SCIENCE FOR EVERYONE

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MODERN GEOLOGY

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Modern Geology

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Preface

It is a great pleasure for me to present this book to an English-speaking reader. Don't be distressed with the name of this book. It is devoted not to a strict scientific analysis of modern geological problems, but to a popular presentation of current principal trends and the latest advances in geoscience.

Since long ago geology in the USSR has not been taught at middle school as a discipline in its own right. Instead, the basic geological notions are distributed over other courses of physical geography. Unfortunately, this doesn't generate an integral view about such geology, a major scientific discipline, of great world-outlook importance.

This book just tries to fill in this gap. It turns out, however, that the problems discussed in it extend far beyond the framework of the middle school-taught physical geography course and are of interest to the students of technical schools studying geology and mining as their principal disciplines. It seems to me that this book could be of importance for specialists in different fields of knowledge as an introductory course.

We didn't deal with the history of geological knowledge, that is, didn't go along a traditional way. The book shows the role of geoscience and applied geology in the life of modern society, particularly in laying out and constructing settlements; it also shows the effects of diverse geological processes on the Earth's surface. "Modern geology" begins and ends with the characteristics of geological processes, their role in human life, and the importance of geology for environmental protection. As a result, a new field of geoscience—ecogeology—can be outlined.

Naturally, it is impossible in one book to describe all geological aspects. Hence I have confined myself to the origin and evolution of the Earth, including its interior; periodization of geological events; volcanic phenomena; endogenous and exogenous processes; paleontology; marine geology; tectonics and the history of the atmosphere and climate. In some places, I was probably subjective to some extent, but I hope that the reader will not be sceptical to the whole book and to its author, who merely expressed his vision of modern geological problems.

Prof. *N.A. Yasamanov*

Contents

Introduction

The notion of geology* is commonly based on school textbooks on natural history, on physical and economic geography, fiction and also on the works of art. In stories and novels that tell us about geologists, how they travel and discover minerals of value, the image of geological profession is covered with romanticism. It is generally accepted that the geologists are untiring travellers and spend most of their time in expeditions crossing inaccessible, uninhabited regions, where they frequently come across difficult and unexpected situations. Many years of experience and the courage of these people allow them to overcome various complex difficulties, and this is true. However, the romanticism conceals hard and painstaking daily labour. Geologists explore the Earth's interior and make discoveries not only during expeditions to distant regions, or "in the field", but also in laboratories located in villages and cities.

* Geology is the science that considers the Earth's structure, its origin, and its evolution.

Here, they carefully treat the evidence obtained during the expeditions, seeking facts indicative of the presence of mineral deposits in the region.

Traditionally we relate with the geological speciality such things as topographic and geological maps, a geological hammer and a surveying compass. At present, studies of the Earth's resources involve application of the most advanced facilities. Not only aircraft but also highly sophisticated spacecraft help scientists to examine the boundless expanses of the Earth. Numerous research vessels with the most perfect navigation, radio, television and geophysical equipment on board sound the floor of the World Ocean, while drilling and dredging make it possible to raise and examine the samples of rocks lying beneath thousands of metres of water at a depth of several hundred metres under the ocean floor. Geologists sink in deep-diving submersibles to great depths and examine the World Ocean floor.

Geology comprises more than one hundred disciplines. Some are closely related to chemistry (geochemical professions), others to physics (geophysical field), still others to mathematics and cybernetics, and, finally, to biology so that everyone will find here easily a calling and interesting work.

The purpose of this book is to show the

role of geological processes in the shaping of the Earth's face, tell the reader about mineral deposits in the Earth's interior, describe in an easy fashion the principal geological avenues and achievements, and outline today's geological challenges.

What is the role of geology in the human society? What are the problems of geological concern today? There are no simple answers to these questions. Geological information is of invaluable theoretical and practical significance. It helps not only to purposefully search for and discover mineral deposits but also to develop the methodological fundamentals of the geology itself and of many associated natural sciences. Advances in geology have allowed us to correctly figure out the time and mode of origin of our planet, as well as its location in space; to trace the evolution of its interior and surface, including its atmosphere, hydrosphere and biosphere; to disclose changes in the chemical and mineral compositions of the Earth's crust and the planet as a whole, etc.

The well-being of human society and the rate of scientific and technological progress invariably depended on the availability of mineral materials. Mineral production, that is the use of underground store-rooms, in its turn depends on industrial progress.

Some chemical elements and their compounds, instead of being utilized, went not long ago to waste as by-products of mineral production. This was the case for trace elements and rare earths, niobium, gallium, tantalum, and others. At present, however, rocks and ores enriched in the compounds of these elements are even specially searched for.

The origin of the Earth, its internal structure, the genesis of the Earth's crust, the formation of mineral deposits, the appearance of living matter, the atmosphere and hydrosphere, and the history of the Earth's climate—here is by no means a complete list of major geological problems. It seemed sometimes that this or that problem had actually been solved, since the vast majority of naturalists had enthusiastically accepted a new hypothesis. All facts seemed to support it. Subsequent data, however, contradicted the concept reigning at that time, and it gave way to another, radically modernized ones. Unlike other natural sciences, geology includes numerous hypotheses and their variations. For instance, more than a hundred hypotheses are concerned with crustal origin. Even dinosaur extinction, which seems to be a specific problem, is explained by tens of hypotheses and suggestions.

In its development, human society has long used natural resources with negligence, pondering nothing. As a result, the ever increasing economic activity has greatly damaged the world around us. It is high time to think of Nature as something delicate and easily injurious, as something that should be protected. Only the rational use of natural resources, accompanied by a scientifically based environmental protection will establish a perfect harmony between humankind and Nature.

It's just the time to take effective measures for solving a problem formulated by an outstanding Soviet scientist Prof. V.I. Vernadsky. Its essence is that the biosphere, where humankind lives, should thoroughly be examined, the geological role of living matter determined, the history of the biosphere reconstructed and trends in the future biospheric evolution outlined. Every educated human should know geological fundamentals, because he (or she) will face geological and environmental problems more than once in his (or her) life.

Great importance is attached in this country to pure and applied geology. Geology is confronted with perplexing problem—to satisfy the needs of the steadily developing industry in mineral materials. It is necessary to continue systematic studies of the Earth's interior within the Soviet Union, to drill deep boreholes in many areas and to strengthen the geological investigation of the World Ocean.

The geological science is versatile. One book cannot show all of its specifics, research techniques and major advances in all of its areas. We hence merely mention here such principal avenues as mineralogy and petrology, crystallography and petrography, geochemistry and geophysics, engineering geology and hydrogeology. This book will help a school teacher to unfold more openly the essence of one of the fundamental sciences and will ease the correct and duly professional orientation of a youngster.

Geology As the Fundamental Science of the Earth

Geology and Humans

One who gets into mountains or on a sea shore for the first time is amased with the beauty and might of the wild Nature. But the admiration gives way to a reverence for the formidable forces hidden inside the planet and acting on its surface. A question arises inevitably: What was here in the past? Could, say, a river to "saw" through a unit of hard rocks to a depth of hundreds of metres? Rock strata are exposed in mountains, on precipitous sea shores and in river valleys. They often lie horizontally, occasionally form a kind of solidified waves of variable amplitude, or are crumpled in a strange and nonunderstandable fashion. These rocks have little to say to an ignorant man. He can merely admire them.

The geologist who can decipher the language of solidified rocks will get an insight into the modes of their origin, the physiogeographical environments that dominated in these regions and the changes that have taken place throughout their prolonged history.

As a matter of fact, rock strata are a stony book presenting the history of our planet. This history is written on each stratum or sequence of strata by specific, frequently enigmatic symbols. The geologist who deciphers the record made by the Nature itself, reading with passion the papers of this wonderful stony chronicle, can restore the pictures of the past. But is it really important for the geologist of today? Indeed, this is undoubtedly of educational value and interesting, but what else? It turns out that on getting insight into the past, the geologist obtains a deeper and more detailed knowledge of processes on our planet; he hence can predict the future with a greater confidence. But this is not his main task. Modern geology is the solid community of interrelated sciences on the structure, composition and history of the Earth. It consists of dynamic (physical) geology, tectonics, historical geology, mineralogy, petrography, crystallography, paleontology, geophysics, geochemistry, economic geology, engineering geology, marine geology, geology from space, etc. Geological knowledge has made it possible to discern trends in the evolution of our planet, and to discover and exploit numerous mineral deposits.

Geological data help to profoundly understand processes on the Earth's surface, comprehend the laws of formation of rocks and ores, seas and oceans, mountains and plains, etc. Studies into disastrous phenomena allow humans to overcome fear of terrible and destroying natural forces after all, no fear arises when you know the causes and extent of a disaster. Everything on the Earth is subject to geological forces, internal (endogenic) and external (exogenetic). The rates of these transformations are different. Thus the appearance of seemingly "eternal" mountain ranges, volcanoes, gourges, rivers and seas is in reality modifying through time, but the modification is so slow that even several human generations cannot notice any substantial change. But some geological processes often cause calamities, because they are short-term and lead to major disasters. Various regions of the Earth experience strong earthquakes, floods and tornadoes, which destroy buildings and transport lines, and kill people and animals.

For instance, the roads and beaches, houses and gardens along the coasts of the Atlantic Ocean, Gulf of Mexico, Japanese Islands and Pacific off Asia from time to time undergo destructive actions of giant waves as high as several tens of metres. They are produced by tropical hurricanes, typhoons and earthquakes in the ocean floor.

A magnificent and threatening example of natural forces is volcanic activity. Eruptions of the volcanoes of Vesuvius and Etna,

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Italy; Krakatau, Indonesia; and Katman, USA, have been described in rather full detail. The volcanoes in Mexico, and Columbia, on Iceland in Kamchatka and on the Hawaiian Islands were repeatedly active in the 1970-1980s. Volcanic eruptions generally bring death and destruction. But they also have a positive aspect, since they are accompanied by ash fallouts that improve soil fertility. An example is the 1956 eruption of Bezymyannyi Volcano.

Mineral resources are of tremendous importance for the life of human society. Throughout its history, humankind has developed a great many methods of mining, treatment, and use of valuable minerals. Metals, fuels, fertilizers, construction materials, abrasives, raw materials for the chemical industry—all this the Earth gives to us. But profound geological knowledge and specialized investigations are needed to discover mineral deposits and make them serve for humankind.

Useful minerals are obtained by running underground and open-cast mines, and boreholes. Owing to the application of highly productive mechanisms, the great amounts of valuable materials whose formation has taken many tens of millions of years are mined. Prolonged and intensive production of certain mineral materials has exhausted their resources. This was, to some extent, the result of squandering of the wealth of the Earth's interior. However, the mineral production is even impossible to decrease, to say nothing of its cessation, because the industrial and agricultural production cannot be reduced. Human society hence faces at least two principal problems connected with a more rational utilization of mineral materials. It is necessary, first, to develop effective techniques of mineral extraction and, second, to extract low-grade ores.

An example of an essential relationship between a human being and Nature is environmental protection from the detrimental effects of the mining industry; such protection is necessary not only to prevent but also to guard against these effects.

Geological Processes

Geologists study our planet, in particular its composition and constitution, crust and interior, history of life and natural landscapes. Objects of research are various natural bodies lying at the Earth's surface or in the Earth's interior, and also the action of diverse geological processes. The last have given rise to rocks and the relief of the Earth, and have been responsible for the evolution of our planet.

With few exceptions, geological processes are extensive and extremely long-lived. They operate in the range from microworld to continents and even the planet as a whole and last hundreds of millions of years. Compared with this, human life, even the life of humankind, is merely a momentous episode in the life of the Earth. Most geological factors cannot, hence, be observed directly. One can judge upon them only from their effects on geological objects, such as rocks (disposition of mineral aggregates in them), geological structures and various types of the relief of continents and ocean floors. To understand these processes, one should reconstruct their evolution in a step-by-step manner, after which the geologist can reconstruct the history of this or that region or segment of the Earth's crust.

The geological processes have been acting on the Earth since its origin. Some of them are caused by forces arising deep in the Earth—these are endogenic processes; others are due to the energy coming to our planet from the outside, basically from the Sun—these are exogenetic processes. The former are volcanic eruptions, earthquakes, mountain building, and horizontal and vertical crustal movements; the latter are the activity of surface and subsurface waters, wind, glaciers, living organisms, etc.

The exogenetic processes level the topographic irregularities produced by the endogenic forces. As a result of weathering, that is the disintegration of rock by gravity, wind, water and organisms, clastic material forms and ultimately accumulates in topographic lows.

Mountains become older and are gradually worn down by exogenetic forces; they are transformed into tablelands and plains, which are then affected by endogenic forces to become mountainous areas again.

Two entities—endogenic and exogenetic processes—are continually confronting each other on our planet. They are changing the face of the Earth all the time—acted in the far geological past and will act in the future.

To judge upon the geological activity of various factors, it is insufficient for one to have some knowledge of their age, extent and duration. It is necessary to comprehend their essence, contents and trend. Hence the development and broad application of a comparative-historical method, known as uniformitarianism, is of great importance for the further development of geology. What is its peculiarities?

Uniformitarianism was first advanced by the British geologist C. Lyell in the 19th century. Its essence is that the forces that are now changing the face of the Earth are essentially the same as those in the far past.

Winds, rains, storms, floods, glaciers, sea waves, volcanoes, earthquakes and other geological forces are all the time changing the Earth's surface. Granite mountains —the symbol of strength and stability— are slowly destructed by geological processes to gradually become sand and clay. Rock fragments transported into river beds and on beaches have long been attrited and are now pebbles and boulders. Those in strata were formed in the past just in the same way. Fossil barkhans and ripple marks on the surface of sands in deserts were generated, like now, by wind in deserts and semideserts.

The geological forces, which manifest themselves during millions and even hundreds of millions of years, can do tremendous work. For instance, a river can cut a giant canyon several hundred metres deep, like the present-day Grand Canyon (Colorado), or completely level off a territory once occupied by mountains. Thus, the Southern Urals and Mugodzhars, which give way in a southerly direction to plains, were once high mountains.

Careful studies of modern geological processes help to properly understand their activity in the far past of the Earth. But the geologist always bears in mind that the evolution of the Earth is irreversible, and cannot imagine that the same geological processes in the past and present could produce absolutely identical results. The composition of the Earth's atmosphere, and the volume and composition of ocean water have changed through time, and this could not help affecting the course and intensity of geological processes.

At present, the past geological epochs are compared with the present ones, not mechanistically but with due account of changes in physiographic conditions and natural processes on the evolution of the Earth.

Geology and Cities

The name of this subtitle is at first glance embarrassing. We have got used to the opinion that the geologist works far from settlements and treats the field data in cities only in winter. However, much importance is attached to engineering geology in planning urban development and constructing buildings and engineering lines. This comparatively young geological discipline solves major and urgent tasks related to human activity. Engineering geology is of large economic significance, because it cannot be avoided in constructing atomic and hydropower stations, transport and pipe lines, and industrial and civil building, and in developing farm lands.

In planning urban development, besides the correct selection of the construction site, it is of great importance to properly use and, which is the main thing, preserve natural landscape, find out the character of ground and solve hydrogeological problems, because buildings should be strong while the population and industrial enterprises should be supplied with clean and technological water, respectively

Broad floodplains of rivers have long considered ideal for town building. A protective dam could protect the city against occasional floods. But the construction here is difficult to make. In particular, difficulties arise during laying the foundations in flood-plain grounds, where the groundwater level is rather high; constructing auxilliary hydrotechnical objects, etc.

The stability of slopes should be taken into account when lying the foundations at foothills and on uplands. Slopes often look stable at first glance, but if they are underlain by clayey rocks, these can spread under a load. When rains are torrential, such slopes often slide so that buildings are wrecked.

In making programmes of urban development, architects pay attention to steep slopes underlain by hard rocks. On the one hand, construction on such rocks improves the stability of the slope; on the other hand, additional difficulties and expenses arise in connection with laying out streets, hydraulic structures—water and sewage lines.

Bedrock composition is of large importance for urban development. If there occur igneous or strongly cemented sandy-gravelly rocks, the result will only be a dearer digging. If the bedrock is shale dipping at a varying angle, slipping of some blocks is possible, with subsequent house demolition. But most hazardous is construction on carbonate rocks. With prolonged water action, limestones and dolomites are leached so that cavities and channels are formed. Some of the cavities are seen on the surface, but more are concealed from the observer. For the foundations of buildings under project to avoid a direct hazard, detailed geological work with drilling is required. Cement slurry is sometimes forcibly pumped through boreholes into porous and cavernous carbonates, and into sand, gravel and pebble units to have them more stable. The slurry spreads through cavities and solidifies to produce a kind of a hard concrete basement under the foundation.

Analysis of air photographs is a sound help in planning settlements; together with ground control, they provide a general knowledge of the geological structure of the area. This is how construction sites are selected in far and poorly populated regions, and airports and other objects are planned. Such an analysis is especially effective for locating construction sites in permafrost areas; the ground control is conducted here during summer field work.

Geological and engineering charts play a significant role in construction surveying. Unlike geological maps, they show the types and specific character of widespread sands and pebbles, easily swollen clays, ground types, and also the depth to and the composition of bedrock, probable landslide sites, water sources, groundwater level, and many other data. Construction of settlements is impossible without these charts.

In planning the development of the present and future urban settlements and in an attempt to protect the environment, we make use of many scientific disciplines. Since the urban and regional planning is a complicated matter, specialists with different backgrounds, including geologists, participate in this important work. The engineering geologist co-operates closely in his activities with the architect and the builder. But the main purpose of geology is to study the structure and evolution of the Earth, and we just dwell upon them.

The Planet Earth

We here deal with the Earth, in particular with its structure, internal state and composition. This subject is a concern of such Earth sciences as geology, geophysics and geochemistry. But before we describe the internal structure of our planet, we will show its position in space and its relations to other celestial bodies.

The Earth is one of the nine planets orbiting about the Sun (Fig. 1). Numerous stars, the Sun being one of them, form the galaxy Milky Way. In its turn, the spiral Milky Way is one of the numerous differently shaped galaxies existing in the Universe. It consists of over 100 thousand million stars. You can thus figure out how diverse and limitless our Universe is. It has been found with the help of optical and radio telescopes that the diameter of some galaxies is equal to thousands of light years*.

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* A light year corresponds to the distance the light runs at a speed of 300 thousand kilometres per second, in one year. This distance is equal to 9.46×10^{12} km.

Fig. 1. The Earth from space

Since both the Sun and Earth are inside the Galaxy and we see its margin from inside, the Milky Way looks like a continuous arcuate band crossing the night sky, rather than a spiral star congestion. That this light-coloured arc consists of stars was first suggested by Galileo early in the 17th century. These stars are too far from us to be seen. The unaided eye can distinguish slightly more than 5000 stars, The Milky Way is a disk about 100 thousand light years in diameter.

The Sun is approximately located at three-fifths of the radius of the galaxy Milky Way. All the stars of the Galaxy, including our Sun with its retinue of nine planets and associated bodies (satellites), orbit about its centre, one revolution lasting 240-250 m.y. The velocity of motion is rather high and has 240 km/s.

The mass of the Sun is 2.25×10^{27} metric tons, which is 329 400 times that of the Earth (6.2×10^{21} metric tons), and its volume is 1 300 000 times that of the Earth. It is the centre of gravity for all the celestial bodies constituting the solar system. Owing to gravity, planets and their satellites, asteroids, comets and meteorites revolve around the Sun.

Our planet rotates about its axis from west to east. Therefore, an observer from the Earth sees that the stars at night and the Sun in the day-time continuously move westwards. All terrestrial planets run along their orbits from west to east in one and the same plane. Even the Sun rotates slowly about its axis in the same direction. All planets except Venus and Uranus rotate about their axis in the same direction in which they revolve around the Sun. Venus rotates in an opposite direction, and the axis of rotation of Uranus is in the plane of its orbit. An absolute majority of the satellites of planets run along their orbits in the same direction in which their respective planets rotate about their axis.

The agreement in the motion of celestial bodies, a remarkable feature of the solar system, shows that the Sun, planets and their satellites are of the same origin. According to astronomers, all of them were derived from a single cloud of interstellar material.

Like other planets, the Earth obtains energy from the Sun, a medium-sized star 1.39×10^9 km in diameter. The energy radiated by the Sun is about 10^{28} J. Nearly the entire energy reaches the Earth's surface as electromagnetic radiation. Its spectrum is broad; it includes X-rays, ultraviolet rays, visible light, heat radiation and radio waves. The ozone layer in the upper atmosphere of the Earth prevents free penetration of ultraviolet and X-rays.

The Sun is a giant natural reactor in which extremely violent nuclear reactions are taking place. Note that its diameter, as a result of nuclear reactions, remains, nonetheless, the same. In the opinion of astrophysicists, the tendency towards an explosion-type expansion is here balanced by the gravitational attraction of material. The surface of the Sun is heated to about 5 500 °C, while at its centre, where nuclear fusion occurs, the temperature is estimated to be 10 million grades centigrade.

The light and heat radiated by the Sun are basic for many geological processes. The heat of the Sun is one of the principal climatic factors. It provides conditions favourable for life on the Earth.

The amount of solar energy reaching the Earth's surface has been practically the same during a long period of time. Life on Earth has been evolving throughout several thousand million years but you know that organisms can live in a very narrow interval of temperatures not exceeding 80-100 °C.

Is the Sun old? This question was put to themselves by scientists very long ago, and many naturalists attempted to respond to this question. The estimates of astrophysics, based on the theoretical considerations of nuclear physics, suggest that the Sun is about 5 thousand million years old. These were supported by geological evidence. The oldest rocks known on Earth were found to form 3.8-4 thousand million years ago. Rocks 4.7 thousand million years old were found on the Moon, and meteorite dating yielded ages of about 4.6 thousand million years. You see that all these dates are similar to each other, and this indicates that the Sun and its satellites were probably generated nearly simultaneously.

The planets orbiting around the Sun (Fig. 2) differ in size and structure. Pluto and Mercury are dwarfs among them, while

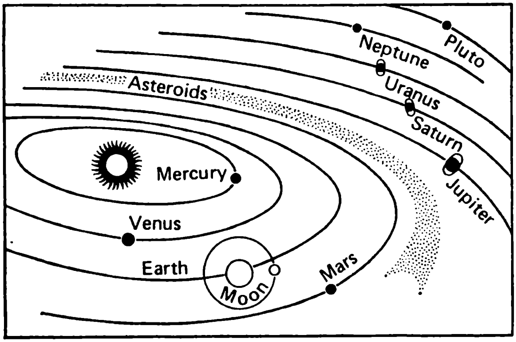

Fig. 2. Schematic presentation of the solar system

Neptune and Jupiter are giants. Some planets are made up of hard materials and are surrounded by a liquid or gaseous atmosphere, others are composed of a dense gaseous material. Mercury, Venus, Earth and Mars, the planets nearest to the Sun, are small and consist of stony or metallic materials. Jupiter, Saturn, Uranus and Neptune are built up of great amounts of gases—hydrogen, helium, and methane—and also of solid ammonia and carbon dioxide. A dense gaseous shell surrounds the solid core. Clearly, many extremely general concepts are very speculative.

The Earth is the largest of the planets orbiting closely to the Sun. Its complete revolution around the Sun along a nearly circular orbit at a speed of 29.7 km/s, takes

365.26 days, its average distance from the Sun being 150 million kilometres. The period of rotation of the Earth about its axis is 23 hr 56 min.

The Shape and Size of the Earth

Astronomical observations, measurements from space and direct measurements on the Earth's surface, have made it possible to determine the shape, size, mass, and gravity and magnetic fields of our planet, heat flow from the Earth's interior, and several physical properties of the Earth's surface. The radius of the Earth averages 6371 km, the equatorial one being 6378.86 km and the polar, 6356.78 km. The equatorial swell and the polar contraction are due to the rotation of the Earth about its axis and due to the inclination of this axis. But as a whole, the Earth is very close in shape to an ellipsoid of rotation, called geoid.

The mass of the Earth is 5.976×10^{27} g, and its volume is 1.083×10^{27} cm^3.

Given the volume and mass of the Earth, you can find its mean density; it is 5.52 g/cm^3, or 5.52 times that of water. It has been found in the laboratory that the density of rocks at the Earth's surface is 2.8 g/cm^3. This suggests that the Earth's interior contains rocks whose density is several times higher than the average for the Earth.

The acceleration of free fall at the Earth's surface is determined with the help of instruments called gravimeters. This acceleration is measured in centimetres per square second. Modern gravimeters have an error as low as 0.001 cm/s^2. The free-fall acceleration at the equator averages 978.049 cm/s^2. This value takes into account the centrifugal acceleration due to Earth rotation, which is equal to 3.392 cm/s^2. No centrifugal acceleration acts at the poles, so the free-fall acceleration is higher there than at the equator, but merely by 1/189.

Deviations from the mean free-fall acceleration are observed at different points of the Earth. These are so-called gravity anomalies, some of them attaining values of several hundred cm/s^2.

Our planet is well known to have a magnetic field. Everyone can check the existence of terrestrial magnetism simply by looking at the arrow of a compass. Compass was invented in China very long ago and has been serving faithfully until now for travellers and seamen. Magnetic induction is measured in Teslas (T). Modern magnetometers, instruments that measure the induction of the geomagnetic field, are very precise.

The magnetic poles of the Earth do not coincide with the geographic one. The north-seeking end of the magnetic needle is attracted to the pole located near Greenland

(73°N, 100°W), while the south-seeking end, to the pole in the Australian sector of the Antarctic (68°S, 134°E). The induction of the geomagnetic field is largest at the magnetic poles (0.7×10^{-4}T at the south pole and 0.6×10^{-4} T at the north pole) and lowest at the equator (0.42×10^{-4} T).

The magnetic needle always points to the magnetic pole. To accurately point to the geographic North Pole, the declination should be introduced into the readings.

What causes such an interesting phenomenon as the magnetic field of the Earth? It is generally accepted that the Earth's core is, in general, a magnetic dipole, like a bar magnet with two poles of different signs. Magnetologists proved that the magnetic poles migrate. The north pole became the south pole at certain periods, and vice versa. Periods of the relatively stable sign of the poles are estimated to range from 700 thousand to 1.5 million years.

It has been known since long ago that heat escapes from depths in the Earth. The existence of a major heat source in the interior stems from volcanic eruptions, when a boiling lava heated to over 1500 °C issues onto the Earth's surface. Measurements in deep boreholes and mines have shown that the temperature rises at a certain rate, namely by 30 °C per 1 km of depth. This is the so-called geothermal gradient. The geothermal flux through land is (1.2-1.6) $\times$

10^{-6} J/cm^2·s. Similar values have been obtained for the ocean floor. The lowest heat flow is observed in the central parts of continents, where the most ancient rocks occur, and the highest heat flow, in areas of today's volcanic activity. Even higher values are observed along the axis of mid-oceanic ridges—long-extending mountain system on the World Ocean floor.

Shells of the Earth

The modern Earth consists of several inhomogeneous shells: the atmosphere, hydrosphere, biosphere, lithosphere, mantle (under the lithosphere) and core (beneath the mantle).

The atmosphere is an outer gaseous shell bounded from below by the solid and liquid surface of the Earth. At present, the Earth's atmosphere contains 5.3×10^3 million metric tons of air, which constitutes one-millionth of the mass of the entire Earth. The air pressure at sea level averages 1.013×10^5 Pa and the density 1.3×10^{-3} g/cm^3.

The Earth's atmosphere is composed of 78.09% nitrogen, 20.94% oxygen, 0.93% argon, 0.033% carbon dioxide, and insignificant amounts of neon, helium, methane, xenon, crypton, hydrogen and other gases. In addition, the air contains thermodynamically active admixtures among which water vapour is most abundant (about 12.4 ×

10^6 million metric tons). Steam can condense to form clouds and fog. Its particles, especially those constituting clouds, redistribute the short- and long-wave radiation in the atmosphere. Together with carbon dioxide, they contribute much to a so-called greenhouse effect. The atmosphere containing much of these particles is transparent to the solar radiation but absorbs the outgoing terrestrial radiation, which eventually returns to the Earth's surface.

Other thermodynamically active admixtures in the atmosphere are carbon dioxide, ozone and various suspended tiny particles, or aerosol.

There is very little ozone in the atmosphere; its fraction is merely one millionth, but it is of utmost importance for life on Earth. Ozone concentrates basically between 17 and 25 km of height; it is derived here from molecular oxygen under the action of ultraviolet rays as the result of photochemical reactions. The entire ultraviolate radiation of the Sun, fatal to living things, is absorbed by the ozone shield, which thus saves life on land and at the ocean surface. The surface of water also absorbs ultraviolet rays; hence hundreds of millions of years ago, when no ozone layer yet existed, life originated and evolved deep in the oceans.

Aerosol dissipates solar radiation, partially reflects it and partially absorbs it, Its role for the Earth is twofold. On the one hand, it prevents solar heat from passing to the Earth's surface; on the other, it absorbs solar radiation and then emits infrared light thus adding some heat to the greenhouse effect.

There are several temperature layers in the atmosphere. The average air temperature at the Earth's surface is + 14.3 °C. Weather-forming processes act in the troposphere, the lower layer of the atmosphere. Its upper boundary lies at heights of 8-12 km outside tropics and 16-17 km in the equatorial zone and tropics. The air in the troposphere is heated by the Earth's surface and hence becomes cooler with height; its temperature lowers, on the average, by 6-6.5 °C per kilometre of height. Atmospheric whirls, among them cyclones and anticyclones, originate and develop here. Nearly the entire steam concentrates and clouds form in the troposphere.

The stratosphere is lying above; its height interval is in the range from 8-17 to 50-55 km. Major atmospheric whirls also form here, and the horizontal air transfer is accompanied by up- and downward air movements.

A characteristic feature of the stratosphere is a temperature rise with height by 1-2°C/km. At the upper boundary of the stratosphere, the temperature turns to be equal to 0 °C, often even higher. The ozone layer, the densest between 18 and 24 km, is precisely in the stratosphere.

The mesosphere lies in the height interval from 50-55 km to 80 km. Here, the temperature drops again at a rate of 2-3 °C per each km to minus 60-100 °C at its upper boundary.

The temperature grows again in the next layer, thermosphere. It becomes zero at a height of 100 km and +500 °C between 150 and 200 km. The temperature is +2000 °C at its upper boundary (height about 800 km). The atmosphere intensively absorbs here the ultraviolet radiation of the Sun, is heated and ionized. Electrically charged ions are generated in the mesosphere and lower thermosphere. That's why the layer between 60 and 400 km of height is generally called the ionosphere.

The mass of the hydrosphere is 1.46×10^6 million metric tons. It is 275 times the mass of the atmosphere but is merely 1/4000 of the mass of the entire Earth. The water of the World Ocean constitutes about 94% of the mass of the hydrosphere; groundwater, 4%; the glaciers of Antarctica and Greenland, nearly 1.8%; and mountain glaciers, rivers and lakes, less than 0.2%.

The area of the World Ocean is 70.8% of that of the globe, and its mean depth is 3880 m. The continents are fringed by a shallow-water zone as deep as 200 m; this is the continental shelf, occupying about 8% of the area of the World Ocean. The World Ocean bed lying at depths of more than 3 km constitutes over 77% of its area. The greatest depth (11 023 m) was recorded in the Mariana deep-sea trench, Pacific Ocean.

Isolated major plateaux, seamounts and long-extending ridges have been distinguished within the oceans. The last, called mid-oceanic ridges, compose a continuous chain of global extent, more than 60 000 km in length. They dominate the floor of basins to heights of 3-4 km and disturb the deep ocean water circulation.

Enormous amounts of chemical elements and compounds are dissolved in ocean water. They are known to dissociate in the solution into positive and negative ions called cations and anions, respectively. The principal cations are sodium, magnesium, calcium, potassium and strontium, and the main anions are Cl, SO_4, HCO_3, Br and CO_2.

Sea water also contains some amounts of gases. All in all, 140×10^{12} metric tons of carbon dioxide (60 times that in the atmosphere) and 8×10^{12} metric tons of oxygen are present in the ocean.

The upper layer of the lithosphere, the stony shell of the Earth (Fig. 3), is called the Earth's crust; its lower boundary is marked by the Mohorovičić discontinuity, the interface between the Earth's crust and

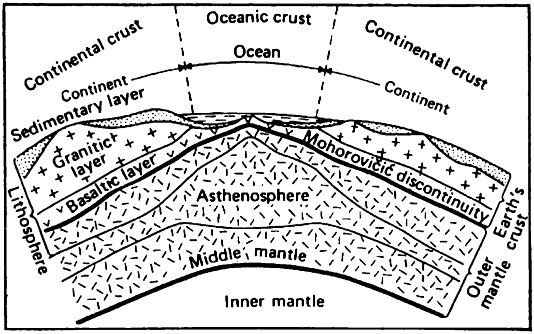

Fig. 3. Schematic presentation of the Earth's lithosphere.

Different crustal types underlie continents and oceans. Mid-oceanic ridges with rift valleys rise centrally in the oceans

mantle. The seismic velocity increases here in a jump-like fashion. There are two crustal types, the continental, which comprises continents, and the oceanic, which underlies the ocean floor. The former is much older; some of its segments are dated as 3.8 thousand million years old, whereas the oceanic crust is little older than 150 million years. The continental crust averages 25-75 km in thickness, while the oceanic crust is much thinner.

The upper continental crust is made up of sedimentary rocks, about 3 km thick, whose mean density is 2.5 g/cm^3. The seismic velocity varies in these rocks between 2 and 5 km/s. Lying below is the granitic layer which, on the average, is about 17 km thick. Its density is 2.6-2.8 g/cm^3 and seismic velocity, 5.5-6.5 km/s. This layer contains the bulk of radioactive elements. It is underlain by the basaltic layer, whose average thickness is 15 km, density 2.9-3.3 g/cm^3 and seismic velocity 6.4-7.3 km/s.

The rock sequence in the oceanic crust is quite different. The ocean floor is underlain by loose sediment averaging merely 0.7 km in thickness; here the seismic velocity varies between 1.5 and 1.8 km/s. The next layer is about 1.7 km thick and is mostly composed of basalts. It is underlain by a layer, about 5 km thick, where the seismic velocity is approximately 6.7 km/s; this layer consists of serpentinites, hot-hydrated deeply lying ultrabasic rocks.

The surface of the oceanic crust is topographically specific. There occur mid-oceanic ridges whose axis is occupied by a rift valley—a long-extending cleft with steep side walls. Other interesting forms are deep-sea trenches, which are not more than several tens of kilometres wide and hundreds of kilometres long. The trenches occur in oceanic margins, separating, as it were, the island arcs from the ocean. Examples are the Kuril-Kamchatka and Aleutian trenches.

