1

Descriptive Oceanography

1.1 Introduction

Before we discuss the chemistry of the oceans, it is useful to review some descriptive features of the oceans. Oceanography is the scientific study of the oceans and can be divided into four major areas:

1. Physical oceanography: the study of the physics of the oceans and their interactions with the atmosphere
2. Biological oceanography: the study of the biology of the oceans
3. Geological oceanography: the study of the geology and geophysics of the oceans
4. Chemical oceanography: the study of the chemistry of the oceans

The basic goal of oceanography is to obtain a clear and systematic description of the oceans. It is hoped that an increased knowledge of the oceans will lead to a better understanding of how they control the climate of the earth and how they can be used as a source of food, chemicals, and energy.

The goal of the physical oceanographer is to obtain a systematic and quantitative description of ocean waters and their movements. The ocean currents circulate continuously with small-scale variations from tides and waves generated by winds and earthquakes. This physical study of the oceans has been examined by:

1. The descriptive approach: where observations are made of specific features and reduced to a single characterization of the general features.
2. The dynamic approach: where the known laws of physics are applied to the oceans. An attempt is made to solve the mathematical equations for the motion of a body acted on by forces.

In this brief review we will be concerned with the descriptive physical oceanography of the oceans. It is important to understand these descriptive features since the movement of ocean waters affects the biogeochemical processes that occur in the oceans. Much of the material covered in this chapter is taken from the books by Pickard and Emery (1982), Dietrich et al. (1980), and Tchernia (1980). These texts should be referred to for further details.

The field of physical oceanography in its modern context was initially based on the collections of physical data on surface currents and winds that were made by Matthew Fontaine in 1855. The HMS *Challenger* expedition (1872 to 1876) was the first to gather oceanographic data from around the world. The *Meteor* expedition (1925 to 1927) yielded the first details of the physics of the Atlantic Ocean waters. In recent years there have been several large-scale research programs that have led to a more thorough description of the oceans. Some are listed below:

1. The Geochemical Oceans Sections Study (GEOSECS) from 1970 to 1980
2. The World Ocean Circulation Experiment (WOCE) from 1990 to 2000
3. The Climate Variability Program (CLIVAR) from 2001 to the present

Early theoretical studies of surface tides were made by Newton and Laplace and of waves, by Gerstner and Stokes. The Scandinavian meteorologists Bjerknes, Ekman, and Helland-Hansen developed the field of dynamic oceanography. Recent studies have examined coastal processes, western boundary currents such as the Gulf Stream, small-scale fluctuations, eddies or rings, bottom water movement, and the use of tracers to study large-scale mixing processes. Currently, physical and chemical oceanographers are participating in the Climate Variability Program (CLIVAR). This study is a continuation of the WOCE program. This global study includes a reoccupation of some of the long lines that were studied as part of the Joint Global Ocean Flux Study (JGOFS) and Ocean–Atmosphere Carbon Exchange Study (OACES) CO_2 programs, which will be discussed later. Future oceanography will have a strong component dealing with satellites and remote sensing techniques utilizing moored arrays of instruments in the oceans. This global ocean observing system (GOOS) will be concerned with making continuous physical and chemical measurements of the Global Ocean.

1.2 Physical Characteristics of the Oceans

The physical characteristics of the oceans and adjacent seas are given in Table 1.1. Several facts to keep in mind while examining this table are that 71% of the surface of the earth is covered by the oceans (361×10^6 km^2); the highest mountain on land is 8,848 m (Mt. Everest), while the deepest ocean trench is 11,022 m (Mariana). The Southern Hemisphere has the largest percentage of water (80.9%). The various depth zones of the oceans are given in Table 1.2. The world oceans (including adjacent seas) are made up of 50% by the Pacific, 29% by the Atlantic, and 21% by the Indian. The major depth zone of the ocean (74%) lies between 3 and 6 km. As will be discussed later, 50% of ocean waters have a temperature range between 1.3 and 3.8°C and a salinity (grams of salt in 1 kg of seawater) between 34.6 and 34.8. The mean depth of the oceans is 3.7 km, the mean temperature is 3.5°C and the mean salinity is 34.7.

