Introduction to Physical and Biological Oceanography

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Preface

The second edition of *Oceanography for Geographers* is being divided into two volumes, a course that has been made necessary by the great volume of new material that has been published since the first edition was published over a decade ago. The first volume concentrates on the geomorphology of the oceans in relation to the exciting new ideas of global tectonics and sea floor spreading, an advance that owes a great deal to Oceanographical work. This second volume deals with some aspects of Physical and Biological Oceanography. The physical aspects that are considered include an introduction to the character of ocean water, its circulation in the form of surface currents and deep water movements. The tides are considered in one chapter and the various waves that disturb the surface of the ocean in another. Two chapters are devoted to the biological aspects of oceanography, the first dealing with productivity and the second with exploitation. This chapter leads on to the final one, which is concerned with the uses and problems of the oceans. These problems stem to a large extent from the fact that the open ocean belongs to all mankind, and legal problems concerning the use of the biological and inorganic resources of the oceans are increasing in importance and complexity. For this reason an appendix by an expert in oceanic law, Edgar Gold, has been specially prepared, and this forms a valuable addition to the volume. We shall depend more and more in the future on the riches of the oceans, including such vital raw material as oil, which is very plentiful in certain areas in the offshore zone, and on the food resources of the sea. These organic resources are very liable to over-exploitation—including such interesting creatures as the Blue Whale, the largest animal to exist on earth—unless international control can be effectively agreed amongst the fishing nations of the world. The oceans are a major field of scientific endeavour at present, and their importance to the world at large can only increase in the future. It is, therefore, increasingly essential that the oceans become better known and that their intricacies are studied more deeply.

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Contents

1 Introduction

1 The scope of this volume

The subject of oceanography covers a wide range of topics. One of the most clear-cut of these is marine geology and geomorphology, which deals with the form of the crust and mantle, and with processes operating within them including those responsible for the distribution of sediment in the ocean basins. These aspects of oceanography were con-considered in volume 1, *Introduction to Marine Geology and Geomorphology*, together with factors concerning the accumulation of and variation in the amount of water in the ocean basin receptacles.

Other major fields of oceanography include physical oceanography, chemical oceanography, and biological oceanography. All these major branches of the subject are interrelated with each other and with geological and geomorphological oceanography. They are only treated separately for convenience, and it is always necessary to bear in mind the connections between them. In this volume the emphasis is placed on physical oceanography and to a lesser extent on biological oceanography, although some aspects of chemical oceanography are also relevant in both fields (for instance, in a study of the fertility of the oceans). Because of the present active interest in all aspects of man's environment, the rapidly growing field of applied oceanography gains importance as a field that draws upon knowledge from studies in pure oceanography and focusses on man's direct involvement as the main user of oceanic resources and wealth. In order to use this wealth wisely, man must learn more and more about the oceanic environment in all the diverse fields of oceanography, and appreciate the ways in which they are linked together. As technology increases in complexity and power, so man's impact on the oceans becomes more and more marked. It is vital that control of use should be agreed upon and implemented as soon as possible, and this control must be based on sound knowledge. Some aspects of the human-based problems (such as pollution and conservation) are considered briefly in this volume, as are some of the legal problems associated with them.

2 Interrelationships in oceanography

2.1 Character of ocean water

In this section some of the links between the different aspects of oceanography that are mentioned in this volume, the broader field of oceanography, and the other sciences with which it comes into contact, will be referred to. The character of ocean water is dependent both upon outside influences and internal processes. The major external influence is that of the atmosphere, which affects the temperature and salinity of ocean water. Salinity, however, is a complex property and lies more properly within the field of chemical oceanography, which is not dealt with here in any detail. Complications in salinity variations are concerned with the dynamic character of the chemical components of sea water and the processes that are involved, which include biological activity as well as geological processes, such as volcanic eruptions and the entrance of chemicals into the oceans via the rivers. An important point in this connection is that each chemical element has a specific residence time in the chemical cycle. The result, however, is to provide a steady-state system approximately, as far as the character of the chemical constitution of sea water is concerned. Thus the proportions of the different elements in sea water are maintained in a constant ratio, which applies throughout the mass of ocean water. There are, however, variations in the total amount of dissolved matter in ocean water, leading to variations both in time and space in the total salinity of the water. It is these variations in total salinity that are closely related to the atmospheric processes that determine the zones of greater and lesser precipitation and evaporation over the ocean surface. Thus the zones of higher precipitation and lower evaporation are those of lower salinity and vice versa. These zones can be directly related to the major pattern of atmospheric circulation discussed in chapter 2. The temperature of the water is also directly affected by the atmosphere, both by direct insolation and through the weather, which is dynamic and hence variable. There are daily, seasonal, and longer-term variations, again both in time and space, of temperature conditions in the ocean waters.

