Homework-2
Bathymetric Charts

[based on the Chauffe & Jefferies (2007)]

2-1. BATHYMETRIC CHARTS

Nautical charts are maps of a region of the ocean which are used primarily for navigation and piloting. Nautical charts map **bathymetry** or the depth of the sea floor below sea level. Historically, the sea floor depths were obtained by lowering a weighted cable to the sea floor - hopefully- and measuring the length of the line/rope. In the deep ocean, this method was inaccurate.

Today, sea floor depths are obtained with a shipboard **depth recorder** system**.** This recorder system has a ship's hull-mounted **sound generator** that emits *sound waves* (or "pings") every second or so. Each ping travels downward **(**see Figure 2-1), bounces off the sea floor and travels upward to a hull-mounted listening device called a **hydrophone**. The recorder computes the depth from the *round-trip travel time* of the ping or **sounding**. The method is much faster and much more accurate than the historical method; and allows for continuous series depth recordings as a ship travels forward over the seafloor.

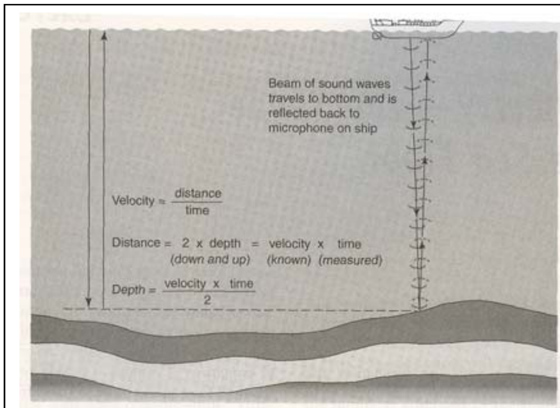

Figure 2-1 Acoustic Depth-Sounding. A ship's hull-mounted "acoustic pinger" emits a series of sound pulses; each of which travels to the seafloor, reflects, and then travels back to the ship's listening device called a hydrophone. The roundtrip travel time of each sound pulse is recorded, and the depth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

The depth recorder system computer computes the water depth, **D**, from the recorded round-trip *travel time* of the sound waves by multiplying the known speed of sound in water (S_w = 1460 meters/second or m/s) by ½ of the round-trip travel time, according to the relation

$$\boldsymbol{D} = S_w \times \tfrac{1}{2} \textit{ travel time} \quad .$$

For Example: If the round-trip travel time is 4 seconds, then the time for sound to reach bottom is 2 sec. Thus, the water depth

$$\mathbf{D}\text{ (in meters)} = 1460\ \frac{\text{m}}{\text{s}} \times 2\text{ s} = \underline{\mathbf{2920\ m}},$$

(where seconds in the numerator and denominator canceled). What would this depth be in fathoms – a commonly-used unit of ocean depth? (A convenient "rule-of-thumb" relating these different units is that 1 fathom = 6 ft exactly; or approximately 2 m because 1 meter = 3.28 ft exactly).

Bathymetric charts are constructed from arrays of depth soundings by drawing a set of **contour lines;** each of which *connects points of equal depth* (or **isobaths**). Consider how the idealized ocean region in Figure 2-2, where the sea floor slopes smoothly away from the coast, would be depicted on a nautical chart. Starting on the left of Figure 2-2, the first contour is the zero (0) foot **datum** (or reference depth), which is determined from a long-term, time-average of sea level or MEAN SEA LEVEL. Wading into the water, the contour line marked "20" connects all sea floor depths of 20 feet (ft) relative to the mean 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

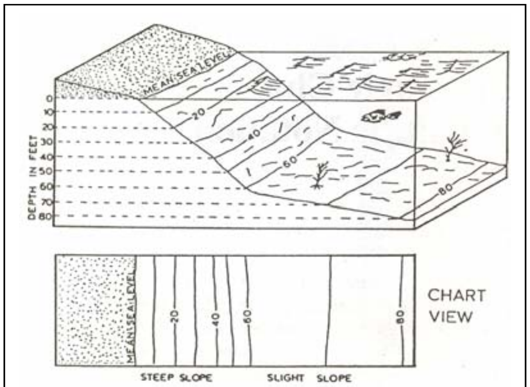

Figure 2-2. The bathymetry (or depth distribution) of the idealized ocean in the upper panel is depicted by the set of depth contour lines (here in units of feet) on nautical chart below. Note that the closer together the contours, the steeper the *slope* of the sea floor.

10 ft for this example.