A classification of the large-scale topographic features of the world oceans is shown in Figure 1.1. The principal features of the ocean floor are shown in Figure 1.2. This figure gives an oversimplification of the actual bottom, but shows the major features. Continental margins show a wide range of unique features, and a number of studies have been conducted of seamounts that occur in deep sea basins. The detailed structure has been recently examined for the mid-ocean ridge systems (see Figure 1.3).

The **shore** is the part of the land mass close to the sea that has been modified by the sea. The continental shelf is seaward from the shore and has a gradient or slope of 1 to 500 and an average width of 65 km. The **break in slope** is the outer limit of the shelf and has a slope of about 1 to 20 and an average depth of 130 m. The **continental slope** is about 4000 m from the shelf to the deep sea bottom. In some places it extends as much as 9000 m vertically over a relatively short horizontal distance (e.g., off the west coast of America).

TABLE 1.1

Area, Volume, Mean, and Maximum Depths of the Oceans and Their Adjacent Seas

Sea	Area (10^6 km^2)	Volume (10^6 km^3)	Depth	
			Mean (m)	Maximum (m)
Oceans without Adjacent Seas				
Pacific Ocean	166.24	696.19	4,188	11,022
Atlantic Ocean	84.11	322.98	3,844	9,219
Indian Ocean	73.43	284.34	3,872	7,455
Total	323.78	1,303.51	4,026	—
Intercontinental Mediterranean Seas				
Arctic	12.26	13.70	1,117	5,449
Austral Asiatic	9.08	11.37	1,252	7,440
American	4.36	9.43	2,164	7,680
European	3.02	4.38	1,450	5,092
Total	28.72	38.88	1,354	—
Intercontinental Mediterranean Seas				
Hudson Bay	1.23	0.16	128	218
Red Sea	0.45	0.24	538	2,604
Baltic Sea	0.39	0.02	55	459
Persian Gulf	0.24	0.01	25	170
Total	2.31	0.43	184	—
Marginal Seas				
Bering Sea	2.26	3.37	1,491	4,096
Sea of Okhotsk	1.39	1.35	971	3,372
East China Sea	1.20	0.33	275	2,719
Sea of Japan	1.01	1.69	1,673	4,225
Gulf of California	0.15	0.11	733	3,127
North Sea	0.58	0.05	93	725
Gulf of St. Lawrence	0.24	0.03	125	549
Irish Sea	0.10	0.01	60	272
Remaining seas	0.30	0.15	470	—
Total	7.23	7.09	979	—
Oceans, including Adjacent Seas				
Pacific Ocean	181.34	714.41	3,940	11,022
Atlantic Ocean	106.57	350.91	3,293	9,219
Indian Ocean	74.12	284.61	3,840	7,455
World Ocean	362.03	1,349.93	3,729	11,022

Source: Data from Dietrich et al., 1980.

The **deep sea bottom** represents the most extensive topographic area (76% of ocean basins) and has a depth between 3 and 6 km. This area is not completely flat but is characterized by welts, furrows, swells, and basins.

The bottom sediments contain material both formed in the sea (pelagic) and brought from the land by rivers and the atmosphere (nonpelagic). The components of sediments can be divided into a detrital fraction transported as a solid and a nondetrital, or authigenic, fraction transported as dissolved matter. Sediments can be divided into four types (see Figure 1.4):