Another shell, the biosphere, has been distinguished on the Earth. This is a worldwide self-adjusting system. It has its own "entrance" and "exit". The former is a solar energy inflow, and the latter is products of the vital activity of organisms. The upper boundary of the biosphere is marked by the ozone layer, which absorbs the fatal ultraviolet rays. An example of self-adjustment is the World Ocean. Rivers discharge into the oceans about 1.5 million metric tons of dissolved calcium carbonate a year, as well as a great number of other elements and compounds. However, the salt composition of ocean water remains the same. Why is this so? Organisms were found to build their skeletons from calcium carbonate. All of its excess is used by organisms. But after their death, their shells are laid down.

The lower boundary of the biosphere is rather vague. Organisms live even deep in the ocean. They were found in the deep Mariana Trench. Various microorganisms use fractures and pores to penetrate into the sediment until the oceanic basaltic layer and continental granitic layer. These layers appear to represent the lower boundary of the biosphere.

About 2 million species of organisms live in the modern biosphere, and each numbers millions and millions of representatives.

In studying the role of the organic world in the life of our planet, Prof. Vladimir I. Vernadsky came to the conclusion that living matter participates actively in all geological processes at the Earth's surface and in the formation of the atmosphere.

The Internal Structure of the Earth

Let us imagine something improbable. For instance, what could we see if the globe were split in half? We could see a body composed of several concentric shells as if put one into another. We could most easily distinguish three geospheres: the lithosphere, the mantle and the core.

The idea of the spherical structure of our planet was pioneered even in the 19th century. Early in the 20th century, the outstanding Austrian geologist E. Suess offered to single out five shells of the Earth each of which was named on the basis of its dominating constituent elements. There were thus distinguished sial (Si + Al), sima (Si + Mg), chrofesima (Cr + Fe + Si + + Mg), nifesima (Ni + Fe + Si + Mg) and nife (Ni + Fe).

Later on, this idea was verified scientifically. Deep boreholes and shafts allow the geologist to examine only the uppermost, extremely thin part of the lithosphere. The depth of 9583 m, reached by a borehole in Oklahoma, USA, has been greatest for long. A programme of exploration with the help of extremely deep holes is under way in the

Soviet Union. The borehole in the Kola Peninsula (the Far North of the USSR) was first to reach a depth of more than 12 km.

Shafts are run to much shallower depths. The deepest shaft is in South Africa (3428 m). If we compare these values with the Earth's mean radius, we'll find that even the deepest borehole has penetrated into the body of the Earth in the same way as a pin into the thick skin of a hippopotamus.

But how do geologists make their assumptions about the internal structure of the Earth? By way of special geophysical instruments and techniques. The seismic method is one of the principal ones. Its essence is as follows. Elastic oscillations that propagate inside the Earth are artificially produced at the Earth's surface with the help of explosions. The denser the material, the higher the seismic velocity. These elastic oscillations do not almost propagate through liquids. On passing through the interface between two media with different densities, seismic waves are partially reflected and return to the Earth's surface, where they are recorded by specialized sensitive instruments. The oscillations that came back to the Earth's surface are used to reconstruct the depth to the interface and even to disclose the physical nature of material.

We have earlier described the structure of the crust, the uppermost part of the lithosphere. Recall that continental crust is made up of three layers, the sedimentary, granitic and basaltic. Oceanic crust absolutely lacks the granitic layer, and here the basaltic layer is several times thinner than that beneath continents.

The Earth's crust is separated from the underlying layer by a surface at which the seismic velocity changes abruptly. At great depths, the basalts may be in a molten state. This weakened layer, which is about to melt or even contains melts of low-melting rocks and occurs beneath the lithosphere, is called the asthenosphere. Since it is plastic, the overlying solid blocks (plates) of the crust can slide over it. Its existence was found by B. Gutenberg who presented evidence that earthquake wave velocities are slowed down below 60 km, after first increasing rapidly from the surface to that depth. That's why the asthenosphere is not infrequently called the Gutenberg discontinuity. It lies at a depth of 120-250 km beneath continents and 30-60 km under oceans. Below the axis of a mid-oceanic ridge, however, it often comes close to the ocean floor.

The layer that underlies the asthenosphere extends to a depth of about 400 km. The seismic velocity rises rapidly at this boundary. Together with the asthenosphere and partly with the lithosphere under the crust, this layer is called the upper mantle. Scientists believe that it consists of dark-coloured dense rocks, probably peridotites, dunites and eclogites.

The middle mantle, or the Golitsyn layer, extends to a depth of 1000 km. Within this layer, another velocity increase is recorded at a depth of 700 km. This phenomenon is also attributed to a further material compaction. The seismic velocity slows down at the lower boundary of the Golitsyn layer.

The lower mantle extends to a depth of 2920 km, and lying below is the Earth's core.

Its outer part, to 4980 km of depth, constitutes 15.16% of the volume and 29.8% of the mass of the Earth. It allows an easy passage of P-waves but does not that of S-waves. This layer is hence believed to be a fluid. In direct confirmations are tidal fluctuations inside the Earth. There exist fluctuations of the Earth about its axis of rotation with a period of 1.2 years.

The inner core has a radius of 1250 km, and composes about 0.7% of the volume and 1.2% of the mass of the Earth. The P-wave velocities are here equal to 11.1-11.4 km/s. But the fact that the S-waves propagate through it suggests that it is solid in the inner part of the core but is about to melt.

Thus the Earth is a complex system. This is a thick-walled sphere that rotates about its axis and revolves about the Sun; its inner hollow is filled with a liquid containing a small, spherical, solid core, which is fixed in the centre by gravity.

How true are the views on rock composition based on seismic velocities? To check them, it is necessary to drill through the entire crust. There exist, after all, places on Earth where the Mohorovičić discontinuity lies at a depth of 5 to 10 km. Drilling to these depths poses at present no problem.

To reach the mysterious mantle. This task was formulated by geologists. But it was first decided to penetrate into the basaltic layer. It was accepted that this layer occurs relatively close to the surface not only within oceans but also in some parts of continents. They selected the Kola Peninsula, and it was here where a superdeep borehole, first in the world, was spudded.

The Kola deep borehole makes an ineffable impression even in outer appearance. The huge surface construction resembles a high factory building. Indeed, this is the whole factory, with all its equipment for lifting and falling of many-kilometre pipes made of special steel. The drilling proper and round-trip operations are carried out electronically. The hole has reached a great depth—a large technical achievement in itself.

The drilling results turned out to be rather surprising. The hole drilled through light-coloured gneiss of Archean age where geophysical evidence suggested the presence of the basaltic layer, judging from an abrupt velocity change. The gneiss is a highly altered, or metamorphosed, rock of sedimentary or volcanic origin, with a high silica content. Quite importantly, this rock is one of the main constituents of the granitic layer. The borehole ran below 12 km, but no basalts were found. Is this a new geological paradox? Missed are the basalts lying under the granitic layer, clearly marked by seismic wave velocities. The reference layer that provided a basis for the inferences made by geophysicists has disappeared. Can it be that all these suggestions of geologists and geophysicists about the deep crustal structure are invalid? No, this is untrue. The superdeep drilling has shown once more how complicated the natural processes are and how intricate the interior structure of our planet is. In this case, a drastic change in velocities is related, not to the transition from the granitic to basaltic layer but to rocks becoming less dense at great depths owing to fracturing when water is released from the crystal lattice of minerals under high pressures and temperatures.

The drilling results make one be careful during the geological interpretation of geophysical data. It should be taken into account that the elevated velocities at depth can be due to different causes. Not only a rock density increase may here play a certain role, but also various long-lived tectonic breaks present at great depths. At the drilling site, major gently inclined fracturing has affected the rock density. As the result of motion along the fault plane, the rock mass became much denser, and this has affected the seismic velocity.

The results of drilling rule out the deeply rooted opinion concerning the temperature distribution deep in the Earth. It has earlier been assumed that the temperature rises with depth but insignificantly within the Baltic Shield. It was expected that the temperature would be 50 °C at a depth of about 7 km and 100 °C at about 10 km. In fact, it was proved to be much higher. To a depth of 3 km, the temperature rose at a rate of 1 °C/100 m, as expected. But then its rise reached a rate of 2.5 °C/100 m. Hence the temperature was 180 °C at 10 km of depth. This high temperature may be the result of an intense heat flow from the hot mantle.

Zones of low-temperature hydrothermal mineralization (copper, lead, zinc and nickel), which were earlier considered to be of near-surface origin, have been drilled through in a 6.5-9.5-km depth interval. Gases and strongly mineralized waters saturated with bromium, iodine and heavy metals were tapped by the Kola superdeep borehole. The gases are helium, hydrogen, nitrogen and methane. The water and gases circulate in broad fault zones. The data obtained indicate that mineralization with a participation of gases and salt water still goes on at large depths.

To obtain knowledge of the deep structure of the Earth, geological investigations should be combined with superdeep drilling and diverse geophysical observations. A great number of superdeep reference boreholes are to be drilled in the USSR, and some of them must reach the Mohorovičić discontinuity. This means that new discoveries in the field of the interior structure of the Earth can be expected in the near future.

The Origin of the Earth and Evolution of Its Interior

The possible origin of our planet thrilled philosophers even far in the past. Although the first concepts were based on direct observations of natural phenomena, most of them were fantastic. Nevertheless, some ideas amaze us by their similarity with our views on the Earth's origin.

The works of Leonardo da Vinci, Nicholaus Copernicus, Giordano Bruno, Galileo formed the basis for advanced cosmogonic views. These were put forward at different times by R. Descartes, I. Newton, I. Kant and P. de Laplace.

The Birth of the Earth

The origin of the solar system has long been the subject of debate since I. Kant and P. de Laplace proposed their cosmogonic theories. For instance, the hypothesis that the planets were condensed from incandescent clots of solar gases has reigned for a long time. It is now postulated that nothing existed at the very beginning. The space, time and matter of our Universe were created about 15 thousand million years ago by the Big Bang. As the Universe expanded and cooled down, matter began to rarefy, and then galaxies and stars started to form from giant nebulae. Our planet system was derived from a cold gas-dust cloud that surrounded the Sun far in the past. The atoms of solar and planetary materials were generated by the explosion of a supernova star; such explosions had occurred in our Galaxy throughout at least 10 thousand million years.

Meteorites—aliens from outer space—are of great value for the scientific elaboration of hypotheses explaining the origin of our planet. On examining stony and iron meteorites, scientists obtain invaluable information and use it widely in their cosmogonic constructions. Additional information has recently been obtained on the chemical composition of lunar rocks, and the atmosphere and rocks of Mars and Venus. It has been found that the chemical composition of meteorites is similar to the average one of the Earth, and their age, like that of lunar rocks, is estimated at 4-5 thousand million years.

The scientific background of modern cosmogonic hypotheses was built of isolated facts. The Soviet scientist, Academician O.Yu. Schmidt, played an outstanding role in the substantiation of the modern hypothesis explaining the origin of the Earth and the solar system.

The initial material of the solar system was a gas-dust cloud. It was in a cold, dispersed state and basically contained volatiles: hydrogen, helium, nitrogen, oxygen, methane, carbon, etc. The primitive planetary material was homogeneous, and its temperature was low.

Under the effect of gravity, the interstellar clouds started to condense. The material contracted to the state of stars, while its interior temperature rose. The motion of atoms inside the cloud accelerated, and some of them collided with one another and fused. Thermonuclear reactions arose during which hydrogen was converted to helium and an enormous amount of energy released.

The ancient Sun—protosun—was born amongst a terrible roar and explosions that accompanied thermonuclear reactions. Its generation is a flash of a supernova, with a great energy release. The protoplanetary cloud then gave rise to planets, comets, asteroids and other celestial bodies of our solar system. The protosun and the protoplanetary cloud, heated to a rather high temperature, originated about 6 thousand million years ago.

The protoplanetary cloud had been cooling down during several hundred million years. The high-melting elements tungsten, titanium, hafnium, niobium, molybdenum, platinum, etc. condensed from a hot vaporous cloud. Solid dust particles appeared, and the previously hot cloud became relatively cold again.

The first planets, among them the primeval Earth, were derived from a cold planetary material approximately 5.5 thousand million years ago. It was a celestial body at that time, but was not a planet as yet; it had neither core, nor mantle, nor even solid surface. The protoearth was a cold accumulation of cosmic material. Because of gravity compaction, heating due to continual impacts of celestial bodies (comets and meteorites) and heat release by radioactive elements, the protoearth's surface began to heat up. No consensus exists on the value of heating. In the opinion of the Soviet scientist V.G. Fesenkov, the material of the protoearth was heated to 10 000 °C to become molten. Other scientists believe that the temperature was a maximum of 1000 °C; some even deny the possibility that the material was molten.

Because the material of the protoearth differentiated, the heavier elements concentrated in its interior and more lightweight, at its surface. This, in turn, predetermined its further division into a core and a mantle.

The Earth had no atmosphere immediately after its formation. This was because the gases from the protoplanetary cloud were lost early in the generation of the Earth—its mass then could not hold them near its surface.

The formation of the core and mantle, and later an atmosphere completed the first stage of the Earth's evolution, a pregeological, or astronomical one. The Earth became a solid planet. Since then its prolonged geological evolution has been under way.

Thus the solar wind, hot Sun's rays and cosmic cold reigned at the Earth's surface 4-5 thousand million years ago. The surface was continually bombarded by celestial bodies ranging from dust to asteroids. Vigorous thermonuclear and chemical reactions took place in the interior of the planet. Energy was released mainly owing to radioactive decay, gravitational differentiation and various phase transitions characteristic of a high-pressure environment.

Gravitational Differentiation

Besides radioactive decay, gravitational differentiation was basically responsible for the stratification of terrestrial material. Dense and heavy substances sank, while more light-weight emerged, as it were, to the surface. As a result, shells arose, that is stratification of the globe started.

Very much heat had stored inside the Earth during a long period, and this caused partial melting of the interior. Heavy elements concentrated in the inner parts of the Earth, while relatively light-weight ones, on its periphery. In the final analysis, the Earth's interior was differentiated into a core and mantle. The core consists largely of iron and nickel, while silicates predominate in the mantle. In the lower mantle, matter is now in a specific, compact crystalline state, and its melting point is very high.

In what way do the light-weight and heavy substances mix up in the course of gravitational differentiation? Is mixing taking place now at all?

Matter is in motion under the effect of heat, and slow convective currents force their ways in the mantle to form cells. Matter rises in some parts of a cell and lowers in others.

The simplest convective cell occupies the entire mantle and has one centre of rise of material from the mantle and one centre of its descent. In this case, the lithospheric plate moves laterally from the site of rise to that of descent. With passing time, continental lithospheric blocks should combine at the site of descent. Oceanic lithosphere should then be located at the site of rise of hot mantle material. Single-cell convection late in the Paleozoic was responsible for the formation of the Pangaea, a giant continent.

A couple of convective cells produces a more complicated picture. They may be open, 'with two appoximately opposite poles of descent of material and a zone of rise approximately in-between. A global extension zone appears here, which is distinguished by a chain of mid-oceanic ridges, while the continents form two groups.

This picture is observed now. One group of continents consists of Africa, Eurasia and Australia, and the other, North and South Americas and Antarctica. They are separated by a global system of mid-oceanic ridges. In itself, the concept of convective cells in the mantle of the modern Earth is not the only one that seems plausible. It meets with many reservations and is under debate.

The partition of materials in the Earth's interior is a rather slow process, but throughout its history the mantle material has been recycled many times. Reflections of the grandeur of phenomena deep in the Earth are vigorous volcanic activity and disastrous earthquakes. The processes at depths are responsible for the motions of lithospheric plates, mountain building, changes in the level of the World Ocean and other tremendous geological phenomena.

The answer to the second question—whether light-weight and heavy materials mix up deep in the Earth—is positive, because otherwise our planet would be lifeless: no internal processes—volcanism, earthquakes, etc.—would take place.

In calculating gravitational differentiation, it is taken into account that the mantle material behaves as a solid body but only when it undergoes a short-term and rapidly changing load. Under the action of a prolonged constant load, the mantle becomes plastic and can flow, as ice. The Earth's mantle acts as a giant gravitational separator. It helps new and new batches of material to reach the core-mantle boundary. The heavier of them, for instance iron, descend and stay at this boundary while the more light-weight ones form ascending hot flows, emerge, so to say, and thus return to the lithosphere.

Gravitational differentiation increases mass concentration towards the centre of the Earth, but the potential energy of the whole Earth decreases. As a result, huge energy is released. This is the strongest source of the energy produced inside the Earth. This energy source has yielded 1.61×10^{32} J from the time of its origin until now.

Theoretical calculations show that the mass of the core first rose slowly but then the rate of its growth attained a maximum, according to the Soviet scientists A.S. Monin and O.G. Sorokhtin, 1.4 thousand million years ago, during the Gothic tectonic epoch. Since then the core has been building up more slowly. Its mass may reach 99% of the maximum possible size in 1.5 thousand million years.

Another energy source inside the Earth is radioactivity. Radioactive decay produces very much heat, whose amount is greatly difficult to estimate. With due account of gravitational differentiation and long-lived radioactive isotopes, A.S. Monin thinks that the total heat release inside the Earth is $2.5 \cdot 10^{32}$ J during 4.6 thousand million years. Some of this heat escapes into outer space (about 10^{22} J). This value was tentatively derived from the value of heat flow. The Earth has radiated $0.45 \cdot 10^{32}$ J throughout its life.

The Origin of the Earth's Crust

The Earth's crust is radically different beneath the oceans and within continents. Two opposite mechanisms have acted throughout the long history of the Earth: erosion and accumulation. The rivers annually discharge into the oceans about 18.5×10^9 metric tons of suspended solids and about $3.2 \cdot 10^9$ metric tons of dissolved substances, and glaciers and wind, 1.5 and $1.6 \cdot 10^9$ metric tons, respectively. Organisms also play not an unimportant role in sediment deposition. In estimating the total amount of sediment transported into the oceans during the Earth's life, we obtain a huge value. It has been found that $10.8 \cdot 10^{20}$ metric tons of sedimentary rocks must have been accumulated in water basins during 4 thousand million years, and, hence, the sedimentary layer of the Earth's crust must have been, on the average, 120 km thick. But the present-day crust, composed of sedimentary, metamorphic and igneous rocks, averages 30-33 km in thickness, and the mass of sedimentary rocks is on the order of $4.7 \cdot 10^{19}$ metric tons. If the calculations are true, all the more so that they have been made by many scientists in this country and abroad, it is evident that much of the sedimentary rocks has somehow disappeared during the evolution of the Earth. Therefore, some efficient mechanisms act which transform them not only into metamorphic but also into igneous rocks. A part of the sedimentary rocks appears to leave the crust and enter into the interior of this planet where lithospheric plates collide, as described in detail below.

Where the lithospheric plates are pushed apart, in the oceanic rift zones, open extension fissures appear and are filled with solidified crystalline materials rising from the asthenosphere. This is a basaltic magma that gives rise to the basaltic layer of oceanic crust. Its upper part is made up of pillow lavas solidified in water. In outward appearance they resemble huge whales set

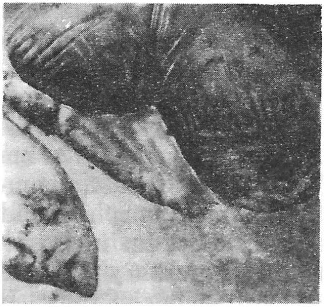

Fig. 4. Pillow lavas on the floor of the Red Sea (depth 2000 m)

in in whimsical poses, or occasionally look like elephant trunks (Fig. 4). The lower part of the basaltic layer consists of closely spaced dikes of fine-crystalline basalts. Each of them once served as a conduite through which lavas issued onto the ocean floor. The total thickness of the basaltic layer is 2 km. Lying below is a layer of igneous rocks (gabbros) and serpentinites. The oceanic crustal rocks are water-saturated. For instance, serpentinite contains up to 10% combined water. Hydration is accompanied by a withdrawal from the rock of silica, calcium, magnesium and the sulphides of iron and some other metallic elements, and, at the same time, an input of potassium, sodium and other elements.

In line with plate tectonics, continental crust forms principally in zones of subduction of lithospheric plates by way of reworking of the oceanic crust itself and the sediment on its top. Not only the magmatism in subduction zones is tens of times more intense than in spreading zones but the very composition of igneous rocks is substantially different in this case. Intermediate and acid rocks—diorites, granodiorites—predominate there, and granitoids prevail where island arcs are shovelled against continental margins.

Dehydration and partial melting of oceanic crust (some scientists are doubtful as to the existence of subduction, though they accept spreading) in the subduction zones are very complicated and multiphase processes.

The Time Scale and History of the Earth

The past... The history of human society, living and inorganic nature, natural events and phenomena—all these subjects are interesting and important not only because their knowledge helps to better disclose the logic and laws of their origin and evolution but also since it provides a deeper insight into the present and the possible future. In studying the modern Earth, geologists are all the time concerned with diverse and different-scale events in its past. And here we are confronted with the problem of geological time.

The Age of Rocks and Geological Time

When and how did volcanoes erupt and how fossil organisms appear and live? These questions always excited scientists.

The correct concept of extremely long duration of geological time became predominating in the geological science far from at once. It was noticed long ago that underlying rock strata are older than overlying strata. This principle makes it possible to date events only relatively, but it does not allow one to estimate geological time quantitatively even if the sediment contains fossils.

It was believed for a long time that the Earth is very young. The Earth and the whole Universe were postulated to have originated during several days about 6000 years ago. But some thinkers of the Antiquity and then scientists of Rennaissance put forward the ideas that the Earth's life is older and its interior and surface have undergone sweeping changes.

The advances of precise sciences—mechanics and astronomy, chemistry and physics—had led to a new approach to the age of the Earth and its constituent rocks. But the biblical texts have restrained progressive ideas for a long time. But even the renown naturalist I. Newton, whose name is associated with the whole epoch in physics and mechanics, estimated the age of the Earth at 6030 years.

G. Buffon, the author of "Natural History" in many volumes, heralded an original approach to estimating the age of the Earth. He was the author of the once widespread collision hypothesis in which the Earth is a fragment split off the Sun as the result of an impact of a giant comet. Hence it is possible to experimentally determine the duration of cooling of a giant hot sphere.

On this ground, G. Buffon estimated the Earth's life at 75 thousand years.

Scientists had quite different views on geological time and the age of the Earth, using in their calculations sedimentation rates or the duration of life of forms, separate assemblages, species, genera, families and orders of animals and plants.

Before we discuss the modern concepts on the Earth's age, we should quite in general characterize crustal rocks. Some of them were mentioned in the previous section.

Rocks are divided into three groups; sedimentary, igneous and metamorphic. The first are derived from the wearing down and redeposition of older rocks (pebbles, sands, sandstones), from the activity of organisms (chalks, limestones, and hard and brown coals) or, finally, from salt precipitation (gypsum, rock salt). Igneous rocks are formed from magma—a gas-enriched silicate melt originated in the Earth's interior. Magma solidification at depth produces coarse-crystalline abyssal, or intrusive, rocks. They are classified into several groups by the content of silica (SiO_2). Acid igneous rocks, containing 65-75% SiO_2, are granites and quarts porphyries. Intermediate igneous rocks contain 52-65% SiO_2 (andesites, granodiorites); basic rocks, 40-52% SiO_2 (basalts and gabbros); and ultrabasic, less than 40% (dunites and peridotites).

At the time of volcanic eruptions the magma loses gases to become lava, which spreads over the Earth's surface. If it cools rapidly, fine-crystalline igneous rocks are formed (porphyries, basalts, etc.). Igneous rocks generally invade sedimentary units in the form of stocks, dikes, and also batholiths, bodies tens of cubic kilometres in volume. Sedimentary units occasionally enclose stratiform intrusive bodies, sills, produced by magma invasion along the surfaces of stratification in these units.

Metamorphic rocks are initially sedimentary or igneous rocks that have undergone recrystallization at high pressure and temperature at great depths. These are various schists and gneisses.

The first attempts to classify rocks by age were based on their relative occurrence. The Italian mining geologist G. Arduino distinguished in the 18th century four types of mountains in the north of the Apennines: primitive, or mineral, made up of unfossiliferous rocks; secondary, built up of fossiliferous marbles and bedded limestones; tertiary, low mountains and hills of gravels, clays, and marls with abundant marine fossils; and quaternary, alluvial fans of earth and cobbles. This terminology was transferred to other regions of Europe, and the names Tertiary and Quaternary even have survived until now.

Geochronology, that is a succession of

time intervals, can easily be distinguished from stratification of sedimentary rocks, especially where the strata lie horizontally. Deeper (lower) strata are always older than the overlying beds in any natural exposure provided we definitely know that their occurrence is not disturbed.

Knowledge of time sequence of sedimentary rocks on the basis of the mutual occurrence of the strata makes it possible to construct a stratigraphic column (the Greek word "statos" means a bed).

It is not difficult to establish the sequence of strata in an exposure. But how can be correlated the exposure located rather far from one another? Where, among them, are older and where are younger or coeval sediments? These questions are difficult to answer, or even impossible if the stratigraphic sections under comparison are located in different countries and, all the more so, on different continents. A help in this case is provided by a paleontological method. As early as the 18th century, naturalists paid attention to the fact that sedimentary strata contain remains of fossil animals in the form of shells and skeletons, and also plant imprints. Also, the fossils in the lower strata differ from those in the upper, younger strata. It was then noticed that beds of marine sedimentary rocks of one and the same age contained identical remains of ancient organisms. This provided a major tool for the subdivision and correlation of sections.

An actual possibility for the construction of a geological scale of relative chronology arose early in the 19th century. Its relative character follows from the fact that an analysis and identification of the species or genus of a fossil remain does not accurately indicate either the time of formation of its enclosing rocks or when the organism lived. It can be found, however, whether the strata are older, younger or coeval relative to a preset stratum and make a correlation. It took less than half a century to create a scale of relative geochronology. It expressed a time sequence of geological events in the crustal history, which have been recorded in sedimentary strata.

Paleontology, one of the most fascinating biological sciences, is closely related with geology. It is concerned with fossil faunas and floras, with their systematic positions in the overall hierarchy of the organic world, and with evolutionary trends.

Based on stages in the development of the organic world and the mineral composition of the enclosing sedimentary rocks, all the stratigraphic units known to date and now widely used—erathems, systems, series and stages—were established during the 19th century. One of the major stratigraphic units is erathem, which consists of several systems. The systems are, in turn, composed of series and stages. Each stratigraphic unit has its own name.

In accordance with stratigraphic units, there have been distinguished geochronological subdivisions each of which depicts the time interval (again in relative chronology) in which the relevant stratigraphic unit was laid down.

The time span required for an erathem to form is designated a geological era, the time of era formation corresponds to a geological period; that of a series, to an epoch, and that of a stage, to a geological age.

Geological Time Scale

Geologists noticed long ago that the history of our planet could be divided into two unequal parts. The ancient, more prolonged part is difficult to study paleontologically because it contains no fossils and many sedimentary units have been strongly metamorphosed. The young part has been studied well, since its constituent strata contain numerous fossils whose amount grows and preservation improves towards nowadays. This younger part of crustal history was called the Phanerozoic eon, that is the time of evident life, by the American geologist Ch. Schuchert. Eon is a time interval consisting of several geological eras. Its lithostratigraphic equivalent is eonothem.

Ch. Schuchert gave the name Cryptozoic to the more ancient and more prolonged part of the geological history (geological time at which evidence of life is concealed). Another, rather widespread name for this time span is the Precambrian. This name has survived since the mid-19th century, when an absolute majority of geological periods was distinguished. All older sediments underlying Precambrian sequences were dated as the Precambrian. Two eons, the Archean and Proterozoic, are now in use instead of the Cryptozoic.

The Phanerozoic sediments are extensive, rich in fossils and relatively accessible; hence their better knowledge. In 1841, the English geologist John Fillips distinguished three eras in the Phanerozoic: the Paleozoic, an era of ancient life; Mesozoic, an era of middle life; and Cainozoic, an era of new life. Marine invertebrates, fish, amphibia and sporophytes governed in the Paleozoic; reptiles and gymnosperms, in the Mesozoic; and mammals and angiosperms, in the Cainozoic.

A sediment sequence laid down during a geologic era is designated as an erathem. Further subdivisions are systems, series and stages. The systems and stages were basically named after the names of geographic places where they were distinguished and examined, or after some characteristic features. Thus the Jurassic system was named after the Jura Mountains in Switzerland,

Geochronological Scale of the Phanerozoic Eon

Era	Period		Time, m.y.	Significant event
Cainozoic KZ	Quaternary		1.8	Onset of humans
	Neogene N	Pliocene	5 ± 1	Flourish of primates
		Miocene	22.5 ± 1	
	Paleogene ₽	Oligocene	37.5 ± 3	Flourish of horses and faunas of open expanses
		Eocene	53.5 ± 3	First primates and horses
		Paleocene	65 ± 3	Flourish of mammals
Mesozoic MZ	Cretaceous K		135 ± 5	Onset of flowering plants and carnivorous saurians

	Jurassic J	190±5	Flourish of corals, ammonites and dinosaurs, onset of birds
	Triassic T	230±10	Onset of dinosaurs and mammals
Paleozoic PZ	Permian P	285±15	Flourish of fusulinides, sharks and theromorphs
	Carboniferous C	350±10	Flourish of amphibians
	Devonian D	400±10	Flourish of fish, first forests
	Silurian S	435±15	Flourish of reef-forming coelenterates
	Ordovician O	490±15	Flourish of brachiopods and cephalopods
	Cambrian ∋	570±20	Onset of invertebrates with hard skeleton

the Permian after the city of Perm, the Cambrian after Cambria, the Roman name for Wales, the Cretaceous is derived from the Latin word for chalk, creta, in which this system was distinguished; the Carboniferous, from coal, etc.

While the rock-stratigraphic scale reflects the succession of sediments and their taxonomy, the geochronological scale implies the duration and a systematic sequence of stages in the history of the Earth. The geochronological and rock-stratigraphic scales of the Phanerozoic have repeatedly been revised throughout the last 100 years.

In geology, however, it is important to know not only the relative age of rocks but also, if possible, the accurate time of their origin. Several methods based on the phenomenon of radioactive decay are employed to determine the age of rocks. Hence the age estimated by one of these methods is called radiometric. Use is made with this connection of radioactive uranium, thorium, rubidium, potassium, carbon and hydrogen. Since we know the half-lives of radioactive isotopes, we can readily determine the age of the relevant mineral and, hence, its enclosing rock.

Various methods of nuclear geochronology have been developed and are in a wide use: uranium-thorium-lead, uranium-thorium-helium, uranium-xenon, potassium-argon, rubidium-strontium, samarium-neodymium, rhenium-osmium and radiocarbon. The contents of radioactive isotopes in rocks and minerals are measured by mass-spectrometers.

These methods are used to determine the age of igneous and sedimentary rocks. As to metamorphic rocks, however, what is determined is the time of the temperature influence and pressure effect on them.

Oldest rocks' radiometric age on Earth is 3.8-4 thousand million years. Some lunar rocks and meteorites are of similar ages.

Archean and Proterozoic rocks are difficult to study, and this predetermined their inadequate rock- and time-stratigraphic division. Look at the Archean and Proterozoic on the modern scale, which is still far from being perfect and detailed.

Another chronological and correlation method used in geology is a paleomagnetic one. It is based on the remanent magnetic properties of rock units. The rocks containing magnetic minerals acquire natural remanent magnetization under the effect of the magnetic field of the Earth. It has been proved that the position of the magnetic poles has repeatedly changed throughout the long history of the Earth. Knowing the remanent magnetization and its vector, and comparing the vectors between each other, one can establish that the rocks are of the same age, which to some extent refines the geochronological time scale.

Archean and Proterozoic Time Scale

Eon	Stratigraphic subdivisions accepted in the USSR		Age of beginning, millions of years ago
Phanerozoic	Cambrian		570
Proterozoic	Vendian		680-650±20
	Riphean	Karatavian	1050±50
		Yurmatinian	1400±50
		Burzyanian	1650±50
	Lower		2600±100
Archean	Upper		3000±100
	Lower		3500?

Principal Stages in the Formation of the Earth's Crust

Dating various igneous rocks has made it possible not only to determine the duration of geological periods but also to distinguish the most ancient rocks on Earth. It is known that life on the Earth began more than 3 thousand million years ago; the oldest sedimentary rocks are a little more than 3.8 thousand years old, and the age of the Earth is estimated to be 4.6-5 thousand million years, though some scientists consider these figures too large.

It has been established that the epochs of vigorous volcanic activity were short-term and were intervened by prolonged epochs of calm magmatism. The former were characterized by intense tectonic activity, that is substantial vertical and horizontal crustal movements.

If we know the age of igneous rocks, we can discern relatively short-term epochs of enhanced igneous and tectonic activity and long periods of relative quiescence. This, in turn, allows us to divide the Earth's history into natural time intervals by the intensity of tectonic and igneous activity. The entirety of data on the ages of igneous rocks is, in essence, a calendar of major tectonic events in the history of the Earth. In the main, it is the age of granite intrusions that was used to specify the age of tectonic cycles. It should be noted, at the same time, that these cycles are often not simultaneous on different continents.

We practically have no factual information about the far geological past. The only suggestion is that basaltic and ultrabasic volcanism was quite active until 3.5 thousand million years ago. At the same time, great amounts of gases escaped from the lavas with the resulting formation of not only a crust but also a primitive atmosphere.

Granitization took place and the first sedimentary basins originated during the Belozero orogeny, early Archean eon, and

Age of Orogenies in the Earth's History

Orogeny No.	Orogeny	Age, thousand m.y. B.P.
20	Alpine	0.05
19	Cimmerian	0.09
18	Hercynian (Variscan)	0.26
17	Caledonian	0.41
16	Salairian (late Baikalian, Sardic)	0.52
15	Katanginian (early Baikalian, Assyntian, Cadomian, Zheleznogorian)	0.65
14	Dehlian (Dalnelandian)	0.86
13	. . . .	0.93
12	Grenville (Satpurian)	1.09
11	. . . .	1.21
10	Gothic (Medvezh'eozerian, Mazatialian, Kibarian, Elsonian)	1.36
9	. . . .	1.49
8	Karelian (Hudsonian, Svekofennian, Bularenian, Laxfordian)	1.67
7	. . . .	1.83
6	Baltic (Ebournean, Penokean)	1.98
5	Early Karelian	2.23
4	Algonkian	2.44
3	Kenoran (Belomorian, Laurentian, Rhodesian, Shamvaian)	2.70
2	Kolian (Transvaal, Saamic)	3.05
1	Belozerian	3.5

the Kola orogeny, mid-Archean eon. This period witnessed the deposition of sands and clays, now strongly metamorphosed, carbonate rocks and even their alteration products.

