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The Sea Around Us

Rachel L. Carson



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Preface to the 1961 Edition

THE SEA HAS ALWAYS challenged the minds and imagination of men and even today it remains the last great frontier of Earth. It is a realm so vast and so difficult of access that with all our efforts we have explored only a small fraction of its area. Not even the mighty technological developments of this, the Atomic Age, have greatly changed this situation. The awakening of active interest in the exploration of the sea came during the Second World War, when it became clear that our knowledge of the ocean was dangerously inadequate. We had only the most rudimentary notions of the geography of that undersea world over which our ships sailed and through which submarines moved. We knew even less about the dynamics of the sea in motion, although the ability to predict the actions of tides and currents and waves might easily determine the success or failure of military undertakings. The practical need having been so clearly established, the governments of the United States and of other leading sea powers began to devote increasing effort to the scientific study of the sea. Instruments and equipment, most of which had been born of urgent necessity, gave oceanographers the means of tracing the contours of the ocean bottom, of studying the movements of deep waters, and even of sampling the sea floor itself.

These vastly accelerated studies soon began to show that many of the old conceptions of the sea were faulty, and by the mid-point of the century a new picture had begun to emerge. But it was still like a huge canvas on which the artist has indicated the general scheme of his grand design but on which large blank areas await the clarifying touch of his brush.

This was the state of our knowledge of the ocean world when *The Sea Around Us* was written in 1951. Since that time the filling in of many of the blank areas has proceeded and new discoveries have been made. In this second edition of the book I have described the most important of the new findings in a series of notes which will be found in the Appendix.*

The 1950's have comprised an exciting decade in the science of the sea. During this period a manned vehicle has descended to the deepest hole in the ocean floor. During the 'fifties, also, the crossing of the entire Arctic basin was accomplished by submarines traveling under the ice. Many new features of the unseen floor of the sea have been described, including new mountain ranges that now appear to be linked with others to form the longest and mightiest mountains of the earth—a

continuous chain encircling the globe. Deep, hidden rivers in the sea, subsurface currents with the volume of a thousand Mississippis, have been found. During the International Geophysical Year, 60 ships from 40 nations, as well as hundreds of stations on islands and seacoasts, co-operated in an enormously fruitful study of the sea.

Yet the present achievements, exciting though they are, must be considered only a beginning to what is yet to be achieved by probing the vast depths of water that cover most of the surface of the earth. In 1959 a group of distinguished scientists comprising the Committee on Oceanography of the National Academy of Sciences declared that "Man's knowledge of the oceans is meager indeed compared with their importance to him." The Committee recommended at least a doubling of basic research on the sea by the United States in the 1960's; anything less would, in its opinion, "jeopardize the position of oceanography in the United States" compared with other nations and "place us at a disadvantage in the future use of the resources of the sea."

One of the most fascinating of the projects now planned for the future is an attempt to explore the interior of the earth by drilling a hole three or four miles deep in the bottom of the sea. This project, which is sponsored by the National Academy of Sciences, is designed to penetrate farther than instruments have ever before reached, to the boundary between the earth's crust and its mantle. This boundary is known to geologists as the Mohorovicic discontinuity (or more familiarly as the Moho) because it was discovered by a Yugoslavian of that name in 1912. The Moho is the point at which earthquake waves show a marked change in velocity, indicating a transition from one kind of material to something quite different. It lies much deeper under the continents than under the oceans, so, in spite of the obvious difficulties of drilling in deep water, an ocean site offers most promise. Above the Moho lies the crust of the earth, composed of relatively light rocks, below it the mantle, a layer some 1800 miles thick enclosing the hot core of the earth. The composition of the crust is not fully known and the nature of the mantle can be deduced only by the most indirect methods. To penetrate these regions and bring back actual samples would therefore be an enormous step forward in understanding the nature of our earth, and would even advance our knowledge of the universe, since the deep structure of the earth may be assumed to be like that of other planets.

As we learn more about the sea through the combined studies of many specialists a new concept that is gradually taking form will almost certainly be strengthened. Even a decade or so ago it was the fashion to speak of the abyss as a

place of eternal calm, its black recesses undisturbed by any movement of water more active than a slowly creeping current, a place isolated from the surface and from the very different world of the shallow sea. This picture is rapidly being replaced by one that shows the deep sea as a place of movement and change, an idea that is far more exciting and that possesses deep significance for some of the most pressing problems of our time.

