THE WORLD OF WATER

SCIENCE FOR EVERYMAN

The following titles
are companion to this volume

OUR ASTONISHING ATMOSPHERE

THE FIGHT FOR FOOD

VIRUS IN THE CELL

---

to be published later

WE LIVE BY THE SUN

ELECTRONS GO TO WORK

by J. GORDON COOK Ph.D., F.R.I.C.

the WORLD of Water

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Preface

MILLIONS of years ago life began in the sea. Formless creatures throbbed in an environment of water. Water permeated their cells, carrying the food and raw materials they needed for life and growth.

To-day, after æons of evolutionary change, living things still exist in water. The chemical processes that make up life take place in water that fills every living cell. In the sea, plants and animals float in water itself; on land, living things enclose in their bodies the water they need. Water is the medium in which life takes place.

Water enters also into every aspect of human affairs. We drink water and wash in it; we use it for generating power and raising crops. Water is an industrial raw material and an extraordinary chemical in its own right. We use fluoridated water to prevent our teeth decaying and heavy water for making atom bombs. Water controls our weather and eats away our land.

In telling this story of water I have omitted the parts played by water in the air. This is described in another book in the series—*Our Astonishing Atmosphere*. Here and there I have touched on subject matter that has been dealt with elsewhere, but from a different point of view. Life in the sea, for example, is discussed as a source of food in *The Fight for Food*. Inevitably there has been some overlapping of information, but I have retained this where necessary to make a coherent story.

J.G.C.

Contents

One LANDS BENEATH THE SEA *page* 9
Two WATER ON THE MOVE 26
Three THE POWER OF WATER 40
Four RAW MATERIALS FROM THE SEA 51
Five PLANTS IN A WORLD OF PLENTY 66
Six ANIMALS AFLOAT 75
Seven A JUNGLE BENEATH THE WAVES 83
Eight LIFE ON THE SEA-FLOOR 94
Nine WATER FIT TO DRINK 104
Ten FRESH WATER FROM THE SEA 117
Eleven DENTAL TREATMENT THROUGH THE TAP 127
Twelve A DELUGE OF DETERGENTS 135
Thirteen H_2O — THE ECCENTRIC CHEMICAL 145
Fourteen HEAVYWEIGHT WATER 156
Fifteen THE WATERLOGGED LIFE OF ANIMALS 166
Sixteen WATER ATTACKS OUR LAND 180
INDEX 191

Illustrations

THE BOULDER DAM *page* 48
CONON VALLEY SCHEME 48
ABIDJAN SEA-WATER-ENERGY STATION 49
THE SEVERN ESTUARY IN MINIATURE 49
MAGNESIA EXTRACTION FROM SEA-WATER 64
SEAWEED 65
DIATOMS 144
DIATOM FOOD RESEARCH 144
HEAVY-WATER PLANT OF NORSK HYDRO 145
ARGONNE NATIONAL LABORATORY'S RESEARCH REACTOR (CP-5) 145
WAIRAKEI GEO-THERMAL PROJECT 160
THE GRAND CANYON, ARIZONA 161
WATER-HOLE IN BRAZIL 161

1

Lands beneath the Sea

HIGH up on their mountain-tops astronomers are peering at the planets that keep us company as we whirl around the sun. They are seeking above all else for signs of life on these strange worlds so far away in space. And in large measure the search for life has become identified with the search for water.

The earth is believed to be unique in the solar system by being part-covered with a layer of liquid water. Some planets have water in the form of ice or vapour; others appear to be devoid of water in any form. Only on our Earth, and possibly on Venus, are conditions suitable for water to persist as liquid that can fill the nooks and crannies in the irregular surface of the planet.

Nearly three-quarters of the earth's surface is covered by water. In the seas and oceans some 300 million cubic miles of water form an immense and life-packed reservoir that is, on average, more than two miles deep.

In these age-old waters chemical reactions took place billions of years ago which culminated in the creation of a living thing. After æons of time life left the waters and crawled on to the land, changing gradually into the creatures that now inhabit the earth.

We human beings, like all the other dry-land animals and plants, no longer make our homes in water; but we are still dependent on it for the gift of life. The processes of life can take place only in the presence of water. The human body is two-thirds water which fills each living cell and forms the bulk of the blood and other fluids that permeate our tissues. Even now, after many millions of years of evolution, the chemicals dissolved in human blood are essentially the same as those we find in sea-water.

Although we no longer depend directly on the waters of the world for our environment, life is conditioned and controlled by the oceans that girdle the earth. The water in these oceans is a reservoir from which we draw the supplies we need for life. Water gives us our weather and makes possible the growth of food-plants in the soil. It modifies the air we breathe and provides the sheltering clouds that protect us from the harsh rays of the sun.

From the earliest times scientists and philosophers have speculated about the origin of the water in the oceans. We now believe that it was squeezed out in the form of billowing clouds of vapour from the interior of a cooling earth; as the temperature of the surface crust diminished the water vapour was able to condense and remain as liquid water. It flowed into the gullies and depressions of the earth's contorted surface, surrounding the higher levels with seas such as we have to-day.

After the first great deluge of condensing vapour had subsided the water amounted to only about a quarter of the volume that now covers the earth. But as the shell of the earth continued to cool and shrink volcanic outbursts brought additional supplies of water from the enormous store that was locked in the earth's interior. A thousand million years ago the waters reached a level similar to that which they occupy to-day.

As the earth's crust settled into its present form the water sheet took up a curious shape in relation to the dry land above sea-level. Most of the water of the world is in the Southern Hemisphere, and most of the land in the Northern Hemisphere. From the Antarctic Ocean which surrounds the land-mass squatting on the South Pole water stretches in three immense gulfs that reach northward and separate the land into its continents. The

Indian Ocean, filling the depression between Africa and Australia, covers an area of seventeen million square miles. Between America on one side, and Europe and Africa on the other, the Atlantic Ocean engulfs twenty-five million square miles of the earth's surface. The Pacific, separating America from Asia, is twice as large as the Atlantic and covers nearly half the earth.

It is easy to think of the oceans as enormous baths of water that have flooded the low-lying areas of the earth. But this is an over-simplification that does not fit the geological facts. The waters of the ocean and the continental land masses are separate entities, each floating independently on the earth's inner shell of basalt rock. The sedimentary rocks and granites of the land are floating like huge rafts upon the basalt, depressing it out of shape like a heavy book lying on a cushion. The ocean waters fill the channels that separate these continental rafts of sedimentary rock; the ocean floor consists, in the main, of basaltic rock covered in many places by a layer of sediment and volcanic debris. Water and land are therefore geologically distinct forms of upper-surface on the earth.

The continental land masses on which we human beings live are apparently in a state of equilibrium with the water on the plastic crust of the earth. Changes in the volume of water can cause inundations of the land surface; but in the long run land will tend to remain above the water as the earth's crust makes the necessary adjustments to meet the changing conditions.

Although the oceans are, on average, about two miles deep, the continental land protrudes for only about half a mile above sea-level. Much of the sedimentary and granite rock that supports the dry land lies below sea-level; the continents float like icebergs on the basalt shell of the earth with most of their bulk beneath the level of the enveloping waters.

In times gone by the earth has passed through ages of climatic extremes. During the Ice Ages water from the sea was built up into immense sheets of ice that covered vast areas of America, Europe, and Asia. These continental glaciers, often several miles in thickness, took so much water from the seas that the level of the water fell by as much as 300 feet. At the present time the earth is believed to be experiencing a period of warming-up; glaciers in the polar regions are melting steadily and the level of the ocean water is rising at a rate of about an inch in twelve years. If this trend should continue until all the ice was melted, and the land-level did not rise through any geological readjustment, a fifth of our existing continental land would be submerged.

The changing level of water in the ocean is marked out by changes in the coastline of our continents. The sedimentary rocks and granite that form the huge land-masses do not fall away steeply into the ocean depths at the shoreline. Around most of the continents the land slopes down gently beneath the sea, forming a shelf that drops perhaps ten feet in every mile. The rocks of the sea-bed in these coastal waters are the characteristic continental rocks; they are covered by sand and pebbles eroded from the seashore and by silt and mud brought down by rivers from the land.

This coastal sea-bed falls away steadily until it reaches a depth of about 600 feet. Then the contours undergo a rapid change. The slope steepens, and the sea-bed falls until it forms an under-water escarpment that plunges downward at as much as 400 feet to the mile. Eventually, at a depth of two or three miles or more, the bottom of the escarpment is reached; this is the bed of the ocean proper—the basaltic rock on which the waters of the world are floating.

The continental shelf, as the sea-shore slope is called, is characteristic of almost every coastline in the world. Sometimes, as off the west coast of South America, the land slopes steeply down into the deep water of the ocean.

But this is the exception. Off the Atlantic coast of America the shelf extends under water for 100 miles or more. Off the Siberian coast of Russia it reaches a record distance of 800 miles into the Arctic Ocean.

During the last Ice Age much of the continental shelf was dry land; the water that has raised the level of the sea to its present height was frozen into a huge layer of ice that rested on the land. Samples taken from the sea-bed of the continental shelf have included fossils and rocks that are characteristic of land conditions.

These shallow waters have for centuries provided the major fishing grounds of the world. Coastal seas, such as the Baltic and North Sea, are typical of the flooded areas of the Ice Age continents. Islands like Britain, separated by shallow waters from the main continental masses, are really sections of the land that have been cut off by the rising waters of the sea. They differ fundamentally from the islands that thrust abruptly from the ocean wastes.

Until quite recently such knowledge of the ocean floor as we possessed was confined almost entirely to the shallow regions of the continental shelves. The deeper regions of the ocean were believed to be little more than inundated plains.

Exploration of the ocean bed is a difficult and often tedious task. Divers cannot operate easily below a few hundred feet; yet there are huge areas of ocean floor as much as four miles deep. The overwhelming weight of water, pressing down with a force of many tons to the square inch, can crush all ordinary forms of diving gear as though in a giant fist. Beneath the sea the light of day is soon blotted out, and even the most powerful lamps can do little to penetrate the gloom of the ocean depths. Even to-day with all our scientific gadgets and equipment we have hardly made a start on the direct exploration of the ocean floor that lies beyond the continental shelves. It is only within the last half-century that we have been able to collect such elementary information as the depth of water in different regions of the ocean and the nature of the sediment that covers the ocean floor. Yet so rapidly are these indirect explorations now going ahead that we already know the seas to cover a territory as fascinating and varied as any land on earth.

Until 1872 almost nothing was known about the depths of the ocean or the nature of the land on which the waters lay. Sounding was carried out with a hemp rope, and a single reading could well take a day or more to obtain. Currents would sweep the line sideways and the accurate pin-pointing of the ship's position was difficult. But in 1872 the first planned oceanographic expedition set out from Britain to begin the scientific study of the oceans of the world. The *Challenger*, an 18-gun corvette of 2000 tons, set out from Portsmouth on a cruise that was to last until 1876 and to make world history as the first real exploration of the mysterious under-water territory that covers nearly three-quarters of the earth.

The *Challenger* girdled the earth during her three-year cruise and made depth-soundings as often as possible under the limitations imposed by the hemp-line technique. Samples of sea-water and sediment were collected from all parts of the globe, and thousands of scientific measurements were made. But even so the *Challenger* expedition did little to clear up any of the major mysteries of the sea; its main value was in showing how much we had to learn.

By 1895 only 7000 soundings had been made in water deeper than 1¼ miles; only 550 were from depths greater than 3⅓ miles. This was all the information available at that time on the topography of nearly three-quarters of the earth's surface. Up to the outbreak of World War I soundings continued and information accumulated slowly. But it was not until after the war that a really quick and reliable method of measuring ocean depths became available. This was the echo-sounder, which developed from the device used by the Allies for detecting U-boats.

Sound-waves will travel through water as they do through air and will bounce back from solid objects that they meet. A submarine, for example, will reflect sound-waves emitted from a surface vessel, and the time taken for the echo to return can be used to estimate the distance between the ship and submarine. This principle was used with great success during World War I.

The distances covered by sound-waves under water are immense. A small explosion under the sea near the American coast can be heard by hydrophones more than 2000 miles away in Hawaii.

By 1920 echo-sounding devices had been developed for measuring the depth of the sea. Sound-waves from an explosive charge set off by a ship will reflect from the sea-bed and send back an echo; the time interval between the explosion and the echo provides a measure of the depth of water beneath the ship.

Echo-sounding proved to be the tool that oceanographers were waiting for. Ships travelling about the oceans could take continuous soundings throughout their journey. Records of sea depths began to pile up more rapidly than they could be assessed, and by the outbreak of World War II we began to build up maps of the ocean bed in the more accessible parts of the world.

Meanwhile other scientific techniques were being adapted to the exploration of the ocean floor. Geological structure has been studied with the help of delicate instruments that can measure variations in the gravitational pull of the earth. The force of gravity depends upon the nature of the materials forming the crust of the earth where measurements are being made. By measuring infinitesimal differences in gravity it is possible to predict the nature of materials in the crust. At sea, for example, the force of gravity is lower than it is on land, as the dense rocks exert a greater pull than seawater.

In the inter-war years a remarkable exploration of the sea-bed with the help of gravity measurements was made by Dr Vening Meinesz, of the Netherlands Geodetic

Mission. Dr Meinesz designed a special type of instrument that could be used in a submarine, and underwater measurements were made in the Atlantic and Pacific. Swinging in the submarine at 200–300 feet, the pendulums of the instrument were undisturbed by movements of the waves above.

These gravity explorations showed that the sea-bed, as had been predicted, consisted of basaltic rock, denser than the sedimentary and granite rocks of the continental land-masses. The measurements helped to map the fissures and faults that geological changes have wrought on the ocean floor.

Meanwhile great efforts were being made to devise methods of bringing up samples of the materials that cover the bottom of the sea. On the basalt rocks a layer of sediment lies, often a mile or more in thickness. This sediment is formed by the tiny organisms and particles that settle with infinite slowness from the water above. It carries within it a record of climatic and geological changes that have taken place in the world through millions of years of time.

It is possible without great difficulty to bring up samples of the ocean bed in a simple grab or trawl, even from great depths. But, in order to find out anything of real scientific value about the sediment of the ocean floor, it is preferable to bring up a 'core' that has been bored from the sediment in such a way that the stratified formation of the sediment is kept intact. By studying these cores the scientist can assess conditions on the earth during prehistoric times.

At the time of the *Challenger* expedition, in 1872, cores were obtained by dropping weighted pipes on to the bottom of the sea; they reached a maximum of about two feet in length. Half a century later the German Atlantic Expedition in the *Meteor* was able to take core samples of only three feet in length. But during World War II Swedish scientists used their enforced inactivity to devise entirely new types of ocean-bed sampler which could bring up cores of tremendous length. By 1942 they were taking cores 45 feet long from the bed of Gullmar Fjord; in 1945 they were able to bring up cores of 65 feet.

In the spring of 1946 a test cruise was made by Swedish oceanographers in the Mediterranean, and the new devices were operated successfully under open sea conditions. The following year, on July 4, a fully equipped expedition left Göteborg in the *Albatross*, a new motor schooner of 1450 tons. The *Albatross* was a floating laboratory equipped with coring and trawling devices that could be lowered quickly on more than five miles of steel cable.

In addition to these devices for sampling the sea-bed, the *Albatross* carried echo-sounding gear that incorporated refinements developed during the war. Swedish scientists had perfected a method of detecting and recording echoes from different layers in the stratified sediments on the ocean floor. In this way they could estimate the depths of sediment lying above the basalt base rock and detect changes in its structure and composition.

From Göteborg the *Albatross* set a course for the doldrums, where the seas were calm enough to enable the deep-sea equipment to be used. From Madeira the expedition followed a straight course to Martinique, taking samples and soundings on the way. By August 27, 1947, the *Albatross* was through the Panama Canal and setting off across the Pacific. For five months she zig-zagged about this huge ocean and eventually sailed between the islands of the East Indies and into the Indian Ocean. By May 1948 the *Albatross* had made her way through the Red Sea and the Mediterranean and reached Monaco. For four months she cruised about in the Atlantic, reaching Göteborg again on October 3, 1948.

During this world-circling cruise the scientists on the *Albatross* took thousands of samples of ocean water and tens of thousands of temperature readings at various depths. Records had been made of the echoes from more than 400 depth-charges, and the profile of more than 17,000 miles of the ocean bed had been drawn in detail with the help of echo-soundings. In the cold-storage chambers of the vessel were 200 sediment cores, totalling more than a mile in length, taken from the ocean bed at great depths in many different parts of the world.

This great post-war cruise of the *Albatross* was the first really large-scale attempt to use modern oceanographic instruments in our exploration of the ocean floor. The information that was collected has been studied by scientists in many countries and will no doubt provide research material for several years to come. But already, from this and other post-war oceanographic expeditions, we have been able to create a picture of the ocean floors such as we never dreamed of twenty years ago.

Great mountain ranges are now known to stretch for thousands of miles beneath the sea, ranges which dwarf the land-based mountains like the Andes or the Alps. The bed of the Atlantic Ocean is split from Iceland to Antarctica by the biggest range of mountains in the world: the Mid-Atlantic Ridge. Seven thousand miles in length, this enormous range is more than 600 miles across at its widest point. The mountains of the Mid-Atlantic Ridge tower more than two miles above the ocean floor, yet on the average the peaks remain a mile below the surface of the sea. Here and there a peak will break the surface, forming the islands of the Azores, Ascension, Sierra Leone, and Tristan da Cunha.

From the sides of the Mid-Atlantic Ridge other sea-bed mountains reach across towards our continents, splitting the floor of the Atlantic into four huge basins.

The existence of these mid-Atlantic mountains was discovered nearly a century ago during the laying of the first Atlantic cables. The mountains were for long known as Telegraph Ridge. But only within recent years, with the help of our deep-sea exploration devices, has the mountain range been mapped with any degree of accuracy.

The origin of the Atlantic mountains is a mystery. Were they thrust up from the sea-bed by some geological upheaval that took place under the cover of the Atlantic water? Or were these mountains once dry land, the lost continent of Atlantis, which disappeared by sinking beneath the waves? The existence of granite in the mountains is an indication that they were at one time part of a continental land-mass. If, as many geologists predict, the earth is slowly drying up the Atlantic Ridge will reappear as a great new continent in the course of a few hundred million years.

In the Indian Ocean a range of mountains runs from the tip of India to Antarctica, and in the Pacific, still almost virgin territory for the seaborne explorer, mountains are known to stretch from Japan to Antarctica and from Central America to the south and west. In 1949 an expedition from the University of California discovered a brand-new underwater mountain range in the Central Pacific. A thousand miles in length and a hundred miles wide, these mountains are half as high as Everest, yet the topmost peaks remain more than half a mile below the surface.

In 1954 Soviet scientists discovered a two-mile-high ridge beneath the ice of the Arctic Ocean. These Lomonosov Mountains, named after a Russian poet, stretch from Greenland to the New Siberian Islands.

Among the many strange features of the ocean bed that accurate soundings have disclosed are the flat-topped mountains known as guyots. Hundreds of these mountains have now been found, especially in the Pacific. They rise like huge cones from the sea-bed, ending in a flat top that may be as much as a mile below the surface of the sea. The smooth-planed tops of the guyots are often garlanded with long-dead reefs of coral and carry deposits of pebbles that are polished smooth as though by surf. Everything points to the fact that the tops of these guyots were eroded by the action of the weather and the waves. Coral, for example, is formed by tiny animals that live only in surface waters; they cannot survive at depths of more than about 180 feet.

If, in fact, the guyots were at one time reaching through the surface of the sea, how did they become covered by such a depth of water? None of the accepted theories of changing sea-levels can account for a lowering of a mile.

It seems most likely that the guyots are volcanoes that were thrust up from the sea-floor millions of years ago. Under the action of the weather the peaks were eroded and flattened; but at some later stage the immense weight of the mountains proved too much for the earth's crust to support. They sank into the plastic rock until the crust was able to bear the strain. This theory is made more credible by the fact that many of the guyots are surrounded by a moat or trench in the sea-floor, as though the underlying rock had been pressed down.

Many of the islands in the Pacific are guyots in the making. They are volcanic cones that have been built up during immense eruptions from the sea-bed. The Hawaiian Islands are projecting peaks of the volcanic ridge that stretches nearly 2000 miles to Midway Atoll. Hawaii itself is the greatest mountain in the world; its volcanic peak reaches half a mile higher from the sea-bed than Mount Everest does from sea-level.

Many of the volcanic islands of the Pacific are sinking slowly into the sea-bed. Often the fall is so slow that the coral organisms ringing the island are able to build their reef of ancestral skeletons fast enough to keep the living layers at surface level. The coral caps of some Pacific islands are thousands of feet thick; the coral skyscraper that sits atop of a submarine volcano to form the Kwajalain Atoll is the largest structure that any living creature has ever built.

When a volcanic island sinks too quickly the coral is drowned and a guyot with its coral fringe is formed. Some corals brought up from guyots two miles under water have been identified as extinct types more than 100 million years old. The Pacific was therefore at least two miles deep millions of years before man appeared on earth.

As though to compensate for the massive mountains that reach up from the earth's undersea crust, there are huge trenches, or troughs, in every ocean. These depressions, often thousands of miles long and hundreds of miles wide, are the ocean deeps. Usually they are found comparatively near to the continental shores, as though the land-masses formed them by pressing down the earth's basalt crust. The deepest ocean troughs are in the Pacific. East of the Philippines is a trench where soundings of more than 6½ miles have been made; similar trenches lie off the coast of Japan and the islands of the Mariana Ridge. In the Atlantic the deepest trenches run alongside the islands of the West Indies. Off Puerto Rico there is a trench some five miles deep.

Most of these immense depressions and folds in the ocean bed have been caused by upheavals that took place millions of years ago. Protected by their layer of water, the mountains and valleys have remained unspoiled by the erosion that is for ever gnawing at the land surface of the earth. Volcanic mountains in the Pacific are often almost perfect cones retaining the shape they built when the lava solidified.

Such erosion as does take place beneath the sea appears to be concentrated on the escarpments forming the edge of the continental shelf. These huge cliffs are scarred by valleys and canyons that reach a tremendous size. Often these submarine canyons are hundreds of miles long and as much as ten miles wide; they cut through the edge of the continental shelf in gashes a mile in depth, as though formed by fast-moving rivers cutting their way to the ocean depths below.

One of the best known of these submerged canyons lies off the mouth of the Hudson River near New York. At least 150 miles in length, this canyon appears to be a continuation of the valley of the Hudson River itself. Many of the biggest canyons lie in this way at the mouths of great rivers, suggesting that they have been cut from the continental shelf when it was above sea-level. Yet many of these canyons are known to be three miles or more below the present surface of the sea. There is no way of explaining how the level of ocean water could have fallen to this extent.

Many suggestions have been made to account for the erosion of these canyons in the submerged walls of the continents. One of the most plausible is that a submarine earthquake may cause a breakaway of some portion of the earth forming the top of the escarpment. Mixing with the water, the earth would create a moving river of mud that gathered speed as its increased density carried it down into the ocean depths. Self-accelerating underwater rivers of this sort are known to occur in lakes, and there would seem to be no reason why they should not happen at sea. As they pour over the submerged cliff-walls, mud-rivers could carve away their canyons just as rivers do.

Support for this theory has come from a study of the underwater earthquake that cut the Atlantic cables off Nova Scotia in 1929. Research has shown that a river of mud was created near the epicentre of the earthquake, about 450 miles from shore. Rushing down towards the ocean floor, this 100-mile-wide, underwater stream cut the cables one after another. By comparing the times and places where the cables failed scientists found that the river was flowing at a speed of 60 m.p.h. when it reached the bottom of the slope from the continental shelf. Thirteen hours later it was still flowing, at 14 m.p.h., some 300 miles out to sea.

Throughout the ages mud has been washed into the ocean in this way from the edge of the land. The great river systems have been eating away at the surface of the earth, carrying suspended particles of solid matter into the sea.

From the air above the ocean dust and germs, pollen and volcanic ash have fallen continually into the sea, settling ultimately on to the ocean floor below. As the living things of the sea itself have died their remains have floated down with infinite slowness, adding to the sediment that carpets the bare basalt rock.

The thickness of the layer of sediment lying on the ocean floor varies greatly from place to place. In some areas there is no sediment at all; in the Pacific and Indian Oceans lava has seeped out and buried the accumulated sediment in a hard, impenetrable crust. Only a thin veneer has been able to collect on the new, volcanic rock floor. During the voyage of the *Albatross* depth-charge soundings showed the thickness of the sediment to be, in general, greatest in the Atlantic, the Caribbean, and the Mediterranean Oceans. Between Madeira and the Mid-Atlantic Ridge the Atlantic floor is carpeted by a layer of red clay 2½ miles thick; in other parts of the ocean sediment is believed to form a layer as much as ten miles thick.

In the Pacific and Indian Oceans sediments deeper than 1000 feet are seldom found. The rate of settling in these oceans is so much slower, and layers laid down in prehistoric times are now buried beneath the lava from submarine volcanic action.

Cores taken by the *Albatross* expedition from the ocean bed have provided a record of changes in the ocean sediment to depths of about 60 feet. Estimates of the rate of settlement are at best a rough approximation, and the rate would inevitably change from time to time. But, assuming that the red Atlantic clay was built up at the rate of about an inch in 3000 years, a 60-feet core taken from the Atlantic will represent a sample of the sea-bed that has settled out during about two million years.

Examination of the stratified layers of sediment in these cores tells scientists something of the changes that the earth has been going through. Periods of climatic warmth are shown by shells from tiny creatures that flourish in tropical seas; Ice Ages are marked by changes in the number and nature of the residues from living things; periods of volcanic upheaval are shown by layers of dust and ash; meteor bombardments leave a concentration of nickel dust in the sediment.

By estimating the proportion of radio-active elements in the sediment at different depths the age of the deposits can be checked. Uranium in seawater is decaying steadily into ionium which settles to the bottom as it is formed. As it takes its place in the sediment the ionium continues to decay into radium, and by estimating the proportions of the radio-active elements it is possible to estimate the time since they settled into the ooze. Some sediments from the Central Pacific are settling at the rate of an inch in 20,000 years. A 50-foot core from these regions is a chronicle of ocean life that goes back more than twelve million years.

The characteristics of the top layers of the ocean ooze vary greatly in different regions of the earth. The red- and chocolate-coloured clays of the Atlantic are largely organic in origin; on the flat tops of the Pacific guyots there is often an almost white calcareous slime that caps the sunken mountains with a snow-like plume; in the deeper layers the dull grey mud is a graveyard of the siliceous skeletons from countless billions of microscopic diatoms that live and die in the plankton of the surface waters. In the deep, dark trenches off the continental coasts sediment drifts down and carries with it the decomposing remnants of living things. Crushed by the burden of accumulating sediments in ages to come, these organic remains may be transformed into oil.

Scattered about on the top of the ocean's sedimentary floor are boulders of continental granite and mysterious patches of sand. Some have been ferried from distant shores by ice-bergs, to be dropped on the sea-bed as the ice-bergs melt. In places, phosphate from the skeletons of marine animals has formed accretions of phosphorus-rich rock. Inside many of these nodules are fossils fifteen million years old. In years to come these deposits could well be a source of phosphorus for the land.

Among the curious objects found on the ocean bed are the 'brownstone' pebbles and rocks that have grown by deposition of manganese minerals from the seawater. These potato-like objects are found where rates of sedimentation are low; inside them a shark's tooth or the earbone of a whale will often be found as the nucleus around which the manganese has been deposited. Radio-activity estimation of different layers inside the brownstone nodules has shown that they grow at the rate of an inch in diameter in about 25,000 years.

2

Water on the Move

THE sea is never still. Even on the calmest summer day ripples will pattern its surface and a rhythmic swell will roll its stately procession of undulations from the horizon to the shore.

These ripples and waves so characteristic of the sea are caused by disturbances on the surface or in the depths below. The wind is the source of most of them. A gentle breeze that merely touches the surface will raise a rash of ripples as it flits across the sea; a lusty gale blowing at 100 miles an hour or more can whip the surface into a storm that raises waves higher than a house.

On the open sea waves travel across the surface as though the water inside them was moving forward. But, in fact, it is only the undulation which progresses; the particles of water in the wave are lifted up and down, following a circular path that leaves them almost where they started from. The movement is passed on from one water particle to the next, so that the undulation of the wave moves across the surface of the sea.

Although the surface water alone experiences the full movement of the wave, the effects are also felt in the water below. The particles of water beneath the wave tend to move in sympathy with their neighbours on the surface, but the oscillation diminishes with increasing depth. At about 600 feet below the surface wave-movement is almost gone.

A wind blowing over the sea can cause all manner of different waves and ripples. Some may be of such short wave-length that only a few inches separate the crests; others may be waves so long that the crests are separated by several miles. Once they have been created these waves will set off in the direction established by the wind; as they travel the wind invigorates them by blowing on the rear of the wave and creating eddies in the air ahead of the wave so that they are sucked along.

Unlike sound and radio waves, sea-waves travel at all sorts of speeds depending on their wave-length—the distance from one crest to the next. As the wind continues to scourge them they grow higher and higher and move ever faster until they break on some far-distant shore.

As the waves are carried along under the influence of the wind their speed across the surface is increased until they are travelling almost as fast as the wind itself. Under these conditions the ponderous swell is given preference by the wind; energy is poured into the waves, enabling them to travel perhaps from one end of the ocean to the other. The smaller waves, unable to charge themselves so effectively from the wind, have relatively little stamina. When the wind has died or the waves have moved away from it the little waves lose themselves in the expanses of the sea. The larger waves, rolling away on a journey of hundreds or even thousands of miles, may gather speed until they are travelling faster than the wind that created them.

In the major oceans of the world the wind can pursue the waves it has raised for immense distances, until they are 30 feet or more in height. But in land-locked seas or gulfs the wind is limited in the distances it can follow the waves, and the heights attainable are limited too. No matter how hard and steadily a wind may blow in the Mediterranean, it will not create waves higher than about 16 feet; the wind cannot follow its waves far enough to increase their size still further.

Blowing over a twelve-mile stretch of water, a 40 m.p.h.

wind can raise waves about 8 feet high; over sixty miles of water the same wind will produce waves 14 feet high; and in the ocean, with a 300 mile uninterrupted chase ahead of it, it will raise waves of 20 feet. A 60 m.p.h. gale blowing over a 1000 mile stretch of open sea can create waves of 40 feet. This is about the maximum height that normal ocean waves attain.

Sometimes waves as much as 100 feet high have been seen in the open sea; the liner Majestic encountered a hurricane in the North Atlantic in 1922, when the waves reached 90 feet in height.

These mammoth waves are generally thrown up by wave-systems clashing in a great explosion of surface water.

When they reach the shore the waves created by a storm at sea are affected by the shallowness of the water over the continental shelf. The orbits of the individual particles of seawater are influenced by the immovable ocean bed; the paths travelled by the water particles become elliptical instead of circular. The water movement is distorted and the undulation crashes as a breaker on the beach.

An ocean swell dissipates enormous amounts of energy as it beats upon the shore. The wind-power stored up in the moving waves can tear great rocks away from the land, grinding them to pebbles and sand. Using these broken rocks as ammunition, the waves can bend the steel girders of a pier and break up concrete sea-walls as though they had been battered by a giant ram.

From time to time a subterranean earthquake causes such disturbance in the sea that immense vibrations radiate in the form of waves. These are the tidal waves, or tsunamis, that often cause tremendous loss of life and property. Earthquakes and volcanic upheavals on the ocean bed do not inevitably cause a tidal wave; usually the waves follow the earthquakes caused by settlement in rocks of the ocean floor. These undersea landslides displace millions of tons of water, and the undulations that follow will travel for thousands of miles before they are absorbed in the normal movements of the sea.

The Lisbon earthquake of November 1, 1755, was followed by a huge wave that sped across the Atlantic; it reached the West Indies as a tidal wave nearly 20 feet high. When the volcano Krakatoa erupted on August 26, 1883, the tidal waves that hit the East Indies Islands were about 100 feet in height. They crossed the Indian and Atlantic oceans, reaching the English Channel as waves an inch or two high; the vibration had travelled half-way round the world in a little more than a day.

Often the undulation of these tsunamis is so slow that they are not felt at sea; a hundred miles may separate the crests of succeeding waves, and an hour or more may pass between the two wave-peaks. But as they approach the coast the waves begin to feel the effect of the ocean floor and build up into walls of water travelling at 300 miles an hour or more.

The first indication of the approach of a tidal wave is often the retreat of the water to an unusually low level on the shore. This is the trough that precedes the wave; it has often attracted people to the shore, only to be caught and drowned by the rushing wave that has followed.

Until comparatively recent times little was known about waves of any sort on the sea. But the scientific study of waves was undertaken during World War II, when information was needed for the planning of the Normandy invasion. Instruments have been developed for measuring wave motion on the sea, and the relation between waves and the winds and storms that create them is better understood.

An instrument is now in use which can measure the pressure of water above it when resting on the sea-bed. By relaying this information regularly to the shore this instrument provides a record of the waves that are passing over-head. An echo-sounder has also been adapted for this purpose; it works the other way round from the ship-borne instrument. Sending out its pulses from the sea-bed, the instrument picks up echoes from the surface; the depth of water above the instrument is a measure of the height of the waves.

The analysis of surface waves in this way has now reached the stage where this information is of meteorological value. Wave patterns are a guide to the wind conditions out at sea, where storms may otherwise blow undetected. With a knowledge of the speed and wave-length of the waves and the times at which they arrive and disappear, the meteorologist can calculate the position of the storm that created them.

As oceanographers have continued with their exploration of conditions in the deeper ocean waters immense undersea waves have been detected which dwarf the grandest of our surface waves. These waves are undulations on the 'surfaces' formed by layers of water of different densities in the ocean depths. Temperature measurements have shown that the surfaces formed by these water layers are moving up and down in waves that reach heights of 300 feet. Their cause remains a mystery.

In every ocean currents are flowing in circulatory movements that have carried the water round and round continuously for thousands of years. These currents are controlled and modified by the varied environments in which the water flows. But in the three great oceans of the world there is a broad pattern of water movement that has been established by the rotation of the earth and the wind systems of the atmosphere.

The Trade Winds, most constant of all the winds on earth, blow towards the equator from the north-east in the Northern Hemisphere and from the south-east in the Southern Hemisphere. These easterly winds create a flow of air above the equator that carries the surface water along in every ocean, moving from east to west. The equatorial currents are the source of most of the water movement that creates the current systems of the seas.

As they flow along the equatorial currents come under the influence of the Earth's rotation. This swings the currents north of the equator in a clockwise direction, and those below the equator in an anti-clockwise direction. So, in all the oceans, huge eddies are created, the water moving round and round, re-entering the equatorial drift each time a circuit has been made.

In the Pacific these current systems rotate in grand fashion on both sides of the equator; in the north Pacific the water of the Japanese current brings warmth to the shores of Alaska and the Canadian coast.

In the Indian Ocean the water circulates steadily south of the equator, but the eddy is complicated and modified by the monsoon winds in the northern ocean.

In the Atlantic the south equatorial current sweeps down the coast of Brazil, then doubles back across the south Atlantic towards Africa and veers north to rejoin the equatorial drift. In the north Atlantic the equatorial current is caught in the convolutions of the Central American coast as it turns northward off the coast of South America. It flows into the Caribbean Sea and up into the Gulf of Mexico. Here it is trapped in the huge loop of land that forms the south coast of the United States; it is denied free access to the North Atlantic by the Florida peninsula and the islands of Cuba and the West Indies. So great is the pressure of water from the equatorial current that the level of water in the Gulf of Mexico is 8 inches higher than it is on the Atlantic coast of Florida. Under this tremendous pressure water is forced into the Atlantic through the ninety-mile gap between Florida and Cuba, forming a warm, fast-flowing river, the Florida Current.

This current carries more than 100,000 million tons of water a minute at a temperature of 80°F. or more. As it flows out into the Atlantic the warm current sweeps along the continental shelf of the North American coast. Off Newfoundland it flows into the open sea, forming the Gulf Stream that carries its warmth on a journey of 5000 miles to the coasts of Europe.

This river of warm blue water in the North Atlantic has been known to sailors for more than 400 years. But the details of its course have remained uncharted; it is difficult to follow the Gulf Stream as it meanders about the ocean, changing its direction and course from day to day.

