Homework 2a
Bathymetric Charts

[based on the Chauffe & Jefferies (2007)]

2-1. BATHYMETRIC CHARTS

Nautical charts are maps of a region of the ocean used primarily for navigation and piloting. These charts display the **bathymetry** or depths of the sea floor below sea level. Historically, the sea floor depths were obtained by lowering a weighted cable to the sea floor. Today, sea floor depths are obtained with a ship-mounted **sonic depth recorder** which bounces sound waves off the sea floor (Figure 2-1a). A **sound generator** on the ship emits sound waves that strike the sea floor and are reflected upward to a listening device called a **hydrophone**. The method is faster, more accurate and allows continuous depth determination as a ship travels. Each measurement of depth to the sea floor is called a **sounding**.

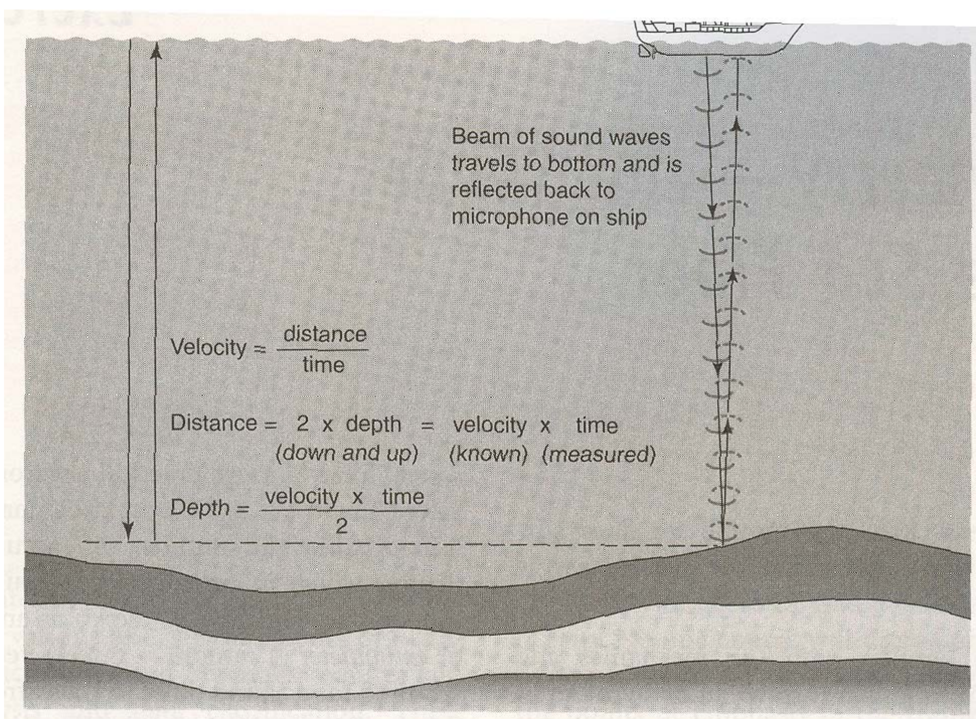

Figure 2-1a.**Acoustic Depth-Sounding.** A ship's hull-mounted "acoustic pinger" emits a sound pulse that travels to the seafloor, reflects, and then travels back to the ship's listening devise called a hydrophone. The roundtrip travel time of the sound pulse is recorded and the depth is computed (see formula). The depth recorder operates continuously making a dense set of depth measurements along the ship's track.

Shipboard computers record the round-trip *travel time* of the sound waves and calculate depth by multiplying the known speed of sound in water (S_w = 1460 meters/second) by half of the travel time:

$$D = S_w \, x \ ½ \ travel \ time \ ,$$

where the depth of the water D in meters is the product of the sound speed in water and one half of the total travel time to the bottom and back. For example, if the total travel time is 4 sec, then the time for sound to reach bottom is 2 sec and the water depth is 1460 m/sec x 2 sec = 2920 m. The sounding depths are shown on the nautical charts like the one in Figure 2-1b.

