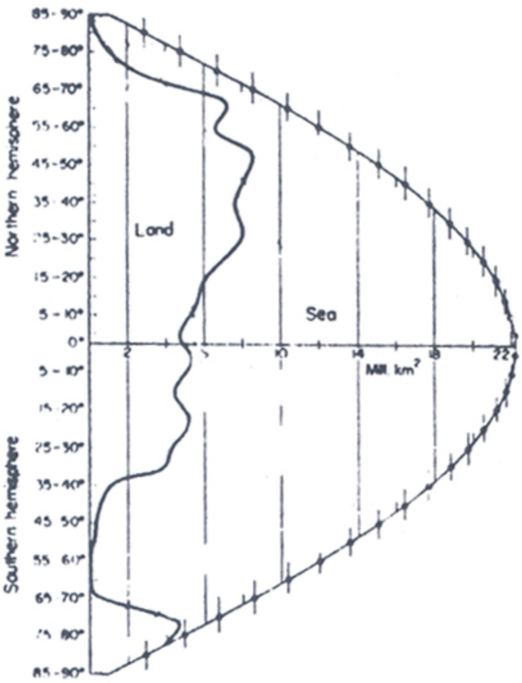
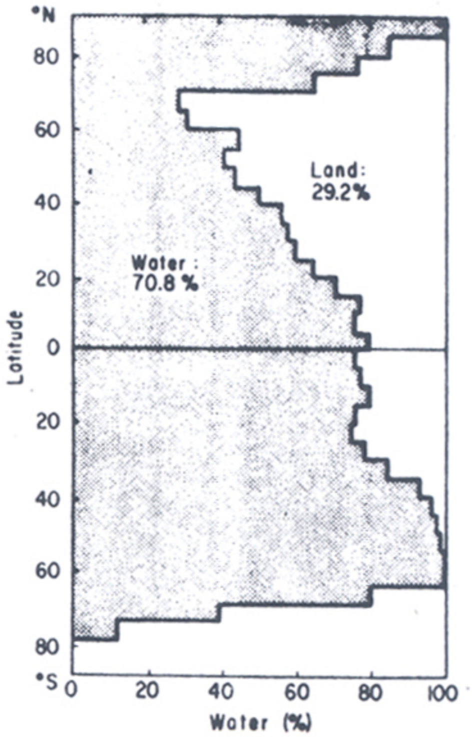
1 EXTENT OF THE OCEANS AND THEIR DIVISIONS

1.1 Distribution of Water and Land

Water covers 70.8% of the surface of the earth. The earth’s surface is 510 million km^2, and of this 361 million km^2 is water. There is comparatively more water in the southern hemisphere than there is in the northern. Figure 1.1 shows the distribution of land and sea at various latitudes. Only around the Antarctic continent is there an uninterrupted ring of water, and all the way up in the north we also have a water cap in the Arctic Ocean. Otherwise the oceans are divided by the continents.



Distribution of water and land between parallels of latitude.



Percentage distribution of water and land areas in five degree zones.

Fig.1.1

In this way the world’s oceans have been divided into three major *oceans*. The Pacific Ocean, with its 165 million km^2, is larger than the other two together (the Atlantic Ocean and the Indian Ocean). Earlier the Antarctic Ocean was considered an independent ocean; now it is most common to divide it among the three major oceans. In addition to the three world oceans, there are several types of smaller seas. A sea is considered a *mediterranean sea* if it is for the most part enclosed by land, with one or more narrow openings to the oceans. An *intercontinental sea* lies between continents, while an *intracontinental sea* lies within a single continent. In addition there also *adjacent seas*, which lie relatively open to the oceans. (For examples see Table 1.1)