Salinity and temperature together determine the density of the water and hence have an effect on its movement, because water that is dense will sink, and this induces further movement of deeper water. The vertical movement of water, related to density, are of considerable significance also in the biological field of oceanography, because the fertility of the water is often directly related to the degree of stirring in the vertical sense. This is because the phytoplankton and other marine plants, the seaweeds, can only make use of nutrients when they are in the upper layers of water to which sufficient light for photosynthesis can penetrate. Density variations are not, however, the only cause of vertical movement of ocean waters, and other interrelationships of vital importance to the fertility of the sea will be mentioned later.

2.2 The role of the oceans in the hydrological cycle

One of the most fundamental cycles that alone maintains life on earth is the hydrological cycle. It is this cycle that makes possible life on land because of the transference of water from the great reservoir of the oceans to the land via the atmosphere. The hydrological cycle depends fundamentally on the interrelationship between the circulation of the ocean and that of the atmosphere, which is one extremely complex, coupled system with numerous highly complicated feedback relationships between the different aspects of the system. Water is withdrawn from the oceans into the atmosphere by processes of evaporation, dependent on air and sea temperatures and on wind strength and humidity. Another important relationship concerning chemical oceanography and the hydrological cycle is the raising into the atmosphere of minute particles of salt and other minerals from the sea as spray. This process plays a significant part in the residence time of sodium chloride in the ocean; it also provides many of the hygroscopic nuclei that enable precipitation to take place more effectively. The salt then returns to the oceans via rainfall, rivers, and other phases of the land stage of the hydrological cycle.

The contrast between an oceanic and continental climate, characteristic of the west and east sides of the continents respectively, also demonstrates very effectively the importance of the oceans in the operation of the hydrological cycle: precipitation is higher on the west, and temperatures are much milder than on the east side.

Still larger climatic events (including major ice ages) have, according to the theory of Ewing and Donn, been brought about by changes in the characteristics of the oceans. They argue that the conditions of the north polar Arctic Ocean control the climate of the areas around its shores and initiate ice ages when conditions are suitable. The most important variable in this connection is the extent of ice cover in the Arctic Ocean. When ice is widespread, precipitation is reduced on surrounding lands, but when ice cover is reduced, precipitation in the form of snow allows ice-sheets to build up, which in turn reduce the temperature, thus causing more widespread Arctic freezing, the reduction of precipitation, and perhaps the onset of a cold interglacial period. This is a complex feedback situation in which positive elements are self-generating up to a point beyond which negative controls come into operation, leading to a reversal of the former change. These ideas are still controversial, but they do serve to illustrate the complex interrelationships between atmospheric and ocean circulation. The theory also provides a link with geological oceanography in the suggestion that the movement of the continents (on their crustal plates) to suitable geographical positions is responsible for the initial change in ice conditions in the Arctic, starting the chain reaction that could lead to an ice age.

The wider repercussions of this major climatic event are so widespread (and are felt in all branches of earth science and biological science) that it is very difficult to identify them all. One or two are mentioned in volume 1, for example the effect of climate on ocean sediments, and the information that can be obtained from a study of ocean cores concerning climatic change and ice conditions in the Arctic. The links between ocean sediment and the climate include important biological ones, because temperature and other characteristics of the surface water determine the species of creatures that can flourish under those conditions, and which form an important element in the sediment that eventually collects on the bottom.

The hydrological cycle is concerned with water in all its forms; as ice both in the form of glaciers and ice-sheets (as well as sea-ice), as water in the liquid form (fresh water on land and salt water in the sea), and as vapour in the atmosphere. The fact that water occurs naturally in all three states is of immense importance in the operation of the hydrological cycle, and also has repercussions in all aspects of oceanography as well as other branches of earth sciences. The interaction between ocean and atmosphere involves all three states of water—the solid, liquid, and gaseous.