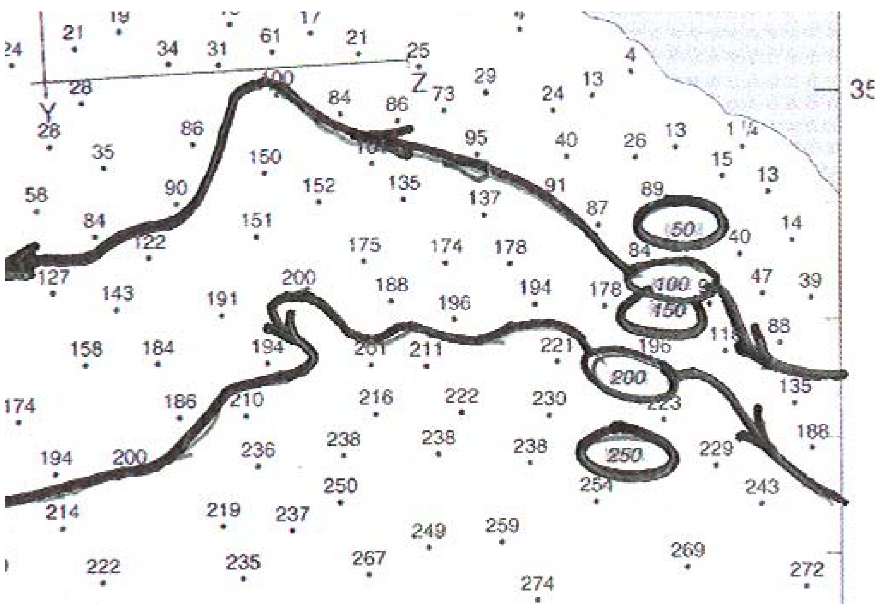

Figure 2.1b A bathymetric chart showing an array of depth soundings (given in fathoms, where 1 fathom = 6 ft). On many charts the soundings are “contoured” to give a more useful visual representation of the regional bathymetry. Here we have drawn the 100 and 200 fathom isobaths, each which connects only those depths with the same depths. Note in this case, the depths on upper side of either of the isobaths are shallower, while the ones on the lower side are deeper. Thus we can see how the sea floor slopes away from the coast, which run diagonally across the upper right corner. What would the 50 fathom, 150 fathom, and 250 fathom isobaths look like? (LEiO)

Bathymetric charts are constructed from arrays of depth soundings by drawing a set of **contour lines** (or **isobaths);** each of which connects points of equal depth. The example in Figure 2-2 shows an idealized region in which the sea floor slopes smoothly away from the coast and how that is represented on a nautical chart. The “20” contour line connects all 20 ft sea floor depths relative to the mean sea level (i.e., the 0 ft **datum** or reference depth, which is determined from a long-term time-average of sea level). Likewise the "40" contour connects depths of 40 ft below sea level and so on. The numbered contour lines are the *index contours*; the unnumbered contour lines are the *supplemental contours*. The difference between two adjacent contours is called the **contour interval**, which is 10 ft for the Figure 2-2 example.

