Geological Oceanography

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1. Submarine geology. I. Title

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Geological Time Scale

Era	Period	Epoch	Age in years
Cenozoic	Quaternary	Recent	10,000
		Pleistocene	1,800,000
	Tertiary	Pliocene	5,000,000
		Miocene	22,500,000
		Oligocene	37,500,000
		Eocene	53,500,000
		Paleocene	65,000,000
Mesozoic	Cretaceous		140,000,000
	Jurassic		200,000,000
	Triassic		230,000,000
Paleozoic	Permian		280,000,000
	Carboniferous	Pennsylvanian	
		Mississippian	345,000,000
	Devonian		390,000,000
	Silurian		430,000,000
	Ordovician		500,000,000
	Cambrian		570,000,000
Pre-Cambrian			

Preface

Eighteenth-century geologists found that most of the sedimentary rocks on the continents had been deposited in the oceans of the past. But it was only towards the middle of the twentieth century that geologists began to study the geology of the sea on a sufficiently large scale to find out what has been going on in our present day oceans, both to explain the origin of marine sedimentary rocks and to make a serious attempt to trace the history of the oceans during the long geological past. Ever since, as the great void existing in the science of geology was realized, there has followed a flood of new literature pouring into the scientific journals, growing on an exponential curve until it is almost hopeless to try to keep abreast of new facts and ideas being brought forth. This book is an attempt to give to students and the interested public the gist of what we have been finding in this new field. Throughout the book non-technical terms and simplified explanations are used to explain the findings of the highly technical books and journals.

Included are the revolutionary new ideas that have come from the marine investigations by geologists and geophysicists who have been covering all of the oceans of the globe using new devices and techniques that were not even dreamed of 50 years ago. Not only has this new flood of information vastly altered the ideas scientists have concerning the history of the earth, but also it appears to have an enormous effect on the world economy and on our industrial potential for the future. Resources that were thought to be nearing exhaustion in our time are being found in great quantities on and below the ocean floor.

Throughout this book, distances are given in feet and statute miles, but, in order to help the conversion to the metric system, distances are also given in parenthesis in meters and kilometers. Some depths are given in fathoms, which are equal to six feet, and these have been converted to meters. However, in some places it was appropriate to use only nautical miles, one mile equalling 6,080 feet.

Helpful suggestions were made by my colleagues Sir Edward Bullard (for Chapter 2), Dr. Robert Arthur (for Chapter 3), and Dr. E. L. Winterer (for Chapter 11). My wife, Elizabeth Shepard, was helpful with the style of the manuscript, and Patrick McLoughlin and Neil Marshall made good suggestions for the illustrations. Nance North was particularly helpful with the bibliography.