In 1951 an expedition organized by the United States Navy Hydrographic Office surveyed the course of the Gulf Stream as it flowed between Cape Hatteras and the Grand Banks. Six ships zigzagged, 150 miles apart, in and out of the current. Positions were checked accurately with the help of radar, and the temperature and flow of the water were measured at regular intervals.

It was found that the Gulf Stream flowed in this region at a maximum speed of about 6 m.p.h. The water reached a temperature of 75°F., falling away towards the edges of the current. Off Cape Hatteras the stream was wandering about the sea and moving laterally as much as eleven miles in a day. It was some fifteen miles wide and a mile deep and carried more than 1000 times as much water as the Mississippi.

As it snakes out into the open sea the Gulf Stream splits into at least four separate currents. Eddies are created in the ocean water, often hundreds of miles in diameter; the currents flowing towards Europe and Africa are often separated by water that is moving back towards the American coast.

One arm of the Gulf Stream veers north-east as it crosses the ocean, bathing the shores of Europe with water that carries heat from the tropical sun. This warmth has a major influence on the climate of Western Europe; without it Britain would be ice-bound in the winter, with a climate similar to that of Labrador.

The other arms of the Gulf Stream swing south as they approach the African coast, rejoining the equatorial drift near the Canary Islands. Altogether the current takes about three years to complete its 12,000-mile circuit of this huge whirlpool in the North Atlantic.

In addition to these immense currents circulating on the surface of the seas, there are stealthy movements of water in the ocean depths. When water is cooled or the salts in it become more concentrated its density increases and it sinks below the lighter surface layers. In the Antarctic Ocean water cooled by the ice flows in a steady stream to the ocean floor. Here it creeps slowly towards the equator, taking six years on the journey. North of the equator it spreads out over the ocean floor to lie as the lowest layer of water in the sea.

In equatorial regions of the ocean water wells up from below to make room for the inflow of cold water from the poles; the equatorial drifts are reinforced by these vertical currents that bring supplies of cold water from the depths below.

In land-locked seas like the Mediterranean evaporation of water is constantly increasing the salinity of the water. As its density increases Mediterranean water flows through the Straits of Gibraltar and sinks half a mile or more into the Atlantic. On the surface of the Straits a current of lighter Atlantic water flows in to take its place. These opposing currents at different levels carried U-boats into and out from the Mediterranean during World War II.

These waves and currents that cause continual movement in the waters of the sea are created by the wind and weather and by the rotation of the earth. But there are other powerful forces playing upon the waters; these are the forces that produce the rhythmic movements of the tides.

For as long as man has sailed upon the sea he has been wondering about the tides. The Ancient Greeks could find no reasonable explanation of the rise and fall of water-level from day to day. For more than 2000 years the tides remained a mystery that was solved eventually, in 1687, when Sir Isaac Newton included tidal movements in his theory of gravitation.

Newton explained that every material thing in the universe attracts everything else. The greater the masses of material involved, and the nearer they are together, the more powerful is the force of attraction between them. The Earth, for example, is attracted by the sun and the moon, and vice versa. Under the effects of these forces the liquid portion of the earth is able to move towards the sun and moon that are attracting it. A 'bulge' is formed in the layer of water covering the earth, the position of the bulge at any time being controlled by the relative positions of the Earth, the sun, and the moon. It is the rise and fall of water level caused by the bulge that we call the tides.

The moon, though tiny by comparison with the sun, is only 250,000 miles away from the Earth; it exerts more than twice the force of the sun, which is 93 million miles away. When the sun and moon and Earth are in line the forces acting on the water are reinforcing one another; the sea is dragged to its highest levels in the spring-tides, when the moon is full or new. But when the moon is at right angles to the sun and Earth the water is being attracted by opposing forces and the tides are at their lowest level—the neaps.

If the Earth was a perfect sphere, and water covered it in a layer of uniform depth, it would be possible to predict the position and height of the tidal bulge at any time. But the strange shapes of the oceans and land-locked seas, and the infinite variation in the configuration of the ocean-floor are complications that affect tidal levels differently in every part of the Earth's surface.

In the great oceans of the world water oscillates to and fro in the huge basins bounded by the land and by underwater mountain ridges. In each basin the water is influenced by the peculiarities of its environment as it moves to and fro; complex, rhythmic movements are set up, which establish the tidal pattern of every place along the shore.

The height and frequency of the tides are therefore widely different from place to place. At the ends of an ocean basin the oscillating water rises higher than in the middle, just as water does when sloshing to and fro in a bath-tub. Some places in the Atlantic have two high-tides in a day; others in the Pacific and Indian Oceans have only one.

The Bay of Fundy, Nova Scotia, lies at the end of a huge ocean basin, and the tidal movement is greater than anywhere else on earth. The water rises and falls through 50 feet or more. In Hawaii, on the other hand, the tides rise less than a foot. These Hawaiian tides are controlled almost entirely by the sun. High tide comes at noon and midnight every day, and low tide at 6 o'clock morning and evening, regardless of the moon's position relative to the Earth. There is a similar sun-controlled tide at Thursday Island off the North Australian coast, where the tidal rise of three feet takes place regularly at noon and midnight every day.

The many influences that control the movement of tidal waters have made theoretical prediction an almost impossible mathematical feat. But oceanographers at the Liverpool Observatory and Tidal Institute, Birkenhead, have superimposed their calculations upon tidal information collected over many years; with this past experience to help them they can predict with accuracy how tides will run in different parts of the world for years ahead.

As ships grow larger and faster knowledge of the tides becomes more and more important. Most of the world's major ports are in tidal waters, and a ship that has to await the tide before entering or leaving port is wasting money at an alarming rate. Timetables are therefore laid down ahead in such a way as to make the most of tidal conditions.

In many parts of the world the movement of tidal water is boosted by the shape of the land past which it flows. Water moving up a funnel-shaped estuary will gather momentum until it rushes into the narrowing inlet at increasing speed. Often a wall of tidal water will be forced into a river, forming the 'bore' that is a familiar sight, for example, on the Severn. In the Amazon a tidal wave ten feet high races up the river.

These local peculiarities of tidal movement are usually so familiar and frequent that they are anticipated by the people of the district. They do not cause great damage. But there are other idiosyncrasies of tidal movement that can cause disastrous and unexpected changes in the water-level. These surges of water are a result of combined meteorological and tidal forces which move millions of tons of water from one place to another in the sea.

The air that presses on the surface of the sea helps to control the level at any place. If the pressure is high the water-level is forced down and water flows away to a place where the air above is at a lower pressure. The seawater acts in this way like a massive barometer, the level of the water varying with the pressure of the atmosphere. A fall of an inch in the barometric pressure is equivalent to a rise of about a foot in water-level.

In predicting the tidal level at any time the oceanographer must know something of the pressure conditions over the sea. This information is now available in many parts of the world, and atmospheric pressure can be taken into account in predicting variations from the expected levels in the tide.

But pressure changes alone cannot account for some of the powerful surges that take place from time to time, when the water may rise ten feet above its anticipated level. These are usually caused, in addition, by winds blowing strongly over the sea; they are the storm surges that are comparatively frequent for example in the North Sea.

When wind blows over the sea it drags the water along by friction with the surface. When the winds blow strongly and for a long enough time they can force a huge volume of water from one place to another, lifting the level of the sea as it presses against the shore. If the water is forced in this way into a funnel-shaped region the effect is all the more intense and the level may rise several feet.

Storm surges of this sort take place from time to time in the North Sea. A northerly wind blowing over the sea will force water south, building up the sea-level as the water flows into the ever-narrowing channel that culminates in the Strait of Dover. If this surge of water is abetted by the flow of the tide the levels may rise high enough to cause disastrous floods. This is what happened when the sea inundated areas of eastern Britain and the Low Countries in January and February 1953.

The practical effects of these storm surges are controlled by the tidal level at the time they occur. If the tide is low a surge that could be dangerous twelve hours later may pass unnoticed.

Research carried out by the Tidal Institute has shown that of every hundred high-water levels in the Thames estuary, two are at least two feet different from the predicted level. On December 31, 1921, the water at Southend rose eleven feet higher than its predicted level. This is the most powerful North Sea surge in living memory; it took place, fortunately, two hours after low water and little harm was done.

In January 1928 a storm surge raised the water level at a more critical point in the tidal rhythm; the Thames overflowed the Embankment, drowning many people in flooded cellars and basements.

On the night of January 31, 1953, Britain and the Low Countries experienced the most damaging storm-surge ever known. A depression crossed from Scotland to Denmark, bringing violent winds blowing from the north. Fifteen billion cubic feet of water was forced into the North Sea from the Atlantic, raising the general level of the North Sea by two feet. As the winds continued to blow they pushed this extra water southward towards the Strait of Dover, the level rising as the channel narrowed. If the surge had taken place when the tide was low all would have been well. But the effects were prolonged and the surge-water remained through the period of high-tide. During the night of January 31 the water was pressed up against the English coast by the rotation of the Earth and poured over the sea-walls to flood the low-lying areas of south-east Britain. By midnight the peak had been reached in the estuaries of the Thames and Scheldt, with the water eight feet above its proper level. The North Sea swept into the Low Countries, causing floods worse than anything experienced since the Middle Ages.

Much of the damage caused by these terrible sea-surges could be avoided if people were given warning of their approach. Unfortunately there is no possibility at present of any accurate long-range forecasting of surges. Caused as they are by localized weather conditions, they can be foreseen only by keeping watch on meteorological charts used for normal weather-forecasting. When strong northerly winds are blowing in the North Sea, and the tides are running high, there is a prospect that a sea-surge will raise the water to a dangerous level.

After the sea-surge of January 6, 1928, in the Thames estuary scientists at the Tidal Institute began a study of the sea-surges experienced at Southend. As a result of this work, it is now possible to detect the approach of a North Sea surge in time to give a few hours warning to coastal areas in south-east Britain. Given adequate information of atmospheric pressures over the North Sea, the strength and direction of winds, and the sea-level at Dunbar, meteorologists can predict the approach of a dangerous surge in time to give six hours warning to towns in the Thames estuary.

It is a tragic fact that this surge-predicting system had been perfected in 1948 and could have given enough warning to prevent much of the immense damage done by the surge of January 1953. But dangerous surges had not occurred for generations past, and there was every reason to suppose that they would not occur in the immediate future. The warning system was disregarded.

To-day the lesson has been learned, and a warning system is in operation on the coasts of Britain. It has been estimated that a surge on the 1953 level may occur, on average, once in about 150 years. But that does not mean that it will be a century and a half before the next one comes. It may be next week or next year or in fifty years' time. Even a few hours' warning of its approach will mean hundreds of lives saved and millions of pounds less damage to property.

If the worst should happen a surge could occur in the North Sea which would raise the level of the water higher than that of 1953. The highest surge known at Southend was the 11 foot one that came on December 31, 1921. If a surge of this depth coincided with an 18 foot spring tide the water would be 5 feet higher than it was in 1953.

Luckily it seems that surges prefer times of low water, so that the chances of inundation by a surge of this height are remote.

The North Sea, by its shape and geographical situation, is particularly susceptible to dangerous surges. But there are many other danger areas in Britain and other countries. In 1721 the good ship *Tabitha* sailed into Liverpool from Norway on a surge; it reached the dock by sailing over the pier. During the early part of the eighteenth century, more than a quarter of a million people were drowned by a sea-surge in the Bay of Bengal. And in 1903 a hurricane swept a wall of water into Galveston, Texas, causing floods that did immense damage and cost 6000 lives.

At the present time we are living in a world that appears to be getting warmer. The polar ice is melting and the level of the seas is creeping steadily higher. As this trend continues the danger from surges must increase and man will be forced to give way before the onslaught of the sea.

3

The Power of Water

THE oceans and seas, the lakes and rivers and ponds, contain only part of the water in the world. There is, in addition, an immense store of water as invisible vapour in the air.

From the vast surface of liquid water that lies over the earth vapour is constantly being drawn up into the atmosphere and swept aloft by the winds. This is the source of the water that falls on to the earth as rain, hail, or snow; it is the water that appears as billions of tiny droplets floating as a cloud or in a fog; it is the water that remains as a gas in the air, helping to shield us from the harsh rays of the sun.

When water evaporates from the surface of the sea it absorbs energy in the form of heat provided by the sun. Charged with this extra energy, millions of tons of water vapour are carried daily over the land masses of the earth. When the air is forced to rise, as it crosses mountains, it expands and cools. It can no longer carry so much water vapour as it did, and some of its burden is released as droplets of liquid water which appear as a cloud. These tiny droplets may coalesce and fall to earth as rain.

Day after day this huge distillation system goes on, bringing water from the sea and carrying it in the form of water vapour to be released as liquid water again in the high places of the earth. As the water falls in the hills and mountains it sets off on a journey again towards the sea; it trickles down the mountain slopes, collecting into swift-moving rivulets and streams; the streams join forces and become rivers that flow steadily over the sloping land.

These streams and rivers are a source of power. Water at a high level is charged with energy; it seeks always to flow downhill to lower levels. Water can do work as it discharges its obligations to the force of gravity; and from time immemorial man has made use of moving water as a source of power.

Even in the earliest civilizations the flow of water in a river was put to work. It floated man's boats from one place to another; it thrust against the paddles of primitive water-wheels and helped him to irrigate his fields.

With the invention of the steam engine the era of water power came to an end. Steam gave man power over which he had more control. He was no longer dependent on the flow of water in a river, which varied with the weather; he could build his mills and factories in places of his own choosing, instead of being compelled to place them near fast-moving streams.

During the eighteenth and nineteenth centuries the rivers and streams flowed over the land as they had for thousands of years. But the energy stored in the moving water was wasted. Then, towards the end of the nineteenth century, steam in its turn gave way before the advance of electricity. Electricity enabled man to liberate the power he needed in centralized power stations; the power for a mill or a factory could travel by wire for hundreds of miles if need be. And with electricity water came back into its own. With the help of electricity the energy latent in high-level water could be harnessed in power stations sited, like the old mills, near water supplies. But this time there was no need for the power to be used where it was generated. It could be sent by wire to the industrial centres needing it.

In the water-wheels that had served before the days of steam, the momentum of water flowing downhill was transferred to the paddles on the wheel dipping into the water. Usually a dam was built near the mill, providing a reservoir that helped to control the water-flow. Fluctuations in the flow of the river were absorbed by the bulk of water behind the dam, so that a reasonably steady flow of water could be maintained in the millstream.

In our modern water-power station the principles have remained almost unchanged. As it flows downhill water pushes against the blades of a paddle-wheel, which is driven round. The detailed structure of the wheel has changed, from an open waterwheel to an enclosed turbine; instead of getting about a third of the available energy from the water, as our ancestors did with the old-type paddle wheel, we now extract nine-tenths of the energy with the help of the modern turbine.

Nowadays we build huge concrete dams high in the hills to provide a reservoir from which water can rush downhill to the turbines. Instead of the head of water of a few feet provided by the old mill-pond we have a head of a mile or more. The greater the height that the water falls, the more energy does it pass on to the turbines. As they spin at terrific speed the turbines rotate generators that transform the energy provided by the water into electricity.

Building a modern hydro-electric plant is a major undertaking that may cost millions of pounds. A great deal of preliminary work is needed before construction can begin; rainfall must be assessed, if possible over many years, in the catchment area that is to provide water; the soil and rock structures must be studied by geologists, and the suitability of local water, sand, and other dam-building materials assessed. But once the dam and the power-station have been built the major costs are over. Hydro-electricity needs no costly coal or oil or other fuel in its production. Moreover, the generating plant is simple, and maintenance and depreciation costs are at a minimum. The machinery lasts twice as long as the machinery in a steam-power station.

Hydro-electricity has obvious attractions to countries that are short of supplies of coal or oil, but well-endowed with rain-soaked, mountain districts. Eastern countries, often handicapped by lack of fuel, are turning more and more to hydro-electric plants to help them in their industrial progress. In Thailand, for example, the Chainad dam project is a hydro-electric undertaking that has cost more than twelve million pounds. It will provide much-needed power and at the same time supply irrigation water to the neighbouring districts.

During the last half-century there has been a steady increase in the development of hydro-electric power throughout the world. Between 1920 and 1950 the output of electricity from water-power stations increased fivefold. But we are still using only about one-twentieth of the water-power resources that are available to us.

In North America and in Europe development of water-power has harnessed about one-fifth of the energy available. But in Africa and South America, which together possess more than twice the water-power resources of Europe and North America combined, only about 1/400th of the power is being used.

In addition to the resources of power available to us in the water that has fallen on land there is an immense supply of power latent in the tidal movements in the sea.

So long as the earth and the sun and moon remain, the water of our seas will rise and fall in the rhythmic movements of the tides. Locked away in these flowing waters are unlimited supplies of energy; energy that could provide power for our industrial world.

Nearly a thousand years ago men were trying to harness this tidal power to their simple machines. In the Domesday Book reference is made to a water-powered mill at the entrance to the port of Dover. This was almost certainly a water-wheel moved by the tidal currents. During the twelfth century a tidal water-mill was at work on the Deben Estuary, at Woodbridge in Suffolk. And in the centuries that followed similar mills were built in other parts of Britain, harnessing the flow of tidal water with the help of the water-wheel.

The first supply of pumped water for London was operated by tidal power. A water-wheel fixed to a raft was moored between two of the piers of London Bridge. As the tidal currents raced past the raft they turned the wheel and pumped water into a water-tower. This tidal pumping-station worked until 1824, when a new London Bridge was built.

In 1790 a tidal mill was built on the river Tamar in Devonshire. This mill is still in operation, although the water-wheel has been replaced by turbines.

These early applications of tidal power were little more than the traditional water-wheel, driven by tidal currents rather than a flowing river. They served where power was needed for driving simple machinery, and the operation of the mill could be fitted in with the fluctuations in tidal flow. But mills of this sort are of little use under modern manufacturing conditions, when a source of controlled and continuous power is generally needed.

The trouble with tidal power is that it comes in fits and starts. When the tide is flowing a great mass of water is moving forward over the shore. Then as high tide is reached the flow of water stops. There is a lull until the water starts ebbing, and movement speeds up in the opposite direction until low water is reached. Any method of using the water movement as a direct source of power must inevitably follow this pattern laid down by the tidal rhythm. A water-wheel attached to electric generators, for example, would produce a supply of electricity only when the tides were on the move. Near high and low water there would be long periods when production was at a standstill.

If this was the only difficulty it might be possible to use tidal generators of this sort for producing power which could be used at specified times of the day. Some industries, for example, can plan production so that they draw on the power supplies at certain times. But the tides, as a rule, reach high water at different times every day. Only in one or two places in the world—at Hawaii, for example—does the tide come in at the same time every day. In Britain each tide follows about 12 hours, 25 minutes, after the previous one. There is a daily lag of about 50 minutes in tidal times. Any tidal generator working directly from the tidal flow will therefore produce its power at different times every day. Direct use of this power is almost impossible under such circumstances.

Added to these difficulties, there is the constant variation in the height of the tides. The flow of water is strongest during the high spring tides and at its lowest during the neaps. The power available from the water varies with these changing rhythms in tidal flow.

To minimize the difficulties inherent in tidal power engineers have suggested impounding tidal water in huge reservoirs from which its flow could be controlled. This is the technique which will probably be used in harnessing tides in the future. It is directly analogous to the damming of river waters in reservoirs for hydro-electric schemes.

In its simplest form a tidal reservoir is little more than a huge basin made by damming the entrance to a suitable estuary or bay. As the tide rises water is allowed to flow into the basin through sluice gates. Then, at high tide, the gates are closed, and the trapped water is allowed to flow out past turbines that are coupled to electric generators. By controlling the flow of water in this way a steady output of electricity can be maintained from high water almost to low water.

This simple basin system overcomes some of the variations in the water flow of the tides. But it is still producing power intermittently, with inactive periods when the tide is low and on the flood. Also, it cannot solve the problem of the variations in the heights of the tides caused by the lunar rhythm.

Nevertheless, the simplicity of this type of controlled tidal power system has attracted engineers, and many suggestions have been made for using power produced in this way.

If electricity itself could be stored economically there would be no problem. But the accumulators we use for electricity storage are cumbersome and inefficient; they are suitable for small-scale use but not for electricity storage on a major scale.

In many of the tidal schemes suggested during recent years it has been proposed that some of the electricity generated should be used for pumping water to a storage reservoir at a higher level. Then, when the tidal flow is no longer able to drive the turbo-generators, electricity could be produced from the high-level reservoir in the normal way.

It is possible that in some parts of the world tidal power stations could be established at different points on the coast, so that electricity would be generated at one when the others were idle. In Britain, where steam-power stations feed their electricity into a communal grid, a tidal generator could feed its power into the grid and a steam-power station could be rested for a corresponding time.

Although the intermittent flow of the tides presents so many difficulties in power-generation, the position is by no means hopeless. Many schemes have been worked out, using one or other of these devices for making use of the discontinuous tidal power.

In some parts of the world conditions are particularly suitable for tidal-power projects. The Severn Estuary in Britain, for example, has a tidal rise of more than 40 feet, and the water could be retained by a relatively simple barrage.

A scheme for damming the Severn was put forward as long ago as 1849. In 1918 a detailed plan was submitted to the Water Power Resources Committee for a barrage to be built at Beachley, with a storage reservoir five miles up the river Wye. Two hundred turbines would generate power as the tide ebbed, and part of the power would be used to pump water into the storage reservoir. Then, as the tide came in, this high-level water would generate electricity until the tidal turbines came into operation again.

This scheme was accepted as practicable, and the Committee recommended that it should be investigated further. Detailed surveys were made in the Severn estuary, and the effects of the barrage on the estuary were examined with the help of a tidal model built at Manchester University. It was concluded that the barrage would not cause any harmful effects or hamper navigation of the river.

In 1933 the Brabazon Report confirmed that the Severn barrage scheme was a practical proposition, although many alterations were suggested; the number of turbines, for example, was reduced to 72. The economics of the project were not attractive at that time, and work on it was not begun.

In 1944 the demand for electricity and the shortage of coal brought the Severn scheme to the fore again. The Minister of Fuel and Power asked for a further report by a panel of experts, and as a result a new scheme was proposed. The number of turbines was again reduced, this time to 32, and the storage reservoir was omitted, as the electricity produced could be fed into the grid.

This latest scheme was estimated at the time to cost about £40 million; it would produce 2300 million kilowatt-hours of electricity and save a million tons of coal a year. It was felt by some of the authorities in the Bristol Area, however, that insufficient was known about the effects of the barrage, and the Government agreed that further research should be carried out with the help of a tidal model at the Hydraulics Research Laboratory.

The Bay of Fundy, the huge inlet which separates the Canadian provinces of Nova Scotia and New Brunswick, is another first-rate site for a tidal power station. The tidal range, which varies from 21 feet during the neaps to 52 feet in the spring tides, is the greatest in the world. Twice a day the Atlantic waters rush through the 235-mile-wide mouth of the bay to flood 40,000 acres of shore. And in places the shoreline breaks up into estuaries which could be converted into tidal-power reservoirs.

During the 1930's work began on a tidal project at Passamaquoddy Bay, on the coast of Maine, which was to harness these Bay of Fundy tides at a capital cost of 156 million dollars. The tidal range at this point in the bay is only 26 feet, but the site was particularly suitable as it could provide two separate basins. These were both to be dammed by a five-mile wall, and the water allowed to flow from one basin to the other so that a continuous output could be maintained.

Several variations of this two-basin system for tidal power stations have been devised, with the object of maintaining a head of water which is independent of the tidal flow. In its essentials the system is extremely simple. When the tide is rising one basin only is allowed to fill. And as the tide falls water flows from this full basin into the empty one, driving turbines as it does so. At low tide the water is emptied from the receiving basin and the reservoir basin is allowed to fill again as the tide rises. In this way the turbines operate continuously, so that the worst fault of the tidal power station is overcome.

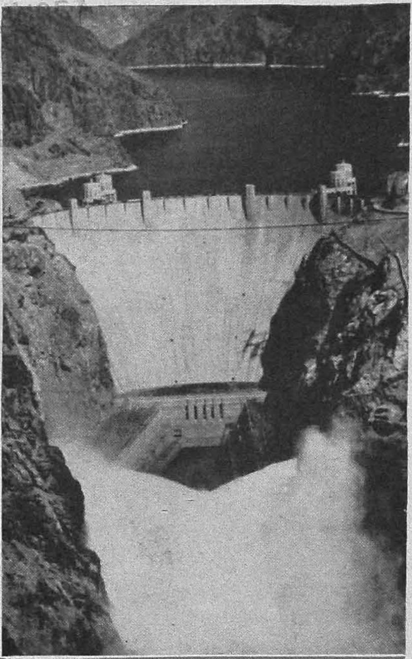
By 1936 the Passamaquoddy scheme had cost some 5½ million dollars, but in that year the United States Congress cut it out of the budget. It was regarded as being more costly than the normal hydro-electric or coal-operated power station.

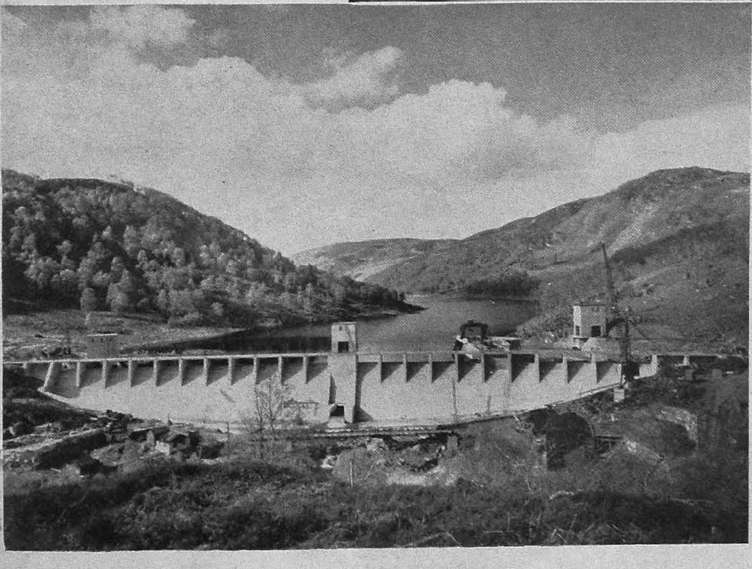
Since World War II the Canadian Government has shown a keen interest in the Bay of Fundy tidal-power project. A scheme proposed by a French-Canadian engineer has been considered, and surveys made. Under this plan a dam would be thrown across the mouths of Shepody Bay and the Cumberland Basin, two inlets that lie side by side forming the top of the Bay of Fundy. These

THE BOULDER DAM

(*Right*) This holds back the waters of the Colorado river, forming the largest artificial lake in the world, 115 miles long. This 727-foot dam checks floods and erosion, supplies irrigation water to hundreds of thousands of acres of farmland, and provides power for Los Angeles and eighteen neighbouring cities.

Photo United States Information Service

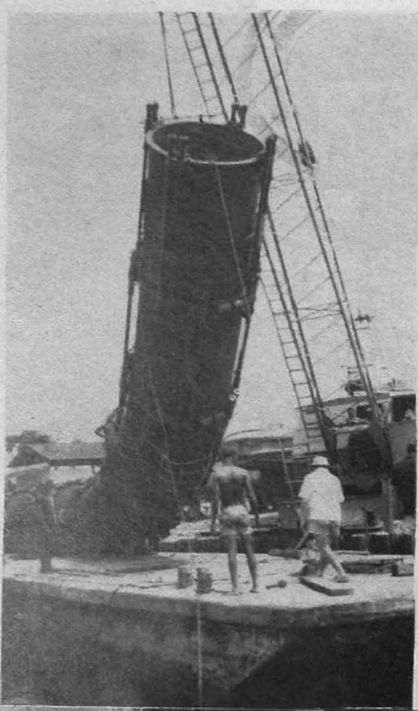




CONON VALLEY SCHEME

This dam, at the outlet of Loch Luichart, Scotland, is 45 feet high and 680 feet long, and has raised the level of the loch by about 40 feet.

North of Scotland Hydro-Electric Board
Photo Whyte's Studio, Inverness



ABIDJAN SEA-WATER-ENERGY STATION

(*Left*) Electricity is generated by making use of the temperature variations of different levels of the sea, cold water being brought from a great depth through this huge water pipe.

Photo Énergie des Mers

THE SEVERN ESTUARY IN MINIATURE

Research is carried out on this model to study the effect of the proposed Tidal Barrage.

Photo Hydraulics Research Station

barriers would enclose about seventy square miles. The rising tide would be allowed to fill the Shepody Basin; the water would then flow via the turbines into the empty Cumberland Basin.

It has been estimated that this scheme, at a cost of £130 million, would provide more than 2¼ million horse-power. It would be the largest hydro-electric plant in the world.

Although these Severn and Bay of Fundy schemes have been under discussion for so long, it looks as though France is to be first in the field with a large-scale tidal power station. In 1954 Electricité de France announced that work was to start in the spring of 1955 on a tidal project in the estuary of the river Rance, near St Malo on the Brittany coast. A concrete dam 625 feet long and 154 feet wide will trap the water of the 27-foot tides that sweep into the estuary. As the basin empties the water will drive 26 turbines and produce 550 million kilowatt-hours of electricity. The scheme is due to be completed by 1960 at a cost of £20 million.

There seems little doubt that this will be but the first of many tidal power stations that will be built in the next decade or two. Once these stations are in operation they can go on generating power without needing any fuel at all. They will be producing electricity that is presented to us by the sun and moon.

In the tides, as in the water that flows over the land, we have a source of energy that comes from the movement of water from one level to another. But there is another source of power wherever water is available at different temperatures. The cold waters of the ocean deeps and the warm waters on the surface are, for example, a potential source of power.

At Abidjan, on the Ivory Coast of Africa, French engineers have built an experimental power station that makes use of the different temperature levels of seawater at varying depths. Warm surface water at 82°F. is used as the source of heat for a steam boiler. A vacuum is created above the boiler water, allowing it to be 'boiled' by the warm seawater. The steam drives a turbine and then passes into a condenser where it is cooled by water at 46°F., brought from a depth of nearly half a mile. As the steam condenses to water it creates a vacuum which 'sucks' more steam through the turbine.

In the experimental plant at Abidjan two generators of 3500 kilowatts capacity have been designed. Water is pumped through 8-foot diameter pipes that are carried out to sea on floats. The 2½-mile-long pipes are rubber-jointed to make them flexible.

The outcome of this first sea-temperature power station will be of interest particularly to tropical countries, where there is a big difference in temperature between the surface and deep water. Stations of this sort could draw their power from the inexhaustible supplies of heat in the sea.

An even stranger source of power from water has been under experiment in Britain. Whenever fresh water mixes with salt water energy is released. The energy provided by a river running into the sea is equivalent to that from a waterfall nearly 700 feet high. If this energy could be harnessed it would provide us with a source of power. Experiments have been carried out with hydro-electric piles built with the help of special plastic membranes. Fresh and salt water flowing through alternate cells, separated from one another by the membranes, generate electricity that can be drawn off from the ends of the pile.

An experimental 3.1-volt pile of this sort has run continuously for three months. It is most effective at high temperatures; like the temperature-difference power project, it is of particular interest to tropical countries.

4

Raw Materials from the Sea

For millions of years rainwater has been falling on the land, trickling through the soil and over rocks into the rivers and down into the sea. Dissolved in the water are minerals that have been etched from the substances of the earth's crust. These minerals are left behind in the sea as the water evaporates once again from its surface and disappears as vapour into the air.

So, through the ages, minerals and salts have been accumulating in the sea, providing mankind with a liquid mine that contains inexhaustible supplies of many of the materials of the Earth's crust.

The concentration of these substances in seawater varies from one part of the world to another. Where rainfall is heavy and evaporation slow, the sea is diluted by fresh water from the skies. In the three main oceans salinity is low near the equator, where rain is so heavy that it overcomes the effect of evaporation. Farther north and south the water becomes saltier as evaporation predominates. And towards the poles the water becomes fresher again. The Baltic Sea, fed by the rains of north-west Europe, is sweeter than the water of the Atlantic Ocean to which it is joined; the Dead Sea, on the other hand, trapped in a hot, parched region of the earth, is so concentrated that the salts are ready to crystallize from the water.

Although the total amount of dissolved material varies from one part of the ocean to another in this way, the proportions of the mineral constituents remain almost constant. Wherever the waters are joined, salts are diffusing to and fro; it is only in isolated waters like the Dead Sea that the constituents of the water differ permanently from those of the ocean as a whole.

Many of the minerals in seawater are in such dilute solution that it is difficult to estimate them accurately. Yet the volume of the oceans is so large that the total quantities of dissolved substances are immense. Every cubic mile of seawater, for example, contains more than 100 million tons of common salt, 6 million tons of magnesia, and 4 million tons of potash. At the other end of the scale there are 7 tons of uranium and 5 grams of radium to the cubic mile. These latter quantities are modest only by comparison with the concentration of commoner minerals. In the 300 million cubic miles of seawater that covers the earth there are at least 2000 million tons of uranium; enough to keep our atomic-energy plants in operation for hundreds of years.

In many parts of the world evaporation of seas in bygone ages has left behind huge beds of salt and other minerals. The salt that lies beneath the fields of Cheshire came from a sea which once covered much of Western Europe. As the water evaporated it left behind the salt which has helped to make Merseyside one of the greatest chemical-manufacturing districts in the world.

At Stassfurt, in Germany, similar beds of salt are layered with strata of magnesium and potassium salts that have brought great wealth to the region.

In countries where these natural deposits of valuable minerals are not to be found people have turned to the sea for supplies of the substances they need. Common salt, for example, is an essential item in human diet and has been used in commerce and industry for hundreds of years. In tropical countries salt is extracted from seawater with the help of the sun; the water is trapped in shallow lagoons on the shore and allowed to evaporate until the solid salt crystallizes.

Salt has been 'mined' in this way from the sea since before the days of recorded history. But it is only during the twentieth century that man has looked to the sea to supply him with other raw materials that he needs. Most of his ores and minerals could be obtained more easily by mining them from the land surfaces of the earth. There was no need to go to the trouble and expense of extracting them from their dilute solutions in the sea. But things are now changing. The rich ores of many of our raw materials are being worked out, and extraction of poorer ores is often difficult and expensive. Meanwhile techniques have improved, and the large-scale extraction of substances from seawater has become economically attractive. Already at least two major industries are using the sea as a source of raw material, and others are preparing to follow.

Since 1924 seawater has been a source of the element bromine. Bromine is a brown corrosive liquid related chemically to the chlorine gas that became so well known during World War I. It is a vital constituent of chemicals needed for dyestuffs and drugs, for the methyl bromide used in aircraft fire-extinguishers, and the silver bromide in photographic films. In the 1920's the demand for bromine soared with the development of 'Ethyl,' anti-knock petrol. Bromine was needed in enormous quantities for making the ethylene dibromide used in the anti-knock fluid.

In 1921 the U.S. production of bromine was 711,953 lb.; by 1942 output had risen to 65 million pounds, most of which was used for making anti-knock fluids. Much of this extra bromine had come from the sea.

The first seawater bromine factory was a floating one, the s.s. *Ethyl.* Cruising off the coast of North Carolina, the vessel extracted bromine from some 5000 gallons of seawater a minute. By keeping on the move the ship could avoid taking in water that it had already stripped of its bromine. This was the main reason for carrying out the extraction at sea. But there were innumerable difficulties, and the floating bromine factory made only one cruise.

In 1931 a site was chosen for a bromine factory on a promontory at Kuré Bay, in North Carolina. Surrounded on three sides by the sea, the site would enable effluent water to be discharged on one side of the promontory and intake water to be brought in from the other. There was therefore no danger of re-treating water that had already been through the factory.

By 1933 this bromine factory was in full scale operation. Sixty million gallons of seawater were eventually pumped through the extraction plant every day, and more than six tons of bromine produced. The output of bromine from this plant was worth four million dollars a year. During World War II a seawater bromine plant was built at Hayle in Cornwall, England. After the war a larger plant was erected at Amlwch in Anglesey.

This bromine project was the first commercially successful attempt to mine the sea for a chemical other than salt. It provided experience of seawater processing which was invaluable in the second modern seawater project—the extraction of the metal magnesium.

