"SEEING" THE BOTTOM OF THE OCEAN

Educational Outcomes: Ocean water that covers almost 71 % of Earth's surface occupies large basins. In most places, the ocean water is so deep (and also turbid due to dissolved substances and suspended particles) that we cannot see the ocean bottom. In even the clearest water, sunlight cannot penetrate to depths greater than about 250 m (820 ft). Historically, exploration of the deep ocean was not possible and its bottom was generally assumed to be flat and featureless. Today, ocean scientists use a variety of methods to investigate the ocean bottom-its composition and topographic features. Some methods are direct and simple such as devices that take physical samples of the ocean floor whereas others, such as acoustic instruments, are more complicated. Instruments aboard Earth orbiting satellites use a microwave beam to accurately determine the distance from orbit to the sea surface. It is known that broad-scale variations in the elevation of the sea surface are largely determined by changes in the topography of the ocean bottom. Relying on these sources of information, ocean scientists are creating a reasonably complete map of sea floor topography. Just as mountains and chasms on land give evidence to Earth's geologic processes, ocean bottom features provide information about the movements of Earth's plates and plate tectonics.

"Seeing" The Bottom of the Ocean

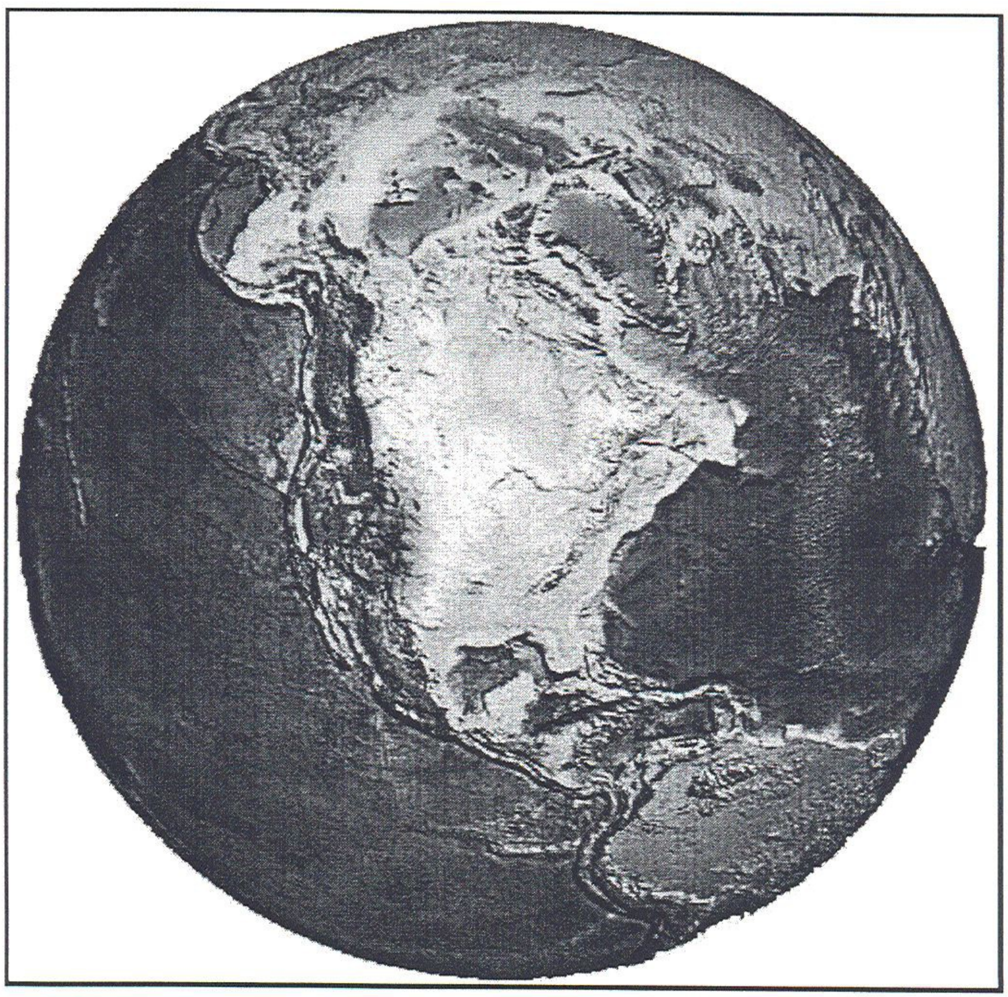

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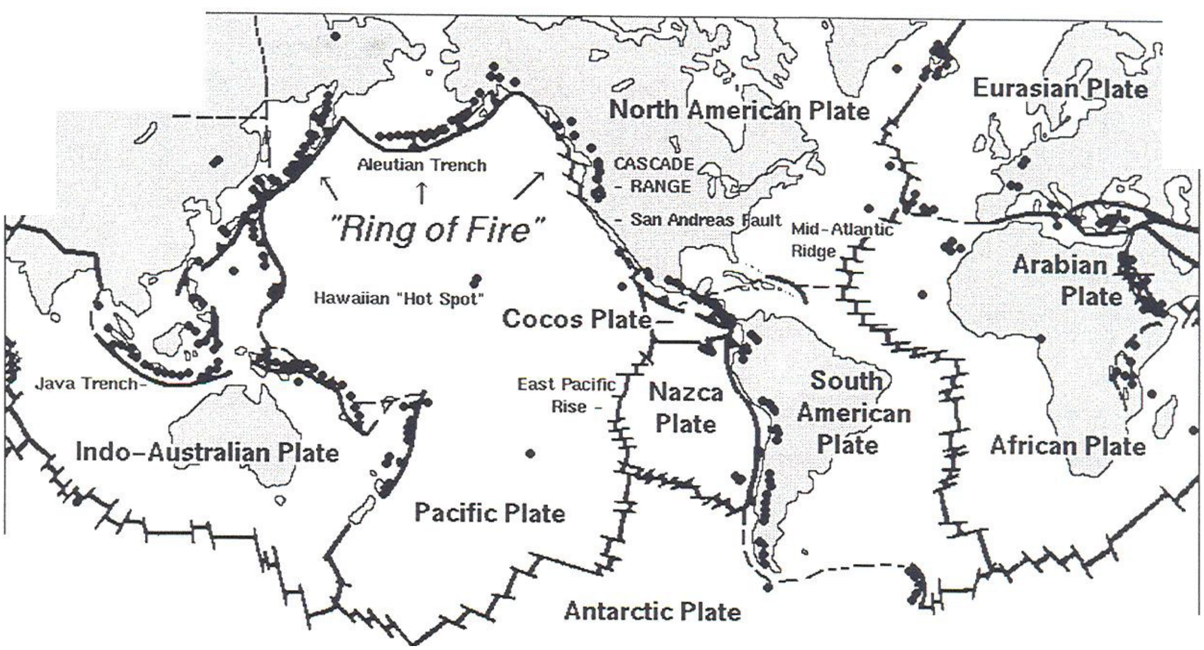
