SCIENCE FOR EVERYONE

P. N. EROFEEV

THE PROGENY OF VOLCANOES

MIR

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Павел Ерофеев

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The Progeny of Volcanoes

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Foreword

The role of the ocean in our lives can hardly be overestimated. It finds its expression in the regulation of the climate and weather, as the source of biological, energy and mineral resources, and as the main waterway between the continents. And not only that! The progenitor of all that exists on Earth may well be regarded as our own future.

The oceanic expanses have stirred people's minds since time immemorial. The inability to understand and explain the natural phenomena in the remote past made seafaring men imagine the most whimsical things about the aqueous cover of our planet. For this reason what we know of the boundless deep from the Ancients is surrounded with an aura of pure fiction. However, genuinely scientific study of the World Ocean has been undertaken over a period of somewhat less than two hundred years, with the most fertile research in this field taking place in the last decades of the twentieth century. The discoveries made within this stretch of time have altered a large number of previously established concepts concerning the nature of the World Ocean. In this respect, Soviet scientists, who have unveiled many a cherished secret of the ocean, deserve the highest merit.

In this book there is historical and current information on the processes that originate in the World Ocean and that give rise to the emergence of various phenomena. The hidden treasures and the practical measures to recover them together with the unsolved mysteries of the green continent and the place and function of the World Ocean in the life of our planet are treated here accordingly.

The book contains some hypotheses that may seem bizarre to the reader. These hypotheses, the authenticity of which the author does not in the least claim to purport, serve rather as a peculiar approach to the phenomena of nature, which helps to visualize them in an unusual light. This particular means employed by the author is intended to make the reading of his book more absorbing and entertaining.

On the one hand, the vast amount of scientific material, fully comprehended and generalized by the writer of this book, qualifies it as a consistent scientific disquisition based on the contemporary achievements in oceanology, while on the other hand, the book represents a closely knit set of poetic essays on the World Ocean, which are founded on the personal impressions and observations of the author. The two aspects are successfully interwoven and produce a coherent and accessible narrative about the Earth's most fascinating object—the World Ocean. This is precisely what distinguishes this book from other similar works.

At this juncture, one cannot but say at least a few words about the author himself—the USSR State Prize Winner Pavel Nikolaevich Erofeev, who has taken part in many oceanological expeditions in different regions of the World Ocean ranging from the polar to tropical latitudes of both hemispheres. It is most fortunate that his enormous experience, which has been filtered by his discriminating perception, has found its expression in the pages of the present book.

A.M. Muromtsev

The USSR State Prize Winner,
Doctor of Geographical Sciences,
Professor of Oceanology

Preface

I made my first acquaintance with the sea as a young man just at the time when World War II had ended. It so happened that I found myself in the region of the Caspian Sea where I was taken on as a collector by a seafaring group of the Azerbaijan oil expedition of the USSR Academy of Sciences. This high-sounding post presupposed a wide scope of occupations ranging from the collection of samples of bottom rocks to the carrying of heavy equipment and other no less prosaic pursuits.

And it was there that I met a remarkable person—the founder of Soviet marine geology, Professor Maria Klenova, under whose guidance the expedition was then doing its research connected with the sea. This encounter drastically changed all my plans. Professor Klenova had the gift of infecting all those around her, and particularly her pupils (one of whom I had eventually become myself), with an insatiable love for the sea.

Much time has elapsed since then, but even now, there is nothing that can obliterate in my heart that very first rung of my career that brought me into propinquity with the ocean.

The author of this book was fortunate to have been a participant and a witness of many events connected with the post-war development of Soviet oceanology, to have seen far-off countries, and to have got in touch with the extraordinary, and at times uncanny, phenomena of nature, to say nothing of having worked side by side with very interesting people: one of them was my friend, a Candidate of the geological and mineralogical sciences, Vadim Lavrov. We had an idea to join our efforts and write a book about the World Ocean. This, however, was not destined to be, since Vadim Lavrov died at the peak of his creative ability. I have profited immensely from my friendship with this talented scientist, whose heart knew no stint of generosity.

I have written this book in memory of my teacher Maria Klenova, my friend Vadim Lavrov, and those scientists who have unsparingly devoted their powers to the making and further progress of Soviet oceanology.

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Introduction

The Blue and Green Expanses of the Earth

The ancient philosophers were the first to give a fairly realistic idea of what the Earth looked like, its size, and the place occupied on it by ocean and land. Homer, for instance, assumed that the Earth was a disc surrounded by the Ocean river. But the great Greek philosopher Aristotle went so far as to adduce some evidence that our planet had a spheroidal form. Eratosthenes, the Greek astronomer and geographer, who lived some time later, was even able to determine the length of the Earth's circumference, which, according to his estimate, comprised 250 000 stades. By taking a single stade to be approximately equal to one-tenth of a nautical mile, one cannot help but wonder at the not wholly inappropriate coincidence of the figure given by Eratosthenes with the actual value of the Earth's circumference. This, however, is not what surprises most. Eratosthenes stated that the inhabited world made for only one-third of the surface of our planet, whereas its remaining space was covered by water. For the ancient times this statement was more than remarkable.

It was the burgeoning period in ancient science of knowledge about the Earth's geography. This was followed by a collapse and centuries of stagnation with the loss of the realistic concepts propounded by the ancients.

The epoch of momentous geographical discoveries marked by the voyages of Columbus, Vasco da Gama and Magellan resuscitated the interest in oceanic studies. Navigators and explorers began to discover hitherto unknown lands, as well as derive and specify new data concerning the geography of our planet. This resulted in that it was reliably established that of the 510 million square kilometres of the Earth's surface, 361 million, or more than two-thirds of it, were occupied by water.

The World Ocean embraces the Earth with inseparable waters and by its nature is an indivisible element that acquires diverse properties with the change of latitudes. Near the shores of Greenland and the Antarctic as well as in the wind-ridden 40-degrees latitudes of the southern hemisphere, storms rage throughout practically the whole year, whereas the tropical regions are scorched by the merciless zenithal sun and calm trade-winds prevail that are disrupted but rarely by hurricanes of great destructive force. The ocean creates a favourable climate for life on the shores of the continents and islands, and influences the climate of the continents themselves and the planet as a whole.

Today, we have a rather clear idea about the topography of the World Ocean floor. But as far back as the beginning of the twentieth century, the ocean floor was considered to be a flat plain lacking in any variety. Untenable as it was, the concept was nevertheless a tangible achievement as compared with the ideas adhered to by the ancients, who regarded the ocean depth as unfathomably infinite.

What actually revolutionized our understanding of the ocean floor relief was the invention of the echo sounder—a device for the continuous measurement of depth variations from aboard a moving vessel. The echo sounder made it possible to determine that the floor of oceans is markedly dissected. Under the water, as on land, there are mountains, gorges, plains, tablelands, volcanic massifs, etc. There are also specific forms of the relief that are typical of the ocean alone. They are called mid-oceanic ridges and make up the enormously large mountain system that passes through the Arctic basin, the Norwegian Sea, the Atlantic and the Indian oceans, and the southern part of the Pacific Ocean. This is the longest mountain chain on Earth, extending over 60 000 kilometres. The area it occupies is nearly equal to the surface of the continents. The ridges rise several kilometres above the ocean bed.

One only needs to give the physical map of the world a cursory glance to discern the long narrow parts that are distinguished by a dense blue colour among the multifarious forms of the ocean floor relief. These are the oceanic trenches—the likewise specific formations in the earth's crust that have so far not been given due consideration. Under the blue cover of the Earth, more than thirty oceanic trenches have been discovered. They are correlated with the greatest depths of the World Ocean. The deepest place in the World Ocean is found to be in the Mariana trench situated in the Pacific Ocean.

Its discovery took some time. In 1927, the instruments installed aboard the vessel of German hydrographers registered the ocean floor in the Pacific and to the east of the Philippine Islands to be as low as 10 789 metres below the water surface. This singular record held out for over twenty years. In 1948, British researchers found to the south of Mariana Island a depth that already measured 10 863 metres. In 1957, Soviet scientists aboard the research vessel *Vityaz*, working in compliance with the programme of the International Geophysical Year, discovered a place in the Mariana trench with a depth of

11 022 metres. More attempts were made to find a deeper place in the World Ocean, but, as can be seen from sea-charts, the depth discovered by the Soviet specialists has so far remained a maximum.

The World Ocean comprises ninety-seven percent of the planet's surface waters and about half of the lithosphere waters, which are found to be in a state of constant movement. This mobility gives rise to various minor and major streams, which serve to maintain the horizontal and vertical water exchange, which in its turn plays a highly prominent role in the life of the Earth and particularly the biosphere. The vastness of the World Ocean and the function it shares in natural planetary processes have led to the assertion that the Earth we live on has taken for itself an inappropriate name. The planet should have been called 'The Ocean' Is this really so?

What is actually known about the relationship between the World Ocean and the dimensions of the Earth presents no minor interest in terms of the contrast. The volume of the World Ocean, estimated at 1338 million cubic kilometres, comprises only one-eight-hundredth of the Earth's volume. The mass of ocean water, if we imagine it to be squeezed into a sphere, has a radius that does not exceed the eleven-hundredths of our planet's radius. A comparison of the ocean depths with the size of the Earth itself presents figures that are even more impressive. On a relief globe with a diameter of one metre where the scales of depths and heights are observed, the greatest depth measuring 11 022 metres is represented by an infinitesimal cavity of only eighty-six hundredths of a millimetre. To bring out the contrast, it would not be out of place to mention that the highest mountain Chomolungma is marked on this globe as rising above the ocean level to the height of only seven-tenths of a millimetre. If, however, we imagine this kind of globe to be flat and with the ocean water evenly spread over it, then the width of its layer will be only a little more than twenty-one hundredths of a millimetre, which is exactly the same thickness as several sheets of paper.

The World Ocean, as we see, is but a thin layer of the Earth. Moreover, its bottom is also earth, though hidden from us by the water. According to scientists, the ocean floor has the key to the mystery of the inner structure of our green planet—by right called the Earth—as well as to the processes relevant to the formation of its surface. Thus, it is clear that it is hardly possible to speak of the World Ocean not in conjunction with our planet as such, for it is no more than its own progeny painfully born, moulded and hardened in the unceasing struggle that has enabled it to win what must be the primary role in the life of the

Earth. There is every reason for the World Ocean to be ever more often regarded as not only the past, but also the future of humankind.

According to data provided by the United Nations Organization, the population of our planet increases annually by 75 million people. Demographers believe the figure will go up to nearly six billion by the year 2000. In this connection, the problems of where to get additional food supplies, and mineral and other resources inevitably crop up. As is known, the Earth's reserves of useful minerals are by no means inexhaustible. From the bowels of the Earth, for instance, twenty billion tons of oil have already been extracted, in addition to which the yearly level of its output, comprising at present approximately two billion tons, is steadily on the increase. The explored reserves of this raw material, however, have so far reached only 62 billion tons. It is not surprising, therefore, that the eyes of humankind are fixed on the ocean.

The shelf of the World Ocean, which has not yet been adequately explored, today yields already about twenty percent of the oil and gas output. There is some reason to believe that oil will be found on the abyssal slopes of the World Ocean floor. Dense saline solutions containing large concentrations of zinc, copper, silver, and other elements were discovered on the bottom of the Red Sea. The floor of many of the regions of the World Ocean is covered with manganese concretions remarkable for their contents of manganese, iron, nickel, copper, cobalt, molybdenum, vanadium, and lead.

The World Ocean is the source of bio resources and a large number of vitally important compounds. The present-day catch of fish by the USSR is equal to ten million tons per year, which makes up approximately fourteen percent of the world output. Today, the World Ocean supplies about fifteen percent of animal proteins.

The ocean fauna, including corals, all kinds of fish, sea fishes, and algae, contains the most valuable biologically active substances as well as those that are used for medical purposes. Even the foam that we see on the surface of the ocean is in itself a biologically active substance, which plays a very significant ecological role in the ocean's life. This cannot but bring to mind the Greek goddess Aphrodite who was fabled to have risen from the foam.

The salt water of the ocean is the most esoteric phenomena of nature, though the vast majority of us look upon it as a most ordinary thing. It represents a solution of a large number of chemical elements with a preponderance of sodium chloride (common salt), and only a little over one-fifth of all of them is accounted for by the sum-total of magnesium sulphate (the

Epsom salts) that gives water its bitter taste, magnesium chloride, calcium sulphate (gypsum), potassium chloride, and a number of other dissolved chemical substances, among which even gold, radium and uranium, however infinitesimal their concentrations might be, are formed. It was within the confines of ocean water itself that about sixty elements of Mendeleev's periodic table were found. If, however, all the microorganisms living in the water were taken into account, it would then be no exaggeration to say that the ocean contains every single element known on Earth.

The presence of salts in ocean water endows it with the following specific properties: a high degree of electric conductivity, a decreased freezing point and thermal capacity, a rise in boiling point, and other properties. If there were such means that could precipitate all the salts contained in the World Ocean, its floor would be covered with a salt layer fifty-seven metres thick.

The very first interpretations concerning the origin of salts in the ocean go back to the earliest periods of our history. Aristotle's explanation of this natural phenomenon was that the sun extracted from the ocean floor a great many substances and vapours that were then mixed with each other and raised to the surface of the water. Aristotle thought that it was there that the sun boiled and burnt them forming salt. Theophrastus, who was Aristotle's pupil and successor, assumed that the ocean floor was covered with saline mountains that were being dissolved in the water. Pierre Simon Fournier, the celebrated hydrographer of the Renaissance, expressed his doubts about this, since, as he asserted, it would have been necessary to have an infinite number of saline mountains to salt such an enormous amount of ocean water and make it acquire a bitter taste. Moreover, the mountains were not to remain undissolved forever.

With the passage of time the range of knowledge widened, and on its basis, the scientific study of the Earth developed further. In the end, many a phenomenon of nature were looked upon in a radically different way. It has become quite clear that the salinity of the World Ocean is the result of continuous and prodigious geological processes. It occurred to those who were concerned with this field of study that, at first, the waters of the World Ocean were fresh and that the salt had been brought to it by the rivers that were dissolving and washing away various rocks.

Hence, the majority of dissolved substances carried into the ocean by the rivers is precipitated, while a certain part of them has to be concentrated in the water, thus increasing its salinity. Hydrochemical investigations, however, prove that the river runoff does not to any marked extent change the nature and proportion of salts in the World Ocean. The chemical composition of river and ocean waters is strikingly different. It was expected that the salts carried into the ocean by the rivers would be manifested in its waters. This, however, is not the case. Judging by the fossil organisms and the ancient beds of rocks, the chemical composition of the World Ocean, at least since the beginning of the Paleozoic period, has not been much different from what it is today.

The idea that the salinity of the World Ocean is indebted to the rivers has proved to be completely untenable. As is actually the case, ocean water is a natural equilibrium solution that is characterized by an unusual chemical inertia. What can really change the saline composition of the enormous mass of water in the World Ocean is only very powerful hydrochemical processes of long duration. The salts that are brought into the ocean by the rivers and that remain in a dissolved state represent but a trifling factor as compared with the required scope of such processes. The impact of river runoff makes itself apparent only in the mouth regions of the ocean.

It has long been observed that there is much in common between ocean water and blood. For instance, the ions of sodium and chlorine (the main chemical components of ocean water) as well as the ions of magnesium, calcium and potassium contained in it are found to comprise the inorganic basis of blood. The proportion of these components in water and in blood is practically the same. The conclusion that suggests itself is that blood may well be regarded as a derivative of the World Ocean. From here it would be possible to throw a bridge across the ages separating us from the advent of living beings on Earth. The analogy between ocean water and blood is accepted as one of the pieces of evidence substantiating the idea that life originated in the aqueous cover of our planet.

The aim of this book is to acquaint a wide circle of readers with the principal achievements of the scientific study of the World Ocean, with the interesting and mysterious phenomena that manifest themselves within the confines of the blue expanses of the Earth, as well as with some problems concerning the use of the ocean's resources and other practical aspects of oceanology.

Chapter 1

The Union of Water and Fire

How Many Volcanoes Are There on Earth?

There are more than eight hundred active volcanoes on our planet and all of them make no secret of their uncontrollable temper. It is not surprising, therefore, that the attention of researchers was primarily drawn to these ferocious manifestations of the subterranean forces. But gradually investigators began to give more thought to the kind of activity that was hidden in the bowels of the Earth by its aqueous cover, and what particular function was shared by volcanism in the geological history of our planet. The not yet copious chronicle of submarine volcanism contains many remarkable pages with narratives of some of the unusual finds and discoveries. But before we get down to these annals, it would be of no minor interest to turn our minds back to the early stages of our history.

In an ancient Polynesian myth it is said that the god Tangaroa created seven heavens and erected the Earth round which they began to circle, with the ocean surging its waves. The story goes on to say that the god Maui, when fishing, once caught a whole island out of the ocean's depth. But the hook accidentally got entangled in the hair of Ru, the god of the winds, who was at that time slumbering in the deep, and who, thus awakened, heaved the surface of the ocean. The wind started to blow furiously, the waves rose at that very instant, and the earth began to quiver. Tongues of flame went up over the mountain tops and huge stones were thrown into the air to pelter down upon the island like rain. Then the ocean left its bed and climbed to the peaks of the highest mountains, thus flooding the island that had been caught by Maui.

The ancient Polynesians can be regarded as the first people on Earth to witness submarine volcanism on such a comprehensive scale, because they live on volcanic islands that not infrequently emerge and disappear before their very eyes. In 1980, a New Zealand pilot saw from aboard his plane how an island was appearing in the Tonga Archipelago in the Pacific Ocean. Flying over that same place everyday, he was astounded to see a rock rising from the seething water. It grew higher every day. In a week's time the island reached sixteen kilometres in diameter. The height of the island, as the pilot estimated, was 1600 metres. Even nowadays, this kind of thing cannot make one but wonder at the omnipotent supremacy of nature and readily acknowledge the astonishment of the ancient inhabitants of the Pacific archipelagoes who created all-enchanting myths about the world we live in when fire and flame brought them into contact with the origin and collapse of monumental volcanic formations.

In this respect, the Pacific Ocean is by no means an exception. From the observation tower that they had built on Fayal Island in the Azores Archipelago, Atlantic whalers watched a rather unusual excitation of the water surface. At first they took it for a kind of forerunner informing them that a school of sperm whales was soon to appear, but very soon the illusions of these harpooners were dispersed. They saw that the water was giving way to a gigantic pillar of vapour, after which the island was seized with most powerful tremors. Thus, on September 27, 1957 there began in the Atlantic Ocean the eruption of the submarine volcano Capelinhos, so named after the nearby headland of the Fayal Island.

Within only a period of twenty-four hours, at the place where the depth measured more than fifty metres, the solid products of eruption formed a hill that surmounted the ocean surface. On the eighth day, the new land had already risen above the water to a height of 115 metres, although the crater still remained below the ocean level. At the place of the eruption, the earth's crust seemed to be breathing, alternating its rises and falls. On the eighty-first day of this kind of activity, the crater rose above the water with fiery rivers of basaltic lava flowing from its vents into the ocean.

What the Capelinhos Volcano displayed was remarkable for its picturesqueness and comprehensiveness. According to the data provided by the Soviet marine geologist Lavrov, who, from aboard the research vessel *Mikhail Lomonosov* watched the volcano, the explosions followed one another at intervals of fifteen to twenty seconds. After the water at the sources of eruption turned into a mass of breaking waves, a black pillar saturated with ash, gases, and volcanic shells began to rise out of the crater. The last of these, having reached a height of several hundred metres, exploded forming black flakes above the crater. Huge lumps and stones fell back into the crater, with the wind carrying the ash aside. But the greater amount of volcanic material continued to stream upwards with the explosion flakes making the black pillar grow ever bigger. The pillar twisted around itself, becoming wider and then settling down on the bottom, and it was only the water vapours impregnated with ash particles that went on soaring into the sky.

In the wake of each explosion a white mushroom-like cloud of vapour that was several kilometres high remained above the volcano. Droplets of water vapours and the minutest ash particles drifted into the upper layers of the atmosphere, where they gave rise to very specific volcanic clouds. The sky over the region of eruption was covered with multicoloured bands of clouds of this kind.

There was hardly enough time for the mushroom-like cloud of one explosion to be dispersed when the next one threw up into the sky an avalanche of various matter from the innermost parts of the earth. Lavrov noticed that the powerful explosions were mute: no noise was heard at all, to say nothing of any deafening rumble, though the *Mikhail Lomonosov* was anchored near the volcano. The sound must have been subdued by the water rushing into the crater vent.

At night, the ocean and the sky were blazing with what seemed to be an endless flame.

According to the estimates of the Belgian geologist H. Tazieff, the liquid, gaseous, and solid substances were ejected from the bowels of the earth into the sky at a rate of three to four hundred kilometres per hour. The force underlying the process causing the release of energy ranged from ten to thirty million horsepower.

The activity of Capelinhos continued for thirteen months. Within this period of time, 84.5 million cubic metres of lava were erupted. The western part of Fayal Island was covered with a layer of ash that was eleven metres thick. It completely destroyed the little village of whalers and practically the whole of Capelinhos lighthouse.

Navigators have witnessed quite a few volcanic eruptions in the ocean. They would discover an island, hoist a flag over it, and the next year send a vessel to it with scientists or colonists on board only to see that it had vanished. In the Mediterranean Sea, one of such islands is known by the name of Julius's Ghost. It was discovered in July 1831. At that time this island was 120 metres high and 1.5 kilometres long. In November of that same year it disappeared. In 1863, navigators saw it again and plotted it on the map. Later, when scientists decided to explore the island, it was not to be found. The island of St. John the Baptist in the Bering Sea had practically the same fate. The island was first sighted in 1796. Soon it was destroyed by a powerful tide. But the volcano again appeared above the sea. This would occur over and over again.

The Falcon Volcano in the Pacific Ocean was witnessed to become ever smaller rather than to grow until it disappeared altogether and became a seamount. In 1952, it was studied by an American expedition, which found an underwater crater out of which a stretch of green water enriched with volcanic ash flowed with the stream. The expedition had hardly reached the shores of America when the volcano quite unexpectedly rose above the water.

The eruptions of volcanoes that take place under water usually remain unknown, unless they reach the surface in the end. Sometimes the activity of submarine volcanoes became known by the pumice floating on the surface of the ocean. But what exactly occurred in the depths remained a mystery. It was the Soviet scientists of the *Mikhail Lomonosov* who had the good fortune of finding and observing a typically submarine volcano. They studied it in the course of their three expeditions, and each time the fire-bearing mountain greeted its discoverers not with explosions but with a serene submarine cloud of liquid and volatile substances that were issued from its crater under the pressure of underground forces. The eruption products were registered by the instruments since they did not lend themselves to be observed most readily with the naked eye. The significance of systematic observations of this unique geological phenomenon for the theoretical foundation of the scientific study of the Earth requires no proof.

What lay behind this discovery is the following. In November 1958, the research vessel *Mikhail Lomonosov* was crossing the strait between the Fayal and Flores islands of the Azores Archipelago in the Atlantic Ocean. The topography of the strait floor had been adequately studied and according to the sea-charts it was known that the depths in it fluctuated between 600 and 1400 metres. In about the middle of the strait the echo sounder registered on the tape the profile of a seamount with an incised top. The recorder registered the lowest point at a distance of 188 metres. And this was at a place where the maps showed depths ranging from six to eight hundred metres! In addition to the line of the floor, the echogram revealed that the mass of water contained a strange 'cloud' with uneven contours, which originated above the depression on the summit and stretched eastwards. The ultrasonic oscillations, transmitted by the echo sounder vibrator to the bottom, were reflected not only from the floor, but also from any fairly compact organisms and substances that were found in the mass of water, whether they were accumulations of minute plants, animals, or shoals of fish. The 'cloud' registered on the echogram, however, did not resemble anything familiar. It took the researchers some time to realize that their vessel was above the active submarine volcano.

From the slopes of the mountain the

dredger excavated samples of rocks that had a vitreous crust and vesicular structure typical of speedily solidified lavas, as well as samples of basalt, volcanic slag, and bombs. Together with the newly formed rocks, basalts of earlier outflows were also lifted up. After this the volcanic origin of the mountain was acknowledged by everyone. The chemical analysis of water that was brought up to the surface with such instruments as water samplers evidenced that the volcano was not dormant. But on the surface of the ocean there were no breaking waves or bubbles of gas.

A stream of markedly mineralized waters issued into the ocean from the volcanic vent funnel which, as had been correctly judged by the echo sounder recording, was exactly the place where there was a depression on the top of the mountain. The amount of silicon contained in these waters was twenty, if not more, times greater than the concentration of this element in the ocean water around. The same could be said of other chemical elements. Under the microscope the water tests showed the presence of ash particles. All the laboratory analyses served to prove that the liquid flowing out of the crater and enriched with the products of eruption, giving it consequently a density different from that of water, had left a trace on the echo sounder tape that gave the impression of a cloud.

The original water from the bowels was responsible for the saturation of the ocean water over two hundred kilometres along the stream. The volcano was named 'Mikhail Lomonosov' after the name of the vessel that discovered it.

Research that has been conducted over the past decades has revealed that contemporary and ancient submarine volcanism is characterized by an enormous range of activity and covers many regions of the globe. Moreover, its propagation is considerably greater than that of terrestrial volcanism. Even a very simple comparison of the areas wherein volcanism develops in the World Ocean and on the continents evidences the predominance of submarine volcanism over that on land. It is only on the floor of the Pacific Ocean that there exist more than ten thousand volcanoes with a height exceeding one kilometre. According to scientists, all the summits of mountains in this ocean are actually volcanoes. A case in point is the coral islands which are formed from extinct volcanoes.

Submarine volcanoes are not evenly situated on the ocean floor. They are found to be concentrated in specific regions of the planet. In the Pacific Ocean, the volcanoes tend to attach themselves to the chain of the archipelagoes of the Samoa group of islands, the Marshall Islands, the Caroline

Islands, the Cook Islands, the Tubuai Islands, the Tuamotu Archipelago, as well as to the submarine ridge of the Kings Mountains and the mountain structure that passes from the Johnston atoll through the Tuamotu Archipelago. In addition, in this ocean there is an extension of the East Pacific Rise together with the volcanic Easter Island, the Colon volcanic archipelago (Galapagos Islands) and the volcanic submarine ridge of the Sala y Gomez which is continued eastward by the volcanic ridge of Nazca.

In the Atlantic Ocean most of the submarine volcanoes draw themselves, as it were, towards the Mid-Atlantic Ridge to the north of which there are the volcanic formations of the Islands of Jan Mayen and Iceland, while to the south the islands of the Azores Archipelago are situated; further to the south there is Ascension Island, Saint Helena Island, Tristan da Cunha Island, and lastly, Bouvet Island. Those that are isolated in the Atlantic Ocean include the volcanic regions of the Canary Archipelago and the Islands of Cape Verde.

In the Indian Ocean, volcanism is preponderantly manifested in its western part. This is where the volcanoes are found to be contiguous with the Comoro Islands, as well as to be situated on the arched underwater elevation between the Seychelles and Mascarene Islands. In this ocean there are also other underwater mountain formations, including the islands that are crowned with volcanic structures.

Submarine volcanoes are also found in the Arctic Ocean and in the Antarctic regions. In 1982, two new volcanoes situated at a distance of thirty miles from each other within the area of the Larsen Ice Shelf in the Antarctic regions were discovered. These volcanoes are in an active phase and one of them recently erupted.

When the loose deposits bedded on the floor of the Atlantic Ocean to the west of Europe were studied, it was found that submarine volcanism was much more developed in the past (the Pleistocene period) than now. Thus, twenty thousand years ago, the bottom deposits of volcanic origin, which are now buried under the newly formed sediments, occupied vast areas on the floor of the northern part of the Atlantic Ocean.

It was quite recently that huge seamounts with wide and flat summits known as guyots were discovered on the floor of the World Ocean. They turned out to be former volcanic islands the peaks of which were at one time truncated by the ocean.

Volcanism in the World Ocean, as distinct from that on land, has been widely spread throughout the whole geological history of our planet as can be ascertained by its highly important role in the geological processes of the Earth. The number of current and ancient submarine volcanoes is overwhelmingly large. So far it has been practically impossible to say how many there are all in all. More than eight hundred active volcanoes that are now registered are but a wee drop as compared with their actual number. Moreover, over three-quarters of the active ones on Earth are situated in the transition zone between the ocean and the continents. This is where the most powerful eruptions take place such as the Krakatoa Volcano that came back to life in 1981. What is still within living memory is the powerful 1883 eruption of this volcano, which was accompanied by tsunamis, the fallout of ash over an area of 800 square kilometres, and the loss of 36 000 human lives.

The transition zones are the island arcs of the Pacific Ocean, which form the so-called Pacific Rim of Fire. It includes the arc of Japan, and those of the Mariana, Philippine, New Guinea, West Melanesian, Aleutian, Kurile Islands, the New Hebrides, and others. The island arcs represent underwater mountain structures that find their expression on the ocean surface in the form of garlands of islands. The greatest Indonesian arc with its ferocious Krakatoa Volcano is also connected with the Rim of Fire.

The volcanoes of the island arcs can more readily be regarded as oceanic formations than those of continental origin.

The Forge of Hephaestus

The waters of the World Ocean hide the life of the ocean floor, which since time immemorial has been considered by people to be the place of eternal rest. However, the peace in the bowels of the ocean floor is but deceptive. There, where it was assumed to reign supreme, a struggle between fire and water has been going on for millions of years. Underwater forces activate the gigantic furnaces and give rise to new mountains and islands, while the ocean makes every possible effort to subdue the fires and wash off the islands. This prodigious natural process, which is called volcanism, has for millennia been surrounded with an aura of arcane transcendence.

Nowadays, the problems of ancient and contemporary volcanism are being tackled by scientists in many countries. A major success in getting down to the bottom of this phenomenon has been achieved by Soviet researchers, who, as a result of their arduous and at times dangerous work, have managed to develop new trends in this field of studies. One of the most tangible attainments in volcanology is that the magnitude of submarine volcanism has been established together with its role in the formation of the Earth.

Until quite recently, submarine volcanism was estimated solely by what was observable during the eruption of volcanoes on oceanic islands. However, in the aqueous medium whose physical properties are markedly distinct from those of the atmosphere, volcanism is characterized by its own specific features. Some of them became apparent to scientists when they were watching the eruption of the submarine volcano of the 'Mikhail Lomonosov' ridge.

To appreciate the role of submarine volcanism in the history of our planet, ancient volcanic processes should be reconstructed on the basis of present-day eruptions; and wishing, as it were, to reveal its secrets to people, volcanism has within the past few decades markedly enhanced its activity. In the beginning of the seventies of this century, the volcano on Tristan da Cunha Island in the south of the Atlantic Ocean ceased to slumber. Since the time the island had been discovered, the volcano had never shown any sign of life. Nobody had ever thought that the island was actually a powder keg with a smouldering wick that had been attached to it for a long time.

At the same time, volcanic activity in the region of Iceland began to manifest itself. This is where the Vestmannaeyjar islands are situated, the name meaning 'the islands of the Westmen'. They were surrounded by sixty extinct volcanoes. The name of the islands is connected with a legend that is somehow :ssociated with the rebellious nature of local underground forces. The legend says that the first inhabitant of Iceland, a Norse viking named Ingolfur Arnarson, had a brother, who, while warfaring, captured ten Irishmen whom he made slaves. One day they rebelled against their master and killed him. They got hold of a small sailing vessel that took them as far as the nearby islands to the south of Iceland where they were soon discovered by Ingolfur Arnarson. Since they were Irish, and the people of England and Ireland were called 'westmen' by the Norse vikings, the islands were accordingly thus named.

Thus, on November 14, 1963 one of the volcanoes in the Vestmannaeyjar Archipelago interrupted its slothful existence. Within a period of only four months it ejected out of its vent 400 million cubic metres of lava and ash. This resulted in the emergence of Surtsey Island, named in honour of Surter, the Icelandic counterpart of Hephaestus, who, according to the ancient Greeks, ruled over the underground kingdom of fire. The solidified lava flows protected the island from being destroyed by the ocean. Its formation was closely watched by scientists. They saw how life itself was beginning to burgeon on the new piece of land: plants, insects, and birds began to appear.

In June 1965, not far from Surtsey Island, Surtlinger islet appeared above the surface of the ocean and existed as such till October of that same year. Then, in 1966, over a period of seven months, the Christmas Volcano located in this region kept erupting, looking out of the water on many an occasion. After this, four craters on the south-eastern shore of Surtsey Island began at one and the same time to shoot fountains of lava to a height of 150 metres.

The obstinacy of Icelandic depths knows no appeasement. Thus, in 1980, in the region of Krafla in Northern Iceland, a volcano, which incidentally did not come as a surprise since its awakening was presaged by numerous tremors of the earth's surface, began erupting.

The Icelanders have experienced no little evil from the restive bowels of their island, but they have learned to harness the hazardous manifestations of volcanism to serve their practical needs. The hot springs, for instance, are used for the heating of dwellings and greenhouses. They also serve the same purpose for the capital of Iceland. The amount of heat that is yielded by the bowels of the Earth per year is exactly equal to what could be derived from three million tons of coal within the same period.

During the 1973 eruption of the Helgafell Volcano on the island of Heimaey, people for the first time in the history of the world tried to resist the oncoming lava in its attempt to destroy the city. The Icelanders poured cold water on the lava and thus prevented its flow at a place only several tens of metres from the factories and moorings.

The activated volcanism displayed a remarkable peculiarity which found its expression in the synchroneity of volcanic processes situated many thousands of kilometres from one another. The eruption of volcanoes on Tristan da Cunha Island, forsaken in the central part of the South Atlantic Ocean and Iceland, took place at practically one and the same time. Though various hypotheses have been advanced to interpret this cryptic phenomenon, no fully adequate solution to this problem has so far been attained. As far as the activation of volcanic activity itself is concerned, there is every reason to assume that we are at present on the threshold of an entirely new epoch of submarine volcanism in the history of the World Ocean. This is substantiated, as it were, by the new articles regularly appearing in the press concerning the emergence and awakening of volcanoes.

If the submarine volcanoes of the Azores Archipelago in the Atlantic Ocean were plotted on a map, it would be possible to draw a straight line from approximately the southeast to the northwest that would intersect the deep faults in the Mid-Atlantic Ridge. What presents no minor interest is that this straight line coincides with a band of seismic foci stretched out along the same direction. The eruption of the Capelinhos Volcano was not accidentally preceded by intense underground tremors. Between only 1931 and 1950 there were 428 earthquakes in the region of Fayal Island, while ten days before Capelinhos erupted, the earth there underwent 450 shocks, many of which had an intensity of up to 10 points. The activation of volcanism on the seamount 'Mikhail Lomonosov' can also be regarded as a consequence of the seismic crisis that began late in the day on May 12, 1958 and continued through May 13. Both these volcanoes are located where the lines of the foci of earthquakes and those of the longitudinal faults in the Mid-Atlantic Ridge intersect. The Icelandic volcanoes are also found to be located at similar intersections of faults.

Thus, volcanic chains and individual volcanoes are located on the faults in the earth's crust. They measure up to several hundreds of kilometres in depth. According to specialists, it is precisely within the zones of these faults that magma originates. Its sources are found at more than thirty to forty kilometres below the surface, i.e. there where the temperature of the earth's matter exceeds one thousand degrees. The epicentres of earthquakes are deposited at exactly the same depths.

The contiguity of the foci of seismicity with volcanism results in the emergence of eruptions. In the ocean, in the wake of seismic activity, or displacements of the earth's crust, it is not uncommon that volcanic systems begin to function.

The Earth's acting volcanoes annually erupt from three to six billion tons of abyssal matter. On the surface of the planet, this matter is introduced into the cycling of geological processes, is thus thoroughly reworked and then serves as the source for the formation of various rocks that become part of the earth's crust. If we take into consideration only the present-day intensity of volcanic eruptions, then over the period covering the history of our planet, which is equal to four and a half billion years, its surface must have received an amount of volcanic products that weighs as much as the earth's crust of the continents and the World Ocean. If, however, the intensity of ancient volcanism was greater than its current variety, it becomes clear that the outer stone envelope of the Earth is composed of deep matter that was erupted by volcanoes from the innermost parts of the planet.

During volcanic eruptions about three or four percent water is released from the magma. The original water containing salts that were dissolved in it was accumulated with the result that it filled all the depressions of the Earth. During the period of the formation of the earth's crust, volcanism was responsible for more than half of all the waters that are now within the confines of the World Ocean. It should also be added that at the expense of contemporary volcanic activity the World Ocean level has been annually increasing by one thousandth of a millimetre. Nowadays, most geologists are positive that volcanism, if not the one and only progenitor of the World Ocean, played at least a major role in giving rise to it, and in the process of this, the salt water of the ocean appeared, accumulated in the course of geological development, and continues to do so now. The ocean was born saline.

Fire and Life

The Earth's hydrosphere, the predominant part of which is made up of the World Ocean, has covered a long path of evolution that was not devoid of many difficulties. It is connected with the origin of life on our planet. We might as well recall the analogy between the salt water of the ocean and blood, the latter being a derivative of the World Ocean, which was born in the fire and flames of volcanoes. In other words, what we see in nature is a concatenation of volatile volcanic formations, ocean water, and blood. The following example is to the point. Volcanoes eject from their innermost parts a large amount of copper, which, as we know, is essential to life. In a living organism, haemoglobin, which functions as the carrier of oxygen, cannot be formed without its participation. Copper is present in almost all the organs of animals, thus fulfilling highly important vital functions. It is even found in proteins. In short, volcanism is the supplier of what proves to be so significant an element for the preservation of life, and not only of this element. Volcanism is the source of practically all the life-giving elements, which are often available in a form that is ready for the assimilation of not only lower, but also higher, organisms. All this has made it imperative that volcanism be considered in terms of biology.

It is only recently that the phenomenon pertaining to the formation of organic compounds in the process of volcanic eruptions was discovered. Among these compounds, amino acids and nitrogen-containing nucleotides, which in themselves are the ingredients of living matter, were found. This discovery gave scientists the idea that volcanic eruption is the first step from inorganic to organic material.

Soviet scientists are working intensely on the role of volcanism in the origin of life on Earth. They have achieved considerable success in these investigations. Volcanic eruptions are now being viewed as powerful natural chemical reactors that form highly complex organic compounds, which gave rise to the molecular evolution of the transformation of matter from its inorganic to organic state. With time this led to the origin of life.

This research was preceded by experiments on the synthesis of biological compounds. Water was poured into a special device that was filled with hydrogen, methane, and ammonia. With electrodes installed in its chamber, a spark discharge of electric current of very high voltage was produced. Heating, cooling, and pressure could be regulated, and a trap for test products was included in the device. This resulted in that to a certain extent it became possible to reconstruct conditions similar to those of volcanic eruption.

By means of this device, amino acids and other compounds were synthesized. In addition, diverse variants of the experiments yielded their own products of synthesis, which depended on the composition of initial substances, temperature, pressure, etc.

In another kind of experiment, a gaseous mixture of methane, ammonia, and water was passed through a glass tube containing quartz sand, silica gel, volcanic lava, or clay. In this case the tube was heated to a temperature of between 900 and 1000°C. As a result of this experiment twelve amino acids were synthesized. The remarkable thing about this experiment was that in the tubes lacking the filler comprising sand, lava, clay or silica gel, it was possible to synthesize only several simple organic compounds under high temperatures. This served to reveal the catalytic effect of the substances, which are similar in composition to the products of eruption, on the synthesis of organic compounds. Various sources of energy were employed in these experiments, including ultraviolet and radioactive radiation.

These experiments enabled the researchers to observe the formation of organic compounds from inorganic ones during processes similar to volcanic eruptions. In fact, during the eruption of a volcano all the components of these experiments are present, viz. gaseous mixture, temperature, pressure, contrasts in temperature and pressure, mineral catalysts, and electric discharges. However, it must be mentioned that the process of eruption is incomparably more complicated and dramatic; therefore, no tenable conclusions can be drawn if solely based on the results of experiments without making a thorough study of the nature of the eruptions themselves. In this respect, the primary role belongs entirely to in situ investigations. And it is to such investigations that scientists have recently given their undivided attention. Fortunately, the activation of volcanism has presented enormous possibilities.

Now let us see what happens inside volcanoes. At the time of eruption, rising pillars of ash and gases that contain water vapour, hydrogen, methane and other hydrocarbons, oxide and dioxide of carbon, ammonia, and nitrogen are usually ejected. The proportional amounts of these substances are determined by the character of the eruption. The ash and gaseous pillar forms during the explosion, when the magma is disintegrated into small particles and emits gas. This is the time when the temperature of the explosion products is equal to approximately one thousand degrees. Soon it drops to several tens of degrees at the expense of cooling of the surrounding air medium. Electric puncture of the ash and gaseous pillar increases the temperature in it again, thus giving rise to its marked contrasts, which, as has been demonstrated in experiments, is extremely propitious for the synthesis of organic compounds.