In 1939 magnesium was a comparatively expensive metal that was made only in modest amounts. It was the strange, inflammable metal that the photographer burned in his flashbulbs. But magnesium came into its own during the war. It could be made into alloys with strengths comparable with that of steel. Yet magnesium is less than a quarter of the weight of steel.

Magnesium was needed urgently and in large amounts for making incendiary bombs and as a constructional metal for aircraft. Once again chemists used seawater as their raw material; every cubic mile of seawater contains four million tons of magnesium.

With the experience of bromine extraction to help a huge magnesium factory was built on the shore at Freeport in Texas. The first ingot of magnesium from the sea was cast there on January 21, 1941.

Every day 300 million gallons of seawater were pumped through the factory, the magnesium being extracted with the help of lime dredged from oyster-shell deposits in a near-by bay. Like the bromine factory, the magnesium factory was built on a tongue-shaped promontory, so that water could be discharged where it would not again be drawn through the extraction plant.

Soon a second magnesium plant had been built at Vilasco in Texas. In Britain magnesium chemicals were extracted from seawater at Harrington, in Cumberland, and at West Hartlepool, but on a much smaller scale.

During the war seawater magnesium became a constructional metal of first-rate importance. In normal thicknesses it does not burn. It can be machined and fabricated like other metals, and its lightness makes it particularly useful in the air.

Cast into giant landing-gear, magnesium held the weight of our heaviest bombers during the war. By 1945 every aircraft built was carrying an average of half a ton of magnesium in it. Engine parts, crank cases, camshafts, brake shoes, seats, wheels—magnesium is used wherever strength is needed without unnecessary weight.

Since the end of the war magnesium has been carving out a career for itself in transport and in general household and consumer goods. Magnesium wheelbarrows and lawn-mowers have been made, weighing only a few pounds. We have had magnesium bicycles and ladders that a child can carry.

Whatever the demand for magnesium may prove to be in years to come, there can be no shortage of raw material. The sea is a magnesium mine with inexhaustible resources; there is sufficient magnesium in seawater to cover the land surface of the earth with a layer of metal nine feet thick.

In bromine and magnesium extraction we have two major industries now established on the seashore. But they are making use of only two of many potentially valuable substances in seawater. During the war British farmers could not get the potash that they needed as fertilizer for their crops; supplies of potash from the Stassfurt mines were cut off, and importation from other sources overseas was difficult. Yet in the sea that surrounds our islands there are unlimited supplies of potash—four million tons or more in every cubic mile.

In peace-time there is no longer any urgent need to develop our seawater potash resources. We can import potash cheaper from the Dead Sea than we can make it from our own seawater. But in years to come we may be compelled to develop the resources available to us in the sea.

Meanwhile we are steadily leaching phosphorus, another essential fertilizer, from our soil into the sea. The phosphates that we use as fertilizer come from rock that is mined in North Africa and elsewhere. As water percolates through the soil it carries away phosphate which is discharged ultimately into the sea. Even more of the phosphorus of our soil reaches the sea in the form of sewage, which contains phosphorus that has come to us in our food. In Great Britain alone we lose the equivalent of 150,000 tons of rock phosphate to the sea in this way every year. The United States loses sixty million tons of phosphate annually in the form of river-borne salts and sewage. Yet the world consumption of phosphate rock for fertilizer is only eighteen million tons a year.

This loss of phosphorus is a steady drain on the resources of the land. Deposits of phosphate rock are ample for our present needs, and we can return supplies of phosphorus to the soil. But this will not always be the case, and we may have to recover some of our lost phosphorus from the sea.

After iron, copper is one of the most useful metals in the world. But the supplies of rich copper ores are showing signs of running low. Already we are using low-grade copper ores that would have been disregarded a generation ago. Yet there is plenty of copper in the sea.

Copper is used by shellfish as a constituent of their respiratory pigment, hæmocyanin; this corresponds to the iron-containing hæmoglobin in human blood. An oyster can extract the copper from a barrel of seawater in a day, using some of it to provide the green colour of its shell. It has been estimated that the oysters of Long Island Sound extract more than seven tons of copper from seawater in a season.

With the help of modern chemical techniques we can do what the oyster does. Copper can be extracted from seawater by a process similar to that used in a water-softener. This could become a commercially useful process in years to come.

Of all the substances available to us in the sea there is none so fascinating as gold. Many estimates have been made of the gold that seawater contains, but the amounts appear to vary widely. It is safe to say that there is at least £10 million worth of gold in every cubic mile of seawater. There is a fortune awaiting the chemist who can devise an economic process for extracting it.

The famous German scientist Fritz Haber tried to extract seawater gold after the first World War. He hoped that it might help to pay off his country's war debts. Haber's ship, the *Meteor*, was fitted out as a floating laboratory and cruised about in the Atlantic searching for the highest concentration of gold that could be found.

Haber discovered that the gold was not dissolved in seawater. It floated about as fine particles which were absorbed by micro-organisms and carried to the bottom. The sludge on the ocean floor is comparatively rich in gold.

Near the coast of Newfoundland seawater contains an unusually large amount of gold. But even here the concentration was not high enough to justify commercial extraction by the methods then known. Haber abandoned his seawater gold mine.

During the 1920's a real effort was made to extract gold from seawater off the Australian coast. A £10,000 factory was built near the shore, and fifty tons of water a day were processed. Several ounces of gold a week were extracted, but the factory did not pay for its keep.

Gold was also stripped from the water passing through one of the United States bromine factories. But after a month the project was abandoned, as the cost of operation was greater than the value of the gold obtained.

Many of these salts dissolved in seawater are used by living things as food. They take part in the chemical interchanges that make up the living processes of the plants and animals of the sea. In these living things minerals from the sea are much more concentrated than they are in the water itself. The oyster, as it digests its barrel of water a day, is able to concentrate the copper from the water into the small space of its body and shell. And by making use of the chemical skill of marine plants and animals we can sometimes save ourselves the trouble of having to concentrate great volumes of seawater.

Seaweeds, in particular, are able to gather all manner of mineral substances into their tissues. As the immense fronds of the seaweeds wave about in the water, they extract and concentrate the minerals into the liquids of their cells. Some seaweeds can collect the traces of uranium from seawater in this way and could become a source of uranium in years to come. Other seaweeds scour the seas for potash salts or soda or iodine.

When industry was in its very early stages these seaweed salts were used as a source of chemical raw materials. Until a century ago seaweed was collected in huge quantities round the rocky coasts of Britain and burned to provide the ash which is known as kelp. In this kelp were mineral salts that the seaweed had concentrated from the sea. The living, organic substances of the plant had been destroyed by burning, disappearing into the air as carbon dioxide and water and other gases.

During the eighteenth century kelp was a source of alkali salts used for making soap and glass. Scottish kelpmakers could not supply enough to meet the huge demand. The price of kelp soared to £20 a ton, and the value of the salts sent from the Hebrides reached almost half a million pounds a year. Kelp-burning became an important activity on the coasts of Scotland, Ireland, and Wales.

But the early nineteenth century saw the collapse of the seaweed soda industry. A synthetic process for making soda was developed in Britain, and by 1840 the demand for soda from kelp had almost died away.

Meanwhile the kelp-burners had found a new market for their wares; they began to supply the world with iodine, which was discovered in seaweed by a French chemist in 1811. During the Napoleonic wars the British fleet cut off supplies of saltpetre from the French. To make their gunpowder French manufacturers used a synthetic process for which alkali salts were needed. Bernard Courtois, a saltpetre merchant, began to use the alkali salts in kelp as raw material. When he cleaned his chemical plant with sulphuric acid he found that a purple vapour condensed to beautiful metallic crystals on the cool parts of his vessels. This was iodine, which had come from the seaweed kelp used as a source of alkali.

By the middle of the nineteenth century iodine manufacture was flourishing; there were twenty iodine factories in Glasgow alone. Kelp-burning had been given a new lease of life; but again it was only a temporary respite. During the 1880's iodine was extracted as a by-product from Chile saltpetre; soon it was ousting seaweed iodine from many of the most important markets. Gradually the seaweed iodine industry has declined, and kelp-burning remains alive in only a few regions of the world to-day. Iodine is still extracted from kelp in France and in Eire and Japan.

Seaweed as a source of mineral salts is now of only minor importance. But seaweed is once again becoming a raw material of great value; this time it is the organic matter of the plant that is providing us with substances we need.

The body-materials of seaweed are, like those of other living things, built up from the element carbon. Carbon atoms in association with hydrogen, oxygen, nitrogen, and other atoms join together in all manner of complex structures and designs to form the carbohydrates, fats, proteins, and other substances that create the living body of the plant. In seaweeds, as in other plants, carbon dioxide gas supplies the carbon needed for making these organic substances. Land plants absorb their carbon dioxide from the air that permeates their leaves; seaweeds take their carbon dioxide from the seawater in which the gas is dissolved. Inside the cells of the seaweed carbon from this carbon dioxide is built up into the complex living substances of the plant, with the help of water and mineral elements that are taken from the sea as well.

When seaweed is burned the organic matter is destroyed. The carbon unites with oxygen of the air, disappearing once again to serve as raw material for another generation of living things. The mineral elements remain behind in the ash.

For a century or more we have been building up our understanding of organic chemistry, the chemistry of carbon. We have put our knowledge to practical use by drawing on the supplies of organic substances found in the plants that grow on land. These substances have become the raw materials of huge industries. Cellulose, the carbohydrate which serves as structural material throughout the plant world, provides us with explosives and paints, synthetic cream and rayon. Plant proteins are being turned into synthetic fibres, and fats and oils are giving us industrial waxes, varnishes, and paints.

Inevitably the attention of our organic chemists has turned towards the seaweeds. Millions of tons of seaweed flourish on the shores of every country that has a coastline. The living cells of these seaweeds are for ever building up carbon dioxide and water into a wonderful array of complex substances, with a chemical skill that we cannot match in our laboratories. In these days of scientific ingenuity it should be possible to use these substances as a source of some of the innumerable consumer goods that are part of modern life.

During the 1930's a seaweed industry was beginning to develop around some of these organic substances in the weeds. In particular a constituent of the brown seaweeds, called alginic acid, had become a raw material of some importance and was being used in many ways. Like cellulose, alginic acid acts as a strength-provider in the plant. It is a carbohydrate built from a complex carbon-atom structure; but it differs from cellulose in the details of its design.

Alginic acid was discovered in seaweed in 1883 by a British pioneer of the seaweed industry, E. C. Stanford. Stanford was an enthusiast who insisted that something must be done about all this vegetable matter that was allowed to go to waste year after year. And he made a wholehearted attempt to establish an industry based on the substances of seaweed.

Stanford built his factories in the Scottish Highlands, near the coast that is supplied so lavishly with the weed. At first he was concerned only with the established seaweed processes; he tried to improve the extraction of iodine and invented better ways of burning seaweed. But Stanford realized that the real future of seaweed lay in the organic material that was burned during kelp-making. He began a systematic study of the chemistry of seaweed and in 1883 discovered alginic acid in the brown weeds that grow so freely on the Scottish coast.

Stanford extracted alginic acid by boiling seaweed with alkali; this changed the alginic acid, which is insoluble in water, into a soluble derivative called algin. The residues of the weed were filtered, and the solution of algin changed back to alginic acid by chemical treatment.

The alginic acid which Stanford made in this way was a slimy mass; it is alginic acid that comes away as slime from a piece of wet seaweed picked up on the beach. Algin, the soluble derivative made by treating alginic acid with alkali, was an extraordinary substance. It behaved like a powerful gelatine; its solutions in water were 14 times as thick and viscous as those of starch and 37 times those of gum arabic. A 2 per cent. solution of algin would only just pour from a bottle; and on drying the liquid a jelly-like substance was left which was entirely odourless, colourless, and tasteless.

Stanford tried to find markets for these new seaweed substances. Algin made its way into the food industry, substituting for gelatine and acting as a thickener for soups, custards, and blancmanges.

But Stanford's seaweed venture failed. The difficulties of collecting the weed, carrying it to the factories and drying it down, and the distance of the factories from the markets were all against it. The seaweed when harvested was 90 per cent. water, and it had to be dried on the spot; otherwise nine tons of water had to be carried to the factory with every ton of useful material.

So Stanford's dream of a thriving seaweed industry did not materialize. He had made a courageous attempt, but economics were against him, and the seaweed factories were abandoned. Stanford had shown that there were new and useful materials in the weed, and his efforts encouraged others to find out more about them. The work he began has continued, and scientific information about the organic constituents of seaweed has accumulated. During the 1930's interest in these seaweed substances revived and a new industry has been making steady growth.

In America, where brown seaweeds grow in profusion off the Pacific coast, a large algin industry is now established. Harvesting is carried out scientifically by boats fitted with underwater cutters that can collect hundreds of tons of weed a day. A time-table is followed which gives the weed a chance to grow again after harvesting, and it has been found that beds can be 'cropped' three or four times a year. By 1941 algin products worth 1½ million dollars were being marketed, and the industry has been growing ever since. In Britain there are now four firms producing alginate products; between them they are making more than a quarter of the world output.

Since algin appeared on the market new uses for it have been discovered. It can be vulcanized to a rubbery material which has been used in typewriter rollers; a cheap, non-inflammable wrapping film can be made from it, similar to cellophane. Innumerable uses have developed from algin's emulsifying and thickening properties. All sorts of foods, medicines, and cosmetics have been compounded with the help of algin; a small quantity added to milk or cocoa before drying makes the powder mix more easily with water. Algin has been used for water-proofing concrete, for fire-proofing wood, and for preventing scale formation in ships' boilers. It has an amazing power of binding powders which do not easily stick together; for example, three parts of algin mixed with ninety-seven parts of soot will form a cement that sets to a hard mass with excellent heat-resistance. It has been used for boiler insulation.

At a seaweed conference held in 1953 scientists from all over the world described many novel uses for algin and other materials. Seaweed is providing us with plastics and with slimming agents. Algin is used for preventing bleeding during operations and for making special surgical gauzes that can be left inside the body to be absorbed after they have done their work. Seaweed products are making machine-belts and sausage-skins, tooth-brushes and dusting-powders.

Like its chemical relative cellulose, the alginic acid of seaweed can be made into artificial fibres. The molecules of alginic acid are long and thread-like and are able to align themselves together like the molecules of cellulose in filaments of rayon.

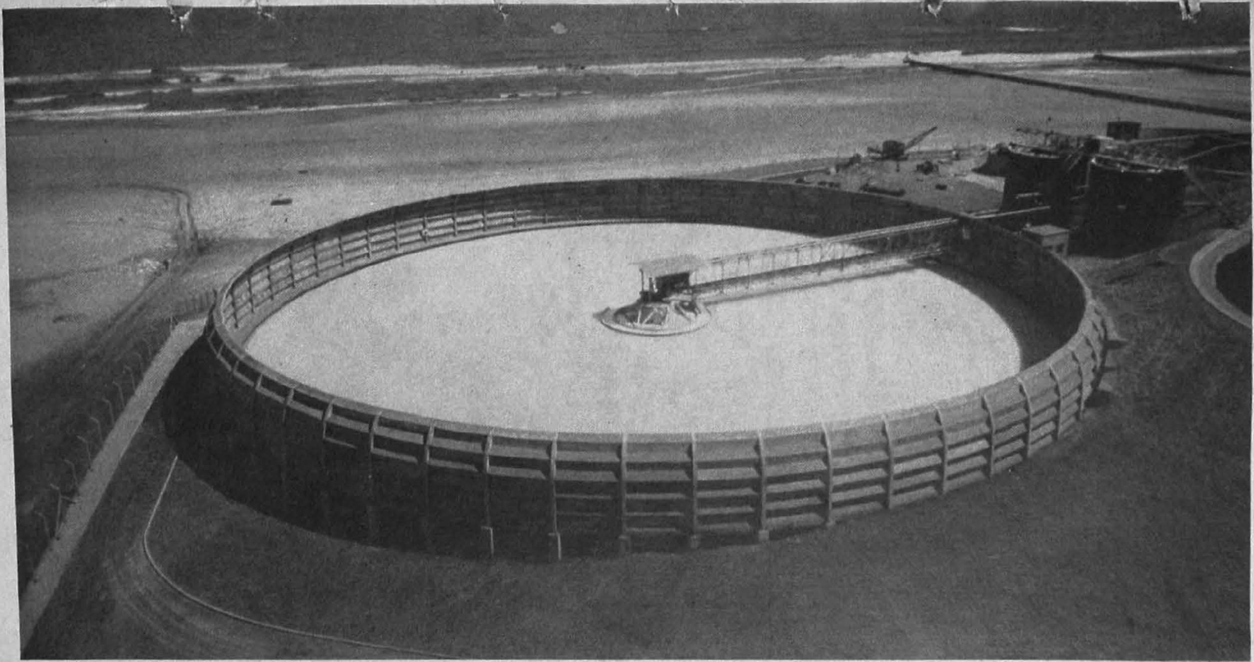
To make 'alginate' fibres solutions of algin are squirted through tiny holes into a bath of acid. As the liquid filaments of algin emerge they are changed into insoluble alginic acid and can be stretched and wound up as solid filaments with a strength comparable with that of viscose rayon.

These alginic acid fibres are, in this form, of little use for normal textiles. Soapy water is sufficiently alkaline to change the alginic acid back to algin, and a fabric made from alginic-acid fibres will dissolve in the wash-tub.

This disconcerting property of alginate fibres has been put to good use in the textile trade. By spinning and weaving yarns or fabrics from these fibres mixed with other fibres all sorts of unusual effects can be obtained when the alginate fibre is washed out. Wool can be made up from yarns in which alginate fibres provide the strength that is needed for processing. When the fabric has been made the seaweed fibre is washed out, leaving a light and fluffy material in which the yarn would have been too weak to withstand processing on its own.

Although these special effects have created a market for soluble alginate fibres, there is some prospect that seaweed rayon may find a major outlet as a general textile fibre. Methods have been discovered for making the fibres insoluble after they are spun; fibres of this sort are made into fireproof curtains for public buildings. They were used in camouflage netting during the war.

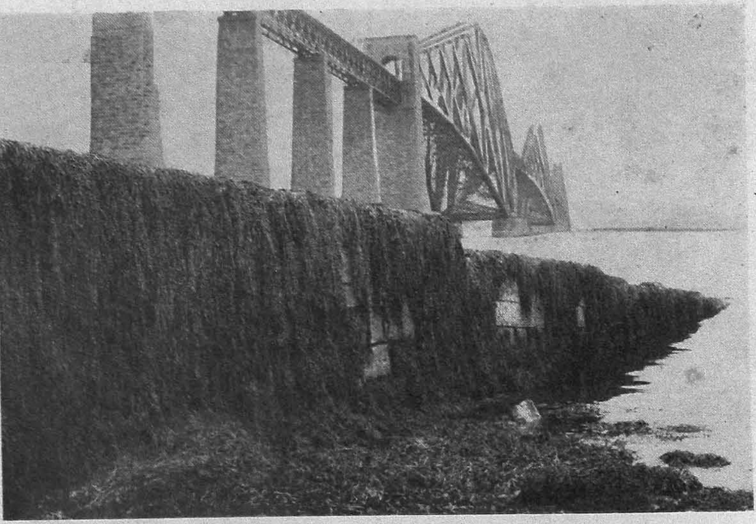
Much of the modern research on seaweed has been concerned with the alginic acid that is extracted from the brown seaweeds. But there are many varieties of seaweed growing in different parts of the world, and they can provide us with other useful products. In the Orient a jelly-like material called agar-agar has been extracted from seaweed and used as a food for hundreds of years. It has become the standard substance for growing cultures of bacteria and is in use in laboratories all over the world. This clear agar jelly comes from a red seaweed that grows in temperate and sub-tropical waters, and before the war

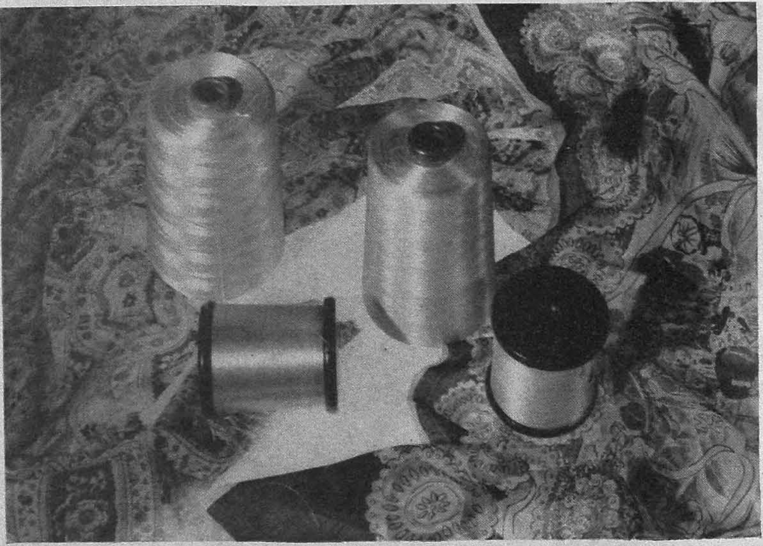


MAGNESIA EXTRACTION FROM SEA-WATER

A factory on the seashore—a huge tank, 240 feet in diameter, in which magnesium hydroxide is settling from chemically treated sea-water.

Photo Steetley Magnesite Co., Ltd





SEAWEED

(*Above*) Millions of tons of seaweed grow every year on the rocky coasts of the continents. Most of it, like this crop in the Firth of Forth, is left to rot.

Photo Institute of Seaweed Research

(*Below*) Spools of seaweed yarn. These alginate fibres, which will dissolve in water, are used for making ultra-light worsteds such as those shown.

Photo Alginate Industries Ltd

Japan supplied 90 per cent. of the demand. When supplies were cut off during the war Australia, New Zealand, Canada, and the United States began extracting agar from the seaweeds round their shores. A close relative of agar is now being made in Britain from a seaweed called Irish Moss. It is widely used like algin, in the food industry, substituting for pectin in jams and for gelatine in meat pies.

Although there are millions of tons of weed washed up annually on the coasts of Western Europe, there are many practical difficulties in making use of seaweed on a major scale. As the demand for seaweed increases the old technique of gathering cast-up weed from the beaches is becoming inadequate. Seaweed in the future will be treated as a crop that must be harvested efficiently and with proper attention to its continued growth.

In Britain the scientific activities connected with seaweed growth and harvesting are co-ordinated by the Scottish Seaweed Research Association. Research is being carried out to provide a background of scientific information on which a seaweed industry can be based.

In common with other raw materials of the sea, seaweed is available to us in almost unlimited quantities if we learn to look after it properly. It could become a crop as valuable to us as any that we now grow on land.

5

Plants in a World of Plenty

ON land, plants and animals live in an atmosphere of gas that is constantly on the move. Winds blow over the surface of the earth, bringing air that is cold one day and hot the next; rain and snow fall on to us from the skies in winter, and in summer the sun dries up the earth. For millions of years life on the land has been learning to adapt itself to an ever-changing environment.

But in the sea, life goes on in surroundings that are calm and serene. Over huge areas of the sea the temperature alters by only a fraction of a degree throughout the year. The concentration of salts changes little in the sea as a whole; and the movements of the water are gentle and regular by comparison with the tantrums of the air above.

Life began in the sea and has developed along simple and straightforward lines. Living things did not need to adapt themselves to a variety of conditions and environments as they were compelled to do on land. Progress has been ordered and calm in the sea, and the living things of the sea have often reached a peak of life-efficiency that makes a mockery of life on land.

In the sea, as on land, plants are the food-makers, turning carbon dioxide and water into organic substances with the help of minerals dissolved in the water. Sunshine provides the energy that maintains the manufacturing processes of life. On land, plants have been forced to equip themselves lavishly to accomplish their task, evolving into ingenious and complex machines. Land plants need roots to grip the earth and hold firm against the shifting winds and to imbibe water and minerals from the soil; they need a network of tubes to carry food and raw materials to their tissues; they need porous leaves that can extract carbon dioxide from the air and turn it into sugar and other substances.

The plants of the sea need neither roots nor leaves; they have no complicated, liquid-carrying system nor do they protect themselves against harsh and sudden changes in their environment. They are simple in structure, each cell operating with a maximum of independence, taking all the substances it needs from the water that bathes the tissues of the plant.

All living things consist largely of water. The chemical processes of the living cell take place in solution in water, and three-quarters of the cell-protoplasm is water. Many plants are nine-tenths water, and shortage of water leads directly to disaster and death. In the sea, life is lived in intimate contact with water; there is no fear of death by desiccation, and marine plants are not equipped to hoard the water in their tissues. Water permeates freely between the plant and the sea in which it lives.

On land, plants live in an atmosphere of air that can absorb almost unlimited quantities of water vapour. If water could pass freely from the living cells into the air the plant would be unable to retain the water it needs for life. Land plants have therefore learned to hold as much water as possible inside their tissues. The outside of the plant is often covered by a tough, waxy skin; the leaf-pores close when water is escaping too fast; in winter the land plant sheds its leaves to restrict the loss of water that would otherwise take place.

In a similar way the plants that grow on land must protect themselves from violent changes in the temperature of their surroundings. They carry off the excess heat of summer by evaporating great quantities of water through their leaves; in winter, they shelter from the bitter frosts by coating their exposed limbs with a layer of bark or by retreating into the protection of the soil.

But in the sea, plants live in a mass of water that changes its temperature slowly and through only a modest range during the year. Sea plants do not protect themselves from extremes of heat or cold. The temperature of their tissues is the temperature of the sea in which they live.

Like the plants on land, marine plants live by absorbing the energy from sunlight and using it to manufacture their body substances. Sea plants have in their cells the same green pigment, chlorophyll, that controls the manufacturing processes of photosynthesis. With the help of chlorophyll the cells of the plants transform carbon dioxide, water, and traces of minerals into the carbohydrates, fats, proteins, and other complex substances that are involved in life. Energy from the sunshine is stored away as chemical energy inside these organic materials.

Without sunshine the sea plant cannot live. The plant life of the ocean is restricted, therefore, to the surface layers which receive enough sunshine to operate the manufacturing processes of the cells.

Sunlight is absorbed as it strikes seawater. The red rays of the sunshine spectrum are removed in the first few feet of water, the green and blue rays penetrating further to give seawater its characteristic colours. In the top 250 feet of the sea there is abundant light for photosynthesis, and it is in this layer that most of the plant life of the sea is found. Between 250 and 600 feet the light is feeble and dim, and insufficient to sustain the vigorous growth of plants. Below 600 feet the sea takes on the stygian gloom that is characteristic of the ocean deeps.

In the well-lit surface layer of the sea, plants flourish with an enthusiasm that is seldom matched on land. These pastures of the sea can yield nearly twenty tons per acre during the year, several times the yield of crops taken from good agricultural soil. They are the food-source of the living things of the sea. These food-producing plants of the sea belong to a family different from that of the crops that yield our food on land. The sea is the realm of the algæ.

Algæ are the most primitive of all plants. They are ideally suited to the uncomplicated existence they enjoy in seawater. With none of the difficulties of land life to trouble them algæ show little inclination to introduce unnecessary complications into their body structures. Each cell lives a life that is essentially self-sufficient, contributing as little as possible to the communal life of the plant structure of which it may form a part.

Many algæ are single-celled plants that float in the surface waters; they form the bulk of the plankton, the layer of living matter that lies like a carpet over the surface of the sea. Most important of these tiny algæ in the economy of the sea are the microscopic diatoms.

The largest diatoms are just visible to the naked eye. Yet when the environment is to their liking these tiny plants can flourish so rapidly that they will colour great areas of the surface of the sea. Each single-celled diatom is enclosed in a translucent casing of silica that is built in two close-fitting halves; one tiny glass-like shell fits accurately over the other like the lid on a chocolate box. The tracery and patterns of the silica shells take on an infinite variety of delicate and beautiful forms.

When there is ample food in the water and plenty of light and warmth to encourage growth the diatoms multiply rapidly by cell-division. Each half of the diatom's shell becomes part of the covering of the daughter cell, a new half-shell growing to form the 'box' inside the old 'lid'.

This method of reproduction by cell division is admirable as a way of mutliplying rapidly when conditions are suitable. Each diatom can divide in a day or less. But the strange chocolate-box shell of the diatom imposes severe restrictions on its occupant. With each division one daughter cell accepts the smaller of the two available half-shells as the 'lid' of its box. Some of the progeny of a diatom are therefore condemned to live in shells that become increasingly tight-fitting with each successive generation. A point is reached where diatoms are strangled to death by the cramped shells in which they are forced to live.

To avoid this catastrophe the diatom may escape from its shrunken shell, expanding to a more comfortable size in a flexible membrane. It grows a new shell and starts all over again.

In shallow coastal waters and over the banks and shoals of the open sea diatoms find plenty of mineral food on which to feed. Like plants in a rich and fertile soil, they multiply rapidly to provide lush 'grazing' for the animals of the sea.

In temperate regions the coming of spring is marked by a vigorous growth of diatoms enjoying the light and warmth of the new season. The water in which they live has been enriched during winter by storms and convection currents bringing minerals from the deep water below. The diatoms have everything they need, and they multiply so rapidly that by summer the surface water may have been stripped of its mineral nutrients. Activity dies down until the autumn, when movement of the cooling water may bring fresh supplies of salts from deep waters.

In tropical waters, where winter and summer bring less-marked temperature changes, the growth of diatoms is steadier through the year. There is no burst of activity in the spring as there is in temperate waters.

Diatoms live in the surface layers of the sea in almost every part of the world. In the Arctic the tiny plants protect themselves from extinction by producing tough spores that can resist the intense winter cold. In spring the release of these spores from the ice brings a burst of active growth comparable with that in temperate regions.

These tiny plants often make up more than half of the living matter that floats as plankton on the surface of the sea. But they are not the only forms of plant life there.

Second only to the diatoms as producers of organic matter are the tiny creatures called dinoflagellata. These micro-organisms, half plant and half animal, are equipped with whip-like appendages; by lashing the water with these whips they are able to move themselves about within the confines of their floating, plankton home. Much of the luminescence of the sea is caused by myriads of dinoflagellata. Other micro-plants form nodules of jelly in the plankton. Some carry tiny plates of shell that act as shields; others are content to leave their naked cells to the mercy of the sea.

With the vastness of the ocean surface as their home, the countless billions of microscopic plants make no attempt to claim a portion of the surface as their very own. Unlike the land plants, diatoms and other tiny organisms have no fixed abode. Carried about by the currents of the sea, they find no difficulty in getting the food they need from sea-water wherever they may be.

Only one thing troubles the diatom as it drifts to and fro in the surface waters; it must stay afloat in the sunlit layer if it is to remain in active growth. Yet the silica shell of the diatom feels the pull of gravity, and the little plant is always tending to sink through the water.

By remaining microscopic in size the diatom has offered as much surface as possible to the sea; its friction is high and it sinks with infinite slowness. To increase its resistance to the force of gravity the diatom has devised long, thin shells, some branched and bent, that reduce still further the rate at which the plant sinks through the water.

But, in spite of its efforts, the diatom cannot remain afloat permanently. One-third of the diatoms die every day; their tiny bodies, wrapped in their fragile, translucent shells, set out on a slow journey to the ocean floor.

Over the ages the shells of countless generations of diatoms have built up into the porous, siliceous earth that is found in vast deposits in many parts of the world to-day.

Though most of the food-production of the sea is done by the floating diatoms and other micro-plants, there is also a huge population of large algæ in the form of the seaweeds that grow on the world's rocky coasts.

In shallow coastal waters the sea is constantly moved and mixed by the tides. Water flows from the land, carrying dissolved mineral salts. And the sunshine can penetrate to the floor of the sea. The waters above the continental shelf are often ideal for plant growth; the floating algæ grow well, and so do their larger relatives, the seaweeds.

Superficially many seaweeds resemble the plants growing on land. They have 'roots' that anchor them to a rock or to the sand on the sea-floor; they have stalks; and they have leaves. But this similarity with land plants does not extend to the internal structure of the seaweed. The 'roots' are not real roots; they are merely hold-fasts that attach the plant to its rock. They seldom carry tissues for sending solutions to the other parts of the plant body. Similarly, the stalk, or stipe of the seaweed is not a true stem; its purpose is to support the fronds of the seaweed near the surface of the water. And the fronds are not leaves; they are built up from individualistic cells that find it suits them to forgo complete freedom in order to retain the advantages of living as part of a larger organization. The seaweed plant, therefore, is a structure that consists of alga cells which have undertaken to co-operate only so far as is necessary to enable them to continue their independent existence satisfactorily.

Most seaweeds are beautifully coloured, and the algæ are divided on a basis of colour into their various families. Whatever their colour, the cells of the seaweeds contain the green chlorophyll that enables them to carry out photosynthesis.

The blue-green algæ contain, in addition to their chlorophyll, a blue substance that dissolves in water when it escapes from the cell. These algæ will tint the sea blue when they die in large numbers; paradoxically it is a red form of blue-green alga that gives its name to the Red Sea.

The sea-lettuce, which is eaten in many parts of the world, is a member of the green algæ. These algæ often cover themselves with a thin shell of lime, leaving spaces at the joints so that they remain flexible in the water.

Most impressive of all the seaweeds are the great brown algæ that grow in the immense forests of the seashore. These are the most highly developed of all the algæ; they range from tiny filamentous plants to the huge kelps that are among the largest plants on earth.

The stipe of a typical kelp plant is hollow; it ends in a hollow, gas-filled bulb that may be as big as a football. Supported by its floating bulb, the plant spreads out its ribbon-like fronds on the well-lit surface of the sea.

Brown seaweeds of this sort grow well in the cooler waters of the world's temperate regions. Millions of tons of kelp grow on the rocky coasts of Western Scotland, in the Orkneys, and off the Atlantic coast of Ireland.

In the Pacific giant kelps grow to 250 feet or more, with fronds that are six feet in width. Off Tierra del Fuego these seaweeds grow to 600 feet, reaching up through water four times as deep as Nelson's Column is high.

Most of the huge brown algæ are perennial plants. The stipes grow longer and thicker year by year; some are as thick as a human thigh and show growth rings like the trunk of a tree. Each spring the fronds are renewed by growing like giant leaves from the top of the stalk.

As the storms of winter beat against the shore they tear off great masses of weed. Millions of tons are thrown up and left to rot on the shore; the rest floats away in the currents, perhaps to continue its life as part of the plankton of the water surface.

In the Atlantic Ocean islands of floating seaweed are swept along by the Gulf Stream to be trapped in the huge eddies that swirl over thousands of square miles of the sea. Between the Azores in the east and the Bahamas in the west there are islands of floating weed as big as the continent of Europe. This is the Sargasso Sea, discovered by Columbus on his journey to America in 1492.

The huge plants of the brown algæ have become the most likely source of raw material for a large-scale seaweed industry. But it is from the most beautiful seaweeds of all, the red algæ, that we extract the agar jelly that is becoming increasingly important as a food to-day.

The red algæ include plants of many different shades, some red, some violet, and some purple. Though smaller than the brown algæ, these red algæ flourish in greater variety and are found in waters all over the world.

Between them the microscopic algæ of the plankton and the multicellular algæ of the seaweeds do almost the entire manufacturing work of the sea. There are a few species of flowering plants that have made a home in the sea, such as the eel-grass which grows submerged under twelve feet of water; but the part played by these plants is insignificant. They are merely stragglers that have made their way into the sea from the fresh waters of the land.

6

Animals Afloat

The plants of the sea, needing light to live, are confined to the sunlit layers of the surface. But the animals of the sea can wander at will through the vastness of their three-dimensional world. Animals live as part of the plankton that drifts on the surface; they live in the dim-lit water, where the sun has begun to lose its power, and in the velvety darkness of the sea reaching down into the six-mile-deep trenches. Wherever there is food to eat animals have made their home in the sea.

Millions of years have passed since the first tremulous stirrings of life were felt in the sea; during that time marine creatures have evolved into the thousands of species that are known to-day. All the great groups of the animal world have their representatives in the sea. Only a few of the sub-groups are missing—the birds and the insects, spiders and amphibia have evolved on land without counterparts in the sea.

In the serene environment of the sea the procession of life has moved steadily along, providing us with a record of evolutionary progress more precise than we have on land. Many animals of the sea have changed little over millions of years. Their technique of living was reached and perfected to suit an environment that has remained almost unaltered through the ages. The jellyfish that drifts in the ocean currents to-day is similar to the jellyfish that lived when life first crawled from the sea on to land.