During the Kenoran orogeny, at the end of the Archean eon, nuclei of would-be major stable geostructural elements of the Earth—hedreocratons—were formed. Later on, the nuclei of cratons continued to build up.

At the time of the Kenoran, Algonkian, Early Karelian, Baltic, Bularenian and Karelian orogenies, there were formed the basements of all known ancient hedreocratons: the East European, Siberian, Chinese, Tarimian, Hindustan, African-Arabian, North American, South American and East Australian. The primeval granitic layer of the Earth's crust was created during nearly one thousand million years (from 2.7 to 1.67 thousand million years ago), while the presence of carbonate sedimentary rocks helped alkaline intrusions to invade. Huge granitoid plutons, more than a thousand of square kilometres in area, which are surrounded by the most ancient sedimentary rocks, fixed the stable crustal segments, called shields, within the hedreocratons. Examples are the Baltic, Ukrainian, Aldanian, Canadian, Guianian, Brazilian and Arabian shields.

Assuming all of the known most ancient

cratons to be similar and have simultaneously formed, a giant single continent of Megagaea (Big Earth) may have existed in the Proterozoic, having been surrounded by the single World Ocean.

Since 1.67 thousand million years ago, the ancient cratons, especially the shields, have been structural crustal elements stable in both time and space. Within these cratons, however, regions of gentle and relatively slight downbuckling (syneclises) were later generated; the crust was split along systems of deep-seated faults of the stabilized ancient mobile belts. In this case, aulacogens—major, long-extending, highly mobile depressions—were sunk. These are, for instance, the Katanga aulacogen in the African craton and the Dnieper-Donets in the East European craton.

During the tectonic cycles that followed, the cratons either still built up at the expense of marginal mobile belts or split up and later experienced motions in different directions at different velocities. A gradual diminution of magmatism intensity has been taking place during the last one thousand million years.

The Gothic orogeny was responsible for the granitization of pre-Riphean rocks and for metamorphism on most of the cratons. The granitization in the mobile belts and further build up of the cratons continued in the middle and especially late Riphean.

The magmatism of the Katangian (early Baikalian) and late Baikalian orogenies varied from craton to craton. Their common features, however, were intensive folding, on the one hand, and, on the other, faulting and motions of major cratonic blocks (lithospheric plates).

As a result, five largest hedreocratons in the southern hemisphere, the African-Arabian, Australian, South American, Antarctic and Hindustan, converged to form the single supercontinent Gondwana, while the East European, North American, Siberian and Chinese cratons were located in the northern hemisphere.

The Caledonian orogeny witnessed not only an increase in magmatism but also the rise and formation in the northern hemisphere of a new supercontinent, Laurasia, combining the above-mentioned cratons. It was separated from the Gondwana by a large ocean, Tethys.

Unlike the older stages, the Phanerozoic orogenies are divided into several episodes, owing to a better preservation and better knowledge of rocks. As during the orogenies, at the time of the episodes the continents stood high above sea level (uplift predominated), magmatism was active, and tectonic movements were intense.

These episodes are called geocratic; they were followed by more prolonged thalassocratic episodes, when the cratons downwarped actively and transgressions set up, that is sea spread over land areas.

As a result of tectonic and igneous activity in the Caledonian orogeny, there were formed major folded mountains in the west of the North American craton (Appalachian Mountains), in Central Asia (Central Kazakhstan, Altai, Sayans, Mongolia), in Eastern Australia, on Tasmania Island and on Antarctica.

At the time of the Hercynian orogeny, the Gondwana and Laurasia collided to produce the single continent Pangaea. As about one billion years ago, the Pangaea continent was surrounded by a single ocean. Intense mountain buildings gave rise to major mountain systems. called the Hercynides. All of them are on the periphery of ancient cratons. These are the Tibet, Hindu Kush, Kara Korum. Tien Shan, Altai, Kun Lun and Ural systems. the mountain systems of Central and Northern Europe, South and North America (Appalachians, Kordilleras), north-western Africa and Eastern Australia. At the same time. the consolidation of orogenic regions gave rise to the whole number of so-called epi-Hercynian, or young platforms: much of the West European craton, Scythian. Turanian. West Siberian platforms. etc.

In the Cimmerian orogeny. intrusions of different compositions invaded mobile belts, mountain building occurred and the Pangaea split apart. The supercontinents Laurasia and Gondwana arose again, intervened by the young ocean Tethys and the South Atlantic, throughout the Triassic, Jurassic and Early Cretaceous. Mountains rose basically at the margins of the Laurasia. The Crimean Mountains and the mountain systems near the Verkhoyanskii Range appeared at that time. Considerable movements also involved the earlier mountain systems of the Appalachians, Caucasus and Central Asia.

The Alpine orogeny began to evolve late in the Cretaceous and continues until now. Not only acid, basic and alkaline intrusions were emplaced in mobile belts, and oceans and continents of modern outlines arose at this time, but also such magnificent mountain systems as the Alps, Dinarides, Himalayas, Andes and Cordilleras were generated.

The geochronological scale was designed with great difficulty and during a long period of time. Many stratigraphic boundaries are still under debate. International symposia have occasionally to be called in order to agree upon where or how to draw the boundary of this or that rock- or time-stratigraphic unit.

The geochronological scale has greatly transformed geology. It has become a natural-historical science. The events in the past were placed chronologically.

This Variable Face of the Earth

"Everything flows, everything changes"—these winged words spoken by philosophers of the antiquity quite accurately reflect the unstable character of natural conditions and all outer shells of the Earth. All people got used to regard the Earth's surface as something solid, reliable and unshakeable. But as soon as a disastrous earthquake or volcanic eruption occurs somewhere on our planet, we fell uncomfortable and helpless in front of the elements. These, as well as tremendous atmospheric phenomena—tornados, typhoons, cyclones and anticyclones,—greatly affect the surface people just stand on. But besides short-term and considerable effects of natural phenomena on the surface, quite diverse geological processes act slowly, gradually on it during many thousands of years. They destroy mountains, widen gourges, change shorelines, produce and destroy deserts.

The Earth's surface is modified by climate (seasonal and duirnal temperatures and humidity), wind, glaciers, surface and subsurface waters, various organisms, etc. But how could scientists discern not even the activity but the results of this or that process? After all, when one says that the river washes away its banks, transports stones, rounds them up, attrites them gradually and carries them out into the sea, this doesn't mean at all that the geologist sits on its bank and walks along its channel for years, and, all the more so, dines into the sea floor to see and trace the entire process of formation of pebbles, their conversion to sand and laying down of sediment in the river channel, flood plain or the sea. Not at all. To derive this trend, scientists compared the shapes and size of stones, from the river headwaters to mouth, analysed the mineral composition of sand, saw the river sometimes undermining its bank, which collapses, or the channel meandering. Although these transformations occur in front of us, they are very slow. After all, for a granite fragment to become a pebble or, all the more so, sand, more than a hundred years are needed.

Just in the same way geologists act when they study the geological activity of glaciers, seas and lakes, wind and organisms. They see the various phases of development of different objects and then put them in a successive order; as a result, all these phases turn out to be linked by a single logic.

Weathering and Soils

The solid outer shell of the Earth, the lithosphere, comprises not only massive hard rocks but also loose sediment derived from the destruction of underlying hard rock or transported from far by wind, water or ice. The loose rocks are frequently changed to become soil. The transformation of a hard rock into a soil is due to the alteration of its physical form and chemical composition under the action of air, water and microorganisms. This long-evolving process is called weathering.

How does weathering act? Whatever hard and massive the rock was it is cut with time by numerous fractures. These are basically due to the fact that rock-forming minerals have different expansion coefficients. The steel constructions of bridges, concrete pavements, steel rails expand in a hot weather and shrink when it is cold. To preserve their integrity, clearances are envisaged in certain places. However, rocks consisting of grains or mineral fragments have no such clearances, and an alternation of heating and cooling due to a diurnal and seasonal temperature fluctuation produces a series of fractures in massive blocks (Fig. 5). This is an initial phase of physical weathering. Water penetrates into the fractures; it dissolves and alter minerals, expands on freezing and widens the fractures.

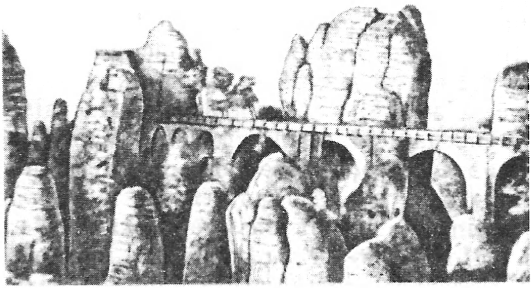

Fig. 5. Whimsical weathered forms of sandstones. Saxonian Switzerland (DDR).
Weathering makes mountain masses discontinuous. They become cut by a joint system

In the final analysis, the hard rock is destructed, or, as geologists say, disintegrated. This implies that it is destroyed mechanically, with the formation of smaller particles of the same mineral and chemical composition.

Plants and animals also disintegrate rocks. If you are on the South Coast of the Crimea, pay attention to Crimean pine fighting for its existence on limestone blocks. Its roots grow into fissures and crevices, widen them, push their walls apart and sometimes even push some rock pieces onto the surface. That the root system is strong can be judged from the whole number of instances. Thus trees grown from a crevice rather often split some blocks of hard limestone and even granite, and in town roots of trees raise and destroy concrete pavements. Rainworms, ants, rodents and other diggers, as well as hoofed animals, also help mechanical disintegration. When we run tonnels, work mines and quarries, and build roads, we also contribute much to the disintegration of massive rocks. Under the action of water and duirnal, monthly and seasonal temperature fluctuations, scales or separate plates flake off a massive rock. In consequence, fresh rock segments are exposed. In some places, once hard, flat-lying rock is cut by a fracture network and look like a cobbled road

After flaking off, if physical weathering goes on, rock fragments consisting of large grains (for instance, granite) undergo further disintegration until mineral grains become isolated. Small grains are removed by water or wind, while large ones remain on site and experience new effects. This is the way the gruss is formed, as in circumpolar countries and in high mountains.

Water is one of the principal weathering agents. On dissolving chemical elements and being saturated with carbon dioxide, water gradually becomes aggressive and affects rocks as a dilute acid. Chemical weathering acts gradually, by stages. First, hydrolysis destroys the crystal lattice of a mineral. Water dissociates into ions of hydrogen and hydroxyl (OH), and then reacts with crystal materials. The ions replace atoms in crystals or react with them thus disturbing the crystal structure. Calcium, magnesium, sodium and potassium dissolve, while aluminium and iron compounds form hydroxides. The latter process is called hydration. Moreover, ferrous iron is oxidized into ferric iron during chemical weathering. This changes not only the internal structure of rock but also its colouration and physical properties.

As a result of chemical weathering, hard rock becomes a loose clayey material whose chemical and mineral compositions depend on the primary composition of the parent rock and on climate. Clay serves as a raw material for the ceramic industry. Refractory kaolin clay is of special value.

Not all minerals and chemical compounds are transformed by weathering. There occur stable minerals, which cannot be affected by chemically active solutions; they gradually accumulate as unstable minerals dissolve and remove.

Gold, diamonds and many other precious stones are released and accumulated as igneous rocks are weathered.

Climate is one of the main factors of weathering, controlling its rate and trend. The hot and humid climate of the equatorial belt is quite favourable for a complete transformation of rocks and deep penetration of weathering agents. The dry and hot desert climate strongly hampers chemical weathering, because water—one of the significant weathering factors—is lacking. Still present little capillary water rises slowly to the surface where it gets rid of salts, which cement loose desert sand to frequently produce a gypsum and salt crust.

Even if the humidity is high, the temperature drop decreases the weathering rate and intensity. In a moderate, relatively humid climate, weathering ceases gradually, and physical weathering comes forward. Rock disintegration is especially severe in a cold climate.

Soil forms a thin layer and is derived from rock weathering. It is composed of several horizons: the upper (humus plus eluvium), rich in organic matter and soil organisms; middle (eluvial), or subsoil, made up of oxidized and leached clay; and lower, built up of loose and soft rock similar in composition to the underlying parent rock. The composition and productivity of soils depend on climate, vegetation, relief, parent rocks and soil organisms.

Surface and Subsurface Waters

Erosion of the Earth's surface starts once a rain drop impacts the earth.

Pay attention to exposed, barren earth after a rain. Earth is removed around each little stone, and only under it, as if under its protection, a tiny area of soil is preserved. When a rain is too strong for the soil to absorb it, excessive rainwater begins to flow down a sloping surface. On its way down the slope, it causes sheet erosion, or sheetwash. The more water runs down the slope, the stronger is erosion. Tens of tons of fertile soil are annually removed from each hectare of land. Small rills are produced on the slope by rivulets. Water in the rivulet applies a strong destructive force and thus affects the slope as an active agent of erosion. The rivulets change the configuration of the slope and wash out small rills and gullies to produce little valleys.

Barren slopes undergo very strong erosion. In constrast, a vegetative cover prevents the surface from erosion for a long time, because it greatly weakens the force of dropping and running water, while the root system of plants fasten, so to say, loose soil particles. Under the action of weathering and sheetwash surficial irregularities are gradually levelled off. The material carried from uplands enters into river valleys. The drainage basin expands, the material transported increases in amount and land planation tends to become ultimately stronger. The drainage basin is lowered at an average rate of 1 to 5 m in 30 thousand years.

Rivers make substantial geological work. They undermine and destroy the walls of valleys, dissolve chemical compounds, transport suspended material and lay it down in lows, where the flow is slower. The amount of material transported and the particle size depend on how deep and fast the river is. Fine particles are transferred in a suspended state, while larger ones (pebbles and boulders) are dragged over the river bottom. After prolonged dragging over the rocky bottom, highly angular fragments are rounded to become flattened pebbles which are later attrited to smaller sizes. The rock fragments, transported over the bottom, plough it, and the channel is gradually deepened.

Any river consists of the main channel and its tributaries. It lengthens, deepens and expands its valley. Rivers in mountainous countries make enormous work. Deep and steep-sided valleys—canyons—are especially expressive. An imposing canyon has been cut by the Colorado River, USA. This is the Grand Canyon, several hundred metres deep.

If the river profile is steep and hard rocks are exposed along it, water falls may form at their exposure. The river bed is then disrupted by water and dragged fragments, and the fall retreats.

Like a living organism, rivers get old. The speed of their flow lowers with time, their channels cut no more into the underlying rock, and lateral erosion ceases.

Shoals are deposited intermittently on either side of the channel. This makes the river bend its channel, that is meander. Rivers often leave their bends, cutting new channels; the cut-off meanders are converted to overgrown oxbow lakes.

Rivers not only make considerable destructive work but also lay down characteristic deposits called alluvium. Fragmental materials ranging in size from large pebbles to clay accumulate on channel shoals, low flood-plains and, finally, in river mouths or deltas. Every year rivers discharge into the sea huge amounts of suspended material. For instance, the Volga carries out 40-50 million metric tons in suspension; Nile, 125 million; Mississippi, about 400 million; and Indus, 450-500 million. Much of this suspension, suspended load, accumulates in deltas. The largest deltas are tens, even hundreds of square kilometres in size. For instance, that of the Mississippi is 150 000 km^2 in area; Niger, 40 000; Nile, 20 000; and Lena, 45 000.

The fragmental material piled in deltas separates the river flow as a whole into numerous distributaries along which water reaches the basin of input. If the sea level rises, a basin or canyon projecting far into the sea is present at the river mouth, an estuary originates instead of a delta. These forms are characteristic of the Ob' and Enisei mouths.

Subsurface, or ground, water performs much work. It occurs in nature as underground lakes and streams, springs, geysers and water in dug wells. Karst caves in limestone masses owe their origin to subsurface water. It is 40 times as much as the water in all lakes, marshes and rivers of the world. A considerable part of subsurface water is derived from atmospheric precipitation in the form of rain or snow. On dissolving various chemical elements and compounds present in rocks, the water is gradually mineralized and, on percolating to considerable depths, is heated. The water released from solidifying magmas is extensive in regions of volcanic activity, such as Iceland and the Kamchatka Peninsula, USSR. The hot solutions there are so mineralized that the ore minerals—copper, lead and zinc precipitate from them. Subsurface waters flow onto the surface as geysers or hot springs.

The life of many people on the globe depends on the purity and amount of subsurface water resources. Many cities are supplied with municipal water from subsurface springs. Much of it is used for irrigation. Calculations show that dug wells and springs yield about 120×10^9 l/day, which is nearly 1/5 of the total water used by humankind.

People dug wells in countries that suffered from water shortage even in ancient

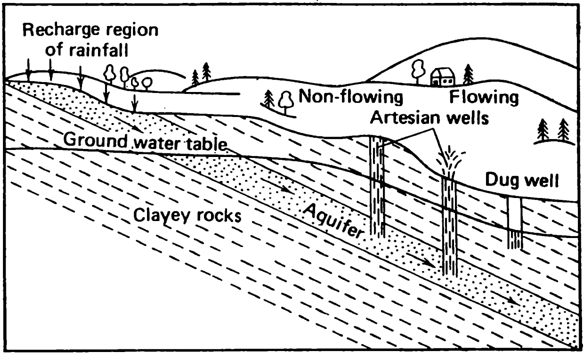

Fig. 6. Schematic cross-section of an artesian basin.
In a water-saturated layer between two clay aquicludes, pressure rises with depth. Water flows out of wells

times. Boreholes to obtain water were first drilled in China and India. Irrigation using water from dug wells was conducted in Ancient Babylon as early as 2000 B.C. Artesian dug wells were widespread (Fig. 6). They are named after the French province Artois, where water in many dug wells rose above the surface and issued vertically upwards. The spontaneous water flow in an artesian dug well is due to a difference in hydrostatic pressure in different parts of the aquifer. Vast artesian basins occur in the European Soviet Union and in the USA.

Water percolates rapidly downwards along fractures. If a rock dissolves easily in water (for instance limestone, dolomite, gypsum or rock salt) karst caves, cavities, sinkholes and channels form in them. These are so-called karst features, and the process of their formation is called karstification. The word karst was derived from the Yugoslavian territory Krš, near Triest, on the northern coast of the Adriatic Sea, where this peculiar relief is best developed. Here formed are sinks resembling furrows, small trenches and crevices as deep as 1-2 m. They extend parallel down the slope. Besides, niches and sinkholes can be distinguished. The latter are most numerous and are variable in size. As a rule, the steep slopes of a sinkhole pass into a channel directed downwards, into which water flows. In some places, for instance in the area of the Crimean yaila *, the surface is covered with such sinkholes, as if with pock-marks. There are 50 to 100 of them within square kilometre. Sinkholes may often form just under our very eyes, and then trees fall and are broken, earth caves in, and a deep sinkhole can soon be found here.

Vertical karst pits and shafts originate occasionally in areas of carbonate rocks, owing to their prolonged dissolution. The pit may broaden so much that it looks like an imposing cave-in or a precipice.

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* It means mountain pasture in Crimea.— *Editor's note.*

Disappearing rivers are typical of karst region. For instance, in the Black Sea coast of the Caucasus, in the area of Gagra, the Zhovekvara River does not enter into the sea but has disappeared, having left behind only its dry channel observed on the surface. Only several hundred metres off the seashore one can see pure river water running into the sea at depth along an underground channel and mixing with sea water.

Karst caves are of great interest to us. These are systems of horizontal and vertical channels, cavities of varying sizes and shapes, which alternately broaden to become huge halls and grottos and pass into narrow fissures. Imposing caves are widespread in many regions of Western Europe, USA and USSR. The Mammoth Cave in the state of Kentucky, USA, is largest. Its extensive labyrinth has not been studied to all its length as yet. It consists of interconnected galaries totalling several hundred kilometres in length, with underground lakes, rivers and waterfalls. In the Soviet Union the Novoafonskaya and Kungurskaya caves are most famous. Giant halls fringed with rod-like stalagmites and whimsically intermingled stalactite, lighted artificially in the Novoafonskaya Cave, are a unique sight.

Glaciers

Ice originates in any place where water is present and the temperature is below zero, that is in lakes, rivers, and seas, on land surface and below, and in the atmosphere. Sea water does not freeze until its temperature is below —4°C. In polar regions, glacier swells, as high as 15 m, are generated along seashores during cold seasons. They protect the shore from the destructive action of waves in winter, and during ice drift the fragments of this ice transport a great number of terrigenous material.

Drifting of the ice in spring is an unforgettable sight. Colliding against one another, ice-floes swell and are split with a roar; they disrupt the steep banks and even the bottom of the river, because many acute angular rock fragments are inserted into the ice, and they affect the sides of the river valley like emery. When ice accumulates in a narrow reach of the river or on a shoal, a buttres is formed. This is the case for many rivers of Siberia and Canada, and here fish suffers from little oxygen.

In areas of negative mean annual temperatures, soils and bedrock are penetrated with permafrost. It occurs as an alternation of frozen ground and ice as seen in the sides of northern river valleys in Siberia. Ice is very sensitive to temperature changes. When temperature falls, the volume of the

Fig. 7. Valley glacier in the Pamirs

soil layer increases, and the soil heaves. When temperature rises, only the upper permafrost level melts, water spreads over the surface, and vast marshes appear in tundra, because massive ice occurs beneath them.

In high mountains and polar regions, moisture first accumulates as snow and then turns to ice, which can flow. Glaciers move slowly along valleys in mountainous regions (Fig. 7), and from the centre outwards on continents (Greenland and Antarctica). They are moved by gravity owing to the ice flow and glide over the Earth's surface. The glacier descending down the valley resembles a river but it flows very slowly.

All glaciers are divided into three major groups: mountain, or valley glaciers; coalescing, or piedmont glaciers; and ice caps, or sheet glaciers. The first arise in high mountains nearly at all lattitudes, being supplied from snow fields. The second are extensive in polar regions at foothills, appearing where valley glaciers enter into vast plains, from which they spread in different directions. The third are huge ice shields in vast land expanses—in Greenland and Antarctica. An ice sheet varies in thickness between several hundred metres over mountains to 4000 m at its centre. Boreholes drilled through the ice allow one to raise cores and hence examine the composition of ice accumulated hundreds and even thousands of years ago.

The glacier strongly affects the topographic relief as a result of both erosion and deposition, the former being due to the removal of loose material, destruction and ploughing of bedrock of the channel and valley sides by fragments frozen into the ice and transported by the glacier over the glacier bed.

If the glacier encounters cliffs or highlands on its way, it smoothes them out, if its thickness is sufficient, and polishes them, leaving behind furrows and scars—the traces of abrasion caused by angular fragments frozen into the ice. Specific glacier landforms emerge, that is roche moutonnée and sheep-back rocks.

Amphitheatre-shaped depressions surrounded by steep rocks—glacier cirques—

form in the upper reaches of glacier valleys as a result of frost weathering. They generally broaden, deepen and are cut back. The space between the cirques gradually narrows down, and sharp-pointed serrated ridges and pyramidal horn peaks ultimately remain.

On their motion, the glaciers catch and transfer an enormous volume of variable fragments, which gradually split up, are rounded and attrite. Various-size granite boulders are common on the East European Plain. No one could explain for long why they are so far from their original place. Evidence for the granite boulders to have been transported by glaciers from Scandinavia were obtained only late in the 19th century. Other definite evidence found at the same time is roche moutonnée, traces of ploughing and accumulative forms of the glacier relief.

On its motion, the glacier carries fragmental material constituting the moraines (Figs. 8, 9). By the location of transport and deposition, there are distinguished subglacial, medial, lateral and terminal moraines. While the first three are in constant motion, the last is immobile and marks the successive stages of glacier retreat. The moraine is rather diverse in composition; it varies between fine clay and loam to pebbles and boulders. All of them are mixed up chaotically and uncemented,

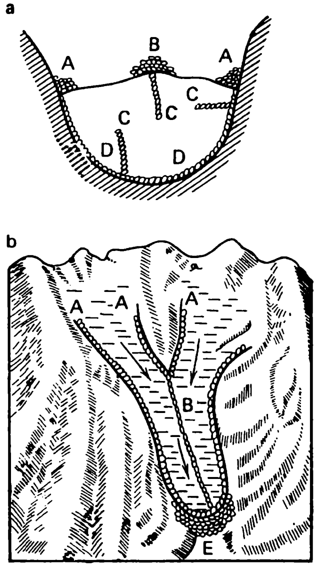

Fig. 8. Location of a moraine in the cross-section of a glacier (*a*) and in plan (*b*).
Moraines: *A*—marginal; *B*—medial; *C*—internal; *D*—basal; *E*—terminal

Besides typical moraines, moraine bars rising out of water some distance from the shore occur on the continental shelf. They arise where the glacier descends right into the sea.

Glaciers undergo melting and evaporation. Melt-water which produces streams forms inside them, especially near their edges. The streams carry much suspended fragmen-

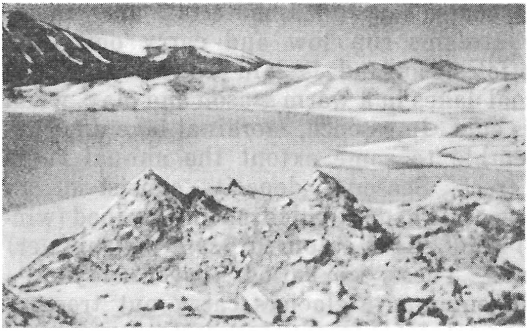

Fig. 9. Terminal moraine and a morainal lake

tal material out of the glacier. Deposits laid down from melt-water streams are called fluvioglacial. They give rise to specific landforms—outwash plains and eskers.

Outwash plains are gently rolling plains beyond the outer edge of terminal moraines. They are underlain by sands, gravels and pebbles. Eskers are long, narrow ridges or swells extending in the direction of glacier motion. They are as high as 50 m and often as long as several tens of kilometres. Eskers owe their origin mostly to intraglacial melt-water streams.

Temporary morainal lakes are often located at the edge of a melting glacier. They appear owing to the buttressing of subglacier streams. In summer, when the glacier melts rapidly, these lakes receive more or less coarse suspended material. In winter, the streams run low and carry only fine particles. So sand is laid down in the morainal lakes in a warm season and clay, when it is cold. In essence, morainal lake deposits resemble to some extent the annual rings of trees. Seasonal deposits consist of an alternation of dark-coloured fine-grained (winter) and light-coloured sandy (summer) bands. These are called varved clays.

In summary, glaciers carry out tremendous geological work; they destroy and level off varying irregularities on the Earth's surface, transfer drift and accumulate it, giving rise to a unique glacier relief.

Wind Action

The dynamics of air masses in the upper and lower atmosphere plays a major part in the evolution of the face of our planet, particularly in the formation of the climate, sea currents and topographic relief of the Earth. Winds are derived from an uneven distribution of atmospheric pressure and are always directed from higher to lower pressure. They cause rough water in large water bodies, but their action on the Earth's surface is strongest in desert and semidesert regions, where the vegetation cover is absent and diurnal temperature fluctuations are broad.

Fine dust shrouds carried by an air flow do not look imposing in the first sight. It turns out, however, that between 10 and 100 metric tons of dust fall on a square kilometre in a dust storm. Especially striking are all-smashing tornados, when houses are disrupted, uprooted trees, cattle and cars are thrown into the air, and so on.

Wind blows out and scatters rock particles; it transports them and accumulates where the speed of air flow drops drastically. Geological processes caused by wind are called aeolian.

In semideserts and steppes, repeated blowouts produce lows, or wind-scoured basins, generally located in the bottom of dried-up lakes. Large blow-out forms, as long as 50 km, are situated in the Gobi Desert, Central Asia, and in the Lybian Desert.

Destructive wind action, deflation, also affects hard bedrock. The mechanism of this action can be observed when a car is drived through a sand storm. Its windscreen becomes dull because of numerous dust impacts, as does its polished painted surface. In the same way, cliffs made up of hard massive rocks are scoured as time goes.

That the work of wind is selective follows from the appearance of specific cornices where a hard rock protrudes, and of niches in loosely cemented or soft rocks. Deflation is responsible for whimsical rocky forms. In his books "From Kyakhta to Kul'dzha"

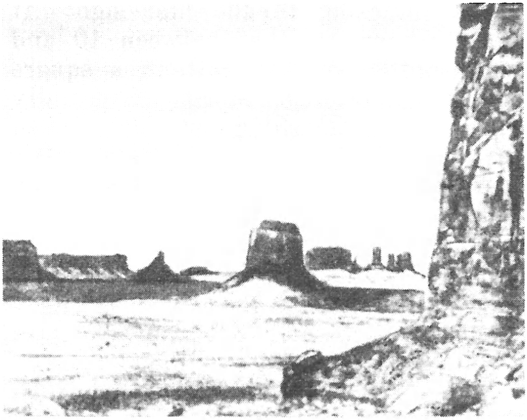

Fig. 10. «Aeolian town», Central Asia.
Weathering and deflation produce whimsical landforms

and "In the Wilds of Central Asia", Prof. V.A. Obruchev excellently describes an "aeolian town" of fantastic figures and buildings (Fig. 10). Their specific character is reflected in their names given them by V.A. Obruchev: Khan's Castle, Monument, Sorceress Tower, Sphinx, Bird, and so on.

Dust particles are transported by wind in suspension, while sand grains, by way of intermittent leaps, jumps, hops and bounces. Particles are transported for great distances. For instance, the volcanic dust erupted by the volcanoes Vesivius, Catmai and Krakatao were in the air throughout several years and rounded the globe several times. The dust from the African deserts is driven by strong trade-winds for more than 3000 km into the Atlantic. The dust from Sahara reaches Southern Europe with swift winds from the south. Red rains, consisting of red desert dust are frequent in Italy.

Forms of aeolian sands and loess are quite interesting and specific. Aeolian sand is derived from winnowing of the loose sediments of rivers, lakes, seas and weathering products.

Loess is extensive in China, Soviet Central Asia, the semidesert regions of western United States, Western Europe and the steppes of the southern Soviet Union. It is a greyish-yellow unstratified rock composed of dust with numerous pores. Although no cement is present in loess, the particles are so compact that vertical walls do not collapse for long.

Aeolian deposits constitute two types of topographic relief: varying barchans in deserts and dunes on sea coasts, lake shores, and the banks of large rivers. Barchans are perpendicular to prevailing winds. These are crescent-shaped sand hills, as high as 15 m, even 30 m. Besides, barchan ridges and numerous hills covered with hummocky or cellular sands are widespread in deserts. Most barchans and dunes are in motion. Some of them, however, can be stabilized by vegetation. The dunes on the coast of the Bay of Biscay, south-western France, move landwards at a speed of 1-2 m/year. On the south-eastern coast of the Baltic Sea, dunes have moved for 13 km during 70 years. Barchans in deserts migrate very rapidly and on a large scale. During a strong sand storm, vast areas of barchan sand get in motion; it buries on its way highs, dug wells and rural settlements. A purposeful fight against sands is hence conducted in desert regions. Their stabilization with the help of plants is a rather effective technique. Roots of trees and shrubs bind sands, and tree crowns slow down the wind. Planting green shelter belts is especially effective in the fight against wind erosion. Tens of hectares of fertile earth have been saved thanks to these measures.

Geological Activity of Seas

Human is always struck by the beauty and might of sea waves. Thus in violent storms, waves as high as a multistory house throw large ships as splinters and dash them upon the shore with an all-crushing force. No concrete barrages can withstand a direct long-term action of storm waves. After all, for instance off the Atlantic coast of America, they affect the shore with a force of up to 30 t/m^2. To prolong, at least to some extent, the life of a coastal barrage, breakwaters are built on the way of wave motion, and these reduce substantially the wave impact energy.

The speed of waves reduces over shoals, owing to friction against the sea floor. They are gradually becoming shorter and ultimately break down in the chaotic noise of the tide. The sea shore is affected not only by waves but also by nearshore currents.

On the Caucasian coast of the Black Sea, storm waves rapidly disintegrate rocks and transfer large blocks. The ruinous effect of waves on the seashore is called abrasion. Water penetrates into the fractures and pores in the sea side, expands them and compresses their contained air. When the wave retreats, the compressed air expands and breaks up the rock composing the precipitous shore like an explosion. Abrasion is repeatedly enhanced if the water contains rock fragments. Tide waves involve pebbles and large rock fragments and strike cliffs by them. The fragments are fragmented but shatter the shore. A wave-cut recess is first formed at its base. Rock cornices ultimately collapse. Later on, another recess is cut in the cliff, and it thus retreats inland, while a platform, called a rock bench, which is inclined seawards, is left behind. A narrow strip covered with gravels, pebbles and sand arises between the inundated terrace and the cliff. This is a well-known sea beach.

Fragmental material is transported land-or seawards by waves and longshore currents. Entering into a bay or a gulf, it settlees down on the bottom and accumulates there. Near the shores, sediments make up beaches, diverse spits, barrier beaches and wave-built terraces.

A typical spit is a seaward beach continuation until the end of the shoal. The Arabatskaya Spit, extending along the shore for many tens of kilometres, is well known in the Sea of Azov. Some spits nearly completely bar the entrance to the bay. Barrier beaches are parallel to the shore, being separated from it by a lagoon. They are produced by waves off a gently sloping shore.

However, the geological activity of sea is not restricted to seashores. It can be compared to a giant organism in which quite diverse processes take place and which interacts intensely with other Earth's shells. Seas and oceans are the largest water bodies. A great variety of organisms live and evolve in them. Complicated processes of sediment accumulation occur in the sea, as do, and not less intensely than on land, the processes of alteration of the sea floor, which is dissected rather severely.

Volcanoes and Earthquakes

No more terrible, imposing and mighty natural phenomenon exists in the world than a volcanic eruption. It has been known since long ago what troubles are caused by volcanoes; few know, however, that the volcanoes are useful in many respects. First, after an eruption, the slopes of the volcano and its surroundings are covered with a layer of fertile ash; second, volcanic activity produces metallic ores and diverse construction materials; and third, warm and hot mineralized springs issue in volcanically active regions. Finally, eruptions provide invaluable information about the composition and structure of the deep interior of our planet.

Volcanoes not only feature the Earth but are widespread on other planets. It is generally accepted that volcanism may play a crucial role in the formation of the outer shells of celestial bodies, among them our planet, and given rise to complex organic compounds.

Present-day Volcanoes

Most of the active volcanoes are restricted to the zone of continent-ocean transition. The so-called Circum-Pacific volcanic belt is well known. This belt, as well as the Indonesian island arc, comprises 75% of all active volcanoes, while the region of the Mediterranean Sea, merely 5% nearly as many as in the interior parts of continents, for instance within the Great African grabens. Volcanoes were active quite recently in the Arabian Peninsula, Mongolia and the Caucasus.