The electric phenomena that occur during volcanic eruptions, though widely spread, have been poorly studied. A large number of researchers have observed frequent spark discharges that were penetrating through the ash and gaseous pillars and clouds of gas above volcanoes. They happened to see flashes of lightning that were several kilometres in length. Where then does the electricity originate when the volcano is in a state of eruption? The ash particles usually have different charges. As a rule, the large particles are positively charged, while the smallest are negatively charged. Why is this the case?

The Soviet researcher A.A. Komarov has recently put forth an original hypothesis that attempts to explain the rotation of the Earth and a number of other no less significant phenomena including the electrical phenomena of volcanism, which is of particular interest to us. A.A. Komarov has suggested that volcanoes represent natural electric furnaces that function on a direct current of enormously great power. According to the author of the hypothesis, the earthquakes that precede the eruptions are brought about by underground lightning with a potential of several million volts that arises as a result of the accumulation of charges on the borders separating the rocks. Owing to the electric charge, the craters of volcanoes are energized, thus giving rise to discharges of thunder. In advancing these principles, the author of the hypothesis has proceeded from the assumption that the electric current must be induced in all current-conductive interlayers of the Earth's geospheres during its rotation.

A. A. Komarov's hypothesis has not yet been acknowledged, though it has a fairly solid physical foundation that gives it the right to be carefully studied and further developed. In any case, its exclusion from the number of planetary processes under discussion, including volcanism, is impossible, since it does throw a sufficient amount of light on many aspects of nature. We can only look forward to this hypothesis acquiring the status of a theory in the shortest possible period of time.

As was noted in the experiments with the tubes, the electrically charged ash particles ejected from the volcanic vent funnels have the function of catalysts. On their surface, which is summarily estimated to be equal to millions of square kilometres in area, water vapours, which promote the synthesis of organic compounds, become concentrated.

An important role in the formation of a volcanogenic substance is played by the contrasts of pressure drops in ash and gaseous pillars. At their origin, in the crater of volcanoes, the pressure of the ash and gaseous mixture reaches hundreds of atmospheres. In the topmost parts of these pillars, the pressure is practically the same as that of the surrounding air medium. It is due to these differences in pressure that incandescent ash is ejected at an enormous rate from the crater into the sky where it gets speedily cooled. This is precisely what preserves the complex organic compounds that are synthesized by volcanoes.

As has been estimated by scientists, over the geological history of the Earth, volcanoes have synthesized an amount of organic substances on the order of 10^{15}.

Thus, we can conclude that volcanism has not only played a decisive role in the formation of the earth's crust and the World Ocean, but has also led to the formation and accumulation of organic compounds, which at one time served as the beginning of the molecular evolution of the transformation of matter from its inorganic to organic form. This resulted in the origin and development of the multifarious forms of life on Earth.

Chapter 2

The Perpetual Movement

The Underwater Mountain Land

There is hardly anyone at present who would assert that the scientific study of the Earth and of mineral resources can be divorced from the geological investigation of the World Ocean floor. This vast and mysterious part of our planet has so far not received all the attention it deserves. Nevertheless, science has already availed itself of a sufficient amount of information to elaborate a theory that guides the wanderings of our imagination into the depths of the Earth and helps us to visualize the essential nature of those processes that are relevant to its development and the formation of individual oceans. Important data concerning the structure of abyssal matter were obtained from research on the volcanic activity on our planet. Volcanoes have functioned as a type of a window through which scientists could watch, as it were, the phenomena that take place in the bowels of the Earth.

Since the very beginning of the Earth, the heated mass of its abyssal matter has been in a state of turbulent activity, intermittently coming up onto the surface. Had this process been interrupted, erosion would have gradually destroyed all the elevations on Earth, and it would actually have become a blue planet covered with a continuous layer of ocean water.

For a long time scientists could not discover what lay behind the dynamic processes, the traces of which in the form of mountains and other formations were visible to them on the surface of continents, and which in the end were discovered by them on the World Ocean floor, proving to be enormous mountain structures, very deep depressions, volcanoes, and volcanic chains. As has already been mentioned, the submarine mountain formations on the World Ocean floor create a distinct relief, which finds its expression in mid-oceanic ridges the length of which measures approximately sixty thousand kilometres. The most prominent part of this mountain system is the Mid-Atlantic Ridge. It is the only one amidst the other ridges that is really in the middle of the ocean. Its crest stretches from the north to the south, and having exactly the same contours as the shores of the Atlantic Ocean, equally divides it into its western and eastern parts.

It was in the mid-oceanic ridges that scientists found the key to extremely interesting and promising theoretical explanations of the dynamic processes taking place on our planet. This, however, will be dealt with after we have touched upon the history of the ridges itself.

The shores of the Atlantic Ocean are characterized by exceptionally remarkable contours. If Africa, South America, Europe and North America were brought together on the map so that their coastal lines would coincide, the contours of the continents would fit each other in exactly the same way as the two halves of a torn banknote. This kind of compatibility has led scientists to the rather simple and original conclusion that in the past these continents comprised a single supercontinent in which, under the activity of the Earth's rotation, a gigantic fissure emerged. America was separated from Europe and Africa and drifted westwards along the viscous abyssal rocks, while the depression that formed was filled with water and became the Atlantic Ocean. Later, when the Mid-Atlantic Ridge was discovered in this ocean, it turned out to be much more difficult to associate the origin of the depression of the Atlantic Ocean with the drift of America. The question that arose was this: if America had sailed away from Europe and Africa, how could a ridge that is from 300 to 1500 kilometres in width and with summits rising to between 1500 and 4500 metres above the ocean bed possibly appear? Perhaps there was no continental drift at all? Perhaps the waves of the Atlantic Ocean are surging over inundated land that had once been Atlantis. This is the opinion adhered to by many geologists.

But as more evidence accumulated on the structure of this cryptic ridge and on the detailed topography of its floor together with the rocks entering into its composition, the more apparent it became to scientists that this serious problem was extremely complicated. Its complexity was further aggravated by the fact that the scientific data that were obtained gave rise to quite controversial statements.

While studying the Atlantic Ocean, it became clear that a deep valley, functioning as a fissure dissecting the ridge almost throughout its length, manifested itself along the axis of the Mid-Atlantic Ridge. Valleys of this kind usually emerge as a result of the activity of tectonic forces of extension and are called rift zones. This is where tectonics, seismicity, and volcanism are most actively expressed. The rift valley of the Mid-Atlantic Ridge was found to be correlated with a large magnetic anomaly. Powerful ascending heat flows were found in this valley. These two factors revealed that the tension fracture in the earth's crust was filled with magnetized abyssal material.

The discovery of a rift valley on the floor of the Atlantic Ocean called to mind the splitting of an enormous supercontinent and the drift of continents. However, this new information, and particularly the characteristic features of the rift's topography, demanded a more up-to-date interpretation of the mechanism of continental drift.

In schematic terms, the Mid-Atlantic Ridge is now represented as a symmetrical mountain structure where the axis of symmetry is expressed by the rift valley. It is of no minor interest that the earthquakes occurring in the Atlantic Ocean are to a great extent connected with the Mid-

Atlantic Ridge, while most of them are immediately associated with the rift valley.

In studying the topography of the ridge and the pieces of rocks that were brought to the surface from the bottom, scientists were surprised to find such regularity in the geological composition of this mountain structure, viz., the farther it was to either the west or the east from the rift valley, the older the relief of the floor was, and the more ancient the rocks making up this uncanny submarine mountain land were found to be. Thus, the basaltic rocks lifted from the crest of the ridge and from the rift valley were, as a rule, several hundred thousand years old, with the age of some of the specimens reaching up to five million years. From the geological standpoint, these rocks are considered to be young. The basalts on the edges of the ridge are considerably older than on the crest; they are thirty million and more years old. Still farther away from the rift valley, i.e. closer to the continents, the age of the rocks has been estimated to be equal to seventy million years. It should be mentioned that no rocks older than one hundred million years have ever been found in the Atlantic Ocean, whereas the age of rocks on land is estimated at billions of years.

These data on the age of the rocks of the ocean floor make it possible to regard the Mid-Atlantic Ridge as a relatively young mountain formation, which even today continues to develop and change. And since the ridge has only recently been formed, it may well be assumed that in the past, in that geological epoch when the ridge did not yet exist, America could have easily drifted away from Europe and Africa. This seemed to be quite clear, but why then up to this very day is the tectonically active fissure in the ocean floor with continuous earthquakes and volcanism situated practically in the middle of the ocean?

On the basis of newly obtained data concerning the relief and structure of the ridge, proponents of the continental drift hypothesis suggested another interpretation of the mechanism underlying the movements of continents. They maintained that the drift of continents had been brought about by the expansion of the floor. And according to these views the Mid-Atlantic Ridge began to be considered an imminent consequence of continental drift. It was not America that had sailed away westwards from Europe and Africa; rather, the two parts of the split supercontinent separated towards the east and the west of the rift valley, respectively, and at the same distance as the ocean floor was expanding. In addition to this, the fissure was being filled from the bottom with abyssal material and products of volcanism, which gave rise to mountain ridges in the same place. But as a result of the continuing expansion of the ocean floor, the fissure was regenerated and the recently formed mountains were shifted to the west and east, while in the middle of the ocean and along the rift valley a new mountain chain emerged. A conservative estimate suggests that the continents were separated at a distance that was approximately equal to the width of the ridge. Calculations have even been made as regards the velocity of the expansion of the ocean floor in the region of the Mid-Atlantic Ridge. According to them, the ocean floor in the northern part of the Atlantic Ocean has been growing in width at a rate of one and a quarter centimetres per year over the past six million years. Still earlier—six to ten million years ago—the velocity of the expansion of the ocean floor was greater and was equal to 1.65 of a centimetre per year.

But let us return to the topography of the ridge and the faults of the oceanic crust. New data have given rise to new problems and controversies. Until recently, it was believed that the depth of the rift valley of the Mid-Atlantic Ridge was more than five kilometres from the surface of the ocean, and that the valley itself was remarkable for the outcrop of such rocks as gabbro and peridotites, the origin of which some geologists associated with the upper mantle of the Earth. However, research that has been conducted over the past decades (among which that undertaken by Soviet scientists aboard the research vessel *Mikhail Lomonosov* is of significance) has made it quite clear that the depth of the rift valley, as measured from the ocean level, seldom reaches four kilometres, to say nothing of exceeding it. At the same time, depths of five kilometres and more are said to be typical of the gorges that transversely split the Mid-Atlantic Ridge. If the rift valley extends from north to south, the deepest gorges splitting the ridge transversely are elongated from west to east. In other words, their origin is connected with an independent system of faults within the oceanic crust. Faults of this kind are called transoceanic. They cross not only the ridge, but also the adjoining abyssal basins, while some of them reach the shores of the ocean.

Thus, the Mid-Atlantic Ridge is characterized by longitudinal and latitudinal faults that split it into large blocks. These blocks are shifted together with the rift valley in the horizontal plane with respect to each other. It should also be added that in the rift valley itself neither gabbro nor peridotites have been discovered. These rocks are found not in the rift valley, but in the transoceanic faults in the zone of the ridge itself as well as at the underwater marginal parts of the continents.

Within the past three decades there has

been a marked activization of tectonic and volcanic processes in the region of the Mid-Atlantic Ridge. Volcanic activity in the Atlantic Ocean has proved to be correlated mainly with the places of intersection of longitudinal and latitudinal faults of the Mid-Atlantic Ridge. In other words, the manifestation of the Earth's inner forces at the present stage of development of the Mid-Atlantic Ridge is found to be connected with tectonic centres. This has made it possible to assume that in the origin and formation of the ocean basin a significant role was played not only by longitudinal structures, but also by transversal ones, i.e. faults. The importance of the latter had not been fully appreciated before. When studying the specimens of rocks that were lifted from the ocean floor during expeditions aboard the *Mikhail Lomonosov*, Soviet scientists noticed that rocks from the latitudinal faults were much older than those from the rift valley. For instance, within the transverse fault that forms the Romanche Trench, rocks were found that were more than twenty million years old, whereas the age of rocks extracted from the crest of the Mid-Atlantic Ridge and the rift valley seldom reaches five million years.

These discrepancies in the ages of rocks that make up the Mid-Atlantic Ridge can be explained from the standpoint of Soviet theoretical tectonics. According to this science, tectonic elements of great extension are developed over a long span of time and can retain their direction from the Proterozoic period, i.e. over a period of five hundred million years. In addition, it is assumed that there are faults not only in the vertical, but also in the horizontal, plane. Owing to the latter, a horizontal dislocation of the individual blocks of the earth's crust together with the vertical faults that are found to exist within them takes place.

A similar tectonic process takes place in the Atlantic Ocean. In the region of the Mid-Atlantic Ridge, for instance, its large blocks are shifted transversely with regard to each other, as a result of which the Ridge, in some of its places, resembles a loaf of bread cut into several slices that are dislocated in transverse direction. All these facts serve as evidence that the transverse faults in the Atlantic Ocean existed prior to the formation of the Mid-Atlantic Ridge and have remained active after this huge mountain system was formed.

The emergence of latitudinal faults can hardly be explained by the activity of the Earth's inner forces alone, without taking into consideration its movements as a cosmic body. It is quite possible to imagine that the Earth's movement in space—its rotation—leads to the formation of intersecting faults, i.e. to the fracturing of the earth's crust. This activity of the external forces is found to be resisted by a different process, which serves to consolidate the dislocations that have emerged and that help to maintain the Earth's structure. This is necessary first and foremost for the equilibrium of forces in the space that is contiguous with the Earth. Most probably, the horizontal dislocation of blocks of the earth's crust along the latitudinal faults leads to a more stable arrangement with a dressing of seams that looks very much like brickwork. The disintegration of the oceanic crust, submarine volcanism, and the increase in the thickness of lithosphere in the central part of the ocean with the formation of the median ridge can all be regarded as part of a process directed at the reconstruction of the equilibrium that has been disturbed by the Earth's movement. Therefore, it is not accidental that in the thin oceanic core the rift zone of the median ridge is superimposed upon the structural plan of the transverse linear faults. There is every reason to believe that this active tectonic zone may well be attributed a highly important function in strengthening the Earth's structure.

As far as their origin is concerned the mid-oceanic ridges all enter into 'family relationships', so to speak, though they differ in age and are at present in different stages of development. They are also distinct from each other morphologically and in the structure of their depths. Thus, the Mid-Atlantic Ridge is the one that is most pronounced and active. For this reason scientists regard it as a kind of model of morphological and geophysical features for the evaluation and contrast of individual integral parts of the planetary underwater mountain system that passes across the Arctic basin, and the Atlantic and Indian oceans, as well as the southern part of the Pacific Ocean. In the Indian Ocean, the ridge has a relief and a rift that are typical of mid-oceanic mountain formations, though this system is now practically inactive. On the other hand, the Pacific ridge is considerably smoothened, and its rift valley does not find any clear-cut expression.

The Wounds of the Earth

In the World Ocean there exists yet another remarkable form of the floor's relief: the oceanic trenches. These are specific formations in the earth's crust that have so far not received all the attention they deserve, and which, according to scientists, share no minor function in the global tectonic processes. Data from the oceanographic encyclopaedia indicate that there are at present twenty depressions with depths varying from six to seven thousand metres, twenty-two trenches as deep as over seven thousand metres, and six trenches with depths of more than ten thousand metres.

There is a definite regularity in the arrangement of oceanic trenches. In most cases, elements of the ocean floor relief are found to be close to the shores of continents, as well as in the proximity of island arcs—the elongated and corrugated parts of the archipelagoes—which represent submarine mountain structures that come out onto the surface of the ocean in the form of garlands of islands. However, there are exceptions to this regularity. For instance, the Romanche Trench in the Mid-Atlantic Ocean, as well as those of Vema and Diamantina in the Indian Ocean are situated at a remote distance from land.

Trenches are usually given the names of nearby continents, states, archipelagoes, and vessels that have discovered them.

Two-thirds of the known trenches, including all those with depths exceeding ten kilometres, are found to be in the Pacific Ocean. This ocean seems to be contoured along its periphery by oceanic trenches that cross along the shores of continents and island arcs. For this reason, the maximum depths in the Pacific Ocean are situated within its marginal parts and not in the central regions, as could readily be expected. The deepest of them include the Mariana, Tonga, Kuril-Kamchatka, Philippine and Kermadec trenches. It is noteworthy that the maximum depths in those trenches, to which the Philippine variety does not belong, were discovered by Soviet scientists in 1957-58 when the team aboard the research vessel *Vityaz* was conducting investigations in the Pacific Ocean.

In the upper regions, the width of the trenches is equal to tens of kilometres and more. The length of these formations reaches up to over one thousand kilometres. Their slopes are exceptionally steep. In the Tonga trench, for instance, the slope of its walls is as great as 45°. At the depth of nine kilometres, this trench is only between three and seven kilometres wide. And this kind of slit in the ocean floor extends over seven hundred kilometres. As a rule, the narrow floor of the trenches is flat and in places measures several hundred metres in width.

A comparative study of the oceanic trenches with the mountain structures that are situated close to them reveals that the dimensions of the relief elements that emerge on the boundaries of continents and the ocean are virtually gigantic. Only at a distance of several tens of kilometres from the highest peaks of the Andes—the monumental mountain ridge that stretches along the western coast of South America—do we find the greatest depths of the Chilean Trench. This is where the difference in the heights of the mountain tops and the bottom of the trench reaches fifteen kilometres. It exceeds the altitude of any mountain peak that exists on land.

The oceanic trenches are exclusive formations in the earth's crust. They seem to dissect the floor of the World Ocean like piercing wounds. The trenches are practically not filled with friable bottom sediments. The latter can be found only in the narrowest middle parts of the trenches, where the width of their flat floor is as great as several hundred metres.

Considerable anomalies of gravity have been registered in oceanic trenches. Epicentres of earthquakes, which indicate that the trenches are seismically active zones of the World Ocean, extend parallel to the trenches.

Indirect methods of research rendered it possible to assume that within the zone of trenches there exist gigantic breaks of the earth's crust, which, according to their size, surpass any formations of this kind on land. These examples serve as proof that deepwater trenches represent those regions of the World Ocean floor that are highly important for the understanding of the geological development of our planet.

The slopes of trenches are preponderantly composed of exposed abyssal rocks. With the current means of submarine investigations, this allows researchers to directly study regions of the earth's crust that until recently were inaccessible.

On the slopes of a large number of trenches there are intermediate ledges or series of terraces. In the Aleutian Trench, for instance, an enormous ledge from twenty to forty kilometres wide and covering up to fifteen hundred kilometres in length was discovered at a depth of about four thousand metres. Ledges of this kind are found in the Kuril-Kamchatka, Mariana, Philippine and other trenches. Their emergence is sometimes due to gigantic gravitational landslides. It is as yet premature to speak of the authenticity of such interpretations, but the very fact that the slopes of trenches have a very complicated structure serves as proof that the factors underlying their formation are by no means homogeneous. The characteristic features pertinent to the arrangement of trenches can presumably reveal a lot about this.

It is noteworthy that individual trenches are characterized by an arched form. Some of them are linear, while others are curved at an angle of up to 90° It has also been noticed that trenches often turn clockwise at an angle of 90° and form, as it were, a loop. It is not surprising that the geography of these formations of the earth's crust is the result of processes relevant to their formation that still remain a mystery.

According to their location, structure, and morphology, oceanic trenches are classified into four types. This sums up a specific and a highly important investigative result, which allows for the planning of new stages in their study. The first type is peripheral; the second is that of marginal seas; the third type characterizes a transverse or ramifying variety; and the fourth group includes parallel and intermediate depressions.

The origin of oceanic trenches is associated with particular geological and geophysical phenomena, which to a certain extent help to understand the nature of these formations. It has been noted that the island arcs sometimes consist of single mountain ridges, though more often there exist paired ridges, inside of which the volcanic zone is usually situated. It is also the place where a wide depression of approximately fifty or more kilometres is found to be parallel to the trench. In front of this depression, a markedly intersected ridge or belt of islands rises. The trench lies parallel to and behind them. This kind of alternation of geological structures is typical of the zones of peripheral trenches. What geologists primarily pay attention to is the composition and structure of rocks that are typical of these zones, since it is these factors that help them to develop hypotheses and theories about the origin of trenches.

This is undoubtedly supplemented by other data. Thus, for instance, information on the fact that oceanic trenches and island arcs are connected with strong gravitational anomalies has been of great significance. Nothing peculiar has been revealed by geomagnetic studies. In a number of cases, geothermal probing has revealed the existence of heat flows in some of the trenches and cold flows in others. This kind of diverse information has stimulated copious contemplation.

Interesting data were furnished by seismic studies. In a peripheral trench it was discovered that a boundary existed between the oceanic type of crust, with a thickness of approximately five kilometres, and the intermediate or continental type of crust. This fact proved to have great scientific significance. It served as a substantial basis for the theory of continental drift.

The zone of the epicentres of earthquakes extends parallel to all the peripheral and marginal trenches. The foci of earthquakes originate near the surface of the trench bottoms from the side of the land and are found at depths of up to seven hundred kilometres. In addition, in this particular case, they are removed from the axis of the trench towards land at a distance of about four hundred kilometres. Cases have been registered when the deep-seated foci of earthquakes were separated from the axis of the trench from the side of the ocean. Instances of this kind are associated with the phenomena of ruptures and dislocations of the earth's crust.

Very little is known about the age and durability of trenches. Hence, in most cases these factors are evaluated on the basis of the geological data that are concerned with the reiterated movements of the earth's crust along the known horizontal faults, which are presumably connected with trenches, as well as on information on other geological phenomena. This was how the age of the Tonga and Kermadec trenches was determined. It was established that they were about seventy million years old. This figure, which can hardly be regarded as absolute, does give us, nevertheless, some idea about the antiquity of those trenches.

For more than a century, geologists had considered oceanic trenches to be troughs of the earth's crust that had emerged as a result of its contraction. These views were wholly refuted after a number of investigations had been conducted and sufficient diverse information on the form and structure of trenches and the phenomena and processes connected with them had been made available.

Nowadays, trenches are referred to as localized underwater fissures in the earth's crust. It is because of the proximity of marked negative isostatic anomalies that scientists have been able to assume that trenches did not exist for any great length of time. However, geological history makes one take into consideration the fact that oceanic trenches could exist over a period of ten million years and more. Current geophysical research presents considerable evidence in favour of the hypothesis of the extension of the earth's crust explaining the origin of trenches. This substantiates the latest concepts relevant to the theory of the Earth's expansion. But it is not as easy to get to the bottom of this problem as it may seem. The origin of trenches finds a fairly adequate explanation in the theory of continental drift, and a large number of facts adduced here serve to consolidate this.

Those who adhere to different theories are availing themselves of the newest data upon which they base their assumptions when it comes to heated arguments. The only thing that has so far been made abundantly clear is that we are in a stage when information on these remarkable formations in the earth's crust is being accumulated. Science, as we know, is in a state of constant flux, and it won't be too long before new investigative techniques will appear, which will undoubtedly speed up our efforts to unveil the mystery connected with the origin of trenches.

The Rotation of the Earth's Crust

The separation of the continents fringing the Atlantic Ocean is only a part of the planetary process whose mechanism has left scientists in a quandary for many years. The scientific world had acquainted itself with quite a few different hypotheses before a surprisingly unsophisticated unique model was elaborated that explained the original causes underlying the drift of continents and other phenomena that form the face of the Earth. A rough idea of this model consists in the following. The surface of our planet is made up of thick strata or, as they are called, plates of the earth's crust. These plates upon which the continents are situated are in a state of constant movement with the continents being dislocated at a rate of several centimetres per year.

To reach this solution, which is now acknowledged by most scientists, it was necessary that concepts of the geological evolution of the Earth that had existed for decades and even centuries be overcome. It seemed quite obvious that the principal field of activity of the inner forces of our planet was the continents. This was primarily conditioned by a lack of knowledge about the topography of the World Ocean floor. And even today, in spite of the most tangible achievements in oceanology, our knowledge of the submarine relief is insufficient. Moreover, there are those who state that the side of the Moon that is hidden from us is better known than the floor of the World Ocean. In addition, no one had any doubts about the stability of the continents with regard to each other. People were perfectly well aware of the orogenic processes on land, of the enormous vertical displacements of the blocks of the earth's crust, and yet it seemed quite incredible to most high-ranking specialists that the continents could have been floating somewhere for millions of years.

The processes that take place on Earth were explained by the compression of the planet as a result of its assumed cooling down that threatened it with thermal death in the end. The Earth was compared to an apple, the peel of which becomes wrinkled as its pulp gets desiccated. Mountains were regarded as the same kind of wrinkles on Earth; the theory of the cooling down of our planet seemed to be extraordinarily scientific and was peripatetic as far as geology textbooks were concerned.

The English physicist Osmond Fisher refuted this theory. He saw the Earth as a prototype of a thermal machine. He distinctly observed the interrelationship between the dislocations of the earth's crust, seismicity, volcanism, and orography, and what was most important, he correctly evaluated the function of oceanic mountain structures in these processes. It took scientists more than seventy years to become fully cognizant of the ideas which in that period were suppressed by the theory of the immobility of continents.

The discovery of radioactivity at the beginning of the twentieth century should have provided ample opportunity for reconsideration of the views on the Earth's inner structure, since our planet had its own source of heat and was thus immune to what was termed as thermal death. As it turned out, the Earth is a living planet. However, even this event could not stimulate a radical review of the concepts that had been so firmly rooted in science.

The most palpably vanquishing criticism of the concepts adhered to by the proponents of fixism (scientists who considered the continents to be immobile) came from the hypothesis set forth by the German meteorologist Alfred Wegener, who was struck by the similarity in the contour of the eastern and western coasts of the Atlantic Ocean. Based on this similarity as well as on a host of common features that were shared by the fauna and the structure of the littoral zones that fringed the ocean of continents, Wegener suggested that hundreds of millions of years ago there existed on Earth a single supercontinent that was split into parts. These parts gradually separated from each other and the space between them was filled with water that gave rise to the Atlantic Ocean.

According to Wegener, the continental drift was conditioned by forces that found their expression under the continents rather than beneath the ocean floor. He compared the dislocation of continents to the movement of some kind of solid masses that were vapourizing the ocean floor like wax. These ideas, expounded by Wegener in 1912, remained unrefuted for only a little over ten years. Those who found them untenable were the geophysicists who produced sufficient evidence that the rocks of the ocean floor were much more stable than the ones found on the continent. This made the drift of the latter improbable.

It should be mentioned that volcanism and earthquakes did not do justice to Wegener since in accordance with his hypothesis they could not have originated within the expanses of the ocean floor and would have had to confine their activity only to around the continents. It should also be added here that Wegener considered that the Mid-Atlantic Ridge, which was then known as a mountain plateau, was part of a submerged continent that had split off.

It was again the geophysicists who gave impetus to the resuscitation of Wegener's hypothesis. From 1950 to 1970 they made discoveries that revolutionized all the concepts pertaining to the earth's crust. Most unexpectedly the ocean floor was found to be formed by a thin film of saxicolous rocks with a thickness of not more than six kilometres rather than the thirty to forty kilometre thick layer of the crust which makes up the continents. This layer is bedded upon a compact abyssal substance called the Earth's mantle. Moreover, it was also made clear that the earth's crust below the ocean had a greater density than that under the continents. Scientists came to the conclusion that two types of the earth's crust existed on our planet: the oceanic and the continental varieties. In other words, continents cannot become oceans, and vice versa.

Geomagnetic research threw some light on the movements of continents. With the continents remaining stable, the magnetic poles must stay immobile all the time. This, however, is not the case, and it was this phenomenon that was taken as evidence substantiating the drift of continents.

When Wegener's ideas were revived, the theory of the Earth's expansion appeared. Scientists began to compare our planet to a football, the outer cover of which is liable to burst when filled to excess with air. Fissures of this kind were attributed to rift valleys, or rifts, as they are called for short. It seemed that things had become quite clear as far as the factors underlying the formation of median ridges and rifts were concerned. The same could be said about the new crust that had emerged along the two just mentioned structures at the expense of an elevation of the abyssal matter. All this was found to be in conformity with the discrepancy in the age of oceanic and continental rocks. The former proved to be younger than the latter, in addition to which the rocks of the rift were the youngest. One of the most important arguments in favour of the theory of the Earth's expansion is the symmetry of the Mid-Atlantic Ridge. Indeed, with an even expansion of the ocean floor after the splitting of the supercontinent, the thus emerging mountain structure must be symmetrical in cross section, which is very much the same as the swelling of the football bladder in the fissure of the outer cover.

As usual, new problems along with the answers to the questions that had been raised appeared. How could it have possibly happened that over the past two hundred million years (the figure, judging by the rocks, indicating the maximum age of the most ancient parts of the ocean floor) the Earth managed to increase its surface by two or even three times, whereas during the preceding more than four billion years of its existence, it had to remain unchanged? If the theory of the expansion of the ocean floor furnished an adequately clear-cut interpretation as to the formation of the median oceanic ridges, the origin of oceanic trenches did not find its place in this scheme.

What helped to find a way out of the impasse was a new dynamic model of the Earth, which began to be elaborated around 1960 with the study of the function of oceanic trenches in planetary processes.

Since its origin the continental crust has not undergone any marked changes except those that are connected with weathering processes. As far as the oceanic crust is concerned, it has by no means remained intact. In the rift zone, the cone is being accumulated at the expense of an elevation of the abyssal matter. This is simultaneously accompanied by its decrease at the other end, dropping into the oceanic trenches, where it integrates with the Earth's mantle, compensating, as it were, for the loss of the abyssal matter that had been used for the accumulation of the crust in the rift zone. This results in an exclusive cycle, which may well be referred to as the rotation of the earth's crust. This becomes quite feasible if huge parts of the earth's crust together with whole continents are dislocated to either side of the rift, leaving newly formed mountains along its length and pressing down on the ocean floor in the region of the oceanic trenches. This kind of cycle covers approximately two or three hundred million years.

According to this plan, the Atlantic Ocean is becoming wider, continuously separating the western continents from the eastern ones. There are no oceanic trenches in the peripheral parts of this ocean; and the continental drift in it occurs as if the Earth were in the process of expansion. The Pacific Ocean presents quite a different picture. Here the continents surrounding it are approaching each other. The oceanic crust in it is absorbed by the oceanic trenches that are situated along the marginal parts of the ocean. Thus, the continents do drift, but their displacement is passive, and they are drawn by the thick plates of the earth's crust to which they seem to be welded.

Scientists believe that the time will come (in several hundred million years, which in geological terms is but an infinitesimal period) when the marginal parts of the Atlantic Ocean will witness the emergence of oceanic trenches. At this time the continents will start approaching each other and in the end both Americas, Europe, and Africa will come together again.

The continents are found to be in a state of permanent movement, being transported by some kind of peculiar conveyor belt. In addition, they are becoming deformed, breaking up, and encountering each other at the instance of the rotation of the earth's crust. They are, however, eternal and cannot disappear altogether. The mountain structures existing on the continents emerged as a result of the collision of continents and the coetaneous contraction of the continental and oceanic crust.

But the new model of the Earth's dynamic processes still did not prove to be perfect. It failed to interpret the irregularity in the distribution of rifts and oceanic trenches on our planet, and did not lend itself to the application of mathematical techniques for calculating the relative movement of different parts of the Earth's surface. The latter is highly important for the comparative analysis of these dislocations with seismicity, the result of which they are found to be. Hence, a logical scheme of the rotation of the earth's crust should have been expressed in terms of a quantitative model. Thus it became necessary to resume the search.

The starting point was a laboratory experiment. Wax was first melted in a large container and then its surface was allowed to cool. A hard film appeared on it. This film was stretched in opposite directions inside the tank splitting it into two parts or plates. As they were thus separating, liquid wax from the bottom of the tank started filling the chinks. Since the surface of the container was continuously being cooled, the melted wax that rose from the bottom solidified, welding itself to the edges of the plates that were separating from each other. Between the two plates that were growing at the expense of the liquid wax, a permanent fissure, or rift, formed. The procedure underlying this experiment is in conformity with what takes place in the Atlantic Ocean.

The experiment was then conducted in reverse order. The wax plates, instead of being separated, were now brought into contact. This led to them overlapping each other. The plate that was superimposed by the other tended to melt and its mass was integrated with the liquid wax. We find exactly the same phenomenon occurring in the oceanic trenches.

In the end, the surface layer of the solidified wax was separated into several plates of different sizes, which were further moved in arbitrary directions. This resulted in that the area of a certain number of plates began to grow smaller, while that of the others was on the increase. This process was in conformity with the direction in which the plates were drifting and the network of 'rifts' and 'trenches' in the experiment.

As far as the continents were concerned, they were represented by pieces of wood that were placed on the wax plates that sagged under their weight and transported them. A somewhat similar phenomenon is also found to exist on our planet, with the only exception that the plates of the real earth's crust are not flat like the wax ones in the experiments; instead, they have a spherical form conditioned by the global structure of the Earth itself.

The researchers were surprised to discover that their experiments had reproduced the previously inexplicable mechanism that was behind the formation of transoceanic ruptures perpendicular to the rifts. In other words, while the two wax plates were separating, fissures appeared that were transverse to the 'rift' along which parts of the plates were displaced. A somewhat similar phenomenon is also existed on the ocean floor. Thus, the Mid-Atlantic Ridge is split by transverse ruptures, which reach the shores of the continents, and its parts are displaced from the longitudinal axis of the ridge in the direction of these ruptures.

The results of these experiments made it possible to develop mathematical methods for estimating the dislocations of the plates of the earth's crust, which were correlated with seismicity, and this paved the way for the prognostication of earthquakes.

In spite of its most apparent character, the model reproducing the dynamics of the earth's crust, which was refined on the basis of experimental results and mathematical solutions, still required substantiation. It was the paleomagnetologists who furnished this.

Under the activity of the Earth's magnetic field newly formed rocks are magnetized and retain this direction. This enables scientists to determine the initial position of rocks in those cases when they are dislocated, and serves as a kind of instrument facilitating the study of the dynamic processes in the earth's crust.

The paleomagnetic investigations revealed that the Earth's magnetic field had many times changed its direction. Nowadays, scientists think that the polarity of the Earth's magnetic field in the geological history of our planet had on average changed every fifteen million years, in addition to which the latest change of poles took place seven hundred thousand years ago.

If continental drift exists, and if within the rift the earth's crust is being accumulated, then (and it cannot be otherwise) as a result of the frequent change of the magnetic field of the planet, saxicolous rocks of oppositely directed magnetization must have formed on the ocean floor as the distance of their drift in either side of the Median ridge becomes greater. Rocks of this kind were primarily found on the slopes of volcanic ridges. Then, with the help of special instruments (magnetometers that were towed by ships), narrow bands that were symmetrical and parallel to the rifts were discovered on the ocean floor. It was determined that they had been formed by abyssal rocks of opposite magnetization. Having established the time when the Earth's magnetic field changed, scientists were able to determine the age of rocks as they drifted away from the rift in opposite directions: that is, they were able to penetrate into the history of the formation and development of oceans.

Owing to these investigations it became possible to elaborate an elegant theory pertaining to the rotation of the earth's crust and to estimate the rate at which the continents are separating, which on average is equal to from two to twenty centimetres per year. According to this theory, the Earth's surface is divided into six enormous plates that include the ocean floor and the continents that are displaced with respect to each other. In those places where the plates diverge there exists a rift, which in its turn serves as the source of abyssal rocks that form the new ocean floor. In the parts characterized by the convergence of plates, we have the trenches through which the ocean floor is submerged into the bowels of the Earth and there melts and is transformed into a different state.

A natural example of this process is the Atlantic Ocean. According to scientists, it is increasing as a result of the movement of three plates. In the south, the African plate, which includes the African continent and the ocean basin fringing the rift, is separated from the southern part of the American plate. In the north, the European plate, which as is well known, also comprises the contiguous ocean basin, is separated from the northern part of the American plate. These movements, however, are not absolutely concordant. The direction in which the African plate moves is somewhat shifted to the north, while that of Europe tends to move southwards.*

In their movement, Europe and Africa collide with each other, jolting the whole Mediterranean and Alpine zone of these continents, which results in violent earthquakes ranging from Agadir and Lisbon to Turkey and further on, as well as in the eruptions of such volcanoes as Etna, Vesuvius, Stromboli, and Santorin. The reciprocal movement of Europe and Africa is equal to approximately one centimetre per year, which in the end threatens to lead to the disappearance of the Mediterranean Sea. It is noteworthy that in its movement the African plate takes a turn owing to which the Red Sea shores separate. The depression of this sea represents a rift, which in geological terms is regarded as young. Scientists believe that its dynamics reveals that a new ocean is being originated within the Red Sea zone.

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* C. Riffayd, X. Pichon. *Expedition "Famous"*. Paris, 1976.

A large number of questions must be answered before the geological consequences brought about by the displacement of continents can be fully apprehended. The nature of earthquakes as such has not yet been made clear, though their interpretation from the standpoint of the theory of the movement of plates represents no minor success. Many processes of orogenesis have not yet been fully accounted for either. There are still quite a few controversial opinions about oceanic trenches. No association has as yet been found between ore-, oil-, and gas-formation and the dislocation of plates, though this kind of relationship undoubtedly exists in nature. The impact of the movement of plates upon the planet's climate still remains a problem. The number of questions remaining is very great indeed. Present-day research is now marked by great activity on the part of scientists to find solutions to these problems, which is bound to result in new discoveries.

It is interesting how conjectures are arrived at in science. Wegener's hypothesis, which was found to be quite extraordinary at the turn of the century, survived for almost ten years before it was refuted as untenable. After a certain period of time, however, its fundamental principles were substantiated. The currently existing continents, as was suggested by Wegener, at one time presented an integral whole—a unique supercontinent to which Wegener gave the name of Pangaea. The Atlantic Ocean as well as the Indian Ocean had not yet been formed. Animals could easily travel from what is now known as Africa to America. The northern part of the supercontinent, which included North America and Eurasia and was called Lavrasia, was being separated from the southern part of the supercontinent, or Gondwana, which comprised South America, Africa, India, Australia and Antarctica with the Thetys ocean wedged between them. The ocean's traces were found on land area.

Wegener's hypothesis made it possible to picture the position of the present-day continents prior to their drift and comprehend from a single standpoint the origin of various mountain structures, oceans, and our planet's climate at the present stage of its development. This is exactly what determined the scientifically progressive role of Wegener's hypothesis.

The existence of continental drift has been proved by a series of original studies, among which a special role is attributed to those results furnished by astronomical research. They made it possible to directly estimate the magnitude and rate of movement of the dislocations at different periods of time.

There are time-service facilities in all countries that observe the rotation of the sky, or to be more exact, of our planet, by the stars, since the sidereal day is what our measurement of time is based on. The Earth rotates irregularly, and hence observations must be conducted constantly in order to account for this irregularity. At present the time-service stations are provided with atomic clocks, which make it possible to introduce very accurate corrections into what is indicated by the sidereal dial. In evaluating the time corrections introduced by the seventeen stations in the USSR, the five stations in Western Europe, the three stations in North America, and the four stations in South America, as well as by the two Japanese, one Australian, and one African station, the Soviet astronomer N. Pavlov discovered a peculiar phenomenon.

According to the corrections that had been made, all the observation stations seemed to have shifted westwards between January and May of 1960. This is exactly what should have happened if the Earth accelerates its rotation. But the interesting thing was that the dislocation of the stations proved to be different, whereas with regard to the immobile stars it should have been the same for each station. This fact served as evidence that what had occurred was actual, rather than conditional, displacement of stations in relationship to each other. This could not have taken place if the continents on which the stations are situated had not been in a state of movement.

During the observation period, the Soviet stations shifted by only 1.2 metres. The figures for other stations are as follows: in Western Europe, 2.4 m; in North America, 9.5 m; in Japan, 10 m; in Australia, 8 m; in Africa, 5.6 m; in the eastern stations of South America, 12.3 m; and in Chile, 16.4 m. It should also be mentioned that in May of that same year there was a devastating earthquake in Chile, which brought about great destruction and took the lives of many people.

According to astronomical tables, the Chilean stations were displaced mainly during February and March, after which the movement ceased only to have the accumulated energy burst in a form of catastrophic shock that changed even the Chilean coastline. This calamity occurred in May.

The astronomical tables helped scientists to visualize, as it were, the displacement of the whole continent, which occurred in jumps rather than smoothly and which covered more than ten metres within a geologically infinitesimal period of time measuring two months.