The sea, in those far-off days, belonged to the invertebrate animals. With water to support them gently and evenly over the entire surface of their bodies, these primitive animals had no need of great structural strength. Skeletons were unnecessary, so the sponges and molluscs, the jellyfish and corals, developed without any complex bone structure. They floated in the currents or anchored themselves to the sea-floor as they do to-day.

As life developed on land, animals found their surroundings less tranquil. Though they could move more easily through the flimsy air in which they now lived, they were denied the support of the buoyant water of the sea. Strong, weight-bearing frameworks were essential to support and protect the tissue masses of the body. Limbs were needed to carry the body and enable it to move over the ground. To fit them for life on the land many animals developed skeletons. The vertebrates had arrived.

In the freshwater lakes and streams of the land life equipped itself similarly with bones. Fishes developed, in which a muscle-controlled skeleton gave the power of movement. And back into the oceans they swam, glorying in the freedom of the limitless, empty spaces of the open sea.

Soon the fishes had established ascendancy over the helpless invertebrates. They penetrated into every region of the sea, living on the invertebrates and on themselves, just as they do to-day.

The animals of the sea live, like the plants, in close contact with the water that provides everything they need. Where the plants feed on dissolved minerals and on carbon dioxide the animals need ready-made organic food. They depend on the plants for food or on other animals that have lived on the plants.

Marine animals do not need to isolate themselves from the materials of their environment. The true creatures of the sea are cold-blooded; their temperature is controlled by the temperature of their surroundings. Water passes freely into the tissues of many marine animals, and the concentration of salts in their body fluids is often very similar to that of the sea itself. Many invertebrates, like the sea-anemone or the jellyfish, are little more than masses of cells held in a permeable membrane. They are the ghosts of the sea.

The fishes of the sea have retained the bones that they brought from the land; but they have adapted them to their simpler needs. With water to support them, fishes have no need of limbs. Movement is graceful; a snake-like wriggle of the body helps the tail to push the fish through the water. The power for this push comes from layers of muscle banked alongside the backbone of the fish. Fins are used mainly for control.

Though water provides buoyancy, it offers great resistance to the movement of a fish. The fish has streamlined itself beautifully to minimize the effort it must make as it moves through the water.

Like the plants and animals of the land, living things of the sea need oxygen to release the energy stored up in their food. Oxygen reverses the process of photosynthesis, turning the carbon of organic materials into carbon dioxide and the hydrogen into water; energy that was absorbed by plants as they made these organic substances is released to provide the energy that powers the living cell.

On land, animals have adopted a complex respiratory system that makes use of the oxygen in the air. But in the sea, animals and plants absorb their oxygen from the water in which it is dissolved. The plants and simple animals take their oxygen directly from the water that permeates their tissues; fishes force the water through their gills, the water giving up its oxygen to blood that flows behind the delicate membrane of the gills.

Marine animals have made no provision for controlling their body temperatures. On land many animals protect themselves from changes in their environment by covering themselves with fur; human beings have abandoned fur and taken to wearing clothes. But in the sea the fishes are content to adopt the temperature of the sea in which they live.

Although the area covered by the sea is two-and-a-half times that of the land, this does not give a true measure of the vastness of the sea as a home for animal life. The sea has depth in addition to area, and animals can move up and down as well as to and fro. This increases the effective living-space of the sea enormously by comparison with the space available to us on land. The depth we occupy on land is only a few feet; birds and insects take to the air, but this is a temporary departure from the solid earth on which they live. In the sea there is a three-dimensional world that extends in depth to six miles or more. It offers more than 250 times as much living space as the land.

Although the serenity of the sea has encouraged life to develop in a simple and efficient way, it has left living things unusually sensitive to changes in their environment. When something happens that brings an unexpected change of temperature or salinity the plants and animals of the sea have no equipment for protecting themselves from the new conditions. A current blown in an unusual direction by the wind may bring a douche of cold water into a warmer region of the sea, causing wholesale slaughter amongst the living things that encounter it.

Hundreds of tons of fish will often pile up on the shore when water temperature or salinity changes suddenly in this way. The Gulf Stream discharges a constant flow of dead plant and animal matter into the Atlantic; carried by the warm water of the Stream, the living things are killed as the tropical waters mingle with the colder waters of the open sea.

In the seas as a whole stability of environment is a characteristic of immense areas of water at every depth. But the temperature, salinity, and pressure of the water vary greatly from one environment to another. Over more than two-thirds of the entire surface of the sea the temperature undergoes a seasonal change of less than 5°F. But there is a difference of more than 50°F. between the surface temperatures in equatorial waters and the waters of the polar seas.

In deeper waters the effect of surface influences becomes steadily less noticeable, and the cold, dark waters below 1000 feet change only imperceptibly as hidden currents creep along the ocean floor. At every level in the sea there are vast three-dimensional territories, all differing in their characteristics one from another, but each is in itself a stable environment that supports its typical animal life.

At the surface of the sea the water is reasonably warm and the pressure little more than that of the atmosphere above. Below the surface layer the water becomes colder until it is permanently below freezing-point at great depths. With increasing depth the pressure of water becomes greater until it may reach 1000 times that of the atmosphere and more.

The salinity of seawater, constant though it is when considered throughout the sea as a whole, will fluctuate considerably between one environment and another. On the surface the microscopic algæ are for ever stripping the water of its minerals and carbon dioxide as they build the organic materials of their bodies. Then the plants and the animals that feed on them die, and their bodies sink through the water, disintegrating and decomposing as they approach the ocean floor. The elements they contain are released once again as simple minerals and carbon dioxide, far from the region of the sea that supplied them to the growing plants.

As the surface waters cool during winter in the temperate zones convection currents are set up, enriching the surface waters with salts from the deep waters below. In many parts of the world, cold water is forced to the surface as underwater currents meet shallow banks or the shore. These currents bring salts to the surface, maintaining a vigorous plankton growth.

In shallow coastal waters the concentration of salts in seawater will often change almost from one day to the next. Water flowing from the land brings dissolved salts from the soil. Heavy rainfall may dilute coastal waters, and intense plant growth denude it of its mineral foods.

Light is of supreme importance to the plant life of the sea. But it affects the animals directly as well and is a factor that influences the environments of the sea. Less than one-fiftieth of the way down towards the deepest levels of the ocean bed the light has gone altogether. Darkness is a characteristic of the bulk of the 300 million cubic miles of seawater in which animals live.

Most animals of the sea have become adapted to life in their selected environment. Through millions of years their bodies have become accustomed to the temperature, pressure, salinity, light, and food supply of the layer of the sea in which they live. But some marine animals have learned to move freely from one environment to another. Mammals, like the whale and the seal, have retained the versatility that they developed during their life on land; they can adapt themselves to changing circumstances and so move freely through changing environments of the sea. The sperm whale will dive from the surface to 2000 feet or more in search of the giant squids on which it feeds. At these depths the whale must withstand pressures sixty times as great as it meets at the surface.

In the open sea such versatility is the exception rather than the rule. The massive, unchanging environments of the ocean offer room enough to their respective inhabitants. But near the shore, where the sea is less stable than in the deep ocean, plants and animals have been obliged to accept unsettled surroundings. Here, where the sea meets the land, marine creatures are at the boundary between one evolutionary environment and another. Some live on the very edge of the sea, partly on land and partly in the water as the tides ebb and flow. Some have crept into the brackish water of estuaries, braving the perils of a shifting sea floor and the dangers from drought and flood as they reach tentatively towards the land. Some, like the eel and the salmon, live part of their lives in the water of the sea and part in the fresh water of rivers.

For millions of years life has been crossing this barrier between land and sea. It is here, on the shore, that we find the most persistent, most versatile lives of the sea.

In the surface layers of the sea, animals live in a world where algæ are multiplying, powered by the light that penetrates the water. The surface of the sea is a world on its own, with vegetable and animal living lives that are closely bound up one with another. This is the food-manufacturing layer of the sea, where animals live that can browse on the plant pastures. These herbivorous animals are the first link in a chain of life that stretches from the surface to the ocean floor.

In the blanket of floating plankton that lies on the sea there are animals little bigger than the diatoms themselves. Protozoa, one-celled animals such as radiolarians, foraminifera, and tintinnids feed on the little plant cells. In the plankton mass, fish and other marine animals leave their eggs to hatch; the larvæ and tiny fish feed ravenously on the micro-organisms surrounding them. As they grow the animals of the plankton eat each other, snatching and tearing at their delicate bodies with a savagery that prepares them for the rigours of life in the water below.

Though they live at the mercy of the winds and currents, many animals of the plankton are able to swim. Their efforts can move them small distances, but more often than not they have little control over the direction in which they travel. Jellyfishes in the plankton grow to three feet or more in diameter, with tentacles seventy feet long; some hoist a 'sail' that catches the wind and carries them through the water.

Most prolific and important of all the animals in the plankton are the shrimp-like crustaceans called copepods. These tiny creatures are the chief grazers of the plankton, feeding voraciously on the diatoms and other microscopic plants. Although only a tenth of the available food of the algæ is turned into flesh of the copepod's body, the creature acts as a storehouse by living for the best part of a year. Where the short-lived diatoms and other plants will die and sink down through the sea, the copepods remain in their countless millions to provide a meaty feast for the fish and mammals that feed on the floating plankton masses. Like the plants of the plankton, the animals are in constant danger of sinking into the deep water below. Many use their limited powers of locomotion to resist the pull of gravity. Often they adopt the system of surface extension used by the diatoms, festooning themselves with a forest of whiskers and spines that increases their resistance to movement through the water.

The food-chain in the sea is fundamentally different from that of the land. On the land many animals of all sizes are able to feed on plants. But in the sea the bulk of the food manufacture is done by the microscopic algæ that float in the surface plankton. Special equipment is needed to enable animals to graze on the tiny plants, and special arrangements are made to pass on the food from the plankton to the fish in the deep waters below.

The copepods, which do most of the grazing of the sea, are equipped with a group of fan-like hairs that can vibrate ten times a second. Little whirlpools are formed, which carry water into a filter that removes the diatoms and other tiny organisms. From the filter the food is passed to the animal's mouth.

In this mass of plant and animal life forming the plankton we have the primary food source of the animals of the sea. Some feed directly on the surface plankton itself. Most fishes are carnivorous, feeding on other creatures smaller or more defenceless than themselves. But there are also many marine animals that depend on the shower of dead organic matter falling from plants and animals that have died in the plankton or in the sea itself.

7

A Jungle beneath the Waves

LIFE below the surface is a savage and unrelenting struggle for existence. With no lush vegetation on which to feed the animals are obliged to eat each other.

In this darting, slashing warfare of the underwater jungle the race is to the swift and the battle to the strong. Few animals on land can match the ferocious power of the hunting shark; few four-legged creatures could outpace the big blue marlin or the tuna as they speed through the water at sixty miles an hour or more.

Life in the ocean is a carnivorous bureaucracy, built on a foundation of humble algæ and rising through a hierarchy of increasing savagery towards the bosses—the sharks that attack almost any other living thing that swims across their path.

Feeding directly on the plankton are the inoffensive browsers of the sea, the herrings and sardines, the menhaden and the mackerel. Some of these fishes enjoy one ingredient of the plankton better than another and will pick out the tiny animals they prefer. Others are too hungry to be fussy; they carry filters in their mouths that comb the plankton organisms indiscriminately from the water. Herrings, for example, are equipped with bony grids that collect copepods very efficiently; the stomach of a herring will often contain 50,000 copepods or more.

Although the majority of these plankton-feeders are small, they swim in enormous shoals among the floating pastures in which they browse. Shoals of herrings in the

North Sea and Atlantic will often contain hundreds of millions of fishes. They are the concentrated flesh-food of the animals of the sea. Salmon and tuna and other big fishes of the surface waters enjoy the herrings and mackerel, just as the latter have enjoyed the copepods and algæ of the plankton. These bigger fishes, in their turn, are hunted by larger, faster, or more powerful animals like the shark or the seal or the porpoise.

The struggle for survival in this eternal warfare of the sea is controlled and balanced by innumerable techniques of attack and defence. The free-swimming fishes are streamlined to help them to glide smoothly through the water; they cover the surfaces of their bodies with slime to reduce the friction that resists their movement. Speed and rapid acceleration are matters of life and death in the sea; the banks of muscle packed alongside the backbone of a fish can give a powerful thrust to the tail that propels the fish through the water. Some fishes take to the air in their anxiety to escape their enemies. Flying fishes leap from the water, gliding for hundreds of yards with the help of outstretched wing fins. They maintain their glide by sculling rapidly on the surface of the water with the long lower portion of the tail.

Though the open waters of the sea are primarily the home of vertebrate fishes they support a population of invertebrates as well. Many of these, like the jellyfishes and crustaceans, have little chance of escaping by sheer speed from their attackers. But the lack of a skeleton does not necessarily prevent the invertebrates from moving rapidly through the water. The giant squid, largest of all invertebrate animals, has developed a unique and efficient system of jet propulsion that carries it through the water at tremendous speed. In place of the 'foot' which is characteristic of many invertebrates the squid has a funnel-shaped device through which it ejects powerful jets of water. These drive along this great creature, six feet in diameter, in a series of jet-propelled leaps.

Some of the fastest of all marine animals are the mammals that have returned to the sea from a life on land. The whale, though a warm-blooded, air-breathing creature, has adapted itself wonderfully to life in the water. Its streamlining is as complete as that of any fish, and in spite of its land-designed skeleton structure the whale is completely at home in the sea. Even the jet-propelled squid is no match for its traditional enemy, the sperm whale, which descends to great depths in search of its prey.

Speed and agility play an essential role in the life and death struggles between animals in the sea; but many creatures are amazingly efficient long-distance swimmers as well. The whale will travel thousands of miles between the food-rich waters of the polar seas and the warm breeding grounds near the tropics. Fish, too, will swim great distances in obedience to instinctive urges. Salmon travel hundreds of miles to return to the stream in which they were born. Eels from European rivers make a journey of 3000 miles to the Sargasso Sea when they are ready to spawn. The tiny larvæ, in their turn, set off on the long journey to the shores of Europe, taking several years over their marathon swim. There are no landmarks in the water to guide them. Yet these little creatures find their way unerringly through the monotonous vastness of the sea.

The sharks, which prowl and kill relentlessly like underwater wolves, are armed with razor-teeth and with the strength to use them. Many battles of the sea are fought between fishes that depend on powerful jaws and teeth. But other weapons are used for attack and defence by the creatures of the sea. Crustaceans, like the crab and lobster, arm themselves with purposeful claws; turtles cover their bodies with armour-plate that can prove too tough for a shark. Even the jellyfishes are not so helpless as they seem; the tentacles they trail in the water are armed with stinging cells which paralyse fish and other organisms they use as food. Sea anemones, on the rocks near shore, carry poison darts in the cells of their waving arms.

Some fishes have developed built-in batteries that enable them to stun their enemies with electric shocks. Other animals, like the octopus, can grip and crush their prey in powerful tentacles. In the tense and nerve-wracking warfare of the sea survival depends largely on surprise and swift attack; the first bite is often the only one in an underwater fight. Alertness and agility are at a premium, and fishes are equipped with tautly tuned senses. Hearing, touch, and smell all play a part in maintaining the vigilance which is essential to survival in the sea. Fishes do not have ears; instead they carry sensitive cells on the sides of the body, which can detect vibrations in the water.

Sight is the sense that plays the most important part of all. Fishes are for ever on the watch for food or enemies. So far as is known, they do not sleep, in the sense that land animals do. Fishes have no eyelids; they cannot close their eyes and rest, but must be constantly on the watch if they are to survive.

With so much depending on sight fishes and other marine animals camouflage themselves with extraordinary skill. In the surface waters red light has been filtered from the sunshine. Free-swimming fishes live in a blue or blue-green world in which the light reaches them from above. Many surface fishes, like the mackerel and the herring, are coloured blue or mottled blue and green on top and silvery white beneath. This gives them an effective camouflage when seen either from below or from above. Many creatures of the surface plankton go to even greater lengths in their efforts to become invisible; fish larvæ, arrow worms, and jellyfishes are often colourless and transparent.

In the shallow waters near the shore fishes that live habitually among the seaweed are striped and mottled. Some prawns can change colour like chameleons to bring them into line with their environment. Flatfishes blend effectively into the mud and sand of the sea bed.

In deeper water, between about 500 and 1500 feet, the blue and green rays of light are absorbed and fishes swim in a zone of perpetual twilight. They are often silvery or grey. Deeper still, where the light has virtually disappeared, many fishes are black or violet or brown.

Marine animals, living in surroundings that include all manner of light conditions, are often remarkably sensitive to light. Plankton organisms and free-swimming fishes make daily migrations through depths of hundreds of feet as they adjust their environment to the light conditions they prefer. This daily rise and fall of animals to different levels in the sea is responsible for the mysterious mass of life that has been called the Deep-scattering Layer.

During World War II sensitive echo-sounding devices were used by hundreds of ships in all the oceans of the world. Observers found that sound-waves were reflected from a layer of solid matter in the water at varying depths. This layer showed up on the echo sounding charts as a 'false-bottom' to the sea; it remained a mystery until after the war and is still only partly explained to-day.

Many expeditions have studied the deep-scattering layer in the sea since the war. It has been found in every ocean and seems to be a characteristic feature of the sea. The layer disappears at night, but reappears during the day as though it consisted of organisms which rise to the surface as darkness falls and descend as the light appears. Sometimes the layer splits up into several layers at different depths.

In transparent tropical waters the deep-scattering layer is at a depth of about 1500-2000 feet; nearer the coast, and in more turbid waters, it is at 1000-1500 feet. Many suggestions have been made to explain the deep-scattering layer. Some scientists believe that it may consist largely of squids; others insist that it is copepods or euphausiid shrimps.

The reflection pattern of the sound-waves indicates that the layer consists of animals less than 1 foot long. Direct sampling of the layer has proved remarkably difficult. The organisms are at such a depth that a net dragged through the water moves too slowly to make a representative catch.

The water in which the organisms live is dark, and there is no easy way of identifying the animals in it. But photographs have been taken and some of the inhabitants of the layer recognized. There are undoubtedly jellyfish, copepods, and euphausiids among the creatures present.

Euphausiid shrimps are known to play a vitally important role in the underwater economy of the sea. Living in great swarms below the well-lit surface zone, these tiny crustaceans intercept the dead material falling from the surface waters. They are scavengers, eating any sort of plant or animal material; with tiny, comb-like limbs they scoop up much of the organic matter of the sea that would otherwise decompose into simple chemicals as it settled through the water. In this way the euphausiids, which are eaten in enormous quantities by other animals, act as a storehouse of food that is second only to the plankton in many waters of the world. Whalebone whales, equipped with enormous filtering mechanisms in their mouths, are particularly fond of euphausiid shrimps; they strain them from the water, tons at a time.

As they struggle to maintain their species in the sea the fishes and other animals produce astonishing numbers of offspring. The size of a fish's family depends upon the degree of protection that the adult gives to its young.

Though some sea creatures bring forth living young, most of them release their offspring as eggs. The eggs are fertilized by appropriate sperms, which are also liberated freely into the water by male fishes. As the fertilized eggs develop they turn into free-swimming larvæ and tiny fishes, which have to fend for themselves in the unfriendly jungle that surrounds them.

Most marine creatures are content to let their offspring make their way unaided in the world. Once the eggs have been set free the parents take no further interest in them.

A fish is as likely to eat her own eggs as any others she finds floating in the sea.

These animals that abandon their eggs to the tender mercies of the sea will often produce prodigious families. A codfish will release four million eggs in a single season, an oyster 100 million, and a sunfish 300 million.

With so many eggs floating about in the sea, it is inevitable that some must escape the ravenous egg-eating fishes and survive the hazards of adolescence to reach adulthood. Indeed, if it were not for the savage massacre of eggs and young fishes in the sea the world would soon be overburdened with fish. The offspring from a single sunfish, left to develop freely, would pack the oceans solid in a season or two. As it is, the odds against survival are so great that nature maintains her marine species in a delicately balanced equilibrium.

Not all sea creatures are content to leave their offspring to the mercy of the sea. Some, like the lobster, carry their eggs attached to hair-like structures underneath the body; others pack their eggs into little pouches. Copepods carry their eggs in flimsy sacs; herrings coat their eggs with glue so that they will stick to rocks. Some parents are affectionate enough to keep an eye on their eggs after they are liberated; the octopus and the blenny will guard their eggs, driving away other creatures that are searching for a meal.

Many eggs float up to the surface and become part of the plankton. As the eggs hatch the free-swimming larvæ feed on the tiny cells and organisms that are everywhere around them. If they are fortunate they reach adulthood before being strained from the water by browsing fishes or whales.

Sharks are often more solicitous of their young than most other fishes. The eggs are hatched inside the shark's body and the young are born alive; eggs are also released inside the leathery cases known as 'mermaids' purses.'

Marine mammals, like the whale, bring forth their young individually and suckle them as mammals do on land. A baby whale will grow at such a rate that it can reach maturity in two years.

Though fishes in the open sea are able to exist by eating one another, the source of all the animal life of the sea lies in the tiny plants that float in the surface plankton. The vigour and vitality of the animal life in any area of the sea depends directly upon the lushness of the vegetation that supports it.

Like land plants, diatoms and other floating plants will flourish where there is an ample food-supply. In seas where mineral foods abound the tiny plants will grow apace, providing an abundance of organic matter for the animal population beneath. The great fishing regions of the sea are regions where rich and nourishing plankton pastures are maintained by water that is well supplied with mineral foods. Near many continental coasts vast currents are forced surfacewards by the sloping barrier of land, bringing fresh supplies of minerals to enrich the surface waters. Off the coasts of North and South America, in the North Sea, and off Japan, Newfoundland, and Portugal there are rich marine pastures that sustain good fishing grounds in the waters below.

Much of the world's fishing industry depends on the free-swimming fishes of the well-lit waters above 600 feet. On the shallow banks off Newfoundland, in the North Sea, and elsewhere the upwelling currents bring nutrients to the floating plankton, and fishes find plenty of food. Altogether fishermen bring more than 20,000 million tons of seafood to land every year. This enormous catch is only a fraction of the amount of food that the sea could provide.[1]

Until oceanographers began to explore the ocean depths it was believed that the animal life of the sea was confined to the well-lit surface waters. But the sea has now been shown to have its characteristic forms of animal life at

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[1] See *The Fight for Food.*

every depth, including the abysmal trenches where water lies cold and still at a pressure hundreds of times that of the atmosphere above.

Even in the clear waters near Bermuda the red rays of the sunlight have disappeared at a depth of 60 feet. By 250 feet, the yellow has almost gone; and at 1500 feet there is darkness.

The fishes have learned to adapt themselves to the diminishing light at these different levels in the sea. In the dim-lit regions between 800 and 1500 feet fishes have large and extremely sensitive eyes. At greater depths the eyes are so immense that the sockets may occupy half of the space of the skull. These owl-like eyes are equipped with spherical lenses and retinas more sensitive than those in the eyes of land-based creatures. Sometimes the pupil of the eyes in deep-sea fishes covers two-thirds or more of the diameter of the eyeball itself. The eyes are often carried on stalks, giving them a telescopic appearance.

Even in the water two miles below the surface, where no light penetrates at all, fishes retain the power of sight. Many are equipped with sensitive eyes, although some carry only degenerate eyes and a few have abandoned them altogether. The eyes of these deep-sea fishes are used for detecting the self-generated light that illuminates so many of the animals of the sea.

Luminescence is a characteristic of animal life at all levels of the sea. A ship moving through the surface waters will leave a luminescent wake, caused by the microscopic creatures of the plankton, which emit light when they are disturbed. The ability to produce light in this way is shared by all manner of animals in the sea. In the dark waters, at great depths, luminescence is the only light available, and it is used freely and with great effect.

Although luminescence has its obvious uses in the darkness of the deep ocean waters, it is often produced for no apparent purpose. Some of the best light-generators of all are creatures that live beneath the mud of the ocean floor.

Many clams glow brilliantly, though hidden entirely from view.

Most of the fishes that live in really deep water are small; they are hideously ugly, with heads that form the major part of the body. Life in the depths is a savage affair, and deep-water fish are armed with powerful jaws and sharp pointed teeth. Sometimes they can swallow other fishes three times as big as themselves.

Much of the dead plant and animal matter settling from the upper layers of the sea has decomposed by the time that it reaches deep water. The elements it contained have returned as simple chemicals to the sea. Food for the free-swimming fishes in the ocean depths is restricted to the flesh that can be snatched from other fishes. Life is lived at a bleak level, and with food very scarce the fishes are small. Their skeletons are rickety in appearance as though they lacked the sunshine vitamin D needed for proper growth.

Even with the help of their luminous identification patterns, deep-sea fishes appear to have difficulty in finding each other. Females cannot rely on meeting a male, and a flashing recognition signal may mean death in the jaws of another fish seeking a meal. Some females have solved this problem by carrying the male around with them in the form of an appendage fused permanently on to the body. The male fish is a parasite attached by its mouth to its partner, with a bloodstream common to both fishes.

Although deep-sea fishes are usually black or brown, many bright-coloured creatures live in deep water as well. Scarlet prawns inhabit waters entirely devoid of the light that can bring their colours to life.

The little we know about creatures living in deep water has come from oceanographic expeditions that have sailed since the end of World War II. When the Danish research ship *Galathea* returned to Copenhagen in 1952 the scientists aboard her brought more than 200 species of deep-sea fish from the waters of the Philippines Trench. Many had not been seen by man before, and had lived at depths of more than three miles.

Although they had been attuned to life at a pressure hundreds of times greater than atmospheric pressure, these animals did not expand and burst as they were brought to the surface. They died of heat-stroke, caused by the rise in temperature from near freezing-point to about 80°F. on the surface.

The ability of deep-sea creatures to withstand great pressures is not so remarkable as it sounds. Water is virtually incompressible, so that the liquid-filled tissues of the animal are not distorted by the tremendous pressure outside them. It is only when there is gas in the animal body that expansion takes place as the pressure falls. Experiments have shown that young trout can live under pressures ten times as great as the normal atmospheric pressure.

Many fishes use air-filled bladders to keep them floating in the water. By secreting or absorbing oxygen between the blood and the air-bladder they can adjust their buoyancy. But fishes living in very deep water have replaced the air of their bladders with light, incompressible fat.

The discovery of animals living in all levels of the sea has opened up a vast new world of scientific exploration. Under the sea we have hundreds of times as much space as there is on land. Every part of it is the home of living things.

Exploring the sea is infinitely more difficult than exploring the land. But gradually we are probing into these deep, black waters, seeking out creatures that have lived there undisturbed for millions of years.

8

Life on the Sea-floor

Life on the ocean-floor has a character all its own. Unlike the fast-moving, darting life of the open sea, where the backboned fishes are in control, the life of the sea-bed is sedentary and slow. Here, on the mud and sand, the pebbles and rocks, are animals that creep and crawl and burrow or cling to the little patch of sea-bed on which they make their home.

When life first crawled on to the land invertebrates ruled the floor of the sea. The waters above them were empty of animal life in the forms that we know to-day. Even now, when the fishes have penetrated into every part of the sea, invertebrates cling to their home on the ocean-floor.

Here, living lives that have changed little through æons of time, are animals so sedentary that they are often mistaken for plants. Sponges grow on the sea-bed in every part of the world, even on the floor of the deepest ocean trench. The cells of the sponge are held simply and loosely together by a fibrous skeleton tissue that supports them in a delicate plant-like structure. Yet the sponge is an animal, feeding on ready-made food that is filtered from water propelled through the pores of the creature's body.

Other animals, bryozoa, grow like carpets of mosses on the rocks; sea-lilies and sea-feathers sprout like vegetables from the mud of the ocean-floor. In every part of the sea and at all depths jellyfishes anchor their masses of pulsating cells among the other inhabitants of the sea-bed.

From these plant-like hydroids, growing as tufts in the forests of seaweed, come tiny jellyfishes that float freely as medusæ in the open sea. Sea anemones flower in profusion, waving their beautiful fronds in the water as they search for their floating food. Though they are often mistaken for plants, these creatures are simple animals. Their cells are arranged in the form of a sack-like body that is little more than a digestive cavity; into it the anemone crams the food that is caught by the poison-filled tentacles. The anemone, like many plant-like animals of the sea, is endowed with limited powers of locomotion. It can creep over the surface of its rock. Or, if it wants to move farther afield, it can blow itself up with air and float away in the water like a little balloon.

Even the corals that grow so profusely in the warm waters of the world are simple invertebrate animals. Millions of tiny, hard-working creatures live in the colonies of coral that fringe islands in the Pacific. From the calcareous skeleton secreted by each coral animal are built the huge underwater structures that sprinkle this ocean with its islands.

Molluscs in great variety live on the ocean-floor. Some, like the mussel, are anchored in place by tough hawsers of tissue. Others, such as the snails, can slither and slide over the rocks and mud as they search for food.

The strange, invertebrate bodies of molluscs are hidden inside their calcareous shells. Oysters, mussels, and clams live in a pair of hinged shells; snails and limpets are content with a single shell; other molluscs, like the Naked Clam, have dispensed with a shell altogether or carry vestigial shells inside their bodies.

Molluscs are equipped with a massive foot that is used, in one way or another, for helping them to move about. They also have a characteristic membrane, the mantle, which is used for collecting food particles from the water.

The foot of a sea-snail is often large and flat to enable it to glide over mud and slime. The free-swimming molluscs have adapted the foot for swimming or, in the case of the squid, for jet-propulsion. In clams and oysters the foot is hatchet-shaped and is used for digging its owner into the sea-bed. Some molluscs can burrow into wood or stone.

The sea-floor, like the rest of the ocean, has its population of worms. Many live in tunnels burrowed into the mud, hiding from the predators that seek them as food. Some worms grow to incredible lengths; one thread-like worm can stretch its body out to seventy feet or more. It is the longest invertebrate known, but is so thin that its body has little bulk.

The molluscs of the sea-floor are generally lethargic, moving slowly if at all. Their food comes to them in the water that they pump through their bodies. They have little need to go in search of richer pastures.

Slightly more adventurous than the molluscs are the echinodermata, the sea-urchins, sea-cucumbers, and starfish that are found in immense numbers wherever there is food on the sea-floor. These creatures cover themselves with horny shells or plates, providing an armour or coat of mail that protects them from their enemies. Sometimes they bristle with spikes and spines like underwater hedgehogs.

Crustaceans abound on the floor of the sea, scuttling among the slow-movers as they search for their food. Like the insects on land, crabs and lobsters carry a skeleton on the outside of the body in the form of a hard, jointed shell.

Food for all these sea-bed animals comes, in the first place, from the plants that live in the sea. Near the shore animals feed directly on the seaweeds and other algæ. Snails rasp at the fronds of the weeds with their rough horny 'tongues'; crabs break bits off with their claws. But only a few sea-bed animals feed directly on plants in this way. Most of them are scavengers, living on the debris of organic matter that sinks on to the ocean-floor.

In coastal waters and over the shallow banks plankton grows richly and fishes flourish in the water below. The plants and animals die, and the substance of their bodies settles slowly through the sea. It is attacked by bacteria and protozoa and other micro-organisms, and the sea-bed becomes covered by a layer of organic matter in which decomposing food and microbes are mixed intimately together. This rich, nourishing, soup-like slime is the detritus, the food that supports life in countless animals that live on the ocean-floor.

Some creatures rootle like hogs in the mixture of mud and detritus. Worms suck the mixture indiscriminately into their burrows, eating anything digestible that they find and discarding the rest. Many build a funnel-shaped mass of mucus in the mouth of their burrows. Water is drawn through the sticky funnel, which becomes clogged with a plug of organic matter. Then the worm eats the food, funnel, and all.

Sea-cucumbers plough through the rich slime, covering a foot or two of ground in a day. On a good inshore bed these curious creatures can eat 500 tons of mud per square mile during a single season.

The bivalve molluscs, like the oysters and clams, are enthusiastic feeders, filtering the detritus from the water with the help of their slimy mantles. Clams lie in the mud, hidden except for their siphons which reach like periscopes into the water above. Through its siphon the clam sucks the detritus, clearing the sea-bed of food like a vacuum cleaner on a carpet.

Starfishes wallow in their slimy food, sweeping the detritus into their mouths with the help of their multiple arms. Sea-urchins feed on the slime over which they crawl. Sponges and sea-squirts filter the water that is impelled through the pores of their bodies. Barnacles catch up their food in the net-like legs that protrude from the top of the shell.

But not all the creatures of the sea-bed are content to feed on the nourishing detritus. Many prefer a diet of animal flesh and prey on the browsers and on each other. Life on the sea-bed is as harsh and savage as life in the water above. Predators prowl on the muddy floor, sucking the molluscs from their shells and snapping up the worms and other helpless creatures that stray from the protection of their homes. Bottom-living fishes, like the cod and plaice, the halibut and ray, all join in the feast, harrying the creatures of the sea-bed wherever they are to be found.

To meet the attacks of their enemies these long-suffering animals have devised many methods of defence. Lacking the speed that enables a fish to elude its attacker, the slow-moving animal of the sea-floor relies very often on armour. Calcium taken from the seawater is built into shells of all shapes and sizes. Limpets live under a rock-like bell tent of a shell; oysters and mussels can hold their hinged shells together with astounding strength. Clams often grow to enormous sizes, with shells four feet wide and weighing a quarter of a ton.

Shellfish can hold on to their armour with tough and immensely strong muscles. The limpet attaches its underside to a rock with the help of a large suction disc; the shell is pulled down on the rock with the limpet locked safely inside. Bivalves attach the ends of their muscles to each of their shells, which are clamped tightly together when danger threatens.

The sea-cucumber, faced with attack by a determined opponent, makes the best of a difficult situation by abandoning its internal organs to the enemy. Half a sea-cucumber, it believes, is better than none. And while the predator is busy with its meal, the eviscerated animal slips away and grows a new set of insides.

Camouflage has reached a high pitch of efficiency on the sea-floor. Flatfishes blend with the sand and mud of their surroundings. Some crabs plant gardens of seaweed on their shells to disguise themselves from prowlers. Shellfish encourage snails to establish colonies on their shells.

But attack, on the sea-floor as elsewhere, is the best form of defence. Even the toughest shell is no match for a determined predator who is after the meat inside. Snails will anchor themselves to the shell of an oyster or mussel and bore a small hole in the shell with the help of their rasp-like 'tongue.' Then, at their leisure, they feed on the helpless mollusc inside.

Starfishes slaughter oysters and other shellfish in immense numbers every season. Attacked by a starfish, the oyster closes its shells and holds them as though in a vice. The muscles of the oyster are powerful and can resist a sudden pull. But they cannot withstand the inexorable tug of the starfish. Straddling the oyster, the starfish grips each shell in its sucker-lined arms; then it tugs, unhurriedly but relentlessly. Slowly the oyster gives way. A chink appears between the shells, and the starfish injects a dose of paralysing poison. The resistance of the oyster is destroyed, and it is at the mercy of the starfish.

Crouching over a limpet, a starfish will anchor its suction-disc arms on the limpet's shell and literally drag it from the rock. To digest its food the starfish does not waste time in eating it first. It squeezes its stomach through its mouth, engulfs the body of the shellfish, and then withdraws its stomach again.

A single starfish can eat six large clams in a day. In the oyster-beds of Long Island Sound starfishes enjoy half a million bushels of oysters in a season.

Under natural conditions the balance of life is maintained on the ocean-bed. But where man has encouraged his favourite mollusc, the oyster, to grow he has disturbed nature's equilibrium, and he must fight continually against other creatures anxious to restore conditions to their natural state. In English oyster-beds attacks by slipper-shells and other predators have wiped out so many oysters that the beds have often been abandoned.

To meet the losses caused by the harsh life of the sea most of the invertebrates of the sea-floor liberate eggs in immense numbers. Floating up through the water, the eggs become part of the plankton on the surface. As they hatch the eggs turn into free-swimming larvæ that are remarkably like one another, no matter from which species of parent animal they came. Enjoying their life of freedom, the larvæ propel themselves through the water with the help of rhythmically beating 'limbs.' Then, when the time comes to settle down, they sink towards the sea-bed and search for a suitable place in which to make their permanent home.

