should orient the "Current Arrow" to the appropriate azimuthal angle indicated in the Data Table, and secure the arrow at the appropriate depth mark on the dowel with clear tape (when the north end of the "North Reference" line is pointing away from you, a "Current Arrow" corresponding to an azimuthal angle of 90° would point to the right at a right angle to the "North Arrow;" a "Current Arrow" corresponding to an azimuthal angle of 270° would point to the left at a right angle to the "North Arrow;" etc.). Next, place the corresponding "Radial Direction" arrow over the dowel and orient the arrow so that it points toward or away from the center of the seamount (array C) as indicated in the Data Table. Secure the "Radial Direction" arrow to the dowel using clear tape. If Radial Current velocity is zero, omit the "Radial Direction" arrow. Repeat

this procedure for each remaining current meter depth.

8. Lead a discussion of the modeled data. It may be helpful to have students attempt to trace the path of a floating object starting at the surface of the seamount near its center (near array C). Students should eventually realize that the data suggest that the object would initially move outward from the center of the seamount. When the object reaches the rim and flank, it begins to move upward (toward the surface) and inward (back toward the center of the seamount). As the object moves over the center of the seamount, it enters a region where the 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 as indicated by the orientation of the "Current Arrows." At stations B1 and B2, currents are weak, with no definite movement in any of the three directions. Currents in the vicinity of seamounts often are much stronger than in surrounding deep ocean waters.

   Once students have drawn their own inferences from the modeled data, show them "Three-dimensional Diagram of Mean Flows in the Fieberling Guyot Circulation Cell." This was a more complex flow than scientists expected to find, and was due to much stronger influence of tides than was expected before actual measurements were made. This is a good example of the importance of direct field measurements to verify theoretical predictions, and how factors that are supposed to be "negligible" (such as tides in the open ocean) may have significant impact under certain circumstances.

   Ask students to infer how this type of circulation might influence benthic communities that depend upon free-floating larvae as part of their reproductive strategy. Students may hypothesize that larvae would tend to be retained near the seamount by this type of circulation cell, and that this would reduce the exchange of larvae with more distant seamounts. In the "No Escape" lesson plan, students will analyze data from a study designed to test this hypothesis.

The BRIDGE Connection

www.vims.edu/bridge/ - In the Navigation toolbar, click on "Ocean Science Topics." In the "Ocean Science Topics" menu, click on "Physics."

The "Me" Connection

Have students describe other examples of circulation cells that directly affect their own lives. These might include atmospheric circulation cells that affect weather and climate, near-shore ocean circulation cells that affect conditions for swimming and surfing, or circulation cells within buildings created by heating/ventilation/air conditioning systems or by natural air flow. You may also want to ask students to think of other examples (from their own experience or from the history of science) in which factors that were presumed to be unimportant or improbable turned out to have a major influence under certain circumstances.

Connections to Other Subjects

Mathematics; Biology; Physics

Evaluation

Develop a rubric for grading students' performance in completing Steps #6 and #7. This could include accuracy, attention to instructions, and appearance of the final model. Have students prepare individual written interpretations of the entire model (Step #8) prior to the group discussion.

Extensions

Have students visit http://oceanexplorer.noaa.gov to find out more about exploration on the Bear Seamount and opportunities for real-time interaction with scientists on current Ocean Exploration expeditions. Remind students that the current system modeled in this lesson is based on measurements at a single seamount; other seamounts may have very different types of currents and circulation. Suggest that students ask scientists if they have found indications of similar or different circulation patterns on other seamounts.

Resources

http://seamounts.sdsc.edu - Seamounts website sponsored by the National Science Foundation

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.

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 D: Earth and Space Science
- Energy in the Earth system