Thus, authentic evidence was furnished to prove the dislocation of continents, the processes of which are explained by the new theory that was based on Wegener's views and that received the name of the theory of the global tectonics of lithospheric plates. However, this theory also has its shortcomings. For instance, it does not provide any explanation for the processes that take place in oceanic trenches, and it would not be wholly erroneous to assume that, as is often the case, it will be revised. And yet this theory can hardly be undermined. Its revolutionary role in science consisted primarily in that it made the World Ocean, which had for a long time been considered geological backwater, be regarded in quite a new light. Suffice it to say that it is precisely there that all the processes pertaining to the formation of the face of the Earth take place.

The concordance of these processes often make people experience their disastrous consequences, as can be exemplified by colossal ocean waves that now and again rush to the shores of continents and islands, smiting everything that they come across on land. A great many travellers have been confronted with this menacing phenomenon of nature while on their expeditions in far-off countries. Among the Russians, one of the first to pay attention to this was the outstanding explorer of Kamchatka, Academician S.P. Krasheninnikov. In his book *The Land of Kamchatka and Its Description* he wrote of the 1737 earthquake and the gigantic waves that accompanied it. In 1854, when the frigate *Diana* was anchored in the Japanese port of Shimoda, the Russian officer Putyatin witnessed the devastating effect of the ocean billows that swept away the coastal part of the city.

This natural phenomenon, which has caused humankind considerable suffering, is called tsunami. Even today it continues to jeopardize the littoral parts of land. Thus, in 1952 it reiterated its detrimental effect on Kamchatka and inflicted no little damage on the Kuril Islands.

During the voyage of the *Beagle*, Charles Darwin happened to watch the aftermath of one catastrophe. The great scientist described the tragic events that befell the town of Talcahuano in his book devoted to the round-the-world tour. Darwin wrote that in the wake of an underground shock (which cannot but bring back to our minds the same kind of tremor in 1960), at a distance of about three or four miles, a huge wave appeared; in the middle of the bay its contours were smooth, but on the shore it washed down houses and trees and continued to rush forward with devastating force. In the deeper regions of the bay it broke into a row of threatening white surfs, which were coming onwards with incredible violence... The first wave was followed by two others, which while receding carried away with them a large amount of floating fragments. At one place in the bay a vessel was now thrown far ashore, now brought back to the sea. The enormous wave must have been advancing slowly since the inhabitants of Talcahuano had enough time to run away to the hills in the outskirts of their town, while some of the sailors got into a boat and sailed into the open sea, hoping that they would be able to overcome the wave if only they reached it before it broke. Fortunately, their efforts were rewarded. All that remained of Talcahuano was a mass of bricks, tiles, and logs.

The people of that little town regarded the disaster as an act of God! They couldn't even imagine that this phenomenon was the result of a natural process brought about by the dislocation of lithospheric plates, the hazardous advent of which scientific achievements are now making it possible to forecast.

In about ninety-five percent of all cases, tsunamis are conditioned by powerful underwater earthquakes. Gigantic waves can also emerge as a result of the eruptive activity of submarine volcanoes and landslides on the slopes of the floor. These factors cause vibrations of the whole mass of the ocean, which are further propagated in the aqueous medium as single waves or groups of them. It is noteworthy that tsunamis occur preponderantly in the Pacific Ocean, since it accounts for most of the earthquakes that take place on our planet.

Above the deep seismic focus that is remote from land the waves are, as a rule, lower than one metre and measuring several hundred kilometres in length. Their height increases as the distance from the focus becomes greater. In 1946, the Hawaiian Islands were struck with a wave that was eleven metres high and that had covered the space of nearly four thousand kilometres before it reached its destination. Destructive waves are particularly large near the shores of Japan, Chile, and Peru. This is where their height can reach thirty or more metres.

The perilous foe encroaches upon the land at a fantastic speed. Thus, in the northern part of the Pacific Ocean and far away from the continents, the velocity is between four and eight hundred kilometres per hour, depending on the location of the epicentre and the profile of the floor that the wave is covering. When the wave reaches the shore, the rate of its movement drops to one hundred or less kilometres per hour.

It is remarkable that in the middle of the nineteenth century an attempt was made to determine the depth of ocean according to the speed of the tsunami, and the results proved to be quite compatible with the data produced by direct measurements. Researchers had established that at a depth of between twenty and thirty metres the waves were propagated at a rate of approximately twenty metres per second; the one-thousand-metre level corresponded to one hundred metres per second; while at four thousand metres, the velocity reached two hundred metres per second. Given these data, one can easily make a reverse calculation provided the velocity at which waves are propagated in the ocean is known. Though tentative, the result does do justice to the research that was carried out in the middle of the last century when oceanography was in an embryonic stage.

At the time of underwater earthquakes, alongside the long oceanic waves—or tsunamis proper—seismic waves emerge in the earth's crust and acoustic ones in the water. The latter are referred to as shock waves. The rate at which they move is very close to the velocity of sound. They are felt by ships when they hit the hull or the keel: the vessel seems to be stranded, and in the past, such places were even plotted on maps. As has been unanimously evidenced by navigators, the seaquakes are accompanied by a thunder-like hollow sound. The speed at which the acoustic waves are propagated is exceeded by the seismic waves which, while hastily making their way through the earth's rocks, seem to be trying to be the first to portend the impending calamity.

In 1968, highly rapid vibrations were discovered in the radio-reflecting layer of the ionosphere. Scientists assumed that they had been brought about by acoustic waves in the atmosphere that had been generated by vertical dislocations of our planet's surface under the activity of the earthquakes that were taking place at that very moment. These suggestions were confirmed. In fact, seismic waves diverging from the epicentre of an earthquake give rise to vibrations in the atmosphere that reach its uppermost layers and that serve as forerunners of approaching tsunami. This phenomenon will undoubtedly be of benefit to humankind and will be employed as a 'barometer' forecasting the invasion upon land of the ocean depth's messengers in the guise of stupendous waves; at present, however, other methods are being employed. For this purpose, bottom instruments recording tsunami have been developed, on the basis of which automatic signalling systems are being devised that are meant to warn the inhabitants of coastal regions of the approach of tempestuous waves within only a few seconds of their origination in the ocean.

Chapter 3

From One Pole to the Other

The Ice Continent

A discovery that was predicted by scientists some decades ago has recently been made in Antarctica. Evidence was found that at one time in the past, America, Antarctica, and Australia formed a single continent known as Gondwana. In Antarctica, petrified remains of marsupials were discovered that had lived forty million years ago and were not larger in size than a rat. Fossilized remnants of lizards, or the so-called king penguins, and big marine reptiles called plesiosaurs were also found.

Among the findings were the bones of marsupial animals represented by three mandible bones, each of which had two or three teeth. By studying these objects, palaeontologists very soon established that the marsupials that lived in Antarctica had very much in common with the animals that densely inhabited South America tens of millions of years ago.

At one time in the past trees were rustling in Antarctica. According to scientists, the land link with other continents could have been disrupted about fifty million years ago. Before then, Antarctica was the place through which marsupials passed when moving from America to Australia.

At the same time, it remains a riddle why this path was not traversed by other mammals.

The discovery made on the ice continent was unique in that it was the first find of mammals in Antarctica. For reasons that have not yet been clarified, this part of the world served animals as a kind of migration filter that only the marsupials were able to pass through. Once landed in Australia, they found themselves in isolation when this continent broke away from Antarctica. Scientists figuratively compare Australia with a type of Noah's ark for the fauna of ancient epochs.

The antarctic find made it possible to specify the age of Gondwana. Until recently it was thought that Gondwana ceased to exist as such in the Mesozoic era, i.e. between 230 and 67 million years ago. The new discoveries reveal that the end of that continent came much later: in the Oligocene period, forty million years ago.

Antarctica, with its unusual nature, entirely changes our ideas about climate, seasons of the year, and atmospheric phenomena. It has quite a few surprises in store for anyone who finds himself there for the first time. One of them is the colour haloes. What gives rise to this phenomenon is the solar rays refracted in the ice crystals that make up the clouds. The Sun becomes edged with multi-coloured rings and false suns appear around the halo, which sometimes seem to be submerged in iridescent bowls. Rainbows emerge in the sky with their ends bent upwards. This phenomenon often lasts for several days running.

Eighty-seven percent of the planet's ice is concentrated in Antarctica. The continuous cover that it forms has an average thickness of two-and-a-half kilometres, with only five percent of the continent's surface remaining free of the ice shield. This is the area of mountain ridges, single mountain ridges, single mountain peaks and oases. The last ones have nothing in common with those in a desert, or the islets of life as they are called. The oases in Antarctica are small regions where there is no ice and where the surfaces covered with either hills or ice react differently to solar radiation.

The term 'oasis' in reference to Antarctica was first used by A. Stephenson: when instead of the expected masses of ice and snow, he saw broad valleys covered with dust through which snow could hardly be discerned, he compared what lay before him with the landscape one was accustomed to see in South Wales. But the valleys were dry, and the dust that was deposited around them facilitated the melting of ice and the exposure of the rocks.

As far as the complexity of research is concerned, Antarctica may well be compared with the World Ocean, the only difference being that instead of water it is covered with ice. Many heroic and tragic pages in the history of our civilization are connected with Antarctica. Ocean and cold prevent people from reaching the ice continent. C. Fleming once gave a picturesque description of the ocean comparing it to the rampart of a fortress that surrounds the Antarctica and guards its secrets against the intrusion of people. The continent is unimaginable without the Southern ocean, since all the expeditions to far-off Antarctica lie across the latitudes of 'roaring forties' and 'furious fifties' before the explorers can start their hazardous journey to the threshold of the continent through pack ice.

In ancient times, Antarctica was imagined to be a blooming part of our planet. Maps labelling it the Unknown Southern Land have reached us from the Renaissance. What we see on them are drawings of green trees, unknown animals, and people. In short, it is a picture of an ordinary summer day. What then can it possibly be: the products of fecund imagination, or echoes of actual knowledge?

As a rule, expeditions are now undertaken to Antarctica at the end of the year between January and March (the end of summer and the beginning of autumn), when research stations and food-supply centres are built in the deeper regions of the ice continent. After that the main part of the expedition returns to the base station to spend the winter there. The coming of spring is marked by the second and most important stage in exploration. It consists of all-round geological, geophysical, and other investigations, which are usually completed by the time of the arrival of the next group of explorers.

In summer, the average monthly temperature even on the coast of Antarctica, where the warm breath of the ocean is felt, is practically always below 0 °C. The exception is the north-western parts and a number of littoral oases in the eastern regions of Antarctica. The summer period lasts only two months (December and January) and differs from the long winter months mainly in the conditions of light, or the polar day. It is quite natural that the summer time is warmer than winter, though frosts know no relaxation. According to scientists, the summer in Antarctica is defined more by astronomical conditions than climatic ones. In this respect, a considerable role is allotted to glaciation, which is immediately connected with atmospheric processes. It is characteristic that the white continent receives solar energy only during a few months, predominantly in summer, but loses it incessantly on account of the high reflectory and thermal radiatory capacity of the ice cover.

In summer the frosts in central Antarctica drop to between —30 and —35 °C. In the mountains of Queen Maud Land, the mercury column of the thermometer does not rise higher than —20 °C. The temperature of the rocks that are lit up by the sun is never above 0 °C. It is interesting to note that the melting of snow and ice in Antarctica takes place when the temperature of the air is below zero. It is hardly credible to imagine the following picture: the weather is clear, streams are running along the sun-warmed slopes and the temperature of the air is —20 °C. In summer months, a great amount of water flows off the Lambert glacier, thus forming whole rivers.

In the coastal districts, the climate is somewhat milder. For instance, in Mirny the temperature of the air in summer sometimes reaches +5 °C. Days like these in Mirny remind us very much of early spring near Moscow. In addition, there is no real polar night or polar day in Mirny, i.e. the light conditions have very much in common with those of the peripheral parts of the polar regions in the USSR.

Mirny is often visited by penguins. There are several species of them. As the explorers say, the Adelic penguins are typical 'seasonal birds'. They come to the coast and the coastal islands at the beginning of spring, hatch and bring up the new generation, and in the end of summer, they return to the ocean and the edge of the ice. The true hibernators are the emperor penguins, or as they are also simply called, the 'emperors' There seems to be good reason to believe that only man and the 'emperors' can survive the Antarctic winter.

Since 1956, Soviet scientists have been carrying out research in Antarctica. They have made quite a few remarkable discoveries, and as a result of their activity and that of the scientists of other countries, the ice continent is losing the aura of mystery. Much has been done to clarify the structure of Antarctica with the help of the hypothetical tectonic map compiled by the scientists. The researchers have imagined the continent to be divorced from its ice cover, and by employing the data of deep seismic probing of the earth's crust and other results of geological investigations, tried to visualize what the hidden face of Antarctica could look like. What strikes one on the map is the abundance of deep faults in the earth's crust. The continent appears as if it has been split into a large number of blocks. In their seemingly chaotic state we can clearly see a certain regularity, which consists in that the colossal geoblocks are cemented, as it were, by a tremendously large network of folded mountain systems.

Antarctica without ice looks very much the same as the other continents of the

Southern Hemisphere. Among them its central position is undisputable and it can be regarded as the core of the supercontinent Gondwana, across which animals had once migrated. The map that was compiled has made it possible to compare the basic geological structures of Antarctica with the structures of the adjoining continents, which were found to share many common features with it. This is what makes the search for mineral resources in Antarctica quite feasible, where copper, nickel, gold, coal and iron ores have already been discovered.

Valuable information about Antarctica has been received from satellites. They made it possible to practically at one and the same time draw the boundary line between blocks of ice and trace the dislocation of ice fields. The variability of ice conditions in the summer months reaches a magnitude that was quite unpredictable. In summer, the ice in some regions recedes to the continent at a rate of 28 kilometres per day.

The Arctic and Its Riddles

The legendary and elusive Land of Sannikov, which the boiler-works industrialist Yakov Sannikov claimed to have seen with his own eyes from a distance of 25 kilometres to the northwest of the Kotel'nyi Island, was coloured by innumerable tales, hopes, and frustrations. For a long time this land was the object of many quests, but now it is known that it does not exist as such. Polar explorers, however, are still of the opinion that the Sannikov Land had actually existed. What is this opinion based on?

The geological structure of the shores and islands of the Arctic seas contiguous with Siberia have quite a few unique features that were brought about by the glaciation that had once seized the region. Even today, with the general warming of the Arctic, permafrost still exerts its marked impact on their shape. In these seas massifs of rock ice comprising parts of the coastlines and forming islands of different size cover the water surface over tens of metres. These phenomena are widespread, for instance, in the Laptev Sea.

Once for exploration purposes we happened to disembark from an oceanographic expedition vessel on an ice shore of the Novosibirsk islands. The coastline was precipitous, and in the low polar sun, the wall of the fossil ice shed a lustreless light. At its foot, covered with ground drifts, brooklets began their movement. Apertures of caves washed out by the sea in the mass of ice were gaping all around. The silence was broken by the fall of melted pieces of the ground cornice that was hanging over the ice wall. The peeled off fragments covered with wilted northern vegetation, together with a great deal of what remained of the ice, formed weird figures that at times looked like chimeras, various kinds of animals, and even people hidden in an ambush.

The solar radiation, rains, currents, waves, and winds do their utmost to destroy the ice shores. This kind of activity is further made possible by the post-winter broken masses of ice, which as if they were huge ploughs, loosen the sea floor near them. The rate at which the shores are destroyed sometimes reaches thirty or more metres a year; on the average, however, they annually recede by approximately five metres.

The Sun with its 'assistants' sweeps away whole islands. Thus, practically within a period of several decades Semyonovsky Island, which had been discovered in 1815 and which then had been about eight kilometres in length, completely disappeared into the Laptev Sea. By 1936, the length of the island had decreased to two kilometres, and there was no more than a shoal of it in 1956. The vast shoal space in its proximity indicates that not very long ago Vasilyevsky Island had also existed. The same fate will most probably also befall the big Lyakhovsky Island, which is composed of fossil ice.

Hence, the suggestions put forward by polar explorers that Land of Sannikov could have been an ice formation that had disappeared in exactly the same way as Semyonovsky and Vasilyevsky islands cannot be disregarded. It is noteworthy that research on the bottom sediments in the region of the Novosibirsk islands does not exclude the probability that there had recently existed an 'iceland' in their neighbourhood, since there, under the water surface, parts of the floor that were composed of fossil ice were discovered hidden behind a thin layer of silt.

The collapse of the northern shores seems to open to us some of the singularly absorbing pages in the history of life on Earth, since during the melting of the coastlines a multitude of the remains of animals of the preglacial epoch that were buried in permafrost come out onto the surface. In this respect, the shore of the Dmitri Laptev Strait is found to be 'fecund' enough to be called Mammothian.

Several years ago Academician N.A. Shilo spoke of an unusual hypothesis according to which in the epoch of the latest glaciation that came to an end ten thousand years ago, the Arctic Ocean represented an immense ice valley that was covered with earth upon which there was a wanton growth of vegetation. Over the vast pasture, herds of mammoths, bisons, musk-oxen, deer, and horses roamed. The idea itself that animals could be grazing on the ice-cover of the Arctic basin seems to be wholly bizarre. Can such a thing even be imagined? And nevertheless the hypothesis is not at all ungrounded.

Scientific studies on the unique geological formations in the north of Yakutia and on the Novosibirsk islands have revealed some specific formations, e.g. thick sheets of ice, covered with a half metre thick layer of topsoil and penetrated through the whole of their depth by round earth pillars that measure three metres in diameter. These pillars are composed of dust, the continental origin of which raised no doubts. Where could it come from to reach the Novosibirsk islands and the north of Yakutia at the time of glaciation? After all, it was the period when the winds were preponderantly blowing from the ocean towards the land.

In the epoch of glaciation it was undoubtedly much colder in the Arctic than it is now. Under such circumstances, as the authors of the hypothesis say, the ocean began to freeze, and its drifting masses of ice were combined into an immobile massif that firmly brought together the shores of the continents surrounding the Arctic basin. In the centre, according to the authors, a great polar anticyclone set in that was more powerful than the one that is now in Antarctica. The cold air began to move southwards, but under the activity of the Earth's rotation, it changed its course and formed a constant east wind of the high latitudes, which is similar to the Antarctic variety. In the upper layers of the atmosphere a very special kind of sucking funnel of reverse direction (a sort of huge 'vacuum cleaner') appeared. In this period an eolian dust accumulated in the middle latitudes, which became responsible for the formation of the widely known loess deposits. Part of this dust must have been sucked up by the powerful Arctic 'vacuum cleaner', which then released it onto the ice.

In summer, when for practically four months the Sun does not set in the Arctic, the layer of dust that covered the ice fields became markedly heated since it absorbed heat more intensely than ice, whose main function is to reflect it. Dockers now make use of this property of dust in the laying of channels along ice to the moorings. At the beginning of the navigation period when the ice has not yet broken up near the shores and in the bays, and the port icebreakers find it difficult to cope with it, black coal dust is scattered in specific directions upon the ice sheet covering the bay. The dust becomes heated by the Sun and the melting ice under it thus diminishes in thickness.

The sun-heated dust wetted by the ice that had melted under it must have acquired fertile soil properties conducive to vegetation. Since the open seas of the World Ocean were far away, the sediments in the Arctic in that period were scarce, and the peculiar polar 'steppe' was not snow-bound. This was why the animals could feed on dry grass even during the winter months.

Scientists are quite positive that this fecund polar region perished not because of the cold, but as a result of a climate that had become much warmer and milder in the postglacial period and which brought about excessively great transformations of the landscape. About ten thousand years ago the warm waters of the Gulf Stream penetrated under the ice shield of the ocean and melted it. The ocean began to relieve itself of the ice and the fertile vastness of the white 'steppe' was split into fragments. Its remains were hindered in their movement within the shallow regions of the shelf, thus forming islands and archipelagoes, while the greater part was carried away to Atlantis and ceased to exist as such.

The dry, cold climate became humid. Snow and glazed frost fell upon the north of Siberia, with the result that Arctic animals were deprived of food, which probably explains why what is now left of the mammoth is nothing but buried bones.

In terms of the hypothesis under discussion, the fate of legendary and actually once existing islands and Arctic lands becomes quite clear. Though not lacking in some controversial and moot points, this hypothesis will nevertheless lead to the reconsideration of a large number of deeply rooted views of the Arctic and its history.

This hypothesis cannot be divorced from another, not less whimsical, one. The Arctic is often referred to as 'the weather's kitchen', in that the coming of frosts, the amount of precipitation, the severity of winter, and the mildness of summer in the middle zones are to a great extent dependent on glacial conditions, the direction and force of winds, and the temperature and humidity of air in the north. In the fifties of the present century, the research that had been carried out over a long period of time revealed such a natural phenomenon as the general warming of the Arctic climate. Its distinctive features in the north were a rise in the temperature of the air and water, as well as a reduction in the amount of ice. As a result of glacial observations, a number of specialists came up with the suggestion that polar masses of pack ice were becoming thinner and that they were to disappear altogether.

The Arctic pack ice represents a thin layer of the ocean and is markedly distinguished from the Antarctic ice cap. Every summer nearly a quarter of the Arctic pack ice melts. As distinct from the other oceanic basins, the Arctic Ocean is surrounded on all sides by land. It receives the warm waters of the Gulf Stream and a certain amount of heat with the waters of the Pacific Ocean through the Bering Strait. This is precisely what accounts for the thick mass of warm water deep in the Arctic Ocean. What prevents the heating of surface waters is the ice cover of the ocean that reflects almost all the solar energy into outer space. Thus, the melting of ice occurs predominantly at the expense of the heat that comes from the abyssal horizons of the ocean.

According to specialists, if the Arctic pack ice melts, the ocean will not freeze again, since the water will start absorbing a considerable part of the solar energy that is now thrown back by the white cover. In addition to this, it is emphasized that during the summer months the region of the north pole receives more of the Sun's heat than the tropical areas of the world, since the Sun does not set there in summer.

Scientists believe that in the Tertiary period, which preceded a whole series of glacial epochs, the Arctic Ocean was free of ice, and this may well be considered to be its normal state. It is also assumed that the glacial epochs can be regarded as some kind of cycles associated with either the presence or absence of ice in the Arctic Ocean.

When the solid cover of the northern basin becomes a liquid, the level of the World Ocean will remain as it was, since the masses of ice that are in the water actually push out a volume equal to what it can receive when the ice melts. The changes of climate, however, will be fundamental and profound. At present, the evaporation of water from the ocean is hindered by its ice cover. The Arctic basin is remarkable for the preponderance of high atmospheric pressure. For this reason the storm paths in the northern continents are deviated southwards. With the disappearance of the polar ice cover, these paths will be shifted completely to the south, and the plains of North America and Central Eurasia will have no precipitation at all. The winds blowing from the Arctic will become humid and heavy snowfalls will occur in the mountains along their path. According to the proponents of these views, all this will inevitably lead to the land being covered with glaciers similar to those that had not infrequently in the past moved towards the south along North America and Eurasia.

Nowadays the warming of the Arctic region seems to have taken a reverse course. In the past few decades a considerable drop in temperature was registered near the Kara Sea and in the northwest of Greenland. The glacial situation in the Arctic basin has become worse, the edge of the drift ice has been shifted, and its movement has been retarded. The scientific literature indicates that the size of the polar ice cover is approaching the value it had at the beginning of the present century. Most likely, the world climate is returning to its typical state, which is less favourable for us, and the deviations from which one cannot possibly exclude. In spite of this, those who adhere to the hypothesis presupposing the thawing of the Arctic pack ice continue to think that the white cover of the Arctic Ocean is vulnerable. They assume that the possible increase in the quantity of solar heat and the probable change in the transparency of the atmosphere as a result of its pollution and other similar factors must necessarily lead to its disappearance. The most ardent proponents of this hypothesis even go so far as to say that it will take place in some ten or twenty years' time. In cases like these it is usual to say, 'wait and see'.

Saline Ice

Every year with the coming of winter the Arctic seas put on their ice cover, which extends from the shores to the drifting masses of ice in the ocean, with which they come into contact, thus forming a vast white plain. This natural process, which at first glance seems to be quite ordinary, has quite a few interesting transformations in store. The salty seawater, as compared with freshwater, freezes at a much lower temperature. What initially appears in the sea is little crystals of pure ice with impregnations of brine. At this moment, water seems to be heavy and to share common features with mercury. After this, the intense growth of ice formations occurs, and depending on the weather and hydrological conditions, they rise to various types of ice.

The short and fleeting Arctic summer, which was succeeded by a northern autumn, is stuck in our memory. With every new day the Sun was steadily setting towards the horizon, curtailing the light part of the day, as if reminding people that the long and severe winter with heavy snowstorms and many months of continuous night was on the threshold. We were completing our scientific observations in the Laptev Sea and our research vessel started on its way from the edge of the perennial drift ice towards the shore in the proximity of Tixie Bay. The weather, as is not unusual in these latitudes in autumn, was clement. The sea could be compared to a boundless tarnished mirror tinged with the colour of lead. Several days had passed, the frost came into its own by casting a whimsical ice net over the water surface. This was followed by the emergence of a grey coating upon the water, which looked like congealed grease. Thus, the remarkable and multilateral process connected with the formation of ice in the sea was taking place before our eyes.

Near the Lena River delta we were confronted with an ice rind—a thin transparent variety of ice that appears in those parts where the freshwaters discharged by the rivers are propagated. We passed across the field of this ice to the accompaniment of an incessant tinkling as of broken glass.*

Cake ice also presents a very interesting spectacle. When the sea is not calm, the formation of ice takes place, as it were, at different points. This causes the water surface to be covered with a mass of disks ('pancakes') with their edges slightly curved.

But it is not only on the surface that the ice begins to develop in the seas. When the freezing water is mixed by powerful currents or disturbances, the ice can form within the mass of water or even on the bottom. In these conditions, prior to the ice-forming process, the water becomes markedly turbid and looks as if fog were spread throughout its mass. With the passage of time, the ice rises to the surface. There have

* This was in perfect harmony with the word 'peel', which is a homonym of the word 'peal', which is in its turn synonymous with 'rind'—the appelation for this kind of ice.

been cases when ships suddenly found themselves surrounded with ice coming up onto the surface. Sometimes this kind of ice brings drowned objects and ground to the surface.

The sea does not resist the frost for long. As soon as the latter takes the upper hand in their struggle, what we see before us is nothing but an interminable grey sheet of ice. It is rather thin, measuring some ten centimetres. It is called 'nilas'—an elastic ice that undulates on small waves. In the course of a certain period of time, nilas is transformed into juvenile ice, which in the end becomes annual ice covered with snow. During the next summer season, a part of it melts, while the rest turns into a very thick perennial mass of ice.

From its inception, the sea ice, consisting of the frozen freshwater and the impregnation of brine, begins to produce small fissures along which the brine slowly flows down. This results in that the ice loses its saline properties. It is of interest that the lower the temperature of the environment, the more saline the ice becomes. In very cold weather, a certain amount of brine is squeezed out to the surface of the ice, making it become moist. If the frost is excessively severe, all the moisture in the brine that has come to the ice surface freezes, and the winter garment of the sea becomes covered with what is called ice flowers, which are made up of little crystals of salt. They hinder the sliding of skis and sledges just as does sand scattered over ice.

Saline sea ice has the remarkable property of losing its salinity and becoming useful as a source of drinking water. Polar explorers make use of this. In perennial masses of ice they find lakes, or snow patches, which emerge when the ice melts in the summer sun, and they use the water for purposes of consumption and technical needs. It tastes very much like distilled water, since like it, it contains a very small amount of dissolved salts.

The transformation of water into ice is a usual phenomenon of nature. But strange as it may seem, ice represents an anomalous body. It is lighter than water, whereas all other solids, with the exception of very few, drown in liquids, which are formed in the process of melting. If ice did not have this property, life in the water bodies over a considerable part of the world would be impossible. The ice cover of water is a poor conductor of heat, and hence decreases its loss from reservoirs and protects them from becoming completely frozen.

Frozen water has for a long time served as a prototype of a crystalline substance. This is what once upon a time gave rise to its name. In ancient Greece the word for ice was 'crystal' Scientists relate it to the lightest and most low-temperature of minerals. These are the characteristic features conditioning its distribution pattern on Earth, where it can be found in the form of sheets, glaciers, and permafrost. One is liable to think that the properties of this well-known formation must long have been discovered. However, this is absolutely not the case, since up to now, the human mind is still puzzled by many of its riddles. Depending on the physical conditions in which the freezing of water takes place, various forms of ice appear, which are distinguished from each other by their structure and properties, with the chemical composition remaining unaltered.

Specialists call ice that is formed in the natural environment 'ordinary', thus distinguishing it from the specific forms that are obtained through artificial means. Among the latter, the amorphous variety is of special interest. It is assumed that it does not exist in nature. This kind of ice was obtained under specific laboratory conditions. Its characteristic feature consists in that it lacks any crystalline structure, as is indicated by its name. Amorphous ice is highly unstable and at a temperature higher than —70 °C acquires a crystalline structure. Thus, on the surface of the Earth and in the atmosphere there are no conditions in which it can exist, which cannot equally be said of outer space.

The other, and presumably the most

remarkable, form of artificial ice is created at a temperature above 0 °C— a fact that cannot even readily be apprehended. This type of ice forms and exists under very high pressure. In the scientific literature it is termed hot ice. This ice, as distinct from the ordinary variety, is heavier than water. For instance, a form of hot ice has been obtained, which melts at a temperature of +200 °C, while at a lower temperature it remains a solid. Two hundred degrees centigrade! Isn't this twice the boiling point of water?! The hot ice that emerges under a pressure of over 48 000 atmospheres and a temperature of +20 °C has a density of 1.67 g per cm^3. This makes its structure approach that of closely packed atoms.

On the whole, our planet cannot support the existence of hot ice either, since the required combination of temperature and pressure for its origin does not exist. Even in the bowels of the Earth where the pressure is what it should be, the temperature is too high and exceeds even the melting point of this formation. Nevertheless, scientists believe that in the world surrounding us there is a medium in which hot ice could be formed and exist as such, and it is the surface of solids that can serve the given purpose. The pressure here, however, is conditioned by the activity of electromolecular attraction.

It is common knowledge that soil absorbs moisture. Some of the water is drawn and closely bound by the little particles of soil. This results in that the so-called adsorbed water appears, which is found to be under considerable pressure and markedly different from the usual variety as far as its properties are concerned. This has given rise to the idea that the thinnest film of water bound by hard particles could be hot ice. This suggestion was put forward in its time by Academician V.I. Vernadsky.

In its properties, adsorbed water resembles a solid, though its structure, if a number of indirect characteristic features are taken into account, should be different from that of ice. If hot ice really does exist in nature, it must be in some cryptic state inaccessible to our direct perception. In other worlds it might be more conspicuous.

In bringing to a close this part of the book dealing with such a remarkable and commonly known substance as ice, it should presumably be added that it finds its expression in nine forms with eight of them crystalline, and one, amorphous. They all have one and the same chemical composition and differ from each other only in their structure and properties. As has already been mentioned, amorphous ice cannot be found in our environment. However, one can come across small quantities of other forms in either the upper layers of the troposphere or in the form of molecular films in the upper horizons of the earth's crust. Only ordinary ice is a widely distributed mineral that can exist in the form of large masses, or ice rocks. According to the admixtures contained in it, the usual kind of ice is categorized as either freshwater, saline, or briny.

There has been ice on Earth for many millions of years. Its total reserves amount to nearly thirty million cubic kilometres, which is equal to the runoff of all the rivers on our planet for a period equal to between 650 and 700 years. The thickest ice beds are found to be in Antarctica, where they reach up to four kilometres in width. About two-thirds of all the Earth's freshwater is contained in the glaciers. At present, with the ever growing demand for water, the possibilities of utilizing icebergs are being investigated. Rational means for their transportation are being elaborated, tugboats are being designed, and coverings for icebergs are being developed lest they should melt while in transport to the place of their destination.

Icebergs

The reader must already be familiar with the enormous amount of ice that is concentrated in the upper latitudes of our planet and that thickly covers Antarctica and many lands of the Arctic. This ice slides down the slopes and valleys towards the sea, where it breaks up and gives rise to floating mountains, or icebergs. It is impossible to forget the view of glaciers and broken off icebergs, lit by the low rays of the polar sun, and preparing to set off on a long journey to the seas and oceans to which they are carried away by the winds and currents. They usually drift in the direction of the equator, and are most likely to appear in one-fifth of the World Ocean's aquatorium, with the Southern Hemisphere accounting for nine-tenths of this fraction.

The fanciful shapes of multicoloured huge masses of floating ice attract attention. It is noteworthy that the northern icebergs are of a greater variety than those in the south. Some of them look like launches, for which reason they are called dry docks. Others produce the impression of towers and steeples. The very small ones are referred to as 'growlers' On the other hand, the icebergs of Antarctica are far greater in size than those in the Arctic. They are predominantly columnar in form, and are sometimes over two hundred kilometres in length. Ice formations of this kind rise above the water to a height of up to one hundred metres. It is assumed that the underwater part of these icebergs is between seven and nine times greater than what sticks out of the water. Hence, the overall height of these bulky masses of ice may well approach one kilometre. The dimensions of the submerged part of the ice mountains depends largely on their inner structure. In the process of formation a large number of air bubbles appear in the body of glaciers. They occupy up to fifteen percent of the whole volume and this influences the extent to which the icebergs are submerged in the water.

There were cases when in cloudy weather, which is typical of the high latitudes of the Southern Hemisphere, seamen took the floating masses of ice for hitherto unknown islands and plotted them on the maps. What deceived them was not only the tremendous size of the icebergs, but also the seagulls and petrels, which encouraged the navigators to believe that what they saw was land. Thus, for instance, the French navigator Dumont d'Urville mistook a gigantic iceberg for an island and called the imaginary piece of land Claire Coast, which nobody after him was able to find since it had drifted away in the ocean waters.

The tragedy of the *Titanic*, which while moving at full speed, struck an iceberg, must for the first time have made the whole world start thinking seriously about the danger that drifting ice mounts present for navigation. On April 11, 1912 the 'unsinkable' *Titanic*, as it was advertised by its owners 'The White Star Company' (since it had fifteen watertight bulkheads), left the shores of England and sailed for New York. And in several days' time, the world heard the news that an unprecedented disaster at sea had taken place in the Atlantic Ocean. The *Titanic*, on her maiden voyage, with about three thousand passengers aboard and the crew, sank near Cape Race. The collision with an iceberg resulted in that an almost one-hundred-metre gash was ripped into the side of her hull.

On April 20, 1912 the *Times* newspaper published a witness's account of this horrible event. It said that it was one o'clock in the morning. The night was beautiful, though cold. From afar and against the starry sky the *Titanic* seemed to be a giant. It would have been impossible to even imagine that something could have gone wrong with this leviathan, if it were not for the sinking of the stem where the water was reaching the portholes. At about two o'clock the incline had increased and the bridge was now wholly submerged. The ship, with its stern upwards, was acquiring a vertical position. At the same time a rumble was heard, which could be detected miles away—the boilers and mechanisms were torn off their places; it was the most fatal sound that had ever been heard in the ocean. Those watching the disastrous consequences were spellbound by what they saw. The ship remained vertical for at least several minutes and looked like a tower of approximately forty-five metres in height that was growing black against the sky. These were the last minutes of the ingloriously perished vessel, whose navigators had been heedless of the warnings from the captains of other boats that there were icebergs in her path.

In 1913 the International Ice Patrol was organized. Its functions consisted in giving radio information about the size, location, and drift of icebergs near Newfoundland—a region of intense seafaring—whioh is annually transversed on an average by about four hundred bulky ice mounts. Their main source is situated in Greenland. The ice sheet, as if it were a gigantic octopus, embraced this part of the world with its frozen tentacles going down into the sea. Depending on weather conditions, the 'glacial octopus' now draws its tentacles in, now out, thus either reducing or increasing the number of icebergs. The Greenland glacier Jaoobshavi, which does not stand still even in winter, 'begets'—as is the figurative expression among polar explorers—over one thousand ioebergs a year. It should also be mentioned that the rate of its movement is much greater than that of the fastest Alpine glaciers.

In the course of their drift, icebergs gradually become destroyed. The average lifespan of these formations is approximately four years, though some of them live for ten years or more. In addition, the Antarctic variety is more stable than its Arctic counterpart. In cold waters, the upper part of ice mountains melts quicker than the submerged sections; in warm waters, it is the other way round. In the latter cases they often become overturned.

There are rocks at the foundation of icebergs, which have been captured by the glaciers during their movement along the slopes and valleys of mountains. This kind of material can be found, for instance, in the Laptev Sea. It can often be seen on the upturned and stranded ice massifs called grounded ice hammocks. Icebergs transport the rocks that they take from land and leave what can be figuratively described as 'visiting cards' on the floor of seas and oceans when they melt during their movement.

The use of icebergs for meeting the demands for water of the Earth's inhabitants, especially in arid countries, may well be regarded as a promising enterprise. However, pessimistic views on this problem also exist. Australian scientists have recently calculated the economic efficiency of supplying water with the help of icebergs. They focused attention on the following difficulties, which await all those who intend to use iceberg water in the nearest future. First, it is necessary to establish the size and state of the ice mass, which can be done with an echo sounder and other instruments. According to scientists, these determinations involve no minor expense. The huge weight and volume of icebergs call for the construction of exceptionally powerful tugboats, which is costly. They have estimated that due to the considerable draught, the ice massif could not be dragged to a distance nearer than twenty kilometres from the shore. Hence, it becomes necessary to lay a twenty-kilometre-long water main. The salinization of icebergs during their transportation is another problem that crops up. Thus, the specialists have arrived at the conclusion that in the foreseeable future this particular source of a water supply cannot be utilized because of the exorbitant price of the final product.

Chapter 4
The Turbulent Ocean

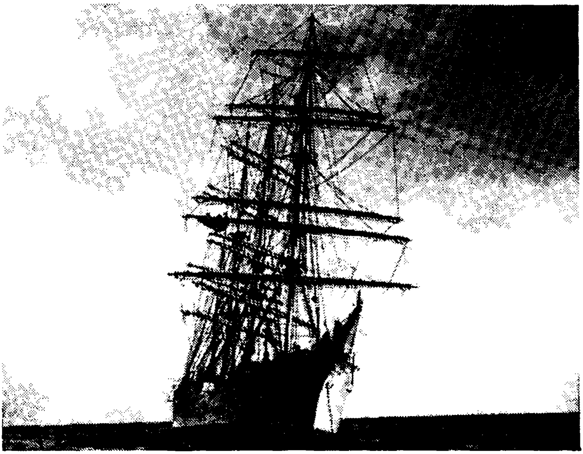
Rivers with No Shores

Since time immemorial people have been aware of currents. With no knowledge of how to explain these phenomena of nature, they most often attributed divine significance to them.

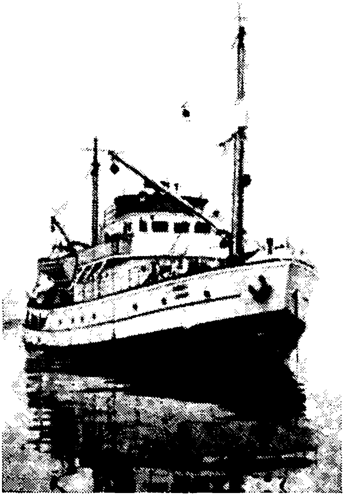
Information on the currents in the straits of Bosporus, Dardanelles, Gibraltar, and Kerch was already given in the works of the ancient philosophers. The ancients were also familiar with the whirlpools in the Strait of Messina, which gave rise to the myth about Charybdis and Scylla—the horrible sea monsters that guarded this strait and devoured everyone who dared to cross it.

The legends are now gone with the wind. Seafarers have discovered that the whirlpools in the Strait of Messina are brought about by reversing currents and that they are quite safe for navigation. There is some reason to believe that the Normans, who at the beginning of the present millennium voyaged to Iceland, Greenland, and North America, also had knowledge about currents, evidenced by their use of such geographical names as the islands of currents, the bay of currents, and others. The Arabs had a fairly clear-cut idea of the monsoon currents in the Indian Ocean and the drifts that were manifesting themselves along the eastern coasts of Africa. Beginning with Columbus's discovery of the northern equatorial current, the Europeans, who had made their way to the spacious expanses of the Atlantic Ocean, very soon found the main directions in which its waters were flowing.