TABLE 1.2

Depth Zones in the Oceans

	Depth Zone (km)												
Ocean Area[a]	**0–0.2**	**0.2–1**	**1–2**	**2–3**	**3–4**	**4–5**	**5–6**	**6–7**	**7–8**	**8–9**	**9–10**	**10–11**	**% World Ocean**
Pacific Ocean[b]	1.631	2.583	3.250	6.856	21.796	34.987	26.884	1.742	0.188	0.063	0.019	0.001	45.919
Austral Asiatic	51.913	9.255	10.433	12.151	6.698	7.780	1.636	0.076	0.058	0	0	0	2.509
Mediterranean Seas[c]													
Bering Sea	46.443	5.975	7.623	10.330	29.629	0	0	0	0	0	0	0	0.625
Sea of Okhotsk	26.475	39.479	22.383	3.403	8.260	0	0	0	0	0	0	0	0.384
East China Sea[d]	81.305	11.427	5.974	1.239	0.055	0	0	0	0	0	0	0	0.332
Sea of Japan	23.498	15.176	19.646	20.096	21.551	0.033	0	0	0	0	0	0	0.280
Gulf of California	46.705	20.848	25.891	6.556	0	0	0	0	0	0	0	0	0.042
Atlantic Ocean[b]	7.025	5.169	4.295	8.590	19.327	32.452	22.326	0.738	0.067	0.012	0	0	23.909
Arctic Med.[e]	47.083	17.427	9.317	11.153	12.834	2.195	0	0	0	0	0	0	3.386
American Med.	23.443	10.674	13.518	15.313	20.796	13.440	2.572	0.193	0.051	0	0	0	1.203
European Med.[f]	22.868	20.814	18.362	30.326	7.426	20.204	0	0	0	0	0	0	0.834
Baltic Sea	99.832	0.168	0	0	0	0	0	0	0	0	0	0	0.105
Indian Ocean[b]	3.570	2.685	3.580	10.029	25.259	36.643	16.991	1.241	0.001	0	0	0	20.282
Red Sea	41.454	43.058	14.920	0.568	0	0	0	0	0	0	0	0	0.125
Persian Gulf	100.000	0	0	0	0	0	0	0	0	0	0	0	0.066
World Ocean	7.492	4.423	5.376	8.497	20.944	31.689	21.201	1.232	0.105	0.032	0.009	0.001	100.00

[a] As a percentage of the surface of each ocean.

[b] Without adjacent seas.

[c] Including Andean Sea

[d] Including Yellow Sea.

[e] Consisting of Arctic Ocean, Barents Sea, Canadian Archipelago, Baffin Bay, and Hudson Bay.

[f] Including Black Sea.

Source: Data from Dietrich et al., 1980.