In the new and more dynamic concept, the floor of the deep sea is shaped by racing turbidity currents or mud flows that pour down the slopes of the ocean basins at high speed; it is visited by submarine landslides and stirred by internal tides. The crests and ridges of some of the undersea mountains are swept bare of sediments by currents whose action, in the words of geologist Bruce Heezen, is comparable to “snow avalanches in the Alps (which) sweep down and smother the relief of the lower slopes.”

Far from being isolated from the continents and the shallow seas that surround them, the abyssal plains are now known to receive sediments from the margins of the continents. The effect of the turbidity currents, over the vast stretches of geologic time, is to fill the trenches and the hollows of the abyssal floor with sediment. This concept helps us understand certain hitherto puzzling occurrences. Why, for example, have deposits of sand—surely a product of coastal erosion and the grinding of surf—appeared on the mid-ocean floor? Why have sediments at the mouths of submarine canyons, where they communicate with the abyss, been found to contain such reminders of the land as bits of wood and leaves, and why are there sands containing nuts, twigs, and the bark of trees even farther out on the plains of the abyss? In the powerful downrush of sediment-laden currents, triggered by storms or floods or earthquakes, we now have a mechanism that accounts for these once mysterious facts.

Although the beginnings of our present concept of a dynamic sea go back perhaps several decades, it is only the superb instruments of the past ten years that have allowed us to glimpse the hidden movements of ocean waters. Now we suspect that all those dark regions between the surface and the bottom are stirred by currents. Even such mighty surface currents as the Gulf Stream are not quite what we supposed them to be. Instead of a broad and steadily flowing river of water, the Gulf Stream is now found to consist of narrow, racing tongues of warm water that curl back in swirls and eddies. And below the surface currents are others unlike them, running at their own speeds, in their own direction, with their own volume. And below these are still others. Photographs of the sea bottom taken at great depths formerly supposed to be eternally still show ripple marks, a

sign that moving waters are sorting over sediments and carrying away the finer particles. Strong currents have denuded the crest of much of the vast range of undersea mountains known as the Atlantic Ridge, and every one of the sea mounts that has been photographed reveals the work of deep currents in ripple marks and scour marks.

Other photographs give fresh evidence of life at great depths. Tracks and trails cross the sea floor and the bottom is studded with small cones built by unknown forms of life or with holes inhabited by small burrowers. The Danish research vessel *Galathea* brought up living animals in dredges operated at great depths, where only recently it was supposed life would be too scanty to permit such sampling. These findings of the dynamic nature of the sea are not academic; they are not merely dramatic details of a story that has interest but no application. They have a direct and immediate bearing on what has become a major problem of our time.

Although man's record as a steward of the natural resources of the earth has been a discouraging one, there has long been a certain comfort in the belief that the sea, at least, was inviolate, beyond man's ability to change and to despoil. But this belief, unfortunately, has proved to be naïve. In unlocking the secrets of the atom, modern man has found himself confronted with a frightening problem—what to do with the most dangerous materials that have ever existed in all the earth's history, the by-products of atomic fission. The stark problem that faces him is whether he can dispose of these lethal substances without rendering the earth uninhabitable.

No account of the sea today is complete unless it takes note of this ominous problem. By its very vastness and its seeming remoteness, the sea has invited the attention of those who have the problem of disposal, and with very little discussion and almost no public notice, at least until the late 'fifties, the sea has been selected as a "natural" burying place for the contaminated rubbish and other "low-level wastes" of the Atomic Age. These wastes are placed in barrels lined with concrete and hauled out to sea, where they are dumped overboard at previously designated sites. Some have been taken out 100 miles or more; recently sites only 20 miles offshore have been suggested. In theory the containers are deposited at depths of about 1000 fathoms, but in practice they have at times been placed in much shallower waters. Supposedly the containers have a life of at least 10 years, after which whatever radioactive materials remain will be released to the sea. But again this is only in theory, and a representative of the Atomic Energy Commission, which either dumps the wastes or licenses others to do so, has

publicly conceded that the containers are unlikely to maintain “their integrity” while sinking to the bottom. Indeed, in tests conducted in California, some have been found to rupture under pressure at only a few hundred fathoms.

But it is only a matter of time until the contents of all such containers already deposited at sea will be free in the ocean waters, along with those yet to come as the applications of atomic science expand. To the packaged wastes so deposited there is now added the contaminated run-off from rivers that are serving as dumping grounds for atomic wastes, and the fallout from the testing of bombs, the greater part of which comes to rest on the vast surface of the sea.