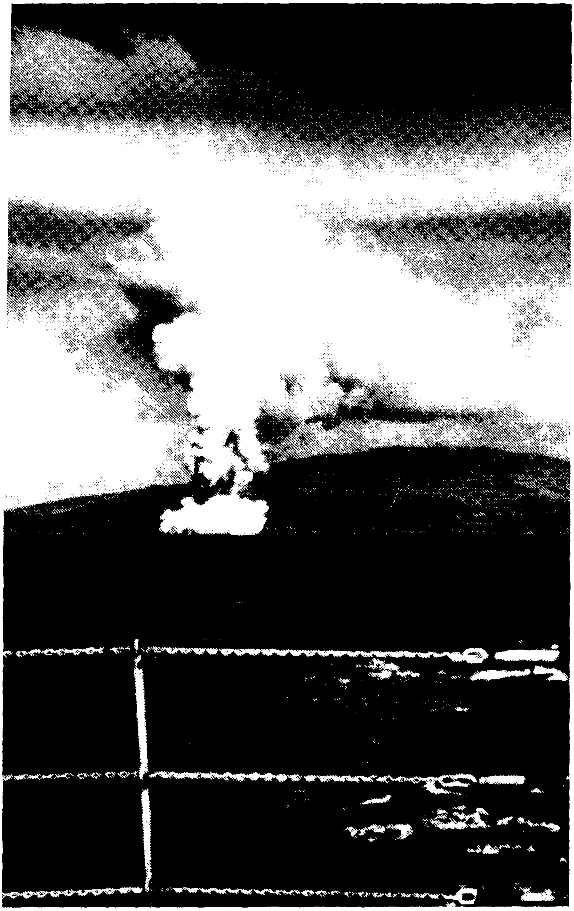
In 1513 a fleet under the charge of Juan Ponce de León, a participant of Columbus's second voyage to the shores of the New World, set off in search of the islands of bliss. At that time the legend that there



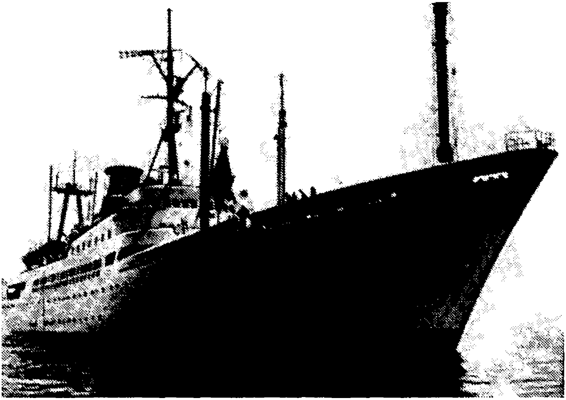
The oceanic sailing ship *Sedov*



The Arctic ice patrol

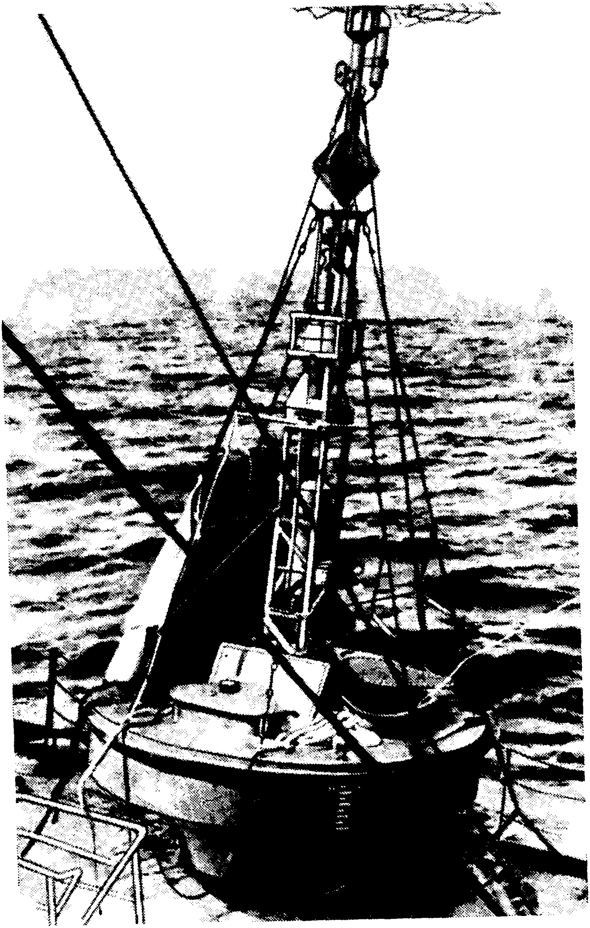


The Capelinhos Volcano

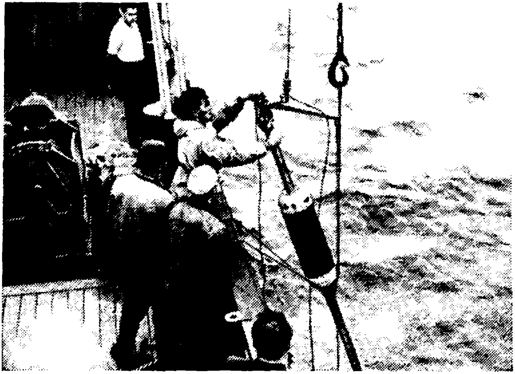


The research ship *Academician Vernadsky* in the Pacific Ocean

Cake ice



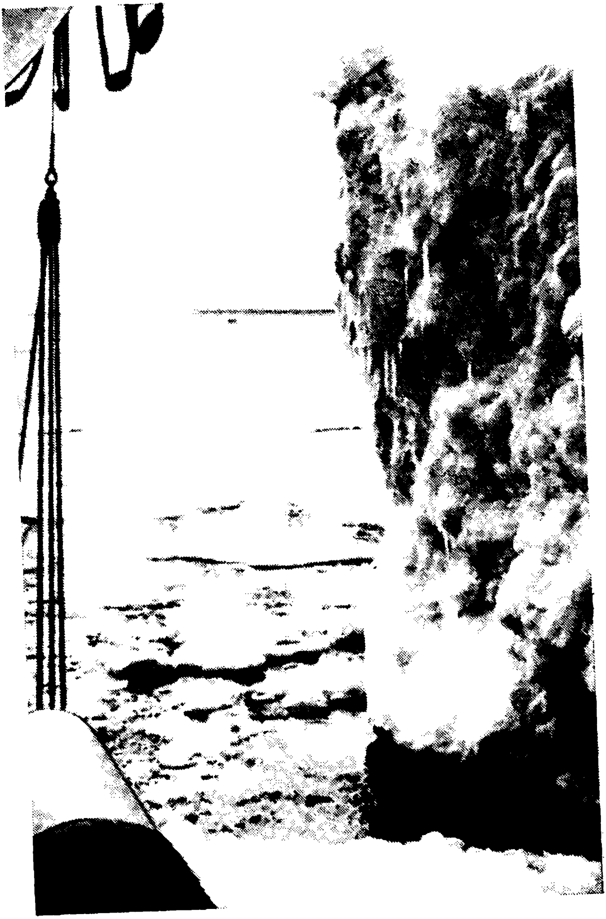
A buoy station



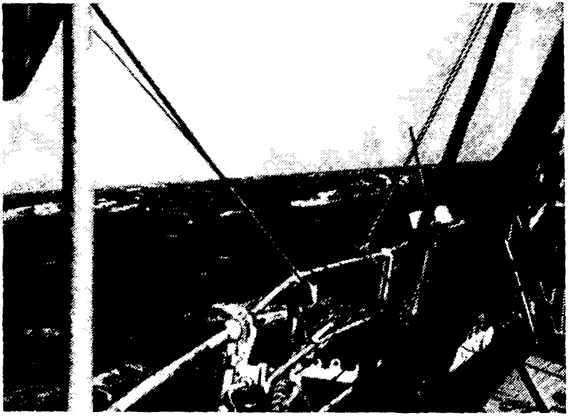
The mounting of an instrument

Current gauges in preparation

Ice shores



A grounded ice hummock



A storm in the ocean

The New Britain Island after sunset

were islands with the 'fountain of eternal youth' and that life there was like a biblical paradise was still credible. There was a fair propitious wind, but as time went by the seafarers noticed that they were moving at a much slower rate than expected. Finally, the vessels began to move ever farther from their destination, though their rigging creaked under the pressure of the favourable wind. Alaminos, the chief helmsman, determined that some strong and yet unknown current was exercising its activity. This event—the discovery of the Gulf Stream by the Europeans—proved to be a most remarkable one in the history of navigation. The enormous ocean current, as has been most picturesquely described by the seamen, does not desiccate at the time of the worst possible droughts and does not overflow during floods.

Since this current was en route to their overseas territories, the Spaniards kept it secret for a long time. But the navigators of other countries were also persistently penetrating into the unexplored spaces of the World Ocean and its mysteries. As early as the second half of the eighteenth century, American marine merchants were successfully making use of the Gulf Stream for navigational purposes. On their voyage from America to England they sailed with the current, while on their way back home they avoided the current. This resulted in that the American ships were two weeks ahead of the English mail packet boats that sailed under English captains who were unaware of the current. W. Franklin, who was in charge of the U.S. Mail, noticed the difference in time between the sailings of American and English vessels. In compliance with his urgent request, the seamen began collecting information on the current, making it possible for Franklin in 1770 to compile the first scientifically based schematic map of the Gulf Stream. The current was depicted as a wide river that carried its waters first along the eastern coast of North America, and then towards Europe.

The Gulf Stream is a real wonder of nature. It exerts enormous influence on the climate in Europe for which it is the 'fountain of eternal youth' in the proper sense of these words. In this respect, the quests for 'the islands of bliss' undertaken by Juan Ponce de León and his men proved to be more than merely successful.

At first it was thought that the current discovered by the Spaniards had its origin in the Gulf of Mexico, for which reason the word 'Gulf' formed part of its name. However, in the later period it was established that the source of the current lay somewhat to the south and east of where it had previously been assumed. It ends in the Arctic Ocean. The tremendous amount of water it carries is ten times greater than the outflow of all the rivers of our planet.

The Gulf Stream is often referred to as the main artery of the Atlantic Ocean. This comparison is somewhat symbolic since the waters that take part in its formation are pushed into the current, which results in that the current starts pulsating as if it were blood that is moved by the heart along an artery. Those who have happened to see the Gulf Stream must have noticed that it flows like a blue river amidst the green waters of the Atlantic Ocean. In the Atlantic Ocean itself there is a place where the waters are even bluer than those of the Gulf Stream. It is the Sargasso Sea.

The Gulf Stream and the whirlpool of waters fringing the Sargasso Sea form an intricate system of surface currents in the North Atlantic Ocean. These currents usually give rise to stable winds of unvarying directions. The latter's role in the movement of surface waters is fairly clearly expressed in the regions of the moderate zone and the trade winds of the tropical latitudes. For instance, the northeastern and southeastern trade winds in both hemispheres of the Earth are responsible for the equatorial currents that are directed westwards, and, in addition, the velocity of these currents is ten times less than that of the winds that bring them forth.

Continuous stable winds cause the water

near the shores to become characterized by wind effected phenomena. Many of us have most probably witnessed the following scene on practically any beach... It is a sultry day and the shore is densely covered with people basking in the scorching rays of the Sun. The sea looks more like a desert with not a single bather enjoying its waters. But then a newly arrived vacationer appears whose body bears not even a vestige of a tan. He looks with bewilderment at those lying on the sand, takes off his clothes, and takes a running jump into the water. In no more than an instant the misguided bather rushes out to be greeted by general laughter. All of the sunbathers know only too well that the temperature of the water is hardly above 7 °C. What brought about this effect was the wind that for a long time had been blowing from the shore relieving the sea of its warm surface layer, which was replaced by the cold water rising from the depths.

The wind effected phenomena also emerge as a result of the displacement of water masses under the impact of the Earth's rotation. This is what accounts for the fact that on one side of the currents there is an accumulation of water, while the other is marked by its withdrawal. In other words, dynamic wind effected phenomena appear, which are accompanied respectively by the uplift of cold water from the deeper regions.

The movement of the World Ocean waters is not confined only to the activity of surface currents and the factors accompanying it. No minor role in the whirlpool of the Ocean is shared by deep drifts, which together with the surface currents participate in the overall circulation of our planet's hydrosphere.

Deep currents mainly emerge as a result of differences in the density of water, which is determined by the water's temperature and salinity. This was substantiated by an interesting experiment. A special transparent basin was divided into two parts by an easily removable watertight partition. Less dense water was poured into one part of the basin, while water of greater density was poured into the other part. Then, the partition was carefully removed and the water that was more dense started to flow along the bottom, pushing the lighter water to the top. This kind of movement continued until the lower part of the basin was wholly covered by the first type of water, while its second variety was spread throughout the upper regions of the basin. If in one part of the reservoir the density of water were increased, for instance, by cooling, and in the other part the water were heated to decrease its density, then the result would be a constant dense circulation of the water, which is exactly what takes place in the depths of the World Ocean, since the waters that are cooled in the polar latitudes force their way towards the bottom.

The cold Arctic and Antarctic waters are submerged to depths of hundreds or more metres, thus gradually entering the vast aquatoria of the World Ocean. The submersion itself occurs until the density of the incoming waters becomes the same as that of the surrounding ones, after which the waters move only horizontally, forming the so-called deep current. Warm waters undergo exactly the same process when they are cooled. The Gulf Stream can serve here as an example. Leaving Spitsbergen behind, its waters are confronted with the cold, though less saline, waters of the Arctic. That is why in this region the waters of the Gulf Stream are first displaced within the surface layers, then when they are cooled, they descend to the lower horizons. It would be of some interest to mention that the waters carried by the Gulf Stream penetrate into the East-Siberian Sea, and that they were found from the drifting station 'The North Pole' even in the centre of the Arctic basin.

The contiguity of cold and warm waters gives rise to a highly interesting phenomenon known as the hydrologic front, which can be compared with the atmospheric front, which emerges when two markedly distinct air masses come into contact with each other. In the frontal zones of the ocean, as within those of the atmosphere, turbulent processes involving the interaction of confronted waters take place. The formation of various fronts is mainly typical of moderate latitudes. Thus, it follows that these latitudes are the main region of the junction and further mixing of both the aqueous and aerial masses. Phenomena of even greater interest are found in the tropical zone of the World Ocean.

An example using the Pacific Ocean may prove to be an adequate starting point for our further discussion. This is where near the equator an enormous trade-wind drift is directed from the east to the west. It is separated into two almost parallel equatorial currents: the southern and the northern one. As a result of the displacement of a large amount of water by this drift, the ocean level at its western marginal parts is nearly half a metre higher than what it is in the east. This difference in the surface levels of the ocean in its turn causes a certain withdrawal of water, or a countercurrent, which passes between the southern and northern streams of the trade-wind drift in the direction where the Sun rises. Under the influence of oppositely directed currents at the equator, abyssal waters that are rich in nutritious salts rise to the surface forming a properly fertilized, rich oceanic 'soil'— the basis for a wanton development of life. The water in these parts is so much impregnated with plankton that it is often compared to a green soup.

And exactly this part of the Pacific Ocean, which seemed to have been already sufficiently studied, surprised scientists and considerably influenced the further development of oceanology. At the beginning of the sixties of the present century that was so replete with scientific events, under the equatorial currents at depths of from 100 to 250 metres, a powerful underwater river was discovered. It measured about sixty miles in width. From the west to the east it carries oceanic waters at a rate of three miles an hour—the velocity of a fast pedestrian. This mighty deep drift, which travels in the same direction as the surface countercurrent that is marked on the maps, was found to be isolated from it. It has also been tentatively estimated that it carries approximately thirty million cubic metres of water a second, which makes up about one-third of what the Gulf Stream expends in the latitude of New York.

This enormous current is by some means or other connected with the displacement of waters on the ocean surface. Therefore, it is quite surprising that this huge current had for a long time not lent itself to observation. However, the ancient Polynesians who inhabited the oceanic islands could perfectly well find their way amidst the difficult currents of the Pacific Ocean and its boundless space. With absolutely primitive means at their disposal, their seafaring mastery was so great that it must be mentioned.

In the remote past the Polynesians were extremely proficient navigators and seamen. Their voyages across the ocean represent a highly commendable page in the history of mankind. Hardly anyone could vie with them for supremacy in navigation. Never heedless of what was going on in the world that surrounded them, they were able to accumulate valuable knowledge about the direction of the winds, oceanic currents, and the position of the stars and planets in the sky. This made it possible for them to attain great mastery in seafaring though the facilities they had at their disposal were only too modest. At the time when the Europeans reached the shores of the Polynesian lands, this country that was lost in the vastness of the Pacific Ocean was still in the Stone Age. Their main tools of labour were sharpened stones, fragments of shells, and pointed bones. With the help of these primitive instruments, the Polynesians built remarkably beautiful boats that were quite fit for their sea exploits and whose carved ornaments made them genuine works of art.

In ancient times the Polynesians canoed up to the regions of Antarctica. In tales of old it is said that what surprised the courageous seafarers most was the snow, which they called rain falling upon the Earth in the form of white feathers. These travels confirm how substantially apprised of geographical facts the Polynesians were and that the stars and planets as well as the currents were not their only guides. They also had a perfect command of making maps. Since the Polynesians had no alphabet, the maps were constructed of little sticks of wood and pebbles, which were arranged in such a way on the ground or in the boat that their contours and pattern could indicate the direction of the forthcoming journey, winds that would be encountered, currents, islands, and archipelagoes. The map was put together only once and had to be well remembered. During their expeditions it was reconstructed from memory.

The powerful shoreless river that was found in the equatorial zone waters of the Pacific Ocean was called Cromwell Current in memory of the American oceanographer who was the first to observe it and who was later killed in an air crash. The discovery of the deep current was quite a surprise for scientists, since there had not been a single known theory of water circulation prior to that period that had contained even a hint about the possibility of its existence.

At the end of the sixties, in the equatorial parts of the Atlantic Ocean, one more drift of the same kind was found—the Lomonosov Current. Some time later, a current known now as the Tareev Current was observed in the Indian Ocean. In these cases it is the Soviet oceanologists who bear the palm.

The discovery of deep equatorial currents called for the reconsideration of a number of established theoretical concepts. In this respect no minor contribution was made by the Soviet scientists who studied the circulation of waters in the tropical zone of the World Ocean. Their research throws a sufficient amount of light on the general nature of deep equatorial currents, though the latter are actually separated from each other by continents and archipelagoes.

The Pacific Ocean recently presented another surprise: at a distance of four hundred kilometres from the Japanese island Ogasawara, an unknown current was observed. The water there circulates in a circle, the diameter of which is equal to about one hundred kilometres. The rotation of water originates at a depth of five hundred metres. The velocity of the drift is approximately ten times greater than that of all the oceanic currents with which we are familiar. The hydrologic cycle that was discovered does not readily lend itself to interpretation. Once every one hundred days it reverses the direction of its movement. At present scientists are trying to find some explanation for this highly unusual phenomenon of nature.

Today scientists are predominantly concerned with yet another natural phenomenon, which was not long ago observed and which is known as the oceanic whirlpools. Their emergence can be traced using the Gulf Stream as an example. Its channel looks very much like a meandering river twining itself around the hills and valleys. On the edges of this current, enormous whirlpools appear. In due course they become separated from the current and continue to function on their own, moving along the ocean like water spouts. They are referred to as either whirlpools or rings. The diameters of these formations reach tens and even hundreds of kilometres, and their lower parts lie at considerable depths. What they are characterized by is their hydrologic and synoptical nature of formation.

Whirlpools are not confined to the Atlantic Ocean alone. They can also be found in the Indian and Pacific oceans. As in the case of atmospheric formations, oceanic cyclonic and anticyclonic whirlpools appear. In the centre of the former and in the peripheral parts of the latter, the abyssal waters rise up and, conversely, within the marginal regions of the former and in the centre of the latter the surface waters are submerged. These vertical movements promote water exchange between different layers of the oceanic waters, which creates propitious conditions for the development of life.

Some of the oceanic whirlpools have existed for a long period of time. There is even the opinion that formations of this kind sometimes do not disintegrate over the course of several years. Hence, they may function as temporary oases of turbulent life in the desert of the open ocean, within which a number of generations of their inhabitants can live and succeed each other.

The regions where the cold abyssal waters rise and that are rich in salts of nitrogen and phosphorus—the fertilizers of the oceanic plain—are biologically most productive. It is worth examining this more closely. From the depths to the surface, 'young' and fertile water enters. Owing to its being sufficiently exposed to the Sun, particularly in the tropical areas, and to its high concentration of oxygen, phytoplankton starts rapidly growing and actively absorbing the nutritious salts, as a result of which the amount of the latter decreases and the 'young' water becomes 'mature' The phytoplankton is then eaten away by the ever increasing number of its zoological variety. When the water loses the majority of its nutritious salts and the zooplankton leaves practically none of the phytoplankton unconsumed, the water becomes 'old'. By that time this water has been carried by the current to a considerable distance from where it comes out onto the surface. This is what accounts for the fact that in those regions where the abyssal waters rise there exists a certain sequence in their distribution. The 'young' water is found to be above the place where they begin their upward movement, the water that is 'mature' and green from the phytoplankton is found along the periphery or in the current, and the 'old' water that is heated by the Sun and that preponderantly contains zooplankton, which is most intensely devoured by the fish, is found still further. This results in that what used to be a nutritious concentration becomes a non-productive, warm, and transparent water.

Studies on the movement of the World Ocean waters present one of the most absorbing aspects of oceanology. Many mysterious phenomena of nature found their simple explanation when the factors conditioning the dislocation of water masses and their routes were made known. Enormous currents as well as those that are not powerful at all transport warmth and cold, bring life or desolation, change the direction of drifts, wash away the floor and shores, and either promote or hinder navigation. If we were to compare our planet to a living organism, there would be every reason to call the currents of the World Ocean the Earth's circulatory system, which has its own arteries, veins, and capillaries.

Waves

Imagine the surf. The waves rush furiously towards the shore, break upon it, and envelop everything with a fog of spray. When such vehemence is abated, there follows their recession. It is an enchanting and placating spectacle from which it is hard to tear one's eyes. And how peacefully one sleeps ashore when the storm is raging! This is probably the only consolation that this kind of activity can render. In all other respects waves make navigation more difficult and hazardous, they destroy the shores and the constructions in the ports. When they collide with an obstacle the height of the upthrown waves becomes very great. The rate at which they precipitate upwards is about seventy metres per second. At one time, near the shores of England, a wave brought down a bell from a lighthouse that had been hanging there at a height of thirty metres above the water level. This, however, is not the limit. On Wist Island in the Shetland Archipelago, reaching a height of sixty metres the waves broke the glass of a signalling lamp in a lighthouse. At the French port of Cherbourg, the waves threw stones weighing as much as three-and-a half tons over a six-metre wall, while at the Amsterdam port they lifted a twenty-metre concrete block and tossed it over onto the pier as if it were a ball. In Scotland the waves destroyed a part of the breakwater, in addition to which they broke through a wall of steel and concrete and shifted massifs that weighed 1350 tons. To imagine the force of a surf one should acquaint oneself with the figures adopted by designers when they calculate the wave loads of the hydraulic structures to be built at ports. Depending on the region of the World Ocean, what is taken for the design parameter is the load upon the vertical wall ranging from eleven to twenty tons per square metre.

Waves are basically of eolian nature. Waves that emerge as a result of the activity of underground forces, which have been treated separately, are not taken into consideration here. How does the eolian excitation develop? A slight breeze develops and the water surface is covered with ripples. As the force of the wind increases the surface tension of water is overcome and gravity waves, whose propagation is determined mainly by their weight, emerge. The longer their length, the more quickly they are propagated.

A further increase in the wind makes the wave grow and become more steep. White caps begin to appear on the crests. The wind pulls off the pointed tops of the waves transforming them into sprays. At the time of intense growth, steep short waves are formed. They are called three-dimensional, since hollows emerge around their tops. The haphazard three-dimensional waves are the most unpleasant ones for navigators. For instance, a ship, moving with a wave, does not only nod, so to speak, to every single crest, but also heaves from one side to the other. It still hasn't been forgotten how in the Laptev Sea this kind of storm put two-thirds of our crew to bed. The only justification was that half of all the men were inexperienced seafarers who were training aboard our ship.

In the cyclones that pass over the ocean, winds blow in different directions. At a certain distance away from the shores, they give rise to waves of different directions, which in the end overlap and collide with each other, becoming thus responsible for the formation of wave cross sea. Looking at it, one gets the impression that the sea is boiling. These waves are called pyramidal.

The maximum height of ocean waves in the water expanses, where the wind and the waves have quite enough room for themselves, reaches more than ten metres. In 1956, oceanologists aboard the diesel-electric ship *Ob* registered a wave that was eighteen metres high. This can be compared to a six-storeyed house.

In addition to wind waves there exists another type of waves called swell. Waves of this kind are usually the echoes or forerunners of a storm. When the storm wind subsides, the waves begin to get smoother, lower, and longer, and for a considerable time afterwards, they roll along the ocean in the form of even and properly arranged swells. Waves that come out of the confines of a cyclone also turn into a swell. Recently conducted evaluations have revealed that the swell of a hurricane raging somewhere in Antarctica reaches our European latitudes.

Near the shores and shallow places, the swell becomes shorter and higher, thus forming a powerful swash. This kind of swash exists practically all the time on ocean coasts since there is always a storm somewhere in the ocean, and it sends its messengers—the surge waves—hundreds and thousands of miles away from itself.

One of the undesirable manifestations of surge waves is the long sloping waves that not infrequently visit bays and ports. The weather is calm. Ships are stationed in the harbour. All of a sudden they come off their moorings, and the cables break as if they were no thicker than strings. The waves, which had entered the port and whose height reaches forty centimetres, draw the ships after them as they recede. This happens because the incoming and outgoing waves are accompanied by horizontal displacements over several metres in the direction of the shore and backwards away from the whole mass of water. Preventive measures against this undesirable phenomenon include the building of additional structures that are meant to guard the entrances to the ports.

When the swell collides with the periodic currents in the straits, cross waves known as lop or overfall appear. Sometimes the height of the newly formed pyramidal waves reaches five metres or more. There are cases when captains take a lop for swashes (breaking waves) that are simmering above the stones hidden by water.

The swell in deep water is propagated at a rate that is approximately twice, or three times greater than that of the hurricane that had given rise to it and that usually moves at a velocity of between twenty and thirty kilometres per hour. The ever-growing swell is a direct precursor of the coming storm.

Even today, storms and hurricanes present no little danger to navigation. What readily comes back to memory is the voyage aboard the sailing vessel *Sedov* in 1957. A situation fraught with crisis and connected with the storm has remained indelible.

We were in the central part of the Atlantic Ocean on our way to the Azores. The wind was getting stronger with every hour. Its gusts reached up to ten points, and the alarm bell had brought all the crew on deck. Orders were given through the megaphone:

— All up! Everybody watch to its mast! Take in the sails!

The sailors climbed quickly up the shrouds, each went to his own yard, the sails were folded and tied up with sheets, and all that remained was the topsail on the foremast.

The mechanics were all ready to start the engine since in this weather it could prove to be useful at any moment.

The rolling grew more intense. Huge billows were crashing onto the deck with the water pouring down on the sailors that were standing at the wheel. The wind was howling furiously in the rigging. The clinometer in the saloon could not indicate how strong the rolling was since its scale with only thirty degrees was inadequate. People were not allowed to go on deck for fear they could be thrown overboard.

At one o'clock in the morning our ship went off a big wave and the second wave that came rolling fell upon one side of our sailing vessel and with a loud noise went over its deck. The ends of the yards were dipped in water and the needle of the clinometer in the chart room stopped at forty-six. The *Sedov* stood still in this position. Everyone held his breath with but a single thought: "Will the ship get up? Will there be enough time? Or perhaps the next wave will cover it as was the case with the *Pamir*, a similar kind of sailing ship that had lost its battle with the waves that same year."

But the *Sedov* did rise. The tops of the masts trembled slowly, and the ship, gaining speed, began to turn to the other side. A sigh of relief was heard. The critical situation lasted not more than several seconds, but seemed to be infinite. What was most aggravating was that the list had been ultimate for this type of ship.

No further risks were taken. The storm sail was taken away, the engine was started and we sailed in another direction. Now the waves were rolling to meet us. What came in place of dangerous rolling was pitching. The ship, whose length exceeded one hundred and ten metres, was now buried in water with its bows, now reared as if it were a racing horse. The man on duty at the fo'c'sle was relieved since ten minutes were enough to make him seasick: with the range of the vertical ups and downs reaching thirty metres, it is by far not everyone who can withstand such upward and downward flights at so great a velocity. The wind continued to howl in the rigging as if it were some kind of wild and fierce animal.

The wind lends the roaring ocean an enormous energy. Waves as high as five metres with a length of one hundred metres per running metre contain the energy that is equal to 3120 kilowatts. In addition to this, each square kilometre of a stormy ocean accounts for the power of three billion kilowatts.

On many occasions during the Arctic Sea expeditions it was possible to watch how our small research vessel was impeded in its movement as if by collision with some kind of viscous underwater hindrance and then would regain its power of movement and go ever faster as though it had freed itself from some invisible shackles. Cases like these are known to seafarers not only in the polar latitudes, but also near the coasts of Scandinavia, Canada, and the Mediterranean Sea.

This phenomenon is called dead water. The celebrated polar explorer Fridtjof Nansen was presumably the first to look into its nature. It was in the Kara Sea that his ship *Fram* found itself in dead water. In an instant, the rate at which the ship was moving dropped from four and a half knots to one, though the depth was quite sufficient and the sea looked adequately calm.

According to the scientist's testimony, the ship seemed to have been drawing after itself the whole surface layer of water. Behind the ship, waves were formed that intersected its wake at an acute angle. At times they went forward to as far as the middle of the ship. *Fram* was turned in different directions and circled, but nothing altered the situation. When the engine stopped, the ship was pulled back as if by an unknown force.

Nansen studied the structure of the marine medium in the region where his ship was. The differences in its properties turned out to be so great that from the surface the seamen scooped out water that was quite fit for drinking, while from the sea valve the water was markedly saline. Nansen came to the conclusion that the phenomenon of dead water occurred there where the dense seawater was covered with lighter layer of freshwater.

As was discovered some time later, during the movement of the ship, waves are formed at the watershed. The majority of the energy that is produced by the ship's engines is expended on their formation, as a result the ship's speed is reduced. Moreover, a solitary wave emerges in front of the ship, which seems to be pushed forward by the ship.

Dead water is connected with the most interesting phenomenon in the dynamics of the World Ocean waters, viz. the internal waves that emerge for one reason or another at the place where liquids of different density are separated. The ocean contains a host of such watersheds since vertically it looks very much the same as a puff-pastry pie.

The internal waves in the ocean can be brought about by marked changes in atmospheric pressure, the impulsive work of wind, surface waves, tidal waves, and other factors.

The size of the internal waves depends on the difference in the densities of the contiguous layers: the smaller the density, the greater the wave's height is found to be. In the deeper regions, where this difference is the lowest, the amplitude of the waves reaches up to hundreds of metres. It is assumed that what caused the disaster of the American atomic submarine *Thresher* was precisely an internal wave of immense size. Under particular circumstances, the size of internal waves becomes so great that they lose their balance and collapse. This results in that an intense mixing of the layers takes place, which finds its most striking expression in the abyssal regions of the World Ocean.

The internal waves are propagated much slower than the surface ones: their period can cover several days. Since a comparison has been drawn, it would not be out of place to mention here that surface waves are a kind of particular instance of the internal variety. They also originate on the border line between the atmospheric and oceanic media, though on account of the difference in their densities, their propagation is incomparably greater and they do not reach any prodigious dimensions.

Internal waves are one of the most important problems in present-day oceanology, since as long as the nature of these formations remains recondite, it will hardly be possible to fully comprehend the dynamics of the World Ocean waters and the processes associated with it.

The division of the watershed surface into layers is connected with a phenomenon that at times plays a peculiar and unexpected role. Thus, for instance, in the Norwegian fjords the freshwater forms a clearly expressed watershed surface. The thin upper layer of freshwater, which is heated in the daytime, is cooled at night, and as a result of this becomes more dense. Nevertheless, it does not become heavier than the saline water underlying it. The latter is heated during the day by the rays of the Sun, which very easily penetrate through the upper layer of freshwater. This upper layer protects the saline water from the loss of heat into the atmosphere, thus performing the function of a greenhouse glass. As a result, in the fjords of Norway at depths of one or two metres from the surface, the temperature of the water in summer reaches 35 °C, which markedly exceeds that of the rest of the water.

Nowadays we are still compelled to accommodate ourselves to the uncontrollable element of the ocean—the waves. But, there is some reason to believe that it will not be long before people will harness the tremendous energy that the tempestuous ocean hides within itself.

'The Red Tide'

We are in the tropical zone of the East Atlantic Ocean. Somewhere over the horizon there rests the sun-scorched coast of Africa... The weather is calm. The smooth surface of the water makes it appear greasy. A thin haze hangs above the ocean, dispersing the Sun's rays. Our research ship, with its white sides glistening, splits the powerful breast of the ocean, leaving behind its stern a blurring trace. All of a sudden, from somewhere at a distance, a sharp and unpleasant smell reaches us. Turning round, I see that the ocean is coloured red and dead fish disturbed by the movement of our ship are rolling on the water surface. This was how for the first time in my life I became aware of a remarkable natural phenomenon known as 'the red tide'

In a number of regions of the World Ocean the water acquires a red colour rather suddenly. What usually brings it about is a violent outburst of the various types of plant, and more seldom animal, planktonic organisms. In this period, the concentration of organisms of this kind reaches hundreds of millions per litre of water. In addition to this, some of them contain toxic substances.

The 'red tide' lasts from several days to two or more months. It disappears as suddenly as it occurs. This natural phenomenon is mostly typical of tropical and subtropical latitudes. There are regions in the World Ocean, where 'red tide' recurs fairly often. It extends over hundreds, and sometimes even thousands, of square kilometres on the surface of the ocean. Not infrequently, 'red tide' becomes responsible for the mass destruction of fish, and hence there is nothing surprising in that within the regions characterized by habitual manifestations of such phenomena, geologists find fish bones buried in the bottom sediments.

The English scientist Sir John Murray studied the bottom deposits of the World Ocean during his voyage from 1873 to 1876, aboard the *Challenger*, which was fitted out by the Royal Geographical Society. He observed the phosphoritic concretions that were abundantly deposited in many parts of the floor and associated their origin with the catastrophic extinction of fish. According to Murray, phosphorites must be concentrated in those places where the mass decay of inhabitants of the ocean occurs, since a highly important component of their bones is calcium phosphate. The opposing argument is that after they perish, the vertebrates come to the surface, bloated by the gases of putrefaction, and currents drive them into different directions, usually bringing them close to the shore. Nevertheless, the fact of mass accumulations of fish bones in bottom sediments raises no doubts. At present it is assumed that the main source of phosphorus contained in the bottom sediments is plankton and that the calcium phosphate of the bones of dead fish is only a secondary source.

In the history of fishery there have been many cases of the catastrophic extirpation of fish. For instance, in 1789 the surface of the Barents Sea, as was recorded by witnesses, was completely covered with dead fish: haddock and pollack. In 1882 exactly the same fate was shared by lopholatilus—the largest industrial fish that inhabits the warm Gulf Stream. Near the eastern coast of America, not far from the Delaware Bay, the number of dead fish was five million. After this, the lopholatilus fishing industry had to close for many years. Examples of this kind can be counted up to the present period. However, 'red tide' has not always been the only factor conditioning the extermination of fish. It is not infrequent that what accounts for the catastrophe are processes that occur in the World Ocean waters either preceding or concomitant with the 'red tide'

Near the shores of Peru there is a small current called El Ninjo. It represents a ramification of the warm equatorial current. El Ninjo does not usually spread far.

But at times, for some inexplicable reasons, it drives back the cold waters of the Peruvian current and its warm streams reach as far as the latitudes of the ports of Pisco and Callao and even those that are more to the south. The temperature of the water near the shores of Peru and Ecuador increases by three to five degrees. At the same time climatic changes on the coast occur. The anchovies acclimatized in cold water do not manage to swim away and thus perish. The same fate befalls the birds that are deprived of this kind of food. Their number drops from thirty million to only five million. Particularly great disasters occurred in the years 1925, 1941, 1951, 1958 and later. As far as the 'red tide' is concerned, it usually finds its expression here in the regions where the cold Peruvian and the warm equatorial currents meet, and the El-Ninjo current is its ramification.

In spite of the enormous variety of phytoplankton that gives rise to 'red tide', it is the algae of dinoflagellulae that are regarded as the poisonous ones. The question of the toxicity of certain algae has not yet been answered. Meanwhile, it has been clarified that the toxins contained in some type of dinoflagellulae belong to the class of poisons that include curare, tetanus, and botulinus. These are exceptionally dangerous deadly poisons. As is assumed, the poison kills the fish, and the putrefaction of the fish enhances the development of 'red tide'. The hydrogen sulphide that evolves during the decay of fish contaminates the air, and contact with this air causes the copper parts of ships to lose their lustre, the houses on shore to become darker in colour, etc. This clearly shows that hydrogen sulphide is a strong pollutant of air. It is noteworthy that when diluted to a concentration of 1:250, the poison extracted from 'red tide' was able to kill fish within one hour. A solution diluted 1:1000 makes fish lose their balance.

Cases have been registered when people were seriously poisoned as a result of eating fish that was caught in a 'red tide' Temporary paralysis is the only safe outcome in instances like these. Poisoning of people and sea animals most often occurs near the western coast of India, and on the shores of the Gulf of Mexico and Florida.

People are also liable to the toxic effect of droplets of water and gas that enter the air. The gas, as has already been mentioned, evolves from the decomposition and putrefaction of organisms contained in the aqueous medium. This causes inflammation of the respiratory organs, eyes, and skin. It is interesting that even the most thoroughly filtered 'red tide' water retains the properties that make a person experience irritations of various kind. During the blooming of one type of algae in New Haven Harbour in the State of Connecticut (USA), the shipyard workers complained of skin irritation that was brought about, as was later discovered, by 'red tide' water. Meanwhile, the algae that were growing in this harbour were quite safe for the inhabitants of the ocean.

'Red tide' and the hazards connected with it were known as early as the ancient times. There is evidence that the native inhabitants of America—the Indians—had an ancient custom that prohibited them from touching the dead fish and eating the molluscs during the period when there were rich accumulations of the minutest algae in the ocean.

In contradistinction to the poisonous algae that bring about 'red tide', there exist other types that also flourish under conditions favourable to the development of 'red tide', though the effect is quite the reverse. For instance, it is owing to them that the growth of herring is hastened.

From what has been said about 'red tide' it is not difficult to infer that one of the important factors conditioning its emergence is the contiguity of two masses of water of different temperature, viz. warm and cold water. It is precisely here where the cold abyssal waters enriched with biogenic compounds—nutritious salts for phytoplankton—rise to the ocean surface. This is characteristic of the zones where the 'red tide' emerges, e.g. the coastal areas of Peru, Chile, Mexico, California, Western Florida, South-Western and South-Eastern India...

The enrichment of surface waters with biogenic substances was what caused the outburst of 'red tide' in the Bay of Bengal, where the South-Eastern monsoon became responsible for the rise of water with an abundance of phosphates and silicon. Specialists have observed that this is the basic factor that leads to the blooming of phytoplankton. At the same time one cannot possibly disregard other factors such as, for instance, the desalinization of waters. Thus, in the period from 1944 to 1952, the blooming of algae near the Coast of Florida was preceded by a constant increase in atmospheric precipitations and their run-off into ocean, where zones of reduced salinity emerged. The stimulating influence of rain on the formation of 'red tide' has also been noticed near the shores of Africa, Peru, and France.

Not infrequently, prior to the appearance of 'red tide', the temperature of the water rises. It is also noteworthy that in the years of increased solar radiation, a maximum number of phytoplankton bloomings is recorded. No minor role in the development of the bloom is attributed to the immobility of the surface layer of the water, which creates favourable conditions for the division of cells with phytoplankton. Thus, the 'red tides' near the shores of South-West Africa are preceded by calm windless days. This is the time when the water surface looks greasy, and it was exactly what the author of this book happened to see in the tropical zone of the eastern part of the Atlantic Ocean when the research ship was on its voyage.

One of the characteristic features of 'red tide' is the rapid growth of plankton populations. 'Red water' contains an increased amount of chlorophyll. Therefore, intense photosynthesis takes place in the upper photic layer. What cannot escape notice is that the zooplankton affects the rate of phytoplankton growth. Sometimes the bloom can begin only then when the zooplankton almost hasn't eaten up all of the phytoplankton. In addition, in the course of its extinction and decay, zooplankton serves to increase the reserve of phosphates and ammonia in water, thus creating favourable conditions for the bloom. Hence, zooplankton is regarded as a kind of regulator of the 'red tide'

In assessing the extent to which certain factors exert their influence on the origin of the 'red tide', scientists draw attention to the fact that in addition to propitious conditions, the emergence of this kind of natural phenomenon requires a starting device, similar to the activity of a sand particle in crystallization of solutions or in the formation of pearls.

Lately, the appearance of 'red tide' has been influenced by the economic activity of humans, particularly in the proximity of enclosed aquatoria, such as inland seas and gulfs. Recent research has revealed that the chemical fertilizers washed away from the fields entering the Black Sea together with the river waters markedly influence the hydrochemical situation on the northwestern coast. Here, biogenic compounds, such as phosphates, nitrates and nitrites, accumulated in surplus. This resulted in the rapid growth of planktonic organisms, which gave rise to the 'red tide' Nothing of this kind had ever been noticed before in this part of the Black Sea.

