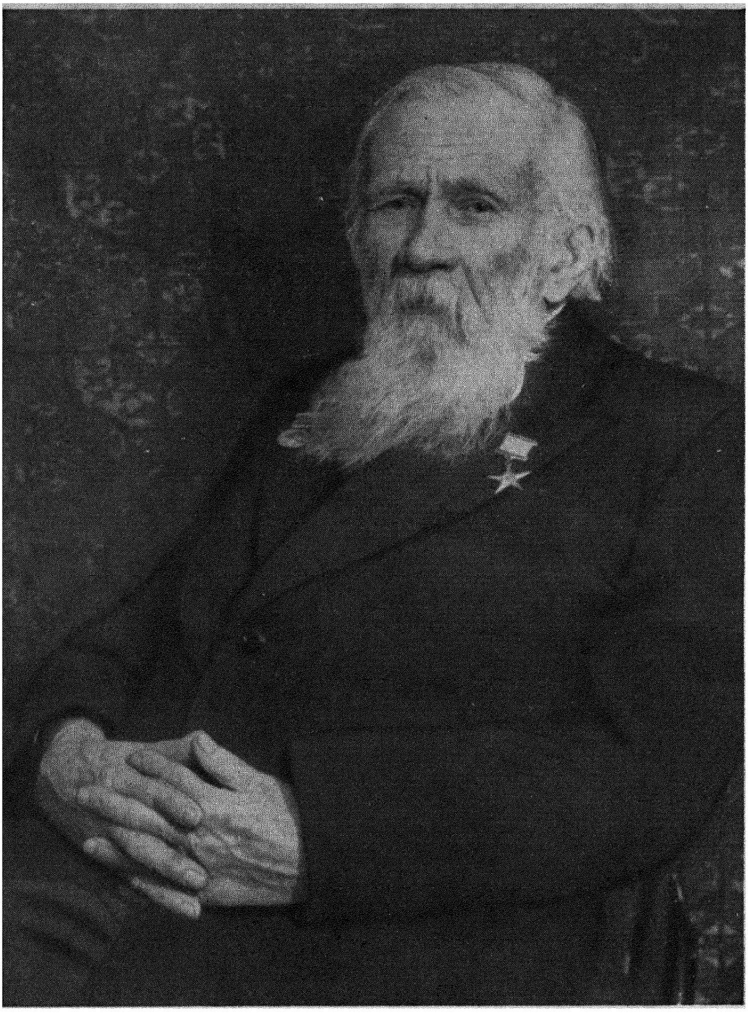

ACADEMICIAN
V. OBRUCHEV

FUNDAMENTALS OF GEOLOGY

POPULAR OUTLINE

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CONTENTS

INTRODUCTION

The reader probably is acquainted with some books of the series: *Physics for Everybody*, *Chemistry for Everybody*, *Mechanics for Everybody*, *Algebra for Everybody*, *Geometry for Everybody* and *Arithmetic for Everybody*. In the form of short stories, these books write of the interesting processes and phenomena that take place in nature, and describe unique mechanisms; they answer riddles in mathematics, physics, chemistry and mechanics, put posers, and explain the fundamentals of some sciences in a simple and entertaining manner. Academician A. E. Fersman in his *Mineralogy for Everyone*, which has had a run of several editions, has shown that this seemingly dry subject, with its enumerations of minerals, their forms, properties and occurrence, is quite fascinating. He has made rocks come alive and has told of their varied uses in everyday life and in technology. The author transports his readers to mountains, quarries and mines, to a fairyland of minerals and crystals.

Geology, therefore, the science of the Earth, which reveals to us how it took shape, its composition and the changes it has undergone in its millions of years—has every right to be interesting. It penetrates deeply into time, explains the changes the Earth's surface has undergone as a result of the processes that we see every day. The sun's heat, the wind, raindrops, dew, frost, the snow crystals, even the plants and animals—all are geological agents whose action we are taught to understand. The Earth's surface, i.e., the landscapes that we often admire, were created by these agents and by others hidden beneath the surface which make themselves felt in such awesome events as the eruption of volcanoes and earthquakes.

The person unversed in geology is like a blind man. He cannot distinguish between various rocks. The different colours of rock tell him nothing. He cannot understand how gullies were formed. He sees layers of rock in some gully and wonders why they are strangely twisted in one place, while elsewhere they stand upright. This person may admire a picturesque cliff, an austere canyon or waterfall, but these sights evoke but superficial impressions. He can only appreciate nature's outward forms, but not the substance of the phenomena, he will see but not comprehend. Geology teaches us to understand nature and learn how it developed.

Moreover, it helps us to prospect for ores, coal, oil, salt and other useful deposits. Without a knowledge of geology we cannot engage in systematic prospecting, we shall simply wander around the country at random in the hope of stumbling on some mineral. Without geology we can estimate neither the quality nor the quantity of the minerals we find, nor be able to exploit their deposits. Thus, geology not only adds to our general knowledge and broadens our horizon, but it is of enormous practical value.

This science is not limited to prospecting for minerals and studying them, it embraces a far wider field. To erect buildings, lay roads, railways and airfields, bore tunnels, build dams for hydropower stations we must make a thorough study of the local ground, we must know its composition and structure. It is impossible to plan and build rationally, with a minimum expenditure of labour, materials and time without geological data.

Geology also studies ground waters, how to extract them to meet industrial and civilian needs, how to drain land, it examines mineral springs and how they reach the surface.

Hence, we are entitled to say that every person should be acquainted with its basic principles. And the purpose of this book is to impart him this knowledge. Geology, therefore, cannot be a collection of stories about interesting things, mysterious events, or instructive comparisons taken at random from the vast realm of science, it must be expounded systematically. The reader will become acquainted with the activity of nature's forces which he can personally observe in the neighbourhood of his town or village, in the highlands or on the plains, with the work of running, still and ground waters, with the activity of the wind and ice and with its results, visible both in the rock formations which make up the land forms and in the destruction and transformation of the latter.

When the reader has become acquainted with the work of these forces, which we call external, he will be told of other forces hidden in the bowels of the Earth which give vent to their energy in mountain-building, eruption of volcanoes and earthquakes. Then, he will be given a brief outline of the Earth's history, of the origin and development of life and he will be told about the catastrophic events that have taken place during this time. He will learn of the formation of useful minerals and the regularity of their occurrence, especially in the U.S.S.R. The concluding chapter deals with geological documents and the methods used in studying traces of past events which throw light on the Earth's history.

This book, naturally, cannot embrace the entire realm of geology; it is confined to *physical* or *dynamic geology*, a branch dealing with the activity of the external and internal forces which shape and change the Earth's crust. Very little is said of *historical geology*, which covers a wide field of the history of the Earth, and only scanty attention is paid to the *science of useful deposits*—the third branch of geology which examines the results of the activity of the natural forces.

Of the fourth branch—*petrography* or *petrology*—the science of rock formations that make up the earth's crust, we give only the essentials. *Physical geology* is an introduction to these more specialized branches of geology and the book serves this purpose.

It is a popular book, designed for young readers who are acquainted with the rudiments of physics and chemistry.

I

WHAT THE BROOK MURMURS

How Water Erodes and Carries Away Soil. Bank Erosion. Log Jams. Gully Formation. Rock Transportation. Regions of Erosion and Deposition. Meanders. Deltas. Shoals and Islands. River Terraces. Base Level. Rapids. Waterfalls. High Water. Torrents (Sills). Alluvium and Proluvium.

What a downpour. Gusts of wind drive the raindrops against the window-panes, where they collect and stream downwards. The sky is murky and it is sloppy and unpleasant in the street. In such weather one prefers to remain indoors where it is warm and cosy and wait for it to clear up.

But let us overcome our reluctance to leave home and put on our high boots, or at least overshoes, don raincoats, or take an umbrella, and set out, preferably for the open country. For when it rains we can see how flowing water changes the surface of the Earth. The heavier the rain, the more effective its geological action.

Erosion. The action of water on the earth's surface can be observed everywhere. Even in town, where the soil is hidden under asphalt or stone, we see that the rain water in the gutter is muddy, discoloured by the sand, dust and rubbish washed from the streets. It is more clearly visible in the country, in the fields and woods, where a heavy rain fills every hollow, every rut with muddy water which erodes the soil and carries away its particles. The kind of soil being washed away can be determined by the colour of the water; if the hollow or rut is cut in black earth the water will be grey, in clay or sandy soil—brown or yellow.

The more rapid the flow, the more silt it carries away, for its carrying capacity, i.e., its ability to pick up and bear away particles, and its erosive capacity—its ability to loosen the soil from the banks—increases.

Let us follow the course of rain water on soft soil, say, on black earth, sand or loam. Where the ground slopes gently, the water trickles slowly in a shallow rut. But now the slope is steeper, the rain burrow gathers speed, becomes noisier and cuts deeper. The sides of the rut are vertical and if we linger a while and look closely, we shall see clods of earth falling here and there, saturate quickly and float away bit by bit. Here tiny waterfalls are formed.

In this manner we have witnessed in miniature the action of running water—the *erosion* and *transportation* of fine matter.

Rain water trickles from ruts and hollows into rivulets, the rivulets join streams which, in turn, flow into rivers. Their waters become muddy after rainy weather. Finally the rivers flow into lakes or seas whose "stagnant" waters receive all the matter, all the debris.

And how, you may ask, do streams and rivers behave in good weather? Their waters seem to be pure and may be safely drunk. If you hold up a glass of water to the light it is quite transparent. But actually this is not so. Pure water is found only in streams and rills which have earthen banks overgrown with vegetation and which slowly flow through meadow land. But not even this water is absolutely pure, for it still contains salts extracted from the soil. An analysis of the water would reveal some milligrams of salts per litre, though it may be quite tasteless.

A muddy river is immediately noticeable. One cannot see deeper than one metre. This shows that the water is not transparent, though in a glass it may seem so. Some rivers are very muddy. The Kura in Transcaucasia, for instance, is dark grey, the Amu-Darya in Central Asia has a coffee-and-milk colour, and the Hwang Ho in China is brownish-yellow (*hwang* in Chinese means yellow). These rivers carry dissolved salts, sand and clay particles similar to those found in the rivulets formed by rain water.