The whole practice, despite protestations of safety by the regulatory agency, rests on the most insecure basis of fact. Oceanographers say they can make “only vague estimates” of the fate of radioactive elements introduced into the deep ocean. They declare that years of intensive study will be needed to provide understanding of what happens when such wastes are deposited in estuaries and coastal waters. As we have seen, all recent knowledge points to far greater activity at all levels of the sea than had ever been guessed at. The deep turbulence, the horizontal movements of vast rivers of ocean water streaming one above another in varying directions, the upwelling of water from the depths carrying with it minerals from the bottom, and the opposite downward sinking of great masses of surface water, all result in a gigantic mixing process that in time will bring about universal distribution of the radioactive contaminants.

And yet the actual transport of radioactive elements by the sea itself is only part of the problem. The concentration and distribution of radioisotopes by marine life may possibly have even greater importance from the standpoint of human hazard. It is known that plants and animals of the sea pick up and concentrate radiochemicals, but only vague information now exists as to details of the process. The minute life of the sea depends for its existence on the minerals in the water. If the normal supply of these is low, the organisms will utilize instead the radioisotope of the needed element if it is present, sometimes concentrating it as much as a million times beyond its abundance in sea water. What happens then to the careful calculation of a “maximum permissible level”? For the tiny organisms are eaten by larger ones and so on up the food chain to man. By such a process tuna over an area of a million square miles surrounding the Bikini bomb test developed a degree of radioactivity enormously higher than that of the sea water.

By their movements and migrations, marine creatures further upset the convenient theory that radioactive wastes remain in the area where they are deposited. The smaller organisms regularly make extensive vertical movements

upward toward the surface of the sea at night, downward to great depths by day. And with them goes whatever radioactivity may be adhering to them or may have become incorporated into their bodies. The larger fauna, like fishes, seals, and whales, may migrate over enormous distances, again aiding in spreading and distributing the radioactive elements deposited at sea.

The problem, then, is far more complex and far more hazardous than has been admitted. Even in the comparatively short time since disposal began, research has shown that some of the assumptions on which it was based were dangerously inaccurate. The truth is that disposal has proceeded far more rapidly than our knowledge justifies. To dispose first and investigate later is an invitation to disaster, for once radioactive elements have been deposited at sea they are irretrievable. The mistakes that are made now are made for all time.

It is a curious situation that the sea, from which life first arose, should now be threatened by the activities of one form of that life. But the sea, though changed in a sinister way, will continue to exist; the threat is rather to life itself.

Silver Spring, Maryland

RACHEL CARSON

October 1960

*For this special edition of *The Sea Around Us*, Rachel Carson's notes have been placed at the end of each corresponding chapter.

I
Mother Sea

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 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 2½ 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 semiplastic 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 ore, 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's oceans 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 rain 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 back-boneless 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 capable of venturing onto the forbidding land. So for more than three-fourths of geologic time the continents were desolate and uninhabited, while the sea prepared the life that was later to invade them and make them habitable. Meanwhile, with violent tremblings of the earth and with the fire and smoke of roaring volcanoes, mountains rose and wore away, glaciers moved to and fro over the earth, and the sea crept over the continents and again receded.

ERAS	PERIODS c. millions years ago Holmes Scale (Revised 1959)	Mountains 	Volcanoes 
CENOZOIC	Miocene 0—1	Coast ranges, western United States; this disturbance probably still in progress	
	Tertiary 1—70	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 70—135	Rocky Mountains, Andes Rising of Panama Ridge; indirect result—Gulf Stream	
	Jurassic 135—180	Sierra Nevada	
	Triassic 180—225		Many volcanoes in western North America, also in New England
	Permian 225—270	Appalachians south of New England	Volcanic outpourings produced Deccan Plateau of India

PALEOZOIC	Carboniferous 270—350		
	Devonian 350—400	Northern Appalachians (this area never again covered by sea)	
	Silurian 400—440	Caledonian Mountains (Great Britain, Scandinavia, Greenland—only their roots remain)	Volcanoes in Maine and New Brunswick
	Ordovician 440—500		
	Cambrian 500—600		
PROTEROZOIC	600—3000± (see p. 211, note 1)	Greenville Mountains of eastern North America (only their roots remain)—age 1000 million Penekean Mountains (Minnesota, Ontario formerly Killarney)—age 1700 million	
ARCHEOZOIC	3000± (see p. 211, note 1)	Earliest known mountains (Laurentian of Minnesota and Ontario—only traces remain)—age 2600 million Earliest known sedimentary and volcanic rocks, much altered by heat and pressure, their history obscure	