The disappearance of 'red tide' is basically determined by physicochemical as well as biological factors. The former include a marked variation in the temperature of water and its intense mixing, the exhaustion of biogenic compounds, the presence of oxygen dissolved in water, and, lastly, the contamination of water by the products of putrefaction, which cause the cessation of the algae bloom. As far as the latter are concerned, it is the eating up of phytoplankton by zooplankton or larger animals. For instance, there are crabs that feed exclusively on phytoplankton.

Attempts to combat 'red tide' are well known. In Japan, chlorine, copper sulphate, and other chemical substances were tried for this purpose. Laboratory investigations have revealed the disastrous effect of a mixture of carbamic acid and tellurite on the organisms causing 'red tide', but the high cost of the preparation has made it impossible to apply it in natural conditions.

'Red tide' continues to remain a scourge for fishing. Nevertheless, this phenomenon of nature is not wholly deprived of other, more beneficial, properties.

The relationships between the animal and plant world in the ocean are very complicated and do not lend themselves to be fitted into any strict scheme. The very same 'red tide' does not always exert a disastrous impact on those inhabiting the waters. It contains quite a few useful substances. The water of the 'red tide' has yielded the well-known to all of us ascorbic acid (vitamin C). Some types of plankton found in it contain a protein similar in structure to the highly nutritious protein of milk—casein. There also exists the opinion that the dried plankton from 'red tide' can be used to feed the animals on land. This can have decisive importance for cattle-breeding in the arid zones of the world where there is almost always a shortage of fodder.

Scientific observations of 'red tide' were begun as early as during Charles Darwin's voyage aboard the exploring ship *Beagle*. A great amount of data has been collected since those days, but the nature of this unique phenomenon in the World Ocean has not yet been made fully clear. In general, 'red tide' is the result of a disturbance in the peaceful coexistence of the populations in the sea and ocean waters. It can be considered a local biological war that has arisen as a consequence of the loss of the biological balance in some regions of the World Ocean when the not altogether clear 'outburst' of specific algae populations contaminates everything that is alive. However, the aggressor soon becomes appeased by the organisms that are antagonistic.

The 'red tide' example reveals that the surface layer of the World Ocean plays a very special role in the vital processes that take place in the aqueous medium. Special mention should be made of the fact that, as shown by scientists, the biological, biochemical and hydrologic processes occurring within the whole ocean mass, are controlled by microprocesses that take place in the surface layer of the waters. Of significance are the microprocesses on the borderline separating the ocean from the atmosphere, i.e. in the near-surface layer, which is markedly distinct from the whole mass of water as far as the biological conditions are concerned.

It is precisely this layer that actively absorbs the solar radiation that falls on the water surface. If we were to observe the distribution of light only within the surface horizons, we would see something of no minor interest. Thus, according to some data, twenty percent of the solar radiation that penetrates the ocean remains within the layer that is only one centimetre thick. At more than five centimetres below the surface, the stream of light already decreases by forty percent. At a distance of ten centimetres, the water now absorbs fifty percent of the light that has fallen on it. Within the one-metre upper layer, sixty percent of the penetrating solar radiation is confined. Moreover, it is the short- and long-wave part of the solar spectrum that is actively absorbed, which is particularly important for biological processes. The most biologically active radiation—ultraviolet and infrared—does not actually penetrate farther than ten centimetres from the surface. Thus, in the near-surface layer of the World Ocean we find the light and thermal conditions most favourable for living processes.

In the near-surface layer there is a concentration of extinct plants and animals, the products of their vital activity, as well as the organic matter that comes with the river waters. It includes a particularly large amount of dead organic matter, which according to some sources, is 50 times that of the living organisms, and according to other data, 500 times more. As compared with the whole mass of ocean water, the near-surface layer contains approximately half of all the dead organic matter.

Scientists have recently discovered that sea foam represents not only a concentration of nutritious particles for marine organisms, but also possesses biologically active properties that either stimulate or suppress the various biological processes of the inhabitants of the waters. Thus, the foam that emerges and accumulates on the surface of the ocean, performs a highly important ecological function. In connection with this one remembers that Aphrodite, the goddess of love and patroness of navigators, as the ancient Greeks told the world, came out of the sea foam, thus enhancing, as it were, its vitality.

In the near-surface water layer we find a special biological community known as neuston. These are plant and animal organisms of small and medium size, hydrobiontes and aerobiontes. As a whole, neuston is made up of organisms ranging from bacteria and plants to larvae and young fish.

The vast amount of dead organisms, the impact of ultraviolet and infrared radiation, and the biological activity of foam are the factors conditioning intense growth of neuston. Figuratively speaking, some specialists call the near-surface ocean layer a kind of 'maternity hospital' for its inhabitants and even for those that live at greater depths. The roe and larvae find an environment in this layer that is very rich in nutritious substances. In addition to this, their development here is stimulated by the ultraviolet and infrared radiation and the biological activity of foam, which has not yet been adequately studied. After spending a certain period of time in this blessed cradle, the larvae of organisms go down to the depths—the place of their permanent residence.

Every night the surface is visited by numerous plankton and other organisms, which stampede to the 'nocturnal refectory' to partake of a sumptuous feast. By morning they go down to their deep regions again, presumably to avoid the effect of ultraviolet radiation.

It has recently been proved that most of the minutest dead organisms do not fall down to the floor, but swim up to the ocean surface, which together with its other functions is also a 'cemetery'

The data collected by scientists concerning the processes that occur in the near-surface water layer reveal that it is in it that the cycle of energy and matter in the World Ocean begins and ends. According to scientists, its role as a 'communication centre' between different parts of the planet's biosphere should be considered decisive in the interrelationship of these parts.

In fact, since solar energy, comprising ninety-five percent of all the energy that enters the aqueous cover of the Earth, is to a great extent concentrated in the near-surface layer of the ocean, this layer's decisive role as a kind of centre of the biological cycling can hardly be refuted.

It is also noteworthy that due to the specific features of the absorption of solar radiation by ocean water, as well as a result of the processes of contact heat-exchange, evaporation, and effective radiation, the ocean surface practically always loses more heat than it receives. This is why a thin cold film of water appears on the surface of the ocean. Its thickness fluctuates from several millimetres to ten centimetres, depending on the specific climatic, weather, hydrologic, and other conditions of the region. This kind of film can exist even when the waves are relatively high. This hydrologic feature of the near-surface layer of the ocean is found to be in conformity with the characteristics that pertain to the vitality of its neuston, which concentrates preponderantly near the 'water-air' boundary.

For comparison let us consider human beings: they also live at the boundary of the aqueous, gaseous, and solid phases of our planet. The fact is that the living conditions here are most propitious, and furnish everything that is essential for life. This is precisely how all other organisms behave on land and sea. In addition to the near-surface layer, the water medium contains other phase boundaries, such as: water—floor, solid particles—water, and floating objects—water.

At these phase boundaries life is in full swing, which accounts for the intense overgrowth on hulls of ships of various organisms that are well-known to every seaman. This overgrowth causes significant damage to navigation, since the coating must periodically be removed from the sides of the ship, or other no less expensive means of suppressing the overgrowth must be employed lest the speed of the vessels should decrease.

This account of the vital activity of organisms that bring about 'red tide' and of the processes that take place at the phase boundaries ends with a few words about the giants of the Earth's aqueous cover. What we have in mind here is not the giants that fill the pages of many travel and adventure books, but the invisible ones, or the true masters of all that is alive in the World Ocean. They actually breathe, support themselves, and are not devoid of memory as well as a number of other properties. They are enormously large biological systems, which consist of simpler parts, with some of which the reader has already become familiar. These elementary biological streams, like rivers or currents, merge into larger ones, thus forming great biological systems covering seas and even the whole ocean. The latter are called ecosystems.

The ecosystem may be compared to a living organism, in which the organic and inorganic exchange are brought together. The Russian geochemist Academician V.I. Vernadsky once called the manifestation of life in the biosphere a 'living vortex' Not only carbon, which is the basis of organic matter, but also a great variety of chemical elements are drawn into this vortex. They enter the living stream from the inorganic world. The 'living vortex' derives biogenic compounds, oxygen, carbonic acid, dissolved organic substance, and organic detritus from the environment. And owing to solar energy, communities of organisms develop on the basis of these substances in the aqueous medium.

Chapter 5

The Paths to the Truth

The Marine Work

Research ships equipped with the most varied apparatus and instruments are now the principal means for studying the World Ocean. Their itineraries are planned beforehand and plotted on nautical charts. They may be the so-called coast-to-coast sections lying across the whole ocean, sections that cover some particular region that is of utmost interest to scientists, or polygons, i.e. specific areas of the ocean that have been strictly limited for a given experiment, and within which continuous observations are conducted.

The research ship usually steers in a given direction and after the required distance has been covered stops for several hours, a day or several days, and sometimes even for months so that scientific observations can be carried out. These stops are called stations.

Scientific observations using instrumental methods are the basic sources of information concerning the World Ocean, and it is the high quality of these methods that scientific authenticity and the practical value of the research results depend on. This is where it would not be wholly out of place to touch upon the historical aspect of what is being discussed.

Scientists first focused their attention on the thermal processes in the World Ocean and the salinity of its waters, which play a very significant role in the water-exchange of the hydrosphere. To measure the temperature of the water it was decided 'to take' the ocean's temperature by means of thermometers, as is customary with people. During the round-the-world voyages of I.F. Krusenstern and Yu.F. Lisyansky from 1803 to 1806 aboard the *Nadezhda* and *Neva* ships, the first scientific measurements of the temperature of the ocean water at great depths were made. Some time later, from 1823 to 1826, the Russian physicist Academician E.Kh. Lents was on a similar kind of expedition aboard the *Predpriyatiye* boat, in the course of which he measured the temperature with the help of an isolated bathometer—a device that he employed to obtain water samples for testing the salinity. The material that was collected during this expedition helped Lents to elaborate the theory of the circulation of the oceanic waters. His method of studying the aqueous cover of our planet found its application in the famous expedition aboard the *Challenger*. Since then Lents's method has become part and parcel of oceanographic research.

At first the deep-water measurements of temperature were made with the help of thermometers, whose accuracy was not wholly reliable. They were succeeded by improved devices that register the measurement by means of tearing off the mercury column when the thermometer is turned over under the water. The high-precision capsizing thermometer appeared in 1925. After several modifications it is still in use today. Bathometers followed practically the same course of development.

With the help of such simple devices as these, a vast amount of scientific material was collected that characterized the temperature and salinity of the World Ocean waters and made it possible to comprehend a large number of regularities pertaining to its nature. Nevertheless, it was only possible to visualize a general pattern, lacking in both the most relevant elements and the most significant details.

Several decades ago the thermobathygraph was invented. It is a device that draws a diagram of the variations of the water temperature according to the depth on a plate inserted in it. At that time it was a big step forward, which made it abundantly clear that the structure of the oceanic medium was much more complicated than what had been imagined. However, even this relatively improved method could not help to discover very important phenomena and processes in the Earth's liquid medium, for their discovery required absolutely new investigative methods.

Therefore, it is not surprising that the traditional methods were replaced by new automatic equipment adequate enough to meet the ever-growing demands of scientists for investigative methods and equipment designed for ocean research.

For instance, not long ago, oceanologists availed themselves of a new high-precision automatic device known as the electronic thermosaltprobe. The author of the present book happened to be not only among its inventors, but also among those who tested and applied it in practice.

As can be remembered, the tests were in progress. The ship stood still at the station. The drum-winch was moving smoothly. With every metre, a cable was released further into the water. Connected to its end was an hermetic container with an electronic measuring device that went down to the ocean depths and sent pulses back along the cable with information about the temperature and salinity of the ocean water and the depth at which the container was at each measurement. The pulses were received by a special instrument that was installed in the laboratory aboard the ship. It worked together with a miniature computer that transformed the information that was received into figures and graphs.

As the measuring container was being submerged, familiar curves indicating the distribution of temperature and salinity in the ocean depths automatically appeared on the plotting boards of bi-coordinate graphical registers. Suddenly the register showed an unusual zigzag.

—'Something is gone wrong!'—said the operator.

—'It doesn't look like it. Repeat the measurement',—replied the person in charge of the test.

And again, at the same depth, the pen of the register was unsteady. It was clear that the instrument had come into contact with an unusual effect in the ocean. With the advent of new technology, cases like these had become frequent in oceanology, which explains why the fact in question deserved proper consideration.

Since information provided by the test instrument on only one occasion could not serve as irrefutable proof that there existed some unknown effect in the distribution of salinity, the data were verified by a traditional method using a garland of bathometers and thermometers. There was no discrepancy between the results.

Thus, while the new device was being put to the test, a thin-layer stratification of the waters was discovered, which could hardly have been expected in the region where the research was conducted.

This example illustrates but a single episode in contemporary oceanological research. Nowadays, in the USSR and other countries, broad-profile oceanological research equipment has been created. Its implementation has made it possible to form a different opinion of the large number of processes in the World Ocean and to discover in it hitherto unknown phenomena, as, for example, whirlpool formations, subsurface equatorial countercurrents, thermohaline thin stratification of waters, and others.

If the measurements are taken at one

station, or what is better, at a certain point and over a long period of time, they will then furnish data on the temporal variability of the ocean medium. Incidentally, these measurements prove that there is nothing more consistent than the inconsistency of the ocean. Temperature, salinity, and other characteristic features of the aqueous medium are liable to change within a fraction of a second. Hence, when the measurements are taken consecutively, from one station of the section to the next, difficulties are bound to arise when the results are generalized, since one has to abstract from time and consider the results of measurements as though they were received at one and the same time. This kind of information is used for the construction of various profiles, maps, and calculations. In spite of the fact that it does contain an element of inconsistency, its year by year accumulation enables researchers to successfully solve a large number of the theoretical and practical problems of oceanology, as is, for instance, the case with various forecasts.

When a time difference during the collection of oceanological data is inadmissible, investigations of the World Ocean are carried out with the help of buoy stations and several research ships working in accordance with a single programme and taking all the measurements in synchrony.

A buoy station consists of an anchored

buoy with instruments suspended on its cable at different horizons. Stations of this kind are set up by research ships at given points in the region under investigation. There are three types of stations.The first carries autonomous instruments that collect data in the built-in recorders of mechanical, magnetic, and other types. After the station has been lifted to the ship, the information is taken from the recorders. The measurement intervals are assigned before the station is erected. The period of time over which the station functions, which can be as long as one month or more, depends on the size of the measurements and capacity of the energy source of the instruments. The second type of station is analogous to the first one, though it operates on acoustic signals, i.e. commands that set the measuring system in motion. The third type comprises stations with radio-channels that connect them with the ship. The information received from them is immediately relayed to the ship, where it is analyzed and systematized in the data processing centre.

Oceanological investigations carried out by a group of ships has so far remained very expensive and is undertaken predominantly when fundamental problems of oceanology are to be solved in accordance with national as well as international programmes. These programmes reveal the desire of scientists to take in with one glance, as it were, the whole of the World Ocean. To a certain extent they manage to do this by means of very complicated measuring and informational oceanological systems stationed aboard ships and on land, whose designs are based on the latest achievements in theoretical and experimental physics, electrochemistry, automation, electronics, and other contemporary fields of science. However, the most important instrument here is mathematical modelling. By creating various mathematical models and combining them with the results of state-of-the-art experimental studies, scientists can actually embrace the most complicated processes and phenomena of the World Ocean in their interrelationship, as if they were seeing the whole Ocean at once. This is indeed a great achievement of modern science, though it does not quench a person's thirst to see a considerable part of the World Ocean, if not the whole of it, with his or her own eyes. Only the astronauts, who can see vast areas of the Earth's surface from orbit, have had this chance.

A View from Orbit

Many a phenomenon in the World Ocean, which stir the imagination of astronauts and at times flummox scientists, lend themselves to observation from outer space. During their flight in the orbital station 'Salyut-6', the cosmonauts V. Kovalenok and A. Ivanchenkov, when watching the World Ocean, caught sight of an unexpected effect. They were approaching the Solomon Islands, which are usually covered with dense clouds. This time there were no clouds, and the ocean had also disappeared, being replaced by three mountain ranges in full detail that had emerged in its place near the Solomon Islands. The commander clearly saw the sinks of ravines and summits towards which rivers and ridges were making their way. At first the cosmonauts took all this for a mirage. The coordinates of this phenomena were immediately sent down to Earth. And it was discovered that on the marine charts mountain ranges that were hidden under a thick layer of water were actually indicated. According to all the precepts of physics the cosmonauts were not supposed to see them. However, the coincidence of not only the place of observation and the location of ranges, but also of the basic shape of the relief that was real and visible evidenced quite the contrary.

As was later suggested by the cosmonauts and specialists, at certain angles of the Sun and angles of observation, the ocean seems to open the mass of water, thus exposing its bed and depths. In connection with this it is of some interest to present one more example of an effect, which the cosmonaut V. Kovalenok happened to see.

Let us refer to the press reports for the information.

"All of a sudden the atmosphere begins to function as if it were a lens. You feel as though you were looking at the Earth through binoculars... or through a lens, to be more exact. Well, you know how a lens clearly magnifies objects in the centre, and less so along the periphery. And now I see a gorge with its minutest parts clearly discernible: the walls that seem to be truncated and the sand wastes. Then the whole thing disappeared and seemed to be normal. It appeared again over Africa. It occurred once more over the ocean when even white horses were distinctly visible..."*

It is difficult to say whether this phenomenon is connected with the remarkable 'supertransparency' of ocean water, which makes it possible to see even the mountain ranges that extend themselves over considerable depths; but in itself it is of no minor interest since the possibility of visual observations from outer space would be greatly expanded if the regularities of the phenomenon were sufficiently understood. As far as the ranges are concerned, there is

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* *Salyut-6*. Excerpts from newspapers in the USSR, the Polish People's Republic and the German Democratic Republic, Moscow: Molodaya Gvardiya, 1978, p. 104.

one more explanation for the depth vision of the cosmonauts.

There is a marked temperature difference in sea and ocean water, which separates the upper layer of warm, and consequently lighter, water from the lower cold waters that are more dense. Within this zone, suspended matter such as plankton accumulates, which creates a greater contrast in it. Recently conducted investigations have revealed that the deep bedding of this zone to a considerable extent repeats the topography of the floor, and is more observable in those places where the depths are not so great, such as above the mountain tops. Thus, there is a kind of hydrologic 'shadow' of the floor's relief in the water, which is situated much closer to the surface than the mountain ranges and is thus more accessible to visual observation. It cannot be excluded that this was precisely what the cosmonauts saw where the mountain ranges were situated in the region of the Solomon Islands. In this case the illumination and viewing angles are decisive and create favourable conditions for observation. The following excerpt from Kovalenok's description in a newspaper article explains this:

"And now as to the shelf. Well, it's like this: it can be seen only when there is suitable illumination. It's better to locate it when the Sun rises over the horizon at an angle of between ten and fifteen degrees. In all other conditions, the ocean is less contrastive."*

The alternating light and dark bands are also visible from outer space. They are considered to be superficial traces of those internal waves that have already been discussed at some length. Even with state-of-the-art means that are at the disposal of oceanology, the study of this natural phenomenon is a highly complicated and painstaking process requiring synchronous instrumental observations at many points of the World Ocean. Prolonged space flights open up new possibilities for the investigation of internal waves, and scientists have already been elaborating methods for such observations.

The cosmonauts provide invaluable information on the dynamics of the World Ocean waters. The colour photographs taken by them have enabled scientists to see with their own eyes the processes that they could only imagine before. A case in point is the Gulf Stream. How many research ships and buoy stations would have been required to form a picture of it in all its variety! The photographs taken from outer space reveal clear-cut boundaries between warm and cold streams: they also show eddies, turbulencies and whirlpools that have separated themselves from the current, and cloud formations repeating the Gulf Stream. By reg-

* Ibid., p. 98.

ularly photographing the currents from space it is possible to follow their life, which is highly important for improving the reliability of weather forecasts, as well as for predicting concentrations of resources, e.g. fish, squids, lobsters, etc.

In the Pacific Ocean, the cosmonauts saw chains of whirlpools on the boundaries of big currents in those regions where there are islands. It seemed to them that the islands were floating on the ocean with a hundred-mile wake following them as if they were ships of great size.

What must have been most remarkable and so far inexplicable was the cosmonauts' observations of the ocean surface relief. Kovalenok discovered elevations of the water surface in various parts of the World Ocean. For instance, in the Timor Sea near Australia he saw an elevation that had the form of a high swell with a length of about 100 kilometres and a width of about 50 metres. In the central part of the Pacific Ocean near the Caroline Islands, the cosmonaut saw a 'hollow' on the water surface, while in the Atlantic Ocean what caught his eye was an 'upwarping', upon which the clouds seemed to be crawling as if it were the summit of a mountain. It should also be noted that formations of this kind on the water surface presumably do not exist for a long time, since some of them had disappeared within several minutes.

And what is really most surprising is that they reappeared at exactly the same place. It would be appropriate here to include Kovalenok's first observations of changes in the World Ocean surface level, the results of which were in their time published in the press.

"The question may sound a bit strange, but do you often see different water levels in the ocean?."

"Oh, as many as you wish. At any rate we can see the ledges... it's difficult to give the actual figures from here, but sometimes they measure up to tens of metres."

"Sometimes we see several small ledges, with little steps following each other..."

"Do such really exist?"

"Absolutely... In both hemispheres, somewhere within the region of 20° latitude they are observed particularly often."

"Well, what you are seeing is very important. Try to locate the exact regions, please."

"O.K. We did see the ledges, but we did not record them, because we couldn't understand what they were. It would be a good idea to include observations of these phenomena in the future training of cosmonauts and in their space programme as well."*

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* Ibid., p. 99.

In spite of the fact that the phenomenon in question was unexpected, this very important dialogue between 'Salyut-6' and the 'Earth' proves that it did not take them unawares. The cosmonauts took heed of what they saw and presented the 'Earth' with yet another quandary. This resulted in that observations of the World Ocean level were included in the programme of future crews of prolonged flights of the 'Salyut' orbital stations.

The phenomenon of a marked change in the World Ocean level has not yet found an adequate interpretation. Attempts to ignore it by regarding these phenomena as an optical illusion have been refuted by numerous observations. As is known, the World Ocean level deviates from the form of an ideal geoid on account of the irregularity of gravitation. But even in the most extreme cases the variations in the ocean level comprise ten metres per 100 km of the distance. Slopes of this kind are hardly discernible from orbit. Changes in the level connected with the currents and wind-effected processes are not prominent enough either to be compared with the phenomena that were observed by the cosmonauts. It has so far been assumed that what the cosmonauts saw was caused by some kind of optical effects. However, we cannot confine ourselves to these arguments alone, since behind them it is possible to see something that is yet unknown in gravitational variations that can exist in the World Ocean.

Space observations are very important for fishery. From orbit one can clearly discern the heterogeneities of the ocean colour, which are connected with the presence of various mineral and organic admixtures in sea water, including tiny living organisms. It should be mentioned again that a blue colour of the ocean indicates a desert, while a yellow colour indicates an outburst of life. When cosmonauts find various yellow and brown spots on the surface of the ocean, they inform fishermen so that the latter can send exploratory ships to those regions. Sometimes the spots are the result of the accumulation of jellyfish, but more often they represent concentrations of phyto- and zooplankton. The presence of plankton indicates that fish are either feeding there at the moment or will be coming to the area shortly. This information is highly important for the fishing industry.

The following excerpt is again a dialogue between 'Salyut-6' and the 'Earth' at the time that Kovalenok and Ivanchenkov were working at the station.

"Hello, 'Photons'." This is the State Centre 'Priroda' (nature). I have something to tell you about your observations of the Sea of Okhotsk. What is taking place there now is the blooming of plankton. This is what the bright green spots on the sea surface were. The specialists from the fishery institutes say that this period is characterized by a marked increase in photosynthesis, and intense reproduction of microorganisms, microzoo-, and phytoplankton. This is exactly where the fish get all the food they want. On the whole, life there is in full swing, and the people from the fishing industry thank you very much for your most valuable information, which we have sent straight to the ships."

"We also have some data on Sakhalin. The same thing can be seen not far from that island. We're now trying to get a clear idea of the boundaries."

"Oh, yes! The fishermen must have the exact boundaries and, if possible, also the migration of spots. You're the only ones who can trace that migration."

"Well, it's a bit tough, but we'll try to do what we can!"

"Thanks. Your observations will help solve the very important problem of evaluating the bioproductivity of the World Ocean. And not only that. You see, according to specialists, so far only five percent of the World Ocean has really been studied."*

It should be said that the final remark was meant to stimulate the creative activity

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* Ibid., p. 102.

of the cosmonauts, since it is hardly possible to concede to this kind of assessment of what has been done to study the World Ocean.

Thus, space research plays a prominent role in discovering bioproductive regions in the World Ocean. Before the two-hundred-mile economic zones were introduced, the shelf waters had served as the principal areas of world fishery. Nowadays, the fishing fleet must enter the open ocean, where the greater part of its boundless expanses are no more than a desert. Among them we can find oases of life, but their discovery requires a great research and exploratory fleet. The help rendered by astronauts guiding the ships to those regions that are most promising for fishing markedly increases the efficiency of this kind of work. However, it must be mentioned that concentrations of fish do not lend themselves to observation from outer space and the fishermen are oriented mainly by the colour differences of the World Ocean surface, whirlpool formations, and frontal zones that can be seen from space.

In the ocean navigators often witness interesting atmospheric phenomena, such as luminescence and aurora borealis. Astronauts also enjoy the privilege of watching these processes on an unprecedented scale. The pilot-cosmonaut K. Feoktistov was the first to see aurora borealis when the spaceship 'Voskhod' was in flight in 1964. Later Kovalenok and Ivanchenkov happened to see the same not only in the polar, but also in the middle latitudes. They encountered this phenomenon on more than one occasion up to the latitude of thirty-five degrees.

When their spaceship was near Australia the cosmonauts saw an aurora of unusual intensity. These were their reports from orbit:

"Oh, what an aurora we've seen! Its magnitude was simply incredible," said Kovalenok.

"And the most remarkable thing about it was that it was the first time we saw it purple," added Ivanchenkov, "It was a blazing glow, and the stripes of colours were actually playing... Some powerful wave would bring up one colour, then another, and it all looked like a rye-field in the wind."

"Colour music... that's what it is," was how Kovalenok described his delight.*

One night when we were sailing in the tropical latitudes of the Pacific Ocean the author saw something that was quite unusual. Almost half of the sky was covered with clouds that were hovering over the horizon, while in the other part of the sky the stars were shining brightly. Suddenly, somewhere on the boundary between the clouds and the clear sky, a feeble silvery scin-

* Ibid., p. 111.

tillation appeared, which gradually took the shape of an arc that girdled the sky and shed a cold light. It seemed to be lifeless and monotonous. But soon a range of colours typical of a common rainbow began to emerge in it. The spectacle was so unexpected that it was difficult to immediately associate it with aurora borealis.

The auroras originate predominantly in the high latitudes of the two hemispheres of our planet. That is why they are called aurora borealis (the northern aurora) and aurora australis (the southern aurora). Meanwhile, as can be seen, they are found in the tropical regions of the Earth as well as in the equatorial parts.

The auroras borealis are of various kind and inconsistent as far as their form is concerned. They can take on all the colours of the rainbow, but mostly they radiate a silvery and silvery-green light. Their brightness is at times comparable to the intensity of the Milky Way, while at other times it is hardly discernible against the dark sky.

For a long time people have been wondering about the whimsicality, variability and unexpectedness of this very special phenomenon of nature. It was mentioned in the classical Greek literature, and the Russians were also familiar with this phenomenon. The Russian writer P.I. Mel'nikov-Pechersky has indicated that in Old Russia every transitional movement of this celestial vision was designated by a word or saying. The initial stage of the glow, when the white light similar to that of the Milky Way spreads across the sky, was compared to driven snow. At a certain moment the glow can turn pink and then crimson. This effect was found to resemble the dawn, while the milky bands drifting across the sky were called 'rays'. The rays acquire the form of colourful rainbows: these were called 'pillars'. Sometimes they turn red. This was described as they are filling with crimson! If what went on in the sky looked like a searchlight rushing over its surface, the pillars were considered to be playing and the flickering of light was personified as 'the breathing of the dawn (or pillars)'

It is difficult to add anything to the metaphorical images produced by the people's fecund imagination. And yet there is a strict scientific classification of these polar lights. They are divided into basic elementary forms: homogeneous arcs and bands, radiant types, diffusional and irregular spots, and large homogeneous diffusional surfaces. In nature polar lights consist of elementary forms that are superimposed on each other, which is precisely what accounts for their unusual variety as a result of the great number of all the possible combinations.

From what has been said it is not difficult to infer that the intensity of polar lights as seen from outer space and from Earth is quite different. Hence, it was not by chance that the cosmonauts paid attention to the scale and magnitude of the polar lights, since they were in a situation that was more favourable for observations than those on the Earth's surface. In addition to the absence of atmospheric disturbances, the cosmonauts could at a glance observe an incomparably greater space than what is accessible to us.

The glow of the upper rarefied layers of the atmosphere emerges as a result of the interaction of the atoms and molecules with the high-energy particles that penetrate into the atmosphere from the faraway regions of outer space. It has been noticed that the frequency and intensity of polar lights are to a great extent connected with the activity of the Sun. During magnetic storms, the polar lights are often displaced to regions that are contiguous with the equator. This is explained by a deformation of the lines of force of the magnetosphere.

As early as the beginning of the century Arctic explorers established that most of the arcs of polar lights had a regular form and that their direction coincided with the geomagnetic parallels, while the bends fairly consistently repeated the forms of the coastal line. This phenomenon was called the 'coastal effect' The Soviet geologist B.S. Rusinov, who had been studying polar lights for over a quarter of a century, came to the conclusion that the outbursts of light were correlated not only with the processes taking place on the Sun and in the upper layers of the atmosphere, but also reflected the geological structure of the locality.

The interaction of the flux of solar radiation, which brings about the polar lights, with the Earth's magnetic field makes this phenomenon a unique 'electromagnetic echo', which characterizes the electric and magnetic properties as well as the structure of the complex of rocks that reflects it. Solar radiations, which give rise to polar lights, simultaneously induce the electric and magnetic fields in the atmosphere and in the earth's crust, which in their turn exert an impact upon the polar lights of the upper layers of the atmosphere. It all boils down to a closed circle that bears much useful information for geologists. In other words, the polar lights can function as geomagnetic indicators when searching for regions with deposits of mineral resources. Thus, it has now already been possible to map almost inaccessible regions where large deposits of magnetite are expected to be found. Trial explorations that have been carried out have confirmed the correctness of this deduction.

The great Russian scientist M.V. Lomonosov was the first who discovered the electric nature of polar lights and determined the height of the glow. He also made the first attempt to classify this celestial vision in scientific terms. In addition, he made several dozens of engravings of polar lights.

Polar lights have for a long time been the object of careful study. Observations from space have provided scientists with greater possibilities to know the nature and consequences of this spectacular event. Polar lights can also serve as a source of information about the processes that take place in the near-earth region of outer space. The artificial creation of polar lights in the atmosphere has recently been attempted.

In nature, there is probably no phenomenon as puzzling as terrestrial magnetism. Space studies have revealed that a magnetic field exists on other planets. Thus, magnetism is not only a terrestrial, but also an interplanetary, phenomenon. This discovery has made the problem more difficult. Nevertheless, Soviet scientists have lately been able to create a new model of the Earth's magnetic field. In this respect, the research carried out in space has been most helpful. Owing to investigations of the magnetic fields in the World Ocean and measurements taken from earth satellites, scientists have been able to produce a unified planetary map of the normal magnetic field of our planet, which can serve as a standard for the singling out of magnetic anomalies. This can help to estimate the geological characteristics of the structure of the earth's crust and serve as a guide to the exploration of mineral resources. The Kursk magnetic anomaly is a clear example of this.

Speaking of the Earth's magnetic field, we have touched upon a very important aspect of outer space observations, viz. the unmanned space vehicles that are equipped with special technology for the study of our planet. It has frequently been assumed that the impartial earth satellites furnish more reliable information than do astronauts, whose perception may to some extent be influenced by their emotions. It's true that when we come into contact with an unusual phenomenon, we cannot easily divorce ourselves from our own perceptual biases. This, however, may be regarded as an advantage rather than a disadvantage, because it is exactly what is beyond the range of those impartial vehicles mentioned above. Even the most simple visual observations from outer space give us more information than what can be recorded on a perfect photograph. What helps one to view a new phenomenon from different aspects is one's emotions, curiosity, and creative appreciation. This is where one's presence plays a decisive role. All this taken together enables us to arrive at a correct assessment of the phenomenon. And only after that there comes the time for the use of various instrumentation, which will start supplying us with systematic information that is necessary for a a profound study of the given phenomenon. At this stage too human interference is required to rectify the instrumental observations.

Orbit remains so far the place where narrow specialists are not allowed to enter. Suffice it to say that at orbital stations scores of experiments are carried out, each of which is related to whole branches of knowledge. The main component underlying the training of astronauts is their ability to correctly understand the requests, assignments, and consultations of scientists in various disciplines and to be able to confer with them on the adequate professional level. The astronaut cannot possibly become proficient in all the branches of science that are dealt with in orbit. He or she must be a specialist in the implementation of these experiments and observations outlined in the programme. Success in this kind of work primarily depends on an inquisitive mind, the urge for a quest, and the thoughtfulness of the astronaut. All this can hardly be demanded of automative devices.

In spite of the wide scope of subjects they have to deal with, many astronauts have favourite branches of knowledge in which they find themselves more proficient than in others. Thus, Kovalenok, who comes from the Byelorussian village of Belaya near a small river called Nacha, became engrossed in the World Ocean. The work he did on the study of the World Ocean became a valuable contribution to Soviet oceanology. After Kovalenok's 140 days in orbit, flight observations of the condition of the World Ocean with the aim of providing further information for fishery and oceanic studies became systematic.

Owing to space flights the vast expanses of the ocean have become accessible to observations within great areas at one and the same time, rather than in limited areas, as can be done from aboard ships. Space has furnished an enormous amount of information, which is hundreds of times greater than the data obtained from oceanographic expeditions over a period of many years. The majority of this information has been received from artificial satellites, which regularly with each revolution collect information on the water temperature, take photographs of the ocean surface and transmit them over radio-channels. In the Soviet Union special facilities ensuring space observations of the World Ocean are being organized. The fishing industry has now got its own headquarters called 'Okean' (Ocean), whose function is to collect and use the information received from space for the benefit of their trade. Space departments at the oceanological institutes of the USSR Academy of Sciences have also been set up. At present we have every reason to say that space has opened an entirely new era in the study of the World Ocean.

Chapter 6
The Storerooms of the Ocean

The Main Treasure

Adequate freshwater in countries with hot climates has been a problem since time immemorial. Even today amidst the din of the mixed crowd flooding some oriental market we can hear the voice of an agile vendor of cold, freshwater advertising his saleable commodity, a gulp of which relieves the enervating heat of the scorching sun.

Sometime in the past market merchants from Bahrain in the Persian Gulf dived to the bottom of the sea to fill their goatskin bags with freshwater that flowed out of the depths. When the sea was calm, the divers inserted long reed pipes into this kind of spring and thus causing the waters to gush out onto the surface in little fountains of invigorating liquid.

In olden times freshwater springs of this kind often played a decisive role when cities and fortresses were defended against the enemy. The Greek geographer and historian Strabo, who lived about twenty centuries ago, described a remarkable island-city situated in the arid eastern part of the Mediterranean Sea. It was an inhabited rock washed from all sides by the waves. During wartime the people living on that island received water from a channel that was running from the coastal region and that got its regular supply from a powerful submarine spring of freshwater. A pumping installation with an upturned wide funnel made of lead was submerged in the channel. Attached to the end of the funnel was a narrow pipeline that came out onto the surface connecting with leather bags. Water from the spring flowed into these bags after having traversed the whole system. Seawater first flowed out and was then succeeded by water fit for consumption.

The submarine sea sources of freshwater exist near the shores of many countries of the world. We can find them near the coasts of Florida and close to the Yucatan peninsula, in the proximity of the Bahama and Hawaiian islands, and near the shores of France, Italy and the Samoa islands.

It is assumed that the underwater sources emerged mainly as a result of the outflow of streams of underground freshwater through the ruptures and fissures in bottom rocks. What accounts for the movement of these waters is the difference in the levels of hydrostatic pressure along the water permeable layers from the land to the sea. Some specialists, in explaining the nature of such sources, give preference to the impact of heat flows that are directed from the depths to the bottom surface, which must be responsible for the circulation of groundwaters. Moreover, what is also taken into account is that the waters of land and sea are connected hydraulically along the permeable rocks.

In those cases when the bottom deposits form an unbroken bedding, the groundwaters ooze through them gradually and immediately mix with the seawater. These springs are difficult to find, but on the other hand, the activity of the abundant and concentrated submarine springs of freshwater leaves a certain trace even on the sea surface and particularly when the depths are not considerable. When the sea is calm, it perceptibly surges above them, while during a storm, it is the other way round—the water on top of the springs shows no signs of movement as if the old sea method of pouring oil onto the surface had been used to appease the waves.

The extent to which the springs are noticeable depends naturally on how much they are employed. For instance, in the Mediterranean Sea, at the mouth of the Rhone river, the springs that come out from the bottom at different distances from the shore give rise to an intense water stream, a real current, which carries anything that comes its way, even a boat, far away into the sea. In the Gulf of Genoa, amidst the saline seawaters, the activity of springs results in the flow of genuine freshwater rivers that go far from the shore.

Some of the underwater springs create not only freshwater streams and rivers near the sea floor, but also give rise to peculiar lens-shaped lakes in the mass of the salty seawaters. These lakes can be found, for instance, near the bottom of the Adriatic Sea, where amidst the warm saltwater with a temperature over 20 °C there is a large cold freshwater lake with a temperature not exceeding 7 °C.

What produces a great impression is the underwater springs near the shores of the Yucatan peninsula where the freshwater springs form unusual vertical wells of cold water, which are used by the local population. They approach these wells in their boats and draw freshwater out of them.

In zones where there is a permanent outlet of freshwater, the local fauna has accommodated itself to the established circumstances and the springs present no danger at all. This cannot be said of the sudden outbursts of such waters. Thus, in 1857, near the peninsula of Florida and Key West Island, it was actually quite unexpectedly that freshwater burst out on the bottom and formed a submarine river with a width of about fifty kilometres. Soon dead fish covered the surface of the disaster region and fishermen received a new supply of freshwater.

Even today submarine springs provide water for the population of those countries where freshwater is still a problem. It is noteworthy that the technology of recovering water from them, as for instance in the Near East, has not changed greatly since the days of Strabo.

Nowadays our water supply does not depend on these springs as much as it did in the past, since it is quite obvious that they cannot possibly meet the demands of people, to say nothing of industry, for freshwater resources. Nevertheless this very peculiar phenomenon of nature continues to remain an interesting object of research for the simple reason that on the World Ocean floor, alongside the freshwater springs, there also exist thermal and highly mineralized waters, which can be used by people for their benefit.

Freshwater is required in ever greater quantities all the time. This is conditioned by the growth of population, as well as the development of industry and agriculture. The melting of only one ton of steel calls for six tons of freshwater, while five thousand tons are required for the manufacturing of only one ton of nylon* (kapron). The amount of water used for irrigation purposes is even difficult to imagine. And yet the reserves of freshwater on Earth are not infinite: they comprise less than one percent of the water resources of our planet.

There is an increasing deficit of freshwater. Its limited supply is further aggravated by the fact that not all the water is accessible for use. Moreover, its distribution on Earth is irregular. Its paucity is felt in those places where it is most urgently required.

Probably, in the past, the deficit of freshwater was felt not only by the inhabitants of arid countries but also by seamen. Many years have passed, but it is still imprinted in our memory how those aboard the *Sedov* sailing ship were surrounded by water but had not a drop to drink.

Nowadays these problems in the life of seamen have disappeared entirely. Freshwater installations are available on every ship today. The evaporators usually function at the expense of the heat that is

* *The Ocean. The Economic Problems of Its Development.* Moscow: Ekonomica, 1975, p. 20 (in Russian).

emitted by the ship's main engines. The distilled water that is obtained in these units is then enriched with salts and other components that form the necessary ingredients of water fit for consumption.

In the not-too-distant future, the World Ocean will certainly become the principal source of freshwater, since ninety-seven percent of our planet's water resources are concentrated within it. The fact that seawater will be made drinkable will primarily improve the water supply of the arid countries.

