MORPHOLOGY OF OCEAN FLOOR AND PLATE TECTONICS

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Contents

Summary

In this chapter, we discuss the morphology of the sea floor and its origin. The development of bathymetry in the twentieth century has lead to the revolutionary geological theory, plate tectonics, which explains the evolutionary processes shaping the Earth's surface. According to plate tectonics, the continents have suffered multiple collisions due to the opening and closing of oceans. Created in the middle of oceans, the sea floor spreads out while experiencing cooling and subsidence, and then subducts along ocean trenches into the Earth's interior. The morphological and geological structures of the sea floor primarily reflect plate tectonics and sedimentation over the last 200 million years. The sea floor is divided into three principal provinces: the continental margins, the mid-ocean ridges and the deep-ocean floors. The continental margins are shallow regions which collect sediment from their adjacent continents. This province is economically very important mainly because of oil and gas exploration and fisheries. Its major morphological features are the continental shelves, slopes and rises, island arcs and backarc basins, and marine canyons and fans. The mid-ocean ridges occupy the middle parts of all oceans except for the Pacific, where the East Pacific Rise is situated in the far eastern regions before meeting North America. Along the crests of mid-ocean ridges are the rift valleys which are spreading centers of the sea floor. Due to uneven spreading speed, there are a great number of magnificent fracture zones cutting perpendicularly through the mid-ocean ridges. The deep-ocean floors are between the mid-ocean ridges and the continental margins, and are mainly the result of cooling and subsidence of the sea floor and continuous sedimentation. This province includes such features as abyssal plains, abyssal hills, seamounts and guyots, seamount chains and ocean trenches. The deepest parts of the ocean floor are in the ocean trenches where

plates subduct beneath other plates, the deepest being the Mariana trench which reaches more than 11,000 meters in depth.

1. Introduction

During most of recorded history the oceans were a mysterious domain for humankind. It was only fairly recently that people started to realize that the sea floor is not flat and featureless. Knowledge of the sea floor has depended on the development of bathymetry. In the nineteenth and early twentieth century, the depths of oceans were measured using a rope with a weight attached to the end. In the 1920s, a technological breakthrough occurred with the invention of the echo-sounder, an electronic device which emits sound waves and receives their echoes from the sea floor (Figure 1). Knowing the sound wave velocity in the water (about 1,500 meters per second) and its travel time between the sea floor and the echo-sounder at the surface of the water, the depth can be accurately calculated. Sound waves in water have played a very important role in the development of bathymetry because most efficient and useful instruments for mapping the detailed topographic features of the sea floor, and for exploring sedimentary and geological structures beneath it, are designed to record the travel times and amplitudes of reflected waves from the sea floor and its subbottom sedimentary and geological layers. The side-scan sonar receives the sound waves scattered back from the sea floor to image the detailed topography, and is useful for finding special objects or for mapping special morphological features on the sea floor. The multibeam ocean mapping system (popularly known as the "swath" system) transmits and receives sound waves at different angles at the same time to efficiently provide high-quality data for the bathymetry and imagery of the sea floor. The subbottom profiler transmits stronger sound pulses than the echo sounder, and records the reflected sound waves from beneath the sea bottom to obtain the profiles of the subbottom structures of sedimentary layers (Figure 1).