River banks unprotected by vegetation succumb easily to erosion. Matted grass roots afford good protection. The banks with little or no vegetation erode quickly, especially in the spring, summer or autumn when the river is in spate and its rate of flow increases.

Banks formed of loose rock: sand, loam, clay and shale, whose particles are not cemented, likewise crumble rapidly. The water cuts grooves into the bank or precipice and with the passage of time whole blocks of the top layers slide or creep into the water, become water-logged, are eroded and borne away (Fig. 1).

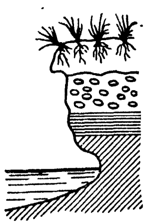

Fig. 1. River bank eroded by current

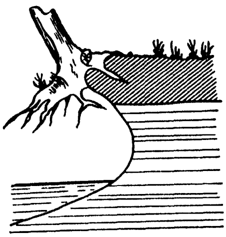

Fig. 2. Eroded bank with tree stump and roots

I once spent a night on the banks of the Amu-Darya and saw how rapidly its soft banks were eroded. In the stillness of the night I heard splashes as lumps of eroded rock fell into the water. Its banks are of loose silt, sand and clay, its current is swift and its water, due to the rapid erosion, is very muddy.

The roots of bushes, trees and grasses growing on soft and easily eroded banks bind the topsoil, forming a layer which temporarily resists erosion; eventually, however, it gives way and collapses (Fig. 2). The turf is eroded and the bushes and trees are borne downstream. When rivers are in flood, particularly if they run through wooded country, they carry away uprooted bushes and trees. This vegetation strands on shoals and river turns, especially when the flood water subsides. The small Ural and Siberian rivers often have *log jams* heaped up in confusion at turns and narrow stretches, making navigation impossible. And much time and labour has to be spent in sawing and cutting them away (Fig. 3). Every year the large rivers flowing into the Arctic Ocean—the Severnaya Dvina, Pechora, Ob, Yenisei, Lena and others carry down to sea vast quantities of drift-wood. In rough weather these trees, stripped of their bark and branches during their long journey, are thrown ashore and left high and dry, covering vast stretches of the coast, providing the population of the woodless tundra with fuel and building material.

River banks formed of hard rock: sandstone, shale, limestone and granite, offer greater resistance to erosion, slowing down but not entirely stopping the water's action. Little by little, in

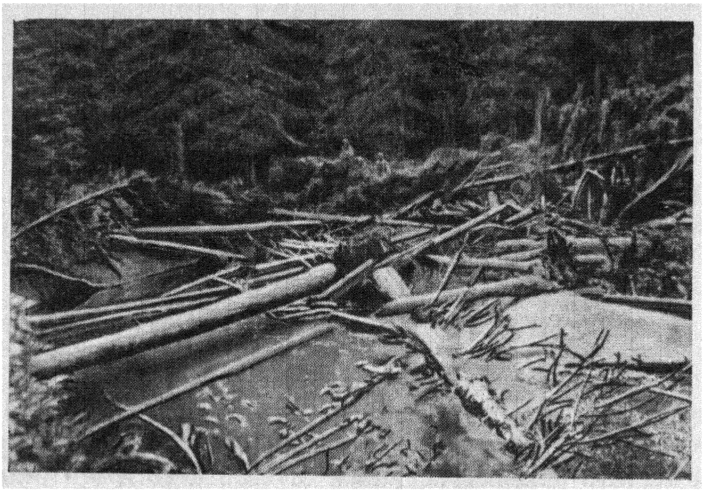

Fig. 3. Log jam on the Poldnevny Tagul River, Salair Ridge, Western Siberia

the course of hundreds of thousands of years, however, they are eroded. In uplands, usually formed of hard rock, we see valleys of varying depth cut by rivers and streams. In places where the rock is exceptionally hard, the valleys become canyons with very steep, sheer or even overhanging cliffs (Figs. 4, 5, 6). Such, for example, are the Daryal Canyon of the Terek River, the Kassarskoye Canyon, and the one in the lower reaches of the Ardon in the Caucasus. The Grand Canyon of the Colorado River in the United States is known for its enormous length and depth. Its steep and at times sheer slopes provide us with an interesting example of alternating beds of hard and soft rock which lie horizontally. Hard beds or series offer better resistance to erosion and evolve sheer banks. Loose or soft beds, being more easily eroded, crumble and form slopes. This is why in river valleys or canyons with such alternations we see tiers of sheer banks of varying height—walls of hard rock and, sandwiched between them, slopes, often overgrown with grass, shrubs and even trees, and corresponding to beds of soft rock (Fig. 7).

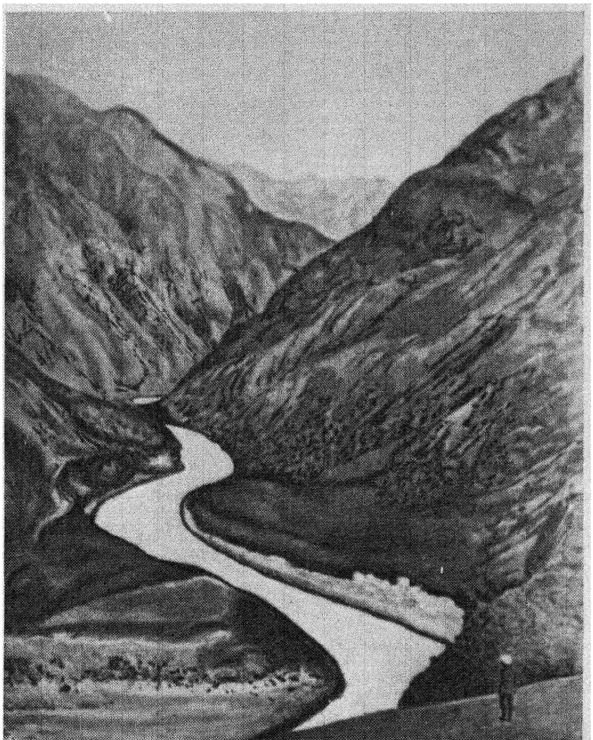

Fig. 4. Canyon of the Saryjaz River, Tien-Shan

Gullies. People living in the European part of the Soviet Union are well acquainted with gullies—deep, long and multi-forked hollows cut into soft rock by the action of running water. In some gullies there is a constant flow of water, while others dry up in good weather and in bad collect the rain water from the brooks and streams in the vicinity.

Gullies, which exemplify the erosive action of water, cause much damage to agriculture. Their heads and branches—lateral

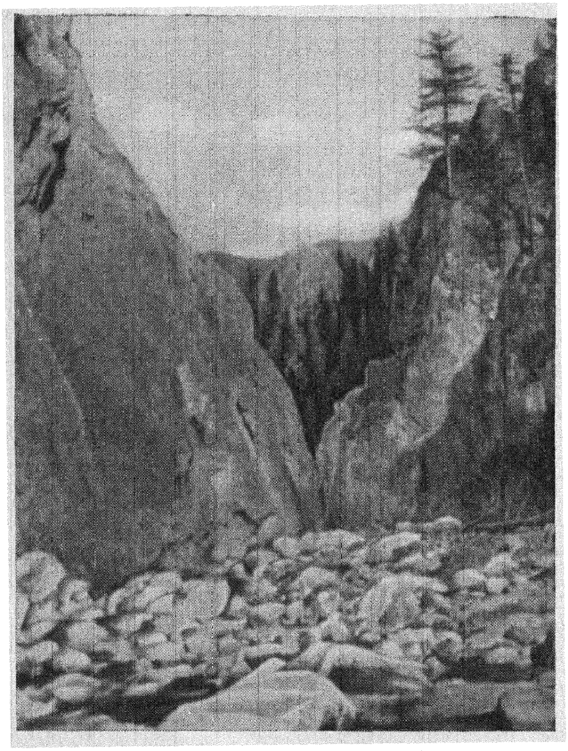

Fig. 5. Epigenetic canyon (cut in glacial valley bottom) in Eastern Sayan

gullies—cut into fields, meadows, orchards and villages. The ruts and hollows, which collect the rain and snow water, find outlets in the gully which, as time goes by, gradually cuts deeper into the soft soil, forming new branches which slowly eat into field and meadow and obstruct the cultivation of neighbouring land.

Besides spoiling land, the gullies quickly drain the rain water from the fields, preventing it from being retained by the soil with benefit to the plant roots; they also destroy the underground water beds and drain the surrounding terrain (Figs. 8 and 9).

Their spread, then, must be combated. Places where the hollows deepen and turn into ruts, the most dangerous, need protec-

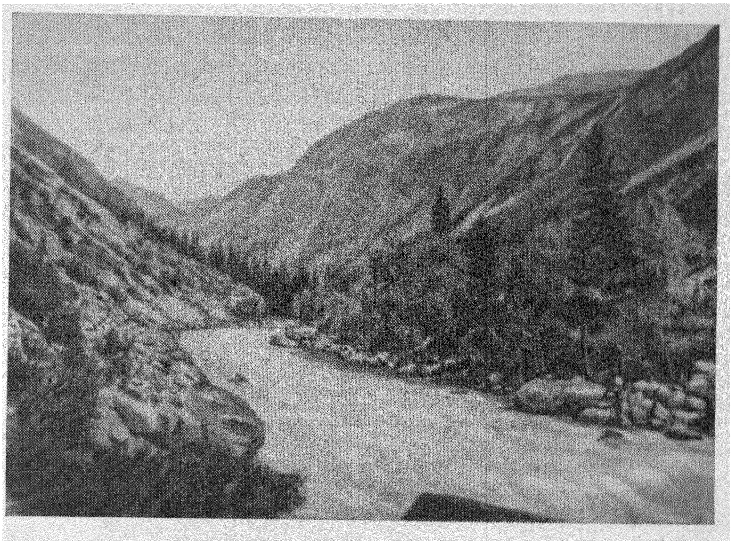

Fig. 6. Uzun-Bom Canyon of the Argut River, Altai

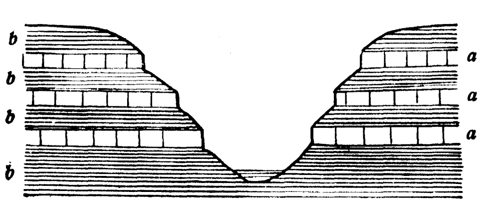

Fig. 7. Section of a river valley
a. Beds of hard rock. *b.* Beds of soft rock

tion. The rain water flowing in the hollows forms tiny waterfalls which rapidly erode the soil and retreat upstream, illustrating graphically how the gully forks out, how its branches widen and deepen at the expense of the land. The gully's bare slopes, from which the rain washes away the soft soil, progressively exposing them, must be banked with turf or planted with bushes and trees.