Figure 1 is a relief map in a globe perspective centered at 45°N, 900W showing land surface elevations in light shades and ocean depths in generally darker shades. Significant ocean bottom elevations above average depths are shown as lighter shadings within the ocean basins. For precise determination of land and ocean locations, consult your globe. (For a view in color, go to: *http://www.ngdc.noaa.gov/mgg/image/relieLslides2.htm£)*

1. Examine the topography of the Atlantic and Pacific Ocean basins you can see in Figure 1. The shading indicates the ocean floor (is) (Is not) flat and featureless.

2. Note in Figure I the fairly uniform shading of the ocean floor between Alaska and Siberia. The shading indicates relatively (shallow) (great) ocean water depths. During the last Ice Age when more water was sequestered in ice sheets and sea level was lower than today, this shallow region of the ocean was above sea level. This so-called *land bridge* is thought to be one of the routes of the first human emigrations into the Americas.

A close examination of Figure I reveals regularities or patterns in the topography of the ocean floor. The darker lines running more or less parallel to the western coasts of the Americas and on to Asia represent ocean trenches (depressions in the ocean floor). Another example of a prominent ocean-floor feature is the mid-ocean ridge that extends roughly north and south through the Atlantic Ocean basin. The trenches and the Mid-Atlantic Ridge are features appearing in the figure that mark boundaries of thick slabs of rock called tectonic plates. According to plate tectonic theory, these lithospheric plates consist of Earth's crust plus the rigid upper portion of the mantle. Plates move slowly around the globe relative to one another atop hotter, more mobile material in the upper mantle (the aesthenosphere). Figure 2 outlines the dozen or so major tectonic plates that cover Earth's surface.

