THE SEA AROUND US

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Also by Rachel L. Carson

UNDER THE SEA-WIND

Beyond all things is the ocean—SENECA

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To COPE alone and unaided with a subject so vast, so complex, and so infinitely mysterious as the sea would be a task not only cheerless but impossible, and I have not attempted it. Instead, on every hand I have been given the most friendly and generous help by those whose work is the foundation and substance of our present knowledge of the sea. Specialists on many problems of the ocean have read chapters dealing with their fields of study and have made comments and suggestions based on their broad understanding. For such constructive help I am indebted to Henry B. Bigelow, Charles F. Brooks, and Henry C. Stetson of Harvard University; Martin W. Johnson, Walter H. Munk, and Francis P. Shepard of the Scripps Institution of Oceanography; Robert Cushman Murphy and Albert Eide Parr of the American Museum of Natural History; Carl O. Dunbar of Yale University; H. A. Marmer of the U.S. Coast and Geodetic Survey; R. C. Hussey of the University of Michigan; George Cohee of the U.S. Geological Survey; and Hilary B. Moore of the University of Miami.

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The front end paper is reproduced from a portion of the map, *Il Mare di Amazones*, by permission of the New York Public Library. H. A. Marmer kindly provided a copy of the old Franklin chart of the Gulf Stream, which is here reproduced as the back end paper. The fathograms on pages 57 and 63 were furnished by the U.S. Fish and Wildlife Service and the U.S. Coast and Geodetic Survey, respectively.

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R. L. C.

Silver Spring, Maryland
January 1951

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Part I

MOTHER SEA

I

THE GRAY BEGINNINGS

And the earth was without form, and void; and darkness was upon the face of the deep.

GENESIS

BEGINNINGS are apt to be shadowy, and so it is with the beginnings of that great mother of life, the sea. Many people have debated how and when the earth got its ocean, and it is not surprising that their explanations do not always agree. For the plain and inescapable truth is that no one was there to see, and in the absence of eyewitness accounts there is bound to be a certain amount of disagreement. So if I tell here the story of how the young planet Earth acquired an ocean, it must be a story pieced together from many sources and containing whole chapters the details of which we can only imagine. The story is founded on the testimony of the earth's most ancient rocks, which were young when the earth was young; on other evidence written on the face of the earth's satellite, the moon; and on hints contained in the history of the sun and the whole universe of star-filled space. For although no man was there to witness this cosmic birth, the stars and the moon and the rocks were there, and, indeed, had much to do with the fact that there is an ocean.

The events of which I write must have occurred somewhat more than 2 billion years ago. As nearly as science can tell that is the approximate age of the earth, and the ocean must be very nearly as old. It is possible now to discover the age of the rocks that compose the crust of the earth by measuring the rate of

decay of the radioactive materials they contain. The oldest rocks found anywhere on earth – in Manitoba – are about 2.3 billion years old. Allowing 100 million years or so for the cooling of the earth's materials to form a rocky crust, we arrive at the supposition that the tempestuous and violent events connected with our planet's birth occurred nearly $2\frac{1}{2}$ billion years ago. But this is only a minimum estimate, for rocks indicating an even greater age may be found at any time.

The new earth, freshly torn from its parent sun, was a ball of whirling gases, intensely hot, rushing through the black spaces of the universe on a path and at a speed controlled by immense forces. Gradually the ball of flaming gases cooled. The gases began to liquefy, and Earth became a molten mass. The materials of this mass eventually became sorted out in a definite pattern: the heaviest in the center, the less heavy surrounding them, and the least heavy forming the outer rim. This is the pattern which persists today – a central sphere of molten iron, very nearly as hot as it was 2 billion years ago, an intermediate sphere of semi-plastic basalt, and a hard outer shell, relatively quite thin and composed of solid basalt and granite.

The outer shell of the young earth must have been a good many millions of years changing from the liquid to the solid state, and it is believed that, before this change was completed, an event of the greatest importance took place – the formation of the moon. The next time you stand on a beach at night, watching the moon's bright path across the water, and conscious of the moon-drawn tides, remember that the moon itself may have been born of a great tidal wave of earthly substance, torn off into space. And remember that if the moon was formed in this fashion, the event may have had much to do with shaping the ocean basins and the continents as we know them.