Table 1.1

		Area of the sea surface in 10^6 km^2	**Sum**
Oceans, without mediterranean and adjacent seas	Atlantic	82.2	
	Indian	73.4	
	Pacific	165.3	320.9
Intercontinental mediterranean seas	Arctic	14.3	
	European	3.0	
	Australasian	8.1	25.2
Intracontinental mediterranean seas	American	4.3	
	Baltic Sea	0.4	
	Hudson Bay	1.2	
	Red Sea	0.5	
	Persian Gulf	0.2	6.6
Adjacent seas	North Sea	0.6	
	Gulf of St. Lawrence	0.2	
	Bering Sea	2.3	
	Others	5.0	8.1
	All seas	360.0	360.9
	Earth's surface	510.1	

Area of all seas in percent of earth's surface is 70.8 %, where depths between 0 and 200 m constitute 5.5 %, and depths above 3000 m 54.6 %

Mean depth of all seas is 3790 m
Mean depth is 0.0006 times earth's radius
Greatest depth is 0.002 times earth's radius

Volume of all seas is $1370 \cdot 10^6$ km^3.

1.2 Depth Measurements

The most obvious method of measuring depth, which has been used throughout history, is to lower a weight down at the end of a rope. This works fine as long as the sea is not too deep. However, when the depth is great, this method will lead to numerous practical difficulties. It is difficult to notice when the weight hits the bottom, and the current can also cause the hemp rope (which was used for a long time) to move away from the desired vertical line. A classic example is the so called “Swedish depth” of 4850 meter between Spitsbergen and Greenland, which was measured in 1868 with ropes; this depth was assumed most likely not to exist, until it was confirmed in the 1970ties by more modern methods.

Later people began to use piano string with an automatic stop when the weight reached the bottom (*e.g.* the Lucas sounding machine). This was more precise and worked faster. Still, with this mechanical method the number of possible soundings was much too few in relation to the great size of the world’s oceans.

It was therefore a radical improvement, both in quality and quantity, when the *echo-sounder* was introduced after the First World War. The idea was old (Aragon 1807) but the technical necessities were first in place 100 years later. The principle of the echo-sounder is very simple. An acoustic signal from the surface is sent into the water. This reflects off the bottom and is received again at the surface (Fig. 1.2) after t seconds. If the depth is D meter, then the signal has gone $2D$ meters in t seconds and we have the formula

$$2D = \bar{v}t\,, \tag{1.1}$$

where $\bar{v}$ is the average speed of sound between the surface and the bottom. The time difference t is small, but with modern technology it can be measured very accurately. The speed of sound in saltwater is now very well known. It varies with temperature, salinity and pressure. Because the salinity in the open sea does not vary much, variations in v are most often due to variations in temperature and depth (pressure).

Numerical example: If $\bar{v}$ = 1500 m s^{-1}, and the depth D is 1500 m, then t = 2 s. Since $2dD/dt$ = 1500 m s^{-1}, we see that dD = 1 meter corresponds to a time difference dt of 1/750 seconds, which can be recorded. When measuring depth, one must take into consideration variations in the speed of sound. There are tables and computer programs that can be used for this in connection to the different ocean and sea areas.