2.3 The interaction of the oceans and atmosphere

The air is the medium by which water is transferred from the oceans to the land. The wind blowing over the water also generates waves, which eventually exert a very significant effect on the edge of the ocean, bringing into being all the diversity of coastal landforms. Wind also plays an important part in the movement of the surface waters and in setting up the circulation of the ocean currents, whereby water of different characteristics is carried away from its place of origin to modify the shore against which it may eventually flow. In this way the distribution of warmth received on the earth is spread more evenly over the surface. The wind also plays its part in inducing zones of upwelling, which are important in connection with the very rich fishing areas that result from the bringing of nutrient-rich waters to the surface by this process.

There are many features in common between the surface circulation of the oceanic waters and the atmosphere above them. There is also another most important interplay between the oceans and the air, which can be seen by studying the hydrological cycle and the part it plays in life on earth. Wind blowing over the ocean takes up water vapour from the surface into the air by evaporation. It can then be distributed over the land surface by the wind and the processes that lead to precipitation. The oceans, therefore, play a vital part in the character of the earth's climate. It is one of the fundamental facts of climatology that the oceanic and continental climates differ greatly, and through their influence on the climate, the oceans play an important indirect part in many aspects of geography. It is difficult, however, to separate cause and effect in the interrelationship between the atmosphere and the oceans. They interact in a very complex way with many feedback loops. The ocean currents and the general circulation of the oceans depend to a great extent on the wind and on heating, cooling, and evaporation, which in their turn depend on the energy of the sun received through the atmosphere. On the other hand, by their transfer of heat to higher latitudes, the currents supply energy which helps to keep the atmospheric circulation going. The relationship between the atmosphere and oceans is in a state of dynamic equilibrium, whereby a steady state of movement is more or less achieved.

The essential difference between the oceans and the land, climatically, is the ability of the oceans to store heat to a much greater degree than the land. The processes of mixing allow the heat to spread through a greater thickness of water, where it is stored to be given off when the air temperature falls; from this follows the effect of the oceans in reducing the extremes of the continental climates. Such effects will be most marked in the zones where the winds carry warmer air from the sea onto the land. This is on the western coasts in the temperate west wind belt, where the warmer water from lower latitudes can penetrate further poleward than normal. Thus the contrast arises between the east and west coast continental climates.

In considering the effect of the oceans on weather, the amount of energy given off by evaporation is strongly localized. It is greatest where the water is relatively warmer than the air, which is mainly off the east coasts of the continents in the temperate regions in winter (for example, where the warm waters of the Gulf Stream give abnormally high sea temperatures). These regions of excess energy loss from the sea are associated with zones of active frontal development. The ocean currents account for the position of these zones of maximum energy loss. The presence and character of water beneath an air-mass can also change its character fundamentally. Polar air moving south to lower latitudes, will gain water vapour over the oceans, while tropical air, moving in the opposite direction in the northern hemisphere, will be cooled and may well lose water vapour by condensation and precipitation. The water vapour that is carried from the oceans into the air is then partly transferred to land and this transfer is of even greater importance. It supplies the capital on which the hydrological cycle operates, bringing water to the land as rain, snow, and other forms of precipitation. It can then go through the cycle by a more or less direct route according to its subsequent movements. Some may be withheld from the ocean for a considerable time as snow, then ice, in which state it may be kept out of circulation for prolonged periods. Some water may return directly to the ocean via the rivers, while some may pass slowly through the earth as groundwater, before re-entering the cycle, via springs and wells. Much water is used by plants, animals, or man on its way through the cycle, but eventually it will return to the ocean.

One effect of the hydrological cycle has been indicated by Thornthwaite (Deacon *et al.*, 1955). He relates Munk's estimate of a reduction of $5 \cdot 10^{19}$ grams of water in the ocean in March, compared with the October volume, to an increase of water on land in the form of groundwater, snow, and other forms after the northern winter period. This demonstrates the dominant part played by the greater amount of land in the northern hemisphere. Defant (1961) gives the following analysis of the water budget of the earth:

Table 1.1 Water budget of the earth

	Precipitation		Evaporation		Outflow Inflow	− +
	10^3 km^3/year	cm/year	10^3 km^3/year	cm/year	10^3 km^3/yr	cm/yr
Ocean	324	90	361	100	+37	−10
Continent	99	67	62	42	+37	+25
Whole earth	423	83	423	83	—	—

The effect of climate is such that the temperature and circulation of the oceans are affected by the external change of radiation as much as the temperature on land, but often these changes can be recorded in the sea more completely than they can on land, where all the deposits are liable to subsequent erosion. In favourable sites in the oceans, the changes of climate can be read with considerable accuracy from the character of the deep sea sediments (see volume 1). The oceans, therefore, also provide a means of studying the changes of climate which they help to bring about.