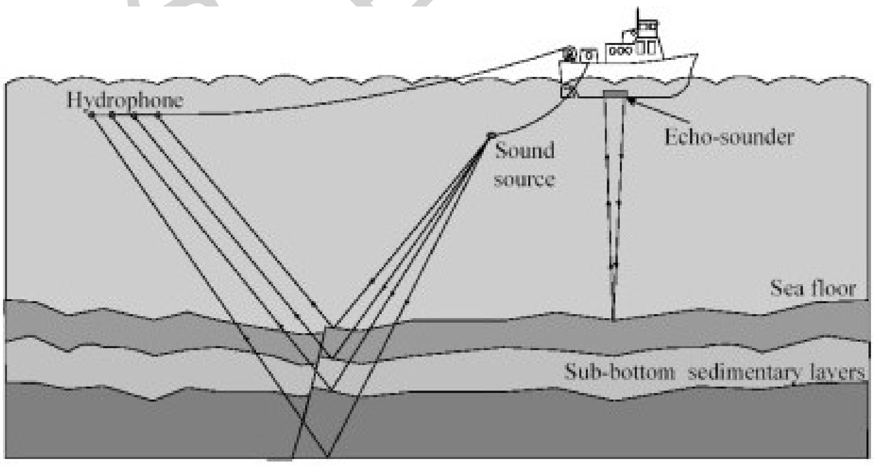

Figure 1: Diagram showing how echo sounding and seismic profiling are used to measure the depths of sea floor and to profile the subbottom structures.

The oceans are so vast that, it is both very difficult and expensive to conduct the bathymetric measurement densely and evenly aboard ships. Because research vessels travel quite slowly (~10 knots) it would take more than 100 years to map the ocean basins even using the latest swath mapping systems. To date, only a small fraction of the sea floor, especially of the southern hemisphere, has been mapped by ships. Therefore, the development in the 1980s and 1990s of bathymetric data acquisition by satellites has been fundamental to obtaining the global topography of the oceans. Satellite altimetry provides data on the sea surface relief which has some relationship with the topography of the ocean bottom due to gravitational force. From this relationship bathymetric data can be computed and the ocean topography delineated.

Our knowledge of the depth and topography of the sea floor has been accumulating rapidly since the invention of the echo-sounder in 1920s, especially since the Second World War. In the 1950s and 1960s, maps of the sea floor for most of the globe were compiled. These showed most major features of the sea floor giving great insight into their tectonic processes. These major features include mid-ocean ridges, flat deep ocean floors and ocean trenches, which together with geomagnetic, seismicity and other geophysical and geological data, led to two revolutionary theories. These were sea-floor spreading, which describes the origin and evolution of the sea floor, and plate tectonics, which indicates the geological processes of the Earth's surface shaping.

In this chapter we shall briefly describe the morphology and structure of the ocean bottom and its origin and evolution.

2. Principal Provinces of Sea Floor

The electronic echo sounder was greatly improved and extensively used both before and during the Second World War, mainly for military purposes. After the Second World War, it was pressed into service to explore the ocean bottom all over the world. A great number of cruises were carried out to collect global bathymetric data, especially aboard American research vessels from the Scripps Institution of Oceanography at La Jolla in California, the Woods Hole Oceanographic Institution in Massachusetts, and the Lamont-Doherty Geological Observatory of Columbia University in New York. During this time, bathymetric data were accumulated rapidly and global bathymetric mapping thus became possible. A mapping project initiated by Maurice Ewing and Bruce Heezen at the Lamont-Doherty Geological Observatory, and later headed by Bruce Heezen and Marie Tharp, led to the publication of the well-known maps of the Pacific, Atlantic and Indian Oceans in National Geographic of the National Geographic Society, Washington D.C. These maps appear in virtually all textbooks on geology and geophysics, and provided the marine geologists and geophysicists with new ideas in their research areas. Figure 2 shows the map of the Atlantic Ocean.

If all the waters of the oceans were removed, what would the ocean bottom look like? One would find that most morphological features of the sea floor are the same as those on land; there are the same mountains, plains, valleys, basins, plateau…etc., but these, in general, have a simpler and more regular pattern than those on land. Figures 2 and 3 shows the major morphological features of the Atlantic bottom.

Figure 2: Morphological diagram of the Atlantic ocean floor, from a painting published by National Geographic Society (U.S.A.) based on bathymetric studies of B. C. Heezen and M. Tharp.

The most conspicuous morphological feature is the magnificent continuous mountain range near the center of the Atlantic, called the mid-Atlantic ridge. This continuous range extends to the Pacific, Indian and Arctic Oceans and encircles the whole Earth, with a total length of about 65,000 kilometers. The mid-Atlantic ridge is symmetrical and occupies about one third of the sea floor of the Atlantic Ocean. With the mid-Atlantic ridge, the deepest parts of the Atlantic Ocean do not occur in its middle as one might expect.