With relatively little labour and materials, most gullies can in time be turned into groves, which render them harmless and create future sources of timber.

Rock Transportation. We have become acquainted with the erosive action of running water. Now let us see what happens to

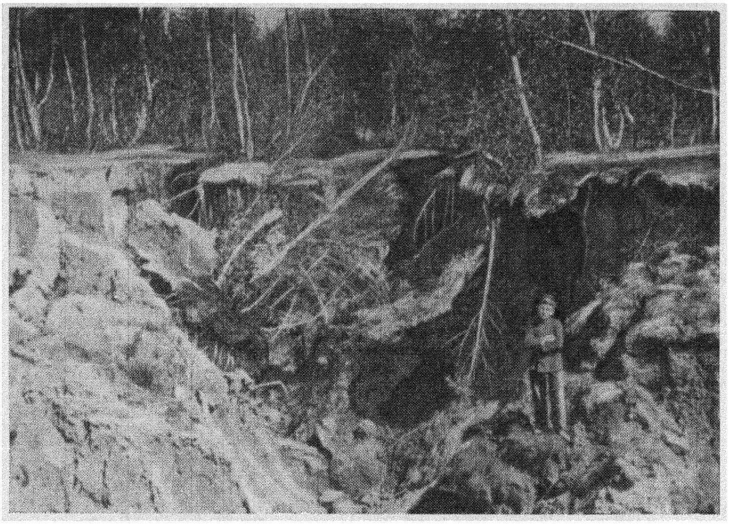

Fig. 8. Upper head of a rapidly expanding gully on the bank of the Tom River, above Tomsk

the material it erodes. The particles of sand and clay which float with the rain water into streams and rivers, together with those eroded by the rivers from their own banks, are carried some distance downstream, depending on their weight. The larger, or heavier particles settle fairly quickly, while the smaller, lighter ones continue on their way. Relatively little of the material, picked up with the spring melt waters or during floods when the river rises and flows quicker, is carried directly to the sea or lake into which the river drains. At this time the river is always muddier than in the dry season. Such muddy and fast-flowing rivers as the Kura, Terek, Amu-Darya and the Kuban swiftly transport their deposits to the sea. The Hwang Ho in China empties enormous quantities of silt into the

Pacific, making it dirty for a considerable area; no wonder this part of the ocean is called the Yellow Sea. The amount of silt annually brought down to sea by some rivers is enormous. It is calculated by taking the quantity of silt in a given volume of water at various times and multiplying the result by the annual

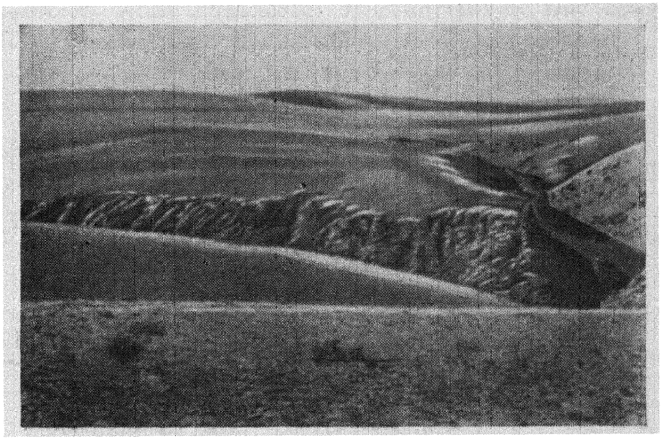

Fig. 9. Two gully tops on the Ust-Urt Plateau, Kazakhstan

volume of water emptied by the river into the sea or lake. Here are figures for the following rivers (in cubic metres):

The Rhine deposits in Lake Constance	8,172,000
The Rioni deposits in the Black Sea	8,000,000
The Ganges deposits in the Indian Ocean	177,000,000
The Amu-Darya deposits in the Aral Sea	44,854,000

The Hwang Ho, when in spate, daily empties into the Yellow Sea 29,160,000 cubic metres of silt and in dry weather 72,576 cubic metres, i.e., four hundred times less. This exemplifies the enormous difference in its action between high and low water. Scientists have not yet estimated the mean number of days the Hwang Ho is in spate, but if we put it at but 30 days and take 335 for low water, we find that it deposits in the Pacific over 900 million cubic metres of silt a year. This would suffice to raise a mountain 900 metres high over an area of about one square kilometre—quite an impressive bit of work for a year! Even such relatively silt-free rivers as the Rioni and Rhine deposit in the

Black Sea and Lake Constance respectively sufficient silt to raise hillocks eight metres high over an area of one square kilometre. This gives us a pretty good idea of the amount of sediment deposited every year in the seas, oceans and lakes by all the rivers in the world. And how much sediment settles at the bottom of the

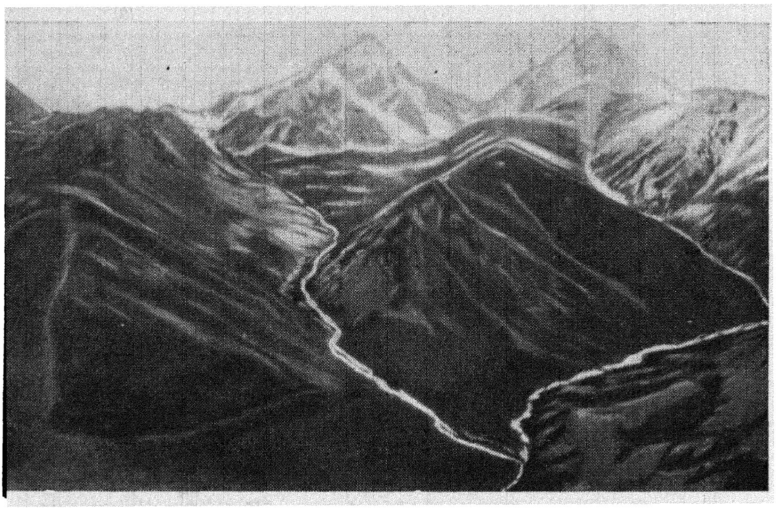

Fig. 10. Upper reaches of the Ui-Tas River, Jungarian Alatau, Kazakhstan

rivers, continually raising them, and how much remains on the floodlands!

Regions of Erosion and Deposition. Now let us study the action of a river from source to mouth in order to understand how flowing water erodes and transports soil.

A river basin is made up of its main stream and tributaries and it is not always easy to determine the branch which merits its geographical name—for instance, the Volga, Dnieper or Don. A branch can originate as a spring rising at the head of a gully, or as a brook, draining a marsh or lake, flowing merrily through a wooded or steppe valley. A number of brooks merge into a stream, while the streams in turn meet and form a river. These brooks, streams and rivers either erode soil and rock or deposit them, depending mainly on their bed gradients which determine their velocity. The quicker the rate of flow, the greater their erosive action and the faster and deeper their beds cut into the valley floor. As a rule the gradient is more pronounced in the river's upper reaches, and it is here that erosion takes place. At first glance this erosive action is barely noticeable, the stream seems to be clear, turning muddy only after rain or when the snow melts, when the water trickling from the surrounding locality brings silt into the stream.

Even in uplands the water in the upper reaches of a river flowing swiftly through a valley of hard rock, along beds of sand, pebbles and boulders, forming in places cascades and

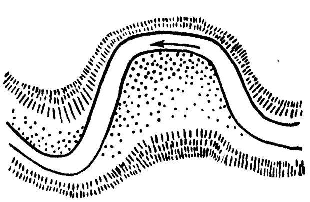

Fig. 11. Formation of a river bend (meander)

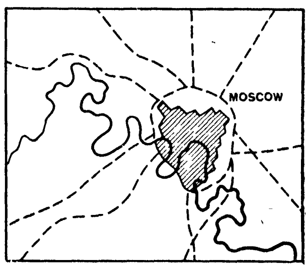

Fig. 12. Meanders of the Moskva River

waterfalls, gives the impression of being clean in dry weather. And yet such rivers erode their beds deeper and deeper, but very slowly (Fig. 10). This action is plainly seen during rain or when the snow melts, when, here and there, the swollen stream erodes its banks, carrying and rolling pebbles and even boulders downstream.

Lower down, where the brooks and streams merge into a broad river, the gradient levels out, the flow is slower and, consequently, cuts less into the bed. This is where the region of lateral erosion begins. The river starts to wind, first eroding one bank and then the other. Its gentle bends gradually become sharper, for the current is always stronger at the concave bank, where the water is deeper, while the sediments are accumulated at the convex bank, where the water is less deep and the flow slower. The eroded bank gradually retreats, and the bends become more and more pronounced, until loops are formed (Figs. 11 and 13). These loops are known as *meanders* from their prevalence in the Meander River in Greece.

Eroding each bank in turn and forcing the high bank to retreat, the river gradually widens its valley, hence the region of lateral erosion can also be called the region of valley widening. Many small and medium-sized rivers which flow through flat country have well-pronounced meanders. The meanders of the Moskva River, within the boundary of Moscow, serve as an excellent example (Fig. 12).

