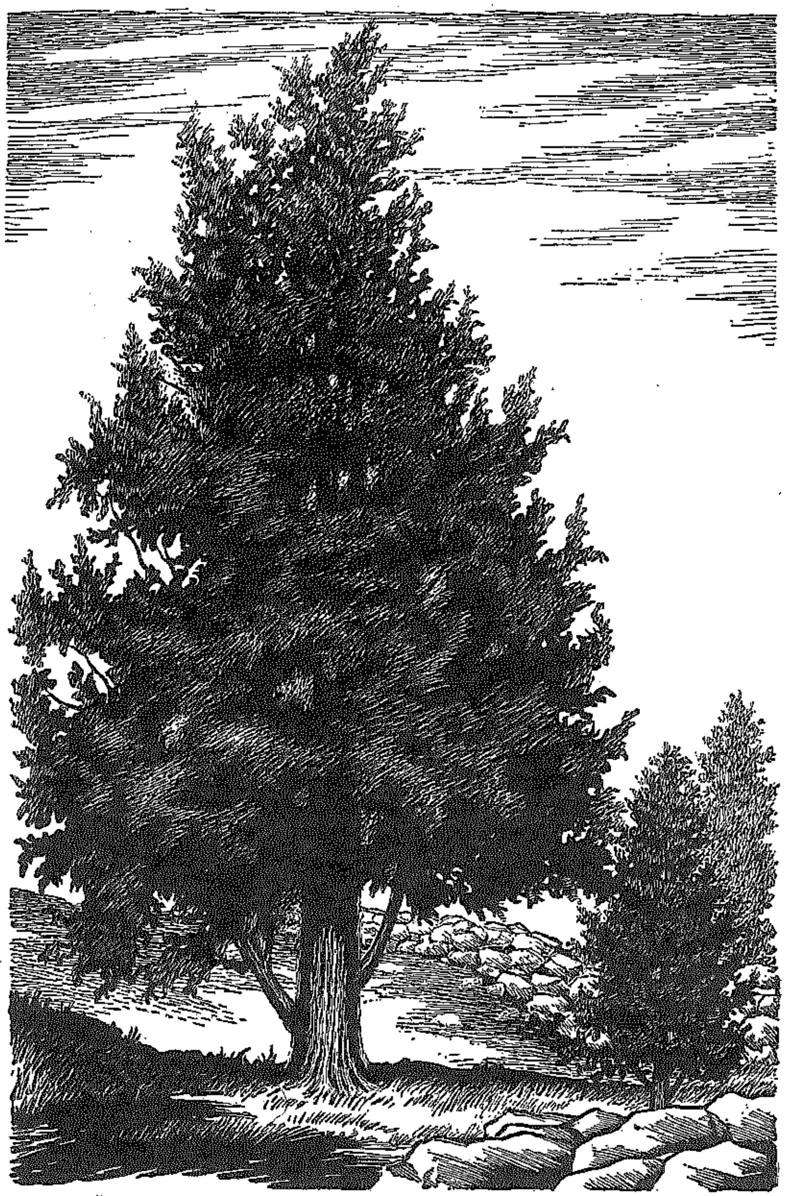

THIS INCOMPERABLE LANDE

A Book of American Nature Writing

Edited and with a history by
THOMAS J. LYON

HOUGHTON MIFFLIN COMPANY
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look. Those who look backward longingly to the end die young, at whatever age.

March Nineteenth. I go to the cellar for the last logs in my woodpile, and disclose a family of mice who have trustingly taken up residence there. Their tiny young, all ears and belly, mere little sacks of milk in a furless skin, lie there blind and helpless, five little tangible, irrepressible evidences of some moment, not so many nights ago, when in between the walls of my house there took place an act to which I am not so egotistic as to deny the name of love.

But it is not this which moves me, but the look in the mother's eyes as she stares up at me, her tail to the wall, all power of decision fled from her. There I read, in her agonized glance, how precious is life even to her. She entreats me not to take it from her. She does not know of pity in the world, so has no hope of it. But life — no matter how one suffers in it, hungers, flees, and fights — life is her religion.

How can we ever hope, then, to commensurate this thing which we too share, when it is its own cause, its own reason for being, when, as soon as we are challenged to stand and deliver it, we tremble and beg, like the trapped mouse?

March Twentieth. To the terror that faces mice and men, a man at least can find an answer. This will be his religion.

Now how may a man base all his faith on Nature when in Nature there is no certain end awaiting the ambition of his race? When all is flux and fleet, the great flood tides of spring that are like to drown him, and the final neap tide of decease? How take comfort from the brave new greening of the grass, when grass must wither, or in the first eery whistle of the meadow larks, saying that life is "sweet-to-you, so sweet to you"? For life is not sweet to all men. It brings some blind into this world and of others requires blood and tears. The sun toward which man turns his face is a brief candle in the universe. His woman and his children are mortal as the flowers.

But it is not life's generosity, so capricious, that makes one man happy. It is rather the extent of his gratitude to life.

I say that it touches a man that his tears are only salt, and that the tides of youth rise, and, having fallen, rise again. Now he has lived to see another spring and to walk again beneath the faintly greening trees. So, having an ear for the uprising of sap, for the running of blood, having an eye for all things done most hiddenly, and a hand in the making of those small dear lives that are not built with hands, he lives at peace with great events.