Volcanic eruptions were also recorded on the World Ocean floor. Many volcanoes hide themselves deep in the ocean; only some of them emerge as separate islands or archipelagos, such as the Hawaii, Galapagos Islands, and Samoa Islands. Volcanoes both in the oceans and on land are confined to fault zones in the Earth's crust. Volcanic chains in the oceans are as long as 2000 km. These are the Hawaiian, Galapagos, Molucca and many other islands in the Pacific, Indian and Atlantic oceans.

The Pacific Ocean is conventionally divided into three volcanic provinces. The western province consists of long chains of the following archipelagos: the Samoa, Marshall, Caroline, Cook, Tubuan and Tuamotu. The central province embraces the volcanic ridge of the Emperor seamounts and the Hawaiian Archipelago. The eastern province contains the East Pacific Rise.

In the Indian Ocean, volcanoes are grouped in the region of the Comoro Islands and extends from the Seychelles to the Mascarene Islands. In the Atlantic, many similar islands are restricted to the Mid-Atlantic Ridge; these are Jan Mayen Island, the Azores, Canary and Cape Verde islands, and Iceland, with its 140 volcanoes of which 26 are active.

The ancients worshipped volcanoes and idolized them. It is not without reason that volcanoes are named after Vulcanus, the Roman god of fire and metalworking. This name was first applied to a small island and a mountain in the Tyrrhenian Sea, near Sicily, because smoke always curled and blazing torches arose over its top.

A volcano mostly looks as a cone-shaped mountain (Fig. 11). Its sides are formed of solidified lava, volcanic gypsum and bombs. A hollow (crater) tops this mountain, in which a lake is not uncommon. A channel that is terminated as a vent at the surface is located on the bottom of the crater. The channel is filled with a congealed lava until a new batch of a molten magma is supplied from depth. Because of the explosion and blow-out of an enormous amount of clastic material, subsidence and collapse, a caldera arises on top of the volcano.

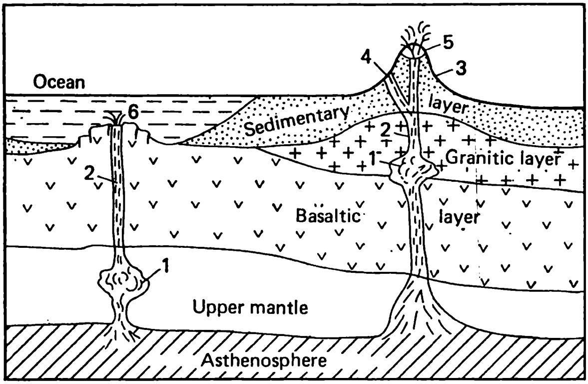

Fig. 11. Structure of a volcanic edifice:
1—magma chamber; *2*—volcanic vent; *3*—volcanic cone; *4*—lateral vent; *5*—crater; *6*—volcano on a mid-oceanic ridge

For instance, Bandaisai Volcano in Japan exploded to produce a caldera 2700 m wide and 400 m deep. Even larger is the caldera of Krakatao Volcano. It is nearly 9 km in diameter, and its bottom is 300 m below sea level.

An eruption of a volcano is a very colourful sight. An underground rumble is accompanied by a ground tremour; volcanic bombs and ashes are thrown high into the air; red-hot lava flows down the slope and spreads over the plain, destroying all living things—this is all impressive. Catastrophic eruptions have survived in the humankind's memory and are recorded in quite various chronicles. Thanks to the Roman scientist Pliny the Younger, we now have his description of the terrifying Vesuvius eruption of 79 A.D., during which an incandescent ash cloud wholly buried the towns Pompeii, Herculaneum and Stabiae. There were eight relatively week eruptions of Vesuvius between the time of Pompeii demolition and the 17th century. As a result of the strong eruption of 1631, a lava flow inundated several villages. Another strong eruption occurred in 1794 and lasted 10 days. After explosions and violent quakes, a lava began to issue from the crater. A red-hot flow rushed down the slopes and rapidly reached Torre-del-Greko, a prosperous town. The town disappeared in several hours; its inhabitants were lost. Even sea could not stop the lava.

The 1883 eruption of Krakatao Volcano, Sunda Archipelago, was grandiose. Krakatao Island, 9 × 5 km in size, was uninhabited, and the eruption was described on board ships present at the time in the Sunda Strait. Four strong explosions occurred on the 27th of August. The roar of one of them was heard at a distance of 5000 km. The ash thrown into the atmosphere to a great height was dispersed all over the world. The waves tsunami, caused by the explosion, rushed over the nearest coasts and killed 36 thousand people. Most of the Krakatao submerged, as did Santorin Island, part of the Ciclade Archipelago in the Aegean Sea. The tragedy unfolded in 1500 B.C.

The 1955 eruption of Bezymyannyy, Kamchatka, and the 1982 eruption of El Chichon, Mexico, were one of the strongest in the 20th century. Mount Bezymyannaya showed no signs of life for long and was believed to be an extinct volcano. Its awakening was heralded by ground tremours, and an eruption started early in the morning on the 22nd of October, 1955. In several days the volcano began to throw volcanic material to a height of 8 km. Giant lightnings sparkled, and explosions occurred throughout November. The volcano crater expanded by 500 m in merely a month. A tremendous explosion took place on the 30th of March, 1956. An ash cloud rose to 40 km in height; an ash fall began. The ash-covered area was 400 km long and 150 km wide. The total ash volume was about 500 million m^3. The outward appearance of the volcano had strongly changed, and its surroundings were covered by cooling lava piles. The terrain around the volcano was quite uninhabited, so this catastrophe did not lead to a loss of life.

In the Soviet Union, the activity of today's volcanoes is under study on the Kurils and in Kamchatka, where the USSR Academy of Sciences founded a specialized volcanological institute whose activ-

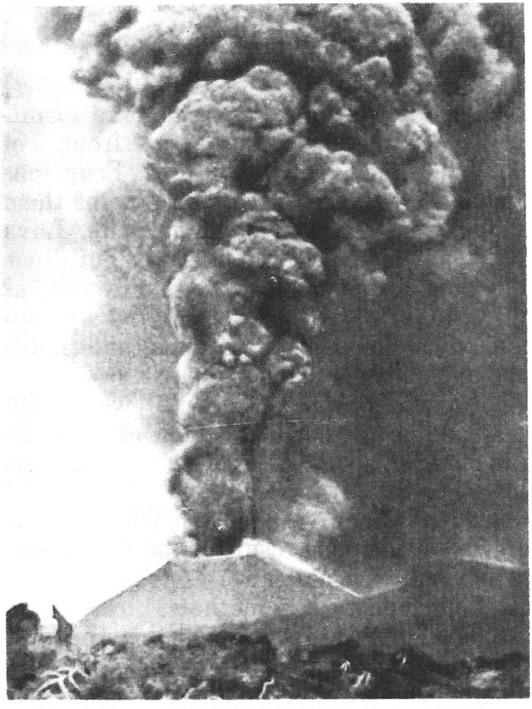

Fig. 12. Tolbachik Volcano in action, 1975 (photographed by N.A. Smelov)

ity is fruitful. The workers of a volcanological station make continual observations at the foot of Klyuchevskaya Sopka (volcano), most active in Kamchatka. All in all, several hundred volcanoes are in Kamchatka of which 30 are active (Fig. 12).

Volcanic Activity

A volcanic eruption is a mighty and formidable natural phenomenon in front of which a human feels helpless. Eruptions inflicted many calamities, and few of them did not lead to a loss of human life. Lava flows destroyed fields and gardens, buildings and whole towns. Volcanic ash covered, as a thick mantle, all objects created by humans, and flourishing gardens and fields were turned to a lifeless desert.

About 25 thousand people were lost owing to the Vesuvius eruption of 79 A.D. An incandescent gas cloud issued by Mount Pelee choked 28 thousand inhabitants of Martinique Island. More than 90 thousand people were lost as a result of the 1914 eruption of Tambora Volcano, Indonesia.

Such disasters are, nonetheless, rare occasions. Volcanic eruptions during the past 500 years have led to a loss of 240 thousand people. Humans now fight against destructive forces. Passive means of defence is sometimes used. Thus settlements are located in relatively safe places, eruptions are predicted to evacuate people from the dangerous zone beforehand.

Active defence means is the destruction of part of the crater by way of bombing and bombardment so that lava could flow in a safe direction.

At the time of Kilauea eruption of 1955 (Hawaii), a swell about 300 m long was piled in front of the lava flow; this swell was oblique to the direction of lava motion. The lava approached the swell and turned along it, so the villagers were saved. In the near future, humans will learn to weaken the force of eruptions. Projects are being developed to drill boreholes to the volcanic vent as deep as 2 km so that gas concentrations could escape through the hole. This is a probable way of explosion prevention.

Much gases and water vapour are thrown out during volcanic eruptions. On condensing, the water precipitates in the area of eruption as heavy rains. Its huge mass, flowing as rough streams down slopes, ravines and gourges, is overloaded with ash, sand and volcanic bombs. A liquid mass of mud descends as an avalanche down the slope of the volcano, disrupting all on its way. At the foothills, the mud flow spreads widely and buries buildings, fields and gardens.

At the same time, the air-fallen volcanic ash and sand are excellent fertilizers. They contain much phosphates, nitrogen, potassium, magnesium and calcium. That's why humans once again and again return to the slopes of volcanoes and again cultivate earth and lay out gardens. This was the case for Vesuvius' slopes; new settlements surrounded by gardens, vineyards and fields appeared in place of the destroyed towns and villages. The slopes of volcanoes in Indonesia, Japan and Pacific islands were also developed rapidly.

Lakes that fill craters are dangerous to some extent, because when a hot magma contacts water an explosion takes place and a huge water mass rushes down the slope destroying all on its way. For safety purposes, tunnels are occasionally run in craters of active volcanoes, and water flows down them in good time before an eruption.

Hot (thermal) waters run to the surface in volcanically active regions. They concentrate at a relatively shallow depth, so the heat of the Earth can be used for the good of humankind. Steam and heated water under great pressure in the Earth's interior are used in Iceland to heat dwelling and green houses, and to produce electric power. In Italy, nearly 10% of the whole electricity is produced with the help of volcanic steam. Use is commonly made of gases and water vapour at 174-240 °C and about 16×10^5 Pa.

A sweeping project has been worked out for the use of thermal energy in Kamchatka. Here are more than a hundred thermal water discharge points, and the Pauzhetskaya geothermal electric power station works, which not only produces electric power but also heat buildings, hot houses and swimming pools.

Scientists are now concerned with a direct use of the energy of eruption. It is enormous in absolute value. For instance, the eruption energy of a small volcano can be compared to an explosion of tens of atomic bombs similar to those dropped by Americans on the Japanese towns of Hiroshima and Nagasaki at the end of the World War II. It has been calculated that the relatively weak eruption of Etna, Sicily, in 1928 produced energy equal to that yielded by all power stations of Italy for three years.

In the Kamchatka Peninsula, with its great many active volcanoes, a project has been developed to obtain thermal energy directly from a magma reservoir. Thus, a hot magma, at 700-800 °C, occurs beneath the crater of Avachinskiy Volcano at a depth of about 4 km. It is recommended that boreholes be drilled towards the reservoir, and cold water pumped along them. It would rapidly turn to steam at depth. Even if but 10% of the heat of this volcanic reservoir were used, it would be enough for a million kW geothermal power station to operate during 200 years.

One of the merits of volcanoes is that they can transfer many valuable minerals, rocks and ores to the Earth's surface. At the time of eruption, copper, tin, lead, silver, gold, nickel and other metals are thrown up into the atmosphere along with gases. For instance, during its eruption Etna Volcano released into the atmosphere 9 kg of platinum, 240 kg of gold, 420 thousand metric tons of sulphur and many other elements and compounds. All of them are finely dispersed, but in some places their fall-outs can be of economic value.

Especially large concentrations of valuable minerals and rocks are observed where thermal springs discharge; here deposits of sulphur, boron, mercury, and so on are not uncommon. Eruption-derived rocks are also of value for humans. Basalts and andesites are not only used in road construction but are also good facing materials. Tuff is an excellent building material. It is cut readily with a common saw and is a good sound insulator. Many houses in Armenia and other regions of the Caucasus are built of tuffs of varied colours.

The prediction of eruptions and control of this element are a complicated matter of utmost importance. This requires that the volcanologists have an excellent knowledge of ancient volcanoes. They should know in detail the very process of eruption not only at the surface but also in the Earth's interior.

The profession of volcanologist requires dedication and courage. An eruption of a volcano is seen many kilometres away.

But it is necessary not only to make photos and movies of the eruption but also to take samples of a hot lava, to measure its temperature at the time of eruption, and so on. The Belgian volcanologist H. Tazieff, also known as the author of books on volcanoes, descended down many times to the craters of active volcanoes and collected samples of lava and ash from boiling lava lakes.

The Soviet volcanologists can observe and directly examine volcanic eruptions in Kamchatka. Once a volcano becomes active, an expedition is fitted out. Scientists are transported by helicopters to the slope of the active volcano. Here they study in detail the composition of the escaping gas, water vapour, volcanic ash and bombs, as well as a still unsolidified, hot lava.

Causes and Distribution of Earthquakes

Earthquakes are related to oscillations of the seemingly hard and immobile surface of the Earth. Humans have been familiar with earthquakes since very ancient times and were always scared by them, because besides volcanic eruptions, floods and typhoons these phenomena caused strong destruction and led to a loss of life. Some tremors lead to more awful consequences than volcanic eruptions do. Tokio, Lissabon, Skoplie, Guatemala, Managua, San

Francisco, Ashkhabad, Spitak, and other cities were once nearly completely demolished by earthquakes.

Seismic waves generated in the Earth's interior radiate at a high speed, like sound waves propagating in the air. These waves are revealed and recorded by special instruments called seismographs.

Rock motion and shock waves are not the only indicators of quakes. Rocks are offset at a depth of several tens and even several hundred kilometres. At the epicentre of an earthquake, that is at the projection of the quake source onto the surface, the tremor leads to numerous dangerous consequences. In towns, for instance, buildings vibrate greatly and collapse. Short circuits and breaks in gas lines cause fire. Loose sedimentary rocks slide and subside owing to earthquakes. Landslides and collapses in mountains and rolling countries are especially striking. At seaside, another danger arises—giant waves tsunami. They are derived from "seaquakes", come across the oceans and seas and rush onto seaside towns, smashing everything on their way.

The intensity of earthquakes is measured to scale, or is expressed as its magnitude. Magnitude is a number proportional to a logarithm of the amplitude, in micrometres, of the largest waves recorded by a seismograph at a distance of 100 km from the epicentre. It varies between 1 and 9.

For instance, if it is equal to 5, this implies that the energy of this quake is 10 times that at 4.

Intensity scales reflect the qualitative measure of the effect of an earthquake on any particular point. It is estimated by way of the 12-point Mercalli scale. The intensity of shocks is decreasing away from the epicentre. A quake of 7 may cause a substantial destruction at the epicentre, but perfectly designed antiseismic constructions can withstand these shocks. Extensive destruction is effected by earthquakes of intensities over 7.

This phenomenon is due to energy redistribution in the Earth's interior. Other causes are both horizontal and vertical tectonic movements, volcanism and excitation of the crust by artificial explosions.

Various oscillations arise many times in the Earth's crust. Some of them are compressive, others tensile, still others laterally thrusting. All of them are directly or indirectly responsible for earthquakes. The strongest seismically active regions are mostly located along the Pacific coast, island arcs and deep-sea trenches (Fig. 13). Up to 90% of earthquakes occur along deep-seated faults in the crust. Merely 5% of all quakes are associated with extension zones along an extensive system of underwater mid-oceanic ridges. A basaltic magma rises here from the interior to split the

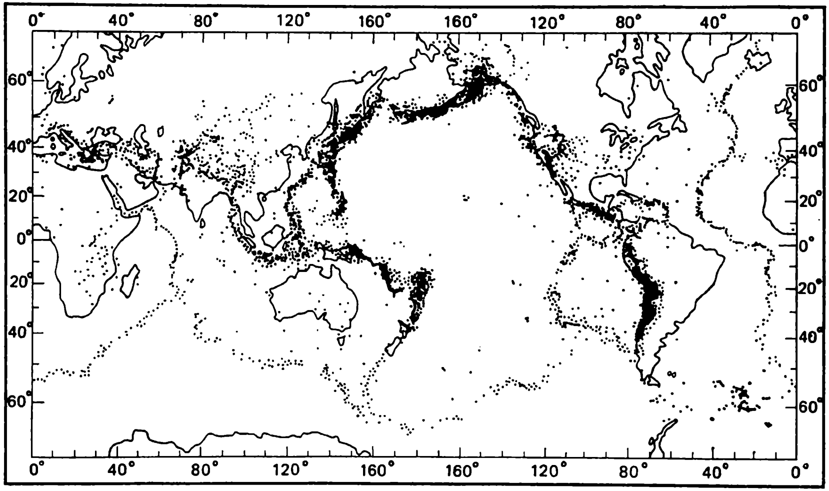

Fig. 13. Global distribution pattern of earthquakes.

The Circum-Pacific belt is seismically most active. Seismically active are mid-oceanic ridges and young mountain-building regions oceanic crust from time to time, which gives rise to longitudinal faults.

Faults responsible for earthquakes also arise in transform fault zones. These zones cut across the mid-oceanic ridges and gradually displace segments of the sea floor to varying distances. An example on land is the San Andreas fault, California. The maximum offset on it during the 1906 earthquake was 7 m.

The Alpine-Himalayan orogenic belt is highly seismic. Turkey is especially subject to quakes. In 1939, about 40 thousand people were lost in Erzinjan as a result of this distress. Since then, another 20 earthquakes took place in that country with a loss of more than 20 thousand people. Most of their sources are restricted to Anatolian fault zone. It continues on the territory of South Transcaucasia, where Transcaucasia earthquake series is connected with active shift along this fault. Among them a strong earthquake in North Armenia that took place in December, 1988. Along this fault Eurasian and African lithospheric plates contact. Lateral displacement is now taking place on this fault. The South block moves westwards at a speed of 10 cm/year.

Local and relatively weak quakes are often due to volcanic activity. Explosions of volcanoes and the rise of magma from a depth of 50-70 km are accompanied by ground tremor.

Two belts, the Circum-Pacific and Alpine-Himalayan, are sites of earthquakes on our planet. The former extends from Chile to Central America, forms an arc in the Caribbean-Antilles region, intersects Mexico, California, the Aleutian Islands, encompasses Kamchatka, the Kurils, Japan, the Philippines, Indonesia and New Zealand. The Alpine-Himalayan orogenic belt embraces the mountain regions in Spain, southern France, Italy, Yugoslavia, Greece, Turkey, southern Soviet Union (the Carpathians, Crimea, Caucasus, Pamirs), Iran, northern India and Birma.

Earthquakes commonly occur in continental margins and volcanic belts. There are places on Earth, however, where, it would seem, no quakes should occur, as, for instance, in East Africa and East Siberia (Cisbaikal, Transbaikal). In fact, these regions are very active seismically.

The interior areas of ancient continental platforms and shields are seismically active but slightly. The Canadian, Brazilian, and Scandinavian shields, Siberia, Africa, Australia and Antarctica rarely experience earthquakes, which take place only in areas of faulting.

Earthquake Studies and Prediction

Earthquakes are recorded with the help of seismographs. It appears that the first instrument of this kind was manufactured in China as early as the 2nd century A.D. Since then these instruments have been perfected all the time and, finally, effective self-recording and very sensitive seismographs were produced about one hundred years ago. A horizontally fixed pendulum is used in the instrument. Records are made with the help of mechanical, optical and electromagnetic elements. They transfer pendulum oscillations to light-sensitive paper rolled on a revolving drum. When the ground is motionless, the pendulum draws a horizontal line; when the ground oscillates the record is a variously sloping rectilinear line.

In recent years, besides sensitive seismographs, various laser instruments are installed in closed shafts and specially constructed concrete bunkers to observe seismic waves propagating through our planet. The laser instruments not only record small seismic waves but also help to monitor major fault zones and detect slightest soil motions.

Man-made explosions causing a series of seismic waves are used widely to disclose the composition of the upper crust but mainly to search for structures favourable for oil and gas accumulations. Seismic waves are detected and recorded by groups of seismographs disposed along a preassigned line.

Different seismic velocities in different rocks and materials make ground to judge upon the general character of materials in the Earth's interior. Research concentrates on the degree of wave reflection and refraction. A series of explosions allows one to determine the depth of a reflector or refractor in different places, pinpoint it on a map and establish the structure of underlying rocks.

Observation and investigation of seismically active regions are carried out with the aim at preventing detrimental effects of catastrophic phenomena. Can we protect ourselves, in some way or other, from earthquakes? After all, many constructions are damaged in settlements at the time of strong underground shocks. The extent of damage depends not only on the intensity of an earthquake but also on the quality of constructions. They are demolished because the ground below them is unstable while their walls are not strong.

Building in seismically hazardous zones is made with due account of many geological factors controlling the strength of constructions. An ideal protection is provided by laying the foundation on a strong rocky ground. In the case of a poorly cemented ground, steep slopes and bulk materials, arched concrete foundations should be constructed. It is undesireable to erect buildings on sea cliffs, near the scarps and deep excavations, or on landsliding slopes, as well as on lands with a high groundwater level.

It has been proven convincingly in practice that ferroconcrete buildings are well steady. To improve the seismic stability of stony and even wooden houses, use is made of tying staples, supports and uprights. A flexible construction is most safe; it moves as a whole, and soil tremors cause no fractures and separate parts of the construction do not impact each other.

During the 1930 earthquake in Italy, the severe destruction was due to the fact that heavy pebbles were used as a constructional material. Many objects in Skoplje, Yugoslavia, were demolished in 1963 because cement was poorly fixed with an unwashed filler, and iron-concrete floors were weak and rested on poorly fixed brick walls.

Humans have long attempted to predict earthquakes. Until now, however, this problem remains to be perplexing and difficult to solve.

One of the common methods of predicting earthquakes is based on an analysis of precursor shocks. More often than not, they are separated from the main shock by very short time intervals. Subsurface shocks can be detected beforehand by seismographs and also can be inferred from the behaviour of animals (dogs howl, sneaks crawl out of their burrows, and so on). Thus, a strange behaviour of animals was noticed at Hainan, China, in 1974. They were becoming more and more excited. In was announced at 2 o'clock on the 4th of February that an earthquake was expected in the near future. Local people quitted their homes. An earthquake of a magnitude of 7.3 took place at half past seven in the morning. It demolished 90% of the buildings, but the loss of life was minimal.

The Soviet scientists have made certain progress in predicting earthquakes. Their predictions are based on changes in rocks under the effect of a quake. It is known that before the earthquake the seismic velocity decreases owing to rock fracturing, and then increases as subsurface water fills these fractures. And an earthquake should be anticipated when the velocity again becomes as usual for these rocks. It is hence possible to predict the time of its start. On the basis of these data, quakes were predicted in the Soviet Union, and one of them nearly four months before. The discovery of the Soviet scientists was later confirmed by the American, Japanese and Chinese seismologists. All of them made a prediction successful where a dense network of seismographs was laid out.

Volcanic eruptions have taken place not only in recent years. They were common also in the far historical and geological past. Vast expanses covered by thick piles of igneous rocks, ash and volcanic tuff suggest grandiose and prolonged eruptions in different geological periods. Approximately the same can be said of strong earthquakes.

Volcanic eruptions and earthquakes need further elaboration, because many vital problems are connected with them in countries with vigorous volcanic activity and severe seismicity. These phenomena have the past, present and future. Until our planet is alive and its interior contains molten material, lava will issue on the Earth's surface, and crustal blocks will move relative one another, causing extremely strong earthquakes.

A Biography of Life on the Earth

Paleontologists study the ancient organic world of the Earth with the help of fossil remains of animals and plants (fossil shells, fragments, occasionally whole skeletons of animals; leaf, sprout and stem impressions well preserved on the surface of rock beds), and of traces of the life activity. The purpose of paleontology is not only to study the structure and outward appearance of fossil floras and faunas or the taxonomy of old organisms but also to establish the time, place and mode of origin and evolution of organic world, to disclose why some groups of organisms extinct and new ones appear.

Origin of Organisms

According to a large body of geological and paleontological information, life on the Earth originated deep in the past, at least 3.5, possibly 3.8 thousand million years ago. The appearance of living matter was a natural result of evolution of organic compounds—the foundation of life. Extremely simple hydrocarbons were becoming more sophisticated until high-polymer compounds appear in the atmosphere under the effect of solar radiation and electric charges. Then their development progressed in the hydrosphere, where high-molecular compounds were formed. They acquired such features of living matter as metabolism and ability of reproduction. The anaerobic character of energy metabolism in the first few hundred million years of existence of living organisms was due to a lack of oxygen in both the atmosphere and hydrosphere.

The first terrestrial organisms have not survived as fossils, but it is suggested that they resembled today's ultra-microbes, which have no capsule. These organisms reproduced by division and had no nucleus.

Minute blue-green algae and bacteria existed deep in the past. All of them were procaryotic forms, that is, their cells had no distinct internal structure, in particular no nucleus. Then came other blue-green algae, which had eukaryotic cells with a complex internal structure and a nucleus, the principal element. The eukaryotic forms were also among bacteria. A new stage in the development of the organic world set up with the appearance of these forms.

Later on, two groups of organisms took the leading position. They could release organic matter from carbon dioxide and water under the effect of solar radiation, that is the life activity of some forms was the result of photosynthesis, while other forms digested the organic compounds available. Therefore, the initial division of organic world into plants and animals occurred in very ancient times.

Small rods, and also thread-like, spherical, disk-shaped and isometric capsules of algae, visible under an electron microscope at a multiple magnification, have been found in rocks laid down about three thousand million years ago. Younger rocks contain products of activity of blue-green algae and bacteria, which often make up giant forms resembling present-day reefs.

The multicellular organisms first appeared because the oxygen content of the atmosphere and hydrosphere gradually rose. The biosphere became thicker in the Proterozoic than in the Archean. Blue-green algae dominated among plants. The world of animals was poorly developed and contained few species. Bacteria were most numerous. These organisms participate actively in decomposition, oxydation and accumulation of inorganic compounds.

Foraminifers, radiolaria, siliceous sponges, coelenterates, worms and representatives of the most ancient arthropods appeared late in the Proterozoic. All of them had no hard skeleton, so their fossil remains are found extremely rare.

Very important biological events occurred

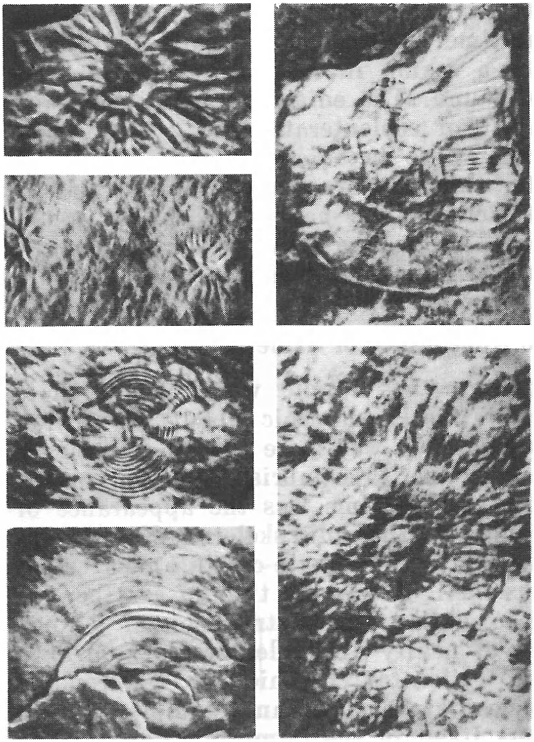

Fig. 14. Well-preserved soft tissue casts of medusiforms and worms that lived about 600 million years. The White Sea coast (after M.A. Fedonkin)

about 600 million years ago. Animals without solid skeleton were widespread at that time. This fauna was called ediacaran after a region in Australia where it was first found. The ediacaran fauna consisted mainly of coelenterates and a number of forms whose taxonomy is still under debate. Remains of compositionally similar but richer fauna have been found in the Soviet Union by M.A. Fedonkin on the coast of the White Sea (Fig. 14).

The Appearance of Skeletal Faunas

Although the organic world was archaic early in the Phanerozoic (about 570 million years ago), it was more diverse and richer than in the Precambrian, and the main thing at that time was the appearance of organisms with a solid skeleton. New organisms had a phosphate-chitin and a calcareous shell. It was the time of a rather rapid formation and distribution of a huge mass of nearly all coelenterates known to date. Trilobites, brachiopods, gastropods, sponges, archeocyatheans, radiolaria, and others lived in the Cambrian Period. The archeocyatheans are organisms that dwelt on the bottom of warm shallow-water seas for a relatively short period. The trilobites are quite specific (Fig. 15). These most ancient arthropods lived on a muddy sea floor, and some even swam freely. The flat body

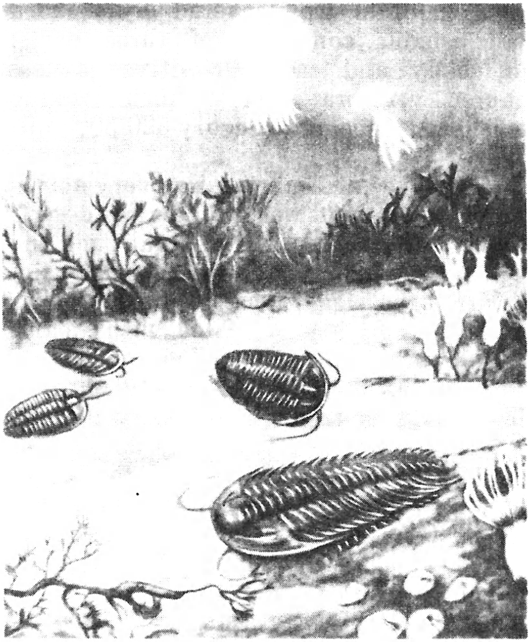

Fig. 15. The floor of a Cambrian sea. A reconstruction of the Czechoslovakian scientists Z. Buriani and Z. Špinar.

Trilobites and brachiopods on the foreground. Sea lilies staggered on thin and tender legs; algae thickets at the background of the trilobite was covered by a hard chitin armour composed of three parts: head, body and tail. Primitive jawless armoured vertebrates very much looking like fish first appeared roughly 520-500 million years ago.

The life in the Cambrian was very active in water, while land was a biological desert. Only near the shore, in the tidal zone the first primitive plants lived resembling algae. But unlike the algae, these could in a while be in the air highly saturated with steam.

The organic world continued to develop rapidly during the Ordovician and Silurian periods, that is throughout nearly 90 million years. Marine coelenterates dominated absolutely (Fig. 16). Land was resolutely settled by representatives of the nearshore rheniophyte flora*; mosses and lycopods appeared and settled slowly over highly humid low coasts.

In seas, trilobites, graptolites, coelenterates and brachiopods played the leading role. The graptolites appeared and evolved rapidly in the Ordovician. They had chitin skeleton of straight and concave branches the sum total of which resemble a low bush. Hydroids and tetracorals first appeared. The coelenterates lived in major colo-

* The rheniophytes were earlier called psilophytaleans. These were ancient vascular herbaceous and wood plants that died out in mid-Paleozoic time.

Fig. 16. The floor of the Ordovician sea is dwelled by colonies of tabulate corals, which look like plates; ball-like hydroid polyps; solitory tetracorals; and conically spiralled gastropods. Carnivorous nautiloids are torpedo-like

nies; they built up long barrier, shore and atoll reefs. The brachiopods had a calcareous shell and a long leg to fix the shell to stable objects or to irregularities in the floor. The first cephalopods just appeared. Perhaps they were among the largest animals for the time being. Nautiloids had a giant multichambered shell as large as 2-4 m. The cephalopods were carnivores, actively hunting for prey near sea bottom.

Merostomes were big carnivores. Their flat body had at its end a long thorn with a venomous gland. Freely buoyant (planktonic) and fixed (benthonic) foraminifers, radiolarians, sponges, worms, pelecypods and bryozoans also dwelt in the sea.

The primitive forms died out slowly at the end of the Silurian. They gave way to more perfect forms, which precisely determined the further development of organic world. A characteristic feature of this development was that animals and plants began to settle not only in the narrow, shallow-water part of epicontinental seas and oceans but also in regions far from sea shores; they mostly spread inland along river valleys.

Rhyniophyta flora dominated on marshy coasts early in the Devonian, approximately 400-380 million years ago. They later died out and were followed by lycopods, equisetaceous plants, ferns and gymnospermous plants. Large scorpions, myriapods and insects lived on land already at that time, whereas vertebrates appeared only late in the Devonian. There were stegocephalians (amphibians).

The Devonian landscapes were specific only within seaside lowlands and the banks of major lakes and rivers. Regions located far from water bodies were devoid of any vegetation.

Fish dominated over othermarine faunas, so it is not without reason that the Devonian is sometimes called a period of fish. Some giant fish were as long as 10 m. The head and the frontal part of the fish body were covered by a thick armour of large bone plates. Besides the armoured fish, cartilaginous (sharks, batoids), tassel-finned and diphonoan fish lived in the sea. The tassel-finned fish had strong fins used by them not only to swim but also to move over the bottom of dried water reservoirs. The skeleton of the finds of these fishes is much alike that of limbs of primitive land vertebrates called amphibians. That's why many scientists believe that they were ancestors of many superficial vertebrates, and the appearance and spreading of diphnoan fish were due to the periodic but short-term shallowing, even drying up of water reservoirs.

The Devonian Period is characterized by a wide development of the brachiopods. The total number of their genera exceeded 320, and they spread in various bionomic zones in the sea. Another group of cephalopods—goniatites—appeared and extensively settled early in the Devonian.

They had a spirally flat, poorly sculptured shell. Corals, especially tetracorals, were extensive. Along with the bryozoans and coral polyps, these formed extremely large reef masses.

The Conquest of Land

During the subsequent Carboniferous Period (350-385 m.y. ago), organisms went on to spread over land expanses. In the beginning of this period tree-like forms of lycopods, arthrophytes and ferns increased drastically in number, but the lower floras—algae, mosses, and mushrooms—continued to develop at the same time. Many tree-like forms were as high as 20-30 m. Shrubs and liana-like forms were also present in the landscape along with tree-like forms. The Carboniferous vegetation varied widely in ecological composition. The plant communities that grew only in relatively cool environments—the so-called Gondwana flora—consisted of glossopterids. Cordaites, as high as 30 m and having long, elongated leaves, grew in regions of a moderate climate. The cordaite brushwoods are not uncommonly called a cordaite taiga, which shows its similarity in growth conditions to the modern taiga. Evergreen forests grew in wet tropical and equatorial regions. They were composed of arborescent lycopods, equisetaceous plants and huge tree ferns.