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

For More Information

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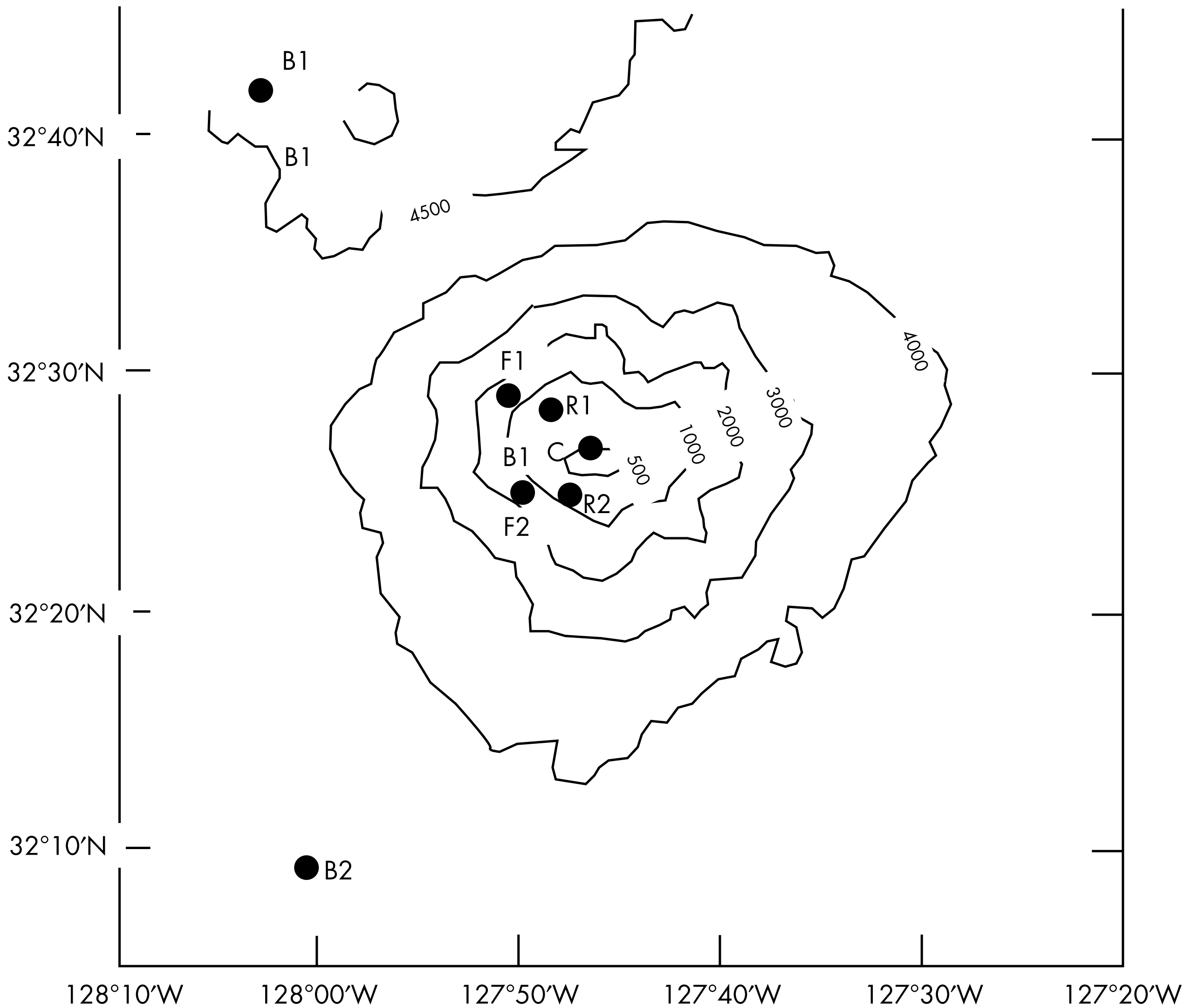
Student Handout