The desalinization of seawater is not something entirely new. In Russia, the first industrial installations appeared at the end of the last century in the cities of Krasnovodsk and Baku. Today the world already knows hundreds of enterprises concerned with the production of freshwater from the waters of the sea. They can be found in quite different areas, as, for instance, in the region of the Caspian Sea, the Middle East, the Mediterranean Sea, North and South Americas, and the islands of the Caribbean Sea. For instance, the inhabitants of the Curacao Islands in the Caribbean Sea use desalted water exclusively. Reference books indicate that the installations functioning on that island produce more than ten million litres of freshwater a day. It is used absolutely everywhere, even by the local brewery whose

'Amstel Beer' is beyond reproof. An attempt to distinguish one type of water from the other was unsuccessful.

The separation of water from the salts contained in it is a difficult process requiring significant effort. The traditional method of obtaining freshwater from the ocean is commonly known as distillation. It has served as the basis for a number of industrial methods among which multiple-stage distillation is most common. Other effective methods include freezing and electrodialysis. In the first case, the ability of saline solutions to form pure crystals of freshwater ice at a particular temperature during their gradual freezing is made use of. The crystals must then only be separated from the residual saline liquid. In the process of electrodialysis, salt and water are separated under an electric field using a semipermeable film.

The major expenditure of the distillation process is the energy that is employed. Hence, success in planning enterprises of this kind primarily depends on the correct choice of energy sources. A very interesting solution to this problem has been found in the USSR. In Shevchenko, a town near the Caspian Sea, scientists and engineers set up distillation units in the same complex where the industrial atomic power station was installed. This resulted in that the inhabitants of this arid region obtained not only electricity but also freshwater from the heat lost during the production of electricity.

Given the contemporary state of technology, the desalinization of oceanwater can already be regarded as profitable. It is also noteworthy that the expenses involved in the production of freshwater from the usual sources are gradually increasing, while those that cover its extraction from the ocean with broadening industrial scales are steadily on the decrease.

The riches that the World Ocean hides within itself are numerous, but it would hardly be an exaggeration to say that its main treasure is water, without which life on Earth would be impossible. The famous French aviator and author Antoine de Saint-Exupéry very aptly remarked that water was life itself. Of all the contemporary scholars, it was Academician V.I. Vernadsky who evaluated the significance of water in the best possible way. This is what he wrote on the subject: "Water plays quite a unique role in the history of our planet. Nothing else in nature could be compared with it as far as its impact upon the basic and momentous geological processes is concerned. There is no mineral, rock or living object on Earth that is deprived of its presence. Water covers all and penetrates everything."

Neptune: The Ocean's Tycoon

Unimaginable riches are hidden in the World Ocean. Its floor became the unpredicted destination of the caravels and galleons of Spanish and Portuguese conquistadors, the vessels of sea-farers from the East, and the light brigantines of pirates of the olden days. Their gold-filled holds have excited the imagination of people for many a century. The undiminishing lustre of the precious metal inside the Spanish galleons sunk by the English and Dutch squadron in Vigo Bay near the northwestern coast of Spain can serve as an example. Legends about those treasures go back to the beginning of the eighteenth century. On its way from America to Europe, a galleon with the largest nugget from the quarries of the New World went down to the bottom of the ocean. Examples of this kind are many. One American journalist has estimated that one-eighth of all the gold that has been recovered since the beginning of the sixteenth century had been doomed to find its grave on the ocean floor.

The hunt for the riches that were devoured by the waters is probably as old as navigation itself. Any success in this field has always been made widely known. The first serendipitous discovery of this kind of treasure is associated with the name of William Phips, a ship carpenter from New

England, who acting in the interests of his parent country, raised a Spanish treasure ship sunk off the Bahama Islands at the end of the seventeenth century.

What is of particular interest is that an illiterate ship carpenter took all the pains to learn to read so as to be able to understand the notes in his possession that contained information about the treasure. In his pursuit Phips made use of a diver's bell, which was quite an extraordinary event in those days. His success was crowned with knighthood and an award of one-tenth of what he found.

Most of the sunken treasures that have been raised to the surface have been appreciated not so much for their value, as for the ingenuity, courage, and perseverance exhibited by people in attaining their goal. People have managed to recover many riches from the realm of Neptune, but the numerous, and often tragic, failures of those in quest of them can hardly be regarded as an adequate price for what was gained.

These riches are found not only on the ocean floor. An enormous natural treasure is hidden in its waters. It is also gold, the amount of which is sufficient to make a cube with sides that are eight hundred metres long. It should be noted that if all the gold found in the history of humankind were put together, it would be enough to form a cube with sides that are only twenty metres long. It has recently been estimated that at the current rate of gold, silver and platinum mining on land, their reserves will last for not more than eighteen or twenty years.

As soon as the treasures of ocean waters were made widely known, numerous projects for extracting them from the ocean immediately appeared. The interest in this gold, which made itself apparent at the very initial stages, could only be compared to people's desire to possess the sunken riches.

Germany in its time expressed significant interest in the natural oceanic gold. The famous German chemist Fritz Haber hoped that his country would be able to settle its reparation debts from the First World War with the help of the precious metal that would be extracted from the ocean using his method. However, the gold escaped him as if it were no more than a mirage. The industrial method of extracting gold proved to be of no avail.

Haber's failure did not slacken the enthusiasm of those who are still today trying to recover gold from the ocean. The temptation of getting hold of Neptune's riches is very great indeed, since it will not be long before the gold reserves on land will disappear altogether. Methods based on electrolysis were tested. Not too long ago attention was focused on the ability of some ocean inhabitants to accumulate rare metals inside themselves. Out of a number of organisms it even became possible to single out the substance that accumulated gold. It was mixed with one hundred litres of ocean water so that this metal could be extracted from the substance: fourteen thousandths of a milligram of gold were obtained. Not long ago a container with ion exchange resin was towed in the ocean. Fifteen tons of water were filtered through it yielding nine hundredths of a milligram of gold in the resin.

Many years of attempts on the part of enthusiasts have so far remained futile as far as the industrial extraction of gold from the ocean is concerned. This is not surprising, since in spite of its great amount in general, the concentration of gold is quite inconsiderable: only eight thousandths of a milligram in a cubic metre of water.

The ocean guards its treasures with utmost sagacity. Up till now, the extraction of only one gram of this metal has called for such enormous expenses that the desire to obtain it wanes. And nevertheless humankind is still hoping to achieve success. The gold reserves on land are getting ever more scarce, while industry requires it more and more with each passing year. The paucity of precious and rare metals jeopardizes the production of semiconductors and electronics, the radio industry and other branches of the economy.

At present, ocean water yields sodium, chlorine, bromine, and magnesium. Let us focus here on the two last elements. The World Ocean gives us 90 percent of the world production of bromine. Its reserves are mainly concentrated in the ocean, thus, bromine is frequently referred to as a sea element. In regard to magnesium, up to sixty percent of it is obtained from the ocean. An enormous amount of electric power is expended on the extraction of these elements from the water. This process presupposes the treatment of millions of litres of water each hour. And yet recovery of these elements from the ocean is profitable because of the demand for these elements. Magnesium, as is known, is used in the production of light alloys, medicaments, fertilizers, and synthetic fabrics. The pharmaceutical industry can hardly do without bromine, which is also required for the production of photographic and film materials and petrol. This list could easily be continued.

With the contemporary level of technology, the extraction of chemical elements from the ocean that are present in smaller concentrations than magnesium and bromine is, as has been shown with gold, not profitable.

However, the limited reserves on land

are forcing scientists to search for new and better technology that could guarantee that the industry becomes profitable. Great hopes are focused on semiconducting membranes and synthetic ion-exchanging resins. According to specialists, by the end of this century it will become expedient to extract uranium from ocean water. In connection with this, it should be mentioned that Soviet scientists were the first to obtain uranium from the ocean. The report on their research, which was delivered at the Geneva Conference on the Peaceful Uses of Atomic Energy, aroused great interest.

Soviet scientists are working on selective ion-exchanging sorption methods. After numerous experiments they managed to find sorbent—a versatile material, which is a mineral known as 'clinoptilolite' It selectively absorbs a whole range of metals. It is noteworthy that with sorption methods, the sorbing substances are reusable. Sorbent, which is based on the dioxide of titanium, also yields fairly good results. It was synthesized specially for the extraction of uranium from ocean water. An experimental semi-industrial installation that will use this particular sorbent is now being constructed.

America, England, and Japan are developing methods for obtaining particular metals, mainly gold and uranium. Soviet scientists, however, have adopted a different course of action, which they think is more economical. What they are trying to do is to extract a number of metals, in addition to the one specific metal, and then, to separate the metals by means of very elaborate processing to first obtain the elements that are most urgently required.

The energy crisis is also forcing scientists to focus their attention on the World Ocean, in particular, on the heavy isotope of hydrogen—deuterium. The Ocean's reserves of it are infinite. The use of deuterium for the production of electric power could provide humankind with electricity for thousands of years to come. What lies at the bottom of this seemingly whimsical assertion put forward by specialists are absolutely accurate estimations. There is some reason to believe that by the end of the present century, the extraction of deuterium from ocean water will be quite economically feasible.

There are waters in the World Ocean where the concentration of chemical elements is much greater than in the liquid medium surrounding them. These are the brines that were found in the Red Sea and some time later in the Atlantic and Pacific oceans. Scientists had to do quite a lot of thinking to find an explanation for this unusual phenomenon. Even today there is not only one opinion concerning the origin of these brines.

The Red Sea is the warmest and the saltiest seawater body on our planet. It occupies a long, narrow and deep basin with precipitous slopes, fringed in places with coral plateaus and a colourful submarine living world that compensates, as it were, for the death of vitality in the scorching desert that surrounds it.

The region of the Red Sea is the most unbearable climatic zone of the Earth. Therefore, it is not surprising that it is often referred to as the 'hotbed' of the planet. Presumably this expression was borrowed by journalists for the assessment of political tensions that led to confrontations in various parts of the world. The climate of this region is determined by the central deserts of the Arabian peninsula and the northern part of Africa, which are well known for their unendurable heat, almost invariably cloudless sky, mirages, and sandstorms.

The most distinctive feature of the Red Sea is the intense evaporation of its water. For long periods of time the Sea does not receive any precipitation; and not a single river flows into it. Only on rare occasions do lavish downpours, filling its dry valleys within several hours, bring turbid clayey streams of moisture to the sea. The losses through evaporation are compensated for by the waters of the Indian Ocean that are driven into the Red Sea across the Babel Mandeb Strait. As a result, powerful and stable surface currents directed northwards emerge in the Sea. But in about the middle of summer, the continuous head winds block the surface currents and then the Sea, in addition to the waters of the Indian Ocean, receives the 'help' of the deep horizons. In all these processes the Suez Canal plays a very insignificant role. Had there not been any connection with the Indian Ocean, the Red Sea would soon have become desiccated, with the memory of itself retained only in the layers of silts and salts.

Isolated deep depressions are found in the central parts of the Red Sea. It was near the bottom of them that a thin layer of concentrated hot brines was discovered: each kilogram of the brines contains up to 270 grams of chemical elements. It should be mentioned here that their concentration in ordinary ocean water comprises approximately 35 grams per kg.

These brines are distinguished from the ocean water by their composition. According to specialists, their origin goes back to ancient times and they have very much in common with the relic brines of the oil holes drilled in different parts of the world. Most scientists are inclined to believe that the brines discovered in the Red Sea could have come from the rocks that are situated in the depths of the floor, which had become exposed owing to tectonic forces. Suffice it to say that the basin of this Sea was formed and developed as a result of complex movements of land that separated the Arabian peninsula from Africa and left only a small link in the form of the Suez isthmus. There is evidence in the scientific literature that since the Upper Tertiary period the Arabian massif has turned 7° anticlockwise.

The brines of the Red Sea and the bottom sediments that are deposited where they are prevalent are enriched with iron, zinc, copper, manganese, silver, and gold. The common features shared by the composition of the brines and the soils prove that the latter originated from the fallout of compounds contained in the brines. This can very well serve as evidence that the geochemical phenomena taking place on the bottom of the deep isolated basins of the Red Sea may be analogous to the formation of ores in ancient times. This may allow scientists to see, in nature itself, how in the remote past some minerals came into existence.

After the hot brines were discovered in the Red Sea, projects for their industrial exploitation were proposed. According to estimates, there are two-and-a-half million tons of zinc, half-a-million tons of copper, and nine thousand tons of silver in only one of the basins of this Sea. The deposits of liquid hot ores are located at a depth of about two thousand metres. This fact, however, has not put off the developers. One West-German firm elaborated a design for a ship that was to raise the liquid ore to the surface via pipes by means of pumps, but they did not solve the question of how to prevent the pollution of the Sea during the raising and reworking of the brines and semi-liquid silts.

The World Ocean is a huge natural reservoir of salt. As early as the ancient times people knew how to obtain cooking salt from seawater. The Egyptians evaporated it in the littoral lagoons under the rays of the scorching sun. In Spain and Portugal this compound was precipitated in artificial evaporating basins. In Scotland and in the north of old Russia, where the sun's rays are not so profuse, the salt was extracted by boiling water on a fire.

Those regions of Africa and Asia that are at some distance from the shores were supplied with salt by caravans that used to make their way across the pristine and carefully guarded paths. There, salt merchants provided the local population with the precious condiment in exchange for an equal amount of gold. In the Roman Empire, salt was often the remuneration for the service rendered by hirelings. And no sacrifice was made without it. In African countries it was regarded as a mascot that protected people from all evil. In Russia even now bread and salt is considered to be the symbol of hospitality.

But a sense of proportion should not be disregarded even when it comes to salt. The hazardous effect of its excess for humans has been proved. When the Romans destroyed Carthage, they filled the ruins with salt lest the city should be resuscitated, and as though the spell had really exercised its magic power, the city never came to life again. This fact should not be ignored by those who scatter salt in the streets to speed up the melting of snow. This has a destructive effect upon the surrounding vegetation, to say nothing of what salt does to cars. An excess of salt is also fatal for the sea. A case in point is the Dead Sea, in which the concentration of salts is as high as up to 437 grams per kilogram of water.

The Dead Sea is also called the Asphalt Sea, since oily formations come out of its depths to the surface. It is about 392 metres lower than the Mediterranean Sea. The area of the basin is approximately 920 square kilometres and its maximum depth is 400 metres. The water is remarkable for the highest concentration of bromine. On the western shore of the Dead Sea, there is a saline dome known as Jebel-uzdam. It rises above sea level to a height of 210 metres. It is assumed that the saline brine travels all the way up from the depths along a fissure in the earth's crust.

If we were to say something about the natural conditions of this godforsaken part of the world, it would be quite appropriate to quote from a book in which it is given a concise and comprehensive definition: "The name of the sea is wholly in congruity with the saturnine picture of death that we see before us. The mountains in its vicinity are barren hills; the shores are deprived of any vegetation, while the water is only inhabited by some primitive organisms, e.g. several types of rhizopods. Fish, crustaceans and various other insects brought to the Dead Sea by the Jordan River and mountain streams instantly find their death in its water. Even aqueous plants cannot survive in it."*

It is of some interest to mention that as a result of the correspondence of the saline composition of ocean water and blood, people do not feel its loss when they cut themselves on shells or corals, or when they are injured by sharp stones during underwater swimming or bathing. This is indeed a reminder that each one of us bears the memory of the ocean, where our remote ancestors lived and evolved.

After a temporary digression let us return to the saline riches of the World Ocean. Nowadays it annually, and without any

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* Derpgols V. F. *The World of Water*, Leningrad: Nedra Publishers, 1979, p. 131 (in Russian).

damage to itself, gives people not less than eight million tons of salt, which makes up approximately one-third of its general output. The extraction of salt from the ocean is a rather time-consuming process. In nature, the complete evaporation of water and sedimentation of the chemical compounds contained in it takes place only in exceptional cases. This typically occurs in the most shallow enclosed bays and lagoons. It is also interesting to observe that the chemical compounds in ocean water undergo crystallization during its evaporation in a specific sequence. Calcium carbonate and iron oxide precipitate first. This is followed by calcium sulphate—gypsum. Then the solution becomes more and more concentrated until sodium chloride, or cooking salt, begins to precipitate. In the course of further evaporation salts of magnesium begin to precipitate out of the solution. This rational property of nature itself is precisely what is employed in the industrial production of salt, which is carried out in artificial multistage basins. In some of them the undesirable compounds are removed, while in others, the required product is precipitated.

The installation of salt-extracting basins becomes possible only in warm and fairly dry countries. Since the water is evaporated by exposure to the Sun and wind, this method cannot be utilized on, for instance, the hot coasts of the Gulf of Guinea, because of the high humidity of the air.

The author of this book is acquainted with salt-mines through first-hand observations. It appears that the present-day technology for obtaining salt from the ocean has retained a great deal from the olden times, though there have certainly been changes in the range of territories, and loading and trans-shipping processes have been mechanized. The productivity of evaporating basins is not high at all, e.g. 1000 cubic metres of water yields a little over a ton of salt. However, this does enable us to receive the product in its pure form.

Nowadays sodium chloride is not only used in cooking: it is also a valuable raw material for industry. Nature seems to have foreseen the high demand and took care of the inexhaustibleness of its reserves. In the World Ocean alone there is an amount of salt sufficient to meet the demands at the current rate of consumption for over one-and-a-half billion years, without taking its secret stores, which have but lately become known, into account.

In 1961, geophysicists discovered that there were structures below the bottom of the Mediterranean Sea that had very much in common with the saline domes on land. The question cropped up: What could they actually be? The possibility that salt deposits were buried in the deepwater parts of the sea far from the shore seemed quite unusual. In 1970 the American research ship *Glomar Challenger*, equipped with an installation for deepwater drilling, set out to where the dome-like Mediterranean structures were located. The boreholes revealed that there was rock salt of marine origin under the thick bedding of silts. Geophysicists came to the conclusion that these deposits spread over a wide territory and were of no minor thickness.

Where could the enormous deposits of salt in the depths of the Mediterranean Sea come from? The only ready answer to this question was that at one time the Sea was separated from the Atlantic Ocean and ran dry only to be filled again with the water of the same Ocean in a later period. To substantiate their assumption, scientists adduced quite cogent arguments. They even estimated that with the cessation of the water supply through the Strait of Gibraltar, the Sea would have had to be evaporated within a period of one thousand years.

The discovery of the salt depository by scientists provides yet another reserve of this valuable food and industrial raw material, whose true amount on Earth is still hardly known.

In the past decades the oil- and gas-bearing reserves of the World Ocean have been estimated over and over again. The bowels of the Earth have already yielded about twenty billion tons of oil. According to some of the published data the explored reserves of oil comprise approximately sixty-two billion tons. Meanwhile its output increases with every year. Since the discovery of new deposits on land is not very promising, it is not surprising that people have now focused their attention on the World Ocean.

Today the shelf of the World Ocean provides more than twenty percent of the oil and gas that are produced. In addition, the oil- and gas-bearing reserves of the shelf have not yet been adequately explored.

Oil and gas deposits have exactly the same origin throughout the whole world. It is not infrequent that the continental oil-bearing structures are continued in the ocean on the shelf and on the continental slope of the floor. Hence, the probability of finding oil in the sedimentary rocks of the World Ocean is the same as that on land, with the only difference that in the ocean its exploration presents much greater difficulties. At present quite a few promising oil- and gas-bearing regions of the ocean floor have been discovered. On the other hand, no authentic information on the potential reserves of oil and their location has so far been made available.

According to specialists, the time will soon come when the geography of the now exploited underwater deposits and their contribution to the world output will change. The main functioning fields are at present situated in the Caspian Sea, near the slopes of Sakhalin, in the regions of the Persian Gulf, and in the Gulf of Mexico. Oil has been found in the Black Sea, the North Sea, and in the Arctic basin. Submarine explorations for oil are being carried out throughout the world. The regions of the continental shelf near the shores of Guiana, Brazil, and Argentina have proved to be promising. Africa is also coming into the international scene. American, British, and Japanese companies are conducting underwater oil-drilling operations near the shores of Java, Sumatra, Kalimantan, New Guinea, and New Zealand. Oil is already being extracted on the shelf of Australia. It should also be mentioned that Japanese geophysicists have recently found oil-bearing structures on the shelf of their own country. Exploratory drilling had confirmed their judgements and revealed that large deposits of oil are located near the shores of Japan.

At one time geologists and geophysicists suggested that oil and gas deposits might exist on the continental slope of the World Ocean floor. Deep-water drilling revealed this to be correct. The American research ship *Glomar Challenger*, while passing a borehole in the Gulf of Mexico when the depth under its keel measured 3400 metres, exposed by means of its drilling installations some oil-bearing beds. They were found to be under the cover of a saline dome and a thick stratification of sedimentary rocks. The event, which seemed unimportant to many people, had decisive significance for science, since it forced researchers to reconsider the geography of oil and gas deposits. Not much later similar structures were discovered at the great depths of the Atlantic Ocean to the west of the Strait of Gibraltar.

Only the very first steps have been made so far in the surveying for oil and gas deposits in the deep-water regions of the World Ocean. It is quite probable that developments in surveying will reveal where the black gold of the future is hidden. At least the current achievements instil hope that the existence of huge reserves of liquid fuel under the ocean bed is not mere wishful thinking.

The vast aqueous expanses of the World Ocean have provided people with food since time immemorial. Fishing is one of the oldest pursuits of mankind. It is noteworthy that a large number of methods and tools for catching fish have over many centuries basically remained the same. This is exemplified by the hooks employed by the Polynesians, who decorated them with multicoloured feathers and towed them on fishing lines in the wake of pirogues.

Aren't they what we now call spoon-baits? Modern fishing rods, harpoons and nets do not differ greatly from their prototypes of the olden days. But all these implements are for coastal fishing. Oceanic fishing, which emerged with the development of navigation, called for the creation of entirely new methods of catching fish and other marine objects. Particular progress in oceanic fishing took place in the post-war period. Special hydroacoustic instrumentation was developed that would facilitate the purposeful search and catch of accumulation of fish. Research in oceanology makes it possible to predict the migration paths of schools of fish, and where the fish aggregate and spawn. Today oceanic fishing is virtually an industry that includes the extractive and transportation fleet, floating and coastal processing plants, ports, refrigerators, ship-repair plants and other installations.

Nowadays the biological potential of the World Ocean has been sufficiently determined and the regions for the most effective fishing have also been discovered. These primarily include regions of marked contrasts in the aqueous medium zones where water masses of different origin come into contact, areas where the outflow of deep waters occurs, and areas characterized by whirlpool formations. According to the estimates made by specialists, the fishing limit should not exceed two hundred million tons a year. This is precisely the figure by which the reproduction of industrial fish is evaluated. The question of fishing limits is by no means groundless. There was a time when it was universally announced that the World Ocean was inexhaustible. However, the development of the fishing industry immediately declared this shaky thesis untenable.

In 1970 the world catch of fish comprised sixty million tons: fish comprised 91 percent of this catch; crustaceans three percent; and molluscs, six percent. It should be noted that not all of this is used for food. About one-third of the catch, predominantly small fish of no great value, is processed into flour, which is then used to feed animals or as fertilizer.

If we consider the given figures, then the biological resources that are used and those that are reproduced are characterized by a ratio of 1 to 3. Even if we consider that the catch of traditional objects of the fishery can reach ninety, or one hundred, million tons per year and the ratio is reduced to 1:2, the prospect will still seem favourable. But the actual state of things is by far not so fortunate. These figures characterize only the overall ratio. If the catch and reproduction of individual species is considered, it becomes clear that many of them are on the verge of extinction since the intensity with which fishery of the most valuable of their species is conducted exceeds the ultimately permissible norms. All this has led to the strict regulation of international fishery. Thus, for instance, the prohibitions on catching herring in the North Atlantic Ocean have made it possible to restore its shoal.

The juridical aspect of fishery does not enter into the framework of this discussion. However, it would hardly be possible not to mention that for the countries where free enterprise is preponderant and where a planned economy does not exist as such, international norms cannot be dispensed with.

The World Ocean hides within itself enormous treasures of food, that can meet the ever-growing demands of people, although their extraction calls for a rational and judicious approach.

The Ores of the Ocean Floor

Among the innumerable riches of the World Ocean there are specific ore formations that are typical of it alone and which must be mentioned.

The author of this book has in his possession a small transparent cube of organic glass. Welded within it is a little black stone with a metallic lustre, whose form and size are very much the same as a pigeon's egg. Engraved on the cube are the words: "Nickel, copper, cobalt, and manganese. Depth—5100 metres". This is a manganese concretion—a keepsake from the Pacific Ocean, where it was raised from the floor to the research ship.

Manganese concretions were first found on the floor of the Atlantic, the Indian, and the Pacific oceans from 1873 to 1876 by the expedition aboard the *Challenger* ship.

Concretions are natural formations, which are predominantly round in form, with a high concentration of mineral substances. They are real metal 'cocktails', consisting of manganese, iron, copper, nickel, cobalt, magnesium, aluminium, molybdenum, vanadium, etc. All in all, 27 chemical elements have been found in these formations. Concretions were called manganese since on the average 27 percent of this element is contained in them.

According to the form and chemical composition, manganese formations in the World Ocean are fairly diverse. They are found on the floor as plates, crusts, stones, and overgrowths on various objects. The size of the concretions themselves reaches that of a cannon ball. What presents no minor interest is that cannon shells raised from the ocean floor have been found to have a manganese overgrowth with all the chemical elements pertinent to it. Investigations have revealed that the overgrowth of these shells occurred at a rate of several millimetres over a period of tens of years.

The structure of concretions is also of some interest. They usually contain a core, which is either the fragment of some rock, a coral remnant washed off an island by a storm, or, lastly, a shark's tooth. The foreign body is covered with the material that forms a concretion having the form of variously shaped concentric rings that look very much like the rings marking the growth on a piece of a sawed-off tree. The obviously layered composition of concretions proves that they have been developing by the gradual, and presumably irregular, deposition of chemical compounds and elements that settle out of the ocean water around the cores. Geochemists became interested in the rate of this process, and used three different radiometric methods to determine it. They obtained the growth rate of concretions, which was found to be equal to ten millimetres over a period of one million years. This very low rate of development may well be compared to the rate of formation of sedimentary rocks in the deepwater parts of the ocean floor, which according to the same methods ranges from one to ten millimetres over a period of one thousand years. It follows from what has just been mentioned that manganese concretions grow approximately one thousand times slower than the rate at which the accumulation of sedimentary rocks takes place, among which they can also be found. The conclusion that is suggested is that concretions must be buried in the sediments, though as has been most convincingly illustrated by numerous photographs of the ocean floor, they actually lie on its surface. It was suggested that concretions were hindered from becoming engulfed by the sediments by the activity of the animals living on the bottom. This statement is rather controversial. Most likely the information about the rate at which the concretions develop is not accurate enough. It is the data concerning the intensity with which the overgrowth of objects raised from the ocean floor takes place—those very same cannon shells that were at one time aboard ships—that makes the reliability of this information questionable. In any case, the time will certainly come when the problem of the growth rate will finally be made clear, since without a solution to it, a correct evaluation of the geochemical conditions in which the concretions are formed is impossible.

Manganese concretions form large accumulations on the World Ocean floor. They are most abundant in the Pacific Ocean, where they are most often found at depths ranging from approximately two to six thousand metres. In some places concretions are so densely accumulated on the floor that in underwater photographs the bottom looks like cobbles.

Basic information on the bedding of concretions on the ocean floor has been received by remote underwater photography and television scanning of the bottom landscapes. There have also been attempts to explore the deposits of concretions with the aid of magnetometric surveying. According to specialists, these methods make it possible to evaluate the approximate percentage content of iron in them and to assess their distribution along the magnetic anomalies.

The reserves of concretions on the ocean floor today are measured in an astronomical figure of 1500 billion tons. This, however, is by far not an exact amount since no sufficient information is yet available on the distribution of concretions in the deepwater regions of the World Ocean. Basing their assumptions on the data that they have at their disposal pertaining to the growth rate of concretions, scientists have estimated that these formations increase at a rate of six million tons per year. This is found to be tenable on condition that their formation is regular in terms of time.

The insignificant rate at which the concretions develop is accounted for by the variety in the density of their accumulations on the World Ocean floor. In some regions the concretions are arranged in single file, as if people had done this; in others, they are completely disarranged. Scientists assume that within an area characterized by intense sedimentation, the concretions are covered with sedimentary deposits in spite of the activity of the bottom-dwelling animals. But, in those places where the process of sedimentation is retarded, the concretions remain on the surface. If the question concerning the burying of these formations in bottom deposits still remains open, their huge accumulations on the floor surface in the deepwater regions of the World Ocean where it is covered with dense clays is an incontrovertible fact. Thus, the regions with an abundance of concretions to the north and south of the equator in the Pacific Ocean represent zones characterized by slow sedimentation. Presumably these zones are precisely the areas where the intense growth of concretions takes place.

One of the first explanations for the formation of concretions was that manganese and iron precipitate from the ocean water forming colloids with a positive charge, which are deposited on various fragments that became the core of concretions. Upon this iron and manganese cover, other chemical elements are precipitated. In this way, layer after layer, the formation of concretions takes place. The predominant opinion today is that concretions emerged as a result of bacterial oxidation and the settling out of manganese and iron from ocean water, which was accompanied by the absorption of other elements from the aqueous medium by concretions. As is actually the case, manganese formations contain a noticeable quantity of organic matter. But in the World Ocean it is found everywhere, including those places where there are no concretions. Hence, until irrefutable proof appears, the opinions concerning the role of biological processes are still being regarded as not more than a hypothesis by many scientists. Since the factors underlying the emergence and formation of concretions have not yet been elucidated, there are at present at least ten hypotheses explaining this mechanism. One of the latest of them presupposes the mechanical fusion of salts into lumps with the synchronous sedimentation of manganese and iron from the ocean water.

The concretions belonging to different regions of the World Ocean are distinguished by their chemical composition. Thus, the concretions of the eastern and northern parts of the tropical zone of the Pacific Ocean are rich in manganese, nickel, and copper. At the same time, in the relatively small areas connected with the American continent, they, though also rich in manganese, contain extremely small quantities of nickel and copper. On the other hand, the concretions of submarine banks and mountain tops have the highest concentrations of cobalt and lead. These regional discrepancies in the composition of concretions have not yet been explained, though great importance is attached to them in the contemporary hypotheses pertaining to their origin.

The discovery of concretion deposits in the Pacific Ocean coincided with the development of research on submarine volcanism. This leads to the revival of John Murray's ideas, which had been in abeyance for some time. Murray had studied concretions that were collected during the expedition of the English corvette *Challenger*. If the metals entering into the composition of concretions are extracted from the ocean water, and the water in the ocean is properly mixed and adequately homogeneous as far as its chemical composition is concerned, then it would be quite natural to expect that, according to their concentration and number of elements, concretions should be homogeneous. This, however, is not the case. Hence, in order to explain the remarkably great variety in the chemical composition of concretions, the existence of additional sources of elements, which they comprise, must be assumed. At present most scientists regard volcanic activity as a source of this kind.

Various substances that enter the ocean water in the process of volcanic manifestations, including metals, will be an additional reserve for the formation of concretions in adjoining regions. It should be mentioned that in a number of concretions that were raised in the zones of volcanism, a great amount of volcanic glass and volcanic minerals that are tightly bound to manganese oxides was found. The hypothesis concerning the role of volcanism in the formation of concretions is substantiated by the comparatively recent discovery of bottom deposits, usually rich in metals and located in some of the active parts of the mid-oceanic ridges. This, presumably, is the result of the fact that volcanic activity supplies metals directly to the sea floor and into the water. However, it must be mentioned that no concretions were found in these regions, though the selection of specimens of bottom rocks was carried out within a fairly dense network.

In almost all the attempts to explain the origin of concretions, what is not taken into account is the formations that are similar to them and that are found in the shallow waters near continents. These concretions, for instance, have been found in the bays of Scotland, as well as in the shoal regions, where there is no trace of volcanic activity. They look like small peas or coins, and their composition is rather varied.

Some of them are enriched with manganese; others, with iron. They all are distinguished from deepwater concretions by the low concentration of nickel, cobalt, lead, and other metals. It is assumed that shallow-water concretions emerge as a result of the precipitation of manganese and metals from the water, which rises to the upper regions along the pores of sedimentary rocks. If this is so, then what becomes apparent is the diagenetic change of noncompact sedimentary deposits, that become responsible for the occurrence of metals of low valency in the porous water. In the process of diagenesis these rocks acquire the property of compactness, and the water contained in them migrates to the surface, where because of quite different geochemical conditions, metals are sedimented.

It should be noted that the composition of individual groups of deepwater concretions is nevertheless similar to those of the shallow-water varieties. Moreover, in the regions of their distribution, the diagenetic enrichment of the surface layers of sedimentary rocks with manganese takes place. There is some reason to believe that the mechanism conditioning the formation of shallow-water concretions also functions at greater depths.

In the discussion on the distribution and origin of the remarkable bottom formations it is not difficult to detect quite a few contradictions and unclear points brought about by the inadequate study of these particularly oceanic ore bodies. Undoubtedly, science will soon have something definite to say on the subject. Now, however, one thing is clear: there are several means by which manganese concretions originate and develop on the bottom of the World Ocean.

For a long time manganese concretions presented scientific interest mainly on account of their inaccessibility and the presence on land of a fairly large number of manganese and ore deposits. It was considered premature to consider these formations a source of industrial raw material. Meanwhile, the reserves of manganese and associated metals in ocean concretions are not only comparable with the deposits on land, but also exceed them to a great extent. If we take into consideration the current rates at which the manganese and ore deposits are exploited on land, then, as has been suggested by specialists, the resources of the ocean will be sufficient for many thousands of years. The mining of manganese concretions from the World Ocean floor can lead to an actual revolution in the mining and ore industry.

At present manganese concretions have drawn the attention of many large mining firms in the world. They have immediately been confronted with two problems: first, the difficulty connected with the raising of concretions from the great depths on an industrial scale; and second, the no less complicated extraction of manganese and metals from them during refining. The fact is that it is precisely the concretions of greater depths that possess the required concentrations of minerals. At the same time, as has been revealed by semi-industrial experiments, their extraction calls for complex and laborious technological processes.

Chapter 7

The Ocean in Jeopardy

'The Alliance of Mars and Pluto'

For millennia the ocean has been pictured in the minds of people as an omnivorous natural element, and it was only their intensive exploration of it that made people think of its fate and realize how vulnerable the World Ocean was and how much care it demanded of those whose vital needs it would then be ready to gratify. But not everybody understands this simple truth. For various reasons the pollution problem of the World Ocean is either glossed over, or aggravated to an appalling scale that threatens the coming generations with innumerable disasters. Most likely the actual situation is somewhere in-between. The only thing that remains irrefutable today is that the World Ocean is truly threatened.

If the exploitation of the ocean by humans continues to be as uncontrolled and rapacious as it was when the pristine nature of the continents was being developed, irrevocable destruction may occur in the oceanic medium. The ecological balance existing in nature is extremely unstable. In technical terms, it is found to be in borderline equilibrium. Hence, the impact upon the environment of new factors, brought about by the activity of humans, or the elimination of ones now existing entails irredeemable consequences, the true significance of which is only now being realized.

At present we still lack a sufficient amount of scientific observations and of generally acknowledged objective criteria, which would make it possible to establish all the cause-and-effect connections that could serve as the basis for humankind's effective global activity to prevent and eradicate the contamination of the World Ocean. We are now at a stage that is characterized by the accumulation and comprehension of various events. Many of them are particularly significant, and it is precisely they that have forced people to take effective measures to save the World Ocean from its treacherous enemy called pollution.

In examining the events that actually took place let us recall the television film showing the oil-covered beaches on the shores of Europe after the disaster of the tanker *Torry Canyon*. One hundred and eighteen thousand tons of oil formed a thin film over many hundreds of hectares on the ocean surface. Then the winds brought the oil to the shore itself. The birds perishing in the quagmire of oil presented a horrendous picture. This was the most obvious consequence of the huge amount of oil that got into the aqueous medium. But in addition to this, there were also disastrous effects that were much wider in scope and not observable: the disturbance of the biological equilibrium of the submarine world.

No less threatening to the World Ocean is the further development of off-shore oil fields in the water, which often leads to oil spills during the drilling of holes, as well as to the formation of oil gushers.

The contamination of the World Ocean by the petroleum products of tankers and other kind of ships has been continuing for a long time. The water used for washing the containers transporting petroleum products was regularly poured out into the ocean. It is not difficult to imagine the amount of oil that got into the water, if we take into account the contemporary scale of shipping.

The incursions onto the shores of oil that has somehow found its way into the ocean have been called the 'black tide' It is considered to be no smaller a scourge than floods and droughts. But it is not only oil that is threatening the ocean. There are sources of pollution that are more treacherous and less noticeable.

Not long ago a sensational piece of news appeared in a magazine stating that in the Kattegat Strait in the Baltics a fortress that had withstood many a storm and both the First and Second World Wars during the long period of its existence had now collapsed. What was most surprising was that its end came not as a result of bombs, rockets, or shells, but because of the activity of housewives and public service departments.

What had actually taken place was that for several years liquid wastes containing cleansing agents were poured out in the vicinity of the fortress. The detergents corroded the clay upon which the fortress had been standing so firmly. The thick foundation of the fortress turned into liquid mud that spread sideways with the result that the walls of the fortress vanished as if they had never existed.

Our life is connected with the cycling of water in nature. The rains wash away products of erosion and human activity from the land into the rivers. They enter the seas and then the oceans. What undoubtedly first bears the brunt are the enclosed seas, whose connection with the ocean is limited. The contamination of the World Ocean by continental runoff, which includes industrial wastes, sewage, erosion products from the land, and chemical fertilizers that are washed away by the rains, is found to be directly proportional to the growth of our planet's population and the intensification of industry and agriculture.

The zone threatened by this type of pollution is still confined to the shores, though it could extend to the shelf and open regions of the World Ocean if effective measures are not taken to reduce and end the hazardous runoff.

Continental runoff also entails bacterial contamination of the World Ocean. It is quite natural that the highest concentration of pathogenic bacteria occurs in the waters of ports, in roadsteads, near beaches, and particularly at the exit of sewage systems that run from the ooastal towns and villages. Fortunately, the waters of the World Ocean have bactericidal properties owing to which the virulence of the microbes gradually decreases.

When discussing humankind's impact on the World Ocean, thermal pollution cannot be ignored. It results from the discharge of waste water from thermal and atomic power stations. Powerful streams that may be compared to rivers flow through these stations. In those areas where the thermal waste waters are discharged, the temperature rises and consequently the conditions of the environment do not remain stable. This inevitably leads to ecological changes. Thus, the heating of coastal water causes some species of organisms to leave their customary habitats, while other species get the opportunity to propagate widely.

In a number of cases thermal pollution can be beneficial such as, for example, when fish and other marine organisms are artificially bred.

The contamination of the World Ocean is a multilateral problem that is closely connected with the life and activity of humankind and its impact not only on the ocean, but also on land.

As was pointed out by Captain V.P. Demyanov, whose observations and opinions entered into the present chapter, a paradoxical thing has happened: every single minute an additional 172 people appear on the Earth, and within that same minute, 44 hectares of land turn into a desert. Modern technology is helping people to dispose of woods and forests—the custodians of life-giving moisture and the 'lungs' of the Earth—at an unprecedented rate. Streams and small rivers that feed the larger ones are becoming desiccated, and thus the age-long harmony of earth and water is disrupted.

The alliance of the Earth and the Water are the source of abundance and prosperity. This idea found its allegoric expression in a painting by the Flemish painter Rubens. On this canvas a full-bodied Flemish beauty impersonates the goddess of the Earth Cybele, while the god of the seas Neptune is represented by a virile grey-bearded old man who is also of strong build. Neptune's son Triton is using all his might to blow into a seashell, and the winged Glory weds the gods of the Earth and the Water with laurels, thus sealing their blissful and fecund union.

This is how the great painter imagined the way to everybody's benefit, happiness, life, and wealth. Much time has since passed. We can only guess what would stir the mind and heart of this great artist if he were alive today. It would not be wholly improbable that the 'alliance of the Earth and the Water' would be replaced by a canvas personifying the painful (for the human race) alliance of 'Mars and Pluto'

We know that Mars is the god of war, and that Pluto—a blind old man—is the god of wealth, who cannot see where he scatters his riches. Their alliance could nowadays be regarded as a symbolic expression of the military-industrial complex. The development of nuclear, chemical, bacteriological, and ecological warfare, in addition to what is at present known as Star Wars, deployed by aggressive groups in the West, are not very hopeful signs for either the land or the ocean. The production itself of arms and other types of warfare has already now taken the lives of people and exerted a deleterious effect upon the environment. The military enterprises in the United States discharge four times more toxic substances into the rivers and lakes than all the non-military enterprises taken together.