Rachel Carson
(1907–1964)

❧ Rachel Carson has affected our time perhaps more profoundly than any other modern nature writer. Her best-known work, *Silent Spring* (1962), is a revolutionary text, educating its readers to "see" at the hidden but crucial cellular and genetic levels, and to realize that our consumer and lifestyle choices are of real and even urgent importance to the health of the natural world which sustains us. These are two significant ingredients of modern ecological awareness.

So important has *Silent Spring* been that we may tend to overlook Carson's other books and the lyric science that made them best sellers. They too have affected perception; it might even be argued that with their dramatic emphasis on relationships of all kinds (wind and water, for example, to take an illustration close at hand), Carson's popular books on the sea promoted just the kind of understanding that would be required for *Silent Spring*. These widely read books continue to give both pleasure and instruction, reminding inhabitants of an increasingly sheltered civilization about the great natural forces that continue to shape life on earth.

Wind and Water

The wind's feet shine along the sea.
SWINBURNE

AS THE WAVES roll in toward Lands End on the westernmost tip of England they bring the feel of the distant places of the Atlantic.

From *The Sea Around Us* (rev. ed., 1961)

Moving shoreward above the steeply rising floor of the deep sea, from dark blue water into troubled green, they pass the edge of 'soundings' and roll up over the continental shelf in confused ripplings and turbulence. Over the shoaling bottom they sweep landward, breaking on the Seven Stones of the channel between the Scilly Isles and Lands End, coming in over the sunken ledges and the rocks that roll out their glistening backs at low water. As they approach the rocky tip of Lands End, they pass over a strange instrument lying on the sea bottom. By the fluctuating pressure of their rise and fall they tell this instrument many things of the distant Atlantic waters from which they have come, and their messages are translated by its mechanisms into symbols understandable to the human mind.

If you visited this place and talked to the meteorologist in charge, he could tell you the life histories of the waves that are rolling in, minute by minute and hour after hour, bringing their messages of far-off places. He could tell you where the waves were created by the action of wind on water, the strength of the winds that produced them, how fast the storm is moving, and how soon, if at all, it will become necessary to raise storm warnings along the coast of England. Most of the waves that roll over the recorder at Lands End, he would tell you, are born in the stormy North Atlantic eastward from Newfoundland and south of Greenland. Some can be traced to tropical storms on the opposite side of the Atlantic, moving through the West Indies and along the coast of Florida. A few have rolled up from the southernmost part of the world, taking a great-circle course all the way from Cape Horn to Lands End, a journey of 6000 miles.

On the coast of California wave recorders have detected swell from as great a distance, for some of the surf that breaks on that coast in summer is born in the west-wind belt of the Southern Hemisphere. The Cornwall recorders and those in California, as well as a few on the east coast of America, have been in use since the end of the Second World War. These experiments have several objects, among them the development of a new kind of weather forecasting. In the countries bordering the North Atlantic there is no practical need to turn to the waves for weather information because meteorological stations are numerous and strategically placed. The areas in which the wave recorders are presently used have served rather as a testing laboratory to develop the method. It will soon be ready for use in other parts of the world, for which there are no meteorological data except those the waves bring. Especially in the Southern Hemisphere, many coasts are washed by waves that have come from lonely, unvisited parts of the ocean, seldom crossed by vessels, off the normal

routes of the air lines. Storms may develop in these remote places, unobserved, and sweep down suddenly on mid-ocean islands or exposed coasts. Over the millions of years the waves, running ahead of the storms, have been crying a warning, but only now are we learning to read their language. Or only now, at least, are we learning to do so scientifically. There is a basis in folklore for these modern achievements in wave research. To generations of Pacific Island natives, a certain kind of swell has signaled the approach of a typhoon. And centuries ago, when peasants on the lonely shores of Ireland saw the long swells that herald a storm rolling in upon their coasts, they shuddered and talked of death waves.

Now our study of waves has come of age, and on all sides we can find evidence that modern man is turning to the waves of the sea for practical purposes. Off the Fishing Pier at Long Branch, New Jersey, at the end of a quarter-mile pipeline on the bed of the ocean, a wave-recording instrument silently and continuously takes note of the arrival of waves from the open Atlantic. By electric impulses transmitted through the pipeline, the height of each wave and the interval between succeeding crests are transmitted to a shore station and automatically recorded as a graph. These records are carefully studied by the Beach Erosion Board of the Army Corps of Engineers, which is concerned about the rate of erosion along the New Jersey coast.

Off the coast of Africa, high-flying planes recently took a series of overlapping photographs of the surf and the areas immediately offshore. From these photographs, trained men determined the speed of the waves moving in toward the shore. Then they applied a mathematical formula that relates the behavior of waves advancing into shallow water to the depths beneath them. All this information provided the British government with usable surveys of the depths off the coast of an almost inaccessible part of its empire, which could have been sounded in the ordinary way only at great expense and with endless difficulty. Like much of our new knowledge of waves, this practical method was born of wartime necessity.

Forecasts of the state of the sea and particularly the height of the surf became regular preliminaries to invasion in the Second World War, especially on the exposed beaches of Europe and Africa. But application of theory to practical conditions was at first difficult; so was the interpretation of the actual effect of any predicted height of surf or roughness of sea surface on the transfer of men and supplies between boats or from boats to beaches. This first attempt at practical military oceanography was, as one naval officer put it, a 'most frightening lesson' concerning the 'almost desperate lack of basic information on the fundamentals of the nature of the sea.'

As long as there has been an earth, the moving masses of air that we call winds have swept back and forth across its surface. And as long as there has been an ocean, its waters have stirred to the passage of the winds. Most waves are the result of the action of wind on water. There are exceptions, such as the tidal waves sometimes produced by earthquakes under the sea. But the waves most of us know best are wind waves.