Nautical charts typically have an array of depth soundings like those seen in Figure 2.3 given in fathoms. The following describes how oceanographers interpret such arrays of depth soundings. Thus, contoured bathymetric charts provide a more useful "picture of the seascape" - not easily seen from soundings alone. For example, note how the 100 fathom and 200 fathom contours bring more order, helping to clarify the meaning of what appear to be a jumble of depth sounding numbers. You have probably already noted 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 2-3, or meters). Try and produce the 50 fathom (fm), 150 fm, and 250 fm contours on the Figure 2-3 chart. Do any of these contours outline submarine hills, valleys, ridges, and/or undersea mountains? Strategies for dealing with such challenges are presented next.

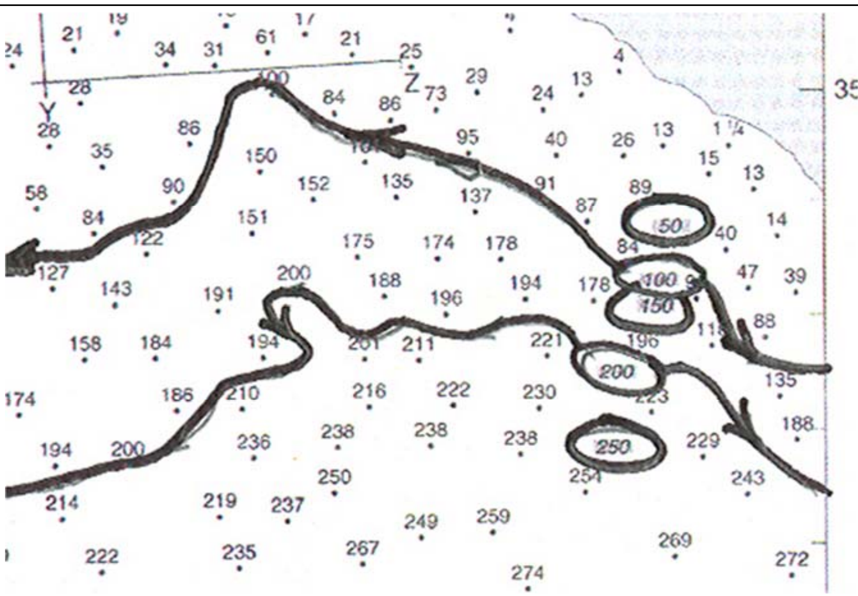

Figure 2.3 A bathymetric chart showing an array of depth soundings (given in fathoms, where 1 fathom = 6 ft) from a survey of an offshore region southwest of Long Beach, California. On many charts the soundings are "contoured" to give a more useful visual representation of the regional bathymetry. The contours representing the 100 and 200 fathom isobaths - each of which connects only those depths with the same depths – are drawn here. In this example, the depths on the upper side of both of 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)***

2-2. CONTOURING A BATHYMETRIC CHART

Guidelines: Constructing a contoured bathymetric chart from soundings.

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

2. Contour lines can end abruptly at the edge of the chart (see Figures 2-2 & 2-3).

3. The distance between adjacent contour lines indicate the steepness of a sea floor **slope;**
   … the closer the contour lines, the steeper sea floor slope (see Figure 2-2).

4. Contour lines can <u>never</u> split or intersect (see Figure 2-4);
   A point of contour intersection would indicate two different depths – an impossible situation!

5. Contour lines can merge at a vertical feature and/or overhanging cliff (see Figure 2-4).

6. Bathymetric contours of an undersea valley have a distinct V-shape which point up-valley (see Figure 2-5).

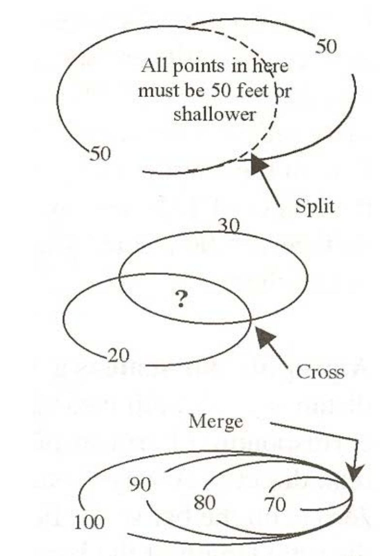

Figure 2-4. Contour lines never split or cross but may merge.

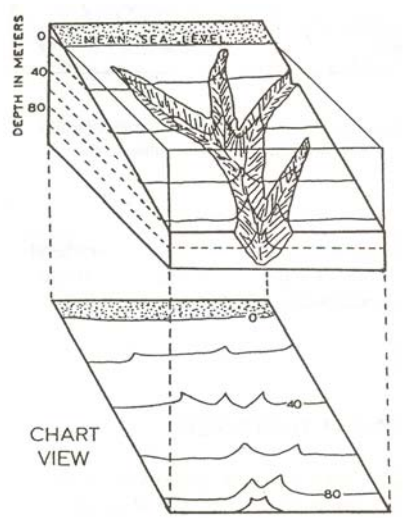

Figure 2-5. Along-coast isobaths that intersect an undersea valley (above) have distinct V shapes on the bathymetric chart (below) that point upslope.