Fig. 1

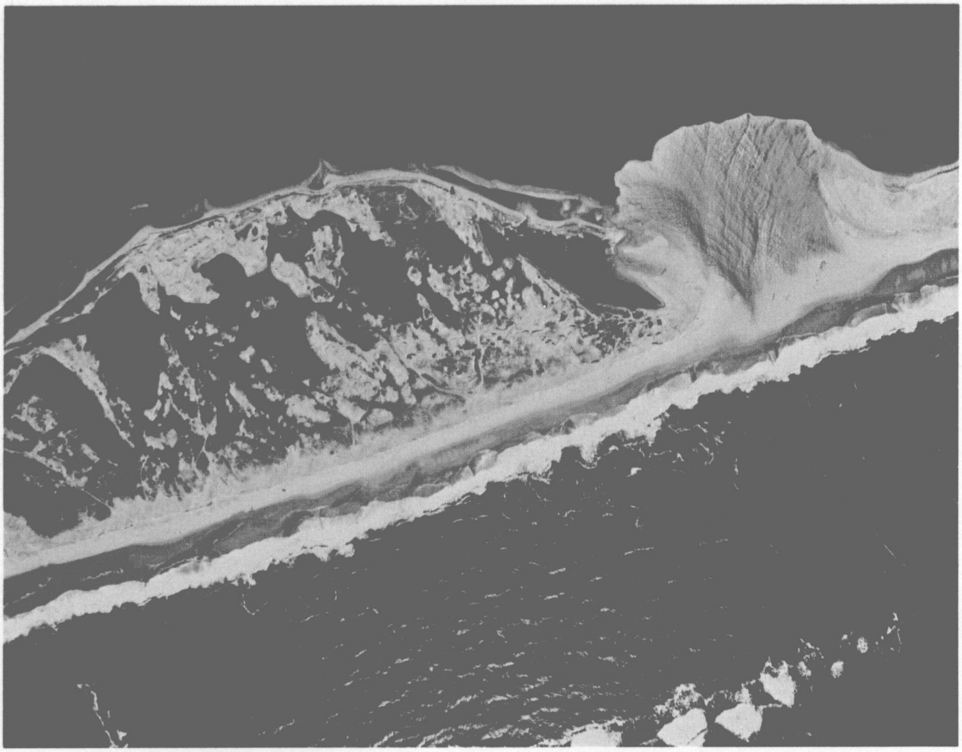

Fig. 2

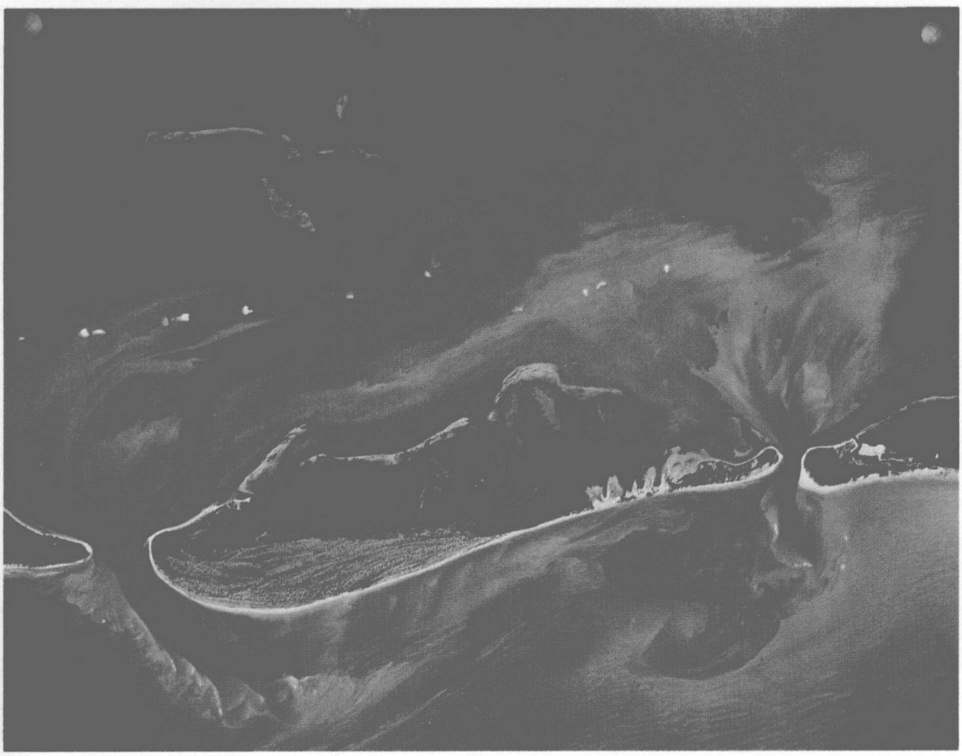

Plate 1

Fig. 1. Barrier island off Nauset Beach, Cape Cod. The barrier was cut through by the hurricane of 1961 and a fan was deposited into the lagoon. Subsequently, a new beach was built on the outside. Photo by U.S. Coast and Geodetic Survey, 1962.

Fig. 2. Showing the deep tidal channels between barrier islands along the southwest coast of Florida. Sanibel Island in center. Photo by U.S. Coast and Geodetic Survey, 1961.