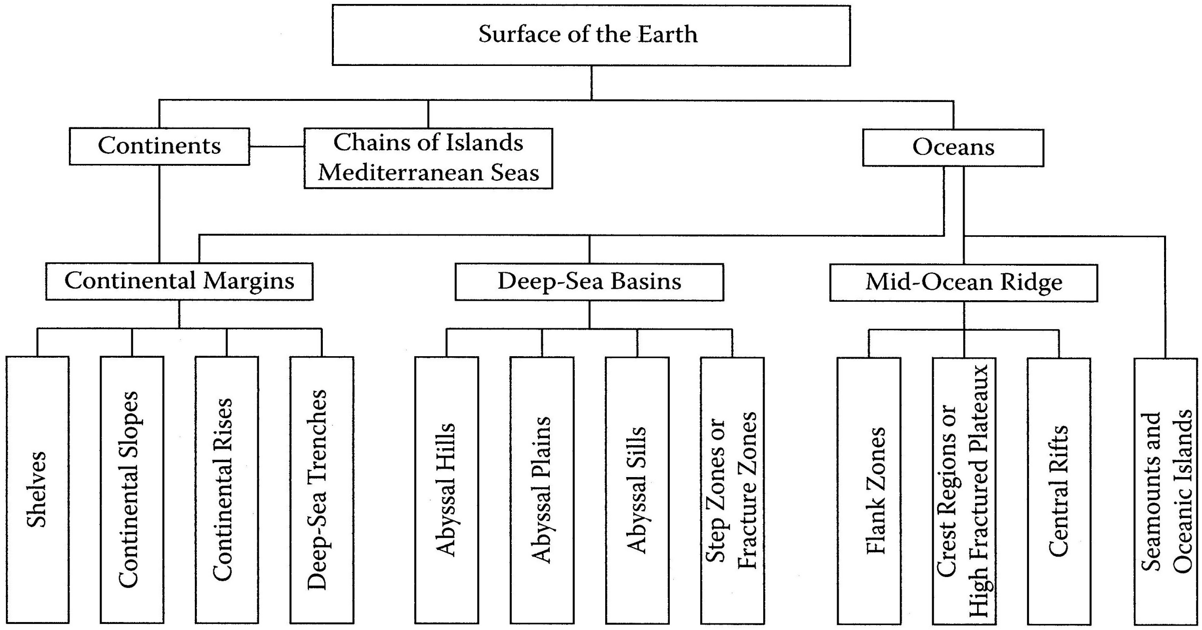

FIGURE 1.1
Divisions of the surface of the earth.

1. Hydrogenous: formed by reactions (precipitation and adsorption) in the water
2. Biogenous: produced by living organisms from the parts of shells and skeletons
3. Lithogenous: produced from the weathering of the earth's surface and transported by rivers and winds to the oceans
4. Cosmogenous: produced from extraterrestrial sources

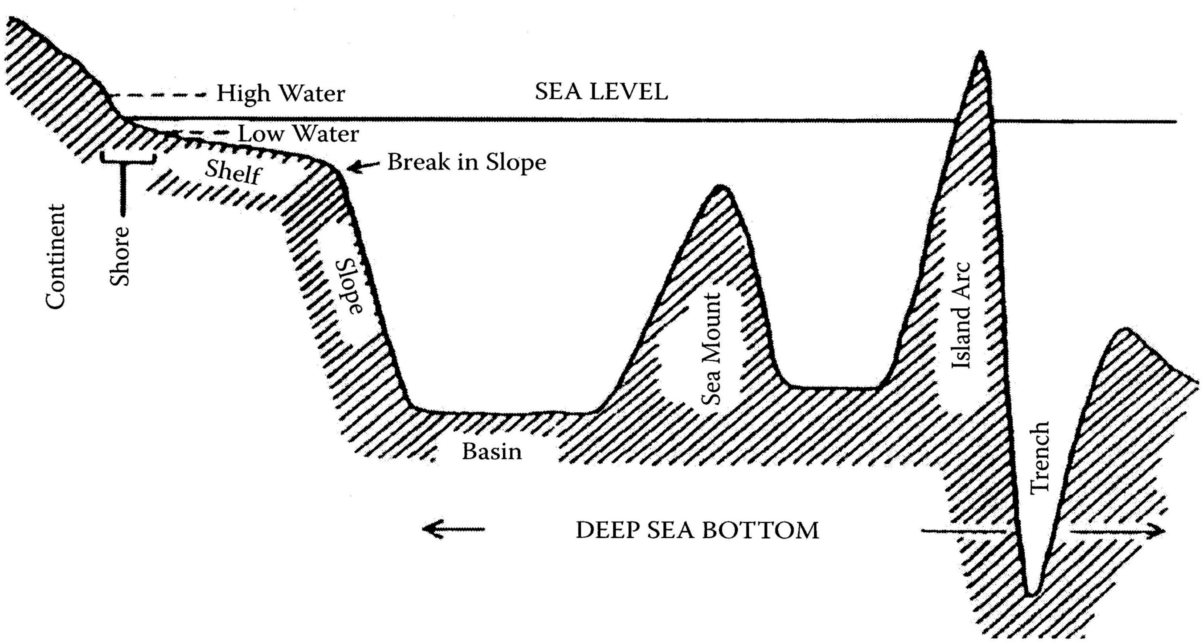

FIGURE 1.2
Structure of the ocean floor.