Vegetation not only developed but also gradually conquered new and new areas, still farther from humid seashore lowlands. Low drainage divides were covered with forests as early as the Carboniferous.

Stegocephalians (amphibians) flourished at that time. They resembled giant modern lizards in outer appearance and lived in strongly marshy lowlands and shallow-water reservoirs. Batrachosaurs, which had some features of amphibians and reptiles, were rather specific animals of that period.

Fish, especially sharks, were still dominant in the sea. Although all the earlier known invertebrate groups are common in Carboniferous time, the primitive forms disappeared almost completely. The graptolites died out, the merostomes and trilobites lived out the remainder of their days, and the nautiloids reduced in number. Both the free-swimming and benthic organisms were common. Diverse foraminifers, brachyopods, goniatids, corals, bryozoans, sea lilies and sea-urchins lived in the sea.

In the Permian Period (285-230 m.y. ago) the organic world began to change. The most far-reaching changes took place in the mid-Permian. New forms of foraminifers and the cephalopods fusulinids and ammonoids became widespread among sea invertebrates. Brachiopods, bivalves and gastropods went on to evolve. Tetracorals, fusulinids and all ancient forms of brachiopods, cephalopods, sea-urchins, sea lilies and fish became extinct only at the close of Permian time. This catastrophic process lasted several million years; it was most probably caused by several factors, both biological and environmental.

The world of plants underwent substantial changes at that time. The higher sporophytes and primitive Gymnospermae were no longer dominating, having been substituted by the more advanced Gymnospermae—cycads, ginkgoaceous plants and conifers.

Being attacked by reptiles, the amphibians gradually retreated. Their area became to reduce slowly. They survived for a long time only in very humid tropical regions. The reptiles evaporated moisture from their skin more intensely and could thus control the temperature of their body. As a result, they could live for some time in the hot and dry Permian climate. Having appeared as early as the Carboniferous (cotylosaurs and pelycosaurs), the reptiles flourished rapidly and spread over principal landscapes. Their advantage over the other terrestrial vertebrates consisted in a perfect lung breathing, and intense circulation and a strong horny cover that protected them from excessive evaporation.

New species and genera of conifers appeared, and cycadophytes and ginkgoaceous plants further evolved in the Triassic (230-

195 m.y. ago). Reptiles still dominated on Earth, but they had changed markedly in composition. The cotylosaurs and the reptile therapsid had given way to dinosaurs. Cephalopods (ammonoids and belemnoids) flourished greatly among sea invertebrates.

The Time of Dinosaurs and Mammals

The organic world of the Jurassic Period (195-137 m.y. ago) was very specific. Gymnospermae dominated at that time. Huge expanses were covered with conifers, bennettites, ginkgoaceous plants and cycadophyte forests. Ferns and lycopods made up underbrush and sometimes major separate thickets. In the Late Jurassic, forests disappeared in vast areas because the climate became dry. There occurred landscapes resembling savannas and semideserts.

Vegetation became differentiated, to a certain extent, both ecologically and climatologically in Jurassic time. In some places there have been found not only a geographical but also a vertical zoning of vegetation, which mainly depended on temperature.

The Jurassic vertebrate fauna was marked by a flourish of reptiles (terrestrial, aquatic and flying forms; herbivorous and predatory representatives) and the appearance of small mammals. The ancestors of dinosaurs were small saurians, thecodonts, widespread early in the Triassic. The taller forms gradually became predominating over the remaining ones. Some Jurassic dinosaurs were as long as 20-25 m and as heavy as 30-50 metric tons. Their four-footed and two-legged representatives are known. Many giants were semiaquatic, because it was easier for them to carry their massive body. Moreover, the water bodies were frequently the place that saved them from the predators. The semiaquatic dinosaurs had their eyes far back and had long nose passages. These allowed them to submerge into the water for long.

Some dinosaurs had membranous limbs, which made them more steady on a muddy, boggy ground. The most characteristic representatives of herbivorous dinosaurs were iguanodonts. These two-legged saurians were upto 10 m long, had tridactylous limbs with membranes and a specific beak.

Carnosaurus was the most terrible predator of Jurassic time. But more terrible predators lived on the Earth in Cretaceous time.

The herbivorous dinosaurs formed herds and bred with the help of eggs, that is like present-day crocodiles and turtles.

Numerous groups of saurians inhabited semienclosed expanses strongly resembling today's savannas (Fig. 17). Boggy or thick tropical forest-covered territories crossed by numerous deep and wide rivers were unfa-

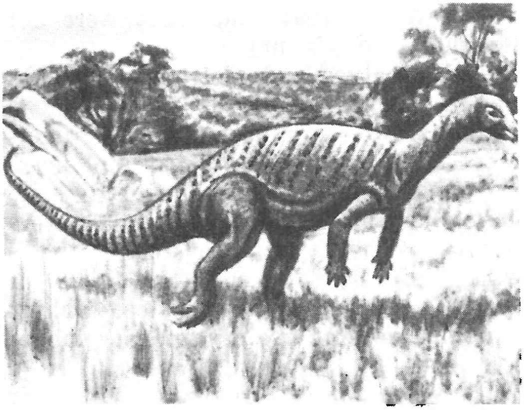

Fig. 17. A phytophagous dinosaur in a Mesozoic savanna (after Z. Buriani and Z. Špinar)

vourable for terrestrial vertebrates to live in.

Ichthyosaurs and plesiosaurs dominated in water bodies. The former were like dolphins; they had a cigar-shaped body, 5-6 m long, and limbs reduced to fins. The plesiosaurs and pliosaurs, their contemporaries, had strong flippers and a long "swan-like" neck topped with a small head. These were terrible sea predators having numerous acute conical teeth in the maw.

Flying saurian reptiles dominated completely in the air. Many had membranous wings spanning 5-8 m. Their body was covered with thick wool and jaws studded frequently with sharp and long teeth. Birds first appeared at that time; they were not larger than today's pigeon.

Diverse bivalved and gastropod mollusks inhabited fresh-water reservoirs and deep and wide, slowly running rivers. The invertebrates in normally salted seas and near-shore areas of oceans were quite diverse. Cephalopods and bivalved mollusks were widespread. The latter consisted of forms crawling on the bottom, attached to or buried into the ground; corals, sea-urchins and lilies; foraminifers; bryozoans; sponges and others.

The development of organisms and their spreading depended more heavily on natural environments throughout the Cretaceous Period (137-65 m.y. ago). They were differentiated in accordance with relevant landscapes and climates. One of the greatest biological catastrophes in the Earth's history occurred at the end of the Cretaceous—giant dinosaurs and large pterodactyls, cephalopods and some other sea invertebrates died out at that time.

In mid-Cretaceous time (about 100 m.y. ago), there took place an important event that governed the further evolution of the plant world—higher, flowering plants first appeared and became predominating in quite diverse landscapes in a score of millions of years. The forests of angiosperms were ecologically rather similar to present-day palms and were located in tropical and damp equatorial regions. In areas of moderate climate, conifers, ginkgoaceous, conifer-broad-leaved and conifer-deciduous forests grew under conditions of an enhanced humidity and a strong cloudiness.

What had caused a renewal of the vegetative cover? It appears that changes in the environment were responsible for the fact that angiosperms spread over the globe very soon, while gymnosperms and cryptogamous plants declined. The concentrations of carbon dioxide and oxygen in the atmosphere enhanced considerably at that time. The climate cooled down, the temperature fluctuated according to seasons, the humidity decreased and the cloudiness reduced drastically.

The vegetative cover differentiated as radically as never before in Late Cretaceous time. Conifer-broad-lived forests consisting of spruce, pine, hemlock trees, plane-trees, trochodendrons, nut trees and beech grew at high latitudes. Ever-green, tropical, moisture-loving forests were located at low latitudes while savannas predominated in regions of a dry climate.

Reptiles—ornithopods, including duck-billed dinosaurs—still dominated in forests and savannas. They look rather terrifying. Even phytosaurs had accoutrement that served not only against the teeth of predators but also as formidable weapons; these are heavy armours as thorns, growths, horny

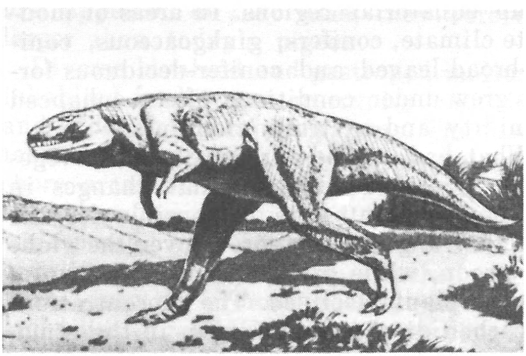

Fig. 18. Meganosaur, one of the Mesozoic carnivorous dinosaurs

collars, spiny crests, or a thick hide covered with small and strong plates.

Many dinosaurs gradually became unrelated to water reservoirs and lived on water divides, in sparse tropical growths of trees and in dry savannas. Tarbosaurs and meganosaurs were the largest and most terrible among predators (Fig. 18). They were as tall as 8-10 m, and had a mouth, with long and sharp teeth, that was so large that a man could freely accommodate himself in it.

Life blossomed in sea basins. Numerous dinosaurs and invertebrates dwelt in near-shore shallow-water regions. The latter consisted of diverse and abundant mollusks, brachiopods, corals, sea-urchins, sea lilies, bryozoans and sponges.

The extinction of animal giants at the close of the Cretaceous and its causes have attracted attention for many years. Dinosaurs had been dominating the animal world throughout nearly 10 m.y. They lived in many landscapes, but suddenly, nearly instantaneous in the geological sense, the giants declined and then died out. Some believe that the dinosaurs gave way to the superior mammals, others refer to environmental changes. Most probably, however, the dinosaur extinction was caused by the whole number of tragically superimposed factors. The most important among them are an enhanced cosmic radiation, a reduced content of atmospheric oxygen, a general cooling of the climate and, as a consequence, changes in landscapes and the food available.

Some scientists suggest that the death of dinosaurs was related to a disturbance in the microelement balance in the soil, others think that the dinosaurs were extensively poisoned by alkaloids present in the composition of angiosperms, and still others refer to an action of some terrible virus infection. As seen, more than enough reasons have been put forward, but none of them can correctly and impartially explain why the dinosaurs died out. True, many of the above factors may indeed have caused the death of a large group of animals but within a limited territory. It is hard to conceive that the dinosaurs were poisoned or affected by an awful epidemic simultaneously or nearly so all over the world. Therefore, this question is still to be answered.

In the last era of the Earth history, the Cainozoic, or an era of a new life, the organic world has acquired the modern features in 70 million years. Angiosperms, among them those similar to the present-day ones, have become dominating plants.

The terrestrial faunas have undergone especially great changes. The expanses cleared out of dinosaurs were rapidly occupied by mammals. The first mammals were small and dwelt in forests and lake-bog landscapes. Various ecological groups of mammals became prominent in the Paleogene Period. There appeared proboscidians, carnivores, primates, hoofed animals, rodents, etc. Some or other mammal groups predominated depending on a particular climate and landscape. Brontotheridae appeared in marshy regions at the close of the Paleogene. Their most typical form is called brontothere, a large extinct, odd-toed herbivorous animal of the hornless rhinoceros family. This fauna was composed of big pig-like creatures, tapir-like and the whole number of other animals.

This fauna gave way to the Indricotherium fauna made up of giant hornless rhinoceros, or Indricotheria (Fig. 19), the ancestors of horses, and rodents. Its principal

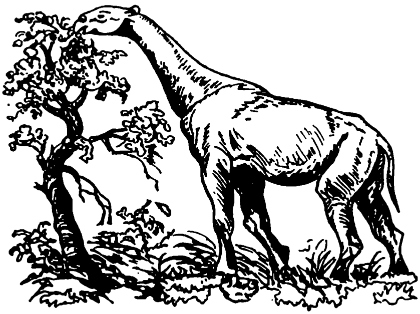

Fig. 19. Indricotherium, a giant Paleogene rhinoceros

habitats were savannas and gallery forests *.

Further evolution of mammals and their differentiation in different environments took place in the Neogene Period. The appearance of taiga, forest-steppe, steppe and mountain meadow landscapes gave rise to relevant ecological assemblages.

Vast tracts were covered with glaciers a little more than one million years ago. This has exerted an especially great influence on the distribution of the organic world.

Tundra and forest-tundra landscapes, and also now-absent periglacial areas, or near-

* Forests that fringe the banks of rivers outside the forest zone.

glacier steppes, first appeared in the Quaternary. They fringed glacier sheets and resembled very much the present near-Arctic tundra.

The severe natural conditions affected the land-dwelling vertebrates. The less adjusted animals became extinct, and new ones appeared which migrated for far distances owing "bridges" between the continents.

In the Subarctic belt, tundra and forest-tundra, mammoths, wooly rhinoceroses, giant deer and bovids, musk oxes, arctic foxes, lemmings, etc. dwelt during the Quaternary. Elephants, rhinoceroses, hippopotami, bears, saber-toothed cats, tigers and mastodons lived in the Moderate belt. Quite diverse were the mammals of the tropical and equatorial belts; they were very similar to the present-day forms.

The Life of Microorganisms

We have earlier described the formation and evolutionary history of multicellur organisms whose living conditions have been inferred from fossil remains of shells of marine and fresh-water organisms, skeletons of vertebrates and plant impressions. But these are not the only constituents of the organic world. Quite numerous microscopic animals and plants have been living and evolving since extremely old times. Their remains have perfectly survived in sedimentary rocks: sandstones and shales, limestones and dolomites.

With the invention of microscope, especially scanning electron microscope*, it has become possible to reveal accumulations of remains of minute organisms in rocks. There were found and described diverse bacteria in Archean and Proterozoic rocks, conodonts in Paleozoic sediments, microscopic foraminifers in the Paleozoic-Mesozoic rocks, nannoplankton and the remains of spores and pollen of various plants.

A simple-to-complex principle is kept in the evolution from the most ancient times. This implies the development from one-celled organisms with a shaped nucleus (eukaryotic organisms) to many-celled malacozoans and later from reptiles to mammals. Mysterious little "chitinous" balls have been found in Proterozoic rocks under a strong magnification. It is suggested that these are enveloped eggs of some, still unknown invertebrates. Microscopic algae can be seen in more ancient sediments, 1300 million years old. But these are not most ancient. Fossil round cells, 12 μm in diameter, which are arranged in couples

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* An instrument in which an electron beam is used to obtain an enlarged image. Scanners, or moving radiation detectors, allow one to examine an object, or its part, from point to point, again and again.

and tetrads covered with a single envelope, have been described in West Australia. They are nearly 3500 million years old and resemble the modern cells of the alga chlorella.

Studies of the most ancient microscopic procaryotic and eukaryotic organisms have shown that it is their activity that formed the initial basis for the appearance and evolution of the multicellular organic world. The eukaryotic forms were responsible for the oxygen-bearing atmosphere of our planet.

How can traces of microorganisms be revealed? A very thin transparent plate—a thin-section—is cut out of the rock, and this thin-section is then carefully examined under the microscope. But this method cannot always ensure that fossils are present in the thin-section. Another method, called maceration, is also practised*. A crushed rock sample is dissolved in acids ranging from a weak solution of acetic acid to hydrofluoric acid. It is suggested that rock particles dissolve in acids while fossils settle down. But one cannot guarantee that some fossils have not dissolved or been severely damaged by the acid. To avoid partial or complete dissolution, various methods of maceration are employed by

* Partial solution, corrosion of a rock sample in an aggressive medium.

using first a weak acid and then stronger and stronger acids and their different doses.

The Soviet hydrobiologist V.V. Koshevoi have found by this method the numerous remains of Proterozoic plankton microorganisms. They resemble the pollen of modern plants at a 1500 magnification. The evidence obtained suggests that the organic world of the Archean and Proterozoic aeons was full of one-celled forms.

On examining the thin-sections of Paleozoic sedimentary rocks under the microscope, geologists observed inclusions quite unusual in shape. Some looked like a horn of an antilope; others, teeth; still others, combs. The unidentified remains ranged in size from fractions of a millimetre to 3 mm. They were called conodonts. These remains are of calcium phosphate composition and hence can be separated by maceration rather easily. The conodonts are divided into three principal groups by outer appearance (Fig. 20): (1) simple, cone-like; (2) complex, curved rods; and (3) flat, with the broad base.

These fossils are problematical; their functions in the body of an animal are yet unknown. The conodonts seem to have affinities with various groups of organisms. Possibly, they are remains of some parts of skeletons of vertebrates or the most ancient fishes. Some scientists consider them to be

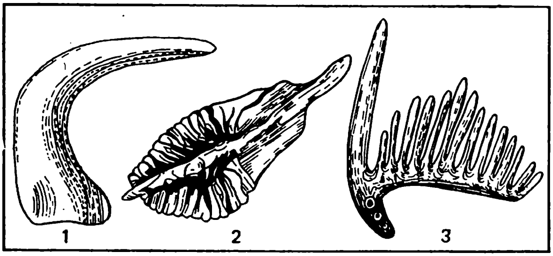


Fig. 20. Some conodont forms known from Middle Cambrian to Late Triassic rocks (after G.I. Nemkov *et al.*).
1—simple conical; *2*—intricate rod-like; *3*—flat

elements of the jaws of mollusks, to be relatives of worms, etc.

The conodonts are abundant in Ordovician, Devonian, Carboniferous, Permian and Triassic sediments and are of utmost stratigraphical importance; that is they can be used to differentiate and correlate sedimentary series. The conodonts are known in marine, lagoonal and fresh-water sediments. Certain conodont forms are characteristics of each stratigraphic level. All this allows one not only to subdivide individual sections but also to correlate them on a regional scale.

With the introduction of polarizing, especially scanning electron microscopy into examining rocks and today's sediments, there were found organisms having a carbonate armour not more than 50 μm in size.

These ultramicro-organisms were called calcareous nannoplankton. The one-celled golden algae, coccolithophorids, dominated among them. They are round or oval and range from 4 to 40 μm in size. The surface of the cell, which contains a core, vacuoles and two chromatophores, is surrounded by a membrane and a thick mucous sheath enclosing coccoliths, buttonlike plates. It is these that are preserved as fossils.

About 200 species of coccolithophorids dwell now in the World Ocean. Their photosynthesis ability determines their maximum depth of habitat as 200 m. After the death of the organisms the dead cells settle slowly onto the bottom. They dissolve in the water undersaturated with calcium carbonate, that is at great depths. As a consequence, the sediment contains no carbonate material at depths exceeding 3500-4000 m.

The coccolithophorids are widespread in the central parts of the ocean, near the shore, and in inner seas. For instance, there are as many as 50 000 of them in a cubic metre of water from the Pacific Ocean. The maximum content was recorded off Senegal, where one litre of sea water contains about 30 million coccolithophorids.

The calcareous nannoplankton is a strong rock-forming material, that is its remains constitute the bulk of a carbonate rock. Its rock-forming role has become prominent since the Jurassic, but it is especially extensive in Upper Cretaceous sediments. A small piece of the well-known writing chalk contains a huge amount of coccolithophorids and minute foraminifers. The latter occur in various Phanerozoic rocks. The development of these one-celled animals depends on the distribution of temperatures, salinity, nutrients and water masses, and on hydrodynamics. The foraminifers range in size from fractions of a millimetre to several centimetres. The nummulites, with their spiral tests, can be regarded as giants among them. In particular, nummulite limestone composes the plates of the Egyptian pyramids.

The tests of some foraminifers consist of horny, chitinous matter; in other foraminifers the chitinous matter was a sort of cement for sand particles, and the tests of still others was calcareous in composition. The foraminifers that become fossils have a strong calcareous or "sandy" skeleton. There occur single- and many-chambered forms. The former resemble little flasks and the latter have numerous chambers arranged along a straight line or spirally.

The radiolarians are widely used to stratigraphically divide and correlate rock sections. Many have a hard, lovely and gracious skeleton of amorphous silica. Some radiolarians have a strontium sulphate skeleton.

Flagellate, blue-green and diatomic algae are also of great importance; many of them are well preserved and are even rock-forming.

Minute spores and pollen produced by ancient plants also not uncommonly form fossils. They are perfectly preserved in various sedimentary rocks of both terrestrial and nearshore origin. There have been developed advanced methods of spore and pollen extraction from these rocks. The probability for at least one plant impression to be found is much less as compared with the amount of spores and pollen in a sample. They can be used not only to date the enclosing rock but also to reconstruct the features of the vegetative cover in the past and determine the relevant climates and landscapes.

History of the Earth's Climate and Atmosphere

Climate exerts a large influence on the organic world. It serves as a natural regulator, so to speak, affecting the abundance and taxonomic diversity of animals and plants and determining the ecological conditions of their existence and settlement. Climate is the leading factor of transformation of a given surface, accumulation of sedimentary rocks, localization of mineral deposits and valuable minerals in various landscape zones. That's why a great attention is given to the reconstruction of the ancient climate to have a better knowledge of the history of the relevant region and to provide a purposeful search for mineral deposits.

But how can one disclose the climatic features of the geological past? Whereas the modern climate can be characterized by way of instrumental records and its effect is well seen in the surrounding landscapes, what evidence allows us to reconstruct the climatic environments in ancient times? It is necessary for the purpose to distinguish the data indicative of the climate, that is those reflecting the climate or arising owing to its direct effect. These are present both in sedimentary rocks and in the organic world. It is well known, for instance, that copious precipitation and a hot climate are essential for coal formation while rock salt deposition requires a hot and dry climate. Coral polyps dwelt invariably in warm and transparent waters. There are found mollusks that preferred to live at moderate temperatures. The distribution patterns of plants also depend on climate. The past temperature regime can be reconstructed by the chemical and isotopic compositions of carbonate shells. Oxygen isotopes, and also such elements as calcium, magnesium and strontium (the last only in the organisms that dwelled in fresh-water basins) concentrate in carbonate shells of invertebrates in accordance with water temperatures. This implies that annual mean temperatures of the habitat can be derived from the ratios of these elements or oxygen isotopes in the shells.

Origin of the Atmosphere

The Earth had neither atmosphere nor oceans at the very beginning, more than 4.5 thousand million years ago. Even the Earth's hard surface didn't exist as yet, so what can we say of the climate at that time? Most probably, it was absent at least 500 million years ago and some time later.

Continual outbursts of various materials from the Earth's interior gave rise to an atmosphere and a hydrosphere. The primitive gas shell of our planet contained no oxygen; it was a mixture of water vapour, hydrogen, carbon dioxide, methane, ammonia, hydrogen sulphide and vapours of hydrochloric and hydrofluoric acids.

The atmosphere became consisting essentially of nitrogen, ammonia and carbon dioxide about 3.5 thousand million years ago. It contained about 60 per cent carbon dioxide. The atmosphere was thin and its temperature at the Earth's surface differed but insignificantly from that of radiation equilibrium. The Earth gave off the same amount of heat to outer space as it received from the Sun.

The temperature near the Earth's surface being relatively low, the steam condensed and a hydrosphere was thus formed. Much of the atmospheric carbon dioxide, sulphur and its compounds, ammonia, and nitric and hydrofluoric acids present in the air and continually supplied from the Earth's interior at the time of eruptions dissolved in the newly-formed ocean.

The temperatures at the surface remained nearly the same for a long time and were in the range of liquid water existence.

Free oxygen appeared in the atmosphere

owing to the effect of solar radiation on the steam molecules and the activity of microscopic plants. It was initially spent solely to oxidize methane, hydrogen sulphide and ammonia whose large amounts were present in the atmosphere, and also to oxidize metals. Because the ozone layer was absent, the atmosphere easily allowed the passage of cosmic rays and the rigid ultraviolet solar radiation. Most probably, it is the ultraviolet radiation that was responsible for the formation of complex organic compounds, even amino acids, out of simple ones in the ancient ocean.

Traces of life were found in rocks 3.5-3.8 thousand million years old. Since the ozone shell was absent, the living creatures could exist only in the water, whose surface protected them from the destructive effect of cosmic rays.

The further development of the biosphere was closely related to free oxygen in the gas shell of the Earth and to the formation of an ozone screen. As the result of inorganic photochemical reactions in the upper atmosphere under the action of sun rays, the molecules of water vapour decomposed. The hydrogen was removed into space, whereas the oxygen atoms combined into ozone.

When the content of oxygen reached a value of 1/1000 of its present content (so-called the Jury point), that is about

1.5 thousand million years ago, organisms appeared to which oxygen was necessary for normal development. Multicellular organisms came into being when the oxygen content reached the Pasteur point (1/100 of today's value). This occurred about 700 million years ago, and a great number of invertebrates came to exist at that time.

Time passed and the composition of the atmosphere had been gradually changed. With the steadily rising oxygen concentration, the atmosphere had been gradually losing carbon dioxide, and its amount had reached merely several percent by Proterozoic time.

Climatic Variations in the Geological Past

Let us look far back into the past, restore the early climate and try to trace its evolution.

It is still difficult to judge of the climates during the Archean aeon, because we have no definite knowledge of this time interval. There is sufficient evidence, however, on the later history of the Earth. Thus we know now that the temperatures on the Earth's surface were very high early in the Proterozoic. Some suggest that they were as high as +100 °C, which is highly doubtful. Most probably, the mean temperature on the Earth was little higher than +50 °C. A severe cooling led then to extensive glaciation as seen from tillites, 2.3-2.5 thousand million years old. They occur in Canada, Scandinavia and South Africa. The climate again became warmer in 300 million years. The temperature rose to + 35 °C. Tropical conditions may have existed at the poles.

Another two ice sheets arose in the Vendian to the Riphean. It was after the next warming that multicellular soft-body organisms may have appeared.

Numerous climatic data have been derived from the strata laid down during the last 600 million years that is during the Phanerozoic.

The Cambrian (570-500 million years ago), Devonian (400-345 million years ago), Early Carboniferous (345-300 million years ago), Mesozoic (235-65 million years ago) and Eocene (53-37.5 million years ago) were warmest. A warm climate, quite like the present-day equatorial and tropical, existed nearly all over the world at that time.

The climate has repeatedly deteriorated throughout the prolonged history of the Earth. There existed not only periods of draughts of global extent but also glaciation epochs. The driest conditions, with the advent of vast deserts and very saline seas, were characteristic of the Cambrian, Early Devonian and Permian.

Strong cooling periods with the develop-

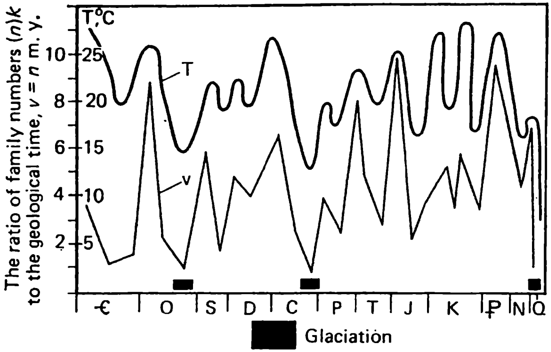


Fig. 21. Fluctuation of mean temperature at the Earth's surface and rates of family appearance in the Phanerozoic.

Temperature rises promoted the origin and evolution of organisms, and temperature falls, especially during glaciations, led to extinctions

ment of thick ice sheets set up during the Late Ordovician (430-450 million years ago). Late Carboniferous (280-300 million years ago) and Quaternary.

With a certain degree of convention, changes in the mean temperatures at the Earth's surface can be plotted versus time (Fig. 21). If we correlate the reconstructed climatic zoning and the character of temperature changes with the evolution of the chemical composition of the atmosphere, in particular with the fluctuations of atmospheric carbon dioxide, the stages in the development of the organic world and the disposition of continents, direct and reversed relationships can be elucidated among these major factors.

The Soviet scientists A.B. Ronov and M.I. Budyko state that the carbon dioxide content of the atmosphere was much higher than the present one in certain time intervals of the Phanerozoic. According to their calculations, which are in very good agreement with geological evidence, the concentration of CO_2 in the atmosphere was over 0.4% in the Cambrian, Devonian and Early Carboniferous, whereas it is merely 0.03% now. The amount of carbon dioxide in the atmosphere tends to decrease, but it rose considerably during some time spans. One cannot help noting a surprising agreement between the temperature curve for the Earth's surface and the CO_2 curve for the atmosphere.

The epochs of the maximum atmospheric carbon dioxide concentration were characterized by high temperatures and vice versa, the periods of substantial cooling and even glaciation corresponded to a drastic CO_2 fall.

The natural question that arises is why did the content of carbon dioxide first rise and then rapidly fall, even as greatly as an order of magnitude? The cause for the rise of CO_2 in the atmosphere could have been an enhanced volcanic activity on the Earth. The favourable climatic conditions and much CO_2 in the atmosphere led, in turn, to an extremely rapid plant growth.

Plants vigorously consumed atmospheric carbon dioxide in the Early Carboniferous, while the plenty of the carbonic acid in the sea water participated in the formation of carbonate sediments and of mollusk shells. As a result, temperatures dropped on a global scale, and extensive glaciation occurred in the Late Carboniferous. Also, the cooling of the lower atmosphere was due to the presence of continents at high latitudes or to the specific distribution of warm and cold sea currents.

The shortage of carbon dioxide in the atmosphere was not uncommon during the Mesozoic. We would be quite right in anticipating not only a severe cooling but even glaciation in these epochs. But the location of continents and relative positions of land and sea had prevented these events. If a sea was located in the polar regions, the glaciation could not be even mentioned because the water in it had a relatively high heat capacity and a low reflecting power. But when a vast land mass was located near the pole, the Earth's surface had a high reflectivity, the sun rays reflected, and a regional cooling of the polar regions was superimposed on the general cooling, so glaciers began to form there.

How valid are these speculations and in what way are they verified by the Quarternary glaciation, the most recent of all? The first indications of a mountain glaciation in East Antarctica are dated as the second half of the Oligocene, that is about 25 million years ago, when the global temperatures were much lower than in the Eocene.

The area of the ice sheet was expanding with passing time. The continuing cooling is in good agreement with a CO_2 fall in the atmosphere, the location of a continent at the South Pole and the appearance of the Drake Passage. Antarctica had earlier been part of the Gondwana and heated by the warm currents running from the low latitudes. But because Australia and South America broke away from the Gondwana, the new circum-Antarctic current arose. It encircled the entire Antarctica and promoted the further cooling of this continent.

In the Arctic basin, the temperatures were rather high despite a cooling at the close of the Oligocene. Relatively high temperatures, about the same as in the modern North Sea, had dominated there nearly throughout the Neogene, and only a strong sea regression with a respective land expansion in the Polar region and, at the same time, a decrease in the role of warm currents from the Atlantic and Pacific into the Arctic basin was responsible for a cooling.

Therefore, the principal causes of climatic fluctuations in the Earth's history, if we do not take into account cosmic events, were the tectonic activity of our planet and the composition of its atmosphere. The climate depended on the relative positions of continents, especially the location of land in the polar regions, when the reflection capacity rose considerably, volcanic activity, the carbon dioxide content of the atmosphere, the distribution of sea currents, areas of seas and land, etc.

Climate and the Evolution of Organisms

The organic world of the Earth is extremely closely related to its habitat. The progressive character of the evolution of all living things in the world is manifested in the higher level of organization and much more intense metabolism. Metabolism quite definitely tends to become more and more rapid throughout the history of the biosphere. Owing to the development of the biosphere, the organisms strikingly tended to gradually conquer the principal arenas of life—from a relatively narrow stripe in the World Ocean early in the Phanerozoic to essentially the entire planet at present. The knowledge of this succession allows one to more clearly understand the basic features of the evolution of the organic world from primitive organisms that dwelt in the shallow-water zone of the sea and first moisture-loving terrestrial forms to deep-sea assemblages and xerophile associations.

Against the background of the overall evolutionary development of the organic world through a long-term transformation and continuity of faunas and floras, a number of revolutionary restructurings can be outlined in the Phanerozoic. This enables one to accept not only the existence of synchronous changes in biological, physiogeographical and geotectonic factors on a global scale but also to estimate the degree of their effect in the geological history of our planet.

The conclusion has been made that the history of climate and the evolution of organisms are closely interrelated. At the same time, living matter affected the environment and transformed it, thus causing changes in the regional and global climate. We have already mentioned the great role of photosynthesizing organisms and marine invertebrates having a carbonate shell in the global climatic fluctuations. Let us discuss another aspect of this problem, namely in what way and how intensely did climate-dependent changes take place in the animal and plant worlds?

The very warm atmosphere saturated with water vapour favoured the emergence of water vegetation onto land and its migration.

The decrease of annual mean temperatures and the aridization of climate had exerted a strong influence on the evolution of plants. In the struggle for existence, progressive groups appeared among plants at that time; these groups were better adjusted to relatively low temperatures rather to their seasonal fluctuations, and to insufficient humidity. The constituents of this group were plants that had annulations and a large ecological potential, and also xerophytes, that is forms well adjusted to a moisture shortage.

Even if we only consider the sequence of major flora groups during the Phanerozoic, we also see the certain effect of climate. The spore plants, which dominated in the mid-Paleozoic era, gradually gave way to more progressive Gymnospermae, owing to a deterioration of climate. In turn, Angiospermae first appeared and spread widely about 100 million years ago.

The effect of temperature on the evolution of marine invertebrates was, above all, manifested in changes in the qualitative composition of biocenoses, that is historically formed assemblages of organisms in a certain area of the biosphere, and it was reflected, if prolonged, in the size, morphology and anatomy of organisms.

The total number of families increased at extreme climatic epochs. The optimal conditions for the existence of organisms are determined by constantly high temperatures. It is at that times that new species of organisms appeared. Coolings led to mass extinction, but the survived progressive forms, adjusted to extreme conditions, turned later to have been extremely productive. Nearly all today's invertebrates are classified into six classes: cartilaginous fish, bony fish, amphibians, reptiles, mammals and birds. Unlike the remaining groups of organisms, invertebrates, especially terrestrial ones, are the most sensitive to climatic effects. In the course of evolution, many of them developed certain protective functions and means.

All the invertebrate classes are known to have originated but during two, rather limited time intervals. The first lasted from the Devonian to the Early Carboniferous and the second, from the end of the Triassic to the beginning of the Cretaceous. With reference to the origin and spreading of invertebrates, the climatic and atmospheric effects are seen very well.

The oxygen content of the atmosphere rose considerably in the Devonian-Early Carboniferous and from the mid-Triassic to the close of the Jurassic, which favoured in itself the vital activity of the invertebrates. But their development was affected by temperature. At both rather high and low temperatures, the activity of the invertebrates generally slowed down considerably.

Land was occupied by plants and invertebrates nearly simultaneously owing to a small temperature fall and substantial aridization. The evolution of amphibians in Early Carboniferous time continued at a humid and warm climate.