Fig. 3

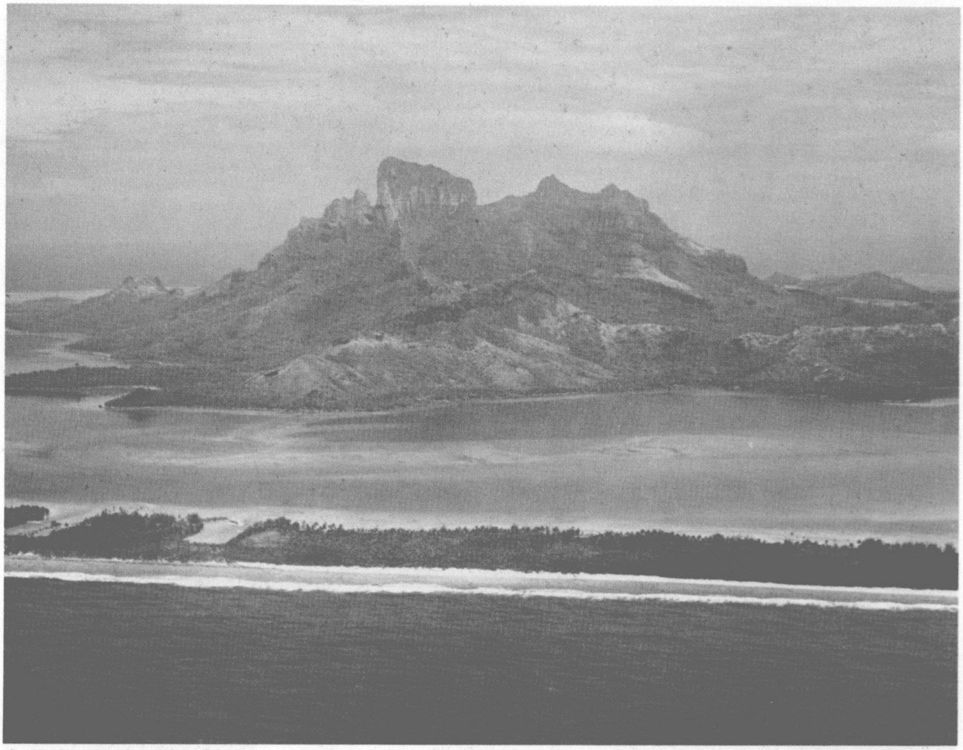

Fig. 4

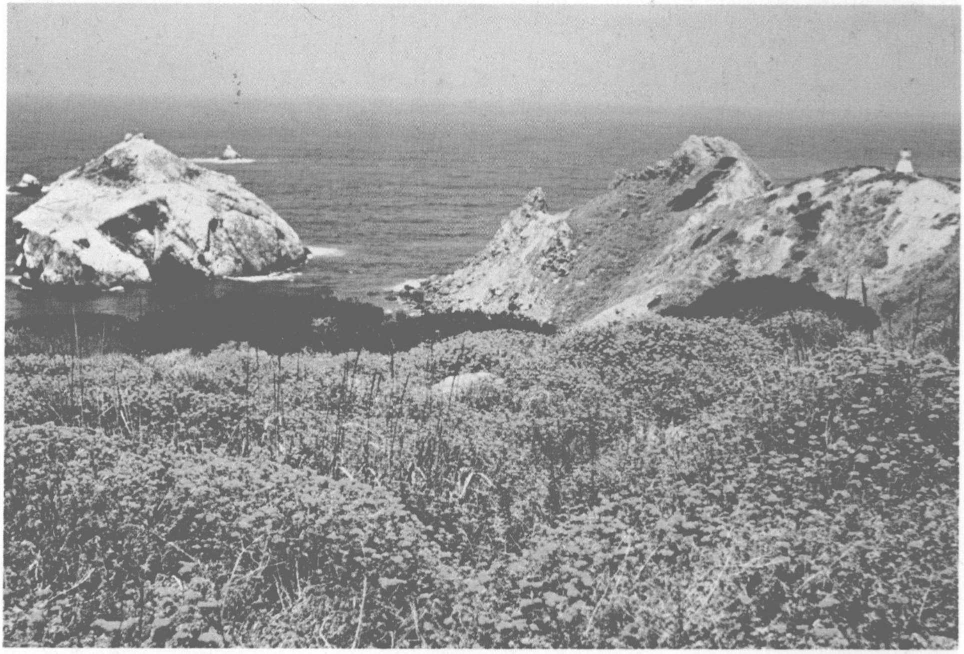

Plate 1

Fig. 3. Bora Bora, Society Islands, showing the partly eroded central volcano and a volcanic coast bordered by a lagoon and a barrier coral reef.

Fig. 4. Remnants of wave erosion at Cape San Martin on the California coast. The stacks are covered with guano, which is a valuable resource actually mined from the small islands off the coast of Peru.