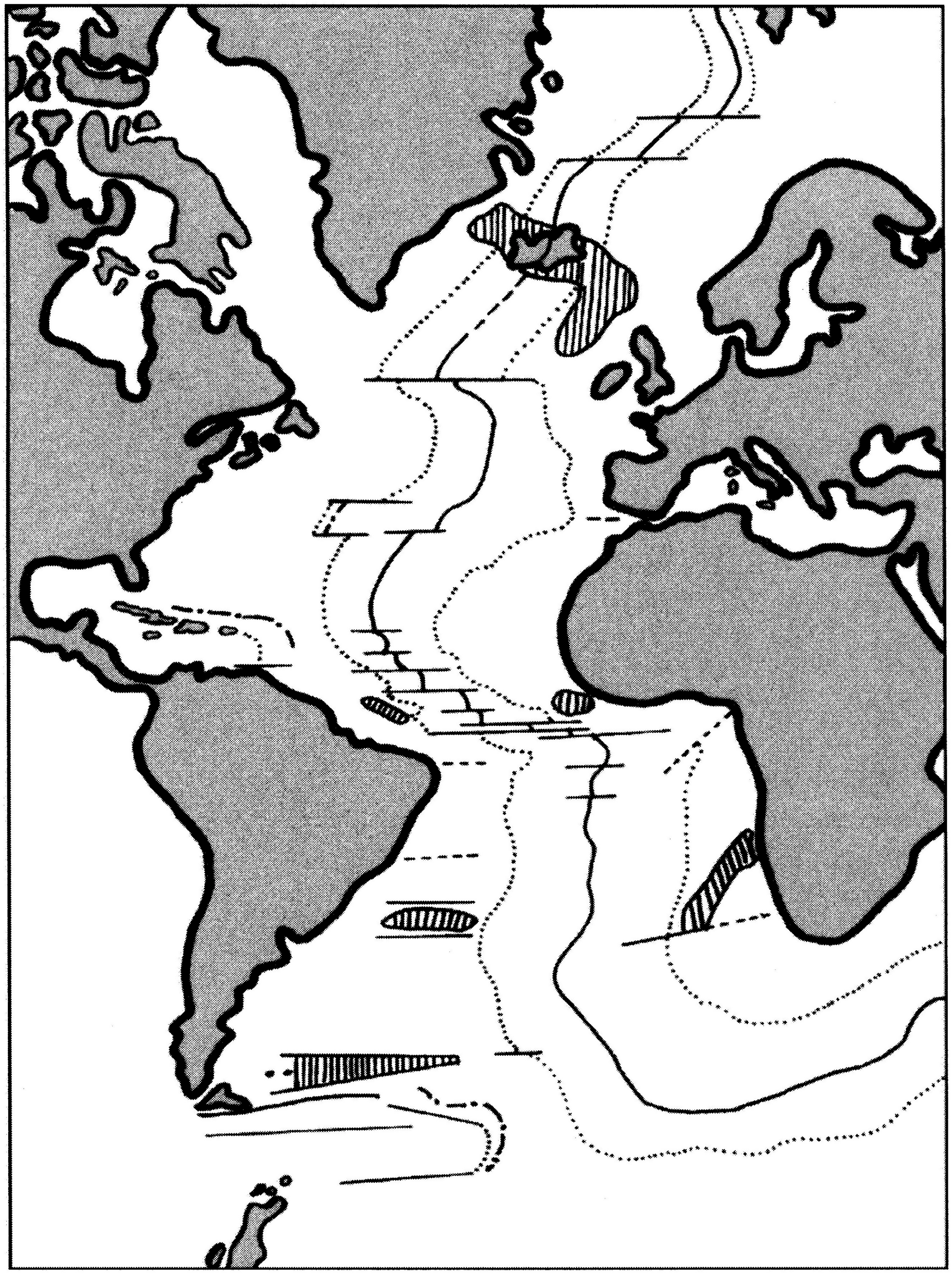

FIGURE 1.3
Active ridge systems in the oceans.