The greater number of amphibian forms with indications of a terrestrial organization correlates sufficiently well with a greater aridization and some temperature decrease early in the Permian. The most ancient reptile groups appeared at the beginning of the Permian and reached a peak in the mid-Permian. Contrary to other invertebrates, they progressed rapidly because they had a more perfect respiration, intensive blood circulation and a solid horny envelop that protected the body from a rapid loss of moisture and heat.

Because the Triassic landscapes were much drier, many organisms, amphibians first, died out. As a consequence, reptiles became dominating on the Earth. They evolved especially rapidly and variously at the close of Triassic time, in the Late Jurassic and in the Cretaceous. And the intermittently humid and warm climate favoured this. Under other conditions, both in a humid climate and landscapes of thick marshy forests and of bogs, and in huge arid regions—deserts and semideserts—the conditions were unfavourable for reptiles.

Areas of temperate temperatures and a weak aridization were the basic foci of formation of new forms and the progressive development of organisms. Thus, the evolution of animals had given rise to species less sensitive to climatic conditions. With the appearance of warm-blooded organisms (for instance, mammals and birds), animals were able to spread to places where they could not have existed earlier.

It is expedient to note here that some scientists account the extinction of dinosaurs and a number of marine invertebrates at the end of the Cretaceous for a drastic deterioration of the climate, assuming that the organic world is strongly climate-dependent.

Climate in the Future

The history of our planet indicates that living matter actively affects the climate, either directly or indirectly, through the environment. The effect has become more intense with the appearance of humans.

Since the human activity turned to be a strong geological factor, and this happened approximately 150 years ago, at the very beginning of the industrial revolution, the influence of humans on nature has become very strong, though not preconceived.

The development of new lands, the construction of towns and villages, industrial production, the consumption of huge amounts of fuel—all leads to the heating of the lower atmosphere. At the same time, much dust, carbon dioxide and the great number of gases detrimental to life are thrown into the atmosphere.

Many years of investigation in remote regions with no production at all, for instance in the area of the South Pole, show that the content of carbon dioxide in the atmosphere has increased during the last 30 years by approximately 15-25%. At the same time, the industrial consumption of oxygen rises annually by 10% and is now roughly 10 thousand million metric tons. Although this tremendous consumption is set off rather rapidly by photosynthesis and the supply of oxygen from the Earth's interior, it may happen that its shortage will become more and more prominent in future.

The second warming in the 20th century started at the end of the 1960s and at the beginning of the 1970s. The first warming took place in the 1920s-1930s and was due to a natural change in the transparency of the atmosphere. The principal cause of the second warming was a CO_2 increase in the atmosphere.

The climatic conditions during the nearest decades in the future are controlled by the growth of the carbon dioxide content and by the variation in atmospheric transparency. Today's human activity brings the atmosphere, and hence the climate, back to the state in the geological past, when the amount of atmospheric CO_2 was several times higher than at present.

Many scientists put forward well-founded suggestions that the mean annual temperatures will rise by 0.3-0.6 °C as soon as the beginning of the 21st century. The forthcoming rise of mean annual temperatures will first affect the natural conditions at high and moderate latitudes, the extension and thickness of ice in the Arctic Regions and the continental glaciation in Greenland and Antarctica. The total amount of atmospheric precipitation will gradually decrease in most continental regions at moderate latitudes. The warming will affect the state of ice sheets; ice will gradually melt and then the temperature will rise at high and moderate latitudes.

Thus the enhanced carbon dioxide content accompanied by a temperature increase will wholly depend on the economic activity of humankind. It is assumed that the production of atomic and solar energy in the middle of the 21st century will gradually reduce the amount of fuels consumed, which, in turn, will reduce the input of carbon dioxide into the atmosphere by nearly 30%.

Marine Geology

The World Ocean covers more than 70% of the Earth's surface, its average depth being 4 km. This is a tiny value as compared with the radius of the Earth, but is quite enough to make the ocean floor inaccessible for direct studies by conventional geological techniques.

Until the mid-20th century, the only means of geological investigation of the sea floor had been piston corers and dredges. Later, various geophysical methods were extensively put into geological practice, such as seismic, gravimetric, geothermal and magnetometric ones.

When using pistons and dredges, geological information was provided only by the uppermost layer beneath the ocean floor. This was insufficient, althoguh modernized piston corers reached a depth of 20-30 m. Geologists were interested in rocks lying at great depths, and, in the main, the possibility of studying oceanic crustal rocks.

Origin and Evolution of Waters of the World Ocean

Ocean water is a complex salt solution that fills ocean basins. Its mass is 1.4 thousand million metric tons and volume is a little more than 1.3 thousand million cubic kilometers, which constitutes nearly 97% of the total volume of the hydrosphere.

Since ancient times humans tried to find out the time and mode of origin of the hydrosphere, as well as of the other shells of the Earth. The concepts on the origin of the oceans are closely related to cosmogonic hypotheses. Depending on the dominating hypothesis, scientists interpret the data on the genesis of ocean waters. One fact, however, has remained unchanged—the ocean is younger than the Earth's crust.

The modern views on the origin of the hydrosphere are based on O. Yu. Schmidt's cosmogonic theory, which implies that the planets of the solar system were derived from a cold gas-dust cloud in which the differentiation of matter took place. The energy produced by radioactive decay heated up the Earth, and during this process the Earth material began to differentiate into shells. Therefore, the water at the Earth's surface has come from depths. The real existence of this process stems from the abundance of water solutions associated with volcanic eruptions and of mineral springs issuing in enormous quantities in the ocean floor.

According to the American scientist G.L. Kulp's calculations, the hydrosphere was formed from the differentiation and outgassing of matter from the Earth's deep interior. This view was further elaborated by Prof. A.P. Vinogradov. He believes that the differentiation is like the zone melting of mantle and crustal materials. Experiments on the zone melting of stony meteorites (they are regarded as similar to the primeval material of the Earth in composition) have shown that their constituent silicate material is partitioned into a refractory and a low-melting-point phase. The former is similar to mantle materials in composition, and the latter corresponds to crustal basalts.

Water, H_2S, HCl, HF, NH_3 and other volatiles escape from the low-melting-point phase during the zone melting. In the course of its upward movement, the heated low-melting-point phase is additionally rich in volatiles, including water. The water enters into various media and environments at different temperatures and pressures, and is released from many elements and compounds dissolved in it. Together with the dissolved compounds, water formed an ocean, while the insoluble gases or those present in excessive amounts (inert gases, carbon dioxide, hydrogen sulphide, ammonia, nitrogen, etc.) produced a gas shell, an atmosphere.

The inflow of water from depths has reduced with passing time because the mantle outgassing has become less intense. A week inflow of interior waters also continues at present.

Three principal types of water participated in the formation of a primitive hydrosphere: (1) the water derived from volcanic eruptions; (2) condensed water produced by the cooling of large intrusive bodies; and (3) juvenile water that rises along fissures and discharges as hot and cold mineral springs. The juvenile solutions originate deep in the Earth, somewhere at the crust-mantle boundary. They rise along deep-seated fault zones and issue into the ocean in the zone of mid-oceanic ridges and rift crevasses. These solutions are very rich in salts. Their salinity frequently exceeds $250^0/_{00}$ and temperature is as high as 60 °C. Owing to these hot brines compounds of different metals precipitate on the ocean floor.

According to the Soviet hydrologist G.N. Kalin, the water inflow from the Earth's interior is roughly 1 km^3/year; some of the water must go away into space, but the value of loss depends on the elemental composition and stratification of the atmosphere, and on the biosphere. The changes in the gas composition of the atmosphere and the appearance of the ozone layer had reduced the amount of water lost into space, and this, in turn, was responsible for the growth of water volume on the Earth's surface.

The amount of water in the oceans was greatly affected by glaciations during which it was reduced while the World Ocean level was lowered. When ice melted rapidly after the glaciations, the amount of water rose. These changes, however, amounted, in essence, to the redistribution of water between the solid and the liquid phase.

The hydrosphere is building up but rather slowly. Calculations indicate that the volume of ocean water was in the early Mesozoic (about 250 million years ago) 95 per cent of the present-day figure.

Why Is the Sea Salty?

Man puts this question more than once. Answers varied, and were frequently controversial and incompatible. Let us discuss the causes of salinity, the time of its origin and the evolution of the salt composition of the ocean.

Sea water is a complex salt solution in which the concentration of salts averages 35 g/l, or $35^0/_{00}$. If the entire mass of ocean water were evaporated, the salt on the bottom would be about 35-40 m thick. Nearly all chemical elements and many isotopes have been found in sea water. The principal elements present in it are the cations Na, K, Mg and Ca, and the anions Cl, Br, SO_4, HCO_3 and HCO_3CO_2. They constitute about 99.88% of the compounds dissolved in sea water. The remaining 0.12% consists of nearly all metals, among them gold, silver and platinum.

The concept of the deep origin of ocean water is decisively verified by a similarity between the salt composition of juvenile water and that of ocean water, and also by the contents of chemical elements in small meteorites, taking into account the water in them.

Prof. A.P. Vinogradov classifies the evolution of the salt composition of ocean water into three stages. The first stage embraces quite an ancient period when no biosphere was actually present, that is more than 3 thousand million years ago. The second stage encompasses the time interval between 3 thousand million years and 600 million years ago and the last, third stage has been lasting since 600 million years ago.

Early in the development of our planet, when the Earth's crust stabilized, a shallow ocean appeared in basins on its surface. The steam escaping during tremendous volcanic eruptions was saturated with such strong acids as H_2CO_3, HCl, HF, NH_3 and others. Hence the water of the primitive ocean was a mixture of dilute acids, carbonic acid having been predominant, among them. Besides the water contained much silica and nitrogen. Carbon and silica precipitated from ocean water in these ancient times. In due time, its acidity was gradually reduced as a result of chemical reactions of strong acids with the salts of strong bases. The input of the products of erosion of volcanic rocks and ash to the ocean accelerated that process.

A.P. Vinogradov believed that the anions of sea water had practically been supplied solely by juvenile waters, and the cations were derived from continents, that is related to weathering on land. Because weathering intensified in time, the amount of cations in the ocean water have been rising throughout the Earth's history.

It has been found, however, that metal-bearing brines issue onto the World Ocean floor, and this makes us revise the time and character of cation supply. Most probably, the cations are of volcanic origin, like the anions in sea water.

In spite of the fact that the salt composition of ocean water differed radically at that time from the present-day one, the ocean could not be "fresh" in no way. Its salinity was rather high even at the time of its origin; it may have been several times higher than now.

Because the ocean was much greater than land in area, gases escaped into the atmosphere predominantly through the ocean. Underwater lava outpourings saturated ocean water with gases. The ocean gave the excess of matter away to the atmosphere, while part of the atmospheric gases dissolved in the water. A specific ocean-atmosphere interaction existed even at that ancient time.

The second stage in the ocean evolution was wholly dominated by the generation and making of the biosphere. The appearance of free oxygen had radically altered the chemical composition of ocean water. The atmosphere became oxidizing, instead of reducing, and this, in turn, caused the transport of nitrogen from the ocean, where it was in the form of ammonia, into the atmosphere as a molecular nitrogen.

The ferrous iron compounds began to pass into the ferric iron ones, which are less mobile. The mobility of sulphur, calcium and magnesium ions changed substantially. Silica was laid down chemically only early in the evolution of the ocean, because the temperature and pressure were sufficiently high at that time. Since the appearance of organisms whose shells consisted of silica, this element has been settled down biogenically throughout the Phanerozoic.

One of the most important stages of oceanic development is related to the evolution of carbon. In one case, it precipitated chemically in the early stage of the ocean history as a result of a temperature and pressure drop. In the other, the carbon was combined in the atmosphere into carbon dioxide, which was then transformed into easy-soluble compounds, such as carbonates, owing to photosynthesis and the vital activity of animals. Many organisms take substances necessary for their skeletons from sea water (most invertebrates have their skeletons made up of calcium carbonate). After these organisms became extinct, huge calcium carbonate masses accumulated on sea bottom, and these were later transformed into organogenic limestones. At the same time, calcium carbonate was laid down chemically in some areas of seas and oceans.

The World Ocean favours a steady cycle of carbon whose excessive amount is removed from the cycle and accumulated on the sea floor thus regulating the concentration of carbon in the atmosphere.

A certain stability of atmospheric composition caused a certain stability of forms of occurrence and migration of the principal elements in sea water. The chloride-sulphide salt composition of the ocean gave way in the late Proterozoic to the chloride-carbonate-sulphate one. There is an opinion that this composition has survived until now.

Thus the following colossal and harmonious equilibrium system has arisen in the world and exists now: atmospheric gases—salt composition—living matter—bottom sediments. The equilibrium disturbances due to tectonic movements, volcanism and other closely associated global processes, such as sea transgressions and regressions, and biospheric crises, led to changes in the configuration of continents, ocean depth and topography, the amount of water, and salt composition.

The Structure and Geology of the Ocean Floor

The depth of sea or ocean is one of the most important conditions controlling the life of marine organisms, the formation of relief and the dynamics of geological processes. A number of bathymetric zones have been distinguished in the ocean (Fig. 22); these are also bionomic ones, because the distribution of marine organisms is vertically zoned.

The littoral zone is located just off the shore, between high and low tides. Its maximum depth is several metres. A specific assemblage of organisms that can withstand dry periods and wave action takes place here. Then comes the sublittoral zone extending to a depth of 200 m. It is especially rich in organic life, is well aerated

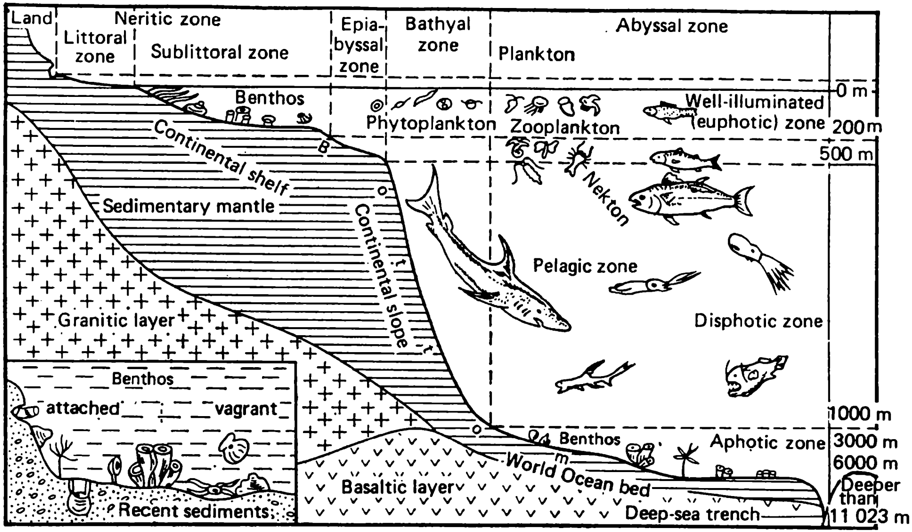


Fig. 22. Bathymetric and bionomic zones of seas and oceans

and has an abundance of nutrients. The epibathyal zone lies between 200 and 500 m of depth. Many combine these three zones into one called the neritic zone. The bathyal zone extends to a depth of 3 km, and the abyssal zone is between 3 and 6 km of depth. The ultra-abyssal zone lies deeper than 6 km. The organic world in the abyssal zone is much poorer both in number and in diversity of forms. The sun light is practically absent. Here animals eat mud containing organic matter introduced from more shallow depths.

The marine organisms whose remains are buried in sedimentary series fall into three categories by their way of life: (1) nekton, actively free-swimming animals; (2) plankton, drifting ones; and (3) benthos, bottom-dwelling ones. Plankton and nekton live in the open sea or in the ocean and are called pelagic forms. The life of benthonic forms is closely associated with the sea floor. The bottom of the sea dwelled by benthonic organisms is also called benthos. Some benthonic forms are attached to the bottom, others lie freely on it and still others crawl over it or bury themselves in it.

There is a half-century tradition according to which the different bathymetric and bionomic zones are considered to correspond to the principal relief forms of the World Ocean floor. Thus the ocean floor between depths of 0 and 200 m is identified with continental shelf. This is a more or less levelled surface of the floor surrounding continents and large islands.

A relatively steep segment of the ocean floor, which is called the continental slope, lies below a depth of 200 m. The ocean floor proper—the levelled-off part of the ocean floor—is located at depths exceeding 3 km. The parts of the ocean floor deeper than 6 km are called abyssal basins.

Little has long been known of floor structure. The holes run by the research vessel *Glomar Challenger* into the ocean floor have really revolutionized this field of knowledge. Until then geologists had studied only rock samples dredged from the sea floor.

The geological information provided by cores from deep-sea boreholes is unique since it can be helpful in deciphering not only the composition and geological age of rocks beneath the World Ocean floor but also the processes preceding the origin and long-term preservation of these rocks.

According to the deep-sea drilling programme, over 600 boreholes have been drilled into the ocean floor between 45 °N and 40 °S, because dangerous collisions with icebergs are possible at high latitudes. There have been drilled and described materials ranging in age from present-day to Late Jurassic (about 160 million years before present), and discerned many major trends.

One of them consists in the fact that the most ancient sediments occur in oceanic margins, whereas the youngest are restricted to the axes of the rift valleys of mid-oceanic ridges. Indeed, each time a new magma batch rises into the rift crevasse, it solidifies there and, expanding during this process, pushes the older rocks aside from the axis. That's why the oldest oceanic sediments, the Jurassic, occur near the continents.

Continents are the main sediment suppliers for the ocean. About 250 thousand million metric tons of suspension is annually transported into the World Ocean. Eighty per cent of them are laid down near the continents, in their margins, while the rest is transferred into the deep zones of the ocean. Terrigenous sediments constituting a specific belt encircle the continents.

In the open ocean volcanic and organic materials play the basic role in sedimentation. The latter are formed from the concentration of skeletons of microorganisms and their life products. The distribution of organic sediments depends on the temperature at the water surface, and water salinity. The volcanic material is composed of ash and pumice thrown out of underwater eruption centres.

Relatively shallow-water carbonate muds develop within mid-oceanic ridges.

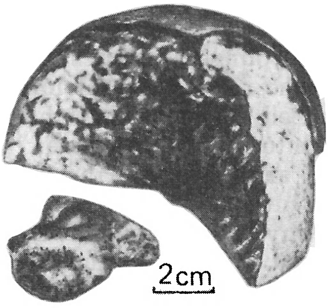


Fig. 23. A manganese concretion from basins off the Cape Verde Islands.

A shark tooth covered with a manganese crust on the foreground

Extremely large mineral bodies have been discovered on the ocean floor; manganese nodules are most extensive among them (Fig. 23). They cover the ocean floor over vast expanses in the form of a cobble roadway. Besides the high contents of iron and manganese, the nodules contain relatively much nickel, copper, cobalt, zinc and some other metals. Accumulations of manganese nodules were found by the first cruise of the *Challenger* more than 100 years ago. They are known now from the various regions of the Pacific, Indian and Atlantic oceans at depth in the range from 4 to 6 km, and also on the floor of the Barents, Kara, Baltic and Black seas.

The nodular ores can be treated to extract titanium, lead, zinc, molybdenum and other components. The main difficulty is how to rise these ores to the surface. The relevant methods are now under development.

So-called metalliferous sediments occur in some places of the World Ocean. They contain manganese, iron and a number of other metals, but less than manganese nodules. But while the thickness of the nodular ores is merely tens of centimetres, that of the metalliferous sediments is tens of metres. About ten major mineral deposits have been discovered in the basins of the Red Sea, which are filled with hot brines issuing from the floor. Metalliferous sediments have been found by the Soviet expeditions in the Pacific, more particularly to the south of the Galapagoss Islands and in some other places where materials are coming from deep in the Earth. Where the basalts heated to 1500 °C are in contact with sea water, hydrothermal springs are located; they transport waters saturated with various chemical elements from the Earth's interior.

In the mid-1970s, the French-American expedition on board a submarine observed an unusual sight. Batches of black water from which chemical elements precipitated in the form of conical hummocks were thrown, like smoke clouds, out of a small cone-shaped height resembling a termite nest. When the submarine began to approach the black water flow, the thermal protection device functioned, because the ambient temperature was 400 °C. Analyses showed high concentrations of zinc, iron, silver, cobalt and cadmium in the water. Large benthonic organism colonies were found near the underwater geyser. Hot water and abundant nutrients supplied from the interior provide the life of the benthonic animals.

The drilled oceanic sediments contain numerous fossil microfauna remains. The investigation of planktonic and benthonic foraminifers, nannoplankton, radiolarians, and diatomic and blue-green algae made it possible to determine not only the age of sediments but also the life sequence of forms, and to refine the geochronological scale.

All the above protozoan microfossils have striking features. First, the planktonic microorganisms moved easily and rapidly for great distances; second, many foraminifers and nannoplankton groups evolved quickly. They even surpassed, in this respect, multicellular organisms, which have been used for long to divide and correlate sediments. At present, examination of the remains of nannoplankton and other microorganisms is a must during any oceanological investigation, especially if made with the help of deep-sea drilling.

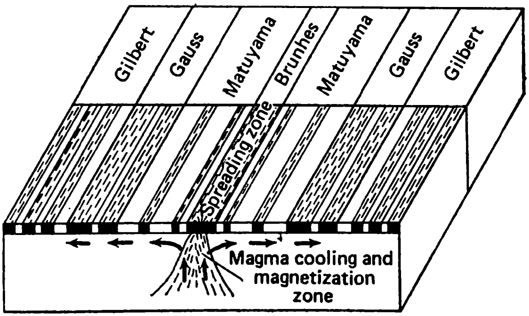


Fig. 24. Model of a "magnetic tape" and a magnetic field reversal time-scale showing a symmetrical disposition of linear magnetic anomalies on both sides of a mid-oceanic ridge

Detailed division of Upper Cretaceous, Paleogene and Neogene sediments have been made for the World Ocean, the marginal and interior seas, and continents. The division is in so great a detail that there have been distinguished horizons, or so-called paleontological zones formed during several thousand years.

The drilling results have proved that not only the age of sediments but also that of linear magnetic anomalies changes towards the axis of a mid-oceanic ridge (Fig. 24). It has been found that a particular rock is marked by a linear magnetic anomaly of the same age. The attitude and the mode of origin of the sedimentary cover beneath the ocean floor both verify and substantiate the concept of sea floor spreading at mid-oceanic ridges and of continual formation of new oceanic crust within their limits.

The changes in the isotopic ratios of oxygen and carbon in sediments and skeletons of microorganisms provide a means to determine the temperatures of ocean water in the geological past. As a result, it became truly possible to establish the ages and causes of global cooling periods and glaciations on the Earth.

Geophysicists offered a three-layer model for the Earth's crust, based on a comparison of seismic velocities alone, before deep-sea drilling was made. In this model, the sedimentary rocks are underlain by basalts resting on gabbroids (basic rocks), which, in turn, lie on ultrabasic rocks, which are among the most compact rocks at the Earth's surface.

Drilling has obtained quite valuable data on the structure of the basalts that occur within not only mid-ocean ridges but also abyssal basins, where they are buried beneath a thick sediment cover. Studies into the composition of hydrothermal waters migrating through basalt piles have provided an extremely valuable information about the salt composition of oceans in the geological past.

About 200 boreholes drilled by the research vessel *Glomar Challenger* ran through the sedimentary column, reached the basaltic layer and even penetrated into it to a depth of several tens of metres. Only several holes were drilled through the basalts to a depth of 300-400 m, and one hole, on the Costa Rica rift in the Pacific, reached a depth of 1075 m beneath the surface of the basaltic layer.

The basalts in the ocean floor differ in chemical composition from those on continents and in continent-ocean transition zones. It has been found that at depth of 15-45 km they were molten, out of the mantle material, which contains little alkalis and light-weight elements and is specific in the composition of strontium and lead isotopes.

The vulcanites of the ocean floor consist of the broad variety of lava flow types, which alternate and absorb sedimentary strata. This suggests a pulsating character of the escape of basaltic flows from the magma chambers in which mantle materials concentrate. The pulses of eruptions in the rift zones of mid-oceanic ridges are due to the intermittent extension and built up of the ocean floor.

Marine Research Laboratories

Fundamental studies of the World Ocean were first conducted by the British vessel *Glomar Challenger*. This research vessel ran from Portsmouth little more than 110 years ago, spent about 3.5 years in the ocean and travelled about 70 000 miles. There has been laid the foundation for oceanography, and depths were measured on the way through all the oceans except the Arctic Ocean. The discoveries made by *Challenger* are among the great marine discoveries of the 15th and 16th centuries.

The scientific personnel measured depths, carried out dredging and trawling, determined the temperature of ocean water at different depths and studied atmospheric and meteorological phenomena, the direction and velocities of surficial and deep-sea currents. Ground and rock samples, plants and animals were dredged from the sea floor.

The results of the cruise were published in a 50-volume official report. Two volumes contain the basic scientific results, another two describe the cruise and the remaining volumes are monographs of the leading scientists of that time, F. Agissiz, H. Moseley, and E. Haeckel.

The *Challenger* expedition was first to discover 715 new genera and 4417 new species of living creatures. This proved convincingly that ocean depths are not lifeless deserts but are dwelled by living organisms. The expedition formed the basis of World Ocean floor investigation, and since then scientists systematically have been studying its geomorphology and geology.

The need for getting knowledge of the Earth's interior beneath the World Ocean is due to the vigorous economic growth and a drastic rise in demand for different mineral materials. The ocean floor studies specifically intensified after it was found that many oil and gas fields on land extend into the adjacent seas.

Drilling within water depths not exceeding 200 m were first made in the early 1960s. Because of this, oil deposits were discovered within the continental shelf off Alaska, in the North Sea, and off Indonesia. At the same time, there arose a need for carrying out investigations and deep-sea drilling in the distant areas of oceans to get insight into crustal structure and evolution.

The drilling vessel *Glomar Challenger* was launched in the USA on March 23, 1968, and the Deep-Sea Drilling Project was started in August of the same year.

The *Glomar Challenger* (Fig. 25) satisfies today's requirements even now and successfully examines the geological structure of the sea floor. It is equipped with facilities both for navigation with the help of artificial satellites, which provide pinpointing with an accuracy of ± 50 m, and for modern radionavigation. The vessel carries six laboratories: the lithological, geochemical, organic matter chemistry, micropaleontological, petrographic and photographic. The

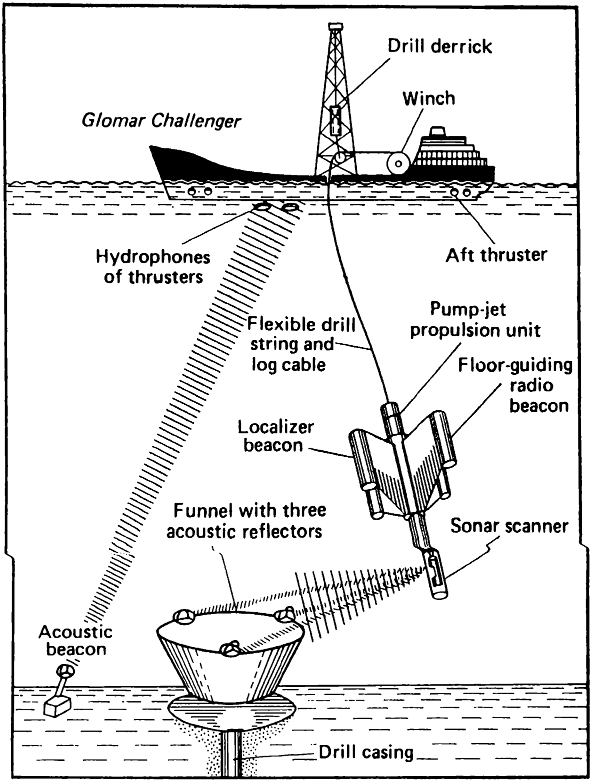


Fig. 25. A diagrammatic presentation of drilling and navigation performed by the r/v *Glomar Challenger*

fuel and food storage allows travelling in the open ocean during three months.

A 47-m drilling rig is in the middle part of the vessel. The lifting device of the rig can raise 500 metric tons; a drill pipe storage is on the upper deck.

The development of the Soviet oceanology and marine geology is closely associated with that of national cruise fleet. Its history began with the research vessel *Persey*. The fleet was launched immediately after the Civil War of 1918-1922. It now consists of more than 70 research vessels. They study the biology, chemistry and hydrology of the World Ocean, global and regional climates, the geology of sea floor, and so on.

The *Akademik Kurchatov* is the flag ship of the Soviet research fleet, and *Vityaz* is the most legendary ship. The *Vityaz* cruise record was the most glorious, the first experimental cruise of this ship was restricted to the Black Sea, and in 1949 *Vityaz* was bound for the Far East. The *Vityaz's* subsequent investigation record for 30 years includes the Far Eastern seas, and the Pacific and Indian oceans. As a result, there have been collected and treated unique hydrological, hydrochemical, biological, ichthyological and geological data.

The *Vityaz* tackled the following two major subjects: the investigation of biology and bathymetry of the Pacific Ocean and the study of geology of abyssal basins. The *Vityaz's* expeditions have discovered and examined submarine seamount countries, lengthy submarine ridges, extensive valleys and deep basins. As a result, the map of the Pacific shows the Obruchev plateau, the Vityaz trench and seamount, the underwater ridges of the USSR Academy of Sciences and Bogorov, and the seamounts of Makarov, Vavilov, Isakov, Papanin, Shirshov, Gagarin, Titov, and so on. There has been examined the Mariana trench and recorded its maximum depth (11 033 m).

In 1966, the national cruise fleet received the new modern research vessel *Akademik Kurchatov*, which took up the torch from the fabulous *Vityaz*. She has made numerous research cruises round the World Ocean to carry out comprehensive studies in quite different regions. Each cruise of the *Akademik Kurchatov* is devoted to a certain problem in geophysics, hydrology, biochemistry, geology or physical oceanology. On board of vessel, magnetic and gravity surveys of the World Ocean floor and deep seismic sounding are carried out, the heat flow through the floor is measured, underwater earthquakes are recorded and trailing and dredging of the ocean floor are carried out. There have been obtained extremely valuable data on the geological structure and tectonics of the ocean floor.

The 30th cruise of 1979 was a qualitative-

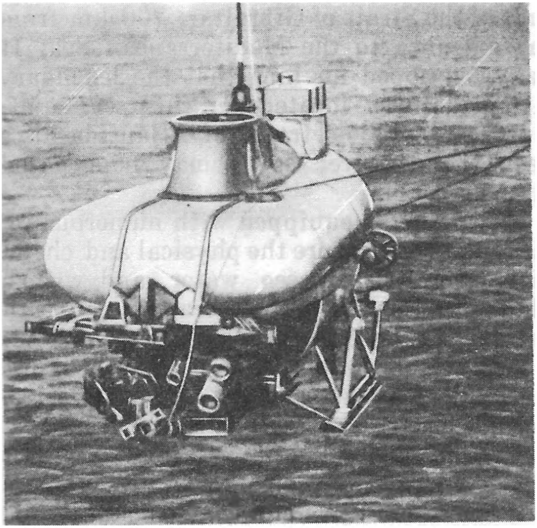


Fig. 26. *Paysis* submerscible (photographed by A.M. Sagalevich)

ly new stage in the work of the *Akademik Kurchatov*. The *Paysis* submersible apparatus (Fig. 26) was on board of the ship, with a crew of three men. This device can freely swim to various depths for a long time. Her strong searchlights catch from the dark wonderful landscapes of the sea floor. The maximum submergence depth of the *Paysis* is 2000 m.

One of the first *Paysis* submergences was targeted on the summit of seamount Amper. This seamount is located at the latitude of the Strait of Gibraltar, 700 km from the entrance to the Mediterranean Sea. It has been hoped for long that the legendary Atlantida was located on this seamount. Unfortunately, no traces of Atlantida have been found there; so it may be situated elsewhere.

The *Paysis* is equipped with numerous instruments to measure the physical and chemical properties of sea water, and with a photographic and TV camera. The investigators can observe the sea floor and the slopes of underwater valleys, as well as use mechanical arms to collect the samples required. The rock sample is received by geologists in a few minutes after it passes through several chambers.

When the *Paysis* submerged in the Red Sea in the early 1980s (all in all, she undertook 26 submergences), she made videofilms, took more than 700 photos of the sea floor and collected nearly 600 rock samples totalling one metric ton. The depth of submergence and the number of unique scientific documents and discoveries are striking. It was found, for instance, that the Red Sea rift is very young; it is merely 4-5 million years old. For a mid-ocean ridge to arise here, the continental margins should be pushed apart for an additional distance of at least 150-200 km. But this will happen only in several tens of millions of years.

Free-swimming submersibles are used to examine ocean depths, epicontinental seas and intercontinental water reservoirs. For instance, the *Paysis* was helpful in the studies of the floor of Lake Baikal, the unique fresh-water body in the world. Located here is a major rift valley which is very much like the Red Sea one, and operating here are processes very similar to those in mid-oceanic ridges.

Some scientists believe that, like the rifts of East Africa, the Baikal rift will be converted, in a distant future, to an extension-induced, extremely deep trough. Such a trough, filled with sea water, is a predecessor of a would-be ocean. This probably implies that a new ocean will some time appear at the centre of Asia and in the east of Africa.

Motions of Continents

The hypothesis of the stable position of continents and oceans has long been dominating in geological science. It was accepted that both arose hundreds of millions of years ago and since then have never changed their location. The sea encroached on lowlands but very rarely, when the height of continents diminished substantially while the level of the World Ocean rose.

The geologists believed stubbornly that the Earth's crust undergoes only a slow vertical movement, which gives rise to a terrestrial and an underwater relief. The movement is frequently of wide range and is rapid, and leads to major disastrous phenomena, for instance earthquakes. There also occur, however, oscillatory vertical movements that are very slow; their rates cannot be recorded even by the most sensitive instruments. Only after a very long period of time it can be found that the mountains have grown by several centimetres, while the river valleys have deepened.

Some naturalists doubted the above postulations at the end of the 19th century and at the beginning of the 20th century; they cautiously put forward the concept of integrity of the continents in the geological past, although they are now divided by extensive oceans. Like many having progressive views, these scientists were in a difficulty because their suggestion could not then be verified. Indeed, while the vertical oscillations of the Earth's crust could be attributed to some internal forces, for instance under the action of the Earth's heat, it was difficult to figure out the displacement of huge continents over the Earth's surfaces.

A. Wegener's Hypothesis

Early in the 20th century, the German geophysicist A. Wegener advanced the idea of movement of continents, which was popular among naturalists. He spent many years in expeditions and lost his life in the glaciers of Greenland in November 1930 (the actual date is unknown). The scientific world was shaken by the news of the death of Wegener, who was in a peak of his creative power. His ideas of continental drift had gained momentum by that time. Many geologists and geophysicists, paleogeographers and biogeographers showed interest in them; there were published works of great talent elaborating these ideas.