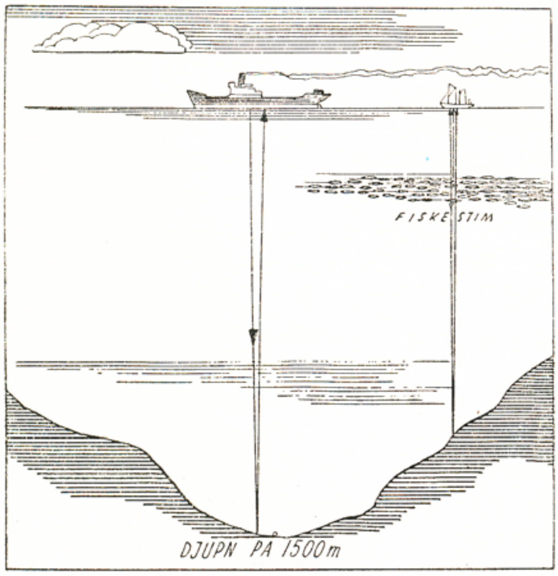
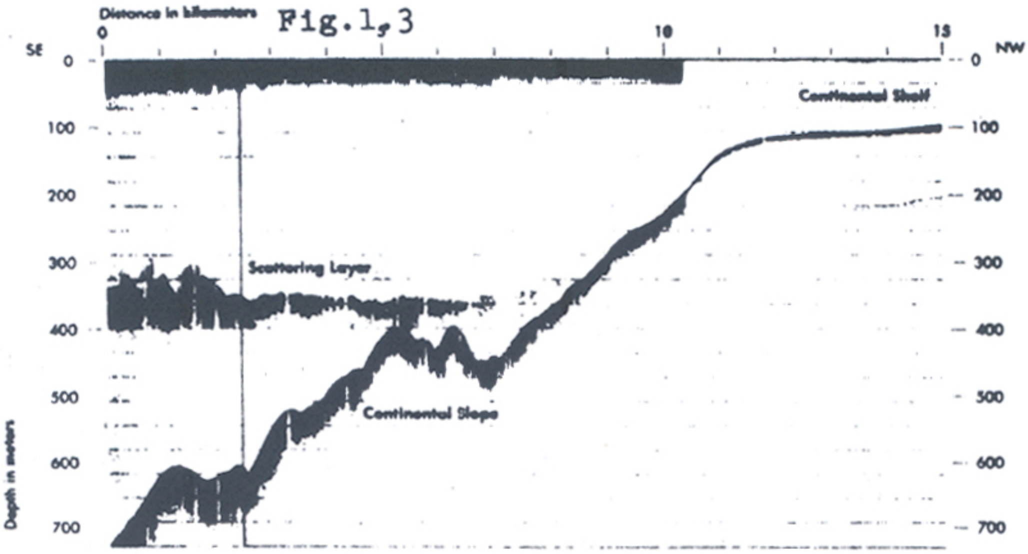


Fig. 1.2 With the echo-sounder we may find the depth to the bottom, or the depth of a shoal

The echo-sounder consists of a sending, a receiving and a recording instrument. In the sender, electric oscillations are converted to mechanical oscillations which are producing sound waves. Certain ferromagnetic materials change dimensions in a varying magnetic field. The effect is reversible, so the same instrument may be used as both the sender and the receiver. The echo goes through an amplifier to a printer which draws a profile showing the bottom depth. We are not going to go into detail as to how this works, or the corrections one must apply. An echogram is shown in Fig. 1.3. The echo-sounder does not only receive echoes from the ocean floor, it will also receive echoes from objects in the water. This has made the echo-sounder very useful to the fisheries. More and more refined uses are being found for this method. With a modern echo-sounder, one can see each and every fish. Sound in seawater will be discussed in more detail in Chapter 3.1c.



Precision echo sounding across the continental margin off Virginia.

1.3 General Features of the Ocean Floor

The principal features of the ocean floor are shown in Fig. 1.4. The *shelf* or *continental shelf* can be considered an extension of the earth's surface. It occupies approximately 7% of the ocean floor. The width varies greatly, from almost nothing to over 1000 km (outside of Siberia). It is difficult to define an

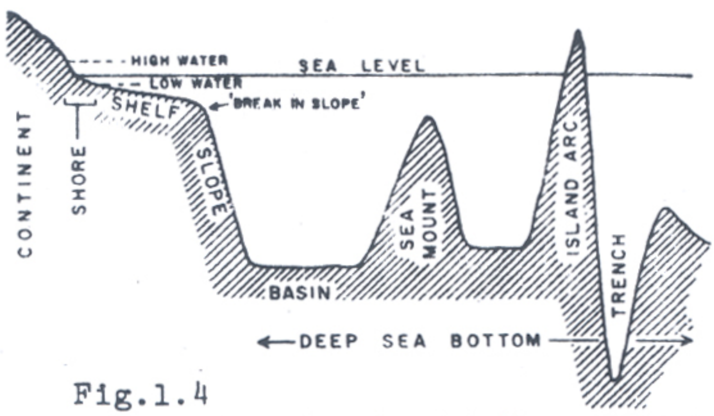


Fig.1.4
Section through ocean floor to show principal features schematically.

exact depth for the end of the shelf; one has to look for where the slope becomes steeper in such a way that the ocean floor becomes the *continental slope*. Approximately 200 m can be used as an average value for the shelf depth.