Fig. 1

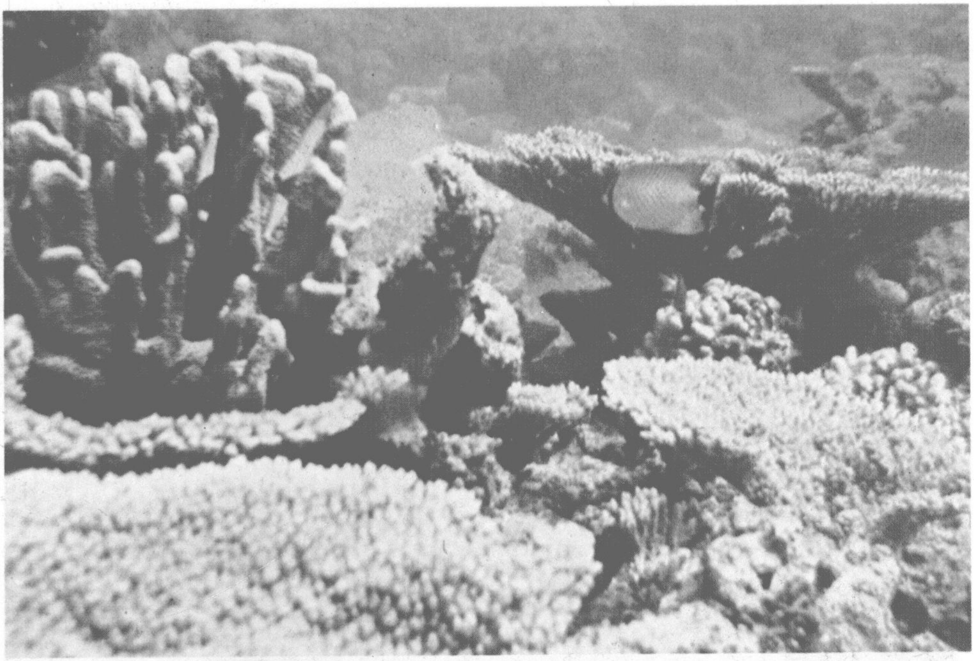

Fig. 2

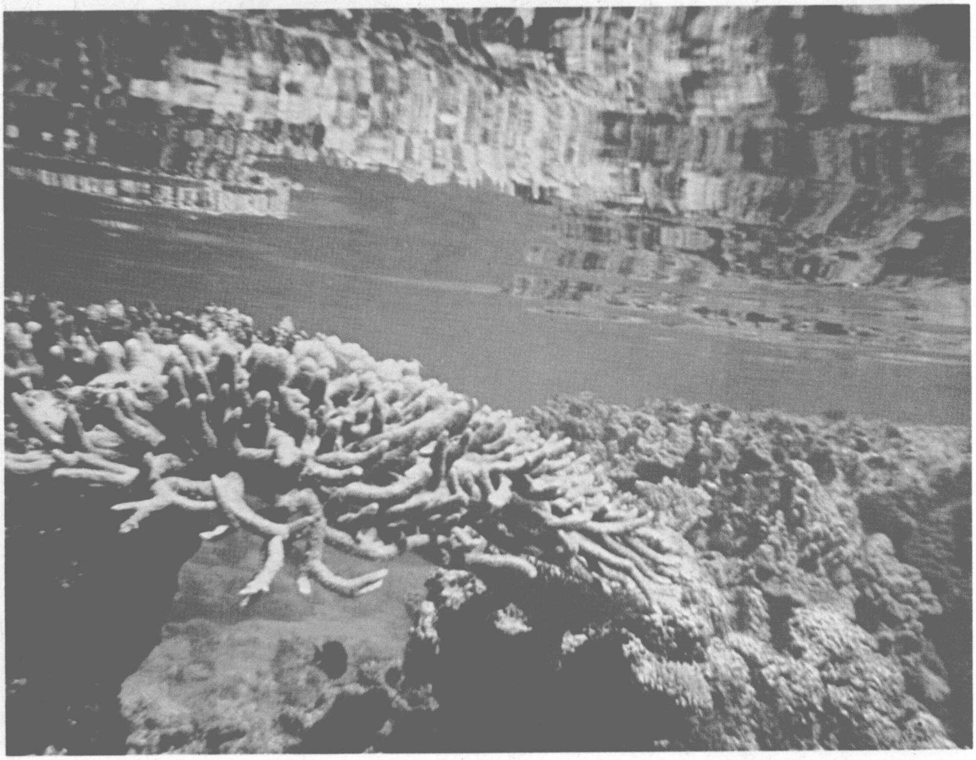

Plate 2

Fig. 1. Actively growing coral reef on the inner edge of the barrier reef off western Moorea, Society Islands.

Fig. 2. A growing reef off the west coast of Moorea with a frond of *Acrapora* forming an arch between two high-standing coral clusters. The upper portion of the photo is a reflection of the reef in the underwater surface.