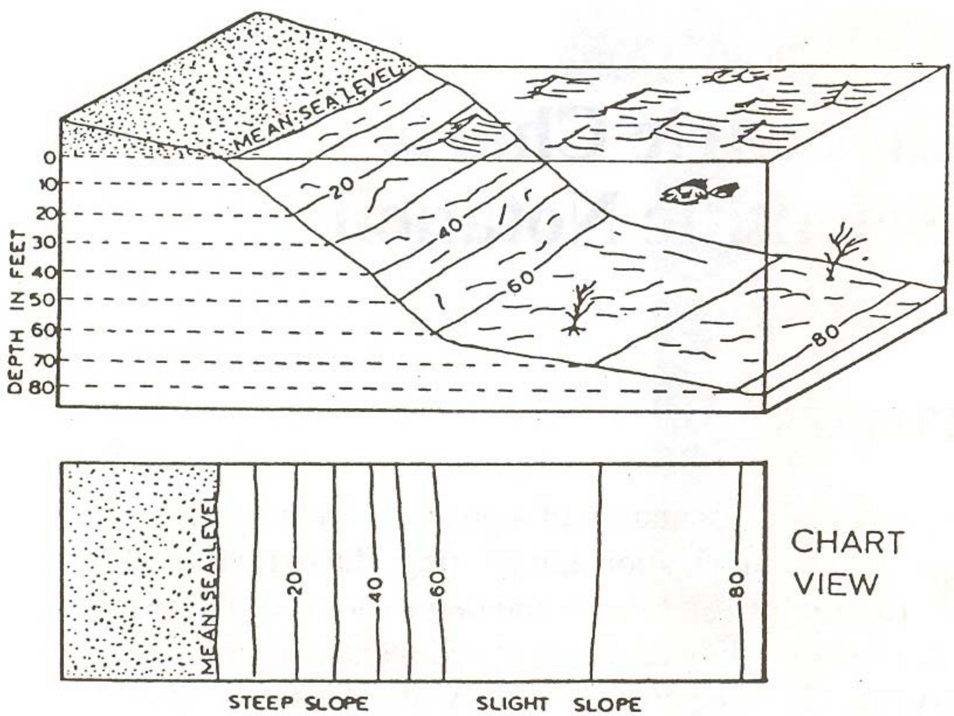

Figure 2-2. The bathymetry or depth distribution of the ocean in the upper panel is depicted by the set of depth contour lines (in units of feet) on chart below. Note that the closer together the contours, the steeper the slope of the sea floor.

Contoured bathymetric charts provide a more useful "picture" of the seascape not easily seen from soundings alone. In a more realistic example of a bathymetric chart, I have drawn the 100 and 200 fathom isobaths approximating the array of depth soundings from a survey of an offshore region southwest of Long Beach, California (Figure 2.1b). Note that depths on charts can be given in a variety of units; e.g., feet –as in Figure 2-2, or fathoms – as in Figure 2-1b, or meters. (A convenient "rule-of-thumb" relating these different units is that 1 fm = 6 ft or approximately ~ 2 m because 1 meter = 3.28 ft exactly). Try and produce the 50 fathom (fm), 150 fm, and 250 fm contours on the Figure 2-1b chart. Do any of these contours outline submarine hills, valleys, ridges, and/or undersea mountains? Strategies for dealing with such challenges are presented next.

2-2. CONTOURING A BATHYMETRIC CHART

When constructing a contoured bathymetric chart from soundings, the following guidelines should be considered.

1. Contour lines connect points of equal depths; usually with smoothly curving lines.

2. Contour lines can terminate abruptly at the edge of the chart (e.g., Figures 2-2 & 2-3).

3. The steepness of a sea floor **slope** (or **gradient)** is indicated by the relative distance between adjacent contour lines; the closer the steeper (e.g., Figure 2-2).

4. Contour lines can never split or intersect (see Figure 2-4), because the point of intersection would have two different depths simultaneously - an impossibility. However, contour lines can merge at a truly vertical feature and/or overhanging cliff (also see Figure 2-4).