Pronounced meanders often originate small lakes and creeks which become isolated from the river. When a river is in spate,

Fig. 13. Meanders and oxbows of the Argun River, Transbaikal Area

it can erode a new bed directly through the neck of a loop, especially if the neck is narrow, and may retain its newly-cut bed after the floods have subsided. The entrance to the loop gradually silts up, and it becomes a long lake, still linked to the river through its outlet (Fig. 14). But the river willingly deposits sediment in the placid waters of the lake, with the result that the outlet slowly silts up either at the point of exit or at some distance away. In the latter case, a creek is formed in which vessels can winter. But the creeks are also short-lived because of the deposition of sediments in the quiet water. Loops of this kind are known as *oxbows*. They shallow, weeds and rushes take root in them, they turn into marshes and, finally, disappear.

It would be wrong to think that river valleys deepen only in the region of erosion and widen only in the region of lateral erosion. In both instances the river, in addition to erosion, also deposits sediments—wherever the current slows down, it deposits silt, sand and pebbles.

Even in the beds of swift mountain streams not always do we find exposures of the hard rock through which the valley is cut, and in many places we see sand, pebbles and boulders. But in the region of erosion these sediments are deposited temporarily; when the river rises again, they will be borne downstream fully or partly. Fine particles are picked up and carried downstream even during low water. In the region of valley widening they are deposited at the convex banks, at the bends, where they lie

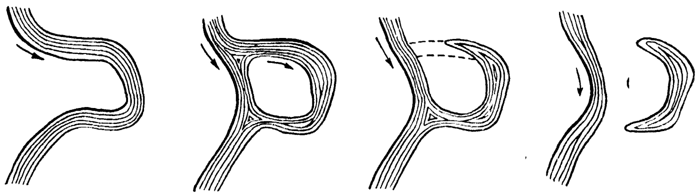

Fig. 14. Transformation of a meander into an oxbow

indefinitely. In this region, in addition to lateral erosion, sediment is deposited, and the entire length of the valley bottom can also consist of layers of this sediment of varying thickness.

But the region of deposition proper is found in the lower reaches of the river, where the gradient is still less and the current slow and where, normally, it is impossible for the water to erode its banks. Here the lighter, finer sediment from the upper and middle reaches is deposited, while most of the coarser, heavier sediment—gravel and pebbles—remains in the middle reaches. The entire river bed and its banks are composed of this fine sediment—silt and sand, sometimes only with interlayers of gravel and pebbles. Even when the river rises and overflows its banks it deposits sediment and rarely erodes it.

Deltas. But many rivers, even in their lower reaches, may not have time to deposit all the sediment they carry. We have already cited figures showing the vast quantities of silt deposited by some rivers in lakes and seas. A considerable part of this settles at the mouth of the river, in "stagnant" water, where it gradually forms a delta. Deltas are usually triangular in shape with their apex pointed upstream. The name is derived from the resemblance to the Greek letter Δ . Consisting of sand, silt and even pebbles (for some mountain rivers are so powerful that they carry coarse material to their lower reaches), the deltas gradually grow and rise out of the water as stretches of low, and often boggy, land (for instance that of the Rioni River). In the area of the delta the river branches out, and splits up into

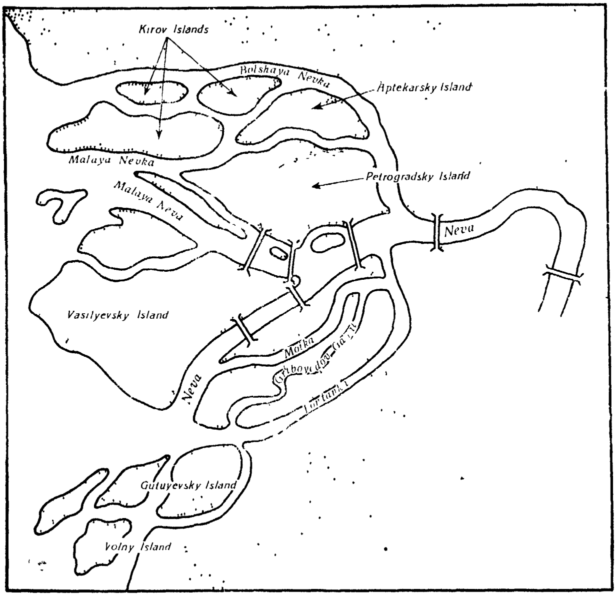

Fig. 15. Delta of the Neva River

a large number of arms, often winding, which change their direction at high water, when the delta is flooded, and small lakes are formed. With the settling of the sediment the delta gradually rises and becomes overgrown with grass, shrubs or even with trees. Many great rivers have very large deltas, for instance the Volga, whose delta has hundreds of branches and arms, the Neva, on the delta of which Leningrad is built (Fig. 15), the Lena, Nile and Mississippi. Deltas also gradually spread out under the water, making the sea shallow in their vicinity.

Shoals and Islands. In the middle, and especially in the lower reaches of many rivers, one often sees islands formed mainly of sediments, and, in rare cases, of stone. The stone islands are rock outcrops, especially of hard rock, preserved from the time the river cut its bed. The Katun River in the Altai, for instance, has in its middle reaches a number of stone islands in the vicinity of rapids. Some of them jut above water level with their rugged edges, while others rise higher and are covered with vegetation. More often they are composed only of sand or sand and pebbles and are built up usually from shoals formed at places where the

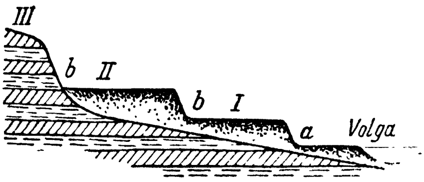

Fig. 16. Terraces on the Volga
a. Floodlands with crest and oxbows
I The first terrace. *II.* The second terrace.
III. The bedrock bank. *b.* Marshy land

current is slow. The shoals grow, rise above the river's mean level, and become covered with vegetation; at high water they are often submerged, a factor which stimulates their growth as their vegetation slows down the current. Many islands originate from drift-wood, from an uprooted tree carried downstream at high water which had been caught and stranded, roots and all, on a shoal, causing the current to slow down and deposit sediments. Some islands are hundreds and thousands of metres long. They divide the river into two or more arms which gradually silt up and become unnavigable.

River Terraces. One can see ledges, called terraces, on the slopes of many river valleys. They may be of hard rock or of pebbles, sand or silt. The ledge nearest to the river bed may rise as a low precipice or slope with grass, bushes and groves growing on its level surface. This terrace is called the flood-plain bench; at high water it is partly or wholly submerged by the swollen river. Above the first flood-plain bench a second bench, which is never flooded, may also rise as a precipice or slope and on its surface fields are cultivated and towns and villages flourish. Frequently one, two, three and more benches varying in height rise above the second one (Fig. 16).

How comes it that these terraces fringe the river valley like the steps of a giant's staircase? They are creations of the river itself, brought into being by the processes of erosion and deposition. A study of these processes will clarify the history of the valley. Each terrace is tangible testimony to the drastic changes

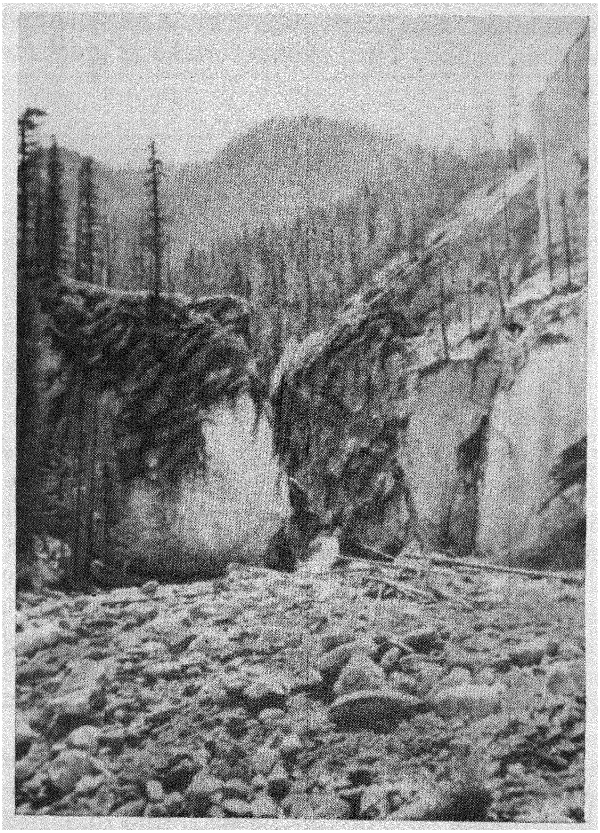

Fig. 17. Erosion terrace in canyon, Eastern Sayan

that have taken place in the process of evolution. If the terrace is of hard rock it tells us that with the passage of time, during which the river here only widened its valley by lateral erosion, some force or other made it cut deeper into the hard rock of the valley floor. This type of terrace is called an erosion terrace (Fig. 17).

If the terrace is of sedimentary rock—layers of sand, silt or pebbles—it indicates that over a more or less prolonged period, of which we can judge by the height of the terrace, the river in this section instead of eroding sediment deposited it in its bed, after which it cut again into its own deposits and eroded them (Fig. 18).