A. Wegener came to the thought of a possible continental motion when he carefully examined the geographical map of the world. He was striken by a wonderful similarity of the outlines of South America and Africa. Later on, A. Wegener examined the fossil record suggesting the presence, some time in the past, of land ties between Brazil and Africa. In its turn, this promoted a more detailed analysis of the geological and paleontological data available and convinced the scientist completely that his suggestions were sound.

At the beginning, it was difficult to discredit the well-developed concept of the stable position of continents, because the mobilistic suggestion was witty but purely speculative, based, at that time, merely on the similarity of configurations of the opposite Atlantic shores. A. Wegener believed that he could convince all his opponents that the continents do drift only after strong evidence, based on copious geological and paleontological information, is obtained.

To verify continental drift, A. Wegener and his proponents put forward four independent lines of evidence: geomorphological, geological, paleontological and paleoclimatic. First of all, there is a definite similarity between the shore-lines bounding the continents on either side of the Atlantic. (The shore-lines around the continents surrounding the Indian Ocean coincide but less distinctly.) A. Wegener suggested that nearly 250 million years ago all continents had been combined into a single giant supercontinent Pangaea, consisting of two parts. Laurasia, which combined Eurasia (without India) and North America, was located in the north, and Gondwana, composed of South America, Africa, Hindustan Australia and Antarctica, in the south.

The reconstruction of Pangaea was largely based on geomorphological data. They are wholly verified by the similarity between the geological sequences of individual continents and between the respective areas of certain types of animals and plants. The whole of the ancient floras and faunas of the southern continents of Gondwana constitutes a single assemblage. Many terrestrial and fresh-water invertebrates, and shallow-water invertebrate forms incapable of active motion for large distances and seemingly living on different continents, turned to be wonderfully akin to one another. It is difficult to imagine how the ancient plants could spread over these continents if they were then as so greatly apart as now.

A. Wegener obtained convincing evidence for the presence of Pangaea, composed of Gondwana and Laurasia, after he had generalized paleoclimatic data. It was already well known at that time that traces of the most extensive sheet glaciation, which occurred about 280 million years ago, had been found on almost all southern continents. Glacier-derived units in the form of fragmental deposits of old moraines (they are called tillites), the remains of glacial landforms and traces of glacier motions are known in South America (Brazil, Argentine), South Africa, India, Australia and Antarctica. It is difficult to figure out, with the present location of the continents, how the glaciation appeared almost simultaneously in the regions located so distantly apart. Moreover, most of the above regions of glaciation are now at equatorial latitudes.

The opponents of the continental drift hypothesis put forward the following arguments. In their opinion, although all these continents were situated at equatorial and tropical latitudes in the past, they stood much higher than now, and this caused the appearance of ice and snow on them. After all, Mount Kilimanjaro is covered with perennial snow and ice. It is hardly possible, however, that the total height of continents was 3500-4000 m at that time. There is no ground to believe in it, because in that case the continents would have undergone intense erosion, and coarse-clastic units should have accumulated around them, like the alluvial fans of mountain rivers. Only fine-grained and chemogenic sediments were laid down on continental shelf. Hence this unique phenomenon of the location of ancient tillites in today's equatorial and tropical regions of the Earth can best be explained by the continent Gondwana, made up of got-together South America, India, Africa, Australia and Antarctica, having been located at high latitudes, near the South Pole.

The antagonists of the drift hypothesis could not imagine how the continents had moved for so great distances. A. Wegener explained it with reference to iceberg motion under the action of centrifugal forces due to the rotation of our planet.

Because this hypothesis is simple and illustrative, and since the evidence for continental drift was convincing, it gained momentum fairly rapidly. However, disappointment followed its success rather soon. Geophysicists were the first who were critical to the hypothesis. They obtained a large body of factual information contradicting the logic of continental motion. This allowed them to prove that the way and causes of the continental drift seemed unplausible, so the hypothesis had been no longer supported by nearly anybody by the early 1940s. By the 1950s, most geologists believed that it should have ultimately been discarded and regarded as one of the historic paradoxes of science that had not been verified and had not withstood the load of time.

Paleomagnetism and Neomobilism

In the mid-20th century scientists started to intensely study the relief and geology of the ocean floor, the Earth's interior beneath it, and also the physics, chemistry and biology of ocean water. Numerous instruments sensed the sea floor. By interpreting seismic and magnetic records, geophysicists obtained new facts. It was found that many rocks become magnetized in the course of their formation in the direction of the pole of that time. This residual magnetization mostly remains the same for many million years.

The techniques of collecting samples and measuring their magnetization with special instruments, magnetometers, is now well developed. By determining the direction in which the rocks of different ages are magnetized, one can find, for the given time interval, changes in the direction of the magnetic field in each particular region.

Studies into the remanent magnetization of rocks led to two fundamental discoveries. First, it has changed from normal, that is like at present, to reverse many times throughout the Earth's history. This discovery was verified at the early 1960s. It turned out that the orientation of magnetization is clearly time dependent, and this was used to design magnetic reversal scales.

Second, some symmetry was established in the magnetization of lava piles lying on either side of mid-oceanic ridges. Such magnetization is patterned in the form of linear magnetic anomalies symmetrically arranged on both sides of the mid-oceanic ridge, and each symmetric pair is of the same age. Moreover, the anomalies become older and older away from the axis of the mid-oceanic ridge. Linear magnetic anomalies are records, as it were, of magnetic reversals on a giant "magnetic tape".

According to the repeatedly confirmed suggestion of the American scientist G. Hess, a partially molten mantle material rises onto the surface along fissures and rift zones in the axial part of the mid-oceanic ridge; it spreads both sides from the axis of the ridge, pushing apart, opening up, so to speak, the ocean floor (Fig. 27). The mantle material gradually fills the rift fracture, solidifies in it, is magnetized according to the contemporary magnetic polarity and then, being faulted approximately in the middle, is pushed apart by a new melt batch. The age of oceans is determined and their history is deciphered on the basis of the time of the reversals and the order of alternation of normal and reverse polarity.

The linear magnetic anomalies were proved to provide information most suitable for reconstructing the magnetic reversals of

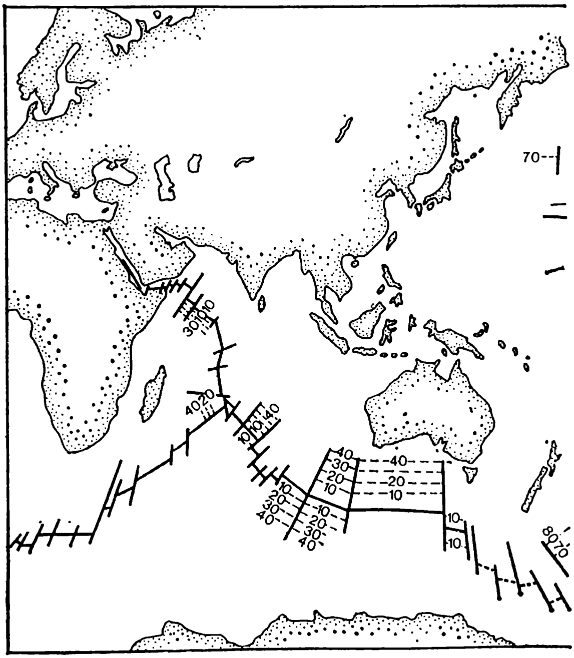
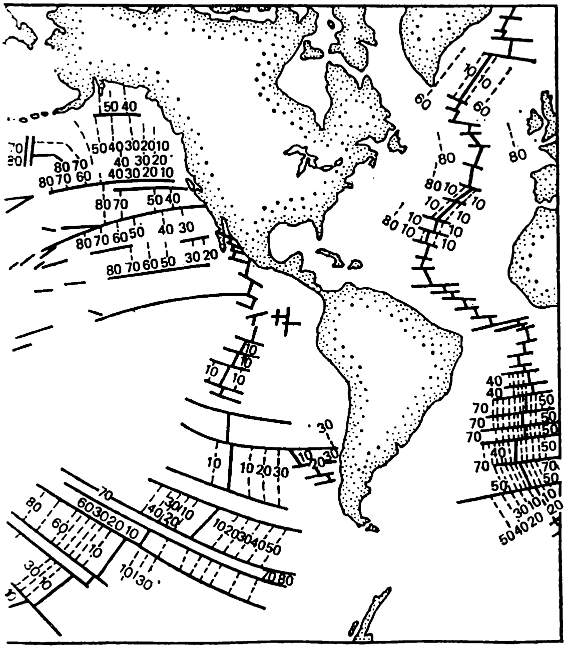


Fig. 27. Oceanic crustal build-up in areas next
Figures, million years;

the geological past. Moreover, the remanent magnetization of old rocks can be used to determine the direction of paleomeridians and, hence the location of the North and South poles in a given geological epoch.

The first pinpointings of the old poles showed that the older the epoch under stu-



to the mid-oceanic ridges, on magnetic evidence.
faults—solid lines

dy, the greater was the difference between the locations of the then and the present magnetic pole. The main thing is, however, that the pole coordinates derived from coeval rocks are the same for each continent but are different for different continents, and this difference rises with increasing age.

One of the paleomagnetic phenomena was a discrepancy between the locations of the old and today's poles. In an attempt to fit them, one should have moved continents each time. It is noteworthy that in fitting the late Paleozoic and early Mesozoic magnetic poles with the present-day ones, the continents were combined into a huge continent looking very much like Pangea.

So stunning results of paleomagnetic investigations promoted returning to the continental drift hypothesis. The British geophysicist E.C. Bullard and his coworkers decided to verify the premise of continental drift—a similarity of the outlines of continental blocks now separated by the Atlantic Ocean. They were fitted with the help of computers, but not by their shorelines, as A. Wegener did, and by the 1800-m isobath, which passes roughly half-way down the continental slope. The outlines of continents on either side of the Atlantic coincided along much of their length.

The Tectonics of the Lithospheric Plates

The discoveries of primary rock magnetization, magnetic reversals symmetrical to the axis of mid-oceanic ridges, changes in the location of magnetic poles with time, and many other findings regenerated the continental drift hypothesis.

The concept of ocean floor spreading away from the axis of a mid-oceanic ridge was verified many times, especially by deep-sea drilling data. Seismologists substantially elaborated the mobilistic ideas. Their investigations refined the distribution pattern of seismic activity at the Earth's surface. It has been found that these zones are rather narrow but lengthy. They are restricted to continental margins, island arcs and mid-oceanic ridges.

The revitalized continental drift hypothesis was called the tectonics of lithospheric plates. These plates move slowly over the surface of our planet. They are as thick sometimes as 100-120 km but more often than not are 80-90 km thick. There exist few lithospheric plates on the Earth (Fig. 28)—eight major and about ten and a half of minor ones. The latter are often called microplates. Two major plates are within the Pacific Ocean; they are made up of a thin and readily penetrable oceanic crust. The Antarctic, Indian-Australian, African, North American, South American and Eurasian lithospheric plates have a continental crust. Their edges (boundaries) are of different types. The edges are called divergent if the plates are pushed apart at them. Mantle material is introduced in the resultant fissure (rift zone). It solidifies on the ocean floor, building up the oceanic crust. New batches of mantle material ex-

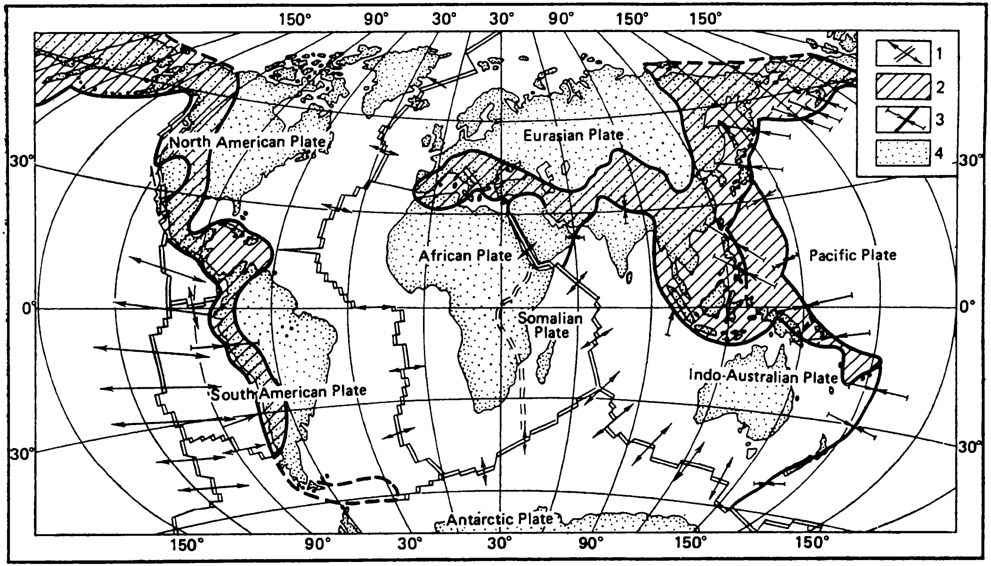


Fig. 28. Today's lithospheric plates of the Earth and directions of their motion:
1—spreading axes and faults; *2*—global-extent compression belts; *3*—convergent plate boundaries; *4*—modern continents

pand the rift zone, which makes the lithospheric plates move. An ocean broadening all the time is generated between the pushed-apart plates. This boundary type is marked by modern oceanic rift fissures along the axis of a mid-oceanic ridge.

The boundaries at which the lithospheric plates converge are called convergent. Complex processes act in the zone of plate convergence. When one oceanic plate collides with the other, oceanic or continental one, it plunges into the mantle. This process is accompanied by crumpling and faulting. Deep-source earthquakes arise in the plunge zone. It is here that the Benioff zones are located.

The oceanic plate enters into the mantle and is partially melted here. Its most lightweight components rise again, after melting, to the surface as volcanic eruptions. The circum-Pacific volcanic belt is precisely of this nature. The heavy components submerge slowly into the mantle even to the core.

Something like hummocking occurs when the continental plates collide. We see this phenomenon each time during ice floating, when ice-floes collide and break up, shovelling one against the other. The Earth's crust of continents is much lighter than the mantle, hence the plates do not plunge into the mantle. They are compressed during their collision, and large mountains arise in their margins.

Numerous investigations conducted for many years have made it possible for geophysicists to determine the average velocities of motion of lithospheric plates. The velocities of conversion range from 0.5 cm/year in the area of Gibraltar to 6 cm/year in the areas of the Pamirs and Himalayas, all within the Alpine-Himalayan compression belt produced by the collision of the African and Hindustan plates with the Eurasian plate.

At present Europe "floats off" North America at a rate of 5 cm/year. But Australia "goes away" from Antarctica at the maximum speed—14 cm/year on average.

The oceanic lithospheric plates move at the highest velocities, which are three to seven times higher than those of motion of continental plates. The Pacific plate is most "rapid", while the Eurasian one, "slowest".

The Mechanism of Motion of Lithospheric Plates

It is difficult to visualize that the extensive and heavy continents can slowly move. It is even more difficult to answer the following question: Why do they move? The Earth's crust is a cooled and completely crystallized mass. It is underlain by the partly molten asthenosphere. It is easy to suggest that the lithospheric plates have resulted from the cooling of the partly mol-

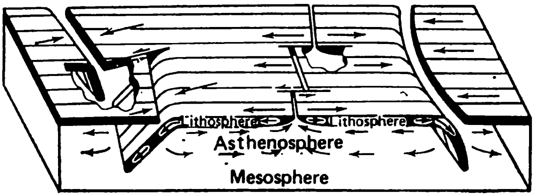


Fig. 29. Diagrammatic presentation of motions of rigid lithospheric plates (after B. Isacks *et al.*, 1968.

ten material of the asthenosphere like ice forms in water bodies in winter. The distinction lies, however, in the fact that ice is lighter than water, while the crystallized silicates of the lithosphere are heavier than their melt.

How are oceanic lithospheric plates formed?

The hot and partly molten material of the asthenosphere rises between the plates to the ocean floor, cools down, and crystallizes to become lithospheric rocks (Fig. 29). The early-formed segments of the lithosphere "freeze" even stronger and are fractured. A new batch of hot material fills these fractures, solidifies and, expanding, pushes apart their walls. The process is repeated many times.

The lithospheric rocks are heavier than the underlying hot material of the asthenosphere. Hence, the thicker the lithosphere, the deeper it subsides into the mantle. But why don't the lithospheric plates sink in the mantle if they are heavier? The answer is fairly simple. They don't sink because light-weight crust, which behaves as a float, is soldered to the heavy mantle part of the continental plate. Hence the average density of the rocks of continental plates is always less than the mean density of the hot mantle material.

Oceanic plates are heavier than the mantle, so they subside into the mantle sooner or later and sink under the lighter continental plates.

Like giant "flattened saucers", the oceanic lithosphere is rather long kept on the surface. According to Archimedes' law, the mass of the asthenosphere squeezed from under the lithospheric plates is equal to the mass of the plates themselves and of the water that fills the lows in them. Long-term buoyancy arises. But this situation cannot last for a long time. The integrity of the "saucer" is occasionally disturbed where excessive stresses originate, and the greater the stresses, the deeper the plates sink into the mantle and, hence, the older they are. Probably, the lithospheric plates older than 150 million years before present underwent stresses much greater than the ultimate strength of the lithosphere itself; they broke up and submerged into the hot mantle.

Global Reconstructions

The remanent magnetization of continental and ocean-floor rocks was used to locate the poles and latitudinal zonality in the geological past. As a rule, the paleolatitudes don't coincide with the present-day geographic latitudes, and the discrepancy grows back to older times.

The combined application of geophysical (paleomagnetic and seismic), geological, paleogeographic and paleoclimatic data allows the reconstruction of the location of continents and oceans for the different intervals of the geological past. These investigations are conducted by many specialists, such as geologists, paleontologists, paleoclimatologists, geophysicists and computer specialists, since not the calculations of vectors of remanent magnetization themselves but their interpretation is hardly possible without computers. The reconstructions were made independently by the Soviet, Canadian and American scientists.

The southern continents constituted the huge single continent Gondwana nearly throughout the Paleozoic. There is no reliable evidence for the presence of the Southern Atlantic and Indian oceans at that time.

The largest continent early in the Cambrian, roughly 550-540 million years ago, was Gondwana. Its counterparts in the

Northern Hemisphere were separate continents (North America, East Europe and Siberia) and few microcontinents. The Paleoasian ocean was located between the Siberian and East European continents, on the one hand, and Gondwana, on the other, and the Paleoatlantic ocean, between the North American continent and Gondwana. Besides, a vast oceanic expanse, analogous with what is now the Pacific Ocean, existed at that old times.

The continents in the Northern Hemisphere approached each other late in the Ordovician, about 450-480 million years ago. Their collisions with island arcs resulted in the built-up of the margins of the Siberian and North American land. The Paleoasian and Paleoatlantic oceans began to reduce, and a new ocean, Paleotethys, arose there in some time. It occupied today's South Mongolia, the Tien Shan, the Caucasus, Turkey, and the Balkan Peninsula. A new water basin also appeared in an area now occupied by the Urals. The Uralian Ocean exceeded 1500 km in width. The South Pole was in north-western Africa at that time.

In the first half of the Devonian Period, 370-390 million years ago, the continents started to combine: the North American one, with West Europe to produce, though not for long, a new continent, Euramerica. The modern mountain edifices of the Appalachians and Scandinavia were the result of collision of these continents. The Paleotethys reduced to some extent. Limited relict basins existed in the place of the Uralian and Paleoasian oceans. The South Pole was located in the area of today's Argentine.

Much of North America was situated in the Southern Hemisphere. The Siberian, Chinese and Australian continents, and the eastern part of Euramerica were at the tropical and equatorial latitudes.

The Early Carboniferous, roughly 320-340 million years ago, was characterized by a still continuing mutual approach of continents (Fig. 30). Orogenic regions and mountain edifices, such as the Urals, Tien Shan, the mountain masses of South Mongolia and West China, and the Salair Mountains, arose where they collided. A new ocean, Paleotethys II (second-generation Paleotethys), was formed. It separated the Chinese continent from the Siberian and Kazakhstanian one.

In mid-Carboniferous time, the considerable part of Gondwana turned to have been in the polar region of the Southern Hemisphere, which led to one of the greatest glaciations in the history of the Earth.

The Late Carboniferous—the beginning of the Permian (290-270 million years ago) was marked by the merging of continents into a giant continental block, the Pangaea supercontinent (Fig. 31). It consisted of

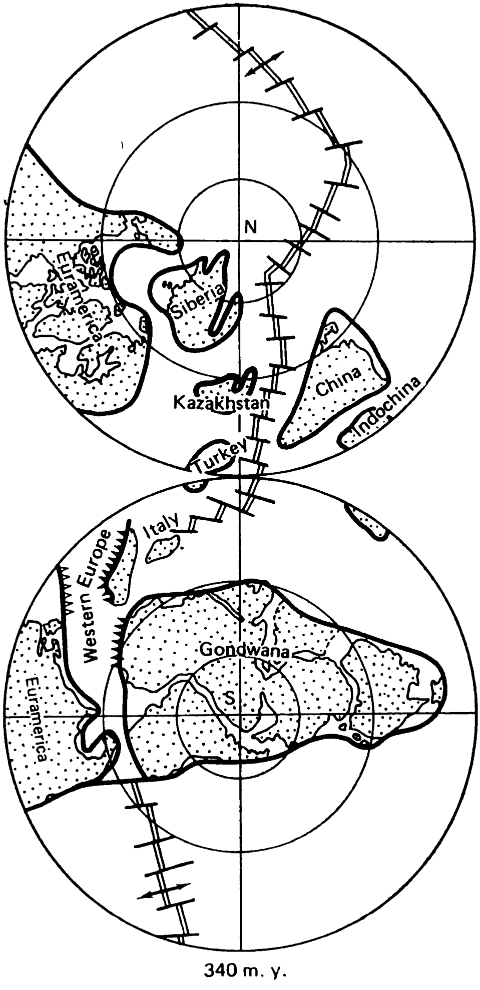


Fig. 30. Location of continents in the Early Carboniferous (340 m.y. ago)

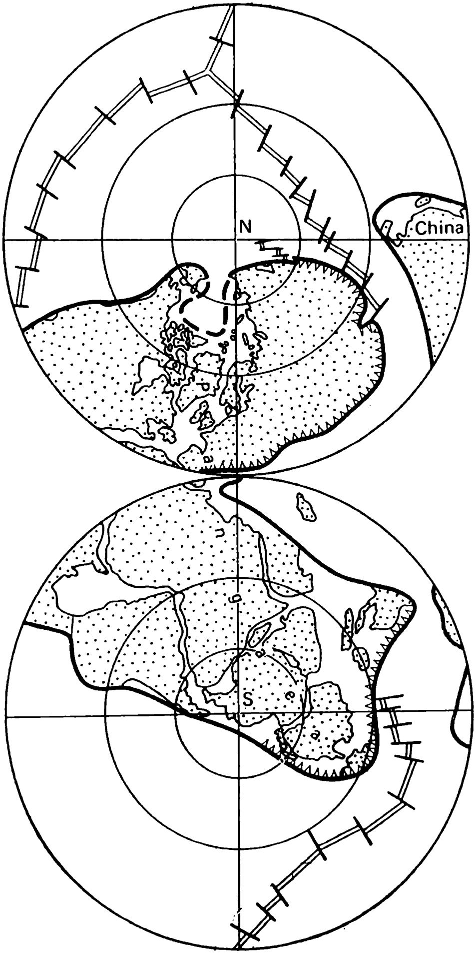


Fig. 31. Location of continents in the Late Carboniferous and Early Permian (290-270 m.y. ago)

Gondwana in the south and Laurasia in the north. Only the Chinese continent was separated from Pangaea by Paleotethys II ocean.

Although the disposition of continents in the second half of the Triassic, 200-220 million years ago, was approximately the same as late in the Paleozoic, the continents and oceans had changed their outlines (Fig. 32). The Chinese continent joined the Eurasian, and the Paleotethys II ceased to exist. But a new ocean basin, Tethys, arose nearly simultaneously and began to expand rapidly. It separated Gondwana from Eurasia. Isolated microcontinents, such as the Indian-Chinese, Iranian, Rhodopian and Transcaucasian, survived within its limits.

The new ocean appeared because Pangaea disintegrated, and all the continents known to date were pushed apart. Laurasia was first to break up in the area of what are now the Atlantic and Arctic oceans. Its separate parts then moved apart to free the place for the North Atlantic.

The Late Jurassic epoch, about 140-160 million years ago, was the time of Gondwana fragmentation (Fig. 33). The Atlantic Ocean basin and mid-oceanic ridges arose in the place of the split. The Tethys continued to evolve, a system of island arcs was located in its north. They were in an area now occupied by the Lesser Cauca-

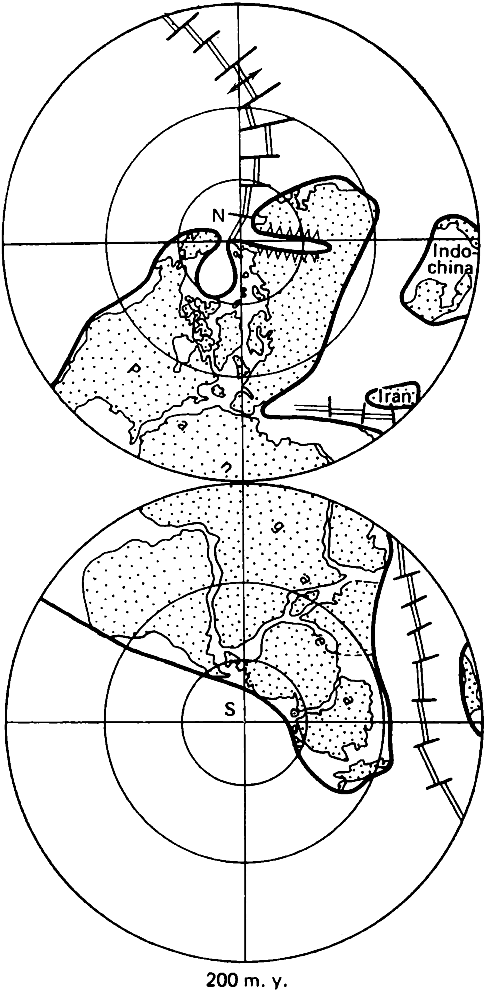


Fig. 32. Location of continents in the Triassic (200 m.y. ago)

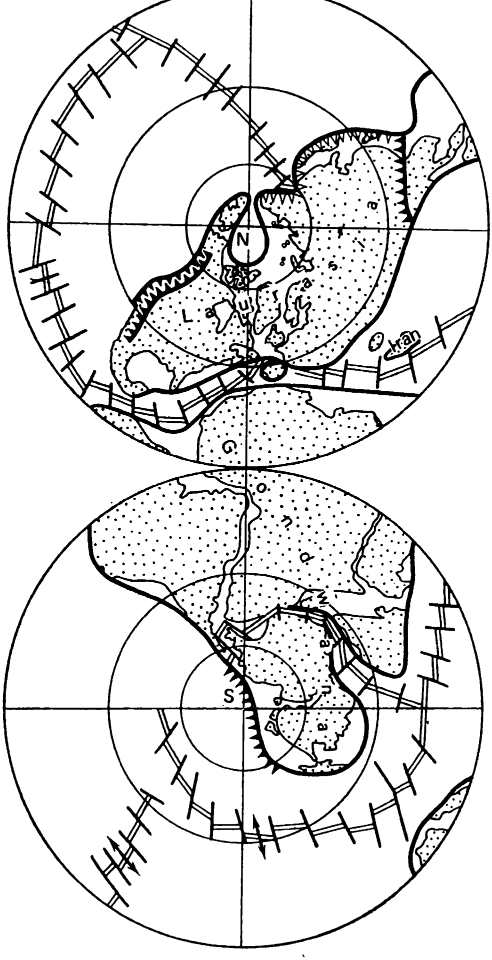


Fig. 33. Location of continents in the Late Jurassic (140 m.y. ago)

sus, Elburz and the mountains of Afghanistan, and separated marginal seas from the ocean.

The continents moved latitudinally throughout the Late Jurassic and Cretaceous. The Labrador Sea and the Bay of Biscay appeared; Hindustan and Madagascar separated from Africa. A strait originated between Africa and Madagascar. The prolonged travel of the Hindustan plate was completed by a collision with Asia at the end of the Paleogene. The result was giant mountain ranges—the Himalayas.

The Tethys Ocean began to reduce and close steadily, mainly owing to the convergence of Africa and Eurasia. A chain of volcanic island arcs arose at its northern margin. A similar volcanic belt formed at the eastern margin of Asia. North America and Eurasia converged in the region of Chukotka and Alaska late in the Cretaceous.

The Tethys has closed throughout the Cainozoic; its relic is the Mediterranean Sea. The collision of Africa with Europe gave rise to the Alpine-Caucasus mountain system. The continents began to converge gradually in the Northern Hemisphere and to diverge in the Southern Hemisphere, forming isolated blocks and masses.

In comparing the arrangement of continents in separate geological periods, we conceive the idea of large cycles in the Earth's evolution, during which the continents intermittently converge and diverge. Each cycle lasted at least 600 million years. There is ground to believe that the formation of Pangaea and its disintegration were not the only events in the history of our planet. A similar supergiant continent also arose far in the past—approximately 1000 million years ago.

Geosynclines as Folded Mountain Systems

While in mountains we admire a colourful panorama and are astonished by the limitless creative and destructive forces of Nature. Snow-white mountain summits stand majestically, huge glacier tongs descend down into valleys, mountain rivers seethe in deep canyons. We wonder not only at the wild beauty of mountain regions but also at the facts we hear from geologists, who postulate that boundless marine expanses occurred in very ancient times areas now occupied by vast mountain countries.

When Leonardo da Vinci found shells of marine mollusks high in the mountains, he came to the correct conclusion that sea existed there in the past; however, few believed him at the time. How could it be that sea had been in the mountains at a height of two or three thousand metres? More than one generation of naturalists made great efforts to prove that such seemed to be an inconceivable event is plausible.

The great Italian was right. The surface of our planet constantly moves up or down. When it subsided, enormous transgressions during which more than 40% of land was covered by sea have repeatedly occurred in the Earth's history. At the time of upward crustal movement, the height of continents increased, and sea retreated, that is a sea regression took place. But how were lofty mountains and vast mountain countries formed?

Views of dominating vertical movements have long reigned in geology; hence the opinion that it were these movements that were responsible for mountain building. Most mountains in the world are restricted to certain belts extending for thousands of kilometres and several tens or even the first few hundred kilometres. They are characterized by severe folding, faulting, igneous intrusions, and dikes cutting through sedimentary and metamorphic units. A slow and steady uplifting and erosion are factors of mountainous relief formation.

The Appalachians, Cordilleras, Urals, Altais, Tien Shan, Hindu Kush, Pamirs, Himalayas, Alps and Caucasus are fold mountain systems generated in the different periods of the geological past during the episodes of tectonic and magmatic activity. The sedimentary column is there exceptionally thick, frequently more than 10 km, which is tens of times greater than on platforms, whose surface is flat.

The finding of extremely thick folded sedimentary series cut by intrusions and dikes of igneous rocks and extending for great distances, though being relatively narrow, provided a foundation for the geosynclinal theory of mountain building put forward in the middle of the 19th century. A long-extending belt of sedimentary series transformed through time into a mountain system was called a geosyncline. In contrast, a stable region of the Earth's crust, where the sedimentary series are thin, is called a craton.

On the globe, nearly all mountain systems that are folded and faulted, and involved in igneous activity are ancient geosynclines in continental margins. Despite their enormous thicknesses, the bulk of sediments there are of shallow-water origin. Ripple marks, remains of shallow-water bottom-living animals and even dessication fractures have been found on the surface of strata. That the sediment is thick suggests a considerable and rather rapid crustal sinking. Besides the typically shallow-water sediments, deep-sea sediments, for instance, radiolarites and very fine-grained sediments with a specific bedding and structure, were found.

The geosynclinal systems have been under study throughout the entire century, and what seems to be a rigorous sequence of their generation and evolution has been established. The only unexplained fact is the lack of today's analogue of a geosyncline. What can be considered a modern geosyncline—a marginal sea or the entire ocean?

But with the elaboration of the tectonics of lithospheric plates, the geosynclinal theory has somewhat been modified, and the geosynclinal systems were matched with the periods of extension, motion and collision of lithospheric plates.

How did folded systems develop? Long-extending belts that subsided slowly were located in tectonically active continental margins. Sediments ranging in thickness from 6 to 20 km accumulated in marginal seas. Igneous rocks in the form of intrusions, dikes and lava sheets were emplaced there at the same time. The sedimentation lasted tens, occasionally hundreds of millions of years.

The geosynclinal system was then slowly deformed and transformed in the orogenic stage. It was reduced in area, was flattened, as it were. Rocks were folded and faulted, and igneous intrusions were emplaced. The deformation led to the displacement of deep-sea and shallow-water sediments, which were metamorphozed at high temperatures and pressures.

Uplift took place at that time, sea was completely withdrawn from the territory, and mountain ranges and masses originated. Subsequent erosion, transport and accumulation of fragmental sediments were responsible for a gradual wearing down of mountains to heights approaching sea level. The same result was produced by a slow subsidence of folded systems in the margins of the continental plate.

Not only lateral movement but also vertical one, mainly owing to a slow displacement of lithospheric plates, participated in the formation of a geosynclinal system. If one plate subducted under the other, the thick geosynclinal sediment within marginal seas, island arcs and deep-sea trenches underwent a severe action of high temperatures and pressures. These are subduction zones, where rocks sink into the mantle, melt and are reworked. Extremely strong earthquakes and volcanism are characteristic of this zone.

Where the pressure and temperature were not so high, rocks were folded and faulted with block displacement.

Where the continental lithospheric plates converged and collided, the geosynclinal system narrowed down greatly. Some of its parts subsided deep into the mantle, others were shovelled against the nearest plate. Squeezed out from the depths and folded sedimentary and metamorphic rocks repeatedly overlapped one another as giant scales with the ultimate formation of mountain countries. For instance, the Himalayas were produced by a collision of two major lithospheric plates, the Hindustanian and Eurasian. The mountain systems of southern Europe and North Africa, the Crimea, the Caucasus, the mountainous regions of Turkey, Iran, and Afghanistan were mainly the result of a collision of the African and Eurasian plates. The Ural Mountains, Cordilleras, Appalachians and other mountainous regions arose in a similar way but at an earlier time.

The History of the Mediterranean Sea

The evolution of the Mediterranean Sea is of special interest in the prolonged history of sea basins. The first civilized states originated around it, and the history of the peoples that live on its coast is well known. But we have to begin our description with the events that took place many millions of years before the first human being appeared here.