There are shallow parts of the oceans around the continents with depth mostly less than one thousand meters, and these are referred to as the continental margins. Between the continental margins and the mid-ocean ridges, the ocean floor is mostly deeper than 3 kilometers. Therefore, all the morphological features of the sea floor of the Atlantic fall into one of the three principal provinces: the continental margins, the mid-ocean ridges and the deep-ocean floors (Figure 3). These three provinces of ocean floor also exist in the Pacific, Atlantic and Arctic oceans. In order to facilitate the discussion of the structure and the origin of the morphological features in different provinces, we shall first introduce briefly the revolutionary theories in marine geology developed in the 20th century which describe the geological dynamic processes resulting in the morphology and structure of the sea floor.

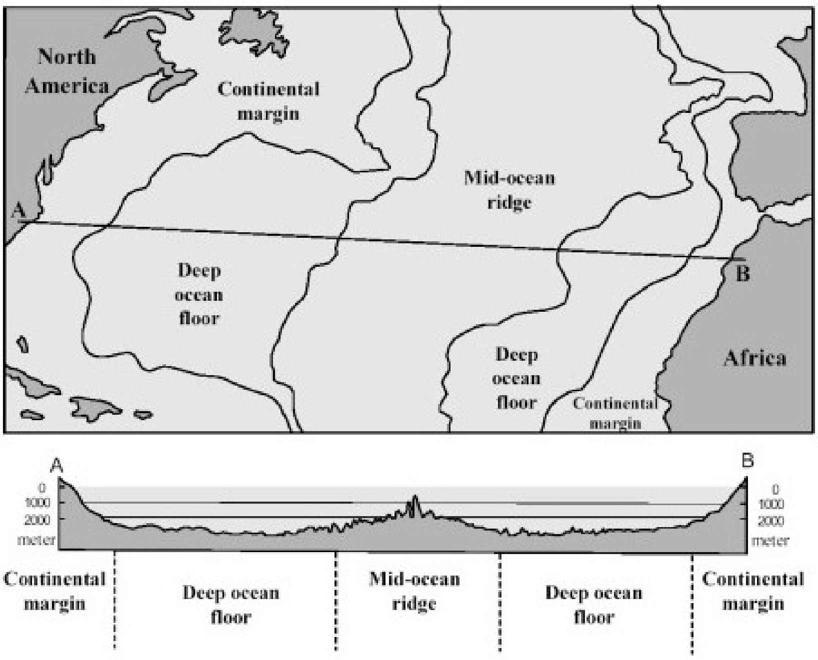

Figure 3: (top) A simplified map of the sea floor of the Atlantic Ocean showing continental margins, mid-ocean ridge and deep-ocean floors; (bottom) A profile of the sea floor along line AB showing morphological features of the Atlantic Ocean in each province (After B. C. Heezen, M. Tharp and M. Ewing, Geological Society of America Special Paper 65, 1959).

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Biographical Sketch

Prof. Chengsung Wang obtained his B.Sc. degree from Department of Physics, National Tsing Hua University, Taiwan, in 1970, his M.Sc. degree from Institute of Oceanography, National Taiwan University in 1972 and his Ph.D degree in Seismology from Research School of Earth Sciences (RSES), Australian National University (ANU) in 1978. He worked as Associated Research Fellow in Institute of Earth Sciences, Academia Sinica (Taiwan), Research Fellow in RSES, ANU, Professor and Chairman in Department of Oceanography, National Taiwan Ocean University (NTOU). He established Institute of Applied Geophysics (IAG) at NTOU in 1994 and was the first director of the Institute from 1994 to 2000. He was also Director of Chinese Geophysical Society (Taiwan) in 1998 and 1999. He is now Professor in IAG, NTOU, teaching courses of Geophysics and Plate Tectonics. His main interests of research are seismology and plate tectonics in the convergent boundary near Taiwan.