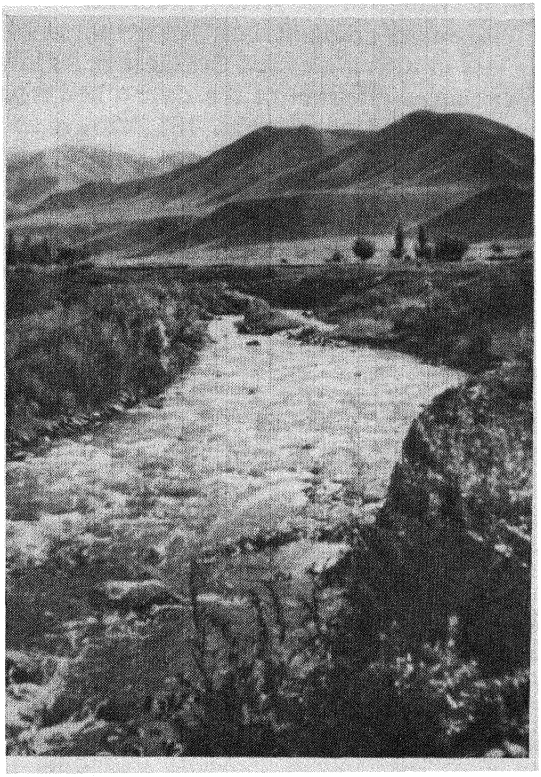

Fig. 18. Terrace in the upper reaches of the Aravan

But what force could have made the river change its action so drastically? At first people thought that because of a change in climate, which had become more humid, richer in precipitation, the river, which until then had been shallow and "puny," received an abundant supply of water and again began to cut into its previous deposits. In some cases this supposition is true. A study of the Quaternary period of the Earth's history, which dates from the appearance of man and continues to this day, shows that periods of dry climate have been succeeded by periods of more humid climate. We shall return to this later on. But in most cases there was another and more important reason for the river changing its action—its increased rate of flow—on which its action chiefly depends. And the reason for this should be sought in the change of the river's gradient.

A river's maximum gradient lies, as we know, in its upper reaches, it is less in its middle, and the least in its lower reaches. Generally speaking, a diagram of the river's bed from source to mouth shows a gradual curve (Fig. 19), known as the graded profile or profile of equilibrium. The level of the lake or sea into which the river flows is known as *base level*, as all the action of the river takes place above this level. Now let us suppose that this base level has subsided because of the lake drying up or shrinking or because of the sea retreating. The subsidence of the base level immediately affects the river's action; the gradual curve breaks, as it were, in the lower reaches and the river, which previously had not eroded but deposited matter in this area, begins to erode and cut into its own deposits. The erosion gradually extends upstream, since the river always works out its new profile backwards. The process may take hundreds and even thousands of years. Cutting its bed in the previous deposits, it leaves part of them on both banks in the shape of benches—terraces—the height of which gradually decreases up the valley. Their height in the river's lower reaches depends on the depth to which its base level has subsided (Fig. 19).

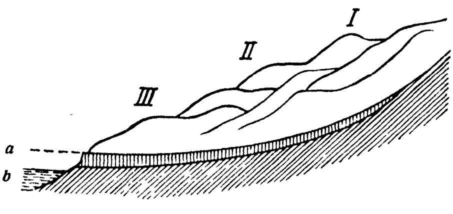

Fig. 19. Base level of a river bed
I. Catchment area. *II*. Region of lateral erosion. *III*. Region of deposition; *a*—the former and *b*—new base levels: terrace is vertically shaded

This same process—the subsidence of the base level, causing the river to cut into its deposits, or even into the bedrock of its ancient bed—may be repeated over and over again, resulting in the valley being fringed by a number of terraces of varying height.

But the same result—an increase in the gradient accompanied by fresh erosion and evolution of a new profile of equilibrium by the river—can be achieved not by the subsidence of the base level but by the elevation of the entire locality. And, if in this case the base level remains stationary, the country protrudes upwards, as it were, more in the river's upper reaches and less in its lower, then the new erosion cycle begins not at its mouth, but at its upper reaches, where the gradient has changed, and

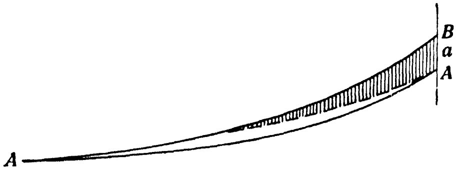

Fig. 20. Change in base level caused by uplift of the land by height *a* at river head

AA—the former base level. *BA*—the new base level; terrace is vertically shaded

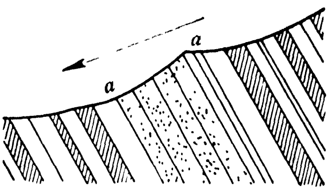

Fig. 21. Formation of a rapid when the river cuts into hard rock *aa*

the gradually evolved new terrace moves downstream. A study of the height and position of the terraces will provide the clue as to their origin, to either the subsidence of the base level or the elevation of the country (Fig. 20).

Rapids. One often sees stretches of mountain rivers, even in their middle and lower reaches, where their waters become turbulent; boulders, covered only at high water, appear in the river bed; sometimes single rocks and whole ridges of rocks are washed and ground by the water. These stretches are called rapids and they obstruct navigation. Only experienced pilots, well acquainted with the rapids at low and high water, can navigate them. Some rapids are navigable when the river is in spate, others take a toll of life and wreck rafts every year, while a third category are impossible to shoot at all. Rapids usually occur at places where the valley bottom is especially hard, offering more resistance to erosion than the stretches above and below. There are many rapids on the large Siberian rivers: the Yenisei, Angara, Podkamennaya and Nizhnaya Tunguska, Vitim, Vilyui, Biya and Katun. The famous Padun and Shaman rapids protrude from the middle reaches of the Angara.

At the rapids the water flows faster, becomes agitated (forming whirlpools), foams, skirts the rocks or tumbles over them, and boils spraying in all directions. Upon shooting the rapids the river calms down. Its swift rate of flow shows that the bed has suddenly steepened because a stretch of exceptionally hard rock has violated, broken its profile of equilibrium (Fig. 21). Above

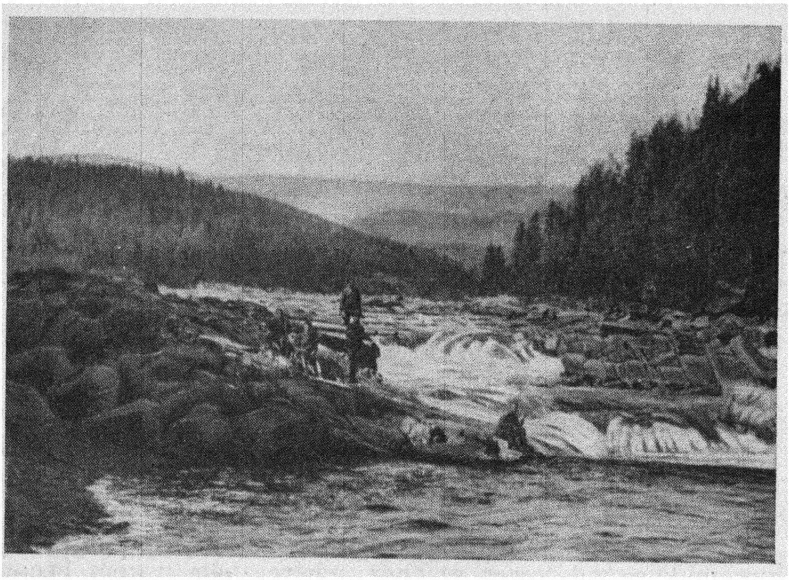

Fig. 22. Rapids on the Biryusa River, Eastern Sayan

and below the rapids the river is either in its region of lateral erosion or even in its region of deposition, but here it lags behind in its development because of the hardness of the rocks, and is still cutting into its bed (Fig. 22).

Rapids are rarely met with on rivers flowing through flat country. The rapids on the Dnieper, near the former village of Kichkas, caused by an outcrop of granite, were dangerous for navigation. Now they have disappeared. The huge dam of the Dnieper Hydropower Station (Dnieproges), which considerably raised the water level, has submerged the rocks; some still remain lower down, but they are by-passed by a canal.

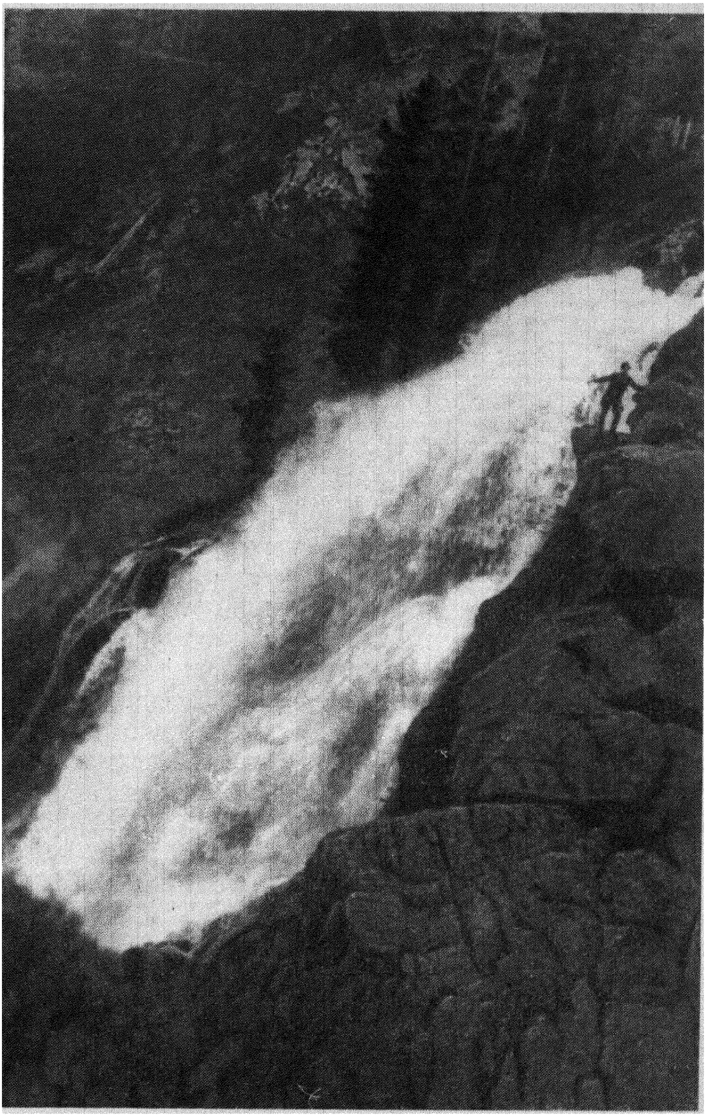

Fig. 23. Kok-Kul Waterfall, Altai

Some rapids can be rendered harmless by blasting.