Active Volcanoes, Plate Tectonics, and the "Ring of Fire"



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.Figure 2. Major tectonic plates that compose Earth's crust and the location of active volcanic belts.

3. According to Figure 2, North America located almost entirely on the (North) (South) American Plate.

4. A (ridge) (Trench) curves down the middle of the Atlantic Ocean basin. This feature is roughly (parallel) (perpendicular) to the boundaries of the continents (and their adjoining shallow continental shelves) on either side of the Atlantic Ocean basin. That is, this feature is roughly midway between the continents of Europe and Africa to the east and North and South America to the west.

5. Geologic evidence indicates that the landmasses on either side of the Atlantic Ocean were once joined together as one super-continent, known as Pangaea. The Atlantic Ocean basin was formed when Pangaea split apart. The volcanically active Mid-Atlantic Ridge marks a (convergent)(divergent) plate boundary.

6. In Figure I, again note the dark shading thin dark lines representing trenches that run along the edge of the Pacific Ocean, northward along the western margin of South America, Central and North America, along the Aleutian Islands, and beyond. Trenches occur where the ocean floor is (rising) (sinking) as tectonic plates collide. These trenches form a ring extending around much of the Pacific Ocean basin is also a site of active volcanic activity, termed the "Ring of Fire."

Whereas the Mid-Atlantic Ridge is the site of seafloor spreading and the formation of new oceanic crust from lava welling up from Earth's interior, a deep-sea trench forms where oceanic crust descends in a subduction zone. Where an oceanic plate subducts under a continental plate, violent volcanic eruptions and strong earthquakes are among the consequences on the nearby continental margins.

7. Using Figure 2 for guidance, mark with solid lines on your globe the tectonic plate boundaries that constitute the "Ring of Fire" circumscribing much of the Pacific Ocean basin. Also draw the position of the Mid-Atlantic Ridge and other plate boundaries of the North American and South American Plates for future reference. Optionally, you might draw all the major plate boundaries on your globe. Compare their global dimensions to the Figure 2 map depiction.

OCEAN BOTTOM TOPOGRAPHY

Educational Outcomes: Ocean depth varies markedly from one location to another. Over large areas water depth is less than 200 m (650 ft); in other areas the water depth is as great as]],000 m (36,000 ft). The average ocean depth is 3796 m (12,454 ft or 2.4 miles). This investigation examines the ocean bottom in vertical cross-sectional profile, including the continental margin and ocean basin.

In places the ocean bottom is almost flat and featureless whereas in other places the ocean bottom consists of lofty ridges and volcanoes. Three distinct ocean-bottom zones are evident. The zone closest to the shore features a very gentle slope extending seaward to a depth of about 200 m (655 ft). From there to a depth of about 3000 m (9800 ft), the water depth increases much more rapidly with distance. Then a relative]y narrow zone is transitional from the steep slope of the previous zone to the more-or-less flat ocean basin (similar to terrestrial talus slopes or alluvial fans which are transitional from mountains to flantlands). The initial, gently sloping zone is the continental shelf; the second, steeply sloping zone is the continental slope; and the third transition region is the continental rise.

The continental shelf, slope, and rise together comprise the continental margin as shown to the right in Figure]. This term is appropriate because the bedrock of the continental margin is the same as the continental plates. From a geological perspective, the continents do not end at the shore, but at the continental rise. At its outer edge, the continental margin merges with the deep-sea floor or gives way to an oceanic trench. An oceanic trench marks the convergent tectonic plate boundary where subduction of the oceanic plate is occurring. Where there are trenches, the continental margin is abbreviated as shown to the left in Figure I.