It is a confused pattern that the waves make in the open sea — a mixture of countless different wave trains, intermingling, overtaking, passing, or sometimes engulfing one another; each group differing from the others in the place and manner of its origin, in its speed, its direction of movement; some doomed never to reach any shore, others destined to roll across half an ocean before they dissolve in thunder on a distant beach.

Out of such seemingly hopeless confusion the patient study of many men over many years has brought a surprising amount of order. While there is still much to be learned about waves, and much to be done to apply what is known to man's advantage, there is a solid basis of fact on which to reconstruct the life history of a wave, predict its behavior under all the changing circumstances of its life, and foretell its effect on human affairs.

Before constructing an imaginary life history of a typical wave, we need to become familiar with some of its physical characteristics. A wave has height, from trough to crest. It has length, the distance from its crest to that of the following wave. The period of the wave refers to the time required for succeeding crests to pass a fixed point. None of these dimensions is static; all change, but bear definite relations to the wind, the depth of the water, and many other matters. Furthermore, the water that composes a wave does not advance with it across the sea; each water particle describes a circular or elliptical orbit with the passage of the wave form, but returns very nearly to its original position. And it is fortunate that this is so, for if the huge masses of water that comprise a wave actually moved across the sea, navigation would be impossible. Those who deal professionally in the lore of waves make frequent use of a picturesque expression — the 'length of fetch.' The 'fetch' is the distance that the waves have run, under the drive of a wind blowing in a constant direction, without obstruction. The greater the fetch, the higher the waves. Really large waves cannot be generated within the confined space of a bay or a small area. A fetch of perhaps 600 to 800 miles, with winds of gale velocity, is required to get up the largest ocean waves.

Now let us suppose that, after a period of calm, a storm develops far out in the Atlantic, perhaps a thousand miles from the New Jersey coast where we are spending a summer holiday. Its winds blow irregularly, with sudden gusts, shifting direction but in general blowing shoreward. The sheet of water under the wind responds to the changing pressures. It is no longer a level surface; it becomes furrowed with alternating troughs and ridges. The waves move toward the coast, and the wind that created them controls their destiny. As the storm continues and the waves move shoreward, they receive energy from the wind and increase in height. Up to a point they will continue to take to themselves the fierce energy of the wind, growing in height as the strength of the gale is absorbed, but when a wave becomes about a seventh as high from trough to crest as the distance to the next crest it will begin to topple in foaming whitecaps. Winds of hurricane force often blow the tops off the waves by their sheer violence; in such a storm the highest waves may develop after the wind has begun to subside.

But to return to our typical wave, born of wind and water far out in the Atlantic, grown to its full height on the energy of the winds, with its fellow waves forming a confused, irregular pattern known as a 'sea.' As the waves gradually pass out of the storm area their height diminishes, the distance between successive crests increases, and the 'sea' becomes a 'swell,' moving at an average speed of about 15 miles an hour. Near the coast a pattern of long, regular swells is substituted for the turbulence of open ocean. But as the swell enters shallow water a startling transformation takes place. For the first time in its existence, the wave feels the drag of shoaling bottom. Its speed slackens, crests of following waves crowd in toward it, abruptly its height increases and the wave form steepens. Then with a spilling, tumbling rush of water falling down into its trough, it dissolves in a seething confusion of foam.

An observer sitting on a beach can make at least an intelligent guess whether the surf spilling out onto the sand before him has been produced by a gale close offshore or by a distant storm. Young waves, only recently shaped by the wind, have a steep, peaked shape even well out at sea. From far out on the horizon you can see them forming whitecaps as they come in; bits of foam are spilling down their fronts and boiling and bubbling over the advancing face, and the final breaking of the wave is a prolonged and deliberate process. But if a wave, on coming into the surf zone, rears high as though gathering all its strength for the final act of its life, if the crest forms all along its advancing front and then begins to curl forward, if the whole mass of water plunges suddenly with a booming roar into its trough — then you may take it that these waves are visitors from some very distant part of the ocean, that they have traveled long and far before their final dissolution at your feet.

What is true of the Atlantic wave we have followed is true, in general, of wind waves the world over. The incidents in the life of a wave are many. How long it will live, how far it will travel, to what manner of end it will come are all determined, in large measure, by the conditions it meets in its progression across the face of the sea. For the one essential quality of a wave is that it moves; anything that retards or stops its motion dooms it to dissolution and death.

Forces within the sea itself may affect a wave most profoundly. Some of the most terrible furies of the ocean are unleashed when tidal currents cross the path of the waves or move in direct opposition to them. This is the cause of the famous 'roosts' of Scotland, like the one off Sumburgh Head, at the southernmost tip of the Shetland Islands. During northeasterly winds the roost is quiescent, but when the wind-born waves roll in from any other quarter they encounter the tidal currents, either streaming shoreward in flood or seaward on the ebb. It is like the meeting of two wild beasts. The battle of the waves and tides is fought over an area of sea that may be three miles wide when the tides are running at full strength, first off Sumburgh Head, then gradually shifting seaward, subsiding only with the temporary slackening of the tide. 'In this confused, tumbling, and bursting sea, vessels often become entirely unmanageable and sometimes founder,' says the *British Islands Pilot,* 'while others have been tossed about for days together.' Such dangerous waters have been personified in many parts of the world by names that are handed down through generations of seafaring men. As in the time of our grandfathers and of their grandfathers, the Bore of Duncansby and the Merry Men of Mey rage at opposite ends of the Pentland Firth, which separates the Orkney Islands from the northern tip of Scotland. The sailing directions for the Firth in the *North Sea Pilot* for 1875 contained a warning to mariners, which is repeated verbatim in the modern *Pilot:*

> Before entering the Pentland Firth all vessels should be prepared to batten down, and the hatches of small vessels ought to be secured even in the finest weather, as it is difficult to see what may be going on in the distance, and the transition from smooth water to a broken sea is so sudden that no time is given for making arrangements.