5. Contours in the region of undersea valleys have a distinct V shape that points up-valley as shown in Figure 2-3.

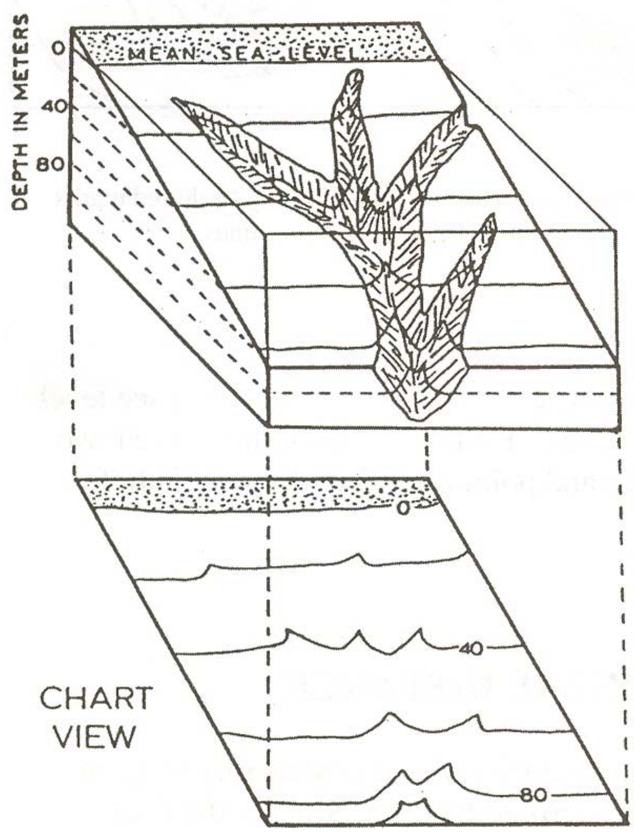

Figure 2-3. Along-coast isobaths that intersect an undersea valley (above) have distinct V shapes on the bathymetric chart (below) that point upslope.

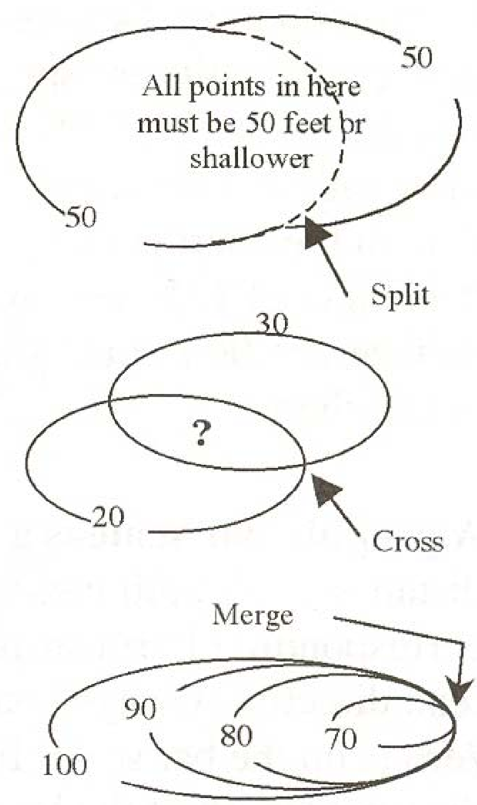

Figure 2-4. Contour lines never split or cross, but may merge.

6. Contour lines always close around bathymetric mounds or depressions that are located locally within the chart domain (Figure 2-5). The contours around a depression are distinguished by small tick marks (hachured marks) that point into the depression.

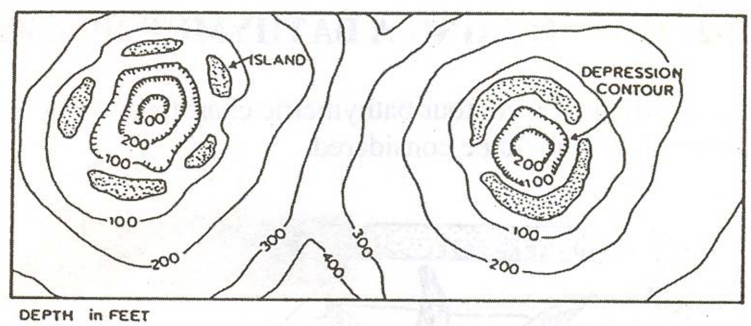

Figure 2-5. Depression contours are indicated by hachured marks (tick marks pointing downslope) on the contour lines.