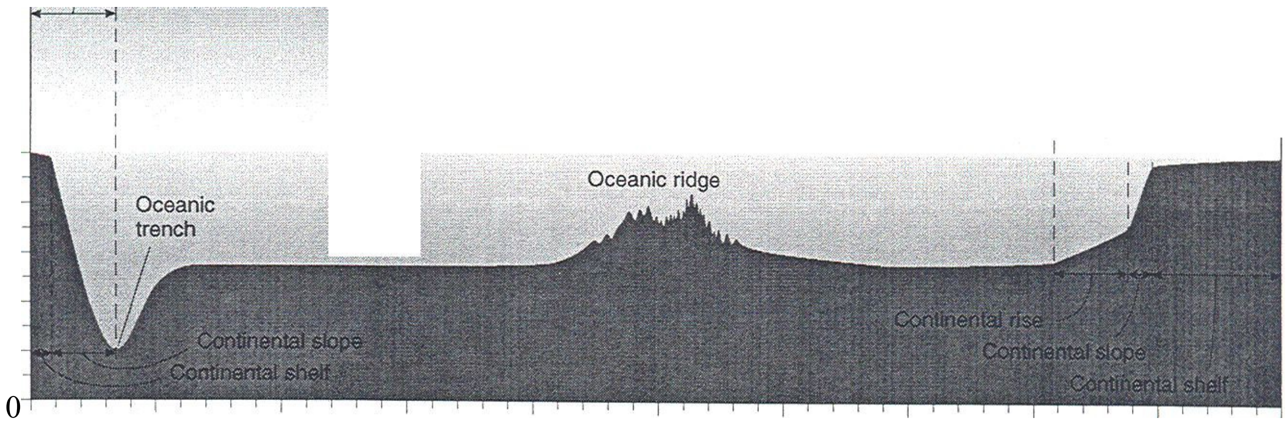

Figure I. Cross-sectional profile of the ocean bottom. (Note: The vertical scale is greatly exaggerated.)

Ocean Bottom Profile

1. In the Figure I schematic view of the ocean bottom above, the vertical scale is given in kilometers. This vertical scale is vastly different from the horizontal scale. The vertical distance between scale markings is (1) (10) (100) kilometers. The ocean trench in the schematic view reaches a maximum depth of (8) (80) (800) kilometers below sea level.

2. The scale markings on the vertical and horizontal scales are equal distances apart as measured with a ruler although they represent different distances. Comparison of the two scales indicates that the vertical scale is exaggerated (l0) (l00) (1000) times relative to the horizontal scale.

3. The right and left portions of Figure I describe general characteristics of the ocean bottom in coastal areas that are tectonically passive or active, respectively. Tectonically active areas, typically associated with plate boundaries, experience relatively frequent earthquakes and/or volcanic activity- Refer to your globe to locate tectonic plate boundaries relative to the east and west coasts of the Americas. Plate boundaries are more closely associated with the (east) (west) coasts of the Americas.

The east coasts of North and South America, with their generally broad continental margins as schematically shown to the right in Figure I, are tectonically (passive)(active). The west coasts of the Americas, with relatively narrow continental margins as shown to the left in the same figure, are tectonically (inactive)(active).

4. On your globe, use a marker to draw a line at 23.5 degrees S latitude from 70 degrees W to 73 degrees W longitude. The eastern end of this line is located over (land) (water) near the (east) (west) coast of South America. Note that the line you drew crosses a tectonic plate boundary.

Topographical relief data in meters with bathymetric (water depth) values indicated by negative numbers are provided in the table below at quarter degree intervals along the 23.5 degrees S latitude line segment from 70.0 degrees W to 73.0 degrees W:

W Long	Elev (m)	W Long	Elev (m)	W Long	Elev (m)	W Long	Elev (m)

70.00	1372	71.00	-4865	72.00	-4258	73.00	-3442
.25	1219	.25	-7075	.25	-3996		
.50	-313	.50	-6029	.50	-3577		
.75	-2549	.75	-4986	.75	-3492		

5. Plot these data on the following graph. Note that longitude values increase from right to left. The 0 line represents sea level. Altitudes and depths are plotted in thousands of meters. Draw a line connecting adjacent data points to produce a profile of the land/ocean vertical cross section:

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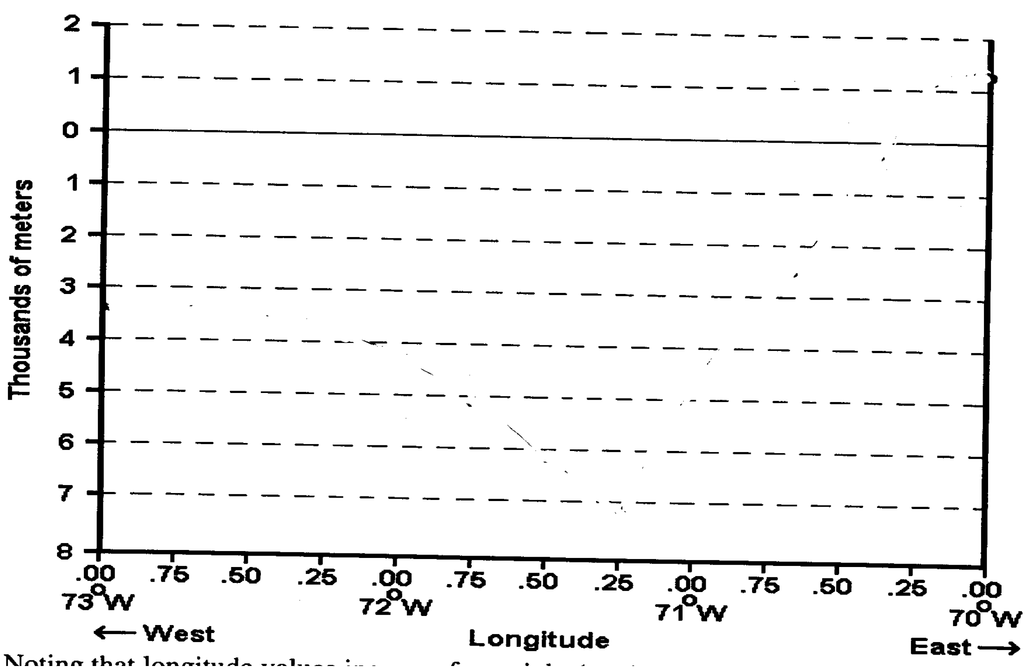


6. Noting that longitude values increase from right (east) to left (west), the coast is located at approximately (70.0) (70.4) (72.4) degrees W. The greatest depth in the vertical profile is located at approximately (71.25) (72.0) (72.5) degrees W. The difference in longitude between the coast and the deepest water locations is __________degrees.

7. At this latitude (23.5 degrees), the east-west distance between lines of longitude one degree apart is 102 km (63.4 statute miles). Consequently, the distance from shore to the greatest depth in the trench is ________ km.

8. According to the graph, the depth of the deep-sea bottom in the open ocean west of the trench is about (3500) (5500) (7000) meters below sea level. The deepest part of the trench is about (1500) (2500) (3500) meters below the bottom of the open ocean west of the trench.

9. Compare this vertical cross-section to Figure I. The profile you drew more closely resembles the (right) (left) portion of the Figure I schematic cross-sectional profile. This profile is characteristic of a tectonically (passive)(active) coastal region.

Figure 3: Bathymetry/topography relief partial view of South America

10. Figure 3 strikingly displays the ocean trench that exists near the west coast of South America. With your globe as reference, draw a line on the map in the figure to show the location of the east/west profile you constructed in Figure 2. To view the bathymetry/topography of the region in color and in greater detail, go to the *DataStreme Ocean* homepage and click on "Bathymetry" in the Geological Section. Click on the square containing the portion of South America where the profile you constructed is located. Click on the image to enlarge it. The view is awesome!