On a small scale variations in climatic elements are also associated with variations of sea level of relatively small dimensions. The amount of water vapour in the atmosphere, differences of temperature and salinity, and variations in evaporation and precipitation all cause changes in sea level. An increase of 1 °F ($\frac{5}{9}$°C) of a water column 183 m deep will cause a rise of 2·54 cm, and if the salinity is decreased from 35·0 to 34·9‰, the level would rise 1·9 cm. The north Atlantic is about 25·4 cm higher in summer and autumn than in spring for this reason. Evaporation and precipitation cause the Pacific to be about 20 cm higher than the mean level of the Atlantic over the whole year, the difference being greatest in October, which is the wet season. This is due to the lower salinity and less dense water of the Gulf of Panama, compared with the Caribbean Sea, in the region where this difference can most readily be assessed. There is also a rise of sea level up the west coast of the USA from southern California to the state of Washington of about 30 cm (Deacon, 1960c).

Regular variations of sea level with about a four-day period have been recorded at Canton Island in the Pacific. These have an amplitude (half range) of 3 cm and can be related to atmospheric waves in the easterly wind zone. The variations of the sea level can be correlated with the north–south wind component related to these atmospheric waves. This example illustrates the capacity of the atmosphere to affect the level of the sea directly. Sea level is rising at present, but the precise cause is not known. It is partly the result of melting ice and partly due to the warming of the water, but other factors probably influence it as well. Sea level is unlikely to become stable as long as large volumes of water are locked up as ice. Sooner or later the ice will melt, but before this there may be another glacial period. When the ice does eventually melt, sea level will rise by about 100 m. Such a change would have profound effects on land, but it may be preceded by a fall if another ice age develops on the scale of the Pleistocene ones.

The relationship between atmospheric and oceanic climatic fluctuations on a small scale is discussed by Dickson and Lee (1969). Sea surface temperature during the period 1958–60 warmed by 1·1°C in the northeast Atlantic (compared with norms for 1900–1940), while the northwest Atlantic cooled by 0·8°C. At the same time precipitation was less in Norway. This was due to blocking of depressions over Europe and their concentration west of Iceland as a result. Anticyclonic conditions lead to horizontal convergence, hence higher sea surface temperatures, while cyclonic conditions lead to thermal doming and cooler water reaches the surface. The increased sea surface temperature gradient could be responsible for the changes in air circulation. In autumn 1958 an abnormally large amount of Atlantic water moved into the Norwegian Sea, spreading into the North Sea in the summer of 1959. The warming spread to the Greenland and Barents Seas in summer 1960. Salinity was also unusually high around Iceland. It is not clear how far this warming initiated the blocking action in the atmosphere. The amount of feedback in the interaction between ocean and atmosphere is difficult to calculate, but probably an important aspect of the coupling of the two systems is connected with feedback.

3 Water movement on different scales

There are many different scales on which the ocean waters move and these have different causes. Some of the movements are cyclic, and can be described as waves, while others are long-term systematic circulations, both in the horizontal and vertical senses. Some appear to be more random fluctuations. In many of these movements, there is a close relationship between the ocean and the atmosphere, but not all of them are due to such a relationship.

3.1 Ocean currents

Of the largest extent, forming a world-wide system, is the dynamic ocean current pattern. This is very closely tied to global atmospheric circulation, since major ocean currents are wind-driven. There is, therefore, a close similarity between the major elements of the two systems; each consists of circulations dependent on the pattern of energy coming from the sun and causing the resultant movements of air and water. Although the similarities between the two systems are striking, even to the reversal of current direction in the Indian Ocean with the reversal of the monsoon wind system, there are significant differences, such as the westward intensification of the ocean current system which has not got an exact atmospheric equivalent. This and several other important major current characteristics are related to variations of the Coriolis effect with latitude, itself due to the rotation of the earth around its axis. This effect influences both air and water, but with rather different results, owing to variations in the character of the two fluids. The relationship between the major ocean currents and the major atmospheric circulation, like so many oceanographical phenomena, is not only a one-way relationship. There are important feedback systems operating, whereby the two systems are intimately coupled together. The oceans provide the water, the evaporation of which supplies much energy to the atmospheric system, and without which precipitation could not occur. Heat is distributed around the earth both by air and water, the air accomplishing about nine-tenths of the work. Further details of the close interaction between the atmosphere and the oceans in setting up the global current system are considered in chapter 3.