The under-water valleys (canyons) are a much debated characteristic, as they cut through the shelf in many places across the coast. Some of them appear to be a continuation of rivers on land (for example, the Hudson, Kongo, Ganges) and others do not. Sediment is often transported through these canyons out to greater depths. From the continental slope, one goes over to the *deep-sea basin*.

The deep sea is divided between larger and smaller basins with more or less defined under-water ridges. These basins have a relatively flat floor, and can be as deep as 6000 meters. One also finds *island arcs* and individual under-water mountains, – *seamounts*. A particularly striking characteristic are the *deep-sea trenches*. They look like long drawn out fissures on the ocean floor, and they are most often found outside of and parallel to the island arcs. They are especially numerous on the west side of the Pacific Ocean but are also found in the Pacific outside of South America as well as a few in the Atlantic and Indian Oceans. In these trenches we have the greatest ocean depths. In the Pacific Ocean, there is the depth of 11000 meters in the Marianer trench. The deepest trench in the Atlantic Ocean is found in a trench outside of Puerto Rico with a depth of 9200 meters.

If we make a frequency distribution of height levels for the earth's surface we end up with a figure such as Fig. 1.5 Here we see two typical levels, one between +1000 and -1000 m and one between -4000 and -6000 meters. One third of the ocean’s floor lies between 4000 and 5000 m depth.

If we integrate the curve in Fig. 1.5, we obtain the *hypsographic curve,* Fig. 1.6. Here the abscissa indicates how many km^2 of the earth’s surface which lie at a higher level than

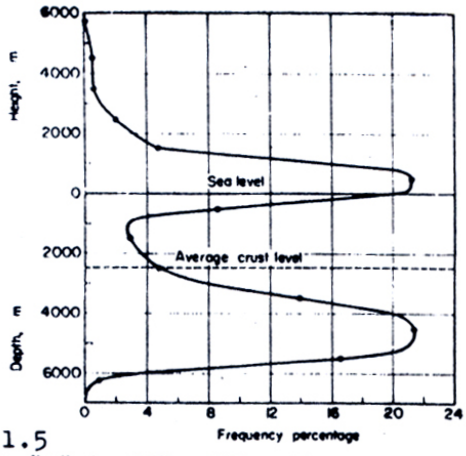


Fig.1.5
Frequency distribution of different height and depth intervals over the entire surface of the Earth.

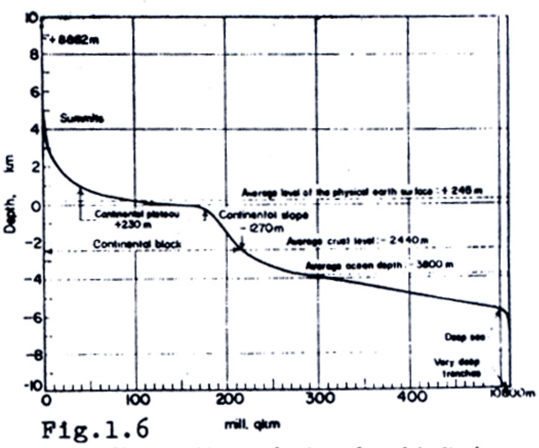


Fig.1.6
Hypsographic curve for the surface of the Earth.