Both roosts are caused by the meeting of swells from the open ocean and opposing tidal currents, so that at the east end of the Firth the Bore of Duncansby is to be feared with easterly swells and a flood tide, and at the west end the Merry Men of Mey stage their revelries with the ebb tides and a westerly swell. Then, according to the *Pilot,* 'a sea is raised which cannot be imagined by those who have never experienced it.'

Such a rip may offer protection to the near-by coast by the very fury and uncompromisingness of the struggle between waves and tide. Thomas Stevenson long ago observed that as long as the Sumburgh roost was breaking and cresting heavily off the Head there was little surf on shore; once the strength of the tide was spent and it could no longer run down the seas a heavy surf rolled in against the coast and rose to great heights on the cliffs. And in the western Atlantic, the confused and swiftly running tidal currents at the mouth of the Bay of Fundy offer such strong opposition to waves approaching from any quarter from southwest to southeast that such surf as develops within the Bay is almost entirely local in its origin.

Out in the open sea, a train of waves encountering a hostile wind may be rapidly destroyed, for the power that created a wave may also destroy it. So a fresh trade wind in the Atlantic has often flattened out the swells as they rolled down from Iceland toward Africa. Or a friendly wind, suddenly springing up to blow in the direction the waves are moving, may cause their height to increase at the rate of a foot or two per minute. Once a group of moving ridges has been created, the wind has only to fall into the troughs between them to push up their crests rapidly.

Rocky ledges, shoals of sand or clay or rock, and coastal islands in the mouths of bays all play their part in the fate of the waves that advance toward shore. The long swells that roll from the open ocean toward the shores of northern New England seldom reach it in full strength. Their energy is spent in passing over that great submerged highland known as Georges Bank, the crests of whose highest hills approach the surface over the Cultivator Shoals. The hindrance of these submarine hills, and of the tidal currents that swirl around and across them, robs the long ocean swells of their power. Or islands scattered within a bay or about its mouth may so absorb the strength of the waves that the head of the bay is free from surf. Even scattered reefs off a coast may offer it great protection, by causing the highest waves to break there, so that they never reach the shore.

Ice, snow, rain — all are enemies of the waves and under proper conditions may knock down a sea or cushion the force of surf on a beach. Within loose pack ice a vessel may count on smooth seas even if a gale is raging and surf is breaking heavily about the edges of the pack. Ice crystals forming in the sea will smooth the waves by increasing the friction between water particles; even the delicate, crystalline form of a snowflake has such an effect on a smaller scale. A hail storm will knock down a rough sea, and even a sudden downpour of rain may often turn the surface of the ocean to oiled-silk smoothness, rippling to the passage of the swells.

The divers of ancient times who carried oil in their mouths to release beneath the surface when rough water made their work difficult were applying what every seaman today knows — that oil appears to have a calming effect on the free waves of the open ocean. Instructions for the use of oil in emergencies at sea are carried by most official sailing directions of maritime nations. Oil has little effect on surf, however, once the dissolution of the wave form has begun.

In the Southern Ocean where the waves are not destroyed by breaking on any beach, the great swells produced by the westerly winds roll around and around the world. Here the longest waves, and those with the greatest sidewise expanse of crest, are formed. Here, it might be supposed, the highest waves would also be found. Yet there is no evidence that the waves of the Southern Ocean surpass the giants of any other ocean. A long series of reports culled from the publications of engineers and ships' officers show that waves higher than 25 feet from trough to crest are rare in all oceans. Storm waves may grow twice as high, and if a full gale blows long enough in one direction to have a fetch of 600 to 800 miles, the resulting waves may be even higher. The greatest possible height of storm waves at sea is a much debated question, with most textbooks citing a conservative 60 feet, and mariners stubbornly describing much higher waves. Throughout the century that has followed the report of Dumont d'Urville that he encountered a wave 100 feet high off the Cape of Good Hope, science generally has viewed such figures with skepticism. Yet there is one record of a giant wave which, because of the method of measurement, seems to be accepted as reliable.

In February 1933 the U.S.S. *Ramapo,* while proceeding from Manila to San Diego, encountered seven days of stormy weather. The storm was part of a weather disturbance that extended all the way from Kamchatka to New York and permitted the winds an unbroken fetch of thousands of miles. During the height of the storm the *Ramapo* maintained a course running down the wind and with the sea. On 6 February the gale reached its fiercest intensity. Winds of 68 knots came in gusts and squalls, and the seas reached mountainous height. While standing watch on the bridge during the early hours of that day, one of the officers of the *Ramapo* saw, in the moonlight,

a great sea rising astern to a level above an iron strap on the crow's nest of the mainmast. The *Ramapo* was on even keel and her stern was in the trough of the sea. These circumstances made possible an exact line of sight from the bridge to the crest of the wave, and simple mathematical calculations based on the dimensions of the ship gave the height of the wave. It was 112 feet.