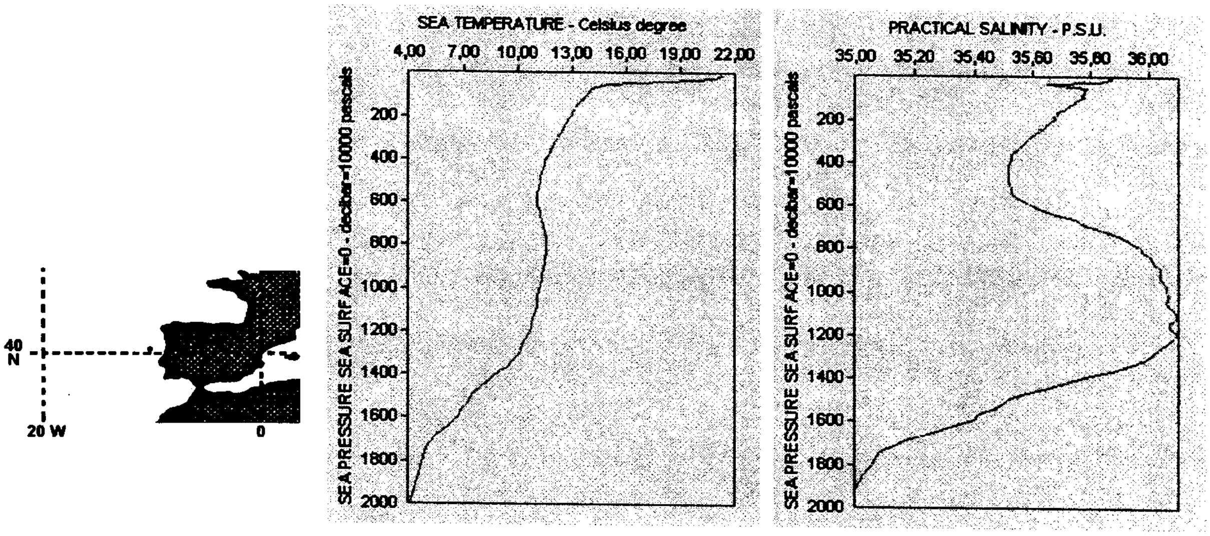
DENSITY -DRIVEN CIRCULATION AND WATER MASSES

Educational Outcomes: Temperature and salinity are two of the most important properties of ocean water; together, they govern the density (mass per unit volume) of seawater. Density differences drive the vertical and horizontal circulation of about 90% of the ocean. Surface seawater that is made denser by cooling, increased salinity, or mixing, sinks to depths where its density is the same as the density of the surrounding water. From there, the water spreads horizontally great distances, leafing between waters of lesser density above and greater density below. It continues spreading outward, at a very slow pace compared to surface-ocean currents, as more water of the same density sinks from above.

The tendency of seawater to seek its own density level, and the lack of energy to mix once away from the surface, leads to the formation of distinctive water masses. A water mass is a body of seawater that is relatively uniform in density and is identifiable based on its temperature and salinity. The subsurface movement of water masses is both vertical and horizontal driven by differences in temperature and salinity, hence it is called thermohaline circulation. Heat transport by moving water masses, likened to huge conveyer belts, is an important control of global climate.

The following investigation of density-driven ocean circulation uses a set of temperature and salinity measurements taken at different depths at a single location in the Atlantic Ocean. The objective is to obtain a global perspective of deep-ocean structure and density-driven circulation.

Figure I contains profiles of ocean temperature and salinity measurements taken on 23 September 2003 by an Argo float profiler off the coast of Portugal at 40.4 degrees Nand 11.9 degrees W. The location of the profiling float is shown in the small map to the left (I a). The temperature profile and salinity profile are shown in (I b) and (I c) with the horizontal scales across the top in degrees Celsius and Practical Salinity Units (PSU), respectively. One PSU essentially equals one gram of dissolved material per kilogram of seawater (or one part per thousand). Typical ocean concentrations are 34-36 PSU, which are 34-36 ppt. or 3.4 to 3.6% salt. For both profiles, depth is given in decibars to the left increasing downward. (One decibar of water pressure corresponds to one meter of water depth.)



(a) (b) (c)

Figure 1. Profiles from Argo float No. 6900180. Float location is shown by the small square in (a) in the Atlantic Ocean west of Portugal, 40.4 degrees N, 11.9 degrees W. Temperature profile is (b) and salinity profile is (c).

1. From the profiles in Figure 1, fill in the values for temperature and salinity in Table 1, Seawater Conditions, below.

Table 1. Seawater Conditions

Depth (m)	Temperature (°C)	Salinity	Density (g/cm^3)	Water Mass Name
200				
500				
1100				
1900				

Data in Table I indicate that the temperature and salinity of seawater [(are uniform) ~] with increasing depth.

2. Next examine Figure 2, a Temperature-Salinity (T-S) Diagram on which are also plotted the typical range of temperature/salinity (density) combinations for various water masses. The T -S diagram is a simple but powerful tool used in seawater density and water mass movement studies. Refer back to Investigation 3A to review the T-S diagram and its interpretation. On the diagram, plot each water sample reported in Table 1 by placing a dot (e) at the location corresponding to its temperature and salinity. Label each water sample by writing its depth next to it.