Sponges are primitive animals, in which the cells are loosely organized to serve the animal body as a whole. They have a remarkable ability to grow from little pieces, and tiny specks of sponge can build themselves into new and fully representative adults—as though an arm severed from a human being could grow another body. The cells from a piece of sponge can be separated by forcing the tissue through fine silk; if the cells are left to float in water they will get together and develop into a sponge again.

Indestructability of this sort is a feature of many simple animals such as those that inhabit the sea-floor. Starfishes, which cause such havoc among the molluscs, are themselves attacked by all manner of fishes and other creatures of the sea. Left high and dry by the receding tide, they are at the mercy of sea birds and enjoyed by many land animals. To meet the threat of extermination by its attackers the starfish emulates the sponge in its ability to regenerate its body tissues. If a starfish loses an arm it can grow a new one. Sometimes a severed arm will grow another body.

The anemone is no less versatile when it comes to growing new organisms from pieces of an older one. Anemones liberate eggs, but they can also divide themselves into pieces that grow into new individuals. Sometimes a fringe of fronds will appear part way up an anemone's trunk; then the top part will break off and set out to become a new anemone on its own account.

Oysters and other bivalves are usually male or female; but, like snails, they can also be hermaphrodites. Oysters can change from male to female and back again.

Like the eggs and young of free-swimming fishes, the offspring of the animals of the sea-floor are fortunate indeed if they survive and reach adulthood. In addition to the normal hazards of the sea these larvæ have an accommodation problem that does not trouble the fishes. As the larvæ grow they settle on the sea-bed in the hope of finding a place to live. Many are anxious to settle permanently once they have decided on a suitable site; their prospects of continued existence depend upon the care with which they choose their future home. Often they are lucky if they can find a vacant space at all.

Near the sea-shore overcrowding is a serious problem. Food is rich in the sunny, shallow waters near the shore. Algæ flourish; their bodies, and the remains of the fishes that feed on them, fall as a continuous rain of organic food on to the sea-bed. There is plenty of food for animals that enjoy the detritus and organic residues, and sea-bed creatures jostle each other for living-room in the limited space available.

The shores of the continents and the shallow banks of the open sea carry an immense population of invertebrates, and overcrowding is a constant threat to individual existence. Oyster larvæ are lucky if they can find room to grow in among all the other shellfish that infiltrate into the oyster-beds. Young oysters that have settled will often be smothered by late-comers growing on top of them.

Near the shore marine animals have other difficulties to face. The shore is a region of unending change, with daily and seasonal fluctuations in temperature and saltiness of the water. The inhabitants of the sea-shore acquire a versatility that is unusual in sea creatures. They can cope with the changing conditions of their environment much better than ordinary fishes can.

Shellfishes are in constant danger from shifting sands and from mud brought down by rivers or washed by rains from the land. They are battered by waves and tormented by tidal currents that threaten to sweep them away. If they live on the edge of the sea they are left high and dry as the tide recedes, perhaps to be scorched in the sun or deluged with fresh-water rain.

Sea-shore animals protect themselves from their surroundings as best they can. Shellfish grow flattened and streamlined to withstand the crash and rush of the waves and currents. They anchor themselves on the rocks with hawser-like strands or fasten their suction-disc feet with a limpet-like grip. Barnacles and corals cement themselves firmly in place. Oysters retire into their shells and shut themselves in so tight that the rain-water cannot get in.

Though the movement of the water near shore is a source of danger to the animals that live there, it is at the same time a blessing in disguise. Unlike the free-swimming fishes, the lethargic creatures of the sea-bed cannot go out in search of their food; they depend on the water bringing it to them, and water movement maintains the supplies that they need.

As the sea-floor descends from the continental shelf towards the deep ocean-bed the rain of organic matter decreases. Fewer plants and animals live in the open sea than in the shallow coastal waters, and there is less material available from their disintegrating bodies. Moreover, with farther to fall, the organic material has more opportunity of decomposing into simpler substances before reaching the bottom. The red mud of the deep-sea floor is often so lacking in detritus that it supports little more than a few brittle stars and bacteria.

In spite of this scarcity of food, there are animals living in the deepest trenches of the ocean. Often these trenches lie close to the continental shores, and there is sufficient life in the surface waters to maintain a reasonable supply of food. Farther away from the shore, where the ocean may be shallower than in the off-shore trenches, the population of the sea-bed becomes thinner.

Until a century ago it was commonly believed that there was no life on the deep ocean-floor. Then in 1860 a broken cable was brought up from 6000 ft. in the Mediterranean; it was encrusted with molluscs and worms. This was the first positive evidence of life on the deep-sea floor.

In more recent times expeditions have brought many living things from the bed of the sea in different parts of the world. The *Galathea* expedition, in 1952, brought specimens of anemones, bivalves, and sea-cucumbers from the bottom of the Philippines Trench. Bacteria were found in mud that was dredged from a depth of more than six miles; they lived under a pressure nearly 1000 times as great as that of the atmosphere and at a near-freezing temperature. As many as three million live in an ounce of sea-bed mud.

These bacteria, living in a world so different from that enjoyed by their colleagues on land, are different in shape and constitution from ordinary bacteria. Provided artificially with the pressure and temperature conditions they enjoy, the deep-sea bacteria flourish and multiply in the laboratory. What do they feed on? Can they, like green plants, synthesize food they need from simpler chemical substances? Nobody knows.

Like deep-sea fishes, the sea-floor invertebrates are adapted to their strange environment. Prawns that crawl on deep-water mud are equipped with antennæ that may be twelve times as long as the creature's body; with the help of these sensitive organs they can grope through their pitch-dark world. Simple animals like the sea-lilies and sea-feathers reach up like slender plants from the mud, moving imperceptibly in the still, dark water from which they extract their food.

9

Water fit to drink

In ancient times people lived beside the stream or well that could provide them with their drinking water. But as towns and cities grew these local supplies of water became inadequate. Water had to be brought from afar to meet the needs of millions of people crammed into a few square miles of built-up land.

To-day a piped supply of clean, wholesome water has become one of the essentials of modern life. Collecting, storing, distributing, and purifying water is an immense and expensive undertaking in every civilized community. In Britain 97 per cent. of the population receive their water as a piped supply. More than a thousand million gallons of water are used in the country every day; the cost of operating British waterworks is at least £30 million a year.

Three thousand years ago huge aqueducts were built in Persia, Babylon, and Egypt to carry water to the bustling towns. Athens was supplied with water in 520 B.C.; it was carried by aqueduct from a nearby spring. Less than 200 years later water was being brought from the Appenines into Rome; the 2000-year-old conduits remain as monuments to the achievements of the Roman water engineers. The people of Rome used about 200 gallons of water per head every day—more than four times the amount of water used by the people of London to-day.

In Britain, as in other provinces of the Roman Empire, water played an important role in everyday life. Ruins of

Roman baths and wash-houses remain in many parts of the country.

When Rome fell the civilization she had established disintegrated and the Dark Ages settled over Europe. The water supply systems crumbled away with the rest of the Roman buildings. Europe had to wait until the nineteenth century before her people could enjoy ample running water again in many of her towns.

During the Middle Ages some towns in Britain developed water supply systems. Water was carried from a spring or pond above the town; the pipes were made from lead or from the trunks of trees. Wooden pipes, usually of elm, were used for 200 years; each trunk was hollowed out, one end being tapered to fit into the funnel-shaped end of another. But these mediæval water systems were restricted in their scope. The pipes were crude and ineffective. They leaked so much that more water was lost in transit than reached its destination.

Also there was no satisfactory way of bringing water from a distant source, particularly when the source was lower than the town or village.

Throughout the Middle Ages most communities depended on rivers that ran near by or on wells that were dug to reach the water underground. Each householder brought the water he needed in buckets from the common supply.

Even in those days people were concerned about the quality of their drinking water. A law was passed in the sixteenth century forbidding "dogges, cattes and anie cattle, carrion or anie unwholesome uncleane things" being thrown into a river from which drinking water was taken.

During the early nineteenth century the simple water pump was mechanized with the help of steam, and one of the greatest problems of water-supply was solved. Water could be pumped up hill if necessary and brought from lakes and streams hundreds of miles away from the town that needed it. At the same time methods of making cast-iron pipes were devised. Soon water was being pumped through pipes to the growing industrial areas of Britain. Water companies, mostly privately owned, brought running water into thousands of homes. Often they brought water-borne filth and germs as well, which caused epidemics of sickness and disease.

During the last hundred years water-supply organizations have amalgamated and grown and have come increasingly under the control of public authorities. More than £500 million pounds have been spent in bringing water to the homes of British people. One company alone, the Metropolitan Water Board, supplies seven million people with the water that they need.

The growth of these immense water-supply organizations has been accompanied by a realization of the need for constant control of the purity of water. Water that contains harmful germs or minerals can spread epidemics of disease or illness over wide areas. Every possible care is now taken to ensure that water is as wholesome as we can make it by the time that it reaches the domestic tap.

There is no shortage of water in the world. In the sea we have a reservoir of water that is ample to supply all living things. But seawater is so rich in dissolved salts that it is unfit for normal domestic or industrial use.

As the winds blow over the surface of the sea they whisk up water that is carried as vapour towards the land. Forced into the upper air by hills or cooled by contact with the earth, the moisture-laden winds abandon much of their water, which falls to the ground as rain or snow.

When it evaporates from the sea the water leaves its dissolved minerals behind. Rainwater is free of the salt and other chemicals; in a sense it has been distilled. But as it falls through the air rainwater dissolves small amounts of oxygen and carbon dioxide, ammonia and oxides of nitrogen, and other substances in the air. In industrial neighbourhoods it may dissolve substantial quantities of sulphuric acid and other materials released into the air by burning coal. It often picks up dust and dirt as well, and germs of one sort or another that are floating in the air. By the time it reaches the ground rainwater may be highly charged with a variety of mineral and living impurities.

As it trickles over the surface of the earth or drains down through the soil rainwater dissolves more chemicals from the minerals that it meets. It may become polluted by animal or vegetable refuse, and when it has reached the status of a stream or river it will often collect supplies of sewage and industrial effluents as well.

As rain water flows along on its journey back to the sea it becomes steadily dirtier and more dangerous. Most rivers receive land-washings, street drainage and sewage effluents from towns along their route. Intestinal bacteria are commonly found in river water; ordinary sewage contains on average 100,000 bacillus coli in every cubic centimetre. Other germs more dangerous to human health may be found in polluted water as well; germs such as those of typhoid, paratyphoid, and cholera.

Until comparatively recent times many communities in Britain and other industrial countries drew their water supplies direct from rivers and streams. No attempt was made to purify the water at all. Epidemics of water-borne disease were frequent; they became more serious as towns and cities grew in size, and river-water became more and more contaminated. In the early nineteenth century many Londoners were drinking raw river-water drawn from the Thames between Chelsea and London Bridge. One large water company, which supplied 7000 families, had its intake pipe within a few yards of the outlet of the Ranelagh Sewer.

The first supply of water was brought to London in 1613 from springs in Chadwell and Amwell. A thirty-eight-mile aqueduct emptied its water into a pond in Clerkenwell. This early water-supply company was financed by James I, who recompensed himself by taking half the profits.

The water supplied by this New River Company was anything but wholesome, by modern standards. But it was a good deal better than the water that was subsequently taken from the Thames itself.

In 1581 an enterprising Dutchman, Peter Morrys, took out a lease on one of the arches of London Bridge. He built a water-wheel and was able to pump supplies of water to the Londoners who lived beside the bridge. When it was later taken over by the New River Company this old London Bridge Waterworks was distributing some four million gallons a day.

The Metropolitan Water Board, which eventually absorbed the New River Company, is still paying £3750 a year to Peter Morrys's descendants and must go on doing so until the year 2082. The payment is made for the use of the waterwheels that Morrys built on the old London Bridge; the wheels were, in fact, demolished in 1831.

As London grew, so the pollution of the river became steadily worse. During the eighteenth century the Thames was still a salmon river. By 1823 the salmon had abandoned it; yet Londoners continued to drink the raw water for many years after that.

In 1831 an epidemic of cholera killed more than 50,000 people in London. Similar epidemics followed in 1848, 1853, and 1865. At this time people still thought of disease as being caused by impure vapours in the air. Pasteur had not then established his germ theory of disease. And dirty drinking water, though accepted with distaste, was not regarded as a menace to public health.

Yet in 1854 a London doctor, John Snow, suspected that an epidemic of cholera in Soho was caused by polluted water taken from a Broad Street well. He persuaded the authorities to remove the handle from the pump, and the outbreak of disease was quelled.

By this time the quality of London's water had become so bad that legislation was being introduced to control the water companies. A Bill was passed which forced the companies to take their supplies from the river above Teddington weir. The water from this source was impure; but it was not so polluted as to offend the senses in the way that the water of the lower reaches did.

Meanwhile, during the early years of the nineteenth century, James Simpson, Consulting Engineer to the Chelsea Water Company, had discovered that he could purify water by filtering it through beds of fine sand. This removed the dirt and floating particles which made polluted water so objectionable. Though Simpson could not realize it at the time, his filtration did much more than that; it removed many of the harmful germs from the water as well.

As the demand for clean water grew filtration was adopted more and more in Britain. So successful was the process that the 'English System' of water purification was used by towns all over the continent. It became the basis of the modern techniques of water purification which have done so much for public health to-day.

An example of the efficiency of sand filtration was provided by the cholera outbreak that raged in Hamburg in 1892. More than 8000 people died in the town following infection of the Elbe by germs from a camp of Russian emigrants. In the adjoining town of Altona only about 1000 people died, and most of these had been living in streets supplied with water from Hamburg mains. The Altona water supplies were sand-filtered.

During the late nineteenth century clean water campaigns in Britain, America, and other industrial countries gradually restricted the epidemics that had been causing so much suffering and so many deaths since the Middle Ages. Small water companies amalgamated, forming organizations with resources that could treat the water adequately. In London, for example, the Metropolitan Water Board was created by amalgamation of eight private water companies and a few small undertakings in the London area. The Board now serves an area of more than 500 square miles, supplying seven million people with as much as 50 gallons each per day.

The Metropolitan Water Board is a gigantic modern water supply organization typical of those that serve our large towns and cities. Day in, day out, it delivers a seemingly limitless supply of clean, wholesome water to millions of homes and factories.

Water for a modern community may come from several sources, all supplied initially by the rain that brings us water from the sea. Countries like Britain, with temperate climates, are provided with a supply of rain that is ample to meet the people's needs. Britain is presented with at least five times as much rain as her animal and vegetable populations can use. But not all the rainwater remains on the land. One-third of it is re-evaporated and returns to the air. Some of the rest flows over the surface, finding its way into streams and rivers as it sets off on its journey back to the sea. The remainder sinks into the ground, soaking into the porous rocks and soil to form the underground water-supplies that lie beneath even the most arid desert land.

Water needed by a modern community is drawn either from the surface water flowing over the land or from the underground reservoirs that hold immense supplies in many parts of the world.

When impervious rocks, like granite, lie near to the surface water cannot penetrate to any great depth and much of the rainwater runs off the surface of the land. In Scotland and Wales and in the Lake District of England the surface rocks are hard and solid; as little as one-hundredth of their volume consists of pore-space into which water can flow. When rain falls on these rocks it cannot penetrate in any appreciable quantity, and water flows away down the valleys towards the sea.

In regions of this sort water is collected and stored by building dams across the valleys; huge reservoirs are formed, in which the water is held by a giant basin of impervious rock. Liverpool draws water from reservoirs in the Welsh hills. Manchester is supplied from Lake Thirlmere, in which the level has been artificially raised.

In Southern England and the eastern and midland counties sedimentary rocks, like chalk, limestone, and sandstone, lie near the surface. These rocks are porous and fill with water like a gigantic sponge. Sandstone can absorb nearly half its volume of water. Some limestones are riddled with caverns that act as underground reservoirs holding millions of gallons of water.

Often the water is retained in these porous rocks by a layer of impervious clay or rock that lies below the sedimentary strata. When the impervious rock slopes down towards the bottom of a hill water from the porous rocks above will spurt from the hillside as a spring. But if the impervious lining of rock dips down in a basin-like hollow it will hold the water above it, forming an underground reservoir.

The city of London is built over a huge natural reservoir of this sort. A basin of chalk sweeps under the city, emerging to form the Chiltern Hills in the north-west and the Downs in the south. Beneath this basin of chalk lies a layer of impenetrable rock and clay, and above the chalk is a lid of clay on which the city stands.

As rain falls on the hills in Surrey, Hertfordshire, and Bedfordshire water soaks into the porous chalk and flows underground to collect in the basin beneath London. It cannot escape through the rock lying under the chalk, nor can it be forced through the surface clay by the head of water in the hill-chalk behind it. A reservoir is formed, with the water maintained under pressure. When a borehole is drilled through the surface clay water is forced upwards by the pressure to form an artesian well.

To-day, about a sixth of London's water is drawn from the supplies underneath the city. So many artesian wells have been sunk that the level of the water has been falling for years. Some wells have run dry as the water has sunk below the bore-holes.

Most of London's water is now drawn from the rivers Thames and Lea. And, in spite of the heavy pollution that mars these rivers, the water that reaches the Londoner's home is wonderfully healthy and pure—a tribute to the efficiency of modern methods of water treatment.

The germs that live in water are surprisingly sensitive creatures. They will die if the water is left to stand, and the storage of water in reservoirs is in itself a purification treatment. Professor Perry Frankland showed that bacteria will survive being carried over Niagara Falls, only to die in the quiet waters of Lake Ontario.

Where water is drawn from a storage reservoir in the hills, it is usually pure and contains few dangerous germs. Every effort is made to prevent unnecessary pollution by protecting the surrounding hillsides. And germs that do get into the water have died of inactivity before they can leave the reservoir.

When the water is taken direct from a river it is often pumped into storage reservoirs. These provide a reserve supply of water and also encourage bacteria to die and floating impurities to settle out. The water may have been standing several weeks between entering the reservoir and leaving it. River-water for London is held in reservoirs in the Thames Valley above Teddington, where huge basins have been scooped from the London clay. Biggest of all, the Queen Mary reservoir covers more than 700 acres and holds nearly 7000 million gallons.

Though storage discourages germs, it tends to encourage the algæ that are always present in water. Living at peace with the world, these tiny plants flourish in the quiet water of a reservoir. They are relatively harmless, but clog up the filters as the water goes through its next purification stage. Also the algæ tend to flavour the water. Each tiny plant has its own characteristic bouquet. Some are described as 'fishy' or 'grassy'; others, even more alarming, as 'pigpens' or 'onions.'

When algæ have overreached themselves in the storage reservoirs chemicals such as copper are used to destroy them. In 800 B.C. it was known that copper could keep water pure; a Sanskrit author described how "It is good to keep water in copper vessels, to expose to sunlight and filter through charcoal." Water is still stored in copper vessels in Eastern countries to discourage algal growth.

The use of copper sulphate as a modern algicide was developed by the United States Department of Agriculture. In extremely dilute solution—far too week to affect human beings—copper sulphate was found to destroy algæ that were clogging water-cress beds. Water will pick up enough copper to kill algæ merely by flowing through a brass tap.

Nowadays copper sulphate is widely used for destroying algæ growing in reservoirs; but if too many algæ have made their homes in the water their decomposing bodies will create another problem for the water chemist.

As it is taken from the storage reservoir or direct from the river water is filtered to remove twigs and coarse particles. This preliminary filter consists of a concrete basin with a porous floor covered by a layer of sand supported on gravel. The water trickles through the sand, leaving the coarse impurities behind.

This first filtration does little to remove bacteria, so the water is given a second filtration; this time through a bed of fine, sharp sand. As it flows the water leaves a layer of organic matter on the top of the sand; this jelly-like mass, or 'biological layer,' traps the germs and destroys them and removes even the finest floating particles from the water.

Sometimes sand filters of this sort will run for months without needing cleaning. But in time the biological layer becomes so thick that the water cannot flow through it. The filter tank is drained and the top layer of sand and organic matter is skimmed off. It can often be rolled up like a carpet.

Successive layers of sand are removed in this way until eventually the filter-bed becomes too thin and has to be renewed with fresh sand.

When sand-filtration of this sort was introduced into England more than a century ago it was meant to remove the more obvious floating impurities from river water. But it was soon realized that the filter did a great deal more than that. It purified the water and made it wholesome, although nobody knew how or why. Even to-day we do not understand how the biological layer destroys bacteria in the water.

As the demand for water increased at the turn of the century slow filtration through these beds of sand was often inadequate to provide the amount of water needed. A new technique was devised, water being forced under pressure through the filter-bed. This speeded up the flow, but reduced the efficiency of the purification. Bacteria and fine particles found their way through the biological layer.

To overcome this drawback to pressure-filtration water chemists now add aluminium salts and other chemicals to the water before it is filtered. These salts release a 'snowstorm' of jelly-like particles in the water, each particle enveloping bacteria and fine impurities and carrying them to the bottom of the settling tank. The jelly-like particles that reach the filter help to make an effective filter-bed.

After coagulation and filtration water is normally free of algæ, bacteria, and other micro-organisms, and of floating particles of inanimate matter. But as an added safeguard water for domestic use is sterilized to make sure that any dangerous germs are destroyed before the water reaches the tap.

Chlorine gas is the usual sterilizing agent. In very small concentrations, about one or two parts of chlorine per million of water, chlorine will kill disease-germs without making the water unpalatable. The gas is usually bubbled into the water as it flows into a storage tank; by the time the water leaves the tank the chlorine has done its work and the water is germ-free and tasteless.

In Britain and other western countries water-borne diseases are now so rare that their appearance makes headline news. Before 1911, when Portsmouth's water was not filtered, the annual typhoid rate was 21 per 10,000 of population. After 1911 filtration helped to reduce the typhoid rate to 8 per 10,000. And since 1925, when water was also chlorinated, typhoid has been almost unheard-of in the town.

During World War II millions of men fought in jungles and deserts, and supplies of wholesome water became as precious as ammunition. In North Africa water was brought to the troops by tankers, and special purification units were devised for treating local water supplies where these were available. Soldiers fighting in the jungle carried tablets that enable them to chlorinate the water they found.

During the Korean War a new type of water-purifying tablet was introduced, in which iodine took the place of chlorine. This iodine tablet was more effective against amœbic dysentery and diarrhœa. It did not flavour the water as the chlorination tablets do, and the water was less objectionable to drink. The dysentery rate during the Korean War was 47 per 1000 between June 1950 and February 1951. By comparison the rate for troops in Asia in 1944 was 93 per 1000 and, in 1943, 181 per 1000.

Though chlorine has established itself as a water purifier during recent years, ozone is becoming increasingly popular. Ozone is a special form of oxygen, in which the atoms are grouped in threes instead of in the normal pairs. It is made by passing oxygen through an electric spark. When ozone is bubbled into water the oxygen atoms revert to their paired existence, the odd remaining oxygen being used to oxidize and destroy any germs it meets.

When ozone is used for purifying water in this way it leaves behind a residue of oxygen, which adds to the sparkle and life of the water. There is no objectionable taste such as chlorine may leave if it is used to excess.

With the help of these modern techniques of purification water is being supplied in enormous quantities to towns and cities all over the world. A typical British town uses between 30 and 50 gallons of water per head of population every day. In the United States, where water hygiene has often reached a fantastic level, the amounts can be several times as great. New York, for example, uses 130 gallons per head every day; Chicago supplies its people with more than 275 gallons each per day.

In London water is distributed through nearly 10,000 miles of pipes; some are four feet in diameter. Purity tests are made at every stage in the water-supply system. Even during the war there was not a single case of typhoid in London caused by infected water.

We tend to accept our drinking water as though it was merely something provided gratis by a bountiful nature. But, in fact, water is a chemical raw material of life that must be collected and purified in tremendous quantities by man. No other raw material is produced in such volume and of such consistent purity.

On an island in Amwell Pond, Hertfordshire, there is a memorial stone which reads "Man cannot more nearly imitate the Deity than in bestowing health." This stone commemorates the opening of London's New River Water supply in 1613. To-day the Metropolitan Water Board helps to maintain the health of seven million people by providing them with water 'fit to drink.' And all at a cost of about 4*d*. a ton.

10

Fresh Water from the Sea

As it trickles over the land and sinks down through the soil water dissolves small amounts of rock and mineral matter. Some of these dissolved impurities are dangerous to human health—for example, when the water has picked up arsenic salts—and must be removed by chemical treatment of the water before it is allowed to reach our homes. Usually the salts are harmless and may, in fact, be beneficial; they are left in the water, and we drink them regularly without even knowing they are there. Water from the tap is pure in the sense that it is wholesome; it is impure inasmuch as it contains a ration of dissolved salts.

Spring water or water from an artesian well is often rich in mineral salts. The water has had ample time to dissolve the minerals as it sinks down through the soil and rocks. It has been filtered of its bacteria and other suspended matter and is normally fit to drink without any further purification. But it is charged with an extra supply of dissolved material instead.

Sometimes the minerals in spring water may include small quantities of salts that have medicinal value. These springs have often become the basis of a spa or health resort. Vichy water contains a dose of sodium bicarbonate that has served to make its health-giving properties famous throughout the world. The waters of Droitwich Spa contain bicarbonate and salt as well. At Harrogate there are springs rich in iron salts and others charged with hydrogen sulphide. Buxton is thoroughly up to date with water that is slightly radio-active.

Even water which has merely trickled over the surface of the land may dissolve sufficient salts to give it noticeable properties. Rainwater is usually acid and corrosive after dissolving carbon dioxide as it drops through the air. It dissolves the calcium carbonate of limestone, chalk, and other common rocks, forming a solution of calcium bicarbonate with the help of the carbon dioxide gas that it contains. By the time it reaches the reservoir river water will often contain enough bicarbonate to give it a sharp, refreshing taste. Thames water dissolves a lot of chalk on its way to the storage reservoirs. The mineral content of many of these surface waters has sometimes given them invaluable properties. The waters of the Trent at Burton, for example, contain a small amount of calcium sulphate which makes them especially suitable for brewing.

The concentration of dissolved salts varies greatly from one place to another, depending on the minerals in the earth on which the rain has fallen. Water that contains a lot of calcium bicarbonate and other salts is described as 'hard'; water that is comparatively free of these salts is 'soft.'

Although the salts dissolved in domestic water are quite harmless, they can be objectionable to us in other ways. They cause real difficulty when the water is used for domestic washing or in industry.

The salts dissolved in hard water will undergo chemical reaction with soap. They turn the soluble soap into an insoluble calcium or magnesium soap. Instead of dissolving in water, the soap floats as a hard scum on the surface. It cannot do its job of loosening dirt and grease until it has finished reacting with the salts dissolved in the water. Hard water not only wastes the soap in this way, but spoils the finish of fabrics being washed in the water by contaminating them with scum. In dyeworks, hard water alters the shades by reacting chemically with the dyes;

in tanneries it attacks the tannin chemicals and affects the quality of the leather.

Much of the water supplied by modern waterworks is used by industry for steam-raising. In power stations and factories, in ships and locomotives the water goes into boilers to be turned into steam. And the minerals in hard water coat the boilers and tubes with a rock-like layer of scale that costs us millions of pounds a year in wasted heat and damaged equipment.

Limestone is the commonest cause of all these scales and furs. Hard water, containing calcium bicarbonate, is heated in the boiler; the carbon dioxide gas that enabled it to dissolve the calcium carbonate from limestone is driven off, and the insoluble calcium carbonate settles out from the water again. Gradually a rock-like scale builds up on the wall of the boiler, providing an effective heat insulator between the water and the furnace. A layer of scale no thicker than a postcard can waste a twentieth of the heat in a steam boiler.

Scale blocks water-pipes and valves and increases pumping and cleaning costs. Salts and dissolved gases in hard water can also corrode and weaken the metal of a boiler.

Even on its way to the domestic user water can attack the metal pipes through which it flows. Acid waters will dissolve small quantities of lead from pipes, sufficient to cause lead-poisoning. Authorities in many districts now insist on copper pipes being used in domestic systems where the water contains dissolved materials that encourage corrosion of lead or iron.

When water is too rich in minerals it is treated at the source by adding chemicals to the reservoir. A careful analysis of the water is made, and calculated amounts of chemical are added to remove the impurity as an insoluble deposit. Lime is often used in this way to soften water that is too hard. Sodium silicate—'waterglass'—is added to prevent lead-poisoning in acid waters.

Although this 'treatment at the source' is used when water is unusually hard, most water-softening is done at the user's end of the supply system. The degree and nature of the softening depends upon the way in which the water is to be used. The softening of industrial water has now become a highly specialized technique; each type of water is assessed and treated individually to provide the type of water that is needed.

The domestic water-softener has now become familiar equipment in the home. Inside the softener water flows over special chemicals called zeolites, which absorb the calcium, magnesium, and other mineral elements from the water, providing sodium in exchange. The sodium salts emerging in the 'softened' water do not react with soap in the way that calcium and magnesium salts do.

When the sodium-providing power of the zeolite is exhausted it can be restored by pouring a strong solution of sodium chloride—common salt—through the softener. The calcium and magnesium absorbed by the zeolite are replaced by sodium, and the softener is ready for action once again.

This type of 'ion-exchange' softener is widely used by industries needing soft water for washing purposes—for example, in the textile trade. But ion-exchange is not a universally useful technique; it does not remove the salts from water altogether, but replaces them by others less objectionable when soap is being used.

During recent years ion-exchange has made great progress, and there are zeolite materials that can soften all types of hard water. Some, made by treating coal with sulphuric acid, exchange the calcium and magnesium in the water for hydrogen. The water emerging from the softener consists of a mixture of acids instead of salts. Other zeolites have been made from special types of resin; they can absorb acids from the water. By combining these two types of zeolite it is possible to produce water that is substantially free of dissolved salts.

The development of these new zeolites has given us a way of making water that is not only softened but is salt-free. It is comparable with distilled water.

This demineralization of hard water has become a high-priority research problem since World War II. Its use has been extended from the purification of hard domestic and industrial waters to the treatment of seawater. It may give the world an entirely new source of the fresh water that it needs so urgently to-day.

Many areas of the earth are barren and unproductive through lack of the water necessary for growing crops. These great arid deserts are often potentially fertile; they can provide the mineral salts and soil-structure that would support a covering of vegetation. But without a supply of water the ground is lifeless.

Even more of the earth's surface is producing only limited returns of crops; the water-supplies are inadequate to maintain a lush, prolific vegetation. Countries with a moist and temperate climate could often benefit from additional supplies. Irrigation would be profitable even in many English fields.

In the arid regions of the East, in Africa, and Australia a plentiful supply of cheap irrigation water could bring immense returns of food to a hungry world. Industry could be established where it is now held up by lack of adequate water resources. Water is an essential raw material for almost every industry. Without water there can be no industrial development on any scale.

A simple, cheap method of removing salt from seawater could bring economic changes comparable with those that we shall get from nuclear energy. The small quantity of dissolved salts in seawater are blocking the way to economic progress in many countries of the world.

Since World War II great efforts have been made to find a way of removing salts from seawater cheaply and on a large scale. Some countries have a direct and urgent interest in this research; in the Netherlands water from wells and rivers is becoming more and more salty, and a cheap demineralization process is a desperate need. Israel has reclaimed once-desert regions, such as the Negev, and must have ample supplies of fresh water for irrigation and industrial development. The United States has immense regions of bleached and arid desert in the west that could be brought under the plough if water was available to make it fertile. These countries are all technically advanced, and faced with a technical problem they have brought immense research pressure to bear upon it. Already results have been encouraging.

The demineralization of seawater differs only in degree from the removal of hardness salts from drinking-water. Domestic water usually contains a few parts per million of salts dissolved in it; seawater contains about 3½ per cent. of dissolved salts. From the practical standpoint, however, the high concentration of salts in seawater makes demineralization into an entirely different technical problem.

The process selected by nature for her immense water-purification system is based on distillation. Water from the sea is turned into vapour with the help of energy provided by the sunshine. Water-vapour disappears into the air, leaving the salts behind in the sea. Then, over the land, the water-vapour turns to rain, bringing the earth its supplies of demineralized water.

For centuries man has been imitating nature to provide extra drinking water when natural supplies were inadequate. Aristotle describes how pure water can be made by distilling water from the sea. St Basil explains how "Sailors, too, boil even seawater, collecting the vapour in sponges to quench the thirst in pressing need."

Distillation is a simple process. Water is heated; it boils and turns into steam. When the steam is cooled, liquid water is formed again. Impurities are left behind in the vessel in which the water was boiled. Distilled water, for example, can be collected by holding a cold plate in the steam escaping from a kettle spout.

Although distillation is so simple, it is an expensive process to use on the scale needed for an industrial or agricultural water-supply. Energy has to be poured into the water to turn it into steam, and energy means fuel such as coal or oil. Fuel is costly in our modern world, and our resources of solid and liquid fuels are not unlimited.

Nature herself draws upon the sunshine that reaches the sea in immense amounts every day. Measured by our everyday standards, the energy she uses is prodigious. To evaporate the seawater needed for 1 inch of rain falling on a square mile of land, for example, we should have to burn more than 6400 tons of coal. The sun lifts millions of times as much water as this into the air every day.

During the last century or so distillation has become more and more efficient as a scientific technique. In spite of its need of costly fuel it has been used for purifying seawater to provide freshwater under special circumstances. Ships and bases on arid shores depend on distillation plants for their water supplies. At Aden distillation was the main source of water until a deep well was sunk in 1927.

Straightforward distillation still serves when cost is a secondary consideration. But the development of modern techniques is reducing fuel costs to the stage where distillation may become cheap enough to supply water on a large scale. In hot countries there is an ample supply of energy provided every day by the sun. This solar energy is free and could be an ideal source of energy for distillation if methods of using it efficiently were to be found.

Distillation itself has improved and ingenious refinements have been devised. It may be possible, for example, to use seawater from different levels as the energy-source for distillation. After World War I a plant was built in Cuba in which warm surface water was evaporated under reduced pressure, the vapours being condensed by cold water brought from the depths. Currents were uncertain at the site, however, and the plant did not work well.

French engineers have built a plant of this type at Abidjan to draw on the energy stores available in the sea (see Chapter 3). The low-temperature steam, after driving turbo-generators, will be condensed to fresh water. Every day 150,000 gallons will be available, in addition to the 10,000 kilowatts of electricity. This type of distillation plant, drawing on the heat resources of the sea, could become a source of cheap fresh water for industry and for irrigation in tropical countries.

When garrisons had to be maintained on Pacific islands during the war fresh water was supplied by another distillation process. Water is heated to turn it into vapour, and the vapour is then compressed. The pressure makes the vapour condense to water again, and the heat set free is used to vaporize more water.

Compression distillation of this type uses less fuel than conventional distillation. Energy is needed only to compress the vapour, and not to heat the water. More than one million men were supplied with fresh water made in pressure stills on Pacific islands during the war. In Bermuda and other isolated communities stills of a capacity of 50,000 gallons a day are now in regular use. Thirty gallons of water can be distilled from seawater at a cost of only 1 lb. of solid fuel

Although these distillation processes have made such rapid progress, it seems likely that they will be overshadowed by new ion-exchange techniques developed in recent years. During World War II great efforts were made to discover a simple and efficient device for demineralizing seawater which could be used by shipwrecked sailors and airmen. Weight and size had to be kept to a minimum, and the device had to be simple enough for an injured or exhausted person to use. A chemical demineralizer was obviously preferable to a bulky and comparatively complex still.

Using ion-exchange materials similar to those in use for domestic water-softening, British scientists developed a simple gadget the size of a packet of tea. Tablets of chemical were added to seawater in a plastic container; the chemicals demineralized the seawater leaving water pure enough to drink.

Though these devices could provide a quart or two of fresh water quickly and easily, they were suitable only for emergency use. The chemicals were expensive and were needed in appreciable amounts. The process, as it stood, was not suitable for large-scale use.

President Roosevelt took a special interest in these ion-exchange materials. In 1943 he maintained that within fifty years they could be providing cheap irrigation water from the sea for the arid regions of Africa, the Middle East, and Australia.

At that time this seemed an over-optimistic prophecy. But as things have turned out President Roosevelt may be proved correct. Scientists in the Netherlands and in Israel have developed ion-exchange processes for purifying the brackish water of rivers and underground streams. And in the United States scientists at Harvard Medical School have constructed special ion-exchange membranes that can be used for the continuous purification of seawater.