Glaciers 	Seas 	DEVELOPMENT OF LIFE
Pleistocene glaciation—ice sheets over vast areas of North America and northern Europe	Sea level fluctuating because of glaciers	Rise of man Modern plants and animals 
	Great submergence of lands Nummulitic limestone formed—later used in Pyramids	Higher mammals, except man Highest plants 
	Much of Europe and about half of North America submerged. Chalk cliffs of England formed	Last of dinosaurs and flying reptiles Reptiles dominant on land 
	Last invasion of sea into eastern California and Oregon	First birds 
		First dinosaurs Some reptiles return to sea 

		Small, primitive mammals	
Glaciers in broad equatorial belts India, Africa, Australia, South America	Extensive seas over western United States world's largest salt deposits formed in Germany	Primitive reptiles Amphibians declining Earliest cycads and conifers	
	Central United States covered by sea for last time. Great coal beds formed	Amphibians developing rapidly First insects Coal-making plants	
		Fishes dominate seas First amphibian fossil	
	Repeated invasions by sea. Salt beds formed in eastern United States	First life appeared on continents	
	Greatest known submergence of North America — more than half of continent covered	Earliest known vertebrates Cephalopods common in seas	
	Seas advance and withdraw, at one time covering most of United States	First clear fossil record dates from this period; all major groups of invertebrates established	
Earliest known ice age		Rise of invertebrates (inferred)	
		Earliest life (inferred)	

It was not until Silurian time, some 350 million years ago, that the first pioneer of land life crept out on the shore. It was an arthropod, one of the great tribe that later produced crabs and lobsters and insects. It must have been something like a modern scorpion, but, unlike some of its descendants, it never wholly severed the ties that united it to the sea. It lived a strange life, half-terrestrial, half-aquatic, something like that of the ghost crabs that speed along the beaches today, now and then dashing into the surf to moisten their gills.

Fish, tapered of body and stream-molded by the press of running waters, were evolving in Silurian rivers. In times of drought, in the drying pools and lagoons, the shortage of oxygen forced them to develop swim bladders for the storage of air. One form that possessed an air-breathing lung was able to survive the dry periods by burying itself in mud, leaving a passage to the surface through which it

breathed.

It is very doubtful that the animals alone would have succeeded in colonizing the land, for only the plants had the power to bring about the first amelioration of its harsh conditions. They helped make soil of the crumbling rocks, they held back the soil from the rains that would have swept it away, and little by little they softened and subdued the bare rock, the lifeless desert. We know very little about the first land plants, but they must have been closely related to some of the larger seaweeds that had learned to live in the coastal shallows, developing strengthened stems and grasping, rootlike holdfasts to resist the drag and pull of the waves. Perhaps it was in some coastal lowlands, periodically drained and flooded, that some such plants found it possible to survive, though separated from the sea. This also seems to have taken place in the Silurian period.

The mountains that had been thrown up by the Laurentian revolution gradually wore away, and as the sediments were washed from their summits and deposited on the lowlands, great areas of the continents sank under the land. The seas crept out of their basins and spread over the lands. Life fared well and was exceedingly abundant in those shallow, sunlit seas. But with the later retreat of the ocean water into the deeper basins, many creatures must have been left stranded in shallow, landlocked bays. Some of these animals found means to survive on land. The lakes, the shores of the rivers, and the coastal swamps of those days were the testing grounds in which plants and animals either became adapted to the new conditions or perished.

As the lands rose and the seas receded, a strange fishlike creature emerged on the land, and over the thousands of years its fins became legs, and instead of gills it developed lungs. In the Devonian sandstone this first amphibian left its footprint.

On land and sea the stream of life poured on. New forms evolved; some old ones declined and disappeared. On land the mosses and the ferns and the seed plants developed. The reptiles for a time dominated the earth, gigantic, grotesque, and terrifying. Birds learned to live and move in the ocean of air. The first small mammals lurked inconspicuously in hidden crannies of the earth as though in fear of the reptiles.