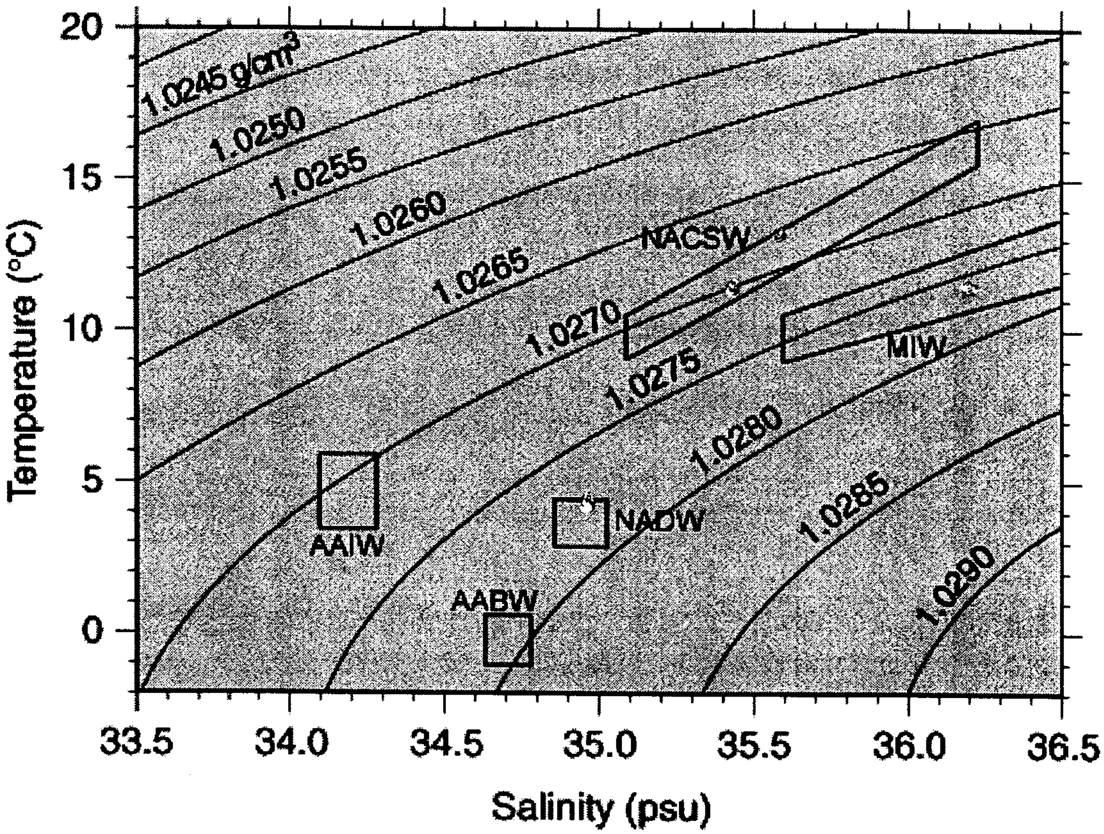


Figure 2. Water Mass Temperature – Salinity Diagram

(AABW) Antarctic Bottom Water (MIW) Mediterranean Intermediate (AAIW) Antarctic Intermediate Water (NADW) North Atlantic Deep Water (NACSW) North Atlantic Central Surface Water

3. As you recall from Investigation 3A, the density of each seawater sample must be specified to several decimal places before significant differences can be seen. Density may be determined by the use of a T-S diagram on which are plotted lines of constant seawater density (isopycnals) labeled in grams per cubic centimeter (g/cm\ Find the

density of each seawater sample (to the fourth decimal place) by interpolating between isopycnals plotted on the graph. Then record the density of each sample in Table 1.

4. Based Qn the densities you determined for the samples, ocean water density at this site (increases) (decreases) with increasing depth.

5. Water masses of different densities tend not to mix. Instead they tend to flow over and under each other in layers, with the denser layers below. This lack of mixing means that each water-mass layer retains its original properties, including temperature and salinity. These properties, in turn, can be used to identify and track the water mass.

Determine the name of the water mass represented by each water sample reported in Table I. The data points you plotted in Figure 2 should fall within (or near) boxes drawn on the T -S diagram. Each box, identified with initials, encloses the typical ranges of temperature and salinity of seawater formed in a particular water-mass source region. The initials are identified below Figure 2. Note that the name for each water mass includes both the source area where it originated (Antarctic, Mediterranean, or North Atlantic) and the relative depth (surface, intermediate, deep or bottom) where it spreads through the ocean. Using the appropriate initials, record the name of each water mass in Table 1.