These membranes are films of inexpensive plastics containing ion-exchange chemicals. Water is allowed to flow into an apparatus containing the membranes, and with the help of electricity the dissolved salts are encouraged to remain on one side of the membrane as the water flows through to the other side. Two streams flow from the apparatus; one stream, representing about two-thirds of the original seawater, emerges as fresh water; the remaining third of the water emerges as a concentrated solution containing all the salts.

Membranes are used in this way by all living things to control the flow of water and salts within the body. Water can flow through membranes forming the cell walls, dissolved salts being left behind. Selective membranes are able to supervise the flow and concentrations of the body fluids. It is not surprising, therefore, that we should be using membranes in an effort to control the concentration of salts in seawater.

A novel type of membrane has been developed by an engineer associated with the University of California. The membrane consists of a thin layer of oil supported by capillary action. Water molecules can diffuse through the oil film, the dissolved salts being left behind. A plant no bigger than a tea-chest, costing about £350, could be packed with oil membranes that would provide 2000 gallons of fresh water every day for twenty years.

There is no doubt that these processes for demineralizing seawater will come into practical use throughout the world. There are many communities where water is so scarce that it is worth £2 or £3 a 1000 gallons. But the real value of demineralization lies in its ability to provide fresh water on the scale we use it in a modern industrial community or for irrigation. And the controlling factor in this case is the cost.

Ion-exchange with a reasonably cheap source of electricity could probably provide water at a cost of 1*s*. 0*d*. to 2*s*. 0*d*. a 1000 gallons. Distillation would cost perhaps ten times as much. Even at a cost of 3*s*. 0*d*. per 1000 gallons water could be used economically on a large scale in many parts of the world. It seems probable, therefore, that the ion-exchange process, which began with our domestic water-softener, is going to join nuclear energy in transforming the face of the earth in years to come.

11

Dental Treatment through the Tap

WITH the growth of huge water undertakings water has become an important factor in human environment. By living in a certain town or village we commit ourselves and our families to drinking water from a certain source. If water was always absolutely pure this would not make any difference one way or another. But water as we get it from the tap is inevitably a solution of many different minerals. The concentration of dissolved substances is usually small. But water is something that we need every day and taken over the years the amounts of the water-borne minerals we drink can be impressive. By drinking water at a rate of two pints a day we imbibe nearly 100 gallons in a year. This may contain as much as three ounces of dissolved lime.

These minerals we absorb with our water are in general absolutely harmless. Hard water has been blamed for everything from housemaid's knee to rheumatism and tuberculosis. But the lime and salt and other common minerals dissolved in water have been there since man drank water from the pools he came across when hunting prehistoric beasts. If they are doing us any harm it is much too late to worry about it now.

Sometimes, as we have seen, these minerals in our water may have medicinal qualities, and we go out of our way to drink them. Occasionally the people of a certain district will suffer through a deficiency of some substance in their water. Insufficient iodine in the drinking water, for example, can give rise to diseases of the thyroid gland. We have in this respect learned to depend on our water for supplies of some of the elements we need for bodily health.

In districts where there is a shortage of iodine in the water supplies of the element may be added deliberately at the waterworks. In this way water is used as a 'carrier' in which we can distribute nutrient salts to every individual in a community. This technique is being widely used to-day to provide a supply of the element fluorine, needed for the growth of healthy teeth.

Fluorine itself is a firebrand element. It is a gas so reactive that it combines chemically with almost everything else it meets. For this reason fluorine is never found free in nature; it is always combined with other elements in the form of minerals, such as fluorspar.

When water trickles over ground that is rich in fluorine minerals it dissolves small quantities which remain in the water that finds its way into our homes. In certain districts drinking water is unusually rich in fluorine.

Since 1908 it has been known that this extra supply of fluorine in drinking-water causes the discoloration of teeth which is characteristic of some localities. Fluorosis, as it is called, appears as white patches on the enamel of the teeth. In severe cases the patches may go brown and the surface of the teeth is pitted. Girls living in a 'fluorosis district' often have their teeth removed as the discoloration becomes unsightly.

Yet the discoloured teeth of a fluorine-rich region have long been known to resist decay better than teeth in districts where there is little fluorine in the water. Examination of mottled teeth has shown that they take longer to dissolve in acid. They contain a higher proportion of fluorine in them than ordinary teeth. It seems that the extra fluorine in the drinking water is able to find its way to the teeth and increase their resistance to decay.

Before World War II scientists had been studying this effect of fluorinated drinking water on tooth-decay. People receiving extra fluorine in their drinking water were apparently quite healthy and suffered no ill-effects from the dissolved fluorides. It was reasonable to suppose that by adding fluorine to drinking water that did not contain it the dental health of whole localities could be improved.

It was shown that mottling of teeth was caused by too much fluorine—far more than was needed to strengthen the teeth against decay. One part of fluorine in every million parts of water would give decay-resistance to the teeth without causing discoloration at the same time.

In 1945 large-scale experiments began in the United States and Canada to assess the effect on teeth of adding fluorine to drinking water. Three communities were chosen: Grand Rapids, Michigan; Newburgh, New York; and Brantford, Ontario. Extra fluorine was added to the water distributed through the public supply systems of these towns; it was dissolved in the water in the form of simple salts such as sodium fluoride.

The fluoridation experiment was planned to last for ten years. During this time dental and medical examinations would be held and the effect of the fluorine assessed statistically.

Long before the end of the ten-year period the extra fluorine was having a dramatic effect, particularly on children's teeth. More communities in the United States began to fluoridate their drinking water, and so much evidence accumulated in favour of fluoridation that by 1951 the American Dental Association had given official encouragement to the new technique.

By 1955 more than 1000 communities in the United States were adding fluorides to their water-supplies, and nearly twenty million people were being given dental treatment via the kitchen tap. Another fifteen million Americans were drinking water in which there was sufficient natural fluoride to protect their teeth.

The effect of fluorine is most pronounced in the case of children. The element makes its way to the teeth as they are being formed and is incorporated in the teeth during calcification. American experience has shown that decay-prevention is most marked when fluorine is provided during the first eight or nine years of life. The influence of fluorine persists into later life, strengthening the teeth of adults who drank fluoridated water during childhood.

Once the teeth have been formed, however, supplies of fluorine in the water have little effect. Adults who have grown up in communities where there is little natural fluorine in the water do not benefit from fluoridation when their teeth have formed.

In Grand Rapids, fluoridation had by 1951 reduced the tooth-decay of six-year-olds by more than half, of nine-year-olds by one-third, and of 13-year-olds by one-sixth.

In Newburgh four years of fluoridation cut the decay of children's teeth by 32.5 per cent. After eight years the rate of tooth-decay was about half the rate when fluoridation began. These results in the test communities have been confirmed by the experiences of other communities who have been fluoridating their drinking water. Tests in twenty-two cities of the United States have shown that fluoridation can reduce the average number of cavities in children's teeth from seven to two. And the cavities are smaller. The overall effects of fluoridation vary widely depending on the local conditions and the amount of naturally-derived fluorine in the drinking water. The reduction in dental decay has been as little as 20 per cent. and as high as 75 per cent.

In Britain the effects of extra supplies of fluorine occurring naturally in drinking water have been studied for some years. As in the United States, it was found that children's teeth were decay-resisting in communities with extra fluorine in the water. In Britain as a whole there are on average 0.2 parts of fluorine per million of water. But in some parts of the country there is more than one part per million of fluorine—enough to ensure decay-resisting teeth. Colchester, South Shields, and Slough are high-fluorine communities; North Shields, Ipswich, and Reading have only insignificant amounts of fluorine in their drinking-waters.

In South Shields, where the water contains 1.4 parts per million of fluorine, the incidence of dental caries in children twelve years of age is 45 per cent. less than in North Shields, where the water contains only 0.25 parts per million.

A study was made of the teeth of expectant and nursing mothers in British communities. Women who had lived all their lives in high-fluorine areas had better teeth and fewer cavities than women in low-fluorine areas. The improvement in dental health was equivalent to an age difference of about ten years.

In 1952 a British mission visited the United States and Canada to study fluoridation results. They reported that the evidence was conclusive; fluorine was undoubtedly effective in improving dental health, particularly of children. The mission suggested that before fluoridation was introduced generally into Britain carefully controlled experiments should be carried out on a large scale. The human 'guinea-pigs' taking part should have periodic dental and medical examinations throughout the experiment.

In 1955 this experiment began and four communities were chosen for 'fluoridation.' Encouraged by the Ministry of Health, Anglesey, Kilmarnock, Darlington, and Watford began fluoridation of their water-supplies.

The British approach to fluoridation has been more hesitant than that of the United States, but there is a good deal to be said in favour of caution. Adding chemicals to the public water supply is not to be indulged in lightly. Experience in the United States and Canada, however, has shown that fluoridation is safe and harmless if it is carried out under proper control. By adding fluoride to water to raise its concentration to about one part per million we are merely doing what nature herself is doing to the water supplies in many parts of the world. The controlled addition of fluorides to drinking-water has been encouraged by medical and scientific authorities in the United States, including the American Medical Association, the American Dental Association, the National Research Council, and the United States Public Health Service.

In 1952 the American Medical Association stated that there is no evidence of toxicity which might deter cities from fluoridating water supplies. The only real difficulty is an increase in the mottling of teeth enamel which occurs in a small percentage of children drinking the water. This is so slight that it does not present any problem with regard to the appearance or strength of the teeth. The use of fluorides in drinking-water at a concentration of up to one part per million is considered safe.

Inevitably there has been a great deal of controversy over this wholesale medication of our water-supplies. The opponents of 'socialized medicine' have come out in full cry against it, proclaiming that it denies the individual his freedom of choice; he has to take his fluorine whether he wants to or not. This attitude has little to recommend it in our modern world. The civilization we have built for ourselves can exist only by restricting the freedom of the individual to some degree in the field of public health. Few people nowadays are anxious to go back to the days when cholera epidemics could be nurtured by unchlorinated water or smallpox could bring death or disfigurement to millions of unprotected people every year. Dental caries is the commonest disease in the world; it affects 98 out of every 100 people. It is not a killing disease and has little dramatic appeal about it. But tooth-decay is insidious in its effects on public health; it poisons the human system with little doses of objectionable material every day, thus weakening the body's resistance and encouraging other more serious diseases to establish their hold.

Sometimes dental caries settles in so soon that first teeth in children are decayed when they appear. On average, children of five have five decayed teeth, and adults often lose all their teeth before they are thirty.

Anything that can be done to improve dental health is worth doing, so long as it is safe and will not harm the body in other ways. Fluoridation has been tried and tested now for many years, and, so far as anything we take into our bodies can be proved harmless, fluoridated water is perfectly safe.

One of the main objections raised by 'anti-fluoridationists' is that we have inadequate control over the amount of fluorine that is absorbed from day to day. Most human foods contain a small amount of fluorine in them; seafoods and tea are particularly rich in the element. The concentration of fluorine in a cup of tea may reach one part per million, equal to the amount that is present in fluoridated water.

It has been found that the body begins to store fluorine when the intake is at about 2 milligrams daily. This amount would be provided by 3 pints of water containing 1 part of fluorine per million and 4 cups of tea. With the fluoride in water controlled at 1 part per million there is little likelihood of anyone absorbing an overdose for prolonged periods.

People have reacted strongly to the suggestion that fluorides are poisonous substances and should not be put into water for human consumption. This argument against fluoridation betrays a lack of understanding of the meaning of toxicity. Many substances eaten regularly are poisonous if taken in unusually large amounts. Aspirins are deadly if we eat enough of them, and so is common salt. The toxicity of any substance depends not only on its chemical nature but upon the amount absorbed by the body.

As in all the familiar controversies over the desirability of eating different forms of human food, the difficulty in the case of fluorine is that the argument cannot be resolved. We can assess the toxicity of a substance taken in single doses or over a few months or even years. But only experience can tell us what is going to happen when we absorb small quantities of fluoride or any other food additive over fifty years. We eat table salt with equanimity to-day because we have been doing so for centuries past. It may be shortening our lives in some mysterious way, but we no longer worry about it. Some day we may find table salt taking over from tobacco as the villain of the piece, and a chemical we have enjoyed for so long will be shunned as a menace to public health.

In the case of fluoride we have reached the stage where we know that it can be of value to us in improving dental health. We have made all the tests that can reasonably be made, and on the evidence the fluoride does not do us any harm. But, as in the case of any modification to the human diet, we must take some sort of calculated risk. We cannot return to the cave-man era when teeth were employed on a 'natural' diet. We must move forward and make use of any help that scientific discovery can give us to maintain our complex, urbanized society.

At one part per million in our drinking water fluoride is odourless and tasteless. It has no adverse effects on industrial processes such as brewing or bottling, baking or laundering. At a cost of somewhere between 4*d.* and 1*s.* 0*d.* per head per year it can do much to improve the dental health—and, in consequence, the general well-being—of our children.

Fluoride has aroused public interest by being added deliberately to water destined for human consumption; but there are other chemicals being added to water in enormous quantities in our homes to-day in the form of cleansing agents and detergents. These, too, are being absorbed into the human body in small amounts over long periods of time. From this point of view they are no less important than fluoride as a problem in public health.

12

A Deluge of Detergents

EVER since human beings learned to live together in herds man has found a virtue in keeping himself clean. Water from the very earliest times has been used for the job. It was available in quantity wherever there was a river or a spring. It could get rid of dirt by carrying it away once it had been removed.

But water itself is an indifferent cleanser of human skin and clothing. Dirt is held firm on these things by grease from the body, and water alone will not wash away the grease. People have been trying to improve the cleansing power of water since before the days of recorded history. The production of cleansers has always been an important activity of civilized man, and to-day it has become one of the great industries of the modern world.

The first cleanser was sand. Prehistoric man rubbed sand on his skin; he literally scoured off the dirt with a layer of skin as well. Then came clay, which was a major improvement on sand. Clay brought science into cleansing by helping water to carry off the dirt as it was removed. The tiny particles of solid that form a clay will remove dirt by mechanical action, like sand. But clay is also a colloidal substance; the particles are so small that they do not settle out from water as easily as do the particles of sand. Clay particles will float about in the water, hanging on to little bits of dirt that have been removed until they can be washed away. Clays are still used to-day in many washing-powders and cleansers.

After clay came soap. Though we have no record of the discovery of soap, it was probably a result of people using ashes from a fire instead of sand or clay. Wood ashes contain alkali, which reacts chemically with fats and oils and turns them into soap. By rubbing his greasy hands in wood ashes and water primitive man would produce a supply of soap for himself *in situ.*

It is known that alkali from wood ashes was being used for cleansing in ancient Babylon. Soap itself was made by heating fats with alkali earlier than 2000 B.C. Medical tablets written in Babylonian cuneiform during the third millenium B.C. describe how soap can be made in this way.

The Berlin papyrus of 1350 B.C. and the Ebers papyrus of 1550 B.C. confirm that the ancient Egyptians were skilled in the art of making many sorts of soap. There are also Sumerian tablets dating back to 2250 B.C. which give precise recipes for making soap; 1 qa. of oil and,5½ qa. of alkali (ashes) are mixed together, dates being added if a soap suitable for scouring wool is to be made.

Since those early days soap-making has remained a craft which now forms the basis of our huge modern soap industry. All sorts of fats, animal and vegetable, are made into soap by processes that have changed little in principle during 3000 years; the fats are still heated with alkali in the way that they were in Babylonian times. But the alkali is now made synthetically by the heavy chemical industry instead of being extracted from wood ashes. By blending and purifying our fats and oils and by varying the manufacturing conditions we can now make a variety of soaps suitable for different cleansing applications.

Like clay, soap is a colloidal substance. It can keep particles of dirt and grease floating in the water, so that they do not settle back on to the skin or clothes that are being cleaned. But soap has another useful characteristic as well; it makes water 'wetter.' That is to say, it helps water to spread over greasy surfaces, penetrating into soiled materials and loosening the fatty substances that make dirt particles so difficult to remove. When the skin is rubbed or dirty clothes are tumbled in soapy water the mechanical action helps to remove the greasy dirt and the soap keeps it floating as tiny globules in the water. It can then be drained away without settling again.

Soap has held a monopoly in the cleansing trade for thousands of years. But it only did so through sheer efficiency. Soap is a cheap and versatile substance than can do most of the jobs the housewife wants it to do. Until comparatively recent times it remained as the world's standard cleanser and was used for almost every type of washing job.

But soap, like most things, has its drawbacks. It does not work well, for example, in water that is acid; for this reason it is useless in many industrial applications, particularly in the textile trade. Also, soap is not satisfactory in hard water. Instead of doing its proper job of increasing the cleansing power of the water, it undergoes chemical reactions with the calcium and magnesium salts dissolved in the water. These salts turn the soap into calcium and magnesium soaps which appear as the familiar scum on the surface. Much of the soap is wasted in producing this scum, and it is not until all the hard water salts have been used up in scum production that the soap can improve the cleansing power of the water. Much of the domestic water of countries such as Britain and the United States contains at least 100 parts per million of calcium carbonate dissolved in it, and more than a tenth of the soap used in the home is wasted in scum formation. This means that about 500,000 tons of soap are manufactured every year for the sole purpose of providing us with objectionable scum.

Until recently there was little that could be done to overcome these deficiencies of soap. But the astonishing rise of synthetic chemistry during the last half-century has brought a new understanding of the nature of all manner of consumer substances, including soap. Scientists have studied the chemicals we describe as soap and know how they help to increase the cleansing powers of water.

The molecule of soap is built from a string of atoms arranged in such a way that one end of the molecule mixes easily with water and the other end with fats and oils. Dissolved in water, these long soap molecules crowd the surface of the water with their water-loving ends in the water and their fat-loving ends pointed away from the water. There is therefore a layer of fat-loving molecule ends covering the surface of soapy water. Whereas ordinary water shows no inclination at all to associate with fats and oils, soapy water with its fat-loving surface will spread enthusiastically over the surface of a greasy, soiled fabric or a layer of grimy skin. The soapy water will penetrate wherever possible to improve its surface contact with the grease, creeping between the grease and the surface to which it is sticking. Mechanical action will lift the grease without difficulty, so that it can go floating away in the water.

When the grease has been removed in this way soap molecules crowd the surface of the little fatty globules in the water. The fat-loving ends are anchored in the globule with the water-loving ends protruding into the water. As each particle of soap is carrying an electric charge, the globule itself becomes charged. All the globules carry similar charges of electricity, so that they repel one another. They remain suspended in the water, instead of getting together so that they can settle out again.

Although soap has enjoyed almost exclusive rights to this fat-penetrating process for so many centuries, it has not been doing so by virtue of any unique chemical constitution. Once chemists understand how soap could help in cleansing they began to construct new substances which could do the same. During the 1930's they made several of these synthetic cleansers, starting from chemicals derived from coal or oil. Some of them could work satisfactorily in acid water, and they were unaffected by the hard-water salts that made soap useless. These new synthetic cleansers found a ready market in the textile trade and in laundries; some of them were used for making shampoos.

During World War II natural fats were in short supply and soap was rationed. So we began to use the synthetic cleansers for some of the household jobs that soap had been doing since the days of ancient Babylon. We found that in many ways the synthetic cleansers served us better. They were not affected by hard water and were admirable for cleaning dirty dishes and for washing clothes. Soap remained the cheap and versatile jack-of-all-trades and was superior for cleaning heavily soiled cottons. But synthetic cleansers had made their way into some sections of the household market and were soon accepted as being more than mere substitutes for the soap that was in short supply.

When the war ended fats remained in short supply. Many natural fats are edible, and the world needed all the food that it could get. Research was stimulated by the successful intrusion of synthetic cleansers into the enormous household market. New and more versatile cleansers were discovered, and the biggest advertising war in history developed as manufacturers fought for control of the kitchen sink.

By the time that soap became more freely available the new synthetic cleansers had settled in. They had acquired a respectable name—detergents—in place of the meaningless 'soapless soaps' that had been inflicted on them in their early days.

Inevitably the name detergent has been used to distinguish the new-type cleansers from the old cleanser soap. But, in fact, the word detergent is synonymous with cleanser; it means something that cleans things. Soap is as much a detergent as any of the wonder-workers that are used so lavishly to-day. It happens to be made from natural fats, whereas most of the newer detergents are made from chemicals derived from coal or oil.

Soap is also regarded, quite wrongly, as a 'natural' cleanser distinct from the 'synthetic' detergents. Yet soap is itself a synthetic material, made by the action of alkali on natural fats. It has been made for so long that it is no longer thought of as a substance manufactured by one of the oldest branches of the chemical industry.

The newer detergents are truly synthetic materials, made by the chemist from simple chemicals without nature's help at all. This chemical control over the manufacture of synthetic detergents means that their chemical constitution can be modified to meet all sorts of different washing needs. They can be tailor-made by the chemist.

The trouble with detergents, from the manufacturer's point of view, is that research has been a bit too successful. No sooner does he bring out one super-detergent than his research team presents him with an even better one. So Plop has to take over from Drub to keep ahead of the competitor's new Fleep. Once more the salesmen make their rounds and the samples come hurtling through the letter-boxes.

To-day there are more than 1000 detergents for the housewife to choose from. In 1941 some 6000 tons of detergents were manufactured in the United States, where the detergent boom began. By 1950 half a million tons were being made and by 1954 synthetic detergents were outselling soap in the household market.

The world production of synthetic detergents in 1952 was about 1,100,000 tons, of which 800,000 tons were manufactured in the United States. During the same year the world consumption of soap was more than five million tons.

In the textile industry there are detergents which can be used under any of the conditions encountered during cleaning, dyeing, and finishing textile fibres and fabrics. They will work in cold, hot, hard, salt, acid, or alkaline waters. With no sticky curds to remove, the textiles can be rinsed easily and completely. In this respect detergents are especially useful for washing woollens, coloured goods, and fine fabrics.

Although the detergent boom has made things so much easier for the housewife and has been of so much help to industry, it has brought with it some problems in public health. Thousands of tons a year of highly active chemicals have suddenly been introduced into everyday life, and they are making their presence felt in many ways.

Brought up on soap, most housewives cling to the belief that the cleansing power of a detergent depends upon its ability to produce a rich luxuriant lather. Many of the most efficient household detergents are virtually latherless, but manufacturers are only human. If the housewife wants a lather she can have it; so a foaming agent is added to produce the desired effect.

This satisfies the customer, but raises problems for the sewage scientist. When the detergents have done their work in the washing-up bowl or the domestic washer they are sent off into the drains and eventually reach the sewage works.

Here sewage is allowed to stand in concrete tanks so that sediment can settle out. But too much detergent in the water maintains the solid particles in suspension. If the detergents are of the foaming type they may build up a layer of foam several feet in thickness that lies on the tanks like a massive eider-down.

When the sewage is aerated by blowing in jets of air bubbles as big as footballs will drift away into the air to burst over the surrounding districts.

This sewage foaming has become a serious problem in the United States, where detergents are used more lavishly than in other countries. The danger first became apparent in 1947 when a detergent manufacturer distributed samples of his product one Friday afternoon to housewives in a small Pennsylvania town. By Monday the local sewage works was blanketed by a multicoloured mountain of slimy foam, and sewage froth was seeping from the drains into the streets in low-lying districts of the town.

Since then the mounting use of detergents has made sewage-foaming into a widespread problem that has yet to find a really satisfactory solution. The methods used for destroying soap in sewage water make use of the recognized weaknesses of soap as a cleanser; 'hardness' salts such as lime are added or the water is made acid. In these ways the soap is destroyed before it can affect the sewage disposal processes. But synthetic detergents derive much of their popularity from their ability to work in water containing hardness salts or acid. They are not destroyed by the traditional soap-removing techniques we use at many sewage works.

Not only do these detergents prevent the proper settling of sewage sludge; they can emulsify long-settled deposits as well. And bacteria that should be helping to destroy the sewage are inactivated, so that the normal processes of sewage decomposition cannot continue.

The overflow from a sewage works is often discharged into a river or canal; by this time it is quite innocuous, and rivers receiving sewage effluent are frequently used as sources of water-supply lower down stream. But when too much detergent is being carried into the sewage works it may disrupt the normal processes so much that particles of sludge are carried over and discharged into the river. The detergent itself will remain in the river water and get into domestic water supplies which use the river as their source.

This raises once again the familiar problem of a new type of chemical being absorbed in small quantities into the human body. Detergents used in the home are harmless in the accepted sense of the word; they do not poison us in doses such as we might normally be given. But detergent in our water-supplies, together with the tiny amounts we get continually from cups and plates, may do physiological damage when absorbed over many years.

In this connexion it has been shown that detergents affect the growth of animals when they are added to the food. But the results, far from being harmful, are apparently beneficial. Pigs, for example, have grown 12 per cent. faster on a diet containing a little detergent as an appetizer. The detergent may make the food more easily digested by breaking up the fatty material into little globules. Or it may help by destroying harmful bacteria in the stomach. Whatever may prove to be the case, the plain fact is that we know very little about the effects of detergents in our interiors. And until we know a bit more it will be as well to avoid absorbing more detergent than we need.

Many housewives have had serious doubts about the effects of detergents on the skin. Detergents have a powerful scouring action and can lift the oils and greases efficiently from soiled materials. Will they not remove the natural oils from human skin and perhaps do other damage as well?

An official report issued in 1954 by a committee set up by the Ministry of Health in Britain confirmed that there has been no increase in the number of cases of dermatitis of the hands since detergents came into widespread use.

It is easy to forget that soap itself can do considerable damage to human skin. Soap can remove the grease from skin, and it is alkaline as well. Too much soap can roughen and dry a sensitive skin and may cause dermatitis by irritating or degreasing the skin.

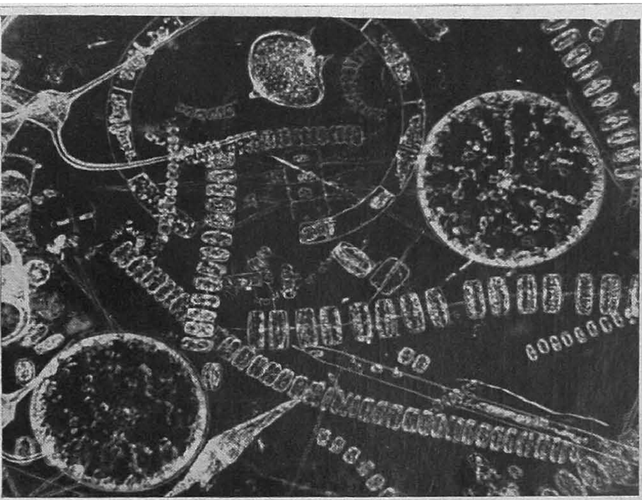
All detergents, including soap, need to be used with reasonable care, and hands should always be rinsed in clean water after coming into contact with them for too long.

The tremendous deluge of detergents that has swamped the housewife in the last few years has tended to obscure the progress made in improving soap itself. One of the disadvantages of soap has always been its natural yellowish colour. But purity is always associated with whiteness, and before the war some soap manufacturers began to mix their soap with a harmless substance that emitted a blue fluorescent light. Mixed with the natural yellow colour of the soap, this blue fluorescence gave the soap a pure white appearance.

These fluorescent substances did not, however, affect the whiteness of the fabrics washed by the soap. They had no power of adhering to the fibres and so adding their blue light to the natural creamy colour of the fibres. But since the war the process has been taken a step further. Blue fluorescent dyes are mixed with soap, so that fabrics washed with it are dyed with a 'colourless' substance that emits a blue fluorescent light. This combines with the yellowish colour of the natural fibres, giving them a dazzling white appearance. These blue fluorescent dyes are now added to many synthetic detergents as well.

From the housewife's point of view the chief disadvantage of soap lies in its inability to cope with hard water. A great deal of research has been carried out to try to improve soap in this respect, and it is possible that some substance may be found that can be added to soap to soften the water in which the soap is used.

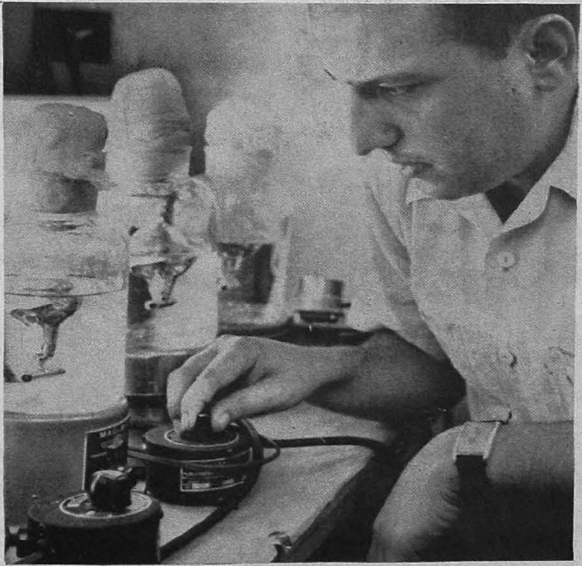
Meanwhile, although one new detergent follows another on to the market at bewildering speed, it is still possible to see how great improvements can be made in the future. Most detergents in use to-day work best, like soap, in hot water. Also the actual removal of the grease and dirt from a fabric must still be done by mechanical action. It is reasonable to suppose that in future we shall see detergents appearing on the market which can clean efficiently in cold water and without any need for rubbing or tumbling of the clothes.



DIATOMS

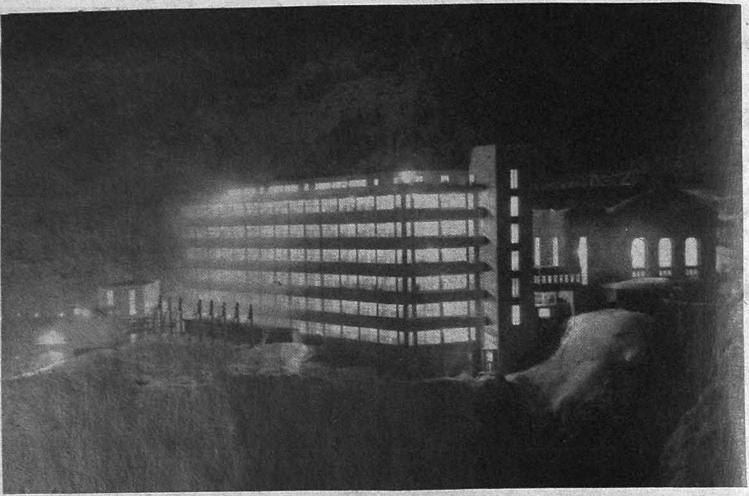
Food for creatures of the sea is made by diatoms that flourish in countless billions in the plankton. Seen through the microscope, these midget plants glitter with all the beauty of a collection of jewels.

Photo Dr J. H. Fraser



DIATOM FOOD RESEARCH

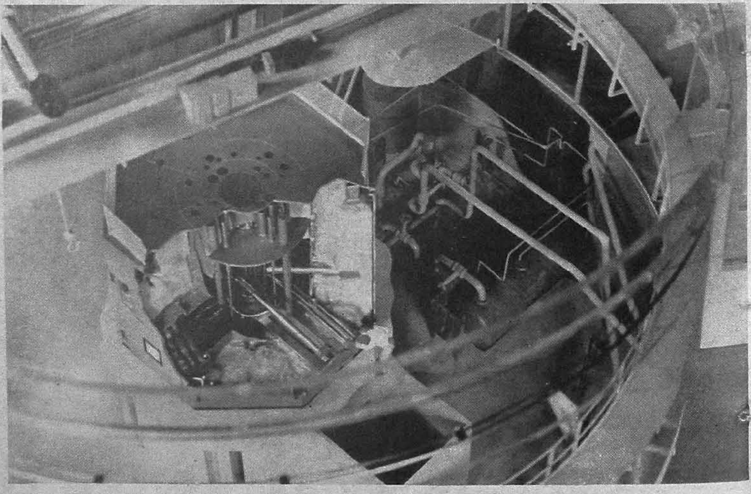
Edward Goldberg, of the Scripps Institution of Oceanography, studies the food requirements of diatoms with the help of radio-active tracers. The bottles are miniature oceans, with fluorescent lamps providing artificial sunlight



HEAVY-WATER PLANT OF NORSK HYDRO

This factory on a snow-covered hillside in Rjukan, Norway, makes one of the most unusual products in the world—heavy water. Norway is the home of this industry, and has supplied atomic energy stations in many countries.

Photo Norsk Hydro



ARGONNE NATIONAL LABORATORY'S RESEARCH REACTOR (CP-5)

This heavy-water moderated and cooled reactor was constructed in 1953. The model of it here shows, in the cut-away section, the uranium-bearing fuel assemblies and the experimental facilities.

Photo United States Information Service

13

H_2O—The Eccentric Chemical

THE philosophers of the world have always been intrigued by the nature of matter. The material things with which we are surrounded exist in all manner of shapes and forms. A stone bears little resemblance to an apple; the branch of a tree has nothing in common with the air that stirs it when the wind is blowing. Yet there is some sort of fundamental relationship between these different things. One form of matter can change easily into another; wood will burn and change into an invisible gas and a residue of mineral ash; iron will rust and change into a heap of red-brown powder.

People have always wondered about the basic structure of material things that underlies these transformations. Since the days of ancient Greece philosophers have tried to bring an understanding of material changes by regarding matter as made from a few elementary substances. These 'elements' combine and mingle one with another to form the various materials we recognize around us. One of the first of all the elements to be selected was the liquid that so obviously plays a major part in everything that is happening on earth. Water.

Aristotle, in the fourth century B.C., devised a 'Four-element' theory of matter, in which water was one of the elementary substances found in all material things. Everything on earth could be regarded, according to Aristotle's followers, as a mixture of the four primary substances: water, earth, fire, and air. Each of these elements brought its own characteristic qualities to the whole; water was cold and fluid, earth was cold and dry; air was hot and fluid, and fire was hot and dry.

In each of the four elements one quality predominated. Earth was essentially dry, air was fluid, fire was hot, and water cold. By mixing the four elements together in appropriate proportions any material substance could be made.

This conception of 'elements' has lain at the back of man's mind for as long as he has been aware of the wonder of his surroundings. It was responsible for the transmutation experiments that kept the alchemists absorbed in their strange rites for centuries; if one thing differed from another merely by containing the four elements in different proportions then it should be possible to change a metal such as lead into the more valuable metal gold. Water, as one of the fundamental elements, played a major role in alchemy; it was accepted as an element until near the end of the eighteenth century.

The idea of elementary substances, or 'elements,' has persisted to the present day and forms the basis of modern chemical theory. But during the eighteenth century it became apparent that the four elements of the early philosophers could no longer serve as a foundation for scientific thought. Indeed it had been shown that the 'elements,' earth, air, and fire, were not elements at all. Earth was a mixture of all manner of different things; air was a mixture of at least two gases, one of them used up when things burned and the other apparently inert; and fire was not a material thing of any sort, but a manifestation of chemical change.

By 1781 only water remained as an 'element' from the four that the old theories had recognized. In that year the famous British scientist Joseph Priestley carried out "a mere random experiment, made to entertain a few philosophical friends" by exploding a mixture of air and 'inflammable air'[1] inside a closed vessel. He found that

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[1] 'Inflammable air' was what we now know as hydrogen.

the explosion created a cloud of vapour that settled as a dew on the sides of the vessel. The dew was apparently water.

This experiment attracted the attention of the Hon. Henry Cavendish, who repeated it and confirmed that the substance produced by burning 'inflammable air' in ordinary air was in fact water. Cavendish published a description of his experiments in the Philosophical Transactions of the Royal Society in 1784; he described how water could be made by the chemical union of two gases, 'inflammable air' and ordinary air. Water, so long regarded as an element, was in fact a compound substance.

This discovery caused something of a sensation in the world of science. Other people took up the research, and it was soon found that the 'inflammable air' was uniting only with the oxygen part of ordinary air. The French chemist Antoine Lavoisier in 1783 made half an ounce of pure water by burning 'inflammable air' in oxygen. Then he split up water into its constituents by passing steam through a ret-hot iron gun-barrel. The oxygen of the water combined with the iron to form a rusty iron oxide, and 'inflammable air' came from the end of the barrel.

Until this time 'inflammable air' had not been given the name by which we know it to-day. It was still just an inflammable gas made, for example, by putting metals into acids. But in 1787 Lavoisier gave 'inflammable air' the name 'hydrogen', from the Greek meaning 'water producer.' Water was established as a substance made by uniting two gases, oxygen and hydrogen. Both gases are now known to be true elements.