There were tides in the new earth, long before there was an ocean. In response to the pull of the sun the molten liquids of the earth's whole surface rose in tides that rolled unhindered around the globe and only gradually slackened and diminished

as the earthly shell cooled, congealed, and hardened. Those who believe that the moon is a child of earth say that during an early stage of the earth's development something happened that caused this rolling, viscid tide to gather speed and momentum and to rise to unimaginable heights. Apparently the force that created these greatest tides the earth has ever known was the force of resonance, for at this time the period of the solar tides had come to approach, then equal, the period of the free oscillation of the liquid earth. And so every sun tide was given increased momentum by the push of the earth's oscillation, and each of the twice-daily tides was larger than the one before it. Physicists have calculated that, after 500 years of such monstrous, steadily increasing tides, those on the side toward the sun became too high for stability, and a great wave was torn away and hurled into space. But immediately, of course, the newly created satellite became subject to physical laws that sent it spinning in an orbit of its own about the earth. This is what we call the moon.

There are reasons for believing that this event took place after the earth's crust had become slightly hardened, instead of during its partly liquid state. There is to this day a great scar on the surface of the globe. This scar or depression holds the Pacific Ocean. According to some geophysicists, the floor of the Pacific is composed of basalt, the substance of the earth's middle layer, while all other oceans are floored with a thin layer of granite, which makes up most of the earth's outer layer. We immediately wonder what became of the Pacific's granite covering and the most convenient assumption is that it was torn away when the moon was formed. There is supporting evidence. The mean density of the moon is much less than that of the earth (3.3 compared with 5.5), suggesting that the moon took away none of the earth's heavy iron core, but that it is composed only of the granite and some of the basalt of the outer layers.

The birth of the moon probably helped shape other regions of the world ocean besides the Pacific. When part of the crust

was torn away, strains must have been set up in the remaining granite envelope. Perhaps the granite mass cracked open on the side opposite the moon scar. Perhaps, as the earth spun on its axis and rushed on its orbit through space, the cracks widened and the masses of granite began to drift apart, moving over a tarry, slowly hardening layer of basalt. Gradually the outer portions of the basalt layer became solid and the wandering continents came to rest, frozen into place with oceans between them. In spite of theories to the contrary, the weight of geologic evidence seems to be that the locations of the major ocean basins and the major continental land masses are today much the same as they have been since a very early period of the earth's history.

But this is to anticipate the story, for when the moon was born there was no ocean. The gradually cooling earth was enveloped in heavy layers of cloud, which contained much of the water of the new planet. For a long time its surface was so hot that no moisture could fall without immediately being reconverted to steam. This dense, perpetually renewed cloud covering must have been thick enough that no rays of sunlight could penetrate it. And so the rough outlines of the continents and the empty ocean basins were sculptured out of the surface of the earth in darkness, in a Stygian world of heated rock and swirling clouds and gloom.

As soon as the earth's crust cooled enough, the rains began to fall. Never have there been such rains since that time. They fell continuously, day and night, days passing into months, into years, into centuries. They poured into the waiting ocean basins, or, falling upon the continental masses, drained away to become sea.

That primeval ocean, growing in bulk as the rains slowly filled its basins, must have been only faintly salt. But the falling rains were the symbol of the dissolution of the continents. From the moment the rains began to fall, the lands began to be worn away and carried to the sea. It is an endless, inexorable process that has never stopped – the dissolving of the rocks, the leaching

out of their contained minerals, the carrying of the rock fragments and dissolved minerals to the ocean. And over the eons of time, the sea has grown ever more bitter with the salt of the continents.

In what manner the sea produced the mysterious and wonderful stuff called protoplasm we cannot say. In its warm, dimly lit waters the unknown conditions of temperature and pressure and saltiness must have been the critical ones for the creation of life from non-life. At any rate they produced the result that neither the alchemists with their crucibles nor modern scientists in their laboratories have been able to achieve.

Before the first living cell was created, there may have been many trials and failures. It seems probable that, within the warm saltiness of the primeval sea, certain organic substances were fashioned from carbon dioxide, sulphur, nitrogen, phosphorus, potassium, and calcium. Perhaps these were transition steps from which the complex molecules of protoplasm arose – molecules that somehow acquired the ability to reproduce themselves and begin the endless stream of life. But at present no one is wise enough to be sure.

Those first living things may have been simple microorganisms rather like some of the bacteria we know today – mysterious borderline forms that were not quite plants, not quite animals, barely over the intangible line that separates the non-living from the living. It is doubtful that this first life possessed the substance chlorophyll, with which plants in sunlight transform lifeless chemicals into the living stuff of their tissues. Little sunshine could enter their dim world, penetrating the cloud banks from which fell the endless rains. Probably the sea's first children lived on the organic substances then present in the ocean waters, or, like the iron and sulphur bacteria that exist today, lived directly on inorganic food.

All the while the cloud cover was thinning, the darkness of the nights alternated with palely illumined days, and finally the sun for the first time shone through upon the sea. By this time some of the living things that floated in the sea must have

developed the magic of chlorophyll. Now they were able to take the carbon dioxide of the air and the water of the sea and of these elements, in sunlight, build the organic substances they needed. So the first true plants came into being.