2-3. CHART SCALE AND HORIZONTAL DISTANCE

Charts represent the Earth's surface, but at a reduced size. To interpret the chart properly, it is important to know the **chart scale,** that is the fixed relationship between a distance on the chart and the corresponding distance on the Earth. For example, when one centimeter (cm) on the chart equals 125,000 cm (which equals 1250 meters (m) or 1.25 kilometers (km)) on the Earth. The chart scale can be given as a fraction 1/125,000 or the ratio 1:125,000. Effectively the size of the Earth's surface has been reduced or scaled down by 125,000 times so that it can fit on the chart. All useful charts contain a **bar scale** (Figure 2-6) which is used to interpret chart distances in terms of real Earth distances. The total length of the bar scale in Figure 2-6 represents a total Earth distance of four km which is subdivided into both 1 km and 0.25 km segments.

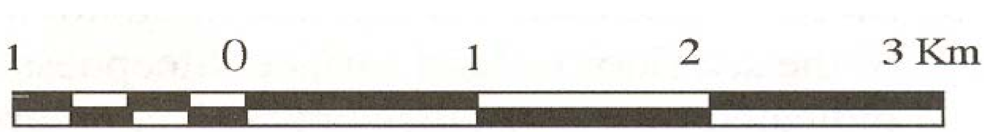

Figure 2-6. Graphic bar scale. Always note the “0” position.

2-4. DETERMINING SLOPE OR GRADIENT

The slope of the sea floor (or gradient) may be numerically expressed as a ratio, percentage, or angle. Slope is the ratio of the relief (or change in depth of a sea floor feature) to the horizontal distance over which the slope is measured, according to

Slope = relief/horizontal distance of slope ,

where Slope units can be feet/mile, meter/kilometer, fathom/mile, or fathom/kilometer.

The slope can be converted to a percentage by converting the slope ratio to a quantity without units and multiplying it by 100% according to

% Slope = (relief/horizontal distance of change in the same units) x 100% .

For example, a slope of 100 ft/mi would have a percent slope of

(100 ft/mi) x (1 mi/5280 ft) x 100% = 1.9%.

Slopes and percent slopes are given in angles (with units of degrees °) in Figure 2-7. Note that a horizontal line has 0% slope and an angle of 0°; and that a 100% slope has angle of 45°. A vertical line has an angle of 90° and a percent slope of infinity.

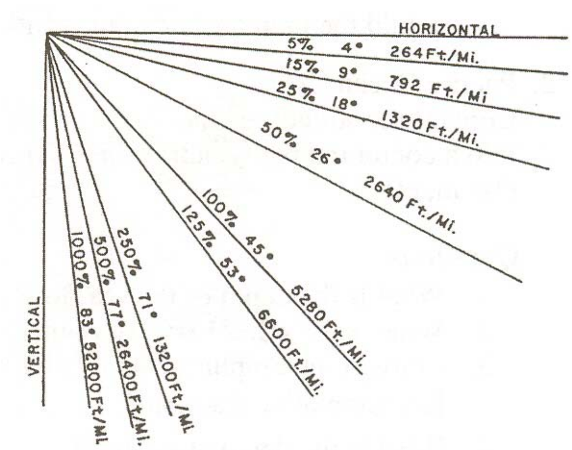

Figure 2-7. The different slopes are given as percent slope, angle in degrees, and feet per mile in the picture above.

EXERCISE 1 - CONTOURING OCEAN BATHYMETRY

A. The Sandy Harbor Chart

Your task is to convert the sounding chart of Sandy Harbor (Figure 2-8) into a contoured bathymetric chart using a *contour interval* of 1 fathom (fm).

- You will notice that part of the *1 fathom depth contour line* has already been drawn by comparing pairs of soundings – the **depth-comparison method**. Beginning on the upper left side edge of the chart, we started the *1 fm depth contour* so that it would go between the 0.1 fm and 1.9 fm soundings as shown. Continuing to the to the right, it is very likely that *1 fm depth contour* lies between the (a) 0.5 fm and 1.9 fm soundings (midway is a good guess); (b) 0.5 fm and 2.7 fm soundings, and (c) 0.5 fm and 1.8 fm, respectively as shown. The *1 fm depth contour* was continued to the right between the appropriate soundings, including the 0 fm depth contour of the coast.