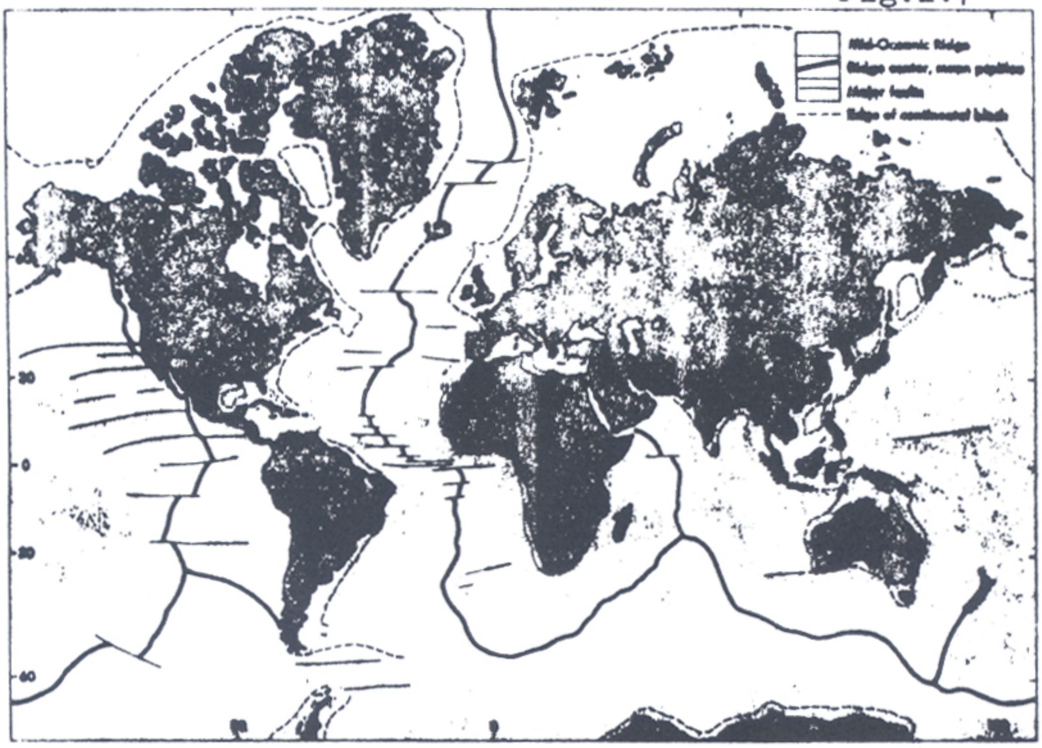
indicated by the ordinate. The curve can roughly be seen as a description of the average depths of the earth’s surface. We can clearly see a division between two “step levels.”

The average depth of all seas is calculated to be 3790 m, and the volume of all the water in the seas is then 1370 million km^3, that is 13 times the volume of land over sea level. But the vertical extent of the seas is still quite small in comparison to the horizontal dimensions.

An important characteristic in the ocean floor's topography is the main system of sub-sea mountain ridges (Fig. 1.7). This is a continuous system of ridges which rise 2- 4000 meters over the ocean floor in the basins. They play an

The major oceanic ridge systems. Because in the Atlantic Ocean the ridge system is almost exactly in the middle of the ocean the system is also called the "Mid-Oceanic" ridge system. The transverse faults are probably the result of differential movement of the ridge areas on either side of the faults due to ocean-floor spreading
(After Heezen, 1963, in The Sea, ed. by Hill.)

Fig.1.7



important role in modern theories of how the ocean became as it is today. For a long time it was believed that the oceans were a very old characteristic of the earth's crust. Wegener (1922) was the first to cast doubt on this belief with his *continental drift theory*. In the last 10 – 20 years a great deal of facts concerning the ocean floor have been joined together and created a logical wholeness for the *plate tectonics theory*. The earth's crust is seen as being divided into a number of "plates" which move relative to one another. A ridge is a border between two plates which are moving away from each other. Here the lava rises up, hardens after some time and creates a new ocean floor which pushes the old ocean floor to the side.