In addition to the production of current means of warfare, particularly nuclear weapons, the testing, storage, servicing, and finally, their burying cause great harm to nature and threaten people with incredible disasters. The World Ocean, which is continuously mixed with storms and currents and has enormous possibilities of purifying itself, with all its vastness is nevertheless incapable of rendering all the wastes discharged into it harmless, of which the most hazardous are those resulting from the production of arms.

At a special conference the world community adopted a convention concerning the 'prevention of sea pollution caused by the discharge of wastes and other materials' Eighty countries took part in elaborating this document. According to this convention it is prohibited to discharge into the water any materials containing mercury and cadmium, radioactive substances with a high degree of radiation, as well as oil products, stable plastics, and agents and materials intended for chemical war.

This agreement was reached at an exorbitant price. The Japanese city of Minamata can serve as an example. This city became widely known when in 1953 more than one hundred of its inhabitants contracted a yet unknown disease. The victims suffered from loss of sight and hearing, their speech and coordination of movement were hindered and, lastly, the symptoms found their expression in cramps and convulsions. Some of these people went totally blind and ended up insane and in a state of paralysis. As was later found out, what lay behind this tragedy was the fish that was caught near the shores where the chemical enterprise 'Tisso' discharged its waste products.

The concentration of mercury in this fish was hundreds of times greater than usual. Only after twelve years did the company built a purification unit. This disease, which 'in honour' of that city was called the Minamata disease, also spread to other regions of the country. Nearly one hundred thousand Japanese became victims of mercury poisoning.

It has been suggested that the mass selfdestruction of sperm whales that throw themvelves onto the shore, is conditioned by the effect of mercury on their nervous system and on the coordination of movements. Cases have been known, for instance, when the so-called 'inebriated' fish, which looked as if it had been anaesthesized, came into people's hands quite freely. Some people, not knowing the causes of 'piscine insobriety', consumed the fish, and consequently, became its victim.

No small amount of mercury is carried by the waters of the Gulf Stream, which brings it into the regions of intense fishing.

People have also suffered a great deal from cadmium. Again in Japan there is a disease known as the 'itai-itai' disease. It finds its expression in the fragility of the bones. A deep breath causes the rib of a person suffering from this disease to break. What causes this kind of infirmity is cadmium.

They Require Special Protection

In continuing this discussion on the contamination of the World Ocean and the ways of solving this complicated problem, it would be best to turn to the Baltic Sea— one of the busiest transportation waterways, through which nowadays nearly one-tenth of all the world cargo passes, although it occupies but a fraction of the area of the

World Ocean. The Baltic Sea is highly susceptible to external influence. As is the case with other continental seas, its link with the World Ocean is minor, and its self-purifying ability is extremely restricted. Meanwhile, its dependence on the continent is enormous. Its borders are contiguous with seven countries, whose industry, transport, agriculture, and public service sectors are well developed. In the port-cities of these countries alone there are almost ten million inhabitants. Two hundred and fifty large and small rivers flow into the Baltic Sea. What do they carry into it? Can this sea control everything that enters its waters?

If we compare the Atlantic Ocean with the Baltic Sea, the figures, which were not considered before, will be very impressive. The Baltic Sea is two hundred times smaller than the Atlantic Ocean in area and almost fifteen thousand times smaller in volume! And if in the World Ocean, as has been estimated by specialists, the number of living organisms has been reduced by half over the past twenty years, what then is the Baltic Sea heading for? Actually, according to the report submitted by the International Union for the Protection of Nature and Natural Resources, seventy percent of the ocean's spawnings have become unsuitable for reproduction purposes, and dozens of the most valuable industrial types of fish have been either wholly or partially destroyed.

What can be said about the Baltic Sea?

One should not ignore one very essential feature of the Baltic Sea: it flows into the Atlantic Ocean supplying it with almost five hundred cubic kilometres of water every year. Let us imagine now that all the straits were shut off. The obvious result would be a rise in the level of the Baltic Sea at a rate of 124 centimetres a year, whereas, for instance, the level of the Mediterranean Sea in these conditions would drop by approximately one metre, since more water is evaporated from its surface than what is brought into the sea. It turns out then that the Baltic Sea can be compared to a huge reservoir, or to the basin of some pollution-control unit, into which the continent 'discharges' its waters before they reach the ocean.

Not very long ago people did not even consider this problem. It was prohibited to pump hold-water overboard when a ship was stationed at a harbour or roadstead. Where was this water pumped to in such cases? ... The sea, of course. But as compared with ships, the seas do not send out any distress signals; they face their destruction mutely. It is the duty of people to notice when the sea is in danger, and to immediately change course and render it the required help.

For this help to be timely and effective, the goodwill of all the states on which the fate of the sea depends is required. And the Baltic States did manifest their goodwill by signing two very important conventions. One of them, adopted in 1973 in Gdansk, addresses the problems of fishing and the protection of living resources in the Baltic Sea and the straits of the Great and Little Belts. It is not difficult to understand the importance of this agreement, if we take into account the fact that the Baltic Sea produces over twelve percent of all the fish in the world. Sprat and codfish comprise the major part of the catch; eel and salmon are also found in that sea.

As regards salmon, until now the international convention of 1885 concerning the regulation of salmon fishing in the basin of the Rhine River has not been cancelled, though in the Rhine today it would not be possible to find anything alive, to say nothing of salmon. Foolish and rapacious management, with only one aim of satiating pecuniary interests, has turned the river that was exalted by the poets of many generations into a runoff ditch in the very centre of enlightened Western Europe. It was only in 1976 that the states bordering the Rhine agreed to protect it through common effort and signed the corresponding convention.

This brief digression on the history of

the Rhine, which was at one time so rich in salmon, will hopefully help the reader to fully appreciate the significance of the second convention that was adopted by the Baltic States in Helsinki in 1974. Seven countries—the German Democratic Republic, Denmark, Sweden, Poland, the USSR, Finland, and the German Federal Republic—agreed to take all necessary measures to prevent the pollution of the sea by air, water, or any other agents containing hazardous substances, which are included in a special list. Among the substances were mercury, arsenic, phosphorus, phenol, and stable pesticides.

Systematic observation of the condition of the seas has been established in compliance with a single system, aimed at detecting the contamination of the sea, determining its sources, and organizing an effective battle against disastrous leaks of oil and toxic substances. So-called monitoring, or systematic control of the physical and biological indicators of the aqueous medium in the Baltic Sea was stipulated and is functioning. Common methods of selecting samples and conducting analyses were clearly defined.

There are no two people on Earth that are completely alike. The same can be said of the seas. Each of them has its own origin, development, and life, its own temperament and fate. Let us now compare the two northwestern seas: the Baltic Sea and the White Sea. Both of them are almost separated from the ocean—only narrow and shallow straits allow a certain water exchange to take place. These two seas share common features, such as shallow depths, a complicated floor relief, a significant continental runoff of freshwater, and related to this, a low salinity.

Winds blow over the expanses of the two seas, thus causing storms, on which the dislocation of surface waters and their saturation with oxygen depend. One would think the situation is identical. However, the two seas are significantly distinct. As compared with the White Sea, the Baltic Sea knows practically no tides. A powerful tidal wave from the Barents Sea—one of the largest seas in the USSR—rolls to the shore twice a day, turning the stones upside down and casting algae over the land before it recedes. Near the Mezenskaya inlet the tide reaches seven metres. Hence, it was not by chance that engineers got the idea to build a large-capacity tidal power station here.

As a result of regular tidal mixing, the deep waters of the White Sea to say nothing of the surface layers, are continuously refreshed. The Baltic Sea was not blessed by nature in this respect: only a single exchange of waters, especially of the deep waters, requires many years.

The absence of tides and a highly unfavourable floor topography, e.g. a number of successive basins separated by rapids, lead to the stable stratification of waters according to salinity and density. This is exactly what explains the extremely unpleasant stagnation of waters in the depths of the Baltic Sea. In the case of stagnation it only seems that nothing takes place. What actually happens is worse than can be imagined, viz. the sometimes irreversible degeneration of the medium.

No storm on the surface, irrespective of its force, can carry life-giving oxygen to the depths. Hydrogen sulphide begins to accumulate in the basins. This is death—the total absence of life in any of its forms, save some of the bacteria.

The deepest depressions of the Baltic Sea are characterized by the periodic accumulation of oxygen and its likewise disappearance due to its expenditure on oxidation. Then the hydrogen sulphide concentration increases as a result of the 'work' performed by the anaerobic bacteria, which do not require any oxygen at all. These 'oxygen-hydrogen sulphide' cycles have recently been manifesting themselves more often, in addition to which the amount of oxygen dissolved in the water has been steadily on the decrease.

Nowadays there is no need to call on people to spare the Baltic Sea, particularly in the busiest periods, when due to the unfavourable climatic conditions, the fresh ocean water passing through the North Sea does not manage for a long time to cross the rapids and drop into the depths of the Baltic Sea so as to freshen at least to some extent the lower, or stagnant, layers of its waters. Today, people with common sense already have no doubts about the fact that the discharge of toxic substances is hazardous to the sea. For this reason the recuperation of the Baltic Sea has become a task of current importance for all the Baltic States.

The Black Sea has a longer path to the ocean than the Baltic Sea. It crosses the Sea of Marmara and the Mediterranean Sea, thus representing a chain of seas. And if the Sea of Azov, which forms a single basin with the Black Sea, were added, the way to the ocean would be much longer.

The Sea of Azov seems like a drop of water containing almost two thousand times less water than the Black Sea, and seventy-five times less water than the Baltic Sea.

Nevertheless, one could hardly call it a shallow bay of the Black Sea since it is quite independent, the chemical composition of the water is different, and it has other highly important features pertaining to climate, weather, etc. of which even... the fish are aware.

It is not accidental that there is no herring similar to the Kerch variety that spawns and fattens in the Sea of Azov and hibernates in the Black Sea. It is caught in the Kerch Strait exactly when it is known to be most tasty. The same can be said of the Azov anchovy, which also hibernates in the Black Sea. According to connoisseurs, it is incomparable with the Black Sea anchovy, the sprat, and sardelle dwelling in other basins.

Unique natural conditions for the reproduction and growth of fish developed in the markedly desalted water of the Sea of Azov. This was exactly what accounted for propitious fishing in this region. Now, however, the situation has deteriorated to a noticeable extent. And this is not because the water was poisoned. It was simply taken away from the rivers before they had enough time to flow into the Sea of Azov. This was why the Sea of Azov began to be filled with the saline water of the Black Sea passing through the Kerch Strait. The waters of the Kuban and the Don rivers are being used more intensively for agricultural, industrial, and domestic purposes. In addition, as a result of the construction of the Tsimlyansk reservoir, the Don may well be said to be flowing more 'quietly' now. The food for fish, which this river used to bring to the Sea of Azov now stays in this reservoir as is the case with any other reservoir, whether it is on the Volga, or on some other river.

Specialists believe that the eradication of this inequity as regards the Sea of Azov will be achieved through the construction of the Kerch hydroelectric generating station, which would regulate the exchange of waters between the two seas: the inflow of salt and heavier Black Sea water in the bottom layer and the outflow of the desalted Azov water in the surface layer.

As can be seen, the water-exchange is a very important factor in the life of the Baltic Sea, the Sea of Azov, the Black Sea, and others. To return to the Black Sea it should be mentioned that it is twenty-five times larger than the Baltic Sea as far as the volume of water is concerned, while their areas are about equal. It seems that the Black Sea should have sufficient resources for self-cleaning and resistance to contamination. This, however, is not the case. The water that is suitable for life comprises approximately thirteen percent of the whole volume of the sea; while the remaining part of the water is 'dead' or poisoned with hydrogen sulphide. It underlies the upper fairly thin layer of warm 'living' water. Hydrogen sulphide is found at depths ranging from two hundred to one hundred and fifty metres or less (in some places as low as sixty metres).

It has been estimated that it takes deep waters 1800 years or more to rise to the surface. This gave some people the idea that the Black Sea could be used for the burying of radioactive wastes. The most ardent supporters of this idea were the war-mongering big-business leaders of the military industrial complex from whom the seas are so very far away. Most recent investigations by Soviet scientists have revealed that the vertical water-exchange in the Black Sea comprised a period of 130 to 400 years. Moreover, it was also established that this period of time is fairly short and the rate at which the deep waters rise can in some cases be found to be even higher.

Attempts to substantiate the possibility of burying radioactive wastes in the Black Sea and the actual dumping of these wastes in the ocean show how far one can go when the specific features of nature are not taken into account. One need not look far for an example. In Great Britain, radioactive wastes were poured down the pipes into the Irish Sea, and in the United States exactly the same was done to the Tennessee River. In the United States radioactive wastes were sometimes buried in the ocean in containers. It is not difficult to imagine what will happen when in due course the containers are damaged. We should not ignore the fact that the World Ocean is a single inseparable whole. There is no sea that will not sooner or later be penetrated by its water.

The danger of radiation injury has forced people to take necessary measures. At present the discharge of radioactive wastes into the ocean has been markedly decreased. Instead they are being buried deep in the ground. Old mines and adits are used for this purpose. The wastes are packed into sturdy containers whose condition can be checked from time to time on land.

The sandy shores of the Mediterranean coast of Africa are genuinely picturesque. The coastal dunes overgrown with ever-green bushes and relict pines stretch over many miles. In some places vertical rocks are near the edge of the water. This beauty, however, is deceptive. The Mediterranean shores are so polluted that they seem to be no better than the garbage dumps in towns. One can find practically anything on those shores! Polyethylene bottles, bags, beer tins, tires... The amount of rubbish cannot even be estimated. Everything that does not sink, to say nothing of black oil, is brought by the waves to the shore.

Some parts of the sea have really become dangerous for the health of people. A single occasion of bathing in this kind of water can result in the contraction of either infectious hepatitis or typhoid fever. For this reason some of the Mediterranean beaches are closed. This was the fate of the universally known Cape of Santa Maria di Leuca. Out of the five hundred organisms that dwelt in it, at least one hundred have become extinct.

The famous French oceanographer Jacques-Ives Cousteau states that in the Mediterranean Sea only oases of clean water remain, and their number is most drastically on the decrease. In his opinion, if measures are not taken, nothing but viruses and bacteria will be found in the fifty years' time.

Ship traffic is less intense in the Arctic seas than in the Southern seas. It would seem that the situation there should be much more propitious. This is true as regards the oil contamination and industrial runoff; but as far as the floating refuse is concerned, things are not very much better than elsewhere. The polyethylene gifts of civilization do reach the farthest shores of the Arctic seas.

The North-Atlantic Current, which is the part of the Gulf Stream, brings all kind of garbage to the Barents Sea and to the shores of the Kola Peninsula. The flow of garbage is constantly increasing in amount and variety. It does not take long for the inhabitants of the Kola littoral zone to learn about the latest plastic containers that are made in the West. On the shores the sea fisheries 'exhibit' fragments of nylon trawls, trawling boat mats, nets, pieces of cables and ropes, polyethylene bags for the salting of fish (many of which are quite fit for use), foam plastic, floats for nets, and other fishing equipment. We could extend the list by mentioning life buoys, life jackets, pieces of furniture from ships, barrels that once contained paint, mops, brushes, etc.

In the course of their travels across the seas many of these things have become overgrown with algae and shells. This indicates that before reaching the shores of gulfs and bays they do have to traverse a long way. In the severe conditions of the polar region all this rubbish remains intact on the shore for many years, only fading in colour under the polar sun in summer.

A new word, now internationally recognized, has appeared in the seaman's language. The word is 'dumping', i.e. the unloading of refuse or garbage. According to estimates, between 1960 and 1970 dumping in the World Ocean annually comprised over one hundred million tons, including the ground that was dug out while dredging the bottom.

Some figures should be mentioned here. Ninety-two percent of the lead, ninety-one percent of the oil, and seventy percent of the mercury that get into the World Ocean are of anthropogenic origin. In the World Ocean there are eight hundred thousand tons of oil aggregates—lumps of split oil—that roam the ocean waters. It has been estimated that within one square kilometre of the surface of the Mediterranean Sea there are more than four thousand different floating objects, the bulk of which consists of polymer articles. The same sea receives about four thousand tons of lead, over two thousand tons of zinc, one hundred tons of mercury and five hundred thousand tons of crude oil annually.

Reasons for Optimism

Though the statistics are rather gloomy, oceanologists are as yet full of optimism. Fortunately, they believe that it is still early to speak of the global contamination of the World Ocean, in spite of the fact that in some of its regions the situation has become threatening. The example of the Baltic Sea shows that the goodwill of people can overcome these difficulties. At the basis of this statement lies the ability of the ocean to heal its own wounds.

The self-cleaning of the ocean medium occurs through complex physicochemical as well as biochemical processes, which involve the foreign substances that got into it. Toxic substances are destroyed and rendered harmless mainly through the activity of microorganisms. Many types of bacteria, yeasts, fungi, and unicellular algae destroy oil products and pesticides, and eliminate the toxic impact of some heavy metals. However, unfortunately, marine organisms do not only render hazardous compounds harmless: they also synthesize such compounds, thus polluting the aqueous medium. Thus, the activity of microbes results in the formation of harmful compounds of mercury, lead, cadmium, and arsenic in the ground. These compounds prove to be more toxic than the metals themselves. They are much more mobile than the metals and are easily returned to the water, giving rise to zones of secondary contamination. A large number of oil-oxidizing bacteria have also been found to be toxic. This fact cannot be ignored when oil-oxidizing cultures are employed to remove oil from natural waters.

The subsiding shells of tiny extinct organisms, as well as various other organic remnants, extract contaminating substances from the water, and carry them down to the bottom. This is yet another process of cleaning the water.

There are several ways to determine the vulnerability of a substance to biological destruction in a water reservoir. However, they do not provide a correct idea about the actual self-cleaning of the reservoir, since traces of the intermediate products resulting from the disintegration of a substance are superimposed on them. In addition, a considerable portion of the decomposition of a substance takes place in the grounds, the true value of which has so far only begun to be studied.

At present investigations on the self-cleaning of the ocean medium are actively being carried out, and permissible levels of the discharge of toxic substances are also being determined. Scientists believe that it is necessary first and foremost to study the coastal ecosystems of the World Ocean where three media in which the living organisms dwell exist side by side, viz. land, water, and air, and where the conditions of life, and types of animals and plant organisms are most varied as well as have the greatest density per unit area. It is precisely these regions of the World Ocean that are unique purification units, in which the removal of a considerable portion of the contaminating substances takes place. These zones are subjected to heavy loads, and the determination of limits for the discharge of hazardous compounds presents a difficult task since each zone is characterized by its own physico-chemical as well as biological conditions of life. If the self-cleaning properties of these zones are overrated, they will simply perish, which is exactly the case nowadays with a large number of the coastal regions of the World Ocean. The contamination of the World Ocean today has become a problem precisely because of the overestimation of its self-cleaning ability.

We cannot possibly rely entirely on the self-cleaning properties of the ocean medium. People must now reduce the contamination of the World Ocean to a minimum. And this is where scientific and technical progress can render considerable assistance. For instance, the development of wasteless technology at industrial enterprises is an effective way of preventing pollution of the environment. The measures preventing the contamination of the ocean should begin on land; then the ocean itself can help to suppress evil.

The World Ocean is an ecological system on which the life and well-being of humankind depend. This is exactly why reasonable people have decided to protect it from pollution for the benefit of those living on our planet today and for future generations.

Chapter 8

This Miraculous Ocean

The Islands of Navigators

People who are not professionally connected with oceanology often look upon exploratory voyages as romantic and adventurous exploits. The World Ocean, however, opens its secrets only to those who perseveringly do their mostly monotonous work. And only by chance does one happen upon some unusual phenomenon as was the case with the eruption of the submarine volcano that was later named mount 'Mikhail Lomonosov'. It is also interesting to meet the inhabitants of other countries, and become acquainted with their culture and the natural environment that seems unusual to us. All this brightens up the humdrum days of an expedition.

The story about the World Ocean and its problems would probably not be complete if an account for at least one oceanographic expedition were not given. Thus, the round-the-world voyage of the modern research ship *Academician Vernadsky* has been chosen. It introduced the author to the people whose life and culture are closely associated with the World Ocean.

This expedition set off on its journey from Leningrad. In its programme aimed at studying the relief and structure of the floor, the optical properties of the ocean water, chemical and biological processes, and the factors underlying the interaction of the atmosphere and the ocean, a substantial place was allotted to the investigation of the Cromwell Current.

The Baltic Sea, the Kiel Canal, the North Sea and the English Channel passed before our eyes as if they were patterns in a kaleidoscope. The Bay of Biscay, famous for its storms, let us into the expanses of the Atlantic Ocean without a hindrance. Then came the time for exploratory research and observations. The work seemed to erase the boundaries between the past, the present, and the future. The events of yesterday appeared remote, while what was to come gave the impression of being unattainable. Life aboard the ship melted into a monotonous invariable rhythm of days that were replete with the expectation of some extraordinary events—a sensation that is not alien to anyone in our position.

Day after day, and from one fact to another, the scientists on the expedition continued their travels into the realm of knowledge. We passed the Atlantic Ocean, which left its memory in the materials that were collected by the geneticists in the Sargasso Sea. Marine genetics is a new science where Soviet scientists have proved to be highly successful. A comprehensive study of chromosomes and their variability in fish had been supplemented with the experimental materials of the expedition. Both the geneticists and the geomorphologists were quite successful. At the time that the ocean floor was being measured they succeeded in finding another submarine volcanic summit similar to mount 'Mikhail Lomonosov'

No sooner have we left Willemstad, a port on the Curacao Island in the Caribbean Sea where our ship had made a stop to refuel and to give the crew a rest, when the pleasant coolness of the Pacific Ocean gave way to the stifling heat of the Panama Canal.

Nature seemed to have awarded the crew for their strenuous labour by letting them behold miraculous dawns and dusks, leaving the most absorbing spectacle for those who stayed awake at night. The interplay of the Moon's light with the clouds and water created whimsical patterns, which had a fascinating effect.

The work aboard the ship is scheduled to the minute. Each member of the crew knows exactly when he is supposed to be on duty. Food is served at specific hours and films are shown daily. On warm evenings and when there is no moon, this kind of recreation takes place on deck. But not all the members of the expedition can follow the prescribed timetable. Experimental investigations or the hydraulogical station cannot be interrupted for a break for lunch. To have a quick snack or get an hour of sleep at night one must find a replacement.

The *Academician Vernadsky* began its work in the region of Oceania. This term covers the largest concentration of islands in the world. It is situated in the central and western parts of the Pacific Ocean, Oceania is divided into Polynesia, Micronesia, and Melanesia.

Polynesia, which is derived from the Greek, means many islands. It unites the islands of the eastern part of Oceania, i.e. the Hawaiian, Line, Ellice, Phoenix, Tokelau, Samoa, Tonga, Cook, Tubuai, Tuamotu, Marquesas, and the Society Islands, and a host of small atolls and reefs. The Easter and Pitcairn Islands are also often considered part of Polynesia.

Micronesia ('the small islands'), in addition to very small islets, mainly comprises the Volcano, Bonin, Mariana, Caroline, Marshall, Gilbert, Nauru and Ocean islands.

Melanesia (the 'black islands') includes New Guinea, the Bismarck archipelago, Solomon islands, Santa Cruz, New Hebrides, Loyalty, New Caledonia, Fiji and a number of other islands and archipelagoes that are found in the southwestern region of Oceania.

New Zealand and the adjoining islands form a special zone of Oceania.

The nature of Oceania differs from that of the surrounding continents. The coral and volcanic islands as well as the archipelagoes entering into it have their own plant and animal world, which developed in conditions of prolonged, and at times complete, isolation from the environmental peculiarities of Asia, Australia, North and South America.

The first European to discover Oceania was Ferdinand Magellan, who at the time of his round-the-world voyage, landed on Guam in 1521. In 1567 the Spaniard Álvaro de Mendaña discovered the Solomon Islands. In his wake, in 1606, Pedro de Queirós found his way to New Hebrides. At about the same time Louis de Torres put the strait that separates New Guinea from Australia on the map. The Dutch mariner Abel Janszoon Tasman and the envoy of Amsterdam merchants Jacob Roggeveen made significant contributions to the discovery of new lands in Oceania.

The French navigator Louis Antoine de Bougainville made a round-the-world voyage between 1766 and 1769 during which he visited Tahiti, Samoa, the islands of the Louisiade archipelago and the Solomon Islands. Three expeditions to the Pacific Ocean were conducted by the famous English explorer James Cook. He studied New Zealand and the eastern coasts of Australia, where, in the outskirts of Sydney, an anchor on a pedestal has been placed in his memory. He also acquainted himself with Tahiti, Marquesas, New Hebrides, and Easter Island. James Cook discovered New Caledonia, Norfolk, and the southern group of Hawaiian islands.

From 1803 to 1806 I. F. Krusenstern and Yu.R. Lisyansky, aboard the *Nadezhda* and *Neva* ships, made the first round-the-world voyage in the history of the Russian Fleet, which resulted in the thorough study of a number of islands in the Hawaiian and Marquesas archipelagoes. From 1807 to 1809 and 1817 to 1819 V.M. Golovin landed on the Hawaiian and Mariana islands. In 1814 M.P. Lazarev discovered five islands in Oceania. Otto von Kotzebue, who also visited Tahiti, Samoa and the Hawaiian islands, discovered hitherto unknown lands in the Tuamotu Archipelago and among the Marshall Islands.

Russian navigators made a considerable contribution to the study of this part of the Pacific Ocean. In memory of their achievements, old sea charts contain over one hundred and thirty Russian names, the greater number of which have been preserved to this day; in addition, more than sixty names of this kind can be found on sea maps published outside the USSR.

If Russian navigators pursued only geographical and scientific aims while investigating the Pacific Ocean, the results of discoveries made by European seafarers consisted in the colonization of Oceania. Without dwelling specifically on this problem, it would nevertheless be appropriate to present the following quotation from a reference book of the USSR Academy of Sciences, in which the consequences of the European encroachment on Oceania are characterized.

"Over the past century the population of Oceania has undergone considerable qualitative changes. According to very conservative estimates, when the Europeans first arrived there were 3.5 million inhabitants in that region: 2.2 million lived in Melanesia, 1.1 million in Polynesia, and 0.2 million in Micronesia. The advent of colonizers led to catastrophic demographic consequences in most parts of Oceania. As a result of the introduction of new diseases (to which the Oceanians could not immediately become immune), the spreading of alcoholism and prostitution, the emergence of a slave trade, and the aggravation of internecine conflicts among the Oceanians themselves (which was conditioned by the widely developed sale of firearms), the number of inhabitants on many archipelagoes began to decrease. Thus, in 1890 the aboriginal population of Polynesia comprised only 180 thousand people, and that of Micronesia was 83 thousand."*

Along with the marked decrease in the local population, there was an influx into Oceania of other people, which to a certain extent compensated for the overall shortage of inhabitants in the region. At the end of the last century and the beginning of the present one the dying off of Oceanians

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* *Okeania (a Reference Book)*. Moscow: Nauka, 1971, pp. 29-30 (in Russian).

has stopped, and their number began to increase gradually. This trend found its expression particularly in the postwar period and primarily on those archipelagoes where the people had won their independence.

This region of the Earth, which is known as Oceania, has a number of interesting features. The emergence of local islands is closely connected with the structure and tectonics of the Pacific Ocean floor. The echo sounders of the *Academician Vernadsky* examined the floor metre by metre. Members of the team that was measuring the ocean's floor were at their registers all the time and thus were able to collect much valuable information about the ocean-bed relief. For instance, in the deepwater depression of the World Ocean—the Tonga trench—which represents a narrow gorge, they discovered a rampart that was up to 130 metres high and extended along the trough over 60 miles; near the Gilbert Islands they found a hitherto unknown fault in the ocean bed, which was confirmed by a magnetic survey.

After five days in Sydney, where participants of the expedition met Australian scientists to exchange scientific information, the *Academician Vernadsky* went to the equatorial zone of the Pacific Ocean to investigate the Cromwell Current. This was the beginning of one of the most strenuous periods of exploratory work—the installation of buoy stations. In order to carry out the required observations, the time of operations was scheduled to the minute. The installation of this kind of station at depths measuring several kilometres calls for complete coordination in the work of the crew and scientists.

In accordance with an earlier established schedule, the navigation officers steered the ship to where the station was to be set up. As soon as the engines stopped, the sailors lowered anchors that were attached to a rope coiled over the drum of a special winch, which by order of the director of the installation, was then set into operation. Under the weight of the anchors, the rope began to disappear into the water. Periodically its movement was halted to attach by means of a small bracket a current meter for measuring the velocity and direction of the currents. It took one and a half hours of very hard work to set up a number of such meters on the rope. Then the sailors, with their boatswain in the lead and with the help of cargo booms and winches, raised the buoy over the deck. The rope with a string of current meters going down into the sea was taken off the drum and fastened to it. With a turn of the cargo booms and a few succinct orders, the buoy, now in water, began sending us joyful greetings via its signal lights.

After this the *Academician Vernadsky* set off to where the next station was to be installed. Within twenty six hours it returned to raise the buoy station, which had taken the required measurements. The results were immediately dispatched to the computing centre, where a spotless environment, electronics and the coolness provided by air conditioners reigned supreme.

After two months of our voyage, time seemed to have slowed down making the days seem much longer. How pleasant it was to find on such days a radiogram from home that had been carefully delivered to one's cabin by the ship's radio operator.

The *Academician Vernadsky* continued westward from station to station along the equatorial zone of the Pacific Ocean. Its itinerary included the Gilbert Islands that formed Micronesia. This archipelago consists of thirty-seven islands and atolls. They are said to have been discovered by the Spanish navigator Mendaña. From the second half of the eighteenth century to the end of the first quarter of the nineteenth century the islands were constantly being investigated by the English. In 1892 they were declared a British protectorate, and in 1915 the islands became a British colony.

Our ship entered the lagoon of the Tarawa atoll and anchored near Betio island whose steep shore is almost completely edged with palms. Their luxuriant crowns serve to protect the island from the rays of the bright tropical sun.

During the Second World War the Tarawa atoll was the scene of heavy battles. To mark the expulsion of the Japanese aggressors, an obelisk was erected at the top of a jetty, guarding the channel leading to the island. On November 20, 1943, American marines landed on the island and almost completely destroyed the Japanese garrison.

Even today the island bears many traces of war. Remains of damaged tanks and landing barges can be found in the water, while the heavy artillery batteries with twisted guns and reinforced concrete shelters on the shore still serve as sad reminders of the past war.

The island has a school for young navigators, which prepares them for local seafaring routes. The teachers of that school, the English civil servants, who are part of the administration, and the local elite live in comfortable cottages that are buried in verdure. Most of the aboriginal inhabitants, however, find hardly enough room in tiny frame-end dwellings with corrugated metal roofs. Some of them live in huts hardly separated from each other. Many live in shacks made of pieces of rusty iron, rags, parts of broken cars and palm branches.

There is no freshwater on the island; therefore, on the roofs of the dwellings and even the shacks there are gutters with containers for collecting water. Some researchers of Oceania claim that on the tropical islands freshwater had not always been vitally essential. In ancient times the inhabitants of the islands bathed in the ocean; when their very simple clothes were soiled they replaced them with new ones; food was prepared in stoves made of earth, for which water was not required; and they quenched their thirst with coconut milk.

The islanders grow coconut palms, fish, and raise poultry and pigs. They seem to care more for the pigs than for their children. On the whole the economy of the Gilbert Archipelago is based on the production of copra—the dried meat of the coconut—and the mining of phosphorites. The owners of these industries are naturally English companies.

In the tropical latitudes of the Pacific Ocean, where on entering the Tarawa atoll the expedition continued its work, the water within the vast spaces is characterized by a high degree of transparency. This is indicative of the poor development of life. However, as a result of the interaction of currents and the exchange of water masses, the transparency of water in these parts is susceptible to marked variations. The stable trade-wind currents wash over a large number of islands and atolls, on the lee side of which there are bursts of trade-wind jets with the rise of deep waters that are rich in nutritive salts and plankton. This is why very specific oases of life—a chain of murky water abundant with fish and other ocean dwellers—are found around islands and atolls extending to a far distance. The cosmonauts saw them when they spoke of what seemed to be floating islands.

What awaited us next was Polynesia—the land of romantic beauty, which was celebrated by navigators and writers and immortalized on the canvases of Paul Gauguin.

In Polynesia there is an archipelago that includes the islands of Upolu and Savai'i. This is where the independent state Western Samoa is situated. The first navigator to notice this archipelago was Jacob Roggeveen.

The evergreen mountainous island of Upolu buried in wanton vegetation, where there are many dormant volcanoes and solidified lava fields, served the expedition as a place of brief respite. The rich beauty of the local environment instantly relieved the tension that anyone is bound to experience in unfamiliar surroundings. For instance, the littoral zone, which was the first thing to come into view when our ship was approaching the island, is really one of the most beautiful places on Earth. At a distance of one mile from land it is possible to see the dark lines of coral reefs against which powerful ocean waves break in their wrath to become thin spreading layers of white foam. Near the shore, knee-deep in water, the fishermen throw a thin net over a shoal of small fish. In the deeper parts of the island mountain tops over-grown with greenery reach the blue sky. Everything is so perfect and beautiful that one cannot help but be filled with delight.

There was a feeling of coolness through-out the island, if that is what one could call the warm humid air replete with the sweet scent of copra that mixed with the intoxicating breeze having the aroma of a tropical forest. All of a sudden the sky was covered with clouds. But cloudy weath-er is incompatible with our perception of sunlit tropical countries. The rainy weath-er does not last long, the clouds are scat-tered, the sun shows up again and the lus-cious foliage of the forest along the moun-tainside finds its reflection in the blueness of the ocean.

Apia, the peaceful and enchanting capi-tal of Western Samoa, is located on Upolu Island. The main street of the town stretches along the shore. The wooden houses on it are either one or two storeys high. There are many churches among them. Religion plays a highly important role in the contemporary life of Samoa. Churches are built with great care and are crowned with tall belfries. This part of the town is inhabited by distinguished people and businessmen, as well as by Europeans, Americans and others from the continents, who are few in number. The common people, however, live on the outskirts, mainly in what are known as native Polynesian huts. They are formed by digging poles into the earth and covering them with palm leaves that serve as a cone-shaped roof. The coconut plantations begin immediately outside the town. Sumptuous crowns of coconut palms provide life-giving shade below them. These trees have for a long time been an exotic symbol of the Pacific Ocean islands. The cool juice of the coconut, which looks very much like milk, is actually a splendid fluid that quenches the thirst, while its meat is used as a food product. Hence, it is not surprising that copra is called the bread of the Pacific Ocean.

The Samoans traditionally lead a very quiet life. It is customary to hear them say that if a Samoan has healthy children, a pretty wife, his own hut and canoe, a banana and coconut tree, and some pigs, he may well be called bright, i.e. he has everything in perfect order.

The Samoans preserve many Polynesian customs and traditions from the olden days. This is most clearly seen in the villages. As a rule, several dozens of families live in a village. The Polynesian concept of a family is quite different from our own views. A Samoan family consists of very many people who are related to one another by consanguinity, matrimony, or adoption. This kind of family is headed by its senior member, whom the Samoans call *matai*. He does not necessarily have to be older than the rest of the family. *Matais* are elected by the whole family and the procedure itself represents a sort of competition of intellect, sagacity, ingenuity, and other qualities among the contenders. The family is interested in keeping up its reputation, and when it comes to electing their leader, naturally gives preference to the most worthy person, rather than to one who is merely advanced in age. The *matai* must conduct himself in a way that does credit to his title and must honour those whose social position is connected with his own. The unanimously elected elder is responsible for controlling the land and other items of property as well as for the distribution of labour and products among the members of his family. The *matai's* role is particularly apparent at the time of weddings, the birth of a child, the reception of guests, and the death of a family member. The family renders its elder specific kinds of service. For instance, if his daughter is getting married, he asks the whole family to get together and they all decide who will make the bride her dress, who will see to the presents and the cooking, in addition to the traditional entertainment, which quite naturally includes singing and dancing. The Samoans said that no objections had ever been raised when assignments of this kind were distributed among them.

Matais are part of the village council, which is headed by their leader. Meetings take place in a specially built hut. The number of pillars in it corresponds exactly to that of the *matais* in the village not excluding the leader himself. This hut looks very much like an ordinary dwelling. The floor in it is covered with screw pine (*Pandanus*) straw mats. It should also be mentioned that Polynesian huts are built without a single nail or any other metallic fastener. Beams are connected by ropes that are made of coconut fibres.

In the hut where the village council meets and which is called 'fono' each *matai* has his own pillar, against which he leans with his back so that he can face all those present. When the council is holding its meeting everyone passing by the hut is prohibited from riding a horse, driving in a carriage, walking under an umbrella or carrying a load on their shoulders. Thus, to show his respect for the leaders, a passerby must dismount from his horse, fold up his umbrella, and remove the load off his shoulders before going by the house where the meeting is held.

Samoan customs are not always readily understood, but at the very basis of most of them lies respect for their seniors. For instance, one does not have the right to take anything in the village without the permission of the leader. The Samoans show great respect to those who duly acknowledge their leaders. In this case they will do everything to please the visitors. It is noteworthy that there are several leaders in a village, and each one of them has his own duties. Thus, there is a special leader who sees to it that the traditions are properly observed.

Western Samoa is a world of amiable, hospitable, and strong people. In the streets of Apia we can see tall athletic men, whose brown skin shines brightly in the Sun from the coconut oil that has been rubbed in. Handsome round-faced women of dark complexion have smooth and somewhat plump figures.

Corpulence and white skin are considered beautiful by the Polynesians. Those who have studied this region have noted that in notable families there was even a custom whereby the children were kept in dark rooms where they were abundantly fed and 'whitened'

The Samoans love dancing, singing, and sports; probably what appeals to them most are the ceremonies, which are accompanied by a refined ritual. A case in point is the very old ceremony known as 'kava'—a ritual that enjoys great respect in Samoa. Kava is an intoxicating drink which is served when important guests are entertained or on some particularly joyous or mournful occasion. This drink is prepared by the most beautiful girl of the village. The way it is consumed is regulated by rigid etiquette. The leaders sit in mute expectation while the drink is being made. Then the bowl passes from one leader to another. Attention is naturally focused on the supreme leader. He is completely absorbed in profound meditation and thus should not talk with either the members of his tribe or the guests. His functions in this respect are taken over by the 'speaking' leader who expounds the deep thoughts of the one who keeps silent.

According to the custom, several drops of the bowl's contents must be spilt on the ground—for the gods—and only then can the fluid be tasted having said the word *manuna*, or 'good luck' The drink is not drunk to the last drop. A little of what is left is again poured on the ground, after which the empty bowls are handed back to those who had brought them.

The inhabitants of the island warmly greeted the participants of the expedition and tried to help as much as possible. It didn't take us long to become friends. We spoke English, Polynesian, and Russian. The babel of tongues made it seem incredible that anything coherent could be made out at all. And yet all was clear and nothing remained unsaid.

A lissome Samoan, who treated us to nature's invigorating beverage, peeled off the outer greenish cover of a coconut by striking it against a pointed tool with movements that had been worked out over centuries. He showed us three hollows on the shell that looked very much like the eyes and mouth of a human being. These features of the coconut had given rise to the poetic myth about the origin of the coconut palm. According to the legend, the eel Tuna and Khina, the beauty, loved each other very dearly. But the envious and jealous admirers of Khina agreed to destroy this love and kill her beloved. Tuna found out about this plan in a prophetic dream, and when he saw his love for the last time, he told her of the impending doom that could not be averted. He asked her to cut off his head after his death and bury it in the ground, and he promised that it would give rise to a tree. The fruits of the tree would provide Khina with food and drink, and lest the object of his adoration should forget him, on each fruit she would see Tuna's eyes that at one time were delighted to behold her and the mouth that spoke to her the words of love.

Khina did what she had been asked. Soon a slender coconut palm covered with a green crown and elongated fruits sprung up. When Khina peeled off the fruit's outer cover she saw on the nut filled with delicious flesh and pleasant juice the eyes and mouth of Tuna.

One of the remarkable events in the course of our stay on Samoa was the acquaintance we made with a group of young people who performed national songs and dances. Once, in the suburbs of Apia, we caught the sounds of Polynesian songs. They reached us from a pavillion that was open on three sides. Those watching the folk concert immediately became the guests of the ensemble, which was conducted by a tall middle-aged Samoan. The concert was unforgettable. For one-and-a-half hours songs and dances were continuously alternated. The performers were indefatigable. Young men of strong build wore bright skirts and necklaces of shells and white flowers decorated their chests. While the girls in bright light dresses wearing flimsy colourful skirts woven out of tapa over them were totally engrossed in the dance. The dance involves the participation of absolutely all parts of the body: hands, feet, fingers, shoulders, hips, eyes, brows, and head. Some of the dancers had tattooed arcs fringing a complicated ornament that began a little above the knees. In Samoa mainly the thighs are tattooed. The guitars and Polynesian wooden percussion instruments that accompanied the dance produced a non-stop musical effect. The dances were emotional, sensual and expressive to the utmost degree. Dancing is a part of Polynesian culture and practically any event can set off a whole series of rhythmic dancing movements symbolizing labour, joy and other aspects of life.