Oceanic circulation also affects many other branches of oceanography, such as ocean fertility, and through this, chemical and biological oceanography and sedimentology. The pattern of land and sea also influences the details of ocean circulation, indicated in the contrast in pattern between the Atlantic and Pacific Oceans. The wide connection between the Atlantic and the Arctic Oceans contrasts strongly with the narrow and shallow Bering Straits that link the Pacific with the Arctic Ocean. The high, very cold southern Antarctic continent also plays an important part in the general pattern of oceanographic circulation, both on the surface and at depth. Thus oceanic circulation, horizontal and vertical, on the surface and at depth, is dependent both on atmospheric circulation and the pattern of world relief and land and sea distribution. Again the relationship is not just one way; the oceans play a vital part in the general air circulation and determine the pattern of land and sea.

3.2 Cyclic movement: waves

As more detailed and accurate direct measurements of ocean water movement accumulate it is evident that major ocean currents are only one of many causes of ocean water flow. The irregularity and variability of flow is to a large extent the result of the superimposition of many different types of movement on each other to form a very complex spectrum. Many movements are cyclic in character in that they are wave motions. Chapters 4 and 5 are devoted to a consideration of a number of different wave motions. Some of them are regular and predictable, but many of them are complex and variable and are caused by a wide range of forces. The most regular and ubiquitous waves are those that give rise to the tides. Their widespread occurrence is due to their extraterrestrial cause in the gravitational attraction of the moon and sun on the ocean water. The action of the gravitational attraction is well known and amenable to mathematical analysis, so that tide-producing forces can be accurately defined and predicted. The reaction of the irregular oceans to these forces is, however, less easy to define, and although the broad pattern of interaction between the forces and the oceans is understood, details still remain to be filled in. Useful computer models have been developed to study these interactions. The response of the ocean basins to the tide-producing forces depends on the size and shape of the basins in relation to the forces, leading to variation in response in the different oceans and seas.

One possible way in which waves can be classified is by their length. Tides are very long waves with periods of semi-diurnal and diurnal lunar and solar dimensions. Period is related to length in that long waves have a longer period ($L = CT$, where L is length, C is velocity, and T is period). Other types of waves of progressively shorter length include surges, seiches, tsunamis, internal waves of various types, surf beat, wind-generated gravity waves, and microseisms, the wind waves themselves covering a considerable range of period from about 30 seconds to about 3 seconds. At the shorter end of the scale there are ripples.

The longer of these waves, the surges, have periods comparable to that of the tide, but they are the result of abnormal meteorological conditions, and thus demonstrate another form of interaction between the atmosphere and the oceans. They are normally generated by intense depressions, such as hurricanes and similar storms. Hurricanes are normally formed over the ocean and depend on the evaporation of moisture from the ocean to maintain their energy; thus the interrelationship and interaction between the two systems is close.

Tsunami, on the other hand, are the result of submarine earthquakes, so that they demonstrate the interaction between ocean waves and the geophysical processes operating in the crust and mantle beneath the ocean floor. Tsunami are long waves that can travel over great distances of water. They move across the Pacific and have lengths of about 800 km. Being long and low they pass unnoticed in the open ocean, but they may become refracted on approaching a low coast and build up to heights that result in major coastal damage and flooding, at a very great distance from their origin.

Perhaps the most readily apparent movement of the ocean water is that resulting from the generation of gravity waves by the wind blowing over the ocean surface. This is another example of the very close interaction between the atmosphere and the ocean: the waves are the direct result of transfer of energy from the moving air to the water across which it is flowing. The precise mechanism by which this transfer of energy is achieved still eludes exact mathematical analysis; the general principles are becoming better known although the matter is highly complex and difficult to test by measurement in the ocean. The result is a wide range of waves of different length, moving in different directions. This situation is best analysed by spectral methods, whereby the complex pattern of waves can be split into the simpler components of which it consists. Each component is regular and sinusoidal in form in deep water, with properties that are clearly defined.

The study of internal waves, which can only be observed indirectly, is less advanced than that of the more obvious surface waves, but interesting data have become available and a wide range of internal wave types have been identified. Another type of interaction is demonstrated in the development of microseisms. These waves have exactly half the period of the wind waves that cause them. They are formed and travel through the earth's crust along the ocean bed when two sets of wind waves interfere with each other on the surface by meeting head on. In this way the atmospheric circulation has an effect on the ocean floor through the medium of wind-generated gravity waves on the sea surface.