7. Contour lines always close around bathymetric hills or depressions that are located within the chart domain (see Figure 2-6).

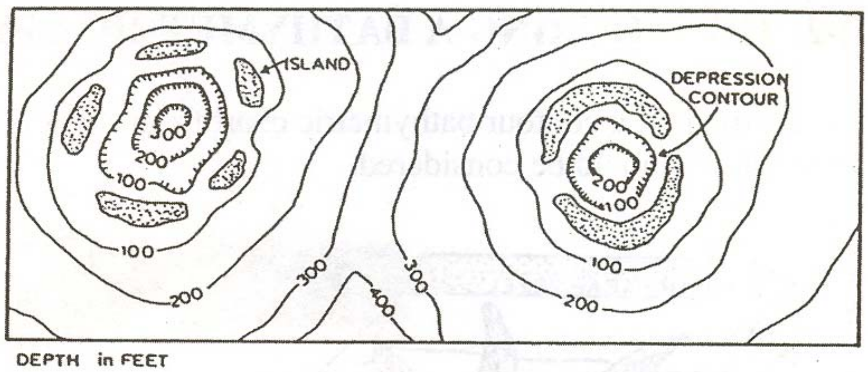

Figure 2-6. Depression contours are indicated by tick marks on the contour lines that point downslope.

2-3. CHART SCALE AND HORIZONTAL DISTANCE

When using charts, it is important to know the **chart scale** - 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 a 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 2-7) which is used to interpret chart distances in terms of real Earth distances. The total length of the bar scale in Figure 2-7 represents a total Earth distance of four km which is subdivided into both 1 km segments to the right of the reference “0” and 0.25 km segments to the left of it..

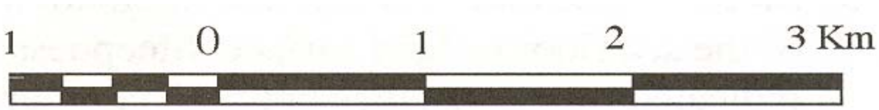

Figure 2-7. Graphic bar scale indicating distance relative to the reference point at the “0”.

2-4. DETERMINING BATHYMETRIC SLOPE

The **slope** (or **gradient**) of the sea floor (see Figure 2-2) may be expressed numerically 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

<u>slope = relief/horizontal distance of slope</u> .

The units of a slope can be expressed as feet/mile, meter/kilometer, fathom/mile, or fathom/kilometer. The better way to express slope is to convert the units in the numerator/denominator of the slope into the same units. For example, convert miles to feet so that the units of the slope are feet/feet; which makes the slope *unitless*.

A *unitless* slope can be converted to a percentage by multiplying it by 100% according to

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

Then a slope of 100 ft/mi would have a percent slope of

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

Slopes and percent slopes can be given in angles (*with units of degrees* °) in Figure 2-8. Note that a horizontal line has a slope of 0% 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.

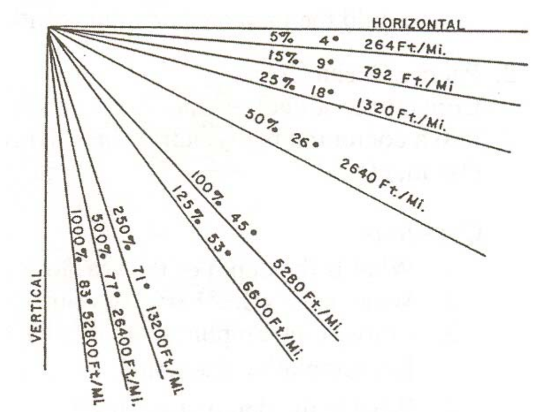

Figure 2-8. The different slopes are given as percent slope, angle in degrees, and feet per mile in the picture above. Note percent slopes of slopes greater than 45° become larger until they become infinite at the vertical.

EXERCISE 1 - CONTOURING OCEAN BATHYMETRY

A. The Sandy Harbor Chart

Your task is to convert the sounding chart of Sandy Harbor (Figure 2-9) into a contoured bathymetric chart with a *contour interval* of 1 fathom (fm). (Reminder: 1 fm = 6 ft ≈ 2 m)

- As discussed above the coastline is the *zero or 0 fathom (fm) depth contour*.