- Now that you have "gotten the hang of it", complete drawing the *1 fm depth contour* as a smoothly curving line along the coast, keeping the larger depth soundings seaward of the contour.

- Now draw the *2 fm depth contour* on the deeper side of the *1 fm depth contour* starting in the upper left. You will note that *2 fm depth contour* will generally "track" the *1 fm depth contour* similar to the way that the *1 fm depth contour* tracked the 0 fm coastline.

NOTE: With experience you will find that you can produce a bathymetric chart that is correct according to the rules of the depth-comparison method, but different in detail with similarly "correct" charts produced by your classmates. How can this be? This apparent contradiction arises because of you do not know with 100% certainty what depths actually lie between the measured depths (i.e., soundings). Uncertainty is present in all technical things that we do. Our job is to minimize it, by developing our intuition about the world in which we live.

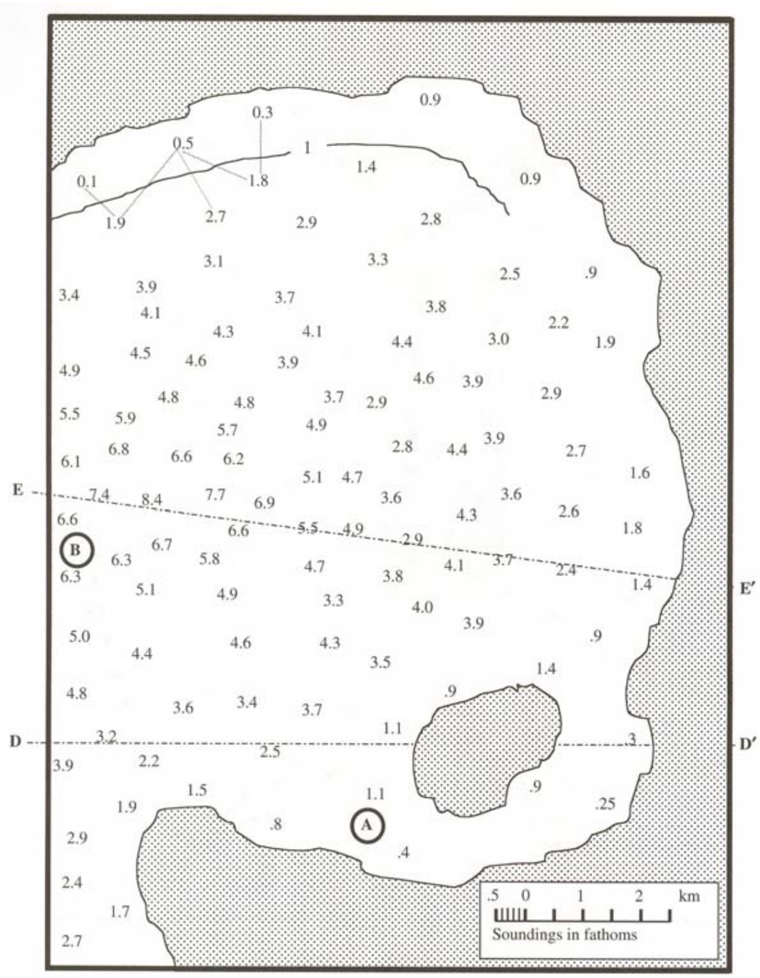

Figure 2-8 Sandy Harbor Sounding Chart

Questions Concerning Your Sandy Harbor Chart

1. What is the depth at point A in fathoms? ______________meters? _______________
2. Where is the deepest part of the bay? ________________________
3. What is the relief (or depth difference) between points A and B? _________________
4. Determine the slope of the bay from points A to B as indicated below:

   ______________fathom/mi ____________% ___________ft/mi ___________m/km
5. What is the chart scale in terms of a fraction? _____________; a ratio? ___________
6. Six inches measured on this chart equals how many feet on the Earth? _____________
7. If the chart had been contoured using meters or yards as the contour interval, would the map appear significantly different?