Waves have taken their toll of shipping and of human life on the open sea, but it is around the shorelines of the world that they are most destructive. Whatever the height of storm waves at sea, there is abundant evidence, as some of the case histories that follow will show, that breaking surf and the upward-leaping water masses from thundering breakers may engulf lighthouses, shatter buildings, and hurl stones through lighthouse windows anywhere from 100 to 300 feet above the sea. Before the power of such surf, piers and breakwaters and other shore installations are fragile as a child's toys.

Almost every coast of the world is visited periodically by violent storm surf, but there are some that have never known the sea in its milder moods. 'There is not in the world a coast more terrible than this!' exclaimed Lord Bryce of Tierra del Fuego, where the breakers roar in upon the coast with a voice that, according to report, can be heard 20 miles inland on a still night. 'The sight of such a coast,' Darwin had written in his diary, 'is enough to make a landsman dream for a week about death, peril, and shipwreck.'

Others claim that the Pacific coast of the United States from northern California to the Straits of Juan de Fuca has a surf as heavy as any in the world. But it seems unlikely that any coast is visited more wrathfully by the sea's waves than the Shetlands and the Orkneys, in the path of the cyclonic storms that pass eastward between Iceland and the British Isles. All the feeling and the fury of such a storm, couched almost in Conradian prose, are contained in the usually prosaic *British Islands Pilot:*

> In the terrific gales which usually occur four or five times in every year all distinction between air and water is lost, the nearest objects are obscured by spray, and everything seems enveloped in a thick smoke; upon the open coast the sea rises at once, and striking upon the rocky shores rises in foam for several hundred feet and spreads over the whole country.
>
> The sea, however, is not so heavy in the violent gales of short continuance as when an ordinary gale has been blowing for many days; the whole force of the Atlantic is then beating against the shores of the Orkneys, rocks of many tons in weight are lifted from their beds, and the roar of the surge may be heard for twenty miles; the breakers rise to the height of 60 feet, and the broken sea on the North Shoal,

which lies 12 miles northwestward of Costa Head, is visible at Skail and Birsay.

The first man who ever measured the force of an ocean wave was Thomas Stevenson, father of Robert Louis. Stevenson developed the instrument known as a wave dynamometer and with it studied the waves that battered the coast of his native Scotland. He found that in winter gales the force of a wave might be as great as 6000 pounds to the square foot. Perhaps it was waves of this strength that destroyed the breakwater at Wick on the coast of Scotland in a December storm in 1872. The seaward end of the Wick breakwater consisted of a block of concrete weighing more than 800 tons, bound solidly with iron rods to underlying blocks of stone. During the height of this winter gale the resident engineer watched the onslaught of the waves from a point on the cliff above the breakwater. Before his incredulous eyes, the block of concrete was lifted up and swept shoreward. After the storm had subsided divers investigated the wreckage. They found that not only the concrete monolith but the stones it was attached to had been carried away. The waves had torn loose, lifted, and bodily moved a mass weighing not less than 1350 tons, or 2,700,000 pounds. Five years later it became clear that this feat had been a mere dress rehearsal, for the new pier, weighing about 2600 tons, was then carried away in another storm.

A list of the perverse and freakish doings of the sea can easily be compiled from the records of the keepers of lights on lonely ledges at sea, or on rocky headlands exposed to the full strength of storm surf. At Unst, the most northern of the Shetland Islands, a door in the lighthouse was broken open 195 feet above the sea. At the Bishop Rock Light, on the English Channel, a bell was torn away from its attachment 100 feet above high water during a winter gale. About the Bell Rock Light on the coast of Scotland one November day a heavy ground swell was running, although there was no wind. Suddenly one of the swells rose about the tower, mounted to the gilded ball atop the lantern, 117 feet above the rock, and tore away a ladder that was attached to the tower 86 feet above the water. There have been happenings that, to some minds, are tinged with the supernatural, like that at the Eddystone Light in 1840. The entrance door of the tower had been made fast by strong bolts, as usual. During a night of heavy seas the door was broken open *from within,* and all its iron bolts and hinges were torn loose. Engineers say that such a thing happens as a result of pneumatic action — the sudden back draught created by the recession of a heavy wave combined with an abrupt release of pressure on the outside of the door.

On the Atlantic coast of the United States, the 97-foot tower on Minot's Ledge in Massachusetts is often completely enveloped by masses of water from breaking surf, and an earlier light on this ledge was swept away in 1851. Then there is the often quoted story of the December storm at Trinidad Head Light on the coast of northern California. As the keeper watched the storm from his lantern 196 feet above high water, he could see the near-by Pilot Rock engulfed again and again by waves that swept over its hundred-foot crest. Then a wave, larger than the rest, struck the cliffs at the base of the light. It seemed to rise in a solid wall of water to the level of the lantern, and it hurled its spray completely over the tower. The shock of the blow stopped the revolving of the light.

Along a rocky coast, the waves of a severe storm are likely to be armed with stones and rock fragments, which greatly increase their destructive power. Once a rock weighing 135 pounds was hurled high above the lightkeeper's house on Tillamook Rock on the coast of Oregon, 100 feet above sea level. In falling, it tore a 20-foot hole through the roof. The same day showers of smaller rocks broke many panes of glass in the lantern, 132 feet above the sea. The most amazing of such stories concerns the lighthouse at Dunnet Head, which stands on the summit of a 300-foot cliff at the southwestern entrance to Pentland Firth. The windows of this light have been broken repeatedly by stones swept from the cliff and tossed aloft by waves.