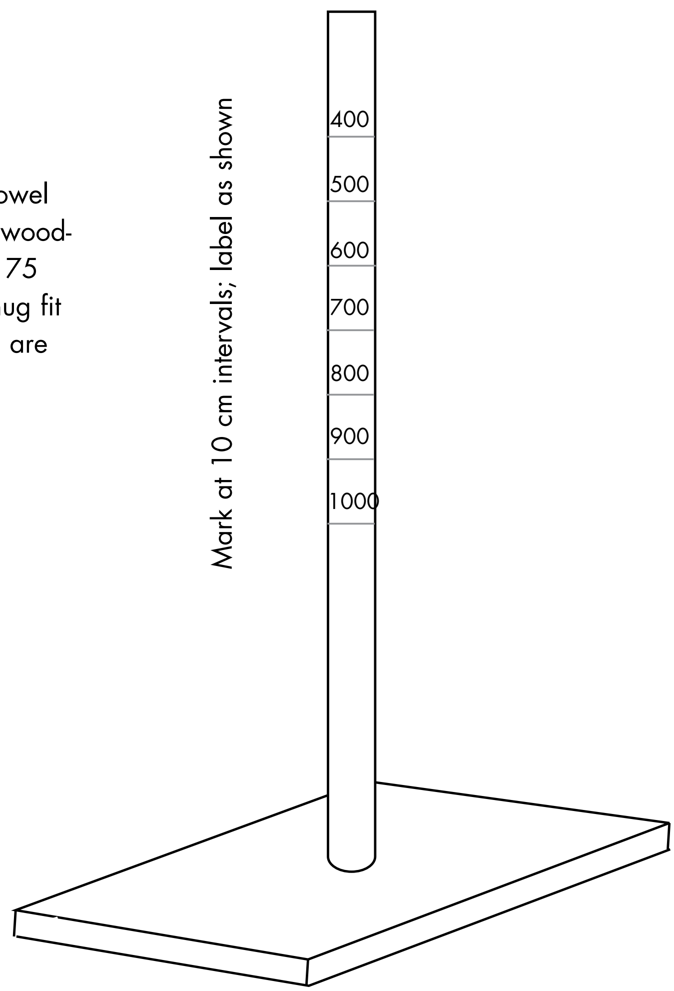
Topographic Map of Fieberling Guyot
Depths in meters
(redrawn from Brink, 1995)



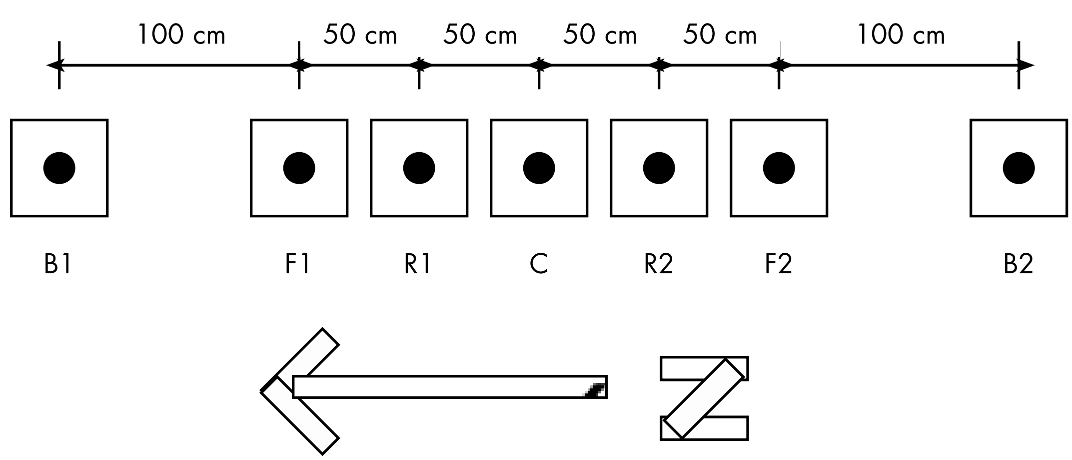
Student Handout

Current Modeling Setup

1. Prepare seven assemblies like this. Each dowel is 25 mm in diameter and 100 cm long. The wooden base is approximately 20 cm square, and 75 mm thick. Drill a hole in the base to give a snug fit when the dowel is inserted. These dimensions are not critical.