Waterfalls. Still more beautiful and majestic are the waterfalls on streams and rivers. These, too, are caused by outcrops of hard rock in the form of ledges or shelves in the river bed from which the river drops from varying heights. Waterfalls are numerous on mountain streams and rivulets, for instance those in the Caucasus, the Altai (Fig. 23) and in Switzerland. They are encountered less frequently on large rivers. The Niagara Falls in North America, and the Victoria Falls on the Zambezi in South Africa are well known. The Kivach Falls in Karelia have several ledges. The Imatra Falls in Finland are virtually steep rapids.

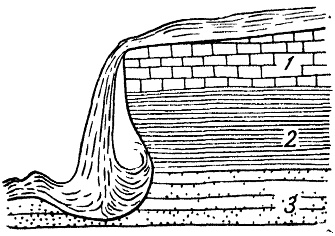

Fig. 24. Section of Niagara Falls

1 Hard limestone 2. Soft shale 3. Soft sandstone

The Niagara waters (Fig. 24) plunge from a height of 50 metres. Goat Island divides the falls into two sections: the Canadian, or Horseshoe Falls, with a frontage of 792 metres and the American Falls (frontage 427 metres). Lower down, the river has cut a narrow gorge ten kilometres long.

The erosive force of water falling from a height is very great, and this is why we often see deep pits and whirlpools in the falls' "plunge pool" floor which undermine the ledge from which the water drops, causing the overhanging rock to collapse, and forcing the waterfall to retreat slowly upstream. The Horseshoe Falls recedes 1.5 metres, and the American Falls, 0.9 metre every year. The ten-kilometre gorge was cut backwards in this manner.

Still more majestic are the Victoria Falls on the Zambezi, which have a frontage of 1,800 metres and a drop of 120 metres, while the Iguassu Falls on the border between Brazil and Argentina have a frontage of 1,500 metres and a drop of 65-70 metres. Below the falls the Zambezi flows through a deep canyon with two hairpin bends which it has eroded itself.

Rapids are sometimes found in canyons. For instance, the Daryal Canyon on the Terek River in the Caucasus is actually a cascade of rapids. The greatest canyon in the world, the Colorado Grand Canyon, which is over 320 kilometres long, 900-

1,800 metres deep and 60-90 metres wide, has a series of rapids along its course.

Under waterfalls below rapids and generally in places with a swift current, the water drills deep holes, known as *potholes,*

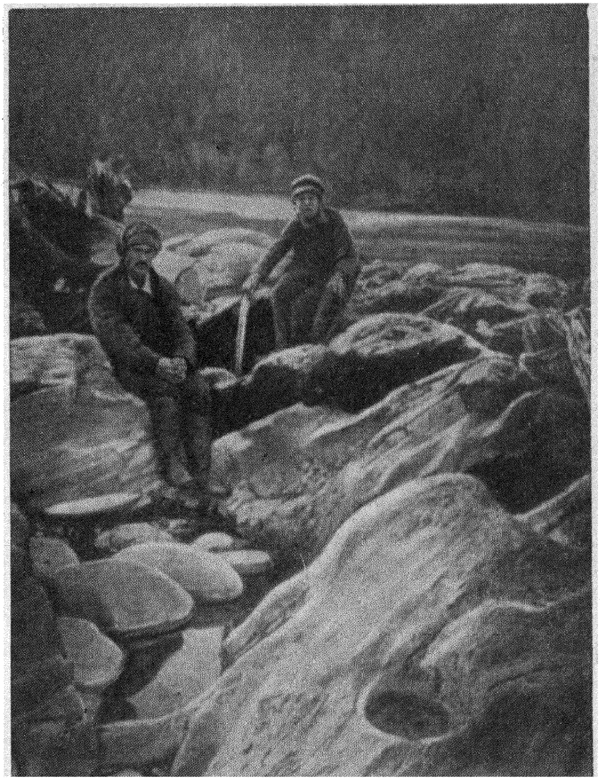

Fig. 25. Potholes in canyon of the Yenisei River, Western Sayan

in the river bed (Fig. 25). The water sets in rotary motion the boulders of hard rock lying on the bed. In the course of time the boulders make dents into the bed, these become deeper and deeper and eventually evolve into pot-shaped holes with cylindrical walls and concaved bottoms. The boulders, too, of course, wear away to some extent. The greater the difference between the hardness of the boulders and the bedrock the quicker the potholes are drilled. Sometimes we meet with whole series of potholes. When they are found above high-water mark we can assume that the river bed was deepened fairly recently.

High Water. So far we have examined the action of running water at mean level, although we have mentioned high water several times. Now we shall speak a little about the behaviour of rivers during high water, i.e., when they are in spate.

In our moderate zone, where the rivers rise in the spring, their high-water mark depends on how rapidly the snow melts. The melt waters fill hollows, ruts and gullies, transforming them into muddy rivulets, making them difficult to jump over and impossible to ford. The streams and rivers which take these waters become swollen, their ice breaks up and floats downstream, the rivers overflow their banks and submerge the flood-plains. If the spring is a cold one, the snow melts slowly and the rivers rise less, but they remain in spate longer. A warm and early spring immediately produces a large volume of water.

Spring waters are muddy and dirty; the streamlets drain the fields, erode their own banks and beds, and bring large quantities of silt and sand to the rivers. In their turn, the swollen streams and rivers erode more vigorously, the volume of water increases and they flood stretches of land normally out of their reach. Rivulets are transformed into wide and deep torrents. Their muddy waters carry uprooted bushes and trees and all kinds of debris washed away from gardens, fields and the streets of villages and towns. The larger the river, the higher it rises; in its lower reaches it rises 10, 15 and even 20 metres above mean level.

Rivers rise not only in spring but in summer or autumn, depending on the duration and force of the local rains. For instance, the spring waters drained by the entire basin of the Selenga River, which flows into Lake Baikal, and by the basin of the Amur River in the Far East, are insignificant as the snowfall there is negligible. But the heavy rainfall of late summer in these areas often causes highly devastating floods—coinciding with the hay-making or harvesting season and flooding the meadows; the unmowed grass is covered with silt and spoilt, the mowed grass is carried away; harvesting is delayed or the harvested grain becomes wet and sprouts.

In countries with mild winters—Western and Southern Europe, the South of the United States and the Caucasus—

where it rains, instead of snowing, rivers rise in the winter and sometimes in the autumn. In the tropics, where the winter is dry and clear and the summer is the rainy season, the reverse is the case.

Whenever rivers rise their erosive and depository action is greatly increased.

Fig. 26. Fine sediment washed down by torrent, Stillwater Mountain, Nevada, U.S.A.

As previously pointed out, when the Hwang Ho River is in flood it carries four hundred times more sediment than at low water. The Ganges, for instance, empties into the Indian Ocean the following quantities of sediment (in cubic metres):

During 122 rainy days	170,000,000
During five winter months	6,000,000
During three dry months	1,000,000

Thus the river carries twenty-four times more sediment during the four months of the rainy season than it does during the remaining eight months of the year.

In countries with a more even climate the volume of river water at high level is two or three times that at mean level, and in countries with wet winters, with abundant snow and rainfall, from five to twenty times and over. The volume of water of the Moskva River, for instance, when in spate, is thirty and even a hundred times greater than that at low water; this was the case during the severe flood in 1880.

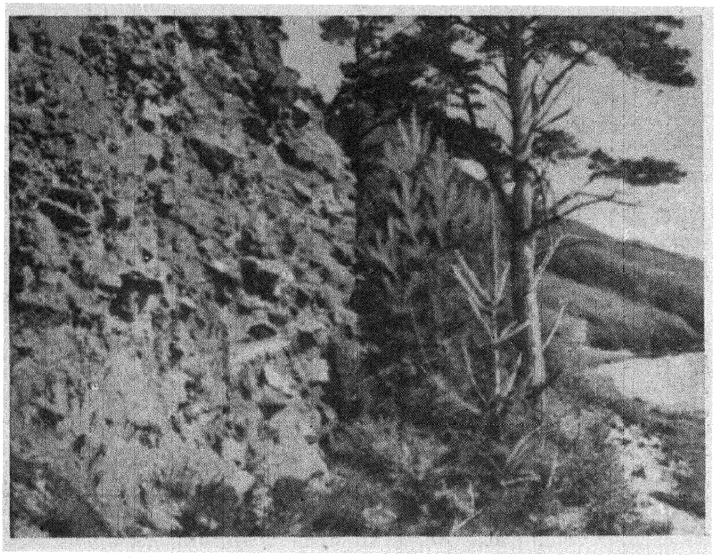

Fig. 27. Proluvium outcrop on shore of Lake Baikal, above a fault precipice of Primorye Ridge, between the Sarma and Khurma rivers

Torrents. Besides the silt, sand, pebbles and shingle which rivers regularly deposit on their valley floors, terraces and flood-plains, similar deposits are also left by torrents. Torrents are typical for deserts and countries with very dry climates, where it seldom rains, but when it does it is sudden. But they also happen very rarely in countries with temperate climates, with evenly distributed atmospheric precipitation. Unlike the fine rains, these torrents quickly run off without being absorbed by the soil. They cause enormous damage and bring heavy losses.

Torrential rains are particularly harmful in the uplands where the deluge of water pours down the slopes of gorges and valleys, bearing away soil, shingle and boulders and depositing them in the plains and valleys. There the waters quickly subside and lose their force, leaving thick layers of sediments on roads, gardens, fields and village streets. Hundreds of tons of this debris have to be carted away, buildings and roads repaired, etc.

In Europe these torrents are known as muris, in Central Asia—sills and their deposits, sill deposits. They sometimes fall

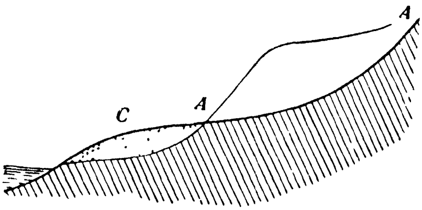

Fig. 28. Alluvial fan *C* transported from lateral valley *AA* into the main valley

in the mountains of Yugoslavia, in the Soviet Union (the Crimea, the Caucasus, Armenia, Turkmenia and Kazakhstan); they are frequent in deserts, where the rainfall is negligible, but as they are particularly violent they bring down to the plains vast quantities of deposits.