Once this chemical composition was known chemists began to measure the amounts of the two gases that combined to form water. Careful experiments showed that oxygen combined with twice its volume of hydrogen; the weight of the oxygen was approximately eight times that of the hydrogen.

As each atom of oxygen is some sixteen times as heavy as a hydrogen atom, this means that water results from a union of two atoms of hydrogen with one of oxygen. The fundamental particle of water—the water molecule—is H_2O.

During the last 150 years water has been the subject of continual study by scientists. And it has emerged as an extraordinary substance that is in many ways unique. Water is unlike most other liquids and disobeys the rules that ought to govern its chemical and physical behaviour. It is the most plentiful substance on earth; and it is one of the most eccentric.

When liquid water is cooled it contracts like any other liquid and so becomes denser. That is to say, the lower the temperature, the greater is the weight of any definite volume of water. This normal behaviour continues until the water reaches 4°C., when the water undergoes a radical change. As it cools still further the water begins to expand; its density diminishes instead of increasing and the water becomes steadily lighter until the temperature reaches 0°C. This is the temperature at which water turns to ice.

When liquids cool and turn into a solid they normally become more dense. A solid is heavier than the same volume of the corresponding liquid at the same temperature. But water, intransigent as ever, does not obey the rule. As water turns to ice it expands rapidly and ice is lighter by about a tenth than the water from which it forms.

These unusual density changes in water at different temperatures are of the utmost practical importance. If water contracted steadily with lowering temperature and then froze into a still heavier solid ice the climate of the world would take on an entirely different pattern.

During winter the water of lakes and seas becomes heavier as it cools. As its density increases the water sinks and displaces the lighter, warmer water, which rises to the surface. This cooling and mixing continues until the temperature reaches 4°C. Then, as the water cools still further the density change is reversed. The water becomes lighter as it cools towards freezing point. Instead of sinking, it lies in a layer on top of the warmer water beneath. Finally, as the water turns to ice, it becomes still lighter, and the ice floats on the surface like a protecting lid.

If the density of cooling water did not change in this unusual way surface water would continue to sink until freezing point was reached. Ice would form at the bottom of lakes and seas and would accumulate from season to season until the waters were entirely solid. In summer only the surface layers would melt and there would be no massive movements of ocean currents to modify the world's weather. The tropics would become unbearably hot and the 'temperate' regions would freeze throughout the year.

The expansion of water into ice is responsible for other phenomena. Water in the crevices of rocks expands in the winter frosts as it turns to ice. The rocks are forced apart and split under irresistible pressure, breaking into smaller and smaller pieces until they eventually become the mineral particles of soil. Ice disrupts the tissues of plant cells as the cell sap freezes in a winter frost. It destroys the structure of the flesh in frozen meat, reducing it to a formless pulp. And it splits the pipes in our domestic plumbing systems, releasing a deluge of water when the thaw sets in.

Compared with other liquids, water has an immense capacity for absorbing heat. Heat must be supplied lavishly to raise the water temperature by a degree or two; conversely, water loses heat slowly, and a drop in temperature is accompanied by the release of large quantities of heat. This great capacity for heat storage enables the seas to modify and moderate the world's climate. Ocean currents like the Gulf Stream carry immense amounts of heat from the tropics to the cooler parts of the world, spreading the sun's heat more equally than would otherwise be the case. Expanses of ocean, like the Atlantic or the Pacific, act as enormous temperature-regulating baths that prevent the climates of adjoining lands from becoming too extreme.

This heat capacity of water is far greater than it ought to be. According to the rules water should not need so much heat to change its temperature. Similarly, water is eccentric in being lighter than the theorists would prefer. It ought to weigh a tenth as much again as it actually does.

Water really has no right to be a liquid at all. Its freezing points and boiling points are far too high. If it obeyed the natural laws that control the behaviour of other substances water would be a vapour at normal temperatures and liquid water would not turn to ice at temperatures where mercury now turns solid.

Though pure water appears to be colourless, it has a pale blue colour when seen in sufficient depth. The blue of a lake or sea is often caused, not by the colour of the water itself, but by the scattering of light that is broken up by countless tiny floating particles.

Water is so innocuous that we can drink it in unlimited quantities without doing ourselves any harm. Yet water is the most corrosive liquid known. It can dissolve small quantities of almost any solid that it comes across. Really pure water is an unknown liquid. The purest water we can get is distilled in apparatus made from platinum, block tin, or quartz. But even this contains impurities dissolved from the vessels in which it is stored or from the gases that rest on its surface. Water comes closest of all liquids to being the alkahest, the universal solvent of the Alchemists.

When water is cooled it changes to ice at a temperature which is always the same for any definite pressure. The freezing point of water at normal atmospheric pressure is taken as 0° on the centigrade scale. Similarly, when water is heated at normal atmospheric pressure it always boils at a definite temperature; this is taken as 100° on the centigrade scale.

Under certain circumstances water can be cooled below 0°C. without turning to ice. If the water is kept absolutely still it will remain liquid to –4° C. A layer of oil on the surface enables it to cool to as low as – 7° C. Water at these low temperatures is super-cooled; it ought to have turned to ice but has not done so. If it is disturbed or a tiny crystal of ice is added the water solidifies immediately. The tiny droplets of water in a cloud are often in this super-cooled condition. Given the necessary stimulus, they will turn to ice that collects into snow-flakes large enough to start falling to the ground.

In a similar way water can be heated above 100° C. without turning into steam. If it is kept quite still the temperature will rise to 105 or 106°C. without the water boiling. Then, suddenly, it will make up for lost time and boil with explosive violence. Water has been heated to 178° C. without boiling by denying it the stimuli it needs to encourage its molecules to escape from one another and ride free as the molecules in steam.

In liquid water the molecules formed from two hydrogen atoms in union with an oxygen atom are able to move about, but they are not entirely free. They are subjected to the forces of attraction from neighbouring molecules. In the body of a liquid these forces attract any individual molecule equally from all directions.

As they move about the liquid molecules bump against one another with a vigour that depends on the temperature of the liquid. When the liquid is heated the molecules move faster and become more energetic.

On the surface of a liquid conditions are not the same as they are in the bulk of the liquid below. A molecule rushing upwards near the surface can shoot out like a miniature rocket into the relatively empty space above. There are few molecules for it to bump against, and only the attraction of the liquid molecules below will pull it back into its liquid home. If it can gather enough energy as it leaves the liquid surface the molecule may shoot into the empty world above, escape from the attractive forces of the liquid molecules, and wander freely as a gas.

The escape of molecules from a surface in this way results in a continual loss of liquid by evaporation. Water evaporates from liquid surfaces all over the world, returning its molecules to the air from which they fell as rain.

The readiness with which water molecules can escape from their overcrowded liquid prison depends upon the temperature of the water. The hotter the water is, the faster the surface molecules can shoot into the air. And the faster they move, the more chance they have of escaping the attraction of the molecules in the liquid. The problem for a water molecule wanting to float away as vapour is the same as that which confronts our space travellers; how can sufficient speed be attained to overcome the attraction of the bulk of matter that is left behind?

When water is evaporating in contact with the air the rate at which the molecules escape from the surface is influenced by the movement of the air. A breeze blowing over the sea will scoop up molecules as they soar from the surface, carrying them away before they can clutter up the air immediately above the water surface. So the way is left clear for other molecules to escape; evaporation is much faster when a wind is blowing.

As water evaporates there is a continuous loss of the fastest-moving molecules from its surface; the slower ones are left behind. As the temperature of a liquid is merely a measure of the average energy of its moving molecules, the temperature of an evaporating liquid always falls. Evaporation causes cooling. The evaporation of water from a wet soil, for example, takes the heat from the soil as well as the water. Evaporation of petrol in the carburettor of a car can turn the moisture of the incoming air into ice.

When water is heated energy can be poured into it to make up the losses due to evaporation. If the heating is strong enough a temperature is reached at which there are so many molecules moving at 'escape speed' that the water surface cannot accommodate them. Bubbles of vapour are formed inside the bulk of the water itself; they rise to the surface and escape. The water is boiling. The temperature at which water boils is always the same for any definite pressure of the air above the liquid. At the standard atmospheric pressure of 760 mm. of mercury water boils at 100°C. As the pressure rises, for example inside the boiler of a steam engine, the boiling-point of the water rises too. And as the pressure falls the boiling-point of the water is lowered.

At Quito, a town in the Andes 9350 feet above sea-level, the pressure of the atmosphere is so low that water boils at 90°C. The temperature of boiling water at Quito is so low that it is difficult to make a cup of tea or to boil an egg. On top of Mount Everest, 29,000 feet high, water boils at 72°C.

Although pressure has such an effect on the boiling point of water, liquid water itself is almost incompressible. By doubling the pressure of the atmosphere above it we can reduce the volume of water by five hundred-thousandths. This is so small that we normally regard water as being unaltered by compression. Yet the volume change has a big effect on the world as a whole; if water was absolutely incompressible the level of the sea would be nearly 120 feet higher than it is to-day, and a twentieth of the present land surface would be under water.

When water is cooled until it turns to ice the movements of the molecules are restricted. In a solid the molecules take up definite positions with respect to one another. They line up into geometrical patterns, forming regular arrangements that control the shapes of solid crystals. Ice crystals, easily seen in a variety of forms as hoar frost or snow, are based on the hexagonal system; they build up into six-rayed stars of bewildering complexity and astonishing beauty.

When water turns to ice there is an increase in volume. An ounce of ice takes up more space than the ounce of water from which it came. If ice is subjected to pressure the ice tries to accommodate the changed circumstances by turning into the water that occupies less space. A skater gliding over a frozen pond is riding on a layer of water rather than on the ice itself. The pressure of the knife-edge on the skate is sufficient to melt the ice.

Like the liquid water from which it comes, ice is an eccentric substance. It exists in at least five different forms, turning from one to the other when it is subjected to very high pressures. As the pressure increases ordinary ice changes its crystalline form and turns into a new ice that is denser than water. Higher pressures produce a third type of ice that is denser still. Of five different types of ice that are known, three are heavy enough to sink in water, a fourth will not exist so long as water is there, and the fifth is the common or garden ice that is lighter than water, and floats.

At the base of a glacier ice is subjected to immense pressures that can bring about changes in its structure. Although ice is a crystalline solid, it behaves in some ways as a liquid, and a glacier actually flows as the ice deforms under its own weight. It takes up the shape of the valley through which it flows, like a piece of solid pitch taking up the shape of a tin in which it is stored.

The peculiar behaviour of water in its various physical forms has presented science with a mystery that has yet to be fully explained. The molecules of water are believed to associate one with another, moving about in pairs or in groups of three or more molecules held together by mutual attraction. This 'chumming up' of water molecules can account for some of its strange characteristics.

In 1933 J. D. Bernal and R. H. Fowler astonished the scientific world by proclaiming that liquid water had an internal structure that was more like a solid than a liquid. The hydrogen atoms in a water molecule can attract the atoms in other water molecules, and in liquid water each molecule has four other molecules taking up neighbourly positions beside it. In liquid water these neighbouring molecules tend to lie fairly often in such a way that they are at angles of 105 to 110°.

In the crystalline structure of solid ice water molecules are arranged in such a way that each molecule has four neighbours lying at angles of about 110°. There is therefore a statistical similarity between liquid water and crystalline ice. Water can be regarded as made up of astronomical numbers of tiny crystals, each one existing momentarily. The composite effect is such as to give liquid water some of the characteristics of a solid.

This theory of an 'ice within water' can be used to explain changes that take place in water and ice. In solid ice the molecules are held in position by mutual attraction but in such a way that they must 'keep their distance.' As the ice is melted to form water the heat loosens the bonds holding the molecules together, but instead of allowing them to scatter it enables them to crowd more closely than before. So the water is denser than the ice.

As more heat is poured into the water bond-loosening proceeds and overcomes the effect of close-crowding at 4°C. Then, until boiling point is reached, the density of the water decreases with rising temperature in the normal way.

When ice is subjected to pressure the attraction bonds holding the water molecules in position are distorted and the molecules are packed closer together, forming the denser types of ice, which can exist at high pressure.

When Cavendish proved in 1784 that water was made from hydrogen and oxygen he set in movement a research that has continued with increasing vigour to the present day. This water, which we find and use in such abundance in our world, is anything but commonplace in its scientific behaviour.

14

Heavyweight Water

DURING the Second World War an apparently harmless factory in Norway became a high-priority target for Allied planes. The factory was manufacturing, of all things, water; but the precious liquid that the Germans wanted was not ordinary water. It was 'heavy water,' to be used in making the atomic bomb.

Heavy water is exactly what its name implies. It is water that weighs more, volume for volume, than ordinary water. At ordinary temperatures it weighs roughly a tenth as much again as the water we get from the kitchen tap.

This extra weight of heavy water is a result of its unusual atomic structure. In ordinary water one atom of oxygen is united with two atoms of hydrogen to form the water molecule H_2O. But in heavy water the hydrogen atoms are twice as heavy as the normal hydrogen atom. They have an extra particle packed into the atomic nucleus, which changes them into atoms of 'heavy hydrogen' or deuterium. This increased weight of hydrogen provides the corresponding increase in weight of the water molecule in 'heavy water.'

Although deuterium is twice as heavy, atom for atom, as hydrogen, it is not a different and distinct element. Deuterium has virtually the same chemical behaviour as hydrogen; it *is* hydrogen, but with rather more bulk than usual. Deuterium oxide, D_2O, is water, although it weighs a little more. In all its ordinary properties it is indistinguishable from H_2O.

Since scientists began studying the finer points of atomic structure they have found that the atoms of many elements exist in two, three, or more forms which differ only in the relative weights of their nuclei. These substances, virtually identical with one another in everything but atomic weight, are known as isotopes.

In 1929 scientists suspected that a double-weight isotope of hydrogen might exist. There were discrepancies in measurements of the atomic weights of hydrogen and oxygen. This could be due to the existence of an isotope of hydrogen heavier than the normal hydrogen.

By December 1930 the existence of heavy hydrogen had been proved. American chemists evaporated a gallon of liquid hydrogen and found that in the last thimbleful there was sufficient heavy hydrogen to be detected by sensitive scientific instruments. Ordinary hydrogen, evaporating faster than its heavier isotope, left behind a gas containing about five times as much heavy hydrogen as there was in the original hydrogen.

In 1932 it was discovered that ordinary water contained a tiny proportion of heavy water in which deuterium took the place of ordinary hydrogen atoms. And when water is split into its two component gases by passing electric current through it the hydrogen oxide decomposes more rapidly than the deuterium oxide. By splitting up a large volume of water electrically it is possible to concentrate the deuterium oxide, or heavy water, which stays behind in the vessel, from which the ordinary water disappears as hydrogen and oxygen. Hydrogen oxide splits more than six times as fast as deuterium oxide.

By 1933 a tiny drop of pure deuterium oxide had been made in this way. Heavy water had arrived.

In the mass of water that covers so much of the earth there is about one part of heavy water to every 7000 parts of ordinary water. Separating the heavy water is a tedious and expensive undertaking, as electricity is needed in great quantities to split up the water into hydrogen and oxygen, leaving a concentration of heavy water behind.

Yet, during the 1930's, there was sufficient scientific interest in heavy water to create a demand for appreciable quantities of it. In 1935 heavy water was produced for the first time on an industrial scale by Norsk Hydro at Rjukan. In Norway water-power made electricity plentiful and cheap, and at Rjuken there was already a factory manufacturing hydrogen by electrical decomposition of water. It was a comparatively simple step to separate heavy water as a by-product from the water-splitting cells. During 1935 the output of heavy water at Norsk Hydro was about 1 lb. per day. By 1939 it had reached 8 lb. a day. But with heavy water now in demand for atomic energy production it is being manufactured in bulk quantities in Norway and the United States.

Before atomic energy laid claim to heavy water as a raw material the small amounts produced in Norway were used by research workers in many parts of the world. The deuterium atoms in heavy water are useful 'tracers,' enabling the scientists to follow the course of hydrogen atoms in chemical reactions. When heavy hydrogen is used in place of ordinary hydrogen it behaves to all intents and purposes as ordinary hydrogen. Inside the body, medicines and foods containing hydrogen will undergo their transformations and reactions if they contain deuterium atoms in place of ordinary hydrogen atoms. But the deuterium atoms can always be detected and distinguished among all the other hydrogen-containing body substances. Their increased weight gives them away; by measuring the density of water taken from a tissue it is possible to tell how much deuterium it contains in place of normal hydrogen. If this deuterium has been given instead of the normal hydrogen atoms forming part of the molecule of a drug we can discover something of what has happened to the drug inside the body. The deuterium does duty for the lighter hydrogen in its chemical reactions, and yet can be distinguished from hydrogen at any time.

Using deuterium as a tracer in this way, biochemists have shown that fat can remain in storage in body tissues even when it is needed for providing energy. Slimming is not so straightforward as it might seem.

Tracer techniques have developed rapidly during the last decade or two, and heavy water and hydrogen are invaluable research tools. But the academic importance of heavy water to-day has been overshadowed by its use in atomic energy production.

In the thermal nuclear reactor uranium undergoes atomic disruption, during which the nuclei of its atoms are split. Fragments of nucleus form the nuclei of other elements, sub-atomic particles called neutrons are fired off, and a surge of energy is released. This disruption of uranium atoms takes place in the form of a chain reaction in the atomic reactor, the debris from one atomic explosion setting off others.

In the thermal reactor used most widely in atomic energy development the neutrons are slowed down after the atomic split by surrounding the lattice of uranium rods in the reactor with a 'moderator.' Graphite and heavy water are both suitable for use as moderators. But heavy water makes possible the construction of smaller and simpler atomic reactors.

Now that heavy water has become available in comparatively large amounts its properties have been studied and compared with those of ordinary water. Heavy water freezes to heavy ice at 3.8°C. and boils 1½ degrees higher than ordinary water. It attains its greatest density at 11.6°C. compared with 4°C. in the case of ordinary water.

The amount of heavy water in natural water is so small that an inch of rainwater falling on an acre of ground contains only half a cubic foot of heavy water. The proportions vary in different parts of the world. Inland seas, for example, are richer in heavy water than are the open seas. Evaporation favours the lighter water, leaving a more concentrated heavy-water mixture behind. Water from a Tibetan lake was found by scientists to be 10 per cent. richer in heavy water than ordinary seawater. The Dead Sea is 20 per cent. richer in heavy water, and water of volcanic origin is often 50 per cent richer. In glacial ice enrichment to the extent of 300 per cent. is believed to have taken place.

Several ways of separating heavy water from natural water have been devised, but the electrical splitting of water into hydrogen and oxygen has remained as the most economic route to commercial separation. The cost of producing heavy water lies mainly in the heavy demand for energy in the form of electricity or steam.

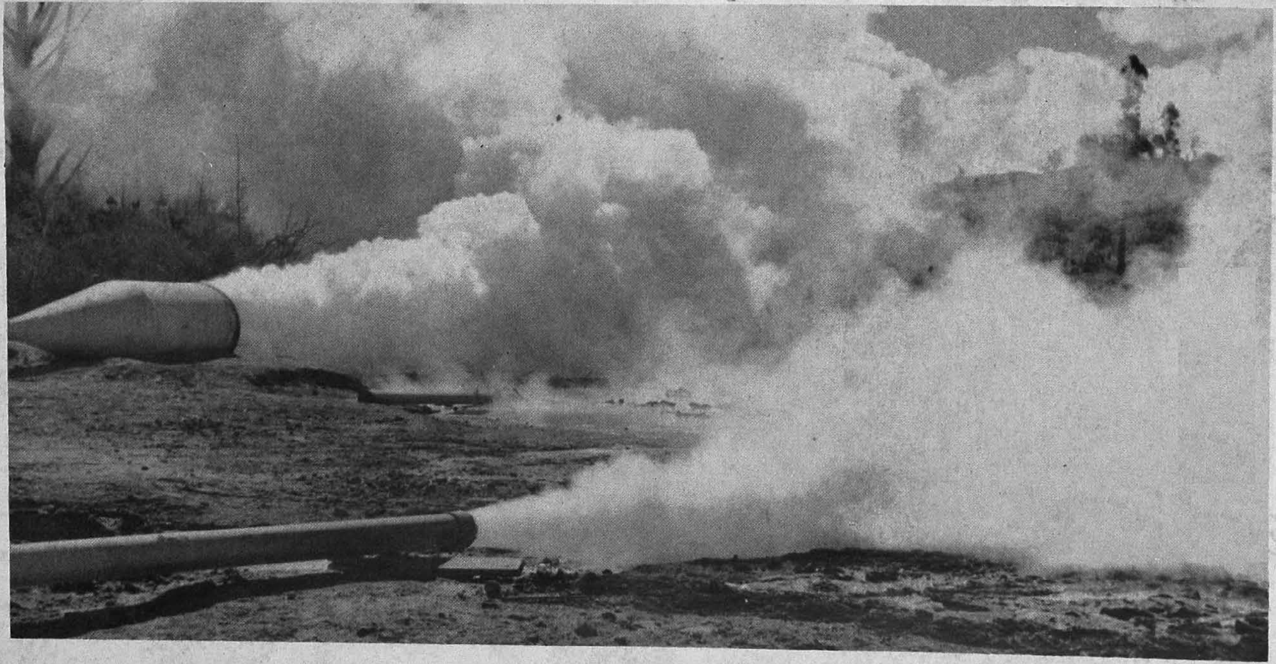
Slight differences in heavy and ordinary waters have made separation by distillation possible. But the straightforward distillation of 250,000 tons of water would be needed to produce one ton of heavy water. Distillation could be used, therefore, only if large quantities of heat were available at little cost.

In recent years techniques of distillation have been making rapid progress. Liquids are being separated one from another in immense volumes every day by the oil industry.

In New Zealand there are geothermal springs where water is heated deep in the earth to come gushing out through surface fissures as steam. In these natural geysers there is a source of free heat that could provide the energy needed for separating heavy water from ordinary water.

In 1954 plans were made for building a heavy water plant at Wairakei, on the North Island of New Zealand, to be completed in 1958. The project was abandoned in 1956.

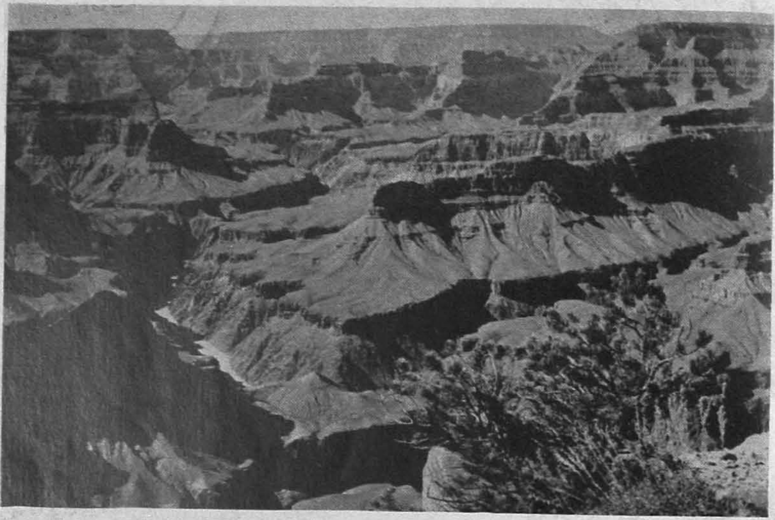
Steam from the Wairakei springs was to be distilled through fractionating towers similar to those used in modern oil plants. The towers were designed by chemical engineers of the Atomic Energy Research Establishment at Harwell. It was estimated that heavy water produced by



WAIRAKEI GEO-THERMAL PROJECT

A small-diameter bore is seen in the foreground, with, in the background, a similar bore fitted with a silencer which reduces to a fifth the noise of the escaping steam.

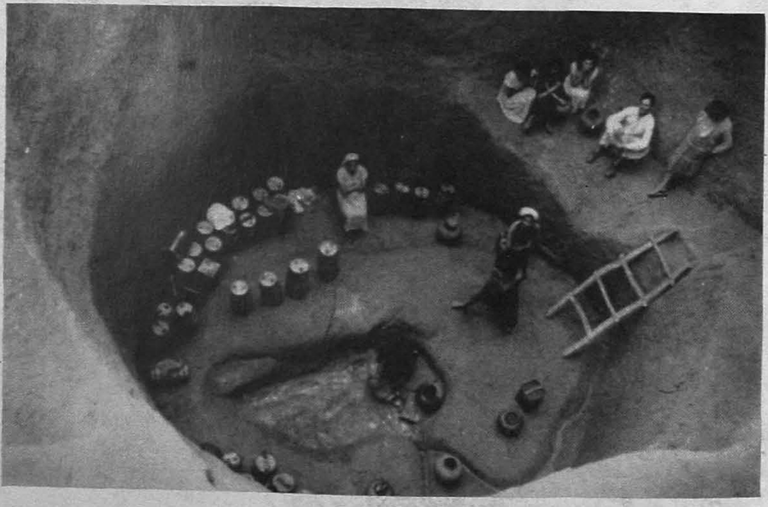
Photo National Publicity Studios, Wellington, New Zealand



THE GRAND CANYON, ARIZONA

For hundreds of thousands of years the Colorado river has been eroding the land. One-hundredth of a cubic mile of silt is carried away from the Grand Canyon every year, forming in the earth a huge gash 300 miles long and often 10 miles wide.

Photo United States Information Service



WATER-HOLE IN BRAZIL

Water is life. In drought-stricken regions man digs holes in the earth in search of water. This ancient water-hole has been deepened by successive generations.

Photo UNICEF

this plant would cost less than the £75,000 per ton that the electrically-made heavy water was costing in 1954.

With heavy water thoroughly established as an industrial raw material—albeit an expensive one—there is now an even heavier form of heavy water appearing on the scene. This is a form of water made from tritium, an isotope of hydrogen three times as heavy as the normal one.

Tritium was made artificially by the British atom scientist Lord Rutherford, who bombarded atoms with the high-speed particles thrown off by radio-active substances. For many years it was believed that tritium did not exist in natural water at all. In 1935 Dr Hugh S. Taylor, of Princeton University, was studying the newly discovered deuterium isolated from heavy water made by electrolytic concentration of natural water in his laboratory. Taylor believed that he detected signs of triple-weight hydrogen in his heavy water; he took a sample of the water to London, where he visited Lord Rutherford. The British scientist was unimpressed and would not believe that Taylor had identified tritium. Rutherford gave Taylor a few drops of heavy water and challenged him to find any tritium in it. The sample was examined with the help of the techniques then available, but the presence of tritium could not be proved.

Since then atomic energy research has given us new and more sensitive techniques for detecting and identifying isotopes, and tritium has been discovered in incredibly low concentration in natural water. It has also been shown that the sample of heavy water given to Dr Taylor by Lord Rutherford in 1935 did, in fact, contain tritium.

Unlike the double-weight hydrogen atom, deuterium, the triple-weight tritium is radio-active. The nucleus of the atom is packed too tight, and tiny, sub-atomic particles are constantly being thrown off by the nucleus of the tritium atom as it disintegrates spontaneously. In twelve years half of any sample of tritium will have decayed in this way, so that its life is comparatively short.

Much of the modern research on naturally occurring tritium has been carried out by Professor Willard F. Libby at the University of Chicago and Dr Aristid V. Grosse at Temple University. As tritium is radio-active, its presence can be detected and the amount estimated by measuring its radio-activity with the delicate instruments that are now available.

In the moisture of the air tritium occurs as super-heavy water to the extent of one part in a million million million parts of ordinary water. It is the rarest natural element to be discovered so far. The total quantity of super-heavy water in the atmosphere would just about fill a teacup.

Tritium is formed as a result of cosmic-ray bombardment of the atmosphere.[1] As they collide with atoms in the air cosmic rays release neutrons which can split the nuclei of nitrogen atoms into helium and tritium or carbon 12 and tritium. The production rate of tritium has been estimated at about one atom per second for every square inch of the earth's surface.

As they are formed tritium atoms replace atoms of ordinary hydrogen from moisture in the air. The super-heavy water is then carried to earth in the rain and continues its steady disintegration as it finds its way into the sea.

Tests have been made on water from many parts of the world's surface and from the air over different regions. The tritium content varies considerably from place to place. Water from the polar regions contains more tritium than water from equatorial regions; cosmic-ray activity is more intense over the poles, where the rays are focused by the magnetic influence of the earth. So by estimating the amount of tritium in sea water scientists can follow the movement of polar and equatorial currents in the sea.

Rainwater is believed to stay, on average, for about three weeks in the air before returning to sea-level. The

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[1] See Chapter 15 of *Our Astonishing Atmosphere*, another volume in this series.

tritium in atmospheric moisture has had little chance to undergo radio-active decay by the time it reaches the ground. Rainwater falling on the sea generally contains less tritium than rain that falls in the central continental lands. Sea rain comes from moisture that has spent only a short time in the air; continental rain has been carried perhaps for thousands of miles in the air and has had a longer time in contact with the atmosphere. It can therefore pick up a bigger ration of tritium before returning to the ground.

In a similar way the amount of tritium in rainwater changes progressively as clouds drift across the land. People living on one side of a mountain range will have more tritium in their rain than people living on the other side.

Measurements have shown that the surface waters of the oceans contain about a quarter of the tritium falling on the sea as rain. There is apparently little mixing of the rainwater into the sea below about 150 feet.

The tritium content of the water from deep wells shows that this water is often as much as half a century old. It has taken all this time to trickle through the soil and rocks of the earth into its underground storage reservoirs. Many volcanic waters, such as those released from the Larderello fumarole in Italy, are almost free of tritium; they are ancient waters in which the tritium has decayed and almost disappeared.

The estimation of tritium in rainwater enables scientists to assess changes in the earth's cosmic-ray activity over years past. Samples of water preserved during any year will be charged with tritium to an extent that is controlled by the intensity of cosmic-ray bombardment during that year. The tritium in the water undergoes its radioactive decay at a known rate, so that by measuring the amount of tritium that remains it is possible to estimate the intensity of cosmic-ray activity at the time when the water was collected.

Professor Willard Libby hit on an ingenious method of getting samples of rainwater that had fallen during past years. He measured the tritium activity of wines of known vintage; the water in the wines would normally be rainwater that had fallen during the year the wine was made.

Dr Libby found that the tritium content of his wines showed little variation in the rain that had fallen over vineyards of New York State and Western Europe during the ten years after World War II.

With the help of modern atomic equipment tritium is now being made in quantity. The element lithium provides tritium when it is bombarded with neutrons in the atomic pile. Tritium is being made in this way at the Savannah River atomic plant.

Like deuterium, tritium is being used as a tracer in chemical and biochemical reactions. It can 'stand in' for ordinary hydrogen, but is detected and estimated more easily than deuterium by being radio-active. Wherever it travels in the body tritium can be followed with the help of a sensitive, radiation-detecting instrument.

Like deuterium, tritium has come into its own by taking part in atomic energy development. It is believed to be a constituent of the hydrogen bomb.

In 1950 physicists at the Los Alamos Atomic Energy Commission laboratory described how the bombardment of tritium atoms with fast-moving protons (nuclei of ordinary hydrogen atoms) could produce helium atoms and liberate billions of electron-volts of energy. Each atom of tritium turning into an atom of helium emitted gamma rays carrying twenty million electron-volts. This is the energy that provides the stupendous punch of the H-bomb.

In this experiment only a few atoms of tritium were involved. To carry out the fusion of tritium atoms to helium on a big scale intense heat is needed, similar to that which makes possible this atomic fusion process on the sun. The only source of such heat on earth is the 'old-fashioned' atom bomb.

Although there is little reliable information about the nature of the explosive reaction in the H-bomb, it seems probable that uranium or plutonium tritide is used. These are substances formed by the chemical union of uranium or plutonium with tritium. They provide the simplest and most intimate way of bringing together a fissionable, atom-bomb element with the tritium that can liberate so much energy as it is changed into helium under the intense heat of the atomic fission.

With three isotopes of hydrogen now known to exist, and at least three isotopes of oxygen as well, there are eighteen possible forms of water molecule all of different weights. The discovery of these isotopes had added another complication to the scientific study of this 'simple' substance that plays so great a part in everyday life.

15

The Waterlogged Life of Animals

In the animal world water plays a part in life no less essential than it does in the world of plants. Water fills the cells and enables the chemical exchanges of living processes to take place. It bathes the tissues in a fluid that makes intimate contact with every living cell. And it provides the liquid bulk of the blood that carries foodstuffs, waste products, vitamins, hormones, and other chemicals from place to place within the body.

Nearly three-quarters of the weight of a human being consists of water; it provides us with an internal environment that enables life to go on in surroundings which are constant and controlled. No matter how hot the sun may shine or the rain pour down upon our bodies, we can be sure that conditions beneath the skin are maintained as we enjoy them. Water is the constituent of the body that administers this interior control.

Most of the body's fetching and carrying is done by the bloodstream. Blood is largely water in which are dissolved a multitude of salts and other chemicals. Innumerable cells or corpuscles are carried along in the bloodstream, like tiny particles of silt being brought down in a flooded river.

Inside the normal human body there is rather more than a gallon of blood, which circulates continually through a closed system of blood vessels. Blood reaches to almost every part of the body, flowing through veins and arteries that vary in size from the large vessels leaving the heart to the tiny capillaries that carry the blood near to the surface of the body. As it flows round and round through its intricate network of tubes blood carries the substances involved in the chemical interchanges of living matter.

Dissolved in the blood are nutrient chemicals derived from our food. These chemicals are carried to all the living tissues of the body, providing the cells with supplies of raw material for maintenance and growth and with energy to serve as a fuel that enables life to go on. As it returns from the tissues blood brings back waste materials discarded by the active cells.

The blood carries small amounts of regulatory substances from one place to another, controlling and influencing the behaviour of individual organs with respect to the body as a whole.

Much of this chemical-carrying job is done by the liquid part of the blood, which can be separated easily from the cells that are suspended in it. When the blood is whizzed round in a centifruge centrifugal force acts as a super-gravity on the blood. The floating cells settle to the bottom of the blood, leaving a clear straw-coloured liquid above.

The sediment contains three types of cell, which together make up about 40 per cent. of the total volume of the blood. There are white blood-cells, which serve as armed guards and attack invading germs in the blood-stream. There are tiny platelets, which play a part in blood-clotting. And there are the red blood cells, which give the blood its colour and enable it to carry oxygen to the tissues.

In the blood of an average man there are about three million million red blood cells to the pint. Women have about 10 per cent. fewer. These cells contain the respiratory pigment hæmoglobin, which combines with oxygen and carries it from the lungs to the living cells.

As blood flows through the fine capillary vessels in the lungs oxygen is absorbed and forms oxy-hæmoglobin in the red cells. When it reaches the tissues the oxygen is released and carried into the cells. Here it 'burns' the food chemicals and releases the energy stored up inside them. This energy maintains the living processes of the cell.

The nutrients used by the cell in this way are organic materials derived from food; they contain carbon and hydrogen. As they react with the oxygen delivered to the cell the carbon turns into carbon dioxide and the hydrogen into water. Carbon dioxide is picked up by the blood and eventually released in the lungs to be exhaled; the water is absorbed into the water environment of the body.

This respiratory activity of the blood is made possible only by the hæmoglobin of the red cells. Oxygen will dissolve in the plasma itself, but only to a small extent. Without the red cells to help, the volume of blood needed by the body would be about seventy gallons. We should have to drink a lot of water, and our bodies would be considerably more bulky than they are now.

The clear, straw-coloured plasma in which the blood-cells float consists of water containing salts and proteins and other dissolved substances. The proteins of blood, making up about 7 per cent. of the plasma, can be separated into many different types. Globulins carry the antibodies that enable blood to cope with diphtheria, mumps, measles, and other diseases. Gamma globulin has been used against poliomyelitis. Fibrinogen takes part in the clotting process that prevents blood escaping freely from a wound. It has been made into sheets and threads and tubes for surgical use. Fibrin foam is applied as a dressing to burns and wounds.

These proteins dissolved in the water of blood play a vital part in controlling the exchange of water between the blood and the tissues. If the albumin content of blood is decreased, for example, water is able to flow more freely into the tissues, causing œdema.