4 Life in the ocean

The life of the oceans, as life on land, is intimately related to its environment. There is a very close connection between the environment and all the processes that determine its character and the life it can support. Marine life is extremely varied, and adaptations have developed that allow creatures to occupy almost every available niche in the environment—from the deepest ocean trenches to the intertidal zone, and from the polar to the equatorial regions, from the land border to the open ocean, and from rocky substrates to the finest clay floor. Life first started in the oceans so that time in which to adapt to this wide variety of environments has been long, and many varieties have evolved. As well as adapting their way of life to their environment, marine creatures must also learn to live with their neighbours to their mutual advantage as far as possible. Thus the biological aspects of oceanography must be considered in terms of ecosystems, the living complex of plants, animals, and their habitat or environment. Man has his place in the marine ecosystem, but he cannot hope to exploit it to his best advantage until he understands its complexities and has the ability to control it (at least to a certain extent) as he does with farming on land. There is still a long way to go before the sea is farmed as efficiently as the land. Such control requires a detailed knowledge both of the quality of the environment and of the life cycle of its living inhabitants, and their interdependence one upon the other.

As on land, the basis of life in the oceans is the plant community, which alone can synthesize energy and living tissue from the raw materials of mineral fertility in the presence of sunlight by photosynthesis. The circulation of the oceans determines those areas where nutrients can reach the upper levels in which alone there is sufficient light for photosynthesis to proceed. Thus those parts of the oceans where upwelling is active are the fertile parts. For this reason the processes by which upwelling takes place are very significant in the marine environment, as only by this means can nutrients be supplied continuously for use by marine plants. Upwelling is caused by the general pattern of circulation, by the effects of the earth's rotation (for example along the equator), and by a combination of rotational effects on wind action. In shallow water rather different processes are involved, and wind stirring as well as nutrient addition from land sources are locally important.

Most marine plants are minute, consisting of the smaller elements of the floating, drifting plankton. Many of the food chains in the ocean are rather long, in that tiny plants, diatoms, and others provide sustenance for small members of the zooplankton, which in turn feed invertebrates and fish, the former often being food for fish. There is a large loss of production of nourishment at each link in the food web; the system is not very efficient if only the higher parts of the web are exploited. Some important species have relatively short food chains, such as the Antarctic whales, who feed directly on the zooplankton which are prolific in the upwelling waters of the southern ocean.

Seaweeds are the other primary producers of organic matter. They have the advantage of being mostly fixed in habitat, attached to the bottom in shallow water. This characteristic makes them more susceptible to exploitation than the more mobile members of the oceanic community. It is, therefore, in this field that some progress in exploitation and commercial development (which could be called cultivation) has been achieved. But on the whole the ocean is still hunted, rather than farmed, for food.

Chapter 6 is a brief introduction to the topic of marine productivity and some of the more important types of marine creatures. These organisms have widely different life habits: some are sessile, others are mobile and move great distances, some change character at different phases of their life, and all vary in their food requirements and living conditions. Many species can, therefore, live together in a community, building up the complex web of the living community or ecosystem by preying on or being prey for others. Chapter 7 introduces ways in which man has exploited and is exploiting this living marine wealth. Further problems associated with the living environment are mentioned in chapter 8, which deals briefly with such matters as pollution of ocean waters and conservation of resources and their fair utilization by different communities of the world. These problems give rise to legal complications, which will only be solved with good-will on the part of all nations. Men have used the sea for a long time, but there is still much to learn concerning its proper use and exploitation.

5 The ocean in exploration and transport

The broad horizons of the sea have always lured the more curious and adventurous members of the human race to seek what lay beyond. From the very earliest days of history and prehistory, men have set out to seek the lands beyond the sea. The ancient Egyptians began marine exploration, but their lack of suitable ship-building material rather limited their vessels and voyages. Heyerdal has, however, recently shown that their papyrus boats were seaworthy and could have been capable of sailing across the Atlantic. The Minoans sailed right round Africa in 600 BC according to some accounts. Many of these early voyages were largely coastal exploration, and although the Phoenicians had sailed to Britain earlier, Pytheas first explored England from the sea in 310 BC. In this way explorers spread out from the more restricted waters of the Mediterranean into the stormier expanse of the open Atlantic Ocean, although they mostly kept fairly close to the shore.

Early boats were difficult to control in rough weather and navigational equipment was