Fig. 3

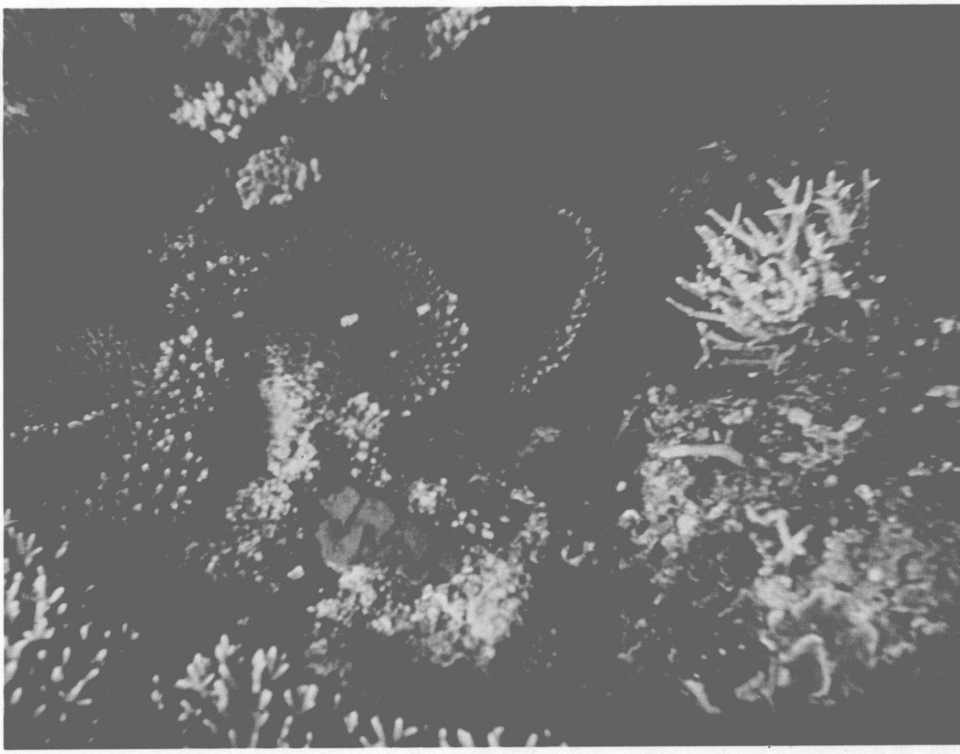

Fig. 4

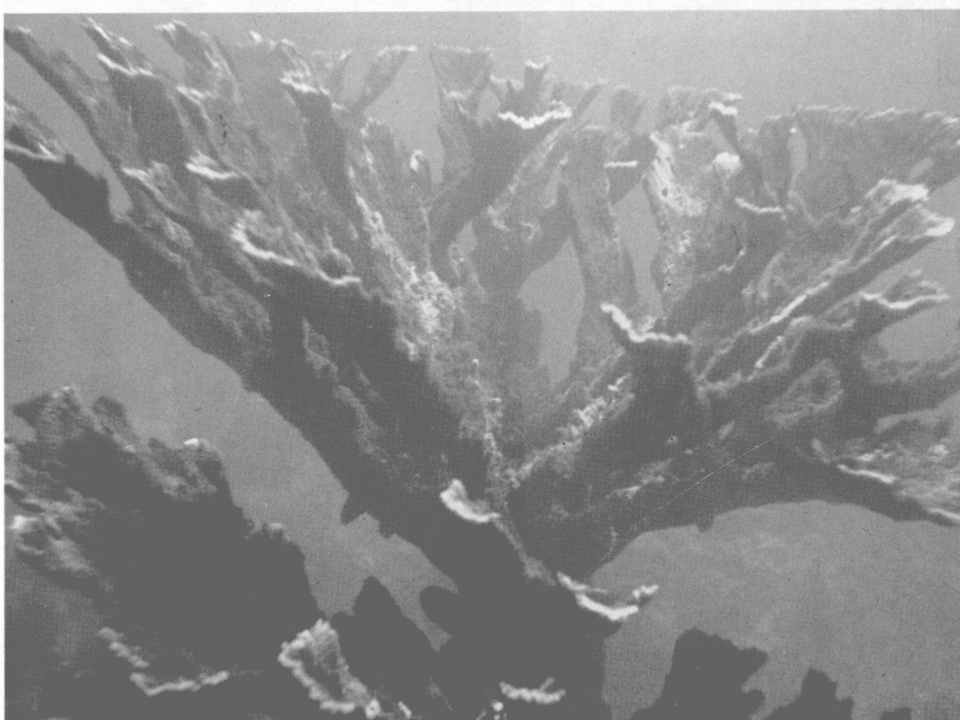

Plate 2

Fig. 3. A partly dead coral reef along the coast of Bora Bora. Note the *Tridacna* clam (blue), which had bored its way into the coral reef.

Fig. 4. The large *Acrapora palmata* coral fronds that are so abundant in the West Indies and Bahama reefs. These are rather easily broken off by large storm waves. Photographed off southeast Martinique Island.

Contents

Introduction

Chapter 1

Just before getting his second prize from the Geological Society of America, Nobel prize-winner Harold C. Urey recalled that when he studied geology in the early part of the century he really did not like it. One is led to wonder how a man who has had such an impact on science and covered such a broad field of interest could have failed to have been aroused by his early contact with geology, which involves so much exciting history of the development of the earth into its present state. But geology was not such a dynamic subject in those days as now. Geology had reached a stage of development when a few famous professors were convinced that they had solved the important problems of the science, and were teaching their students the law and gospel as if it were a religion. I remember in my student days feeling depressed that I had not become a geologist when there were still many problems to be solved. This, of course, was before geology underwent its great revolution. Quite suddenly during the 1960s, we found ourselves discarding most of our philosophy of the orderly development of the planet, and taking up what at first seemed a prophetic dream of continents splitting apart and new oceans forming. Suddenly many of the puzzles of geological history began to make sense, and we began to discard most of the ideas that we had thought were so well established. Today, with these new developments, geology has really become an exciting subject.