6. Examine Figure 3, Atlantic Ocean Vertical Cross Section, along a north/south line. It shows the general form of the layered structure of the Atlantic Ocean (South and North). Arrows portray the density-driven circulation of water masses. Almost all the water masses identified in this investigation originated in a few relatively small regions of the ocean surface where a density increase, due to low temperature, high salinity, and/or mixing, results in water mass formation and sinking. Note that for most water in the ocean, the sinking of cold dense water at high latitudes drives the circulation. These water masses and deep currents also circulate through the other major ocean basins.

Highlight with a pencil or pen the 40 degrees North latitude line in Figure 3 to represent the location of the Argo float in Figure I. On the vertical line, plot the depths specified in Table I. (Be sure to first convert meters to kilometers.) Label each water mass sample with its initials from Table 1. Do your identifications of the samples determined by use of the T -S diagram conform (or come close to conforming) to the printed identifications of water masses in Figure 3? (yes)(no).

Vertical Cross-Section

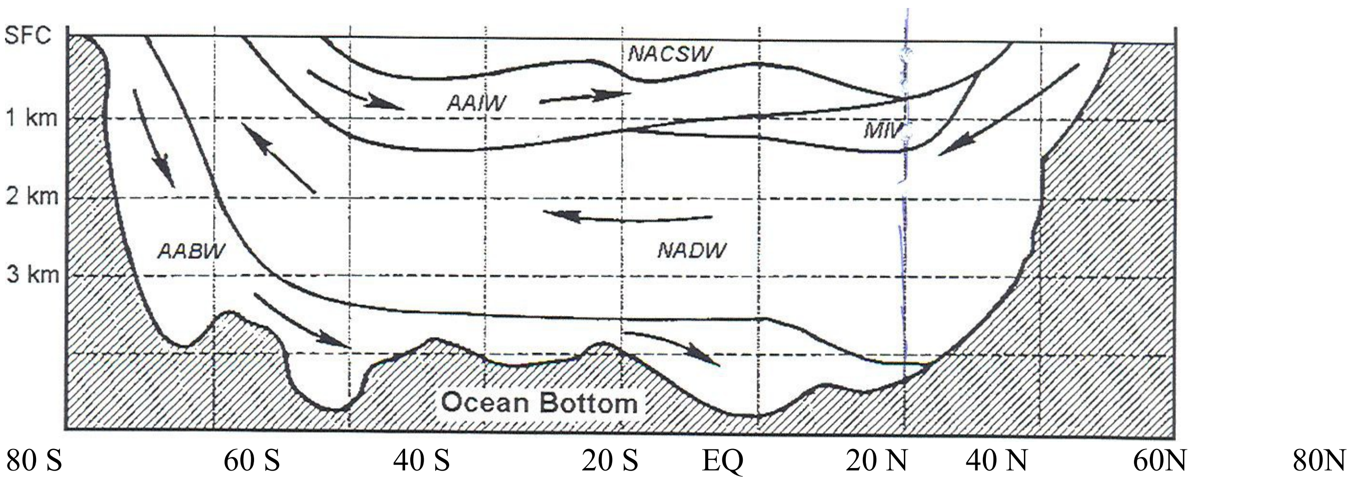


Figure 3. Atlantic Ocean Vertical Cross Section

7. When compared to the approximately 1.0 km per hour speed of most wind driven surface currents, the velocity of a density driven deep ocean current is much slower, typically covering about 1.0 m per hour. At this speed, to travel the approximately 9,000 km distance from its Antarctic source area to the sample site in the North Atlantic would take a density-driven current such as Antarctic Bottom Water close to (1) (10) (100) (1000) (10000) years. (Hint: 1 m/hr = 24 m/day = 8766 m/year = 8.8 km/yr)

9. The circulation of the deep ocean is driven by the increase in density of surface water due to changes in its temperature and/or salinity. A major mechanism whereby the density of surface waters at high latitudes is increased is by (cooling) (heating). The density of surface water at any latitude is increased by net (precipitation) (evaporation).