It is impossible to convey the charm of those songs and dances: one must see and hear all this oneself. And one cannot help but agree with travellers who say that without getting acquainted with Polynesian songs and dances no person can say that he or she knows something about this wonderful land, since the function they have in the life of Polynesians is no less significant than food, sleep, and love.

One of the most interesting features of Western Samoa is the house situated at Vailima near Apia. It once belonged to Robert Louis Stevenson, the author of *Treasure Island*, who came to these parts when he was already a famous writer. His lung disease forced him to look for a place with a mild climate. He was recommended to settle in Italy, but his family decided that they should all go on a voyage in the Pacific Ocean to find a new place to live. When Stevenson was in Australia his health deteriorated and the doctors' verdict was 'Oceania or death!'

In 1889 Stevenson landed on the shore of Western Samoa. At that time German, English, and American cruisers were patrolling near Upolu Island. In those days Apia was the centre of political intrigue: foreign diplomats were planning the annexation of the islands in the southern part of the Pacific Ocean.

The Europeans and the native population of the island helped Stevenson to build a large house and he settled down. In a letter to his friend he wrote that he had found happiness and peace, and that the local people had come to love him. At first Stevenson became friends with the German, English and American consuls, but after some time he saw very clearly that tyranny reigned supreme on the island. The Europeans were brutally exploiting the native inhabitants and were mocking their customs and traditions. Once and for all Stevenson became the defender of the Samoans, who admired him and to whom he was forever known as *Tusitala*, i.e. the storyteller.

Stevenson published a book in which he told the truth about British colonial policy. He demanded that the consuls treat the local population humanely. All this won Stevenson the devotion of the Samoans. In 1893 they built a road connecting the writer's house with the shore and called it the 'path of the loving heart'.

In Western Samoa the writer produced *The Beach of Falesa*, *David Balfour*, and other books. In all his writings of those days Stevenson openly and dauntlessly took the side of the oppressed, proclaiming good and despising evil.

In December, 1894 Stevenson died. The islanders buried him on top of the extinct volcano Vaea. With their knives and axes they cut a tomb in the form of a sarcophagus and on one side the words 'The Grave of Tusitala' were incised. The other side bore the words of Stevenson's epitaph written by him long before his death.

The life of Samoans as well as of all Polynesians is closely connected with the ocean. Navigation greatly influenced the development of their culture. Since olden days Polynesians have been known to be wonderful navigators and seafarers. Their oceanic voyages represent a glorious page in the history of humankind. At one time, the French traveller Louis Antoine de Bougainville was astounded to discover how proficient the inhabitants of Samoa were at building their boats and sailing them. He called the archipelago "the Island of Navigators"

It can well be said of the Polynesians that they are the only people on Earth who came to their new homes via the sea, though even today the Samoans associate the islands with the legendary Hawaiian ancestor and think that they originated precisely on these islands. Some ethnographers refer Samoa to the centre of Polynesia. Although in geographical terms the assumption is tenable, it cannot be considered irrefutable as regards the cultural impact on Polynesia and the migration of people. However, without delving deeper into ethnography, we can quite assuredly call the Polynesians, and the Samoans at that, the children of the ocean, its integral part. This is what distinguishes them from all others in the world.

In the western part of Upolu Island there is a place connected with the history of navigation. It is Cape Lefatu. It is surrounded by a picturesque littoral zone twenty-five kilometres in length. Its landscape is considered to be the model of beauty of the South Seas. In ancient times many large canoes sailed off the tip of this cape towards the scattered islands and atolls in the Pacific Ocean. The local legend says that it was exactly on Cape Lefatu that in the year 1250 the Samoans won a decisive victory and expelled the aggressors from another archipelago, who had occupied Samoa in the first half of the thirteenth century.

On January 1, 1962, Western Samoa became an independent state. Colonialism had left deep traces on the political, economic and cultural life of the new state. Agriculture forms the basis of its economy. Modern industry does not exist there as such. The Samoans are doing their best to rid themselves of the insidious consequences of foreign rule. They have already done much to resuscitate their national economy, culture, and art. There can hardly be any doubt that the talented Samoans will overcome all difficulties.

We came across a very interesting fact in a small village on the ocean shore. The first thing that struck our eye was a graceful canoe that was fit to carry no less than one hundred people. It was in such boats that the great voyages were made in the distant past. The boat was protected from the rays of the scorching sun by a cover of palm leaves. The polished sides of its body made of sturdy dark brown wood shone brightly. A very complicated ornament of woodwork decorated the bow. It was a work of art in the true sense of the word.

Along the shore and near the water were small canoes belonging to the local fishermen. These boats are designed in a very interesting way. The long and narrow bottom is cut out of a whole chunk of wood and wooden planks form its sides, each of which consists of three units. All the parts of the hull are firmly attached to each other by means of ropes that are made of coconut fibres as in ancient times. These ropes do not deteriorate from the rain or seawater, and are thus safely used for various construction purposes. The ropes are passed through small holes, which are thus completely closed so that water cannot get into the boat. The hull of the boat is connected with the beam by means of poles. Ropes are also used for this purpose. The boat is built without a single nail.

This fact serves as proof that though the glory of Polynesians as navigators has fallen into abeyance, their ancient art of making boats has not become obsolete at all.

At the end of our sojourn on Upolu Island we made excursions into its deeper regions, which looked so different as compared with the scenery of the shores. There, in the canyons, waterfalls were rushing down; the smooth waters of transparent lakes seemed to be reflecting in a mirror the blooming vegetation around them, and turbulent mountain brooks were making their way through the rocks. The summit of Upolu Island looked out on Sawai'i—the second largest island of Western Samoa—which can be reached in a local boat within one-and-a-half hours.

Time went by very quickly, and it was a pity that we had to part with the island that we had grown so fond of and its amiable and gifted people. The *Academi-*

cian Vernadsky left the port of Apia during a downpour. Rain is a good omen when one sets off on a journey. Judging by our own impressions of Samoa and its inhabitants we could not but wholeheartedly agree with this omen.

We left Upolu Island behind, and a blue cloudless sky spread out over the ship. It reminded us of the paean of ancient Polynesian navigators that was addressed to the God of the Ocean:

O, Tangaroa, in the boundless space!
Disperse the clouds of the day,
And those of the night.
Let Ru behold the firmament with stars
And have them lead him to the land of his desires.

The Coral Islands

In the western part of the tropical zone of the Pacific Ocean some mighty hand seemed to have scattered upon its surface a garland of coral atolls, which are several tens of kilometres in diameter. It is hard to imagine that these enormous structures were erected by the most primitive types of organisms.

One cannot but feel amazed when seeing an atoll for the first time. The coral atoll comes into view almost unexpectedly, emerging over the horizon as if it were a mirage. Upon approaching the atoll it appears that the mirage submerges and what we see before our eyes is an island with a refulgent interplay of light and colour. Throughout their length, the steep shores of the atoll are covered with palm trees that stretch their luxuriant dark green crowns towards the blue sky. The heavy ocean waves that cast their blue shadow over the green waters of the lagoon break upon the reef in a torrent of foaming tide near the immaculately white shores.

For more than a century scientists have been trying to explain the origin of atolls—this truly remarkable phenomenon of nature. The characteristic structures of coral formations, among which atolls are distinguished by their specific contours, indicate that they possess the key to understanding a number of important processes that take place on the ocean floor, since there is some reason to assume that the atolls keep the agelong annals of the fluctuations of the ocean floor level.

An active role in the creation of coral islands is played by coral polyps in addition to such reef-building organisms as lime-secreting algae, which often perform a substantial, and even the main, function in structures of this kind. However, with their exotically attractive appearance, the corals outshine the other builders of these unusual constructions and usurp the renown of modest toilers. It is precisely for this reason that the noun 'atoll' is preceded by the adjective 'coral' as its qualifier.

As far as the origin of coral structures in the ocean is concerned, scientists share quite different opinions. The first scientific explanation for the origin of atolls was furnished by Charles Darwin. In accordance with his theory coral islands emerge in the course of a slow subsidence of the ocean floor. This theory has not been universally recognized, though until now it has not lost its significance. Numerous attempts to revise it have so far been vanquished by the results of geological and geophysical research.

The reef-building organisms can live only within a restricted interval of depths. Their active growth is connected with the wave-cut zone, where owing to the intense mixing of waters they are sumptuously provided with nutritious substances. The life and development of reef-building organisms also necessitate an abundance of light, high temperature, a specific salinity of the water with an adequate quantity of oxygen in it and a low concentration of carbonic acid. This is why the tropical islands present a wonderful object for the settling of corals and the formation of barrier reefs around them. When the island becomes submerged, the reef fringing it grows in height with corals and becomes a barrier reef. However, when the island disappears in the depth of the waters, a ring reef, or atoll, remains in its place on which under the activity of waves islets accumulate formed by fragments of corals that are firmly cemented by calcareous material. The width of these islets does not usually exceed five hundred metres, while the length varies from tens of metres to several kilometres. These islets, looking like a necklace with elongated beads, form an atoll with a lagoon where slow-growing types of corals that prefer calm waters take root. Together with the small skeletal fragments of calcareous organisms, which are washed into the lagoon by tides, they cover its floor.

A typical representative of coral islands is the Tarawa atoll in Gilbert archipelago. The floor of its lagoon is covered with coral sand, and wilted shrubs of corals rise over it. The Sun's rays illuminate a myriad of tiny particles in the water, which reduce the visibility to several metres. On the other hand, the landscape under the water on the outer oceanic side of the atoll, which is washed by transparent waters, is really beautiful. This is where we have a variety of colours and forms. What we see is a kaleidoscope of multicoloured colonies of corals that may be big and branching like bushes, rounded like handmade bowls, shaped like globes made of filigree plates, or like roses woven from delicate petals. Iridescent little fish move freely among the corals. They are not even afraid of humans in the water, and continue to assiduously bite at the coral shrubs. Gastropods crawl on the bottom, while resting within the depressions are the 'traps of death', or Tridacnas, whose weight can reach several hundred kilograms. Under the fragments of corals sea urchins covered with notched spines also take refuge.

The corals, as well as many other ocean dwellers, are subject to storms and typhoons, which sometimes erase considerable areas of reefs and cast what is left of them onto the shore. What cannot escape notice is that there is not a single islet of atolls that rises over the ocean surface to heights greater than those that could be reached by the fragments of coral rocks thrown by the waves. Changes in the contours of atolls can also take place due to frequent earthquakes in the Pacific Ocean. It is not infrequent that the further growth of reefs is affected by the tropical rains that freshen the ocean water around the islands and are hazardous for the corals.

Darwin thought of substantiating his theory by drilling a deep hole on some atoll so as to reach the root foundation of the island. This was destined to take place at a later stage. The first attempt to do the drilling was undertaken from 1897 to 1898 on the Funafuti atoll. There the borehole reached a depth of 334 metres. It went through the cemented surface of the coral material, the friable calcareous sand, the rock that looked like chalk, and the dolomites that alternated with soft and brittle formations. All the deposited layers through which the borehole passed represented rocks of organic origin. Further drilling seemed to be impossible. According to Darwin's theory the floor within the region of Funafuti atoll sunk to a depth exceeded that reached by the borehole since reef-building organisms, which can live only near the ocean surface, were found in all the rocks.

Not long ago drilling on the Marshall Islands revealed that the atoll where the borehole was made had a volcanic foundation under it. In other words, the volcano that had disappeared in the deep was covered with a thick calcareous mantle that originated at a depth of 1400 metres below the ocean level. This confirmed the prognostication of the great natural scientist Darwin, at least in respect of a particular group of islands. However, there are still many gaps in the knowledge about the origin of coral structures, which continue to stir the inquisitive minds of scientists. The only fact that does not call for special comment is that the ocean and the inexorable wind are the creators and the destroyers of coral islands. These islands that hardly rise over the water surface now grow fast, now slow, now seem to be on the verge of destruction or disappear altogether. And their origin continues to remain a mystery. They are a kind of tombstone on top of the submerged islands. Almost every atoll, although it may rise to only several metres above the ocean, crowns the summit of a steep peak that is higher than many mountains on land. In the foundation of atolls there often lie volcanoes that have been extinct for between seventy and one hundred million years.

Important technical and biological aspects are involved in the study of coral structures and particularly the corals themselves. Thus, in tropical countries, the skeletons of madrepore corals have long been used for the production of such building material as lime. Chalk and cement are also produced from them. Japanese dentists have recently begun using coral material for tooth fillings. They say that coral fillings and dentures are more durable than those made of the usual stomatological materials.

The ancient manuscripts contain recipes for medicinal compounds containing corals. These compounds were employed to treat melancholy, as well as heart, brain, stomach, and liver disorders, and rheumatism and fever. The recipes are as naive as they seem. But contemporary medical science reveals that the people of ancient times were able to see the medical value of corals. Suffice it to say that the use of black corals, gorgonians, is nowadays not excluded. Over the past decades scientists have established that certain corals contain biologically active substances, such as prostaglandins, which stimulate protein, carbohydrate, and mineral metabolism in the living organism. This is where scientists are confronted with problems of extreme significance, whose solution will provide indispensable preparations for the prevention and treatment of a large number of diseases that affect human beings and animals.

In recent years researchers have started regarding coral formations as possible collectors of oil. What started this was the fact that corals and lime-secreting algae, which are closely connected with them and had existed for over 500 000 million years, constantly covered a substantial amount of organic remains that could be transformed into oil products.

In the USSR, near Sterlitamak, there are high hills, or shikhans as they are called, which represent reef formations and are used by scientists as the basis for establishing the regularities that underlie the distribution of the remains of living organisms in contemporary and buried reefs. It should also be mentioned that certain gas fields are geographically correlated with these reef formations now buried on land. Hence, there is every reason to believe that coral islands in the World Ocean can turn out to be the receptacles of oil or gas.

The Sea Without Shores

There is a part of the World Ocean, which though not confined by land, nevertheless has every right to be called a sea. It is known as the Sargasso Sea or the sea without shores. Its boundaries are formed by currents that cover the expanse of the ocean with a huge oval ring, within which there is hardly any noticeable and consistent movement of water. The enormous oval of the Sargasso Sea extends over five thousand kilometres from the west to the east and over two thousand kilometres from the north to the south. Calmness and mildly alternating winds prevail over this sea. Its water is as blue as the sky above it. The azure of the sky and that of the exceptionally transparent water are shaded by the yellowish and brownish coloured seaweed (of the genus *sargassum*) that float either singly, or in bunches and even whole fields or bands. One square kilometre of the sea surface accounts for between one and two tons of seaweeds on the average. Because of the absence of storms and tempests the sea was called the 'Lady's sea' in the Middle Ages.

The Sargasso Sea was discovered by Christopher Columbus during his first voyage to the New World in 1492. In *Essays on the History of Geographical Discoveries*, published by I.P. Magidovich, this event was described as follows:* "On September 16 a lot of bundles of green grass that seemed to have been recently torn away from the soil gradually came into view." However, the fleet had for three weeks been moving westwards across this strange aqueous space, where "there were so many weeds that the sea looked as if it was swarming with them". The lead was cast several times but did not reach the bottom. In the first days the vessels driven by the fair wind moved easily through the weeds until the weather became quite calm and they practically ceased to sail altogether... "Since the sea continued to be calm and smooth the people began to grumble that the sea in those parts was very strange and the winds would never start blowing again and they would never be able to return to Spain."

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* In the literature on Columbus's voyages it is recorded that his own diary had been lost. The existing *Diary of the First Voyage* by Christopher Columbus is actually only a rendering produced by Bartolomé de Las Casas, to which the reader is referred by I.P. Magidovich.

As can be seen, Columbus confined himself to only brief comments on the Sargasso Sea. On the other hand, the travellers of a later period created many a tale and legend about it. Time has dispersed wanton fantasy, primarily that concerning the alleged fact that the sargasso weeds impede the movement of ships and even capture them. It is indeed very strange at present to read notes on the Sargasso Sea that were made in the middle of the last century by such navigators as William and Robert Chambers. In their words, this sea was a tremendously large cemetery containing the parts of all types of ships and tonnage, covered with algae and shells. They thought that the Sargasso Sea was the centre of a huge whirlpool and that all the ships that were either lost or retarded in their movement by the calm had been mercilessly dragged into the centre of the whirlpool. This absolutely whimsical story further stimulated the fecund imagination of science fiction writers.

The author of this book observed the Sargasso Sea on two occasions, and what was most remarkable about it was the fact that it had a very specific living world of its own—a world that one could seek in vain to find anywhere else.

The sargassum weeds lead a plankton-like way of life and are entirely independent of any littoral zone. For some time scientists were unable to find out where these algae came from. Only recently it was thought that they are brought there by currents after they become separated from the shores of the Antilles, the Bahamas, Cuba, Jamaica, and the coast of the Gulf of Mexico. It was assumed that in the Sargasso Sea these algae live afloat for some time after which they die and drop to the bottom. It was explained that the algae sink after becoming overgrown with tiny marine animals and a calcareous cover, as well as after the loss of gas that is contained in the floats that look very much like grapes collected in whole bunches. However, one thing is quite clear: the dead algae do sink. They reproduce and live in the Sargasso Sea. They reproduce by gemmation.

The sargassum weeds, like a dense forest or thicket, serve as a habitat for whole populations. They are inhabited by specific types of shrimps, little crabs, sea-horses, molluscs, worms, and hydroids. All the inhabitants of the seaweeds bear traces of the colour of the weeds. Small lumps of the roe of flying fish are attached to the algae. Great pipe-fish, porcupine fish, and mackerel freely float among the seaweeds. A school of flying fish fly up from the water and glide over its surface, making sudden turns to avoid their dangerous pursuers. Another remarkable dweller of the weeds is the sargassum fish whose configuration and colour repeat the leaf-like parts of plants. The lateral fins end in digital appendages with which this fish crawls along the algae. It is sometimes impossible to catch sight of this fish that hides itself among the weeds.

There are cases when Siphonophora (remarkable medusa-like creatures, which have a special kind of swimming bladder and long tentacles) became hopelessly entangled in the weeds. When the weather is calm, or in the absence of a current, these tentacles hang several metres down so as to catch food. If the wind starts to blow or the Siphonophore gets into a current, it stretches its tentacles almost horizontally thus forming something like a train. The tentacles of the Siphonophora are located on only one side of the fin. This helps these organisms to overcome the deviating impact of the Earth. It should be recalled that it is the Coriolis force that explains the deviation to the right of water masses and streams in the ocean of the northern hemisphere, and to the left in the southern hemisphere. Correspondingly, the Siphonophora of the northern and southern hemispheres of our planet have an opposite asymmetry in the arrangement of their tentacles. It should also be added that Siphonophora are beautiful and poisonous at the same time. Any contact with them

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causes skin burns because of the toxin secreted by the stinging cells that are located in the surface layer of the skin of Siphonophora.

Living organisms have a remarkable quality of accommodating themselves to the environmental conditions. The Soviet biologist N.I. Tarasov states that the characteristic structure of Siphonophora, which have only recently been understood by the scientists investigating the laws governing the movement of liquids, reveals the great power of natural selection in the animal kingdom. For many millions of years the Siphonophora that could accommodate themselves to the conditions of movement survived.

The sargassum weeds prefer warmth and cannot stand any marked drop in the water temperature. This is why they are not brought by the currents up to the shores of the continents. A bottle thrown into the currents that encompass the sea completes the circuit in the course of two or three years. What most often becomes the exit from this clockwise rotation called the 'sargasso roundabout' is the Gulf Stream.

The ocean currents, which become either weaker or stronger, are dislocated in space. These variations depend on a large number of factors, including the seasons of the year. Corresponding to these fluctuations, the borders of the sea without shores also change. The central part of the sea coincides with a region of high atmospheric pressure, or the anticyclone, for which reason calm weather, alternating winds, and a clear sky are preponderant in the Sargasso Sea.

The surface waters of the Sargasso Sea, which account for nearly sixty types of flora and fauna, are extremely sparse in plankton. This is why they are so transparent and blue. The upper two hundred metres of the Sargasso Sea are approximately fifty times sparser in plankton than the waters of the cold Norwegian Sea. On the other hand its depths abound in plankton, which are also quite varied. One more interesting fact that should not be ignored is that a number of planktonic organisms dwelling in the deeper regions of this sea can be found on the surface of the Norwegian Sea.

Near the surface of the southwestern and central parts of the sea without shores, the larvae of American and European eels are found. Within these regions of the Sea, at depths of about four hundred metres where there is practically no light at all, eels that have come all the way across the rivers of two continents spawn once in their lifetime. The newborn eels then set off on a long journey back to those rivers whence their progenitors came. They will live there for several years only to also retrace the path predestined for them by nature.

The floating accumulation of sargassum weeds, which comprises over fifteen billion tons, and the fauna that inhabits them take an active part in the life of our planet's biosphere. Biologists have estimated that the nocturnal 'inhalation' of oxygen by the sargassum weeds is equal to tens of billions of litres. In the daytime the weeds return a hundredfold amount of life-giving gas into the atmosphere. These weeds intensely accumulate vitamin B_{12}, which is formed on the basis of the cobalt contained in water. According to scientists, the sargassum weeds contain many metric centners of this biologically active substance.

The Sargasso Sea is one of the yet unstudied and attractive regions of the World Ocean, which presents enormous scientific and economic interest. It should be mentioned that this area, as well as the whole World Ocean, is greatly jeopardized by pollution from oil products, from wastes resulting from human activity, and from other components. Traces of this pollution are particularly apparent when we examine the branches of sargassum weeds. In many places they are covered with a film of oil, while among the grape-like floats there are a great amount of congested lumps of oil.

The unique plant and animal world

of the Sargasso Sea requires a rational economic approach as well as protection, which, however, cannot be achieved without studying the sargassum weeds and their unusual population in order to discover how to promote the reproduction of this remarkable flora and fauna.

The Variegated Ocean

The ocean is multifariously colourful. We can observe it for hours on end never tiring of its seeming monotony. When the weather is calm, the unruffled mirror-like surface of the water lighted by the Sun looks white, particularly near the horizon, whose contours are blurred rather than distinct. But as soon as a gentle wind leaves ripples on the ocean, it acquires a rich blue colour that starts playing upon its surface. It only requires a cloud to cover the sun for the water to immediately darken. When the sky is covered with heavy rain clouds, the ocean becomes as leaden and morose as the sky itself, and at sunset the water blazes with a purple colour.

Direct and scattered radiation falls on the surface of the World Ocean. To a great extent it is reflected by the water, but some of it penetrates into the darkness of the depths. It is the reflected light that is responsible for the inconsistent colour of the ocean surface. The fact is that its spectrum is practically identical to that of the light that floods the water surface. This is precisely why on a clear day the blue colour of the sky is seen in the ocean, whereas on a cloudy day, all that we can see in the water is the darkness of clouds.

However, the colour of the World Ocean is due not only to the reflection of the light. If this were the only factor, all the oceans and seas would look exactly alike, and would change their appearance only with a change in the weather, time of day, and seasons of the year. But every little part of the World Ocean actually has its own colour, and this has even found its expression in the names given to a number of seas.

An ocean's individual colour is connected with the luminous radiation that penetrates into the depth of the water mass and which on its way is many times scattered by the water molecules themselves as well as by the minutest particles contained in the water, and plant and animal organisms. In addition to this, a particular amount of light is thrown back forming a flux of light reaching the water surface. This results in that the water returns to the atmosphere a part of the light that has entered it, which already has a spectrum that is markedly distinct from the luminous radiation that falls on the ocean.

Pure water usually releases the blue component of the light flux. The presence of particles and some organisms, depending on their nature and concentration, displaces the spectral component of the ascending radiation into the green and even yellow region. The Yellow Sea can serve as an example. It owes its name to the colour of the waters washed from the land with loess-like deposits. The colour of the Red Sea can be explained by the periodic blooms of microscopic blue-green algae, which at that time acquire a red shade of colour.

Thus, the colour of the ocean is made up of the light flux reflected by the water surface and the radiation that is returned from its depths owing to the process of scattering. If scattering did not occur at all and the ocean completely absorbed the light falling upon it, it would seem black. But what actually takes place is that the ocean's colour passes through all shades ranging from dark blue to almost red. And the fewer impurities there are in the water, the more blue the ocean's own colour becomes. It is interesting that on land the colour of a desert is yellow, while in the sea, a yellow colour is likely to signify wanton life activity, whereas a blue colour is the sign of its absence, or of the emptiness of the sea.

The visible colour of the ocean greatly depends on the angle of observation. For instance, when we look far across the ocean, less of the ocean's own colour and more of the luminous radiation that is reflected by the water surface is perceived. For this reason the ocean becomes paler near the horizon. The waves increase the richness of colour perception, since the eye meets the water surface mainly at sharp angles and perceives predominantly the light that is exiting the water.

The ocean with its variety of colours is not only a festive garment, but also a natural source of information about the aqueous environment of our planet. In order to understand the distribution of waters of various origin and condition, as well as of the impurities contained in them, oceanologists aim at singling out the water's own colour from the light flux that issues from its surface but is not connected with its reflection. This, however, is not an easy task.

Attention has been focused on the colour of the ocean for a long time. The famous navigator Otto von Kotzebue during his voyage aboard the *Ryurik* between 1815 and 1818, compiled one of the first instructions concerning the observation of the colour of water. It contained directions on how to qualitatively evaluate the colour of water. The first instrumental methods, which also predominantly give a qualitative colour pattern, appeared only in the nineties of the last century. At that time, the Swiss geographer Forel suggested a simple instrument he had made himself that could be used to determine the colour of water basins. It consisted of a set of test tubes containing liquids of different colour. Each test tube was numbered. The colour of the water was visually compared with the colour of the liquid contained in the test tubes, and the number of the appropriate test tube was taken to be the colour index of the water. With a number of modifications the set of tubes has reached our days and is successfully used in oceanography. This method of determining the colour, though not wholly infallible, has nevertheless made it possible to accumulate and systematize a vast amount of information. Owing to its simplicity and accessibility, the method has served as the basis for the zonation of the World Ocean according to colour.

In 1939 a new instrument appeared in the Soviet Union. It was called a hydrophotometer and came to be the progenitor of a large number of apparatus that are employed for the assessment of the actual as well as the seeming colour of the ocean. In the first case, instruments that are submerged are used; in the latter instances, remote measuring devices are installed on planes, helicopters, and earth satellites. This has made the discovery of biologically productive regions of the World Ocean from outer space feasible, though the distortion of the light flux by atmospheric processes does present significant difficulties.

A substantial role for the life existing in the World Ocean is played by the propagation of light in the mass of its waters. The ocean depths are usually associated in our minds with the crepuscular and nocturnal period of the day when the whole splendour of colours fades away. Nevertheless the solar light that illumines the Earth does not leave the aqueous cover of our planet unheeded, although compared with the land and ocean surface, it does not manage to penetrate everywhere.

As has already been mentioned, the regular patterns of light propagation in the oceanic medium are determined by two physical processes: absorption and scattering. The former is no more than the transformation of radiant energy into its other types, while the latter finds its expression in the deviation of the light rays from their initial direction by the water molecules and the particles contained in the water. In addition to this, scattering, which does not infrequently occur in water, is much more intense than absorption. Owing to scattering, the ocean water is permeated with an infinite number of light beam of most varying direction. This effect was brilliantly described by Thor Heyerdahl who observed the subaqueous light phenomena during his voyage on the Kon-

Tiki raft. He wrote that under the water reigned a very unique suppressed and shadeless illumination. One wondered where the light came from. It was not as if one were on land. Light spots flashed everywhere and the Sun seemed to be evenly spread all over the place rather than stationed at one particular point. After the bright tropical sun, the underwater light had a highly softening, pure, and pleasant effect. Even if one looked down into the perennial night of the depths, the eye was gratified by the blue radiance of the water penetrated by the Sun.

Absorption and scattering give rise to the overall reduction of light in the ocean water. The light is usually evaluated with the help of an index for the vertical reduction of light, which characterizes the reduction of the descending light flux. In the ocean water different components of the solar spectrum are reduced unevenly, which results in that the depth influences the spectral composition of light. Moreover, depending on the specific features of the water masses, this process has its own characteristics. At the same time all the waters of the ocean share a common property: the red part of the spectrum is markedly reduced with depth.

The disappearance of the red colour with greater depth gives rise to some fascinating underwater chromatic effects. According-ing to Jacques Yves Cousteau and his colleague F. Dumas the blood of a harpooned fish is green under water. The first time the divers were astounded to see that when they began to swim with their trophy up to the surface, the blood turned brown at a depth of fifty-five feet; at a distance of twenty feet from the surface, the blood acquired a pink colour; and on the surface, it had its usual red colour.

As is known, the colour of objects depends on what rays they reflect most intensely, as well as on the spectral composition of illumination. Consequently, if, for instance, some red object were illumined by a light flux where this particular colour were absent, it would no longer seem red.

The change in the spectral composition of the light that penetrates into the depths impoverishes the colour perception of the silent world. But if the ocean depths were illumined with a bright white light, it would then be possible to see how rich and variegated the colours of Neptune's kingdom are.

In the book *The Silent World* Cousteau and Dumas tell what happened when they directed the reflector of a luminaire at the slope of a reef. A genuine explosion of colours occurred! The light beam discovered the dazzling interplay of colours with a preponderance of blue, red, and orange; it could not but remind one of the pictures painted by Henri Matisse. For the first time since the world was created the whole splendour of that crepuscular zone came into being.

The penetration of solar light into the darkness of the oceanic depths and the optical properties of the World Ocean waters play a decisive role in the development of life in the Ocean. This can be exemplified by the process of photosynthesis. The energy of solar light causes the transformation of inorganic compounds into organic ones. The depth at which photosynthesis can take place depends mainly on the amount of solar light that falls on the ocean surface and the transparency of the waters. Some words must be said about the depths upon which the daylight falls.

According to the American biologist Beebe, who went one kilometre down into the bathysphere, the darkness there seemed to be more black than could be imagined. To determine the depth reached by the daylight, special experiments were carried out with the help of photographic plates, which are far more sensitive than the human eye and can capture the ultraviolet part of radiation. According to these tests the limit to which light penetrates into the ocean is taken to be equal to 1500 metres below its level. The plate that was extracted from that depth did not have a light mark.

Modern light detectors constructed on the basis of photoelectronic multipliers have made it possible to more accurately estimate the propagation of light in depth. Under favourable conditions of the illumination and transparency of water light detectors of this kind would capture approximately one photon per second at the depth of 1000 metres, and one photon a day when the depth was as low as 1200 metres. The results of the calculations revealed that in the period of three hundred years one photon reaches a depth of 1500 metres. The penetration of solar light into the deepest depression of the World Ocean, lying at a depth of 11 022 metres below surface level, is so improbable that it could hardly have occurred in the history of humankind.

The process of photosynthesis takes place only in the upper layer of the ocean waters, which is approximately one hundred metres thick and is called the photic (illumined) zone. This remarkable and completely natural process of transforming inorganic compounds into organic ones is accomplished by the algae, using solar light as energy. A multitude of algae capable of photosynthesis are found in the World Ocean. They yield about seventy-five percent of the synthesized organic matter of the Earth.

The process of photosynthesis does not

depend on the intensity of light alone. The formation of an organic substance also requires nutritive salts, which are supplied and preserved within the confines of the photic zone as a result of the activity of bacteria and the regeneration by sea animals, as well as at the expense of the mixing and rising to the surface of cold deep waters rich in nutritive substances.

The absorption of solar energy by plants takes place with the help of pigments, which represent catalytically active compounds that absorb light in specific regions of the spectrum. Chlorophyll is a pigment of this type. It functions as a unique 'trap' for light, absorbing it in two narrow parts of the spectrum. It should be mentioned that ocean water also absorbs light of exactly the same spectral composition, taking it away, as it were, from chlorophyll. Nature, as if wishing to abolish the consequences of this flagrant inequity, provided algae with a complex system of pigmentation, which is susceptible to radiation in other regions of the spectrum. Thus, the additional pigments absorb the energy in those spectral regions that are inaccessible to chlorophyll and supply the latter with it.

During photosynthesis the algae make use of only a minor fraction of the solar energy that gets into the ocean. The remaining fraction is lost in its waters. The influence of luminous energy on the algae is still not entirely clear. In modern scientific studies of the ocean the problem of 'light and photosynthesis' stands alongside the other important theoretical and practical tasks that biology is to tackle.

The World Ocean has its own sources of light that embellish it no less than solar radiation. In the night the ocean is often illuminated with mysterious stirs of water that produce whimsical phosphorescent patterns, which have frequently inspired writers of seascapes to describe them in poetic terms.

"It was as though the water had been set on fire... The bluish bands upon it were lying like the folds of a shroud. The widely spread pale glow flickered on the water surface. But it was only the fire's ghost... The fishermen's nets under the water looked as if their threads were aglow. Half of the oar was as black as ebony while the other half that was under the water was shining like silver. The drops falling back into the water from the oar were showering its surface with stars... If you dropped your hand into the water and removed it, it seemed to acquire a fiery glove; the flame, however, was dead and you could not feel it!" This was how Victor Hugo in his novel *The Toilers of the Sea* described this fascinating phenomenon of nature—the luminescence in the World Ocean—which is most often brought about by bacteria and infinitesimal organisms like chaeropods and marine bristle-worms. Shrimps, molluscs, starfish, medusae, corals, and many other inhabitants of the waters also emit light. It would be of some interest to note that certain dwellers of great depth have light-radiating organs, which often represent highly complicated natural optical devices.

The ocean contains a host of glowing organisms. Fish can also shine. In some cases the luminescence of large specimens is caused by bacteria that have settled on them; in others, it is the glowing slime produced by the glands and covering the body of a fish that makes the fish a source of light. Some animals eject a fiery cloud. The English zoologist Sir John William Aleock, when observing a lobster with a glowing secret, which was raised from a depth of one thousand metres in the Bay of Bengal, saw how it released a blue flaming substance as soon as it found itself aboard the ship.

Many researchers and navigators encounter the phenomenon of luminescence in the ocean. From 1880 to 1883 the French expedition aboard the ships *Travailler* and *Talisman* explored the Sargasso Sea. One of its participants, Marquis de Folin wrote the following:

"It was indeed a surprise when what we found in the net was a great amount of Gorgonia, looking like small bushes, which then started to radiate flashes of lightning that were so bright that the twenty torches illuminating the deck seemed quite dim. The tips of all the twigs and branches of polyps radiated beams of light, the power of which was now becoming weaker, now stronger. The light changed from mauve to purple, from red to orange, from blue to various shades of green, and sometimes it was as white as white hot iron. Meanwhile, the predominant colour was green, with the other ones flashing now and then only to blend with it later."

Researchers consider luminescence to be a defence mechanism for many dwellers of the ocean that is intended to mislead and astound predacious enemies.

A number of animals do not glow at all and actually release into the water such luminescent substances as luciferin and luciferase, which react with the surrounding water and produce a glowing cloud covering their flight, while other animals strive to fade into the dull background. It is noteworthy that at depths of up to seven or eight hundred metres, to where the solar light can still penetrate through the mass of water, the inhabitants, if one were to look at them from the bottom, all seem to be dark silhouettes. This is probably why the phosphorescent organs of a large number of fish, squid, and crustaceans that are found at such depths are located on their undersides. Everything seems to indicate that they are quite able to adjust the intensity and angular distribution of their own light to that coming from the Sun.

The sources of living light are undoubtedly used by predators for hunting purposes. Suffice it to mention the 'headlight' of the diaphanous fish, or the luminaires below the eyes of the twinkling fish, which serve as a kind of bait for their victims.

Most of the ocean dwellers manufacture light in their organs. However, there exist some squid and fish in which glowing bacteria are found to live symbiotically. Since the bacteria glow incessantly, the animals employing them for these purposes are characterized by a complicated system of light guides and valves, with the help of which luminescence is controlled. Researchers have not yet been able to ascertain whether these bacteria are inherited or acquired by the animals from the environment.

Ocean luminescence is stimulated by various mechanical and chemical factors. For instance, the stronger the waves, the brighter the ocean flames up at night. This kind of light can sometimes be so strong that it can be taken for the glow of lights over a big city far away. There are instances when cylindrical colonies of sea animals called Pyrosomatidae are raised aboard the ship. Outwardly they look very much the same as cucumbers that at times reach a length of more than one metre. The term 'Pyrosomatidae' is derived from the Greek words meaning 'fire' and 'body' If Pyrosomatidae are pressed they start radiating a bright light, which alternates with flashes of blue, yellow, or violet radiation. In a dark room, the captured pyrosomatidae flash up like the neon lights used for advertising. Their light is sufficient to read ten lines in a book.

Luminescence has often misled navigators. For instance, in the Red Sea, the glowing crests of waves may easily be taken for breaking waves or surfs. In such cases the captains become anxious lest their ships should find themselves in the proximity of reefs, though in fact there are tens, if not hundreds, of metres of water under its keel.

The luminescence of waves and of jets in the wake of ships is not difficult to explain. At the same time there are light effects that present a mystery in the proper sense of this word. These are the 'milk sea', or 'white waters' and 'light wheels' Milk luminescence is observed preponderantly in the region of the Arabian Sea between July and September. Those who have witnessed it say that the sea looks as if it had been covered with a blanket of sparkling light that has the colour of milk split over its surface as far as one can see. This effect is sometimes compared to a snow-covered plain.

An effect that is even more esoteric is the 'light wheels' It looks like spikes of rotating wheels, which move along the water surface at very great speed. Their diameter reaches hundreds of metres. To get a better idea of this phenomenon, it would be best to recur to what those who have witnessed it say. According to them 'at first bands of light appear as parallel lines that pass by the ship at a rate of approximately one per second. But in five minutes' time they start circling round it, approaching the ship from all sides. At times the light bands formed starlike rotating figures. On one occasion two different 'wheels' came into view. This phenomenon was so supernaturally arcane that it could impart nothing else but a superstitious dread that made the person on duty come down to the bridge, convinced that he had become a victim to hallucination* It must be mentioned that no cogent theory throwing any light on this phenomenon has so far been elaborated.

The living sources of light are spread throughout the depths, including the ocean

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* *Za Rubezhom*, 1984, No. 27, (1252), p. 19 (in Russian).

floor. Researchers, who have dived deep down into the water in their scuba suits, have compared the kingdom of darkness there with a black sky dotted with twinkling stars. In the perennial night of the depths they saw the lights of life: the fish, like ships, were carrying 'signal lights' that flashed up with the bright blinding light of living beings, which sometimes, as if they were fiery dragons, ejected flames from their mouths. The divers also saw ancient animals of the family of coelenterates called 'sea feathers', which were permanently attached to the bottom. By the brightness of their glow they may well be compared to street lamps.

'Sea feathers', just as corals, sponges, and hydroids, lead a sedentary way of life. Their ancestors already inhabited the seas during the Paleozoic era, which is evidenced by the rock beds corresponding to that geological period of time. And there are not many who know that nowadays this kind of 'vegetation' exists at the greater depths of the World Ocean and there forms vast glowing meadows.

Deprived of solar light, the dwellers of the eternal darkness of the depths create their own luminaires—small cold 'suns', giving light to the impenetrable night around them.

The study of the optical effects of the water masses in the World Ocean, as well s the light effects in its waters that are rought about by solar radiation and the uminescence of organisms lies within the lomain of a special branch of science cnown as hydrooptics, which over the past decades has become closely related to biology and biochemistry.

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The author has managed to dwell on only some of the aspects of life in the World Ocean. This is conditioned by the fact that all the achievements in oceanology can hardly be presented within the confines of a single book rather than by the paucity of information on what comprises a particular world of its own on our planet. For this reason the author endeavoured to select what in his opinion may be of greater interest to the reader.

The World Ocean is the future of humankind, and on their way to it people should not only fully understand its ferocious nature and make it serve their needs, but also take good care of it lest it should perish. The whole history of the study and development of the World Ocean proves that it is only by peaceful means and the joint efforts of all the nations of the world that this noble and great aim can be achieved.

To the reader

Mir Publishers would be grateful for your comments on the content, translation and design of this book.
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SCIENCE FOR EVERYONE

Before setting out to acquaint the reader with the mysteries of the World Ocean, the author had himself explored the vast areas of the oceans covering the surface of our planet and had also done a great amount of research in the fascinating domain of oceanological studies. Fully aware of the fact that not all of his future readers would be competent enough to make their way through the complicated language used by the scientists in interpreting the data of their analysis, the author made every possible effort to facilitate his narrative without trespassing on the essence and scientific value of the research that has been undertaken. This book provides the reader with a host of facts about the World Ocean that are not merely informative, but are also bound to create an integral picture in the reader's mind and thus widen the scope of his or her scientific, historical, and cultural background.

ИЗДАТЕЛЬСТВО МИР