Sill deposits differ from those of the rivers in their extremely chaotic mixture: huge rocks, gravel, sand and silt, all are mixed up in confusion, regardless of size or weight. As a rule river deposits are stratified and graded: we see a layer of sand of a certain thickness sandwiched between layers of silt or shingle—the latter being of a uniform size, and this stratification recurs over and over again in a bank or terrace. Only in the mountains, in the area of erosion, where the heavy rain quickly increases the volume of water, does stratification become chaotic, similar to sill deposits (Figs. 26 and 27).

Later we shall describe several instances of catastrophic torrents.

The deposits left by running water are known as alluvial deposits or *alluvium*, while sill deposits are called *proluvium;* the latter include the deposits of torrents which flow down from the mountains to the plains, leaving their rock-waste in the form of flat fans in the foothills. Similar fans, only steeper ones, can be found at gully heads and valley outlets of mountain streams. In the latter case the stream, which on the steep slope swept along the coarse sediment, loses its energy because of the abrupt change in its gradient, and it hurriedly drops its boulders and pebbles in disorder. If the valley has been cut through loose and soft rock, the deposits are of sand, silt and rock fragments. Fans of this kind are called *alluvial fans*. Actually they are miniature deltas, differing from river deltas by their steeper angle of inclination and chaotic formation (Fig. 28).

II

AT THE SEA-SHORE

Surf Waves. Marine Erosion. Notches and Terraces. Gently Sloping and Steep Shores. Shore Swells. How Pebbles Migrate. Currents. Sedimentary Rock Formation. Stratification. Outcrops. Estuaries, Lagoons, Limans, Lakes.

We have become acquainted with the action of water in constant motion flowing down the earth's surface gradients as rivulets, streams and rivers, and with how they change the surface on their way. In some places the water erodes and destroys the layers of the earth's crust, elsewhere it deposits the products of its destructive work, the boulders, gravel, sand and silt, i.e., it forms new layers.

The volume of moving, *flowing* water on the earth's surface is not particularly great. A far greater volume is in a calm state, filling small and large depressions such as lakes, seas and oceans.

But this "stagnant" water, as it is called, also changes the earth's surface, for not everywhere and not always is it quiet and motionless.

In lakes, seas and oceans, considerable volumes of this "stagnant" water are continuously migrating, forming currents, and the wind, transmitting its force to the surface layers in all the basins of "stagnant" water, agitates them. In some places the pounding sea waves erode the shore, in others they deposit sediments and build up the shore.

Surf Waves. To observe the action of the surf waves one must go to the seashore or a large lake, for on ponds or small lakes even strong winds cause only small waves whose action is barely noticeable. First of all let us watch the wave motion. Upon approaching the shore the relatively smooth billows of the agitated sea undergo an abrupt change; their crests rise quickly, tilt forward and topple over. This happens because near the shore the sea is shallow, and the wave's surface water, driven forward by the wind, surges ahead of its deeper water, the motion of which is slowed down by the friction against the sea bottom. Moreover, the water of the preceding spent wave, receding along the slope of the sea bottom, undercuts the oncoming wave.

When the wave breaks it develops considerable force. This can be experienced by proffering one's back to a wave while bathing. A large wave can knock a bather off his feet and toss him about like a cork. This breaking of the waves near shore is known as *surf*. It has been estimated that surf waves can exert pressures from 3,000 to 30,000 kilograms per square metre. In stormy weather they can move and even toss rocks weighing hundreds of tons across piers and can drive small ships ashore. Surf spray dashing against cliffs rises to a height of 60 metres and over. The windows of a lighthouse in Scotland, 80 metres above sea level, are sometimes broken by stones cast up during stormy weather. Waves which do not topple over also exert enormous force when they pound against cliffs in deep water.

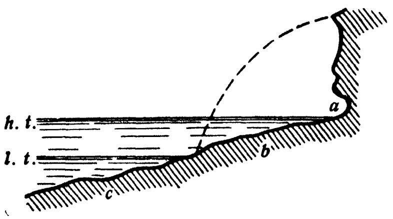

Fig. 29. Cliff erosion

a Surf notch; *b*. Surf terrace at high-tide level—*h. t.*; *c*. Surf terrace at low-tide level—*l. t.*

Marine Erosion. By continuously attacking the steep shore the surf waves gradually erode it. They wear away a horizontal groove in the rock at sea level called a *notch* (Fig. 29, *a*), the dimensions of which depend on the hardness of the rock (Figs. 30 and 31). This notch gradually deepens until with the passage of time the overhanging layers collapse and the steep shore recedes. The surf waves continue their action and eventually a smooth shelf is evolved at the base of the cliffs, slightly slanted towards the sea, called the wave-cut *terrace*, which slowly eats into the steep shore (Fig. 29, *b*).

At sea-shore tidal places, where the sea level changes four times a day—twice reaching maximum and twice minimum level, two wave-cut terraces, divided by a small precipice, are eroded during both tides—one more smooth, below the level at high tide, the second, below that at low tide (Fig. 29, c). This erosive action by the surf is always stronger during high tide.

The wave-cut terrace remains clean and packed by the surf waves only if the steep shore is of loose rock, which is pounded into fine particles and borne away. When the coast is entirely or

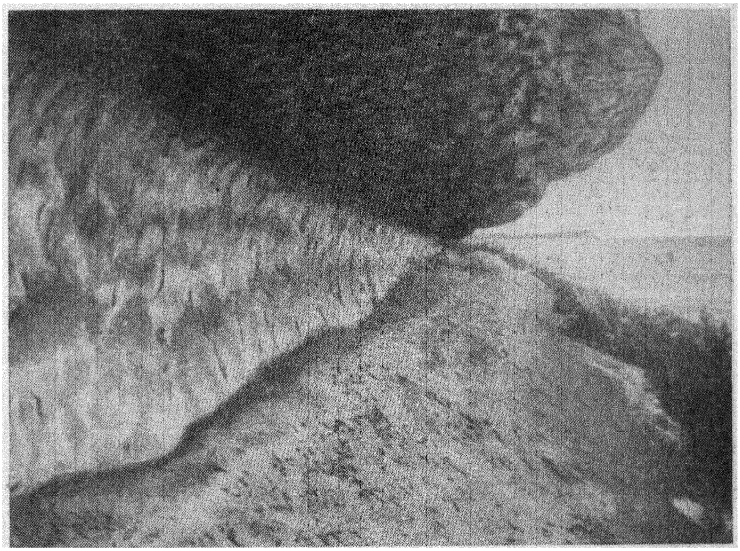

Fig. 30. Surf notch in horizontal beds on Nikolai Island, Aral Sea

partly of hard rock, the wave-cut terrace is strewn with the fragments resulting from the erosion and collapse of the shore. The waves roll these fragments about, they rub against one another, are gradually rounded and turn into the boulders and pebbles which usually fringe a more or less wide stretch at the foot of the cliffs, forming a beach.

Sometimes on wave-cut terraces one can see rocks of different size and shape called stacks—residual rock of the steep shore still being eroded and destroyed by the surf. These stacks are often weirdly shaped. They resemble pillars, towers, gates of different size, etc. (Fig. 32).

When the level of the sea or lake remains constant for some time, the gradually receding steep shore eventually finds itself out of reach of the waves. At first the shore is eroded by the waves of any storm, then, as it retreats, it is reached only by the waves of the more violent storms, until, finally, it is beyond the reach of any waves. Then its retreat, which had slowed down progressively, stops, and landslides gradually round out the shore and it becomes covered with vegetation. But the boulders and pebbles on the wave-cut terrace within reach of the waves

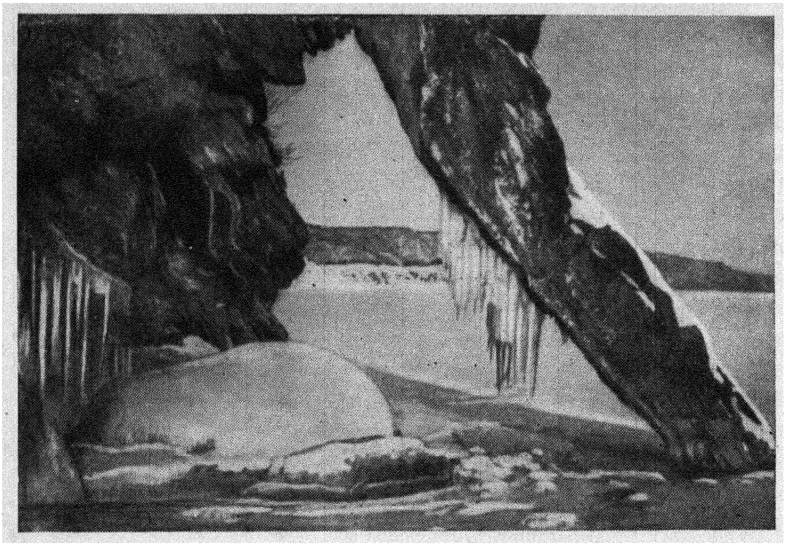

Fig. 31. Surf notch in sharply inclined beds, Khobot Cliff, Shaman Cape, Lake Baikal

continue to be rolled about, worn away, and pounded into fine particles. Boulder and pebble beaches are formed in this manner at the base of retreating steep shores, which one can observe on the Black Sea shore of the Crimea and the Caucasus and elsewhere.

But the sea level is not always stationary. Exact observations have established that in some places the mainland slowly rises, while it appears that the sea is retreating, that its level is subsiding. In other places it is the mainland that is subsiding, while it seems that the sea is advancing, its level rising. When the sea retreats, the steep shore gets out of reach of the surf action more quickly and becomes immobile, but when the sea advances ever more stretches of land are seized and gradually transformed into wave-cut terraces.