For millennia beyond computation, the sea's waves have battered the coastlines of the world with erosive effect, here cutting back a cliff, there stripping away tons of sand from a beach, and yet again, in a reversal of their destructiveness, building up a bar or a small island. Unlike the slow geologic changes that bring about the flooding of half a continent, the work of the waves is attuned to the brief span of human life, and so the sculpturing of the continent's edge is something each of us can see for ourselves.

The high clay cliff of Cape Cod, rising at Eastham and running north until it is lost in the sand dunes near Peaked Hill, is wearing back so fast that half of the ten acres which the Government acquired as a site for the Highland Light has disappeared, and the cliffs are said to be receding about three feet a year. Cape Cod is not old, in geologic terms, being the product of the glaciers of the most recent Ice Age, but apparently the waves have cut away, since its formation, a strip of land some two miles wide. At the present rate of erosion, the disappearance of the outer cape is foredoomed; it will presumably occur in another 4000 or 5000 years.

The sea's method on a rocky coast is to wear it down by grinding, to chisel out and wrench away fragments of rock, each of which becomes a tool to wear away the cliff. And as masses of rock are undercut, a whole huge mass will fall into the sea, there to be ground in the mill of the surf and to contribute more weapons for the attack. On a rocky shore this grinding and polishing of rocks and fragments of rocks goes on incessantly and audibly, for the breakers on such a coast have a different sound from those that have only sand to work with — a deep-toned mutter and rumble not easily forgotten, even by one who strolls casually along such a beach. Few people have heard the sounds of the surf mill practically from within the sea, as described by Henwood after his visit to a British mine extending out under the ocean:

> When standing beneath the base of the cliff, and in that part of the mine where but nine feet of rock stood between us and the ocean, the heavy roll of the larger boulders, the ceaseless grinding of the pebbles, the fierce thundering of the billows, with the crackling and boiling as they rebounded, placed a tempest in its most appalling form too vividly before me ever to be forgotten. More than once doubting the protection of our rocky shield we retreated in affright; and it was only after repeated trials that we had confidence to pursue our investigations.[1]

Great Britain, an island, has always been conscious of that 'powerful marine gnawing' by which her coasts are eaten away. An old map dated 1786 and prepared by the county surveyor, John Tuke, gives a long list of lost towns and villages on the Holderness Coast. Among them are notations of Hornsea Burton, Hornsea Beck, and Hartburn — 'washed away by the sea'; of Ancient Withernsea, Hyde, or Hythe — 'lost by the sea.' Many other old records allow comparison of present shorelines with former ones and show astonishing annual rates of cliff erosion on many parts of the coast — up to 15 feet at Holderness, 19 feet between Cromer and Mundesley, and 15 to 45 feet at Southwold. 'The configuration of the coastline of Great Britain,' one of her present engineers writes, 'is not the same for two consecutive days.'

And yet we owe some of the most beautiful and interesting shoreline scenery to the sculpturing effect of moving water. Sea caves are almost literally blasted out of the cliffs by waves, which pour into crevices in the rocks and force them apart by hydraulic pressure. Over the years the widening of fissures and the steady removal of fine rock particles in infinite number result in the excavation of a cave. Within such a cavern the weight of incoming water and the strange suctions and pressures caused by the movements of water in an enclosed space may continue the excavation upward. The roofs of such caves (and of overhanging cliffs) are subjected to blows like those from a battering ram as the water from a breaking wave is hurled upward, most of the energy of the wave passing into this smaller mass of water. Eventually a hole is torn through the roof of the cave, to form a spouting horn. Or, on a narrow promontory, what began as a cave may be cut through from side to side, so that a natural bridge is formed. Later, after years of erosion, the arch may fall, leaving the seaward mass of rock to stand alone — one of the strange, chimneylike formations known as a stack.

The sea waves that have fixed themselves most firmly in the human imagination are the so-called 'tidal waves.' The term is popularly applied to two very different kinds of waves, neither of which has any relation to the tide. One is a seismic sea wave produced by

[1]From *Transactions*, Geol. Soc. Cornwall, vol. 5, 1843.

undersea earthquakes; the other is an exceptionally vast wind or storm wave — an immense mass of water driven by winds of hurricane force far above the normal high-water line.

Most of the seismic sea waves, now called 'tsunamis,' are born in the deepest trenches of the ocean floor. The Japanese, Aleutian, and Atacama trenches have each produced waves that claimed many human lives. Such a trench is, by its very nature, a breeder of earthquakes, being a place of disturbed and uneasy equilibrium, of buckling and warping downward of the sea floor to form the deepest pits of all the earth's surface. From the historic records of the ancients down to the modern newspaper, the writings of man contain frequent mention of the devastation of coastal settlements by these great waves that suddenly rise out of the sea. One of the earliest of record rose along the eastern shores of the Mediterranean in A.D. 358, passing completely over islands and low-lying shores, leaving boats on the housetops of Alexandria, and drowning thousands of people. After the Lisbon earthquake of 1755, the coast at Cadiz was visited by a wave said to have been 50 feet higher than the highest tide. This came about an hour after the earthquake. The waves from this same disturbance traveled across the Atlantic and reached the West Indies in 9½ hours. In 1868, a stretch of nearly 3000 miles of the western coast of South America was shaken by earthquakes. Shortly after the most violent shocks, the sea receded from the shore, leaving ships that had been anchored in 40 feet of water stranded in mud; then the water returned in a great wave, and boats were carried a quarter of a mile inland.