As it flows round, carrying the nutrients and waste materials from one part of the body to another, blood also distributes the heat that is freed by the reaction of food chemicals with oxygen in the tissues. Blood acts in this way like the Gulf Stream and other great currents of the sea, which modify the world's climate by carrying heat from the tropics to the colder regions of the earth. Without blood to spread available heat throughout the body we should develop hot-spots in some tissues and chilly areas in others.

This consistent internal environment maintained by the blood is a characteristic of the human machine. It enables each part of the body to live in a desirable and unchanging climate, with everything provided in the way of food supplies and other services. Water is the fluid that makes this hot-house environment possible.

With so much depending on the circulatory system of the body arrangements have to be made to ensure that it can operate efficiently. Any fault or variation in the water balance has an immediate and drastic effect on the body's well-being. Special mechanisms control the supply of water so that it can go on distributing heat and nutrient and waste materials throughout the tissues.

Water is always being lost from the body. It escapes as moisture in the breath, and it is used for carrying away dissolved waste materials in the form of urine. It evaporates constantly from the skin, exuding from the sweat pores in amounts that vary greatly with external conditions. To make good these water losses, the body has to take in fresh supplies from day to day and release them into the blood and tissue fluids in the quantities needed to maintain a proper balance.

Much of the water we need comes from the water and other liquids that we drink. As water enters the stomach some is absorbed and finds its way into the bloodstream. The remainder passes with the food into the intestines, helping to digest our food by maintaining it in a liquid form. Then, after it has served its purpose, this water is absorbed through the walls of the intestine and enters the bloodstream. The residual undigested food material is left behind.

The solid foods we eat provide us with a lot of our drinking water. Bread is nearly 40 per cent. water, and cakes 60 per cent.; fish contains 85 per cent. of water, meat more than 60 per cent., and vegetables 90 per cent. or more. But in addition to this direct supply of water from solid food we manufacture appreciable amounts of water from the hydrogen that is burnt during the oxidation of food chemicals in the cells.

All organic foods that we get from plants and animals contain carbon and hydrogen united together, and with other elements, in innumerable ways. Sugar and fats contain only carbon, hydrogen, and oxygen; proteins contain nitrogen as well, with small amounts of other elements. When nutrient chemicals from these foods react with oxygen in the cells the hydrogen yields water which is released in the body. We can therefore manufacure at least part of the water we need from dry food.

In most mammals, including man, this internal manufacture of water is inadequate to replace the water that is lost by the body. But some animals can exist entirely on dry food, making the water they need from the hydrogen burnt in their cells. The clothes moth, for example, can apparently live on dry-as-dust fibres containing only a trace of moisture, yet will generate enough water from the hydrogen in wool to lay eggs that are mostly water.

The little kangaroo rat is an even more remarkable water factory. This rat lives happily in deserts where there is no water at all. The desiccated sand-dunes of Death Valley in California are a favourite home. Here the kangaroo rat feeds entirely on seeds and other dry food. Yet it can maintain the water balance of its body in surroundings where a human being would survive for little more than a day without water.

Scientists have studied the kangaroo rat to find out how its water-supply system works. The animal has been found to contain 65 per cent. of water—about the same as other mammals living in more temperate surroundings. And it can maintain this water content no matter if it drinks water or not.

Like other rodents, the kangaroo rat has sweat-glands only on the toe pads. And it has fewer here than other rodents. It therefore loses little moisture through its skin. Also, the urine of the kangaroo rat contains 24 per cent. of urea compared with 6 per cent. in the urine of man. It is twice as salty as seawater.

This conservation of moisture in urine means that the kangaroo rat must have remarkably efficient kidneys. The animal can in fact drink seawater and extract fresh water from it. If a human being drinks seawater he tends to dehydrate his body; more water is needed to supply the urine that carries the extra salts away.

Though the kangaroo rat has cut down to a minimum its loss of moisture through the skin and in urine, it has been unable to do anything about the moisture that escapes in its breath. In the hot, dry desert air the rat cannot manufacture enough water from its food-hydrogen to make up the loss of moisture from its lungs. It therefore stays underground in its burrow during the hottest parts of the day. Here the humidity of the air is higher and the loss of water is kept at a minimum. At night the rat can emerge without fear of desiccation in the desert air.

These nocturnal habits of the kangaroo rat serve another useful purpose as well. Without an adequate supply of sweat glands and without sufficient water to spare even if it had them, the rat cannot operate the body-cooling mechanisms that human beings use. Water cannot keep it cool in hot surroundings by evaporating from the skin. The rat has no way of cooling itself in the hot sun during the day.

Other animals living in arid or desert environments are less fortunate than the kangaroo rat. The camel, for example, cannot escape from the blistering sun of the Sahara by crawling into a burrow in the sand. It must put up with the heat and manage on a minimum supply of water as well.

Unlike the kangaroo rat, the camel cannot make-do on the water manufactured from the hydrogen in its food. Instead, it has worked out a system of making the most of the water it drinks and has devised ways of eking out its body water to enable it to survive for long periods without drinking. Camels can work in the blazing heat of the desert for a week or more without water.

The camel is commonly believed to carry water in its hump, which is supposed to act as a built-in tank. But this is now known to be a fallacy; the camel's hump contains solid fat. Nor does the camel store water in any of its multiple stomachs. It does not store extra bulk supplies of water at all; instead, it has learned how to make better use of the water in its tissues and can survive dehydration to a remarkable extent.

Like the kangaroo rat, the camel uses great ingenuity in avoiding unnecessary use of its water supplies. The camel's kidneys extract less than a pint of water a day from the blood, even when the animal has all the drinking water he wants.

In the heat of the sun the camel does not keep cool by exuding water in the form of sweat, as human beings do. Nor does the camel pant like a dog, evaporating water from the mouth to cool the body. Camels keep their mouths shut, even in the hottest Sahara weather. The loss of water by sweating or from the mouth is almost negligible.

Like the human inhabitants of the desert, the camel has learned the value of 'clothing' to protect it from the sun. Its fur is thick but is provided to keep out the heat rather than to prevent it escaping from the body as it does in a cold-climate animal.

In spite of its fur the camel cannot avoid getting hot in the desert sun. But instead of cooling its body by water evaporation the camel takes the line of least resistance and merely allows its body to heat up. Human beings, like most mammals, cannot stand temperatures more than a few degrees above their normal body temperature. But the camel has learned to put up with a rise in body temperature from 93°F. to as much as 104°F. without ill effects. This not only avoids any waste of body water in keeping the animal cool, but reduces the amount of heat that is absorbed from the animal's surroundings.

For long it was thought that the camel did not have any sweat-glands at all. But research has shown that the camel's skin has emergency sweat glands scattered over most of the body surface.

These glands come into operation when the body temperature reaches danger point, at 104°F. Water is then evaporated from the skin to prevent any further rise in temperature. But even under these conditions the camel manages to avoid being seriously inconvenienced by its water-loss. It does not draw on the water of the blood, but takes its supplies from the tissue fluids and from the insides of the cells themselves. In this way the camel prevents any serious changes in the amount of water in the blood, so that the essential processes of the body can go on undisturbed. The animal can put up with the discomfort caused by changes in the dehydrated tissues so long as it can restore them to normal in a reasonable time.

By adapting its water mechanisms to desert life the camel has learned to survive under conditions that other animals cannot tolerate. When it is eating plenty of lush vegetable food, as it does in winter, the camel does not bother to drink at all. It finds enough water in its food to serve its modest needs. During summer, when there is little moisture in its food, the camel will need a drink after about four days. If necessary it can do without water for a week, even in the hottest summer weather. During this time the camel may lose more than a quarter of its weight as water is taken from its tissues to meet the needs of perspiration and digestion. Yet a good drink will restore the animal to its normal condition and it is ready to dehydrate itself again.

The belief that camels can store up a supply of water is still widely held, but it is fundamentally wrong. The camel that has quenched its thirst is really no more waterlogged than any other animal. Its ability to do without water is a result of its being able to put up with greater body dehydration, rather than to any store of extra water.

Experiments carried out by UNESCO scientists in the Sahara have shown how camels differ from other animals in this respect. Kept on a dry diet a camel loses 0.9 per cent. of its body weight during a January day; on a hot June day it loses 2.2 per cent. of its body weight. A donkey, on the other hand, loses 3 per cent. of its weight on a January day and 7.7 per cent. on a June day.

One camel went down from 660 pounds to 458 pounds after being without water for 17 days. Then it quenched its enormous thirst by drinking 16 gallons of water in ten minutes, increasing its weight by nearly one-third as the water soaked into its dried-up tissues.

Unlike the camel, human beings and most other mammals cannot stand any great upset in the water-content of the tissues. If the loss of water from the human body took place steadily throughout the day it would be a relatively simple matter to maintain the water balance in the body. But water is lost at a rate that depends on the state of our external environment and on the activity of the body itself.

On a hot day water exudes rapidly from the pores of the skin, evaporating and helping to cool the body. If at the same time we are indulging in violent exercise extra heat is generated inside the body and the flow of sweat increases. We can lose water in this way at the rate of half a gallon an hour. To quench our thirst under such conditions we may drink as much as a gallon of water in a very short time—enough to dilute the body fluids appreciably.

Disease and illness can affect the amount of water lost through the alimentary tract. Diarrhœa upsets the digestive system, and water cannot be absorbed from the food materials in the intestines; this water is lost from the body, and diarrhœa can dehydrate the body sufficiently to cause death, particularly in small children.

These fluctuating losses of water from the body would be reflected in the water mechanisms of the body if arrangements were not made to meet the changes. The internal environment must be maintained at a steady temperature, and the concentrations of the many salts and chemicals regulated. The supply of water has to be controlled continually and its dissolved materials adjusted to keep the body working properly. This is the job that is entrusted to the central laboratory of the human system, the kidneys.

The kidneys are often regarded simply as the organs that extract waste products from the blood, releasing them in the form of urine. But the kidneys are now known to do a very much more versatile job than that. They are delicate instruments that control the balance of water and dissolved substances in the body.

There are two kidneys in the human body, one on each side of the spinal column. Each kidney is connected to the circulatory system, so that one-fifth of the blood pumped by the heart is continually flowing through them. All the blood in the body circulates through the kidneys every three minutes. Although the kidneys make up only $\frac{1}{200}$th part of the body weight, more than 425 gallons of blood are pumped through them every day. As it enters the kidney the blood is distributed through innumerable tiny capillaries which carry it into the filtering system of the kidney tissue. Then the blood is collected together again and emerges through a single vein to re-enter the bloodstream.

Each kidney is equipped with a million or more filter units which strip the waste products from the blood and send them off as urine to the bladder. At the same time these filter units serve as sensitive water-balance mechanisms which regulate the amount of water and dissolved materials circulating in the blood.

In each filter unit of the kidney a fine blood vessel comes into intimate contact with a tiny tube called a tubule. As blood flows along water and dissolved salts and other substances pass through the walls of the blood vessel into the tubule. The blood cells and protein are left behind in the blood. Then the watery solution begins to travel through the tubule towards the opening which leads to a large vessel connected to the bladder.

If the kidney did nothing more than this the water and sugar and salts that seep into the tubules would find their way into the urine. Something like 180 quarts of liquid would flow from the kidneys to the bladder every day, carrying with it the water and invaluable salts and nutrients needed by the body. But, in fact, only about two quarts of water are released in the form of urine. The remaining 178 quarts are reabsorbed into the bloodstream as the liquid flows along through the tubules on its way from the kidney.

The filtration mechanism of the kidney is therefore a to-and-fro affair. First the water and dissolved substances leave the blood vessels and enter the tubules, leaving the cells and protein behind. Then most of the water and the useful dissolved materials are reabsorbed from the tubules into the blood, leaving the waste products such as urea to continue on their way to the bladder dissolved in a relatively small amount of water.

This amazing double-filtration process copes with tremendous volumes of body fluid. Although each kidney is no larger than a clenched fist, it contains incredible lengths of tiny tubes packed into each of its million filter units. The capillary blood vessels and the tubules are entwined around each other, twisting and turning to allow as much contact as possible between the vessels. Each tubule in a human kidney is about 1½ inches long; if the two million tubules in the two kidneys were strung together end to end they would stretch for about fifty miles.

The liquid flowing through these tubules has plenty of opportunity of undergoing its partial reabsorption into the bloodstream before discharging into the bladder. Water that enters the tubules from the blood passing through human kidneys every day carries about 2½ lb. of common salt with it. But only a fraction of an ounce escapes in the urine; the rest is reabsorbed into the blood before leaving the tubule. In the same way the kidneys filter and reabsorb 1 lb. of sodium bicarbonate and 5 ounces of glucose.

This reabsorption process that takes place in the tubules of the kidney is capable of sensitive adjustment and maintains the balance of water and dissolved materials in the body fluids.

Most of the water and salts that enter a tubule are reabsorbed before they have travelled far. Only about an eighth of the water is absorbed in the last section of the tubule, and this water is used for adjusting the amount of fluid that remains in the blood.

The absorption of this last-stage water from the tubule into the blood is controlled by a hormone released by the pituitary gland. If a lot of hormone is released all the water is reabsorbed, so that the urine flow is reduced; if the hormone release is restricted reabsorption diminishes and more water enters the bladder.

Control of the kidney tubules is therefore vested in the pituitary gland, which directs operations through its release of this antidiuretic hormone. And the activity of the pituitary gland is in turn influenced by conditions in the body as a whole.

When the water supply is falling low we experience the sensation of thirst. The flow of saliva falls off, and the mouth feels dry. This is the alarm signal sounded by the body. And to meet the situation the pituitary gland speeds up its secretion of antidiuretic hormone. So reabsorption of the water from the tubules to the blood is increased, and there is less water lost in the urine. Similarly, if too much water is being drunk the pituitary cuts down its production of antidiuretic hormone. Less water is reabsorbed from the tubules to the blood, and the urine flow increases.

Many things can influence the amount of water released by the kidneys in this way. Emotional experiences such as excitement or fear will often cause a rise in blood pressure. The blood flows faster through the kidneys, and more water is secreted in the urine. In cold surroundings the skin is cooled and the blood-supply is speeded up to try and counteract the loss of heat from the body surfaces. This again makes more blood pass through the kidneys, and more urine is excreted.

Alcohol tends to cut down the release of antidiuretic hormone by the pituitary gland, so that reabsorption of water from the kidneys is diminished, and more water passes to the bladder. Half an ounce of alcohol releases about a quarter pint of water. Spirits such as gin or whisky have a dehydrating effect on the body; they stimulate an increased flow of urine by affecting the hormone output of the pituitary gland. Beer, with only 4 – 5 per cent. of alcohol, boosts the water flow from the kidneys by increasing the actual amount of water in the blood.

The human kidney is remarkably competent in its control of the body's water balance and can deal with sudden and drastic changes in the water situation. The kidneys have immense reserves, and people can live almost as well on one kidney as they do on two. Survival is possible with kidneys operating at only a twentieth of the normal efficiency.

When the kidneys fail the body is unable to dispose of its urea and other waste products from protein metabolism. These substances accumulate and eventually the body is poisoned.

In some forms of heart disease the kidneys cannot function at a proper rate. Blood does not reach the kidneys in sufficient quantity, and water is not removed in the amounts needed to maintain the body's water balance. Fluid accumulates in the feet and legs, where blood circulation is often poor, and may ultimately collect in the abdomen and chest.

Diseases of this type can now be treated with the help of special sulpha drugs. These drugs suppress the activity of an enzyme in the kidney tubules which encourages salt to return to the blood. Salt is therefore excreted more rapidly by the kidneys.

As the amount of salt in the body goes down so the body finds less need for the water in which it is dissolved. One ounce of salt can hold six pints of water in the body. When salt is excreted the kidneys get rid of the water faster than they would otherwise do, so counteracting the effects of the poor blood flow.

Drugs of this sort have had remarkable results in removing fluid from the body. Patients have lost four stones in weight in a fortnight as fluid has drained from their waterlogged bodies.

This method of influencing the water balance of the body has also been used in treating glaucoma, an eye condition caused by excess fluid pressure. When the exit channels from the eyes are blocked fluid accumulates and causes intense pain. If the pressure is not relieved the optic nerve ends may be destroyed, and permanent blindness results. With the help of sulpha-type drugs that affect the salt-regulating enzyme in the kidney tubules more water can be removed from the body fluids and the pressure of glaucoma is relieved.

The recognition of the part played by the kidney in the water and chemical balance of the body has stimulated research into the activities of this accomplished organ. There is still much we do not know about the way in which the kidney does its job. But we have discovered enough already to show that the kidney is one of the most remarkable controlling devices in the human body.

16

Water attacks our Land

EVERY drop of rain that falls to earth is a little bomb that blasts away some portion of rock or soil. The disruptive effect of each individual drop is infinitesimally small; but the cumulative achievements of the rain are such that they can raze whole mountains to the ground. Year after year, through countless ages of time, rain has been eating away at the land. The 'eternal' mountains that we recognize to-day are transient features of our earth. Rain is still battering away at them as it did when the rocks reared up to form huge plateaus from which our Alps and Himalayas, our Rockies and our Andes have been carved. Some day, millions of years from now, these mountain ranges that we recognize will have disappeared from the earth, battered and broken by the unceasing bombardment of the water that falls as rain. New mountains will have formed from new convolutions in the crust of the Earth which will in their turn have been gouged and chiselled by rain.

Rain presses home its attack on our earth as it flows on its tortuous journey to the sea. It soaks into the soil and drains through cracks and fissures in the rocks, dissolving away minerals and salts that it meets. Charged with carbon dioxide from the air, rainwater is acid. It etches and corrodes the limestone that covers so much of the earth, carving great slices from the surface of the rock.

Limestone is often criss-crossed by little crevices or 'joints' that form natural channels for the water. Rain beating on the bare surface of limestone rocks will flow away down these joints, enlarging the fissures to leave pinnacles of rock pointing skywards like huge fingers. The flow of water over these rocks carves the fantastic shapes that are found in the limestone of many humid lands.

Though limestone is so easily dissolved by rain, water will attack almost any of the rocks of the earth's crust. Water is a first-rate solvent, and an active chemical too. Each raindrop may dissolve a particle so small that it cannot be measured; but the pelting of rain over a million years will carry away tons of the toughest rock. Even granite gives way before the onslaught of the rain. As it dissolves and corrodes the more susceptible constituents of a granite rainwater will break up the rock into a spongy mass to depths of many feet.

In these fissures and cracks that are opened in the rocks rainwater collects to form tiny land-locked pools. At night the water freezes, and the ice expands with irresistible force. The rocks split and break up into finer and finer particles until eventually they are incorporated in the soil.

So, in one way or another, rainwater makes its mark on the land as it sets off towards the sea. It has dissolved where it can and chiselled and chipped at the rock with a variety of chemical and physical implements. This is the beginning of the process of erosion, the wearing away of the land that has been going on incessantly since the rocks reared up from the earth. It is the disintegration process that provides the mineral basis to our soil. Nothing we can do will prevent it; like the evaporation of water from the sea, it is part of the inevitable cycle of natural change on the surface of the earth.

This slow, steady attack by rain is aided and abetted by the wind and by the temperature changes that help to break up the surface rocks. Erosion is the result of a concerted attack by the atmosphere, with water playing the leading role. Wherever the land is lifted high into the air, erosion is at its most effective. Mountains are a challenge to the atmosphere, and the battering of rainwater over the ages is steadily wearing them down.

This basic, geological erosion forms a background to the agricultural erosion that has become so important to-day. Where inadequate cultivation has weakened the soil, water and wind can carry away the particles at an accelerated speed. Top-soil containing the rich plant nutrients is carried away by fast-running streams that bite into powdery land beaten flat and impenetrable by the heavy rain.[1]

By the time that it collects into a stream rainwater has already done a lot of damage to the earth. As it flows along it carries its dissolved minerals, together with a charge of solid floating particles that have been swept up from the broken surface. But the water carries on with its erosion as it makes its way in an ever-widening stream towards the sea.

Just as the trickle of rainwater eats away the rock on which it falls, so does the rushing stream carve great gullies from the land over which it flows. As rivulets ran down the sides of primeval plateaus they cut sharp V-shaped channels in the sloping walls. In the course of time the walls of these gashes were weathered and worn, and the outlines smoothed into the valleys that divide our mountains to-day. The peaks that tower so high in the great mountain ranges of our present-day world are mere remnants of tables of rock that were lifted by movements in the earth's crust when the world was young. These mountains have been carved from mammoth slabs of rock by the water that ran down the sloping sides.

On limestone rocks a stream will continue the work that its water began when it reached the soil. Cutting into the sensitive rock, the rushing water carves out huge gorges and caves. Often a stream will fall headlong into holes that reach down into underground tunnels and caverns dissolved from the rock. At Gaping Ghyll on Ingleborough,

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[1] There are accounts of accelerated erosion in *The Fight for Food.*

in Yorkshire, water disappears into a shaft 365 feet deep. The Cheddar Gorge is believed to have been formed by the collapse of an underground cave cut from the limestone by flowing water.

The abrasive power of a stream depends on the speed of the water and the amount of solid matter carried in it. A fast-moving river will sweep along sand and other floating particles, which scrape and scratch at the rock over which the water flows. The Grand Canyon in Arizona has been carved by the silt-laden waters of the swift Colorado River. For 300 miles the river has chiselled a monstrous gash in the soft shales and limestone, forming a gorge that is ten miles wide and over half a mile deep.

The Colorado River carries one hundredth of a cubic mile of silt from the Grand Canyon every year. Assuming that the river has always eroded at this rate, the gorge is 200,000 years old.

The Niagara River, on the other hand, is clear and silt-free. It drops 165 feet over the limestone wall of the falls, scouring the rocks below in a cauldron of whirling water and stone. As the limestone is worn away, the overhanging rocks fall into the river below.

The falls are eating their way backwards from Lake Ontario to Lake Erie. The gorge below the falls is now seven miles long, and is increasing in length at about two feet per year. On this basis the Niagara Falls are 20,000 years old.

Gradually, as it scrapes away at the rock of its bed, a river will fall towards sea-level. Its tumultuous flow will slacken, and the water pushed on from behind will absorb its energy by meandering over a flat valley floor towards the river mouth. Then, tilted up by a change in the earth's crust, it may find a new life in a restored gradient; it will start to cut through once again as it seeks to carve out a course towards sea-level. The meandering course of the original river will turn into a tortuous gorge such as that of the river Wear below Durham.

When land is broken up by the forces of erosion rocks are released as particles of varying sizes. These particles are graded and separated by rivers, the larger ones being left near the source and the silt floating on towards the sea. As the river flows into the sea the movement of the water is slowed, and the silt settles out in huge fan-shaped banks that creep gradually out into the sea. Through these mud banks the river water escapes in slow-moving streams that break up the mud into a delta.

The mud of a delta lying at the mouth of a large river is formed of soil that has washed from the land. The Mississippi, draining nearly 1¼ million square miles of land, has built a delta from particles scoured by the rain from this huge region of the United States. Every year the water of the Mississippi carries 80 tons of dissolved material, 288 tons of suspended silt and 32 tons of bed-soil *from each square mile of its basin* into the Gulf of Mexico. During the last 125 million years the river has scoured some 15,600 million million tons of rock from its drainage basin; the central plain of the United States is being eroded at the rate of 1 foot in every 7000–9000 years. Since man appeared on earth the Mississippi has lowered the surface of the land by about 150 feet.

The Nile has for centuries been flooding the plain of Egypt with water brought down from the Abyssinian highlands. Carried in the water are silt and dissolved material etched by rain from the mountains. Every year 57 million tons of silt and 20 million tons of dissolved substances are brought to Aswan from an area of 1½ million square miles of the river's basin.

Between Khartoum and Aswan the Nile is biting into its floor, and between Aswan and Cairo it is cutting into the silt deposited in centuries past. This re-excavation is due to the steepening gradient of the river caused by the effect of its erosion on the earth's crust. The material brought from the Abyssinian mountains to be deposited in the evergrowing delta has shifted an enormous load from one part of the basin to another. This has tilted the Nile Valley so that the gradient of the river has increased, the flow of the water has quickened, and the erosion of the river bed become more serious.

If it is assumed that every square mile of the earth's land surface is losing 300 tons of matter by erosion every year, some $2\frac{1}{5}$ cubic miles of land is being lost into the sea annually. At this Mississippi-like rate the entire land surface would be reduced to sea-level in about 14 million years.

Much of the earth, however, consists of desert or arctic regions where erosion is not so active as in the great river basins. The time required for smoothing down the earth to sea-level is therefore very much greater than this.

On high mountain slopes and in the lands near the poles, ice takes over from water the attack on the land. As snow falls in regions of permanent cold it builds up great layers often hundreds of feet thick. Pressing down with enormous force, it squeezes and compacts the snow underneath, turning it into solid ice. So, near the top of a mountain a glacier is formed.

Though the ice of a glacier is solid and crystalline, it can flow like a plastic (see Chapter 13). It glides down the sides of the mountains, riding the rough places in the rocky walls until it reaches the warm air of the lowlands. Here the ice melts, and the glacier ends in a glittering cliff that dissolves in a sparkling stream.

As it flows down the valley a glacier pushes and scrapes with incredible violence at the walls and floor of its channel. The rocky projections are smoothed and polished, and the valley is gouged into a U-shaped trough. At the head of the valley new ice is continually formed from the snow that fills the space left as the glacier slides away down the valley. The new ice cements the glacier to the rock wall of the mountain; as it, in its turn, is dragged downward it tears off great slabs of rock from the mountain-side. In this way a glacier gnaws steadily at its mountain, carving out huge, bowl-like depressions and creating the jagged, broken peaks that are characteristic of glacial ranges.

In its slow journey down the valley a glacier continues to collect stone from the walls of its channel. Rocks fall from the frost-broken slopes above, often to find their way to the base of the glacier by way of the crevasses that break up its surface. Embedded in the ice, these rocks help to roughen the base of the glacier as it rasps at the floor of its channel.

When the glacier melts its burden of rock is deposited in great heaps, or moraines. The moraines left by ancient glaciers often span their valleys, acting as dams behind which lakes are formed.

In the high mountain regions where glaciers remain today erosion by ice is continually in progress. The scraping and scratching of a glacier is local in its effects; but the results are impressive and are helping to disintegrate the high mountain ranges.

In polar regions ice lies in a layer hundreds of feet thick; we know little of its effect on the land beneath. But in the great Ice Ages that occurred on earth thousands of years ago the polar ice sheets extended over more than a quarter of the present land area of the earth. Canada and part of the United States were buried beneath thousands of feet of ice; in Europe the ice-cap covered the whole of Scandinavia and the British Isles and penetrated far into Western Europe.

During a period of perhaps a million years this ice sheet retreated and grew several times, planing and polishing the surface of the earth like a huge milling machine. The rounded hills of Scotland were rubbed smooth by the ice that lay over them for so long. Thousands of lakes were gouged from the surface of Europe and Canada; masses of stone were carried for hundreds of miles from the places where the ice rubbed them from the earth. There are boulders in Yorkshire and other parts of eastern England that were carried by ice from Norway. In Canada and north-west Europe the ice scraped away soil to a depth of some twenty-five feet leaving the bed-rock polished and smooth.

In the highlands outside the area of the ice sheet glaciers formed in the valleys. As the ice retreated the glaciers melted, leaving the typical U-shaped valleys with their deep-scratched rocks and moraines as evidence of the erosion they achieved.

Erosion is only one of several influences that affect the profile of the earth. As erosion wears away the existing mountains and high lands the earth is countering the effect by lifting new plateaux imperceptibly higher and higher above sea-level. These plateaux will become the mountain ranges of the future, replacing our present ranges which are slowly being washed into the sea.

By comparison with this immense earth-shifting job carried out by nature the achievements of our bulldozers and mammoth scrapers seem puny and insignificant. Nature's tools are simple, slow, and wonderfully effective. Most important of all is the 9000 cubic miles of water that runs off the land into the seas every year.

When a river reaches the coast its rushing water is checked and its energy absorbed by the heaving bulk of the sea. But its attack on the land goes on, pressed home by the waves that batter relentlessly against the shore.

The immense power of the sea is packed into its waves, which can break up the toughest sea-walls and tear down huge rocks from the base of a cliff. With its foundation removed, a cliff crumbles and falls; the boulders and rocks that fall on to the beach are picked up by the sea and hurled back like sling shot against the cliffs from which they came.

As the rocks are swept up by the sea they are pounded one against the other. Abraded and shattered, they become smaller and smaller. Rocks turn to pebbles, and pebbles to sand. The smaller they are, the more easily the sea can sweep them along with the help of its currents and tides.

So, along thousands of miles of its coast, the land is being eaten away by the sea and dispersed in the boundless expanses of the ocean.

The results of this attack by the sea are controlled by the strength of the rocks against which the waves beat. Where the rocks are hard the sea will probe and pry, seeking for weak spots and carving the rocks into tortuous shapes. The pinnacles and skerries, the inlets and caves of a rocky shore are patterns created by the sea as it beats against rocks of varying resistance. Ultimately a coast of this sort is eroded to a straight and featureless cliff.

When the rocks of the coastline are soft the shore tends to slope gently from the land to the sea. The waves have found little to resist them, and have carried their work to completion.

The fate of the material torn from the shore depends on the prevailing flow of off-shore currents and tides. Down the east coast of England shingle and sand is carried southward until it comes up against barriers that counter its flow. Great promontories are built up, such as Spurn Head that sweeps like a curving arm into the Humber estuary. On the south coast of Britain the flow of sea currents has built up the eighteen-mile-long Chesil Beach that joins Portland Island to the mainland. The pebbles of this beach are carried by the sea from Budleigh Salterton, where they are gouged from the cliffs by the battering waves.

This movement of shattered rock in the form of shingle and sand goes on continuously in the sea. The smaller the particles, the more easily can the sea sweep them along. Sand is shifted from one home to another until eventually it is swept beyond the edge of the continental shelf and finds a permanent resting-place on the ocean floor.

Erosion of the sea is taking place against a background of constantly changing sea-levels. The movements of the continental land-masses and the sea are reflected in the emergence and submergence of coastal areas. All over the world immense geological shifts are taking place. Land is tilting under the effects of changing loads; great folds are being pushed up imperceptibly to form the mountain ranges of the future, and the tilt of the coastline is changing.

These effects are superimposed on the normal erosive effects of the sea. Where the coastline is emerging from the sea flat coastal plains are formed by the floor of the shallow sea-bed. Carried by the tide and the waves, sand is pushed up to form sand-bars and shoals. The east coast of the United States, with its long, sandy beaches, has been formed from land that is emerging slowly from the sea.

When the sea-level rises with respect to the land the water flows in until checked by high ground. It inundates valleys, creating an indented coast with isolated peaks left as islands off-shore. Western Scotland with its lochs and countless islands is a coast formed by submergence in this way. When the valleys have been gouged out by glaciers before being drowned the walls of the inlets are sheer and stark, rearing abruptly from the sea. The walls of Norwegian fjords, formed by inundation of glaciated valleys, are often thousands of feet high.

At present the east coast of the United States is believed to be sinking below the sea at a rate of two feet in a hundred years. In Europe there is a tendency for the land to rise in the region of the Baltic and along the north coast of the Mediterranean. France is being tilted up, so that the gradient of the Rhône Valley is falling. Eventually much of northern France will be inundated by the sea, and the Baltic will become dry land again. At the present rate of tilt Finland will have a frontier with Sweden in about 10,000 years.

These localized changes in the relative levels of sea and land are part and parcel of world-wide fluctuations in the shore-line. Three hundred and fifty million years ago the sea was 600 feet higher with respect to the land than it is to-day. Much of our present land was, for millions of years, part of the ocean-floor. Then the seas subsided, and tiny islands turned into huge continents. These massive inundations have come and gone at intervals of many millions of years as the world has grown old. Marine fossils have been found in rocks 15,000 feet above the earth; rocks that form part of our continental mountain ranges were once covered by the sea.

These periodic changes in the level of the sea have left their marks on the land. Waves of primeval seas have carved out cliffs that are now high up on our mountain slopes; beaches and shingle banks are left hundreds of feet above sea-level.

Nobody knows why these changes took place in the relative levels of water and land. Nobody knows whether the volume of water has changed sufficiently to account for them or whether the land itself has risen and fallen. All we can measure are the relative changes in levels of water and land.

It may be that water has seeped from the earth in sufficient volume to cause these great floods. Volcanoes on the sea-bed are still discharging 'new' water into the sea.

It may be that the recurring ice-ages have dried up the seas by piling their waters as solid ice on the land. Then as warmth has returned to the earth waters from the melting ice have coursed over land that has settled and sunk under the weight of the enormous ice load it has carried. Or it may be that the continents have sunk as radio-activity has softened the rocks on which the land-masses lie.

Whatever may have caused these recurring changes in sea-level, there is no doubt that they have taken place. Today we believe that the water is rising again in the world as a whole. The ice-caps are melting in Greenland and Antarctica, raising sea-level by eight inches in 100 years. Some day the sea will be encroaching over the lands on which we now live. And the waves will pound at the rocks, hammering them small and grinding them one against the other until water has once again asserted its mastery over the land.

Index

Abidjan power station, 49
Agar-agar, 64
Albatross expedition, 17
Algæ: in plankton, 69; in reservoirs, 112
Alginic acid, 61
Alkali from seaweed, 58
Anemone, locomotion of, 95
Antidiuretic hormone, 177
Artesian well, 111

Bacteria from deep-sea floor, 103
Biological layer on sand filter, 113
Blood, composition of, 166
Bromine from seawater, 53
Brownstone pebbles, 25
Buxton water, 118

Camel, water conservation in, 171
Cavendish, Hon. Henry, 147
Chainad Dam, 43
Challenger expedition, 14
Chlorine as sterilizer, 114
Cholera epidemics, 108
Clay as a cleanser, 135
Compression distillation, 124
Continental shelf, 12
Copepods in plankton, 81
Copper in seawater, 56
Currents, formation of, 30

Deep-scattering Layer, 87
Detergents: development of, 139; effect on sewage, 141; effect on skin, 143
Detritus, 97
Deuterium, 156
Diatoms, 69
Droitwich water, 117

Echo-sounder, 14
Eggs from fishes, 89
Equatorial currents, 30
Erosion, 180
Euphausiid shrimps, 87

Fibres from seaweed, 63
Florida Current, 31
Fluorine in water, 128
Foraminifera, 81
Fundy, Bay of, 48

Galathea expedition, 92, 103
Glacier, erosion by, 185
Gold in seawater, 57
Grand Canyon, Arizona, 183
Gravity measurements, 15
Gulf Stream, 32
Guyots, 19

Harrogate waters, 117
Hawaii, underground mountain of, 20

Ice: density of, 149; various forms of, 154
Iodine: from seaweed, 159; as a sterilizing agent, 115
Ion-exchange, 124
Irish Moss, 65

Kelp, 58
Kidneys, 175
Kwajalain Atoll, 20

Lavoisier, Antoine, 147
Liverpool Observatory and Tidal Institute, 35
Lomonosov Mountains, 19
Luminescence, 91

Magnesium from seawater, 54
Mammals in the sea, 85
Mariana trench, 21
Meteor expedition, 16
Metropolitan Water Board, 108
Mid-Atlantic Ridge, 18
Mississippi, erosion by, 184

New River Company, 108
Niagara Falls, 183
Nile, erosion by, 184
Norsk Hydro, 158

Ozone, 115

PASSAMAQUODDY BAY SCHEME, 48
Phosphorus in seawater, 56
Pipes, wooden, 105
Plankton, 69
Potash in seawater, 56
Priestley, Joseph, 146
Protozoa in plankton, 81

RADIOACTIVE SEDIMENT, 24
Radiolarians, 81
Rance tidal power scheme, 49
Rat, kangaroo, 170

SARGASSO SEA, 74
Scale formation, 119
Sediment on ocean floor, 23
Severn barrage scheme, 46
Sharks, 85
Soap as cleanser, 136
Sponge, 94
Squid, Giant, 84
Stanford, E. C., 61
Starfish, 99
Surges, 36

TIDES, 33
Tintinnids, 81
Trenches, ocean, 21
Tritium, 161
Tsunamis, 28

VICHY WATER, 117

WAIRAKEI SCHEME, 160
Water: demineralization of, 122; density of, 148; distillation of, 122; evaporation of, 152; filtration of, 109; hardness of, 118; heat capacity of, 149; power of, 40; supercooled, 151
Waves, formation of, 26

ZEOLITES, 120