Examples of the various types include:

1. Hydrogenous: aragonite ($CaCO_3$) in the form of "whitings" on the Bahama Banks, manganese nodules (MnO_2) in the deep Pacific, iron hydroxides (Fe_2O_3), sulfates ($CaCO_4$) and phosphates ($Ca_3(PO_4)_2$)
2. Biogenous: calcite ($CaCO_3$) from foraminifera and cocoliths, aragonite from pteropods, silica (SiO_2) from radiolarians and diatoms

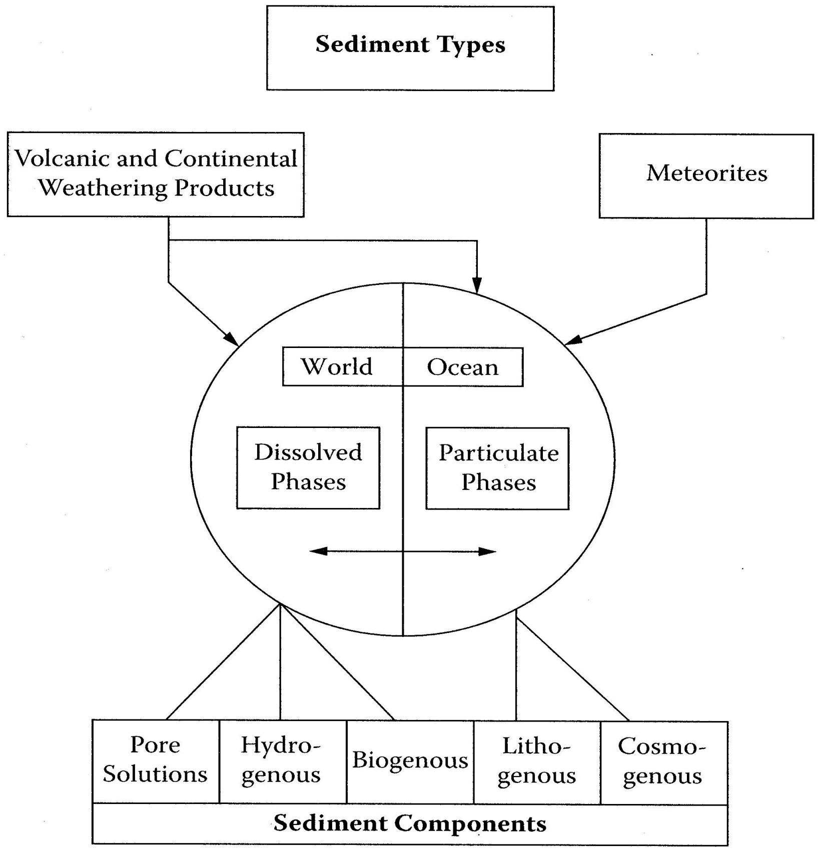

FIGURE 1.4
Types of ocean sediments.

3. Lithogenous: clay minerals (Al silicates) and quartz (SiO_2) as rock fragments transported by wind, rivers, glacial waters, and volcanic sources
4. Cosmogenous: ferric meteorites (Fe_2O_3) from outer space.

More will be said about the chemistry of deep sea sediments later.

1.3 Distribution of Temperature and Salinity for Ocean Waters

Much of our descriptive knowledge of the physics of the oceans comes from an examination of the properties of seawater from place to place. Our knowledge of the distribution of various properties comes from the collection of measurements made at oceanographic or hydrographic stations. Properties such as temperature, salinity (the approximate grams of sea salt in 1 kg of seawater), the concentration of oxygen, nutrients, and so on are measured as a function of depth. These measurements at a given station are plotted as a function of the depth (which can be related to the pressure, 10 m ~ 1 bar) and are called a vertical profile. Profiles from a string of stations can be combined to form a vertical section. The common values of a given property are connected to give a contour of the property of interest as a function of depth and distance. Similar contours of common properties can be made of surface waters and waters at a fixed depth (e.g., 4000 m). The contour lines can