2. Arrange the assemblies on the floor like this. Use masking tape to make a north arrow as shown.



Student Handout

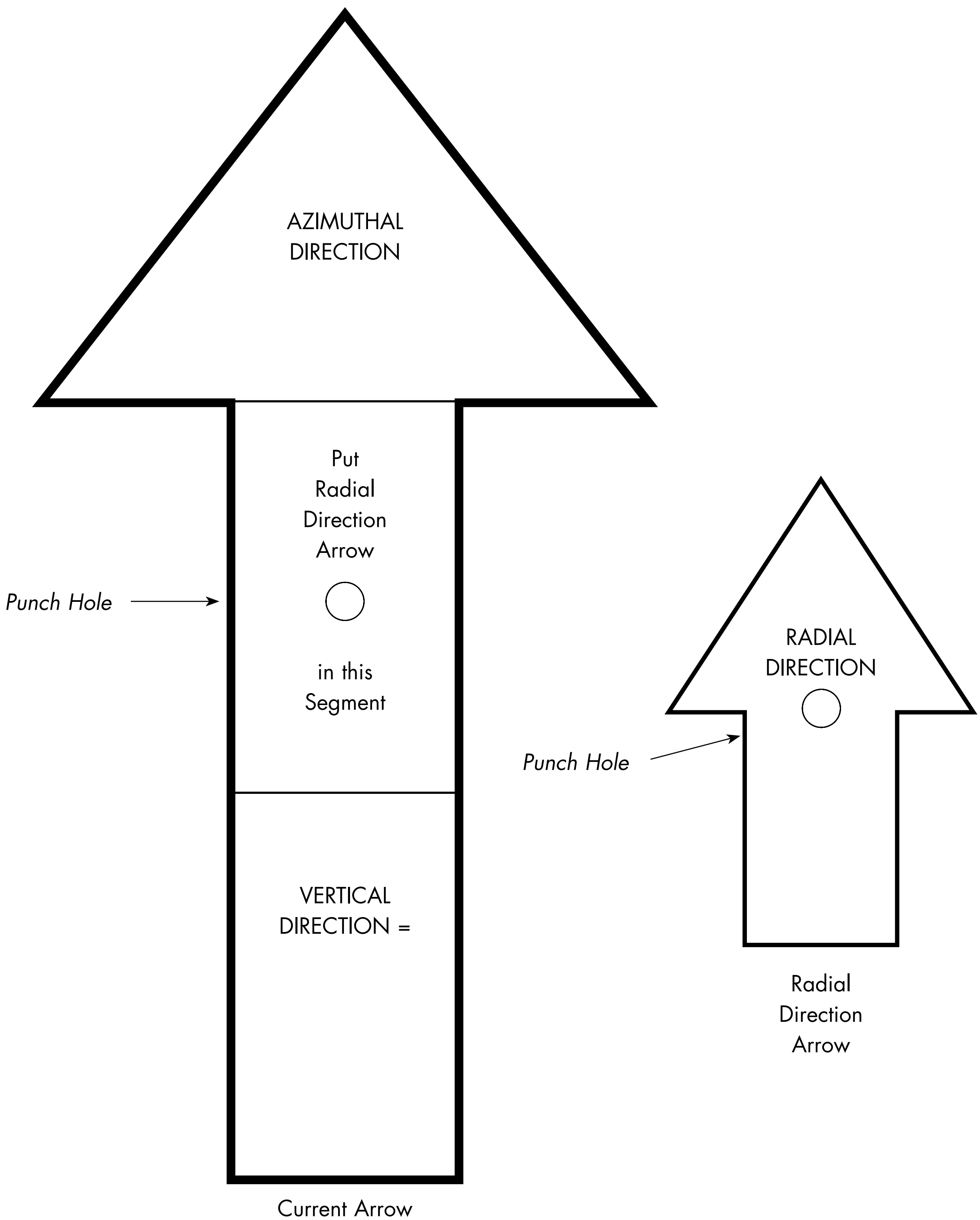
Data Table for Mean Direction and Velocity of Currents Above Fieberling Guyot

Array, Depth (m)	Radial Flow		Azimuthal Flow		Vertical Flow	
	Direction	Velocity (cm/sec)	Direction*	Velocity (cm/sec)	Direction	Velocity (cm/sec)
C, 450	in	2	20	4	down	8
C, 500	out	4.5	45	4.5	down	6.5
R1, 450	in	1	60	8	–	0
R1, 500	out	2	76	10	–	0
R1, 600	out	3	90	6.5	–	0
R2, 450	in	1	290	6	–	0
R2, 500	out	2	280	9.5	–	0
R2, 600	out	3	300	7	–	0
F1, 450	out	0.5	50	4	up	1.5
F1, 700	–	0	85	3.5	up	1
F1, 1000	out	0.5	78	1	up	1.5
F2, 450	–	0	275	5	up	1
F2, 500	out	0.5	300	7	up	1.5
F2, 650	–	0	290	7	up	0.5
F2, 900	–	0	285	1.5	up	1
B1, 450	–	0	220	0.5	–	0
B1, 700	–	0	45	0.5	–	0
B1, 1000	–	0	90	1	–	0
B2, 450	–	0	60	1.5	–	0
B2, 700	–	0	265	0.5	–	0
B2, 900	–	0	180	0.5	–	0

* Degrees clockwise from true north

Student Handout

Current and Radial Direction Arrows



Student Handout

Three-dimensional Diagram of Mean Flows
in the Fieberling Guyot Circulation Cell
(redrawn from Mullineaux and Mills, 1997)