This ominous withdrawal of the sea from its normal stand is often the first warning of the approach of seismic sea waves. Natives on the beaches of Hawaii on the first of April 1946 were alarmed when the accustomed voice of the breakers was suddenly stilled, leaving a strange quiet. They could not know that this recession of the waves from the reefs and the shallow coastal waters was the sea's response to an earthquake on the steep slopes of a deep trench off the island of Unimak in the Aleutian chain, more than 2000 miles away; or that in a matter of moments the water would rise rapidly, as though the tide were coming in much too fast, but without surf. The rise carried the ocean waters 25 feet or more above the normal levels of the tide. According to an eyewitness account:

> The waves of the tsunami swept toward shore with steep fronts and great turbulence . . . Between crests the water withdrew from shore, exposing reefs, coastal mud-flats, and harbor bottoms for distances up to 500 feet or more from the normal strand-line. The outflow of the water was rapid and turbulent, making a loud hissing, roaring, and rattling noise. At several places houses were carried out to sea, and in some areas even large rocks and blocks of concrete were carried out onto the reefs . . . People and their belongings were swept to sea, some being rescued hours later by boats and life rafts dropped from planes.[2]

In the open ocean the waves produced by the Aleutian quake were only about a foot or two high and would not be noticed from vessels. Their length, however, was enormous, with a distance of about 90 miles between succeeding crests. It took the waves less than five hours to reach the Hawaiian chain, 2300 miles distant, so they must have moved at an average speed of about 470 miles per hour. Along eastern Pacific shores, they were recorded as far into the Southern Hemisphere as Valparaiso, Chile, the distance of 8066 miles from the epicenter being covered by the waves in about 18 hours.

This particular occurrence of seismic sea waves had one result that distinguished it from all its predecessors. It set people to thinking that perhaps we now know enough about such waves and how they behave that a warning system could be devised which would rob them of the terror of the unexpected. Seismologists and specialists on waves and tides co-operated, and now such a system has been established to protect the Hawaiian Islands. A network of stations equipped with special instruments is scattered over the Pacific from Kodiak to Pago Pago and from Balboa to Palau. There are two phases of the warning system. One is based on a new audible alarm at seismograph stations operated by the United States Coast and Geodetic Survey, which calls instant attention to the fact that an earthquake has occurred. If it is found that the epicenter of the quake is under the ocean and so might produce seismic sea waves, a warning is sent to observers at selected tide stations to watch their gauges for evidence of the passage of the racing tsunamis. (Even a very small seismic wave can be identified by its peculiar period, and though it may be small at one place, it may reach dangerous heights at another.) When seismologists in Honolulu are notified that an undersea earthquake has occurred and that its waves have actually been recorded at certain stations, they can calculate when the waves will arrive at any point between the epicenter of the quake and the Hawaiian Islands. They can then issue warnings for the evacuation of beaches and waterfront areas. And so, for the first time in history, there is an organized effort to prevent these ominous waves from

[2]From *Annual Rept.*, Smithsonian Inst., 1947.

racing undetected over the empty spaces of the Pacific, to roar up suddenly on some inhabited shore.[3]

The storm waves that sometimes rise over low-lying coast lands in hurricane zones belong in the class of wind waves, but unlike the waves of ordinary winds and storms, they are accompanied by a rise of the general water level, called a storm tide. The rise of water is often so sudden that it leaves no possibility of escape. Such storm waves claim about three-fourths of the lives lost by tropical hurricanes. The most notable disasters from storm waves in the United States have been those at Galveston, Texas, on 8 September, 1900, on the lower Florida Keys on 2 and 3 September, 1935, and the catastrophic rise of water accompanying the New England hurricane of 21 September, 1938. The most fearful destruction by hurricane waves within historic time occurred in the Bay of Bengal on 7 October, 1737, when 20,000 boats were destroyed and 300,000 people drowned.[4]

There are other great waves, usually called 'rollers,' that periodically rise on certain coasts and batter them for days with damaging

[3]From the time of its establishment up to 1960, the warning system has issued eight alerts warning residents of the Hawaiian Islands of the approach of seismic waves. On three of these occasions, waves of major proportions have in fact struck the islands. None have been so large or so destructive, however, as those of May 23, 1960, which spread out across the Pacific from their place of origin in violent earthquakes on the coast of Chile. Without such warning the loss of life would almost certainly have been enormous. As soon as the seismograph at the Honolulu Observatory recorded the first of the Chilean quakes the system went into operation. Reports from the scattered tide stations gave ample notice that a seismic wave had formed and was spreading out across the Pacific. By early news bulletins and later by an official "sea wave warning" the Observatory alerted residents of the area and predicted the time the wave would arrive and the areas to be affected. These predictions proved to be accurate within reasonable limits, and although property damage was heavy, loss of life was limited to the few who disregarded the warnings. Sea wave activity was reported as far west as New Zealand and as far north as Alaska. The Japanese coasts were struck by heavy waves. Although the United States warning system does not now include other nations, officials at Honolulu sent to Japan warnings of the wave which, unfortunately, were disregarded.

The warning system now (in 1960) consists of eight seismograph stations at points on both eastern and western shores of the Pacific and on certain islands, and of twenty widely scattered wave stations, four of which are equipped with automatic wave detectors. The Coast and Geodetic Survey feels that additional wave-reporting tide stations would improve the effectiveness of the system. Its principal defect now, however, is the fact that it is not possible to predict the height of a wave as it reaches any particular shore, and therefore the same alert must be issued for all approaching seismic waves. Research on methods of forecasting wave height is therefore needed. Even with its present limitations, however, the system has filled so great a need that there is strong international interest in extending it to other parts of the world.