Another group of organisms, lacking the chlorophyll but needing organic food, found they could make a way of life for themselves by devouring the plants. So the first animals arose, and from that day to this, every animal in the world has followed the habit it learned in the ancient seas and depends, directly or through complex food chains, on the plants for food and life.

As the years passed, and the centuries, and the millions of years, the stream of life grew more and more complex. From simple, one-celled creatures, others that were aggregations of specialized cells arose, and then creatures with organs for feeding, digesting, breathing, reproducing. Sponges grew on the rocky bottom of the sea's edge and coral animals built their habitations in warm, clear waters. Jellyfish swam and drifted in the sea. Worms evolved, and starfish, and hard-shelled creatures with many-jointed legs, the arthropods. The plants, too, progressed, from the microscopic algae to branched and curiously fruiting seaweeds that swayed with the tides and were plucked from the coastal rocks by the surf and cast adrift.

During all this time the continents had no life. There was little to induce living things to come ashore, forsaking their all-providing, all-embracing mother sea. The lands must have been bleak and hostile beyond the power of words to describe. Imagine a whole continent of naked rock, across which no covering mantle of green had been drawn – a continent without soil, for there were no land plants to aid in its formation and bind it to the rocks with their roots. Imagine a land of stone, a silent land, except for the sound of the rains and winds that swept across it. For there was no living voice, and no living thing moved over the surface of the rocks.

Meanwhile, the gradual cooling of the planet, which had first given the earth its hard granite crust, was progressing into its deeper layers; and as the interior slowly cooled and contracted,

it drew away from the outer shell. This shell, accommodating itself to the shrinking sphere within it, fell into folds and wrinkles – the earth's first mountain ranges.

Geologists tell us that there must have been at least two periods of mountain building (often called 'revolutions') in that dim period, so long ago that the rocks have no record of it, so long ago that the mountains themselves have long since been worn away. Then there came a third great period of upheaval and readjustment of the earth's crust, about a billion years ago, but of all its majestic mountains the only reminders today are the Laurentian hills of eastern Canada, and a great shield of granite over the flat country around Hudson Bay.

The epochs of mountain building only served to speed up the processes of erosion by which the continents were worn down and their crumbling rock and contained minerals returned to the sea. The uplifted masses of the mountains were prey to the bitter cold of the upper atmosphere and under the attacks of frost and snow and ice the rocks cracked and crumbled away. The rains beat with greater violence upon the slopes of the hills and carried away the substance of the mountains in torrential streams. There was still no plant covering to modify and resist the power of the rains.

And in the sea, life continued to evolve. The earliest forms have left no fossils by which we can identify them. Probably they were soft-bodied, with no hard parts that could be preserved. Then, too, the rock layers formed in those early days have since been so altered by enormous heat and pressure, under the foldings of the earth's crust, that any fossils they might have contained would have been destroyed.

For the past 500 million years, however, the rocks have preserved the fossil record. By the dawn of the Cambrian period, when the history of living things was first inscribed on rock pages, life in the sea had progressed so far that all the main groups of backboneless or invertebrate animals had been developed. But there were no animals with backbones, no insects or spiders, and still no plant or animal had been evolved that was

ERAS	PERIODS c. millions years ago	*Mountains* 	*Volcanoes* 
CENOZOIC	*Pleistocene* 0 – 1	Coast ranges, western United States: this disturbance probably still in progress	
	Tertiary 1 – 60	Alps, Himalayas, Apennines, Pyrenees, Caucasus	Great vulcanism in western United States formed Columbia Plateau (200,000 square miles of lava) Vesuvius and Etna began to erupt
MESOZOIC	*Cretaceous* 60 – 130	Rocky Mountains, Andes Rising of Panama Ridge: indirect result – Gulf Stream	
	Jurassic 130 – 155	Sierra Nevadas	
	Triassic 155 – 185		Many volcanoes in western North America, also in New England
PALEOZOIC	*Permian* 185 – 210	Appalachians south of New England	Volcanic outpourings produced Deccan Plateau of India
	Carboniferous 210 – 265		
	Devonian 265 – 320	Northern Appalachians (this area never again covered by sea)	
	Silurian 320 – 360	Caledonian Mountains (Great Britain, Scandinavia, Greenland – only their roots remain)	Volcanoes in Maine and New Brunswick
	Ordovician 360 – 440		
	Cambrian 440 – 520 ±		
PROTERO-ZOIC	520 ±	Killarney Mountains (Canada, Minnesota, Wisconsin – only their roots remain)	
ARCHEO-ZOIC	2100 +	Earliest known mountains (Laurentians of Canada – only traces remain) Earliest known sedimentary and volcanic rocks, much altered by heat and pressure, their history obscure	