Look, for example, at the Atlantic Ocean in Fig. 1.8. Only 100 -200 million years ago, America and Europe-Asia were side by side. Then they began to sail away from each other,

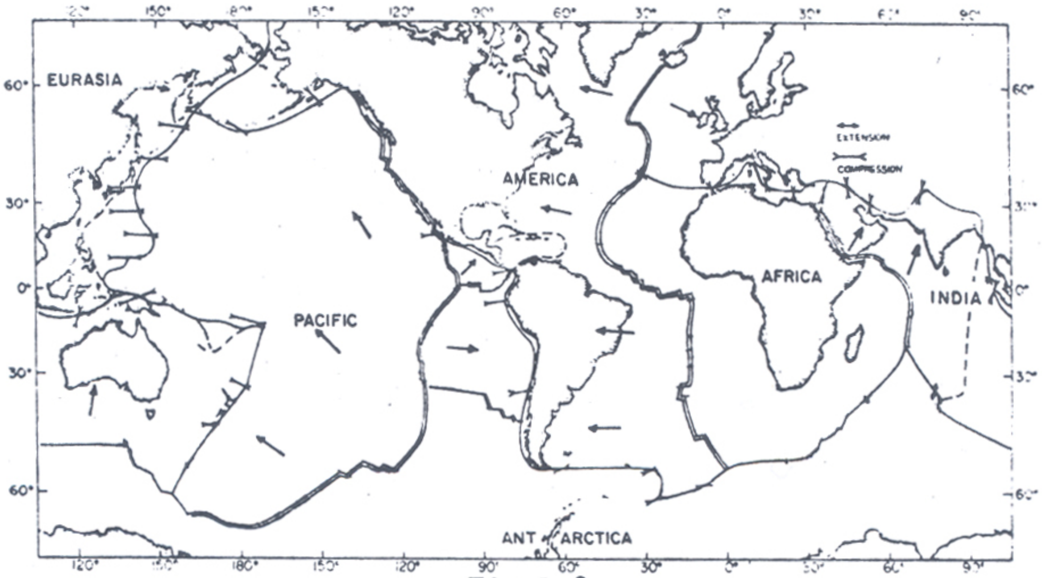


Fig.1.8

each on their side of the fracture zone, which with time became the *Mid-Atlantic Ridge*. This indicates an average speed for the two plates of a few cm per year. The earlier mentioned deep-sea trenches are also connected to this plate movement. This is where two plates hit against one another, the one goes under the other and melts when it has gone deep enough (Fig. 1.9). During this process the deep sea trenches come into existence as long, narrow ditches in the earth’s crust. This process has been especially active on the west side of the Pacific Ocean. Because of this, the Pacific is getting smaller while the Atlantic Ocean is becoming larger. (3-5 cm per year).

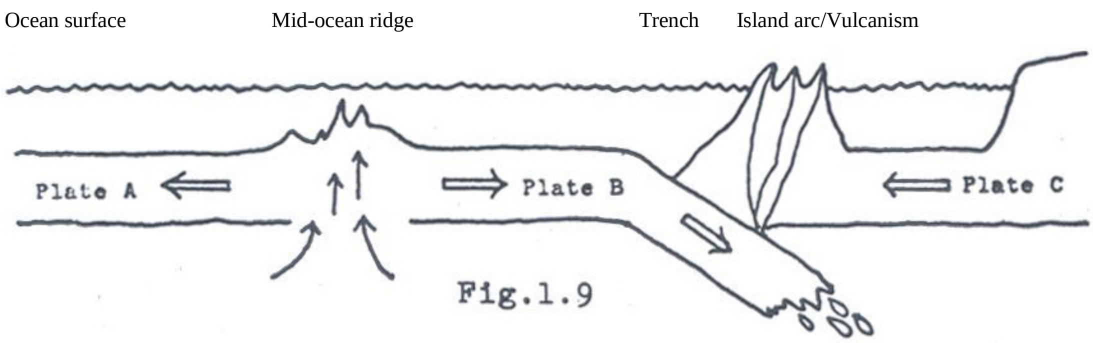


Fig.1.9