[4]The flood of ocean waters that overwhelmed the coast of the Netherlands on February 1, 1953, deserves a place in the history of great storm waves. A winter gale that formed

surf. These, too, are wind waves, but they are related to changes in barometric pressure over the ocean, perhaps several thousand miles distant from the beaches on which the waves eventually arrive. Low-pressure areas — like the one south of Iceland — are notorious storm breeders, their winds lashing the sea into great waves. After the waves leave the storm area they tend to become lower and longer and after perhaps thousands of miles of travel across the sea they become transformed into the undulations known as a ground swell. These swells are so regular and so low that often they are unnoticed as they pass through the short, choppy, new-formed waves of other areas. But when a swell approaches a coast and feels beneath it the gradually shoaling bottom, it begins to 'peak up' into a high, steep wave; within the surf zone the steepening becomes abruptly accentuated, a crest forms, breaks, and a great mass of water plunges downward.

Winter swell on the west coast of North America is the product of storms that travel south of the Aleutians into the Gulf of Alaska. Swell reaching this same coast during the summer has been traced back to its origin in the Southern Hemisphere belt of the 'roaring forties,' several thousand miles south of the equator. Because of the direction of the prevailing winds, the American east coast and the Gulf of Mexico do not receive the swell from far distant storms.

The coast of Morocco has always been particularly at the mercy of swell, for there is no protected harbor from the Strait of Gibraltar southward for some 500 miles. The rollers that visit the Atlantic islands of Ascension, St. Helena, South Trinidad, and Fernando de Noronha are historic. Apparently the same sort of waves occur on the South American coast near Rio de Janeiro, where they are known as *resacas;* others of kindred nature, having run their course from storms in the west-wind belt of the South Pacific, attack the shores of the Paumotos Islands; still others have been responsible for the well-known 'surf days' that plague the Pacific coast of South America. According to Robert Cushman Murphy, it was formerly the custom

west of Iceland swept across the Atlantic and into the North Sea. All its force was ultimately brought to bear on the first land mass to obstruct the course of its center — the southwestern corner of Holland. The storm-driven waves and tides battered against the dikes in such bitter violence that these ancient defenses were breached in a hundred places, through which the flood rushed in to inundate farms and villages. The storm struck on Saturday, January 31, and by midday of Sunday one-eighth of Holland was under water. The toll included about half a million acres of Holland's best agricultural land — ravaged by water and permeated with salt — thousands of buildings, hundreds of thousands of live stock, and an estimated 1400 people. In all the long history of Holland's struggle against the sea, there has been no comparable assault by ocean waters.

of shipmasters in the guano trade to demand a special allowance for a certain number of days during which the loading of their vessels would be interrupted by the swell. On such surf days 'mighty rollers come pouring over the sea wall, and have been known to carry away forty-ton freight cars, to uproot concrete piers, and to twist iron rails like wire.'

The slow progression of swell from its place of origin made it possible for the Moroccan Protectorate to establish a service for the prediction of the state of the sea. This was done in 1921, after long and troublesome experience with wrecked vessels and wharves. Daily telegraphic reports of the condition of the sea give advance notice of troublesome surf days. Warned of the approach of swells, ships in port may seek safety in the open sea. Before this service was established, the port of Casablanca had once been paralyzed for seven months, and St. Helena had seen the wreckage of practically all the ships in her harbor on one or more occasions. Modern wave-recording instruments like those now being tested in England and the United States will soon provide even greater security for all such shores.

It is always the unseen that most deeply stirs our imagination, and so it is with waves. The largest and most awe-inspiring waves of the ocean are invisible; they move on their mysterious courses far down in the hidden depths of the sea, rolling ponderously and unceasingly. For many years it was known that the vessels of Arctic expeditions often became almost trapped and made headway only with difficulty in what was called 'dead water' — now recognized as internal waves at the boundary between a thin surface layer of fresh water and the underlying salt water. In the early 1900's several Scandinavian hydrographers called attention to the existence of submarine waves, but another generation was to elapse before science had the instruments to study them thoroughly.

Now, even though mystery still surrounds the causes of these great waves that rise and fall, far below the surface, their oceanwide occurrence is well established. Down in deep water they toss submarines about, just as their surface counterparts set ships to rolling. They seem to break against the Gulf Stream and other strong currents in a deep-sea version of the dramatic meeting of surface waves and opposing tidal currents. Probably internal waves occur wherever there is a boundary between layers of dissimilar water, just as the waves we see occur at the boundary between air and sea. But these are waves such as never moved at the surface of the ocean. The water masses involved are unthinkably great, some of the waves being as high as 300 feet.

Of their effect on fishes and other life of the deep sea we have only the faintest conception. Swedish scientists say that the herring are carried or drawn into some of the fiords of Sweden when the deep internal waves roll over the submerged sills and into the fiords. In the open ocean, we know that the boundary between water masses of different temperatures or salinities is often a barrier that may not be passed by living creatures, delicately adjusted to certain conditions. Do these creatures themselves then move up and down with the roll of the deep waves? And what happens to the bottom fauna of the continental slope, adjusted, it may be, to water of unchanging warmth? What is their fate when the waves move in from a region of arctic cold, rolling like a storm surf against those deep, dark slopes? At present we do not know. We can only sense that in the deep and turbulent recesses of the sea are hidden mysteries far greater than any we have solved.