When they went ashore the animals that took up a land life carried with them a part of the sea in their bodies, a heritage which they passed on to their children and which even today links each land animal with its origin in the ancient sea. Fish, amphibian, and reptile, warm-blooded bird and mammal—each of us carries in our veins a salty stream in which the elements sodium, potassium, and calcium

are combined in almost the same proportions as in sea water. This is our inheritance from the day, untold millions of years ago, when a remote ancestor, having progressed from the one-celled to the many-celled stage, first developed a circulatory system in which the fluid was merely the water of the sea. In the same way, our lime-hardened skeletons are a heritage from the calcium-rich ocean of Cambrian time. Even the protoplasm that streams within each cell of our bodies has the chemical structure impressed upon all living matter when the first simple creatures were brought forth in the ancient sea. And as life itself began in the sea, so each of us begins his individual life in a miniature ocean within his mother's womb, and in the stages of his embryonic development repeats the steps by which his race evolved, from gill-breathing inhabitants of a water world to creatures able to live on land.

Some of the land animals later returned to the ocean. After perhaps 50 million years of land life, a number of reptiles entered the sea about 170 million years ago, in the Triassic period. They were huge and formidable creatures. Some had oarlike limbs by which they rowed through the water; some were web-footed, with long, serpentine necks. These grotesque monsters disappeared millions of years ago, but we remember them when we come upon a large sea turtle swimming many miles at sea, its barnacle-encrusted shell eloquent of its marine life. Much later, perhaps no more than 50 million years ago, some of the mammals, too, abandoned a land life for the ocean. Their descendants are the sea lions, seals, sea elephants, and whales of today.

Among the land mammals there was a race of creatures that took to an arboreal existence. Their hands underwent remarkable development, becoming skilled in manipulating and examining objects, and along with this skill came a superior brain power that compensated for what these comparatively small mammals lacked in strength. At last, perhaps somewhere in the vast interior of Asia, they descended from the trees and became again terrestrial. The past million years have seen their transformation into beings with body and brain and spirit of man.

Eventually man, too, found his way back to the sea. Standing on its shores, he must have looked out upon it with wonder and curiosity, compounded with an unconscious recognition of his lineage. He could not physically re-enter the ocean as the seals and whales had done. But over the centuries, with all the skill and ingenuity and reasoning powers of his mind, he has sought to explore and investigate even its most remote parts, so that he might re-enter it mentally and imaginatively.

He built boats to venture out on its surface. Later he found ways to descend to

the shallow parts of its floor, carrying with him the air that, as a land mammal long unaccustomed to aquatic life, he needed to breathe. Moving in fascination over the deep sea he could not enter, he found ways to probe its depths, he let down nets to capture its life, he invented mechanical eyes and ears that could re-create for his senses a world long lost, but a world that, in the deepest part of his subconscious mind, he had never wholly forgotten.

And yet he has returned to his mother sea only on her own terms. He cannot control or change the ocean as, in his brief tenancy of earth, he has subdued and plundered the continents. In the artificial world of his cities and towns, he often forgets the true nature of his planet and the long vistas of its history, in which the existence of the race of men has occupied a mere moment of time. The sense of all these things comes to him most clearly in the course of a long ocean voyage, when he watches day after day the receding rim of the horizon, ridged and furrowed by waves; when at night he becomes aware of the earth's rotation as the stars pass overhead; or when, alone in this world of water and sky, he feels the loneliness of his earth in space. And then, as never on land, he knows the truth that his world is a water world, a planet dominated by its covering mantle of ocean, in which the continents are but transient intrusions of land above the surface of the all-encircling sea.

* Our concept of the age of the earth is constantly undergoing revision as older and older rocks are discovered and as methods of study are refined. The oldest rocks now known in North America are in the Canadian Shield area. Their precise age has not been determined, but some from Manitoba and Ontario are believed to have been formed about 3 billion years ago. Even older rocks have been discovered in the Karelia Peninsula in the U.S.S.R., and in South Africa. Geologists are generally of the opinion that present concepts of geologic time will be considerably lengthened in the future. Tentative adjustments of the length of the various periods have already been made (see chart above) and the age of the Cambrian has been pushed back 100 million years compared with the dating assigned to it a decade ago. It is in that immense and shadowy time that preceded the Cambrian, however, that the greatest uncertainty exists. This is the time of the pre-fossiliferous rocks. Whatever life may have inhabited the earth during that time has left few traces, although by indirect evidence we may infer that life existed in some abundance before its record was written in the rocks.