B. Pacific Ocean Chart

Convert the sounding chart of a portion of the southern Pacific Ocean (Figure 2-9) into a contoured bathymetric chart. Draw contours for 100 m, 200 m, 400 m, 600 m, etc.

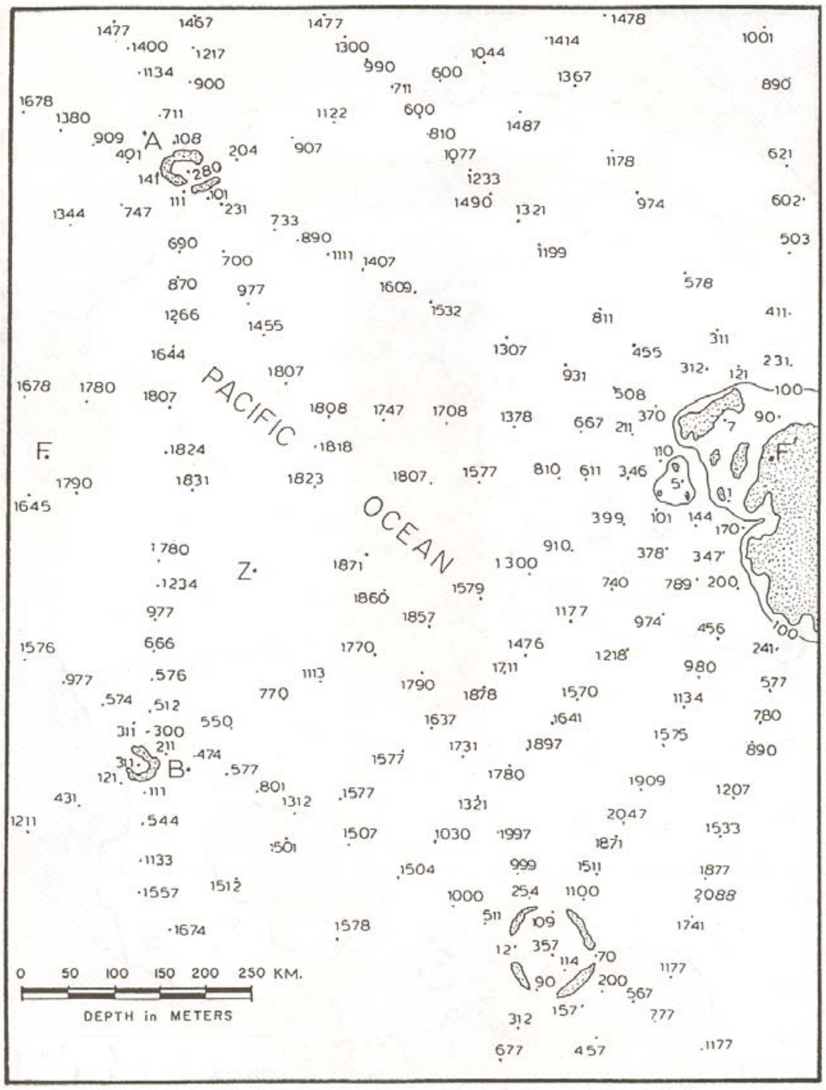

Figure 2-9. Sounding chart of a portion of the southern Pacific Ocean.

Questions Concerning Your Pacific Ocean Chart

1. What is the depth of the sea floor at point A? ____________B? ________________
2. What is the relief between points A and B? ____________________
3. Convert the graphic scale into a chart scale as a fraction 1: ___________; ratio 1 in: ____________________
4. What is the depth at point Z? ____________________