The new concepts have developed to a great extent because geologists working for centuries on land finally decided to go to sea and find out what was under the unexplored 72 percent of the earth's surface. Before World War I, marine geology was almost unknown. In 1923, when I first began on a very small scale to study the sea floor, I was literally the only geologist in the United States, perhaps in the world, who was working in this field. The old textbooks generally had a chapter about the ocean, but a large part of it was based on speculation that dealt little with facts. One reads in these old texts that most of the ocean floor is montonously flat, like the great plains of the central United States. When soundings were hundreds of miles apart, as they were before the days of echo soundings, there was no way to question this concept; but in 1920 echo soundings were invented, and this allowed us to make continuous profiles of the sea floor without even stopping the ship. The ocean floor proved to be as irregular as the land. Similarly, it seemed logical to believe that ocean sediments should be coarse grained near the shore, where the fine sediments are removed by the breaking waves, and fine grained farther from the land. This is how they were described in the old textbooks. When I began collecting sediments on the continental shelf off New England, I was amazed to find that here the sediments, instead of being finer as I got farther from shore, often were coarser. As more and more samples were taken by various investigators, it became evident that this finding off New England was by no means unusual. It began to look as though the ocean floor was more complicated than had been generally believed.

Many other discoveries soon followed. Maurice Ewing, of Lamont-Doherty Geological Observatory, began his innovative career in the 1930s, developing such things as underwater photography using cameras lowered to the bottom. From these photos we began to find evidence that the sea bottom processes were much more active in deep water than had been supposed. Ewing also was a leader in developing sound-transmission methods that gave us our first ideas of what was under the bottom. Some other geophysical methods were used to investigate the ocean floors. Vening Meinesz of Holland started measuring gravity from a submarine. Sir Edward Bullard, of Cambridge University, and Roger Revelle, of Scripps Institution of Oceanography, began taking heat measurements from probes stuck into the bottom, and Victor Vacquier, now of Scripps Institution, started measuring the magnetism of the sea floor. All of these methods gave startling results.

Finally, scientists decided it was time to have a look at the bottom from deep-diving vehicles. In 1945, Auguste Piccard built the Bathyscaphe, essentially an oil-filled sea-going balloon with a diving bell attached, and made the first deep dives to the ocean floor. Jacques Cousteau was soon to follow with his remarkable explorations in the *Diving Saucer.* Other deep-diving vehicles were developed, and at last geologists were given the opportunity to look at the interesting features their instruments had been detecting from surface operations. During World War II, the first development by Cousteau and Emile Gagnan of what is now called scuba diving has allowed many geologists to observe the shallow sea floor for themselves.

Ocean-floor drilling has given us a vast fund of information. We have uncovered old sunken land masses, discovered numerous reversals of earth magnetism, and filled in many gaps in the history of the earth. Unique fossils have been discovered. Areas now in the Northern Hemisphere have been found to have been formerly in the Southern Hemisphere. The drillings have demonstrated that the crust under the oceans has been sliding so actively under the continents that in no place can we drill down into sediments as old as the earliest marine sediments discovered on the continents.

The British *Challenger* Expedition, 1872-76, gave scientists the first indications of the nature of the ocean basins, but little progress was made until World War I aroused interest in sending sound waves through the sea in order to detect the presence of submarines. We now know that sea mammals had been using a similar method for countless ages so they could penetrate murky water and find hidden food. After the war was over, scientists used the echo method to tell the depths of water under ship keels, and echo sounding soon followed. Thus a sounding could be obtained by measuring the time between sending a signal and receiving an echo, which takes a few seconds in the deepest water as compared to half a day by the old vertical cast method of lowering a weight attached to a line and observing on a counter the amount of wire suspended below the ship. Although World War II threatened to wipe out civilization, this war led to many important scientific developments. In testing different sound frequencies to help locate submarines, scientists found that low frequencies were capable of sending sound waves through the sea floor and getting reflections from deeply buried layers of rock. These sound-transmission methods have revolutionized the field of marine geology. Not only has science benefited, but industry, particularly in the search for new energy sources, has been given a new method of locating petroleum. Many localities where adjoining land areas have no sign of oil now have prosperous oil fields on the adjacent sea floor, discovered largely as a result of surveys with underwater sound.