By studies of the rocks themselves geologists have established a few good benchmarks standing out in those vast stretches of time indicated on the chart as

the Proterozoic and Archeozoic Eras. These indicate a billion-year age for the ancient Grenville Mountains of eastern North America. Where these rocks are exposed at the surface, as in Ontario, they contain large amounts of graphite, giving silent testimony to the abundance of plant life when these rocks were forming, for plants are a common source of carbon. An age-reading of 1,700,000,000 years has been obtained in the Penokean Mountains of Minnesota and Ontario, formerly known to geologists as the Killarney Mountains. The remains of these once lofty mountains are still to be seen as low, rolling hills. The discovery of even older rocks in Canada, Russia, and Africa, dating back more than 3 billion years, suggests that the earth itself may have been formed about 4½ billion years ago.

The Pattern of the Surface

*There is, one knows not what sweet mystery
about this sea, whose gently awful stirrings
seem to speak of some hidden soul beneath.*

HERMAN MELVILLE

NOWHERE IN ALL the sea does life exist in such bewildering abundance as in the surface waters. From the deck of a vessel you may look down, hour after hour, on the shimmering discs of jellyfish, their gently pulsating bells dotting the surface as far as you can see. Or one day you may notice early in the morning that you are passing through a sea that has taken on a brick-red color from billions upon billions of microscopic creatures, each of which contains an orange pigment granule. At noon you are still moving through red seas, and when darkness falls the waters shine with an eerie glow from the phosphorescent fires of yet more billions and trillions of these same creatures.

And again you may glimpse not only the abundance but something of the fierce uncompromisingness of sea life when, as you look over the rail and down, down into water of a clear, deep green, suddenly there passes a silver shower of finger-long fishlets. The sun strikes a metallic gleam from their flanks as they streak by, driving deeper into the green depths with the desperate speed of the hunted. Perhaps you never see the hunters, but you sense their presence as you see the gulls hovering, with eager, mewling cries, waiting for the little fish to be driven to the surface.

Or again, perhaps, you may sail for days on end without seeing anything you could recognize as life or the indications of life, day after day of empty water and empty sky, and so you may reasonably conclude that there is no spot on earth so barren of life as the open ocean. But if you had the opportunity to tow a fine-meshed net through the seemingly lifeless water and then to examine the washings of the net, you would find that life is scattered almost everywhere through the surface waters like a fine dust. A cupful of water may contain millions upon millions of diatoms, tiny plant cells, each of them far too small to be seen by the human eye; or it may swarm with an infinitude of animal creatures, none larger than a dust mote, which live on plant cells still smaller than themselves.

If you could be close to the surface waters of the ocean at night, you would realize that then they are alive with myriads of strange creatures never seen by

day. They are alive with the moving lamps of small shrimplike beings that spend the daylight hours in the gloom of deep water, and with the shadowy forms of hungry fish and the dark shapes of squid. These things were seen, as few men have seen them, by the Norwegian ethnologist Thor Heyerdahl in the course of one of the most unusual journeys of modern times. In the summer of 1947 Heyerdahl and five companions drifted 4300 miles across the Pacific on a raft of balsa logs, to test a theory that the original inhabitants of Polynesia might have come from South America by raft. For 101 days and nights these men lived practically on the surface of the sea, driven by the trade wind, carried on the strong drift of the Equatorial Current, as much a part of the inexorable westward movement of wind and water as the creatures of the sea. Because of his enviable opportunity to observe the life of the surface while living as an actual part of it for so many weeks, I asked Mr. Heyerdahl about some of his impressions, especially of the sea at night, and he has written me as follows:

Chiefly at night, but occasionally in broad daylight, a shoal of small squids shot out of the water precisely like flying fish, gliding through the air as much as up to six feet above the surface, until they lost the speed accumulated below water, and fell down helplessly. In their gliding flight with flaps out they were so much like small flying fish at a distance, that we had no idea we saw anything unusual until a live squid flew right into one of the crew and fell down on the deck. Almost every night we found one or two on the deck or on the roof of the bamboo hut.

It was my own definite impression that the marine life in general went deeper down in the daytime than during the nights, and that the darker the night was, the more life we had around us. At two different occasions, a snake-mackerel, *Gempylus*, never before seen by man except as skeletal remains washed ashore on South America and the Galapagos, came jumping clear out of the water and right up on the raft (once right into the hut). To judge from the huge eyes and the fact that the fish has never before been observed, I am inclined to suspect that it is a deep-sea fish that comes to the surface only at night.