- Note that part of the *1 fathom (or 1 fm) depth contour line* has already been drawn by comparing pairs of soundings – the **depth-comparison method**. Beginning on the upper left edge of the chart, the *1 fm depth contour* goes between the 0.1 fm and 1.9 fm soundings as shown. Continuing 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 starting in the upper left, draw the *2 fm depth contour* on the deeper side of the *1 fm depth contour*. 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 *uncertainty*, by developing our intuition about the world in which we live.

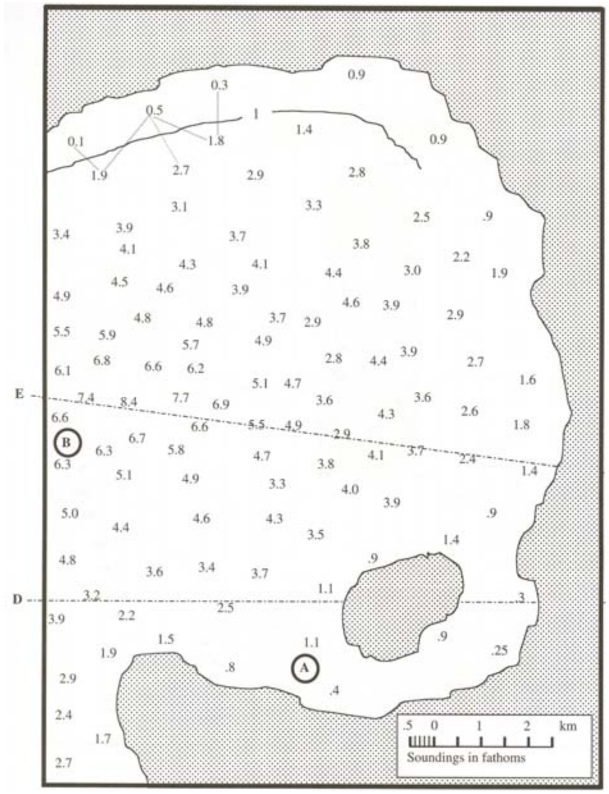

Figure 2-9 Sandy Harbor Sounding Chart.
Note the distance scale in the lower right

Questions Concerning Your Sandy Harbor Chart (Figure 2-9)
Show your work clearly on a separate piece of paper.

1. What is the chart-scale in terms of a fraction? _____________; a ratio? ___________

2.What is the depth at point A in fathoms? ______________ meters? _______________

3. Where is the deepest part of the harbor? _____________________ How deep is it?_________

4. What is the relief (or depth difference) between points A and B? _________________

5. Determine the slope of the harbor from points A to B as indicated below:

______________ fathom/mi _____________ ft/mi _____________ % _____________ m/km

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?

Commented [K1]: Moved 5 to 1 for more fluidity.

Commented [K2]: Exchanged % and ft/mi like the slope tutorial

B. Pacific Ocean Chart (Extra Credit)

Convert the sounding chart of a portion of the southern Pacific Ocean (Figure 2-10) into a contoured bathymetric chart by drawing in contours for 200 m, 400 m, 600 m, 800 m, 1000 m 1500 m, and 2000 m isobaths.

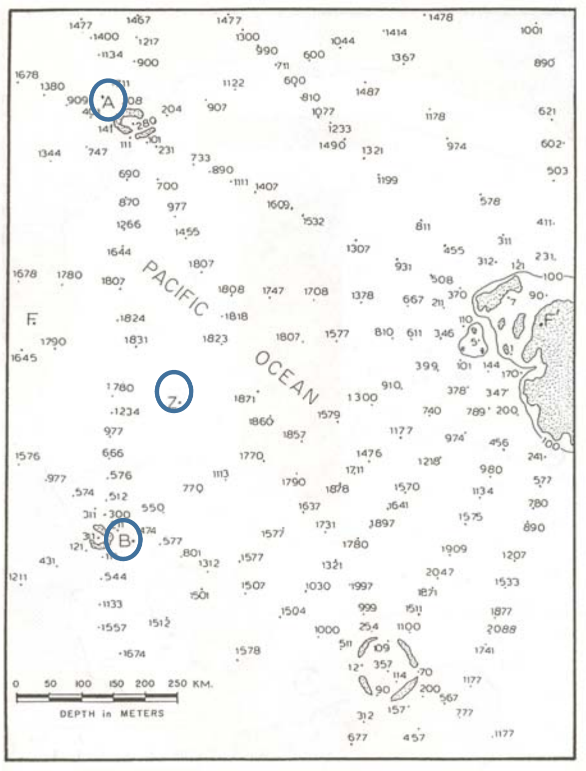

Figure 2-9. Sounding chart of a portion of the southern Pacific Ocean.

Figure 2-10 Sounding chart of a portion of the southern Pacific Ocean. Note the distance scale in the lower left

Questions

Concerning Your Pacific Ocean Chart (Figure 2-10)

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? ____________________