Nearly 200 million years ago, the place now occupied by the Mediterranean Sea was the extensive and deep Tethys Ocean; Africa was at a distance of several thousand kilometres from Europe. Major and minor archipelagos were located in the ocean.

These regions are now well known; they are in South Europe, and in the Near and Middle East—Iran, Turkey, the Sinai Peninsula, the Rhodope, Apulia and Tatra mountain masses, South Spain, Calabria Meseta, the Canary Islands, Corsica and Sardinia were situated far to the south from their present location.

A fault appeared between Africa and North America in Mesozoic time. It separated the Rhodope-Turkey mountain and Iran mass from Africa, and a basaltic magma rose along it, oceanic lithosphere was formed and spreading, that is pushing apart of the ocean floor, took place. The Tethys was in the tropical region of the Earth, extending from today's Atlantic Ocean through the Indian Ocean, which was its part, to the Pacific Ocean. The Tethys was most extensive roughly 100 to 120 million years ago and then was gradually reduced. The African lithospheric plate converged slowly with the Eurasian one. India separated from Africa about 50-60 million years ago and began its unprecedented drift northwards until it collided with Eurasia. The Tethys shrank gradually. What had been left by merely 20 million years ago was the marginal seas—Mediterranean, Black and Caspian, whose sizes, however, much exceeded the present-day ones. Subsequent events were not on a smaller scale.

In the early 1970s, evaporites—variable rock salts, gypsum and anhydrite—were found in the Mediterranean floor under a loose sedimentary unit several hundred metres thick. They were formed by vigorous water evaporation about 6 million years ago. But could the Mediterranean Sea get dry? It is this hypothesis that was put forward and is supported by many geologists. They suggest that the Gibraltar Strait became closed 6 million years ago, and the Mediterranean Sea was converted to a huge basin, 2 to 3 km deep, with small, salty, intermittently dried-up lakes. The sea floor was covered by a bed of solidified dolomitic mud, gypsum and rock salt.

Geologists have established that the Gibraltar Strait opened from time to time, and water from the Atlantic Ocean ran through it onto the floor of the Mediterranean Sea. When the Gibraltar Strait opened, a water fall arose with a discharge that was 15 to 20 times that of the greatest Victoria Fall, Zambezi River, Africa (200 km^3/year). The Gibraltar Strait closed and opened at least 11 times, so that the evaporite unit is about 2 km thick.

When the Mediterranean Sea was dry, the rivers that ran down the sides of its basin cut long and deep canyons. One of these has been found and traced for about 250 km from the present-day Rhone River valley down the continental slope. It is filled with very young, Pliocene sediments. Another example of such a canyon is the underwater extension of the Nile River as a sediment-filled canyon traceable for 1200 km from the delta.

When the Mediterranean Sea was no longer connected with the ocean, a specific, strongly freshened basin occupied its place—its remains are now the Black and Caspian seas. This fresh-water, sometimes salt-water basin, called para-Tethys, extended from Central Europe to the Urals and Aral Sea.

Given the pole location and the modern speeds of motion of the lithospheric plates, spreading and subduction rates, one can outline the way of would-be continental drift and imagine their location at any time.

Such a prediction has been made by the American geologists R.S. Dictz and J.C. Holden. In their opinion, in 50 million years the Atlantic and Indian oceans will spread at the expense of the Pacific Ocean, and Africa will move northward so that the Mediterranean Sea will be gradually closed. The Gibraltar Strait will disappear, while the "turned-around" Spain will close the Bay of Biscay. Africa will be split by the Great African Faults, and its eastern part will move north-eastwards. The Red Sea will expand so greatly that it will separate the Sinai Peninsula from Africa, Arabia will move north-eastwards and close the Persian Gulf. India will push Asia stronger and stronger; hence the Himalayas will grow. California will be separated from North America along the San Andreas fault, and a new ocean basin will form in its place. Considerable changes will take place in the Southern Hemisphere. Australia will cross the equator and abut against Eurasia. This prediction requires substantial specification. Much remains debatable and unclear.

Earth's Natural Resources and Environmental Protection

Our blue planet is an oasis of life in the cosmic desert of the solar system. And human dominates now in this oasis, being less dependent on the unfavourable natural forces. It should be admitted, however, that the prosperity of human society is, nonetheless, determined by the state of the environment and the wealth of natural resources.

Geoscience plays a large role in getting knowledge about natural resources, in particular, the time and place of their origin and distribution patterns. Geologists not only solve problems connected with mineral exploration and mining; together with biologists and ecologists, they develop the most effective measures to prevent the detrimental effects of open-cast and underground mining operations on the atmosphere, forests, fields, and surface and ground waters. The same problems arise in connection with the location of mining enterprises, power stations, major constructions and, finally, utilization of wastes.

Like useful minerals, natural resources are traditionally divided into energy and mineral resources.

Energy Resources

Energy resources include fossil fuels and some kinds of energy (solar, tidal, etc.). These are, first, materials that have concentrated and long preserved the solar energy—accumulations of organic remains of ancient representatives of the animal and plant worlds; second, minerals and rocks rich in various radioactive elements, for instance, uranium and other ores; third, hydraulic, fourth, solar and geothemal energy, the last being the heat of subsurface springs.

A complex mixture of liquid hydrocarbons occurs in nature as petroleum. There are two concepts of its origin. Some regard petroleum as a product of inorganic origin; others, of organic. The proofs of the latter are rather convincing. Many accept that petroleum is derived from remains of plants and animals; 99% of its pools occur in sedimentary series*.

The process of conversion of the source organic matter into petroleum is still un-

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* Because petroleum is highly mobile, it often migrates and concentrates in metamorphic and even fractured igneous rocks.

ravelled. Certain bacteria, particular pressures and temperatutes, a hydrocarbon inflow from the Earth's interior, and time are believed to be favourable factors.

The role of bacteria in petroleum formation consists in the fact that some of them can extract oxygen, nitrogen, phosphorus and sulphur from organic matter and thus increase the relative concentration of hydrocarbons. Other bacteria themselves produce the natural gas methane, but it is unknown whether it can be converted to petroleum and if so, then how?

The rocks in which petroleum occurs are divided into parent and reservoir rocks. The former are thick series of dark-coloured clays or clayey limestones containing finely dispersed organic matter. Petroleum accumulates in reservoir, that is permeable, rocks. These are sand-stones or porous limestones, including reefs, and dolomites. Enormous petroleum reserves are rather often contained in buried reefal masses.

Giant petroleum deposits are clustered in the Near and Middle East. Extremely large petroleum regions are the countries of the Arabian Peninsula, and also Iran, Syria, the countries of the Caribbean region, USA, Canada, Mexico, some countries of South America, and Indonesia. In the Soviet Union, petroleum regions are in West Siberia, the Ural-Volga interfluve and in the Caucasus. Petroleum is produced from the Caspian Sea floor, on the continental shelf of the North Sea, and in a number of other areas.

Natural hydrocarbon gases occur together with oil; they fill in reservoirs the free space above oil pools or form pools of their own value. Natural gas consists mainly of easy-inflammable methane. Petroleum deposits are also accompained by ethane, propane, buthane and bensol vapour. Natural gas is not only a high-quality fuel but also a valuable raw material for the chemical industry. It can readily be transported for great distances by using pipelines.

Specific kinds of energy sources are brown and hard coals, which were known to humans as good fuels long before the discovery of the inflammability properties of oil and gas. Enormous amounts of coal have been mined from the Earth's interior to use in economic activities. Nevertheless, coal resources are so huge that they will satisfy the present level of demand during many years.

Hard and brown coals partially retain the structures of the source vegetative material. Many coal seams display well-preserved coalfield imprints of leaves and sprouts, and also the fossil remains of tree crowns to say nothing of the branches and trunks.

Fossil coals consist of products of decomposition and alteration of vegetative remains derived from dead-off trees and bushes. The buried vegetative matter is converted to peat and then to coal with a participation of microorganisms, under the pressure of the above-lying strata and at relatively high temperatures. For coal to accumulate it is necessary not only the presence of enough vegetative matter but also certain climatic conditions.

The Lower Devonian coals of the Barzasskoe deposit, the north-western termination of the Kuznets Basin, and on the Medvezhii Islands, Barents Sea are the oldest in the USSR. As a rule, the coal seams of economic value accumulated in the Carboniferous, Jurassic and Cretaceous.

Oil shales and bituminous sandstones are also energy sources. The latter contain viscous asphalt resulting from incomplete oil extraction or from withdrawal of lightweight petroleum fractions. Oil shales are bituminous clayey or calcareous rocks that catch fire from the flame of a match. They burn with a smoking flame and have a characteristic bitumen odour. They owe their origin to a long-term alteration of algae and plankton in shallow fresh- and salt-water bodies. On the floor of these bodies, the dead-off material decomposed with no air access, and the sapropel formed in this way mixed with mineral materials and packed under the weight of the rocks lying above.

Oil shales are largely used for direct burning. However, they are not uncommonly treated thermally to produce gas and liquid fuel or various lubricants and combustibles. Enormous oil shale reserves have been discovered in West Siberia, Brazil, USA and South Africa. In the USSR, they are recovered in Estonia.

Mineral Resources

The properties of valuable minerals have been studied through many centuries, since extremely old times, when the human first took a stone and used it as an artifact. In the beginning, on casually finding concentrations of useful, valuable minerals, for instance copper, tin and iron bodies, the explorers and miners paid attention to the characteristic features of these bodies and then tried to use them for finding new mineral occurrences.

The experience gained by the explorers was accumulated and expanded for many years until it was generalized by progressive-minded geologists who formulated the basic principles of the search for mineral deposits.

At present, the appraisal of mineral potential, and mineral exploration are a discipline of its own in geoscience. It is concerned with the mode of origin and the environment of localization of mineral deposits, and the data gathered are used to distinguish the characteristics helpful in, first, predicting the location of, and then finding mineral occurrences.

A large group of minerals results from the action of supergene, or exogenetic processes.

Other mineral deposits are generated in the Earth's interior by endogenetic processes—magmatism, volcanic activity and metamorphism, that is by changes in the state of material at high temperature and pressure.

What processes are supergene and what is their nature? These processes are a function of a complicated interaction among the atmosphere, hydrosphere, biosphere and upper lithosphere. Temperature fluctuations, running waters in which various compounds are dissolved, including organic acids, and microorganisms participate in gradual wearing down of rocks lying at the Earth's surface. As a result of weathering, solid massive rocks first transform into loose and then into clayey materials. These are called weathering crusts. Rocks are not merely disintegrated, easily soluble components are withdrawn from them. Hence the weathering crust is gradually enriched with valuable components. Aluminium and iron hydroxides, and phosphorus, manganese, nickel, cobalt, and titanium oxides form in them concentrations of economic value.

Weathering crusts are destructed with time. Part of loose materials is blown away by wind, and the other part is eroded. While being transported, the loose material becomes rather frequently enriched with valuable components and reworked additionally. Fine particles transported by wind or surface waters (in solution or suspension) are ultimately laid down in topographic lows or marine basins to give rise to sedimentary mineral deposits. These include potassium and rock salts, gypsum and dolomite, phosphorites, placers of precious metals and stones, limestones, dolomites, manganese and iron ores, etc.

A rapid burial of plant remains without oxygen excess in lakes and marshes, and in coastal lowlands covered by thick forests resembling mangrove swamps leads to the formation of extremely large brown and hard coal deposits.

Climate is a major geographic factor. It is directly responsible for the appearance of landscapes and for changes in the face of the Earth. Many mineral deposits originate only under definite climatic conditions. Examples are metalliferous weathering crusts, aluminium ores (bauxites), iron and manganese ores, phosphorites, rock and potassium salts, gypsum and anhydrite, placers of noble and trace metals and stones, hard and brown coals, etc. Each of the above types of useful minerals forms in a quite definite climate and landscape. Some concentrate in the nearshore zone of warm seas, others in shelf seas having an elevated salinity, still others, on coastal plains and, finally, on elevated land expanses.

If we know the climate when this or that ore mineral was formed, as well as the paleoclimatic features of the territory, we can predict the precipitation of certain ore types with a high precision. Hence, the reconstruction of the ancient climate is a major factor of locating a mineral deposit. More and more mineral deposits are discovered now precisely by way of paleoclimatic and paleolandscape studies. These are conducted both on a global scale and within limited areas.

Weathering crusts are generated most rapidly in a hot and humid climate. Metalliferous crusts under these conditions are restricted to elevated plateaux and plains covered with wet forests. The weathering crusts on coastal plains and in humid terrains are valuable raw materials for ceramic industry.

With passing time, weathering products are transported by superficial waters and wind to accumulate gradually in topographic lows. On the way, these products are enriched with ore minerals thus giving rise to secondary deposits in metalliferous weathering crusts.

In regions of a relatively cool climate, rock reworking amounts to mechanical disintegration. Rock fragments of different sizes are transported by streams. During their transfer in suspension and by way of traction over the river bottom, the fragments are abraded even more so that their ore minerals contained (heavy fraction) in them settle on the bottom. The result is river placers of gold, platinum, tin, diamond, zircon, ilmenite, etc. Similar placers form along the shores of seas and large inland water bodies. The tidal movement of water masses and sea currents play the leading role in the concentration of such ore minerals.

Shallow-water sea basins in regions of a hot and dry climate, where evaporation prevails strongly over moistening, gradually become even shallower and more salty. High-magnesian carbonates (dolomites), sulphate sediments (gypsum and anhydrite) and chlorides (potassium, sodium and magnesium salts) accumulate in shallow-water embayments and lagoons nearly separated from the open sea (as the Gulf of the Kara-Bogaz Gol), as well as in semi-isolated seas, as the present-day Red Sea.

Seas in hot and dry regions are climatically most favourable for phosphorite formation. High-quality phosphorites are laid down near the shoreline, in areas of strong underwater currents and especially where the ocean water rises from the depth. The quality of the phosphorites is much lower in tropical seas with an intermittently humide climate, and they do not form any commercial concentrations in a humide climate.

Iron ore bodies are restricted to the nearshore zones of seas, where the temperature is relatively high, and are absent in seas with a moderate or a moderate-cold climate.

Endogenic mineral deposits are of a more complex nature and of a different character of valuable component concentration. They are divided into two large groups: magmatogene and metamorphic. Throughout the prolonged Earth's geological history, molten magmas have risen repeatedly from the depths of our planet and solidified at its surface. Besides magma intrusion and outpouring, so-called hydrothermal and metasomatic processes took place. The former are due to the activity of hot water solutions of magmatic origin and the latter, the interaction of sedimentary or igneous rocks with hot water solutions. During these processes, there occurs severe rock alteration.

Iron, copper, gold, tungsten, molybdenum, niobium, thorium and beryllium ores are associated with acid intrusions (granites, granodiorites, etc.), because they contain much silica. Dikes of acid composition—pegmatites—have elevated concentrations of trace elements, such as lithium, caesium, beryllium, niobium, tantalum, zirconium, thorium and uranium.

Niobium, rare earths, barium and zirconium are enriched in alkaline intrusions (syenites and others). Intrusive and extrusive rocks of basic and ultrabasic compositions are relatively enriched with chromium, nickel, cobalt, platinum and diamonds.

As a result of metamorphism, that is the action of high temperatures and pressures, and exchange chemical reactions, which take place at the same time, metamorphic mineral deposits are formed. Graphite, corundum, talc, serpentine and chlorite concentrate in gneisses, schists, quartzites, and hornfels. Metamorphic processes are responsible for a number of deposits of iron, tungsten, molybdenum, gold, cobalt, tin and some other ores.

We have told you only about some types of mineral deposits with an emphasis on the governing formative process, that is on their genetic aspect. At the same time, each type has specific features, which control the distribution and localization of mineral deposits in the Earth's crust.

Mineral deposits are divided into two major groups: metalliferous and nonmetalliferous.

Various metals are extracted from the ores of the former group. Not only separate metals, but also their melts and compounds are used in industry. For instance, iron compounds are utilized in mineral painting manufacturing and cement production; manganese compounds are widely used in medical industry and agriculture.

Metalliferous deposits are classified into those of ferrous and alloying metals (iron, mangenese, chromium, titanium, vanadium, nickel, cobalt, molybdenum and tungsten), non-ferrous metals (aluminium, copper, zinc, lead, tin, bismuth, arsenic, antimony and mercury) and precious metals (gold, silver and platinum), rare and trace and radioactive elements. The genetic types of these deposits and the modes of their origin are diverse and complicated, and are under a constant study.

The nonmetalliferous mineral materials are those giving rise to nonmetallic elements (sulphur, phosphorus, chlorine, lime), compounds of metals with other elements (potassium, sodium, barium and strontium compounds) and some nontraditional kinds of fuel.

The nonmetalliferous mineral deposits include chemical raw materials (phosphorus, sulphur, boron, rock and potassium salts, and strontium) and commerical materials. The latter are diamonds, graphite, mica, asbestos, talc, fluorite, barite, corundum and piezoelectric crystals. Ceramic and construction materials—masses of clays, various kaolins, feldspars, gypsum, anhydrite, diatomites, tripolies, gaizes, sands, gravels, precious, semiprecious and facing stones—are of large economic importance.

Most mineral deposits are concealed from direct observation and description. Hence geologists have to solve complex problems connected with their location.

In order to approximately locate a supposed concentration of a valuable mineral, enormous work should be done. Thus it is necessary to analyze the geological and tectonic structure of the region, determine the composition of rocks and reconstruct the geological history of the region. All these data are gathered in the course of field investigations and then are treated and analyzed in the laboratory. After concrete indications of a mineral deposit, for instance, samples of valuable minerals, have been found, the region is covered with a geophysical exploration and drilling. This helps to delineate the discovered body. Then geologists determine its economic value and only then give the new deposit over to miners.

On the Protection of the Earth's Interior and the Enviroment

More than 100 thousand million metric tons of various ores, fossil fuels, construction and other types of materials are annually extracted from the interior of the Earth. As by-products, while mining mineral materials, barren rocks left behind at the sites of mining operations are also treated. Many scientists predict that early in the 21st century, the consumption of mineral materials will reach a value of 500-600 thousand million metric tons and that of drinking water, over 30 thousand cubic kilometres in a year.

The economic activity of humans is now of global extent and has become comparable with many geological processes actively affecting the Earth's landscapes. The long-continued consumer's attitude to Nature has led to the exhaustion of the store-houses of our planet; more and more frequently, manufacturing processes detrimetally affect the environment. The humankind now faces a first-priority problem of protecting the Nature from pollution. It is being tackled by large teams of scientists, among them geologists. This is understandable because the exploration, extraction, and processing of mineral materials cannot be performed without due regard for environmental protection.

Because the natural environment is disturbed as a result of exploration and exploitation of mineral deposits, there has arisen the problems of protection of the Earth's interior and the rational utilization of natural treasury. Not long ago, mineral materials were extracted from shallow depths and mining operations were at a low technical level. As a result, the humans affected the Earth's crust to a lesser extent than now. At present, however, their negative influence on the Earth's interior is much greater. Thus hundreds of thousands of boreholes are drilled each year to different depths, their total length being tens of thousands of kilometres. The number of holes within mineral deposits under exploration is especially large; here, 20-25 holes are located within each square kilometre. Numerous shallow holes are drilled in the course of engineering geological studies in settlements. For instance, more than 200 kilometres of holes are annually run only in Moscow.

Although the drilling of each hole can be compared to a pinprick, this is definitely detrimental to the environment. The hole intersects various aquifers some of which are saturated with strongly mineralized water under a high pressure. Casing strings prevent the waters of different aquifers from mixing but not always hinder their spontaneous flow from depths onto the Earth's surface. Sometimes this leads to oil flowing with a pollution of the territory about the hole or to an introduction of polluted surficial water into the aquifers containing a pure, high-quality water. Cases are known where, owing to water quality deterioration, the use of drinking water from enormous artesian basins was ceased because salt water or oil had penetrated into them.

Exploring openings exert a considerable influence on the interior of the Earth. More than 17 mln m^3 of ground are displaced each year in the course of running pits and trenches. These now cover vast expanses and strongly affect the landscape.

Subsurface mineral extraction poses problems of its own, whose consequences may be felt many years after its completion. First, the picturesque landscape around mines is transformed owing to refuse dumps—hills of waste rock mined from under the earth. Second, the surface is not infrequently sinks, after extraction has ceased, above the previous mine opening, and this is hazardous for local people.

A negative consequence of underground mineral extraction is also the deterioration of atmospheric composition due to pit gas, and products of coal, oil shale, and peat combustion.

Not less dangerous is also the fact that abandoned openings substantially disturb the circulation of subsurface water and enhance the chemical effect on the environment. The waste rock fragmented and transported onto the surface contacts with atmospheric and ground waters and dissolves partially in them. The concentration of various elements in the water sometimes rises so greatly that it becomes chemically agressive.

During open-pit mining, much fertile earth is taken out of agricultural use. Investigations show that each hectare of earth disturbed by mine openings exerts a detrimental influence on the hectare untouched by these openings. To reduce the unfavourable effect of open-pit mines on the environment, these mines are filled with ground or artificial lakes are created in their place. After restoration of soil fertility, some areas of previous mines are used as recreation zones.

However, what can be done for small open-pit mines is difficult, sometimes useless, to do for large open-pit mines. For instance, in North Kazakhstan iron ores are extracted at the Sokolovsko-Sarbayskoe deposit from an open-pit mine 400-450 m deep and 2-3 km in diameter.

Enormous masses of waste rock covering beds of valuable mineral materials are displaced in large open-pit mines.

There were taken and displaced 170 mln m^3 of rock during the development of iron ore bodies in two open-pit mines, the Mikhailovskii and Lebedinskii, of the Kursk Magnetic Anomaly deposit.

Other detrimental effects on the environment are disturbances in the composition, quality and behaviour of percolating atmospheric water, and subsurface water pumping aimed at ground drainage; the latter leads to a water level fall in a radius of several tens of kilometres; this in turn, diminishes the water supply of settlements and industrial enterprises.

A specific landscape with a characteristic relief of technological origin is formed in major mining districts. Examples are the Donets and Kuznets basins, the surroundings of the town of Rudny in North Kazakhstan, and areas of intense mineral extraction in the Urals and Siberia.

Areas of open-pit mines look desolate for a long time—gaping openings occasionally filled with water, piles of waste and barren ground. During mining operations, dumps grew around open-pit mines. These dumps were worn down by rain water so that river water contained much suspended mud.

At present, mining enterprises are taking a number of environmental protection measures. These, in particular, are the reduction, if possible, of areas of waste rock and tailing discharge, and land restoration. The latter consists in the following. On starting mineral extraction, trees and shrubs are carefully replanted, and the layer of fertile soil is removed from the territory of a would-be open-pit mine and stored in a certain place. The non-operating mine is filled with wastes from dumps and covered by the soil, and then the land is handed over to agricultural enterprises.

Serious problems arise in connection with oil as a pollutant not only in the course of its extraction but also at the time of its transport. Many states are concerned with pollution due to unintentional oil blow-outs in the course of its production off California, Alaska, in the Gulf of Mexico and in the North Sea. The press repeatedly reports about accidents with tankers and supertankers, when oil flows out of them and covers sea water as a vast black patch which moves slowly towards the seashore poisoning all living things.

What are the principal ways of solving problems connected with environmental pollution? These are maximally safe oil transport and development of new methods of its transport by pipelines, reducing the combustion of fossil fuels and replacing them by less toxic energy sources, extensive land restoration, etc.

To provide the rational and comprehensive utilization of mineral materials and protection of the Earth's interior, the Supreme Soviet of the USSR adopted in 1975 the Fundamental Legislation of the USSR and Soviet Union Republics on the Earth's Interior.

The basic requirements to the protection of the Earth's interior are a detailed and comprehensive geological exploration of the interior; complete extraction and rational use of both major and minor valuable minerals; prevention from the detrimental effects of the work performed at mineral deposits under exploitation on the preservation of mineral materials or on their qualities; prevention from the pollution of the Earth's interior during the underground storage of oil, gas, and other materials, and elimination of negative effects of production and processing of some or other mineral materials.

The long-term integrated operational-research programme *Lithomonitoring of the USSR* is under development. The purpose of this programme is to monitor and assess the state and possible changes of geological, hydrogeological and geological engineering conditions under the effect of the technogenic factor.

The notion of monitoring, meaning a system of observations of changes in the environment with a purpose of its protection, has taken a momentum among geologists and geographers. As to the term lithomonitoring, it is taken to mean observation only of the lithosphere. Record in due time of even insignificant changes on the Earth's surface and in its interior will help to predict the course of events and, if necessary, to prevent negative consequences of economic activity.

Lithomonitoring implies the construction of observation stations and test sites aimed at studying surficial geological processes and ground-water behaviour. It is important to have the reference areas of an undisturbed lithosphere so that what has been could be compared with what is now. Such reference areas should be natural reserves, whose purpose would be to keep intact unique geological objects. The test sites would serve to develop protective measures. Such an area is now in action in the Crimea.

Lithospheric observations cannot be visualized without remote sensing techniques employed from air- and space-craft, since the face of the Earth renders changes in its interior. Aerial photography has long been an integral part of geological exploration and engineering. Together with aerial photographs, radar and infrared images are used to solve geological problems. Regardless weather and time, radar imaging produces "portraits" of the Earth where they are impossible to obtain by other means. Such an all-seeing eye makes it possible to monitor from aircraft an area concealed most of the year by thick clouds. Infrared photography, based on changes in the intrinsic and reflected radiation of natural objects, reveals surficial elements whose temperature differs though insignificantly from that of the background. It is especially efficient in regions of vigorous volcanic activity, thermal waters and some mineral deposits.

The development of space has provided for geoscience an enormous body of information in the form of many tens of thousands of images obtained in the various ranges of electromagnetic spectrum. Application of the totality of remote sensing methods to lithomonitoring helps to produce a comprehensive picture of the state of the lithosphere at a given moment. Large mining enterprises and the zones of their strong influence on the environment are lighter on aerial photos and space images because the remaining landscape has different reflecting and radiating properties. Oil-producing complexes are well observed on night-time images. "Hot" open-pit mines, dumps and rail belt lines are clearly seen on spring-time images, when the snow cover begins to disappear.

Note that lithomonitoring is a painstaking work associated with a continual monitoring of changes in the technogenic and natural landscapes. In regions of open-pit mining, it is possible to discern the distribution of ravines and recommend which of them can serve as dumps. Indirect indications point to the consequences of underground mining. Since a mine affects the behaviour of surficial and ground waters and this, in turn, exerts influence on the vegetative cover, any changes are easily detected by remote-sensing imaging.

The rational utilization of the mineral

wealth of the lithosphere and other natural resources is a global problem of today. It can be solved, not by one or several countries but by the whole humankind.

Humans have been extracting and processing many kinds of mineral materials since times immemorial. Recently, they more and more frequently extract minerals and rocks that have previously been of no economic value bacause of their low quality. Industry is developing, as is the technology of mining and ore processing; as a result, the previously unprofitable underground treasuries are now used in economic purposes.

Natural resources are now being exploited intensively, still with insignificant expenditures as to money, time and labour. Despite the application of modern mining and processing techniques and exercising due environmental protection measures, global changes in the outer shells of the Earth are taking place under the effect of economic activity. These changes occur in front of us. Thus, agricultural production is expanding, more and more sophisticated mechanisms are manufactured and more and more electric energy is produced. This means that requirements to soil fertility and the efficiency of interior wealth utilization will grow.

The economic outlays are now on hand. Nearly all territories useful for agriculture have been ploughed, more than half of the forests have been destroyed, many species of animals and plants have disappeared, a fresh-water shortage is felt in many regions and rich mineral deposits located near economically developed areas have been or are about to be exhausted.

The biosphere is transformed to an increasing extent under the influence of economic activity. On our blue planet, natural landscapes retreat gradually under the effect of the technogenic landscape. Many industrially developed regions have a stunted vegetative cover while the atmosphere above is polluted with smog. Desert and semidesert landscapes appear instead of forest-cleared areas.

Can we find an exit from this seemed to be closed circle? Yes, of course. Closed geological processes and cycles are acting in nature. They continue for thousands and millions of years. To reduce the damage inflicted to the environment, humankind should develop such technological processes (geotechnology) that could be, so to say, a natural continuation, a supplement to the closed natural processes.

The time is up for the development and wide use of diverse geotechnologies by which the Earth's resources could be mined and processed with a provision of ecologic purity, closeness to global natural cycles, with the least possible wastes.

It should be noted that geotechnologies cannot at all be unified and used equally well in extremely different terrains and for all kind of mineral materials. They are unique for each region and must best fit into the surrounding landscape changing it in no way, be adjusted to the given relief, soils, subsurface and surficial waters, forests, animal world, cities and villages.

Geotechnologies can be used in different industries, but we concentrate on the prospects of the so-called "underground" geotechnology. To extract and process mineral materials that are necessary for humankind, 150 thousand million metric tons of waste rock are removed onto the surface each year. They are commonly overburden rocks, which are taken during the development of open-pit mines and piled at open sites as dumps (rocks containing a small amount of ore and hence of no economic value) and rocks extracted from mines and underground openings. By the 21st century, the total amount of rock raised to the surface will have increased four- to sixfold. Not more than 5 per cent of this amount will constitute the end product, but even this figure seems to be overestimated.

The shortage of many mineral materials forces us to penetrate deeper and deeper into the Earth's interior. The total length of underground workings is many times the distance from the Earth to the Moon. The depth of these workings increases from year to year, but it cannot grow indefinitely because of too high temperatures at these depths. Even in open-pit mines, it is difficult to work at a depth of more than 400 m since ventilation is bad there and temperature is high. In deep underground mines (3-4 km), the temperature is so high that miners can work here only a few hours, hence the necessity of robot miners.

So we cannot cut into the interior endlessly. And what about economic needs in mineral materials? The decision is the only one—extraction of elements from the relevant rocks whatever the concentration of these elements. Until recently it has economically been considered unprofitable to extract ore minerals whose content of the respective rocks is below a certain value. This is because we go on the use of old technologies developed decades ago. Now we are in need of highly effective technologies designed to extract metals from low-quality ores. This way has been already outlined.

Microorganisms are used for the extraction of some useful components. These invisible toilers take from rocks disseminated iron, copper, lead, zinc, titanium, cadmium, even silver, gold and platinum. Such a technology helps to process hills of rocks piled around open-pit and underground mines. After the valuable component has been extracted, it is expedient to utilize the rock as a building material by making from it sand, clay, gravel and cement. As a result, there will be obtained not only an additional raw material necessary for industry but also vast expanses now occupied by dumps will be released from them. Millions of hectares of the earlier valuable and fertile soil must be returned to agriculture.

The human society has long reconciled itself with the negative consequences of mineral extraction, while ecological consequences were considered part of production costs. The negative effects of traditional exploitation of mineral deposits have accumulated for several hundred years to pile up at present. Today everybody is concerned with the ecosystem destruction and the growing pollution of the environment. In consequence, geotechnology should be used as widely as possible. But there is another problem—the lack of research developments, and this problem is under a continual attack by scientists.

Thus humans are a geological factor regardless our will and desire. In gaining an insight into geological processes, the following three specific features should be taken into consideration:

this effect is exerted on nearly every habitat on the Earth's surface;

the duration of this effect is still insignificant as compared with that of geological time;

this effect can be kept within reasonable frame in order not to disturb the geological equilibrium.

The extent to which humans affect geological processes is controlled by demand in natural raw materials and by landscape changes according to these or those needs of human society.

Humankind is a great geological force that transforms the nature of our planet. Until recently, the mind of humans has served to conquer Nature. But now we should refuse from dominating it, as well as from being under its blunt domination. We should co-operate with Nature, use it and, at the same time, support and protect it.

Conclusions

We tried to tell the reader about not only modern geoscience but also about its relations to other sciences. It is already known how complicated and long the Earth's history is, how the stages and periods of formation of the Earth's crust and other shells are established. We have known much, but much should be further known of stages in the evolution of our planet, of its composition and constitution at its depths. The Earth lives. The geological processes at its surface and in its interior become alternatively more calm and more active. The continents slowly drift spending enormous amount of energy in this process. In saying about geology and its achievements, we have made an attempt to show what disciplines exist in geology and what discoveries await the future researchers.

We didn't attempt to touch upon all sides of modern geology and its advances in different directions. The introduction of precision physical and chemical methods of research by using the most recent technology has greatly expanded the possibilities of mineralogy and crystallography. They help to discover new minerals and establish intricate links between elements. All this and, above all, comprehensive knowledge and the high level of research technology make it possible to synthesize practically all minerals known to date. At present it is possible to create in the laboratory high pressures and temperatures approximately the same as exist in the Earth's interior. This means that geology is on the way to reconstruct the processes taking place deep in the Earth and the primeval planetary material.

Radical changes have occurred in geoscience during the last decades. A new approach to geological investigations is now in use, and our knowledge of all natural sciences has expanded significantly. Many discoveries of those years are due to the fact that now geologists consider our planet to be an entity but with all its details.

In recent years, a new field of knowledge—cosmic geology—and new science—comparative planetology—have arisen. Geologists explore the planets of the solar system from mineralogical, geochemical and structural viewpoints. Thanks to spacecraft, lunar ground was transported to the Earth and studied here comprehensively. Our nearest neighbours—Mars and Venus—have been studied geochemically with the help of descent vehicles. Geology has gone nowadays far beyond the exploration of the planet Earth. It helps to gain knowledge of the structure and evolution of the planets of the solar system. A large breakthrough in this direction was made in March 1986, when Halley's comet met in the far outer space with *Vega*-1 and *Vega*-2 space vehicles.

Besides the exploration of the Earth's deep interior and the planets of the solar system, geologists are to solve one of the most urgent global problems of today—provision of humankind with mineral materials. The wealth of human society, its near and far future will depend on this. The mineral material problems arose because

(a) although much diverse valuable minerals still occur in the interior of the Earth, their use will have to be paid by humankind at a higher and higher price;

(b) the bulk of mineral materials cannot essentially be replenished by natural processes and is of a limited volume; this poses serious economic, research and political problems for society;

(c) rapidy rising expenditures related to the exploration, mining and processing of mineral materials make prominent the global problem of economical and rational utilization of natural resources.

The humankind is strong enough to solve this problem, but it will be done as a result of a combined effort of all the countries of the world.

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SCIENCE FOR EVERYONE

The principal advances in geoscience are discussed in this book. Prof. N. Yasamanov tells us about the role that geology plays in human society, about the Earth's structure, origin and history. He describes the beginnings of life on Earth, the distribution of natural resources over the globe and the problems connected with environmental protection.The book is intended for senior schoolchildren, teachers and all who are interested in Earth sciences; it would also be helpful for students of geological exploration in technical schools

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