On dark nights we could see much marine life which we were unable to identify. They seemed to be deep-sea fishes approaching the surface at night. Generally we saw it as vaguely phosphorescent bodies, often the size and shape of a dinner plate, but at least one night in the shape of three immense bodies of irregular and changing shape and dimensions which

appeared to exceed those of the raft (Kon-Tiki measured about 45 by 18 feet). Apart from these greater bodies, we observed occasionally great quantities of phosphorescent plankton, often containing illuminating copepods up to the size of a millimeter or more.

With these surface waters, through a series of delicately adjusted, interlocking relationships, the life of all parts of the sea is linked. What happens to a diatom in the upper, sunlit strata of the sea may well determine what happens to a cod lying on a ledge of some rocky canyon a hundred fathoms below, or to a bed of multicolored, gorgeously plumed seaworms carpeting an underlying shoal, or to a prawn creeping over the soft oozes of the sea floor in the blackness of mile-deep water.

The activities of the microscopic vegetables of the sea, of which the diatoms are most important, make the mineral wealth of the water available to the animals. Feeding directly on the diatoms and other groups of minute unicellular algae are the marine protozoa, many crustaceans, the young of crabs, barnacles, sea worms, and fishes. Hordes of the small carnivores, the first link in the chain of flesh eaters, move among these peaceful grazers. There are fierce little dragons half an inch long, the sharp-jawed arrow-worms. There are gooseberrylike comb jellies, armed with grasping tentacles, and there are the shrimplike euphausiids that strain food from the water with their bristly appendages. Since they drift where the currents carry them, with no power or will to oppose that of the sea, this strange community of creatures and the marine plants that sustain them are called 'plankton,' a word derived from the Greek, meaning 'wandering.'

From the plankton the food chains lead on, to the schools of plankton-feeding fishes like the herring, menhaden, and mackerel; to the fish-eating fishes like the bluefish and tuna and sharks; to the pelagic squids that prey on fishes; to the great whales who, according to their species but not according to their size, may live on fishes, on shrimps, or on some of the smallest of the plankton creatures.

Unmarked and trackless though it may seem to us, the surface of the ocean is divided into definite zones, and the pattern of the surface water controls the distribution of its life. Fishes and plankton, whales and squids, birds and sea turtles, all are linked by unbreakable ties to certain kinds of water—to warm water or cold water, to clear or turbid water, to water rich in phosphates or in silicates. For the animals higher in the food chains the ties are less direct; they are bound to water where their food is plentiful, and the food animals are there because the water conditions are right.

The change from zone to zone may be abrupt. It may come upon us unseen, as our ship at night crosses an invisible boundary line. So Charles Darwin on H.M.S. *Beagle* one dark night off the coast of South America crossed from tropical water into that of the cool south. Instantly the vessel was surrounded by numerous seals and penguins, which made such a bedlam of strange noises that the officer on watch was deceived into thinking the ship had, by some miscalculation, run close inshore, and that the sounds he heard were the bellowing of cattle.

To the human senses, the most obvious patterning of the surface waters is indicated by color. The deep blue water of the open sea far from land is the color of emptiness and barrenness; the green water of the coastal areas, with all its varying hues, is the color of life. The sea is blue because the sunlight is reflected back to our eyes from the water molecules or from very minute particles suspended in the sea. In the journey of the light rays into deep water all the red rays and most of the yellow rays of the spectrum have been absorbed, so when the light returns to our eyes it is chiefly the cool blue rays that we see. Where the water is rich in plankton, it loses the glassy transparency that permits this deep penetration of the light rays. The yellow and brown and green hues of the coastal waters are derived from the minute algae and other microorganisms so abundant there. Seasonal abundance of certain forms containing reddish or brown pigments may cause the 'red water' known from ancient times in many parts of the world, and so common is this condition in some enclosed seas that they owe their names to it—the Red Sea and the Vermilion Sea are examples.

The colors of the sea are only the indirect signs of the presence or absence of conditions needed to support the surface life; other zones, invisible to the eye, are the ones that largely determine where marine creatures may live. For the sea is by no means a uniform solution of water; parts of it are more salty than others, and parts are warmer or colder.

The saltiest ocean water in the world is that of the Red Sea, where the burning sun and the fierce heat of the atmosphere produce such rapid evaporation that the salt content is 40 parts per thousand. The Sargasso Sea, an area of high air temperatures, receiving no inflow of river water or melting ice because of its remoteness from land, is the saltiest part of the Atlantic, which in turn is the saltiest of the oceans. The polar seas, as one would expect, are the least salty, because they are constantly being diluted by rain, snow, and melting ice. Along the Atlantic coast of the United States, the salinity range from about 33 parts per thousand off Cape Cod to about 36 off Florida is a difference easily perceptible to the senses of human bathers.