The juncture between the land and the sea, called the shoreline or the coast, is worthy of much study by man, largely because it is subject to so much change. People like to live closer to the ocean, partly because the ocean is a great source of food, and partly because of the beauty of the coastal scenery and the joy of swimming in the sea. Also, the climate is almost always pleasanter along the coast, warmer in winter and cooler in summer. However, much of the habitation along the coast is on the sandy platforms that adjoin the shore, and these are just the places where the shorelines are subject to such rapid change. A great storm or a tidal wave (tsunami) may cause the loss of houses that have been built near the ocean so that the residents could have a fine view of the sea. We are gradually learning to avoid building on these threatened areas, and we are finding ways to provide protection for communities already constructed there. A few years ago we knew very little about the great sea waves that accompanied earthquakes and the great surges of sea onto the land during hurricanes, but now they are well documented and we are learning how to reduce their destruction.

Geology professors used to teach their students that the deep-ocean floor was covered with the limey or siliceous remains of the small animals of the sea, except at great depths where these organic remains had been dissolved and where a reddish clay covered the floor. Now that we have made extensive collections of sediments from the deep oceans we have found that sands are not infrequent among the sediments of the deep-sea floors. As for red clay, it is actually very rare, although a brown clay is a common type of deep-sea sediment. One of the great surprises has been the discovery of extensive zones where the deep seas are paved with rounded nodules of manganese. These contain such a quantity of cobalt and nickel that there are now plans to quarry them from surface ships and giant dredges. It is even thought that this type of mining may largely replace mining on land, at least for these two metals.

In these days of extensive scuba diving and of the use of face masks by swimmers, we are learning much more about the coral reefs that are so abundant in the tropical areas. It is only since World War II that we have fully appreciated the significance of a theory developed by Charles Darwin more than 100 years ago. Darwin conceived the idea that the ringlike coral reefs, known as atolls, are the result of coral growing around ocean volcanoes that were sinking while the reefs grew upward until the volcano peaks had disappeared, leaving only the surrounding reefs. We find that there are many flat-topped mountains in the ocean that are as much as a mile below the surface. These are thought to be sunken shoals that did not have upgrowing coral masses to keep building the platforms to the surface as the shoals sank.

Another exciting discovery of recent years is the numerous oval-topped hills that stand above the deep-ocean floor along the continental margins, particularly on both sides of the Atlantic. They are also located in portions of the deep inland seas that are largely landlocked, notably the Mediterranean and the Gulf of Mexico. As a result of drilling, we have now established that many of these are domes of salt that have been pushed up through the sediment covering the ocean floor, and are comparable to the salt domes that have proven of such enormous value in the search for oil on the continents and the continental shelves. To have salt in the large quantities necessary for the formation of salt domes that are thousands of feet thick and cover large territories means that huge salt lakes or seas existed in a climate that was arid enough to evaporate the water and concentrate its relatively small salt content until it became deposited on the bottom in thick layers. How could this have happened in what was the ancestor of the great oceans? There are many puzzling things about the ocean floor, and it is only recently that we think we have begun to solve many of these mysteries. Clearly, we are in the midst of a great detective story and our new methods in oceanography are bringing in information so fast that we can now speculate on many strange features that formerly seemed almost impossible to comprehend.

Suggested Supplementary Reading

Davis, R. A., Jr., *Principles of Oceanography* (Menlo Park, California: Addison-Wesley Publ. Co., 1972), Ch. 1.

Ross, D. A., *Introduction to Oceanography*. (New York: Appleton-Century-Crofts, 1970), pp. 29-40.