Ocean temperatures vary from about 28° F. in polar seas to 96° in the Persian Gulf, which contains the hottest ocean water in the world. To creatures of the sea, which with few exceptions must match in their own bodies the temperature of the surrounding water, this range is tremendous, and change of temperature is probably the most important single condition that controls the distribution of marine animals.

The beautiful reef corals are a perfect example of the way the inhabitable areas for any particular class of creatures may be established by temperatures. If you took a map of the world and drew a line 30° north of the equator and another 30° south of it, you would have outlined in general the waters where reef corals are found at the present time. It is true that the remains of ancient coral reefs have been discovered in arctic waters, but this means that in some past ages the climate of these northern seas was tropical. The calcareous structure of the coral reef can be fashioned only in water at least as warm as 70° Fahrenheit. We would have to make one northward extension of our map, where the Gulf Stream carries water warm enough for corals to Bermuda, at 32° north latitude. On the other hand, within our tropical belt, we would have to erase large areas on the west coasts of South America and Africa, where upwelling of cold water from lower ocean levels prevents the growth of corals. Most of the east coast of Florida has no coral reefs because of a cool inshore current, running southward between the coast and the Gulf Stream.

As between tropical and polar regions, the differences in the kinds and abundance of life are tremendous. The warm temperatures of the tropics speed up the processes of reproduction and growth, so that many generations are produced in the time required to bring one to maturity in cold seas. There is more opportunity for genetic mutations to be produced within a given time; hence the bewildering variety of tropical life. Yet in any species there are far fewer individuals than in the colder zones, where the mineral content of the water is richer, and there are no dense swarms of surface plankton, like the copepods of the Arctic. The pelagic, or free-swimming, forms of the tropics live deeper than those of the colder regions, and so there is less food for large surface-feeders. In the tropics, therefore, the sea birds do not compare in abundance with the clouds of shearwaters, fulmars, auks, whalebirds, albatrosses, and other birds seen over far northern or far southern fishing grounds.

In the cold-water communities of the polar seas, fewer of the animals have swimming larvae. Generation after generation settle down near the parents, so that large areas of bottom may be covered with descendants of a very few animals.

In the Barents Sea a research vessel once brought up more than a ton of one of the siliceous sponges at a single haul, and enormous patches of a single species of annelid worm carpet the east coast of Spitsbergen. Copepods and swimming snails fill the surface waters of the cold seas, and lure the herring and the mackerel, the flocks of sea birds, the whales, and the seals.

In the tropics, then, sea life is intense, vivid, and infinitely varied. In cold seas it proceeds at a pace slowed by the icy water in which it exists, but the mineral riches of these waters (largely a result of seasonal overturn and consequent mixing) makes possible the enormous abundance of the forms that inhabit them. For a good many years it has been said categorically that the total productivity of the colder temperate and polar seas is far greater than the tropical. Now it is becoming plain that there are important exceptions to this statement. In certain tropical and subtropical waters, there are areas where the sheer abundance of life rivals the Grand Banks or the Barents Sea or any antarctic whaling ground. Perhaps the best examples are the Humboldt Current, off the west coast of South America, and the Benguela Current, off the west coast of Africa. In both currents, upwelling of cold, mineral-laden water from deeper layers of the sea provides the fertilizing elements to sustain the great food chains.

And wherever two currents meet, especially if they differ sharply in temperature or salinity, there are zones of great turbulence and unrest, with water sinking or rising up from the depths and with shifting eddies and foam lines at the surface. At such places the richness and abundance of marine life reveals itself most strikingly. This changing life, seen as his ship cut across the pathways of the great currents of the Pacific and the Atlantic, was described with vivid detail by S. C. Brooks:

Within a few degrees of the equator, the scattered cumulus clouds become thicker and grayer, a confused swell makes up, rain squalls come and go, and birds appear. At first there is only a greater abundance of storm petrels, with here and there petrels of other kinds hunting along utterly indifferent to the ship, or small groups of tropic birds flying along with the ship, off to one side or high overhead. Then scattered groups of various petrels appear, and finally for an hour or two there are birds on every hand. If one is not too far from land, a few hundred miles perhaps, as in the case of the south equatorial drift north of the Marquesas, one may also see multitudes of sooty or crested terns. Occasionally one sees the grayish blue form of a shark gliding along, or a big purplish-brown hammerhead lazily

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