Hence, given prolonged subsidence of the mainland, extensive areas are created, which are smoothed by the advancing sea—areas of marine abrasion, i.e., scraped-off surfaces.

Gently Sloping Shores. Now let us visit a gently sloping shore and observe the action of the surf there. When the crest of a

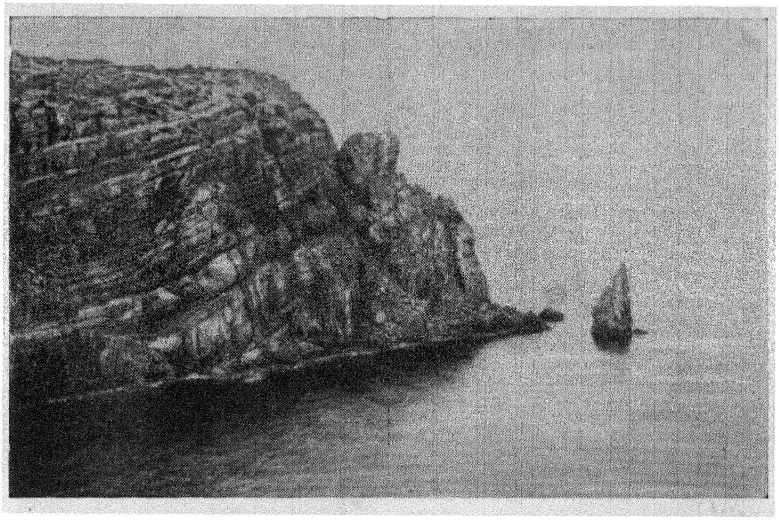

Fig. 32. Steep rocky coast practically without a beach. South Crimea

wave topples over, the mass of water surges up the gentle slope, bringing myriads of sand particles and pebbles, and in stormy weather even boulders, with it. The higher the water advances, the more it thins out, until, finally, at the water's edge, it completely soaks into the ground and does not recede like the rest of the water (Fig. 33). It is here at the upper edge of the ascending water, that the sand and pebbles are deposited, while below this edge the water returns the sediment back to sea. Thus, the shore is gradually built up in this manner, and in calm weather we can see a number of slight swells on it. The flat swell of sand and small pebbles nearest the water's edge was made by the last weak surf. The second swell, a little higher up, consisting mostly of larger pebbles, corresponds to the most recent storm, while the farthest and highest, an agglomeration of large stones, testifies to a severe storm which had raged perhaps six or twelve months earlier, when the waves swept inshore, stranding even boulders.

These swells, called *shore swells* (Fig. 34), run parallel to the shore. The ones nearest the water's edge have been recently

Fig. 33. High tide on flat coast of Ceylon

formed, they often change their position, depending on the force of the wind and surf. When the swell is completely beyond reach of the surf, we can say that the sea has retreated from its former shore line, and this can be explained only by the elevation of the mainland, for the total volume of sea water does not change so rapidly. It is another matter if we find old swells on the shores of a lake, where they show that the volume of water is diminishing, i.e., that the lake is drying up (Fig. 34).

With the elevation of the mainland we can see, in addition to shore swells far from the existing shore line, high above water level, dried-up wave-cut terraces and notches, water-worn cliffs and heaps of boulders at the foot of cliffs. Seen on the shores of a lake, this is evidence that it is drying up.

Sometimes, if the mainland rises sufficiently rapidly, we can also see overhanging valleys, i.e., rivulet valleys or gullies whose mouths are situated higher than shore level, due to the valley floor having been cut at a slower rate than the rise of the mainland, or the drying up of a lake. The water from these valleys falls from a height or streams over steep slopes to the beach

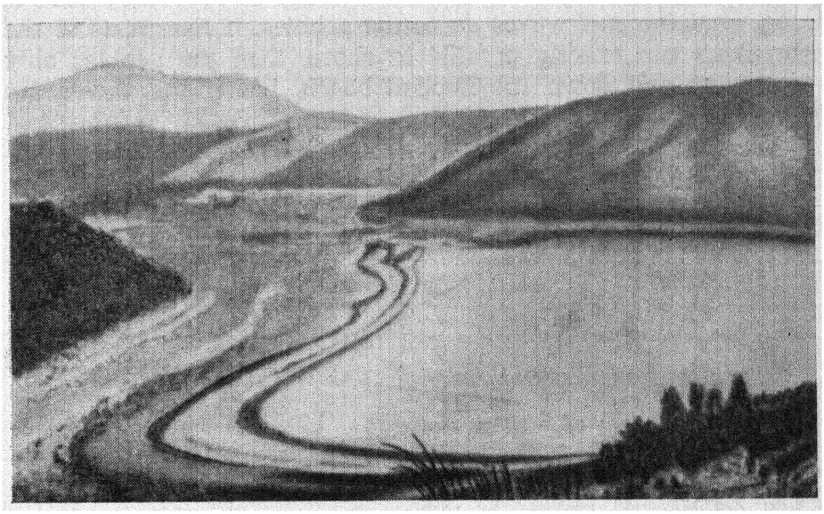

Fig. 34. Shore swells on Lake Thurston, California, which is drying up. The lake was dammed by volcanic lava

below. Overhanging valleys are found on the west coast of the island of Sakhalin, which has recently experienced a rapid uplift.

Pebbles and boulders are found on the shores of seas and lakes and on shore swells if the gently sloping shore becomes steep at no great distance. Wherever the steep shore is very distant the rock waste of the gently sloping shore is entirely sandy, or even silty and muddy. This is the case on the northern shores of the Caspian, on parts of the Crimean coast (Yevpatoria, Sivash), the shores of many lakes in the steppeland north of the Caspian, and in Siberia. These gently sloping shores, especially those near the estuaries of large rivers, are often overgrown with rushes, which weaken even powerful waves and facilitate the building up of the shores.

How Pebbles Migrate. If, however, the steep shore is located at no great distance, the rock-waste may form shore swells and beaches even several kilometres away from the rock outcrop, and we must understand how the rock-waste migrates, what force moves it. The surf waves seem to roll pebbles only up and down but not along the shore.

Actually this is not so, and it can easily be proved by observing what the surf waves do to the pebbles. If the crests of the breakers run exactly parallel to shore, then the pebbles only move up and down the flooded beach, but if the waves are

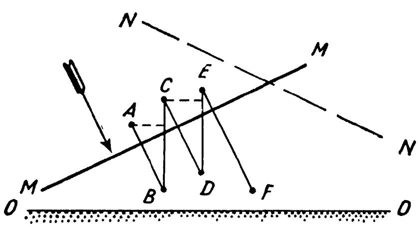

Fig. 35. Movement of pebbles along shore. Arrow shows wind direction

MM—crest of slanting wave; *OO*—water's edge; *NN*—wave slanted in different direction; *ABCDEF*—path traversed by pebble

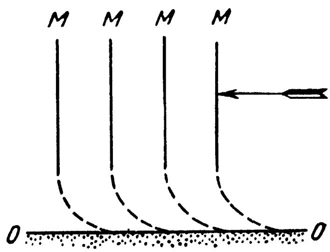

Fig. 36. Movement of pebbles along shore. Arrow shows wind direction

MM—wave crest; *OO*—water's edge

slanted, i.e., approach shore from an angle, then the pebbles move along the beach in zigzag fashion, as shown in Fig. 35.

Let us follow the path of a pebble, say of a red or white one for convenience's sake. A slanting wave *MM* sweeps it up at point *A* and carries it to point *B*. When the water recedes, the pebble does not return to point *A*, but together with the water rolls down the beach's steepest incline to point *C*. The next wave picks it up and carries it to point *D*, and when the water recedes it rolls down to point *E*, etc., thus each time the pebble moves along the shore the distance of a perpendicular line dropped from the lower part of its position to its line of retreat, i.e., from point *A* to line *BC*, from point *C* to line *ED*, etc. This movement, naturally, is often interrupted and for long. A particularly powerful wave may toss our pebble to point *F*, near the water's edge, where it can lie until a larger wave comes along and picks it up, or perhaps sweeps it into a crack for a time.

If the reader happens to be on the South Coast of the Crimea or on the Black Sea shore of the Caucasus he can easily observe this movement. With a sufficiently strong slanting wave, you should select a noticeable pebble, observe its movement for a time, and then measure the distance it has covered from the point you first started your observation.

If the slanting waves come from the opposite direction (*NN* on Fig. 35), the pebbles, of course, will move backwards. Waves

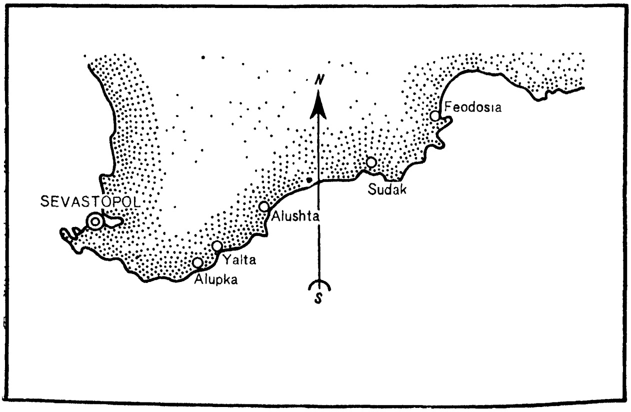

Fig. 37. Map of South Coast of the Crimea

running perpendicular to the shore will, upon approaching it, also slant (Fig. 36). Generally speaking, the movement of the pebbles in any direction depends on the prevailing direction of the strongest winds blowing slantly inshore. For instance, the prevailing winds between Alupka and Feodosia in the Crimea blow from south-west to north-east with the result that pebbles migrate more from Feodosia towards Alupka, rather than in the opposite direction. It is not surprising then that we find pebbles on the beach at Alushta which have come all the way from the coastal cliffs at Kara-Dag and Sudak, and on the Alupka and Yalta beaches we find pebbles from Ayu-Dag and Gurzuf, besides, of course, the dominating local rock-waste (Fig. 37).

Very large quantities of pebbles which have migrated from afar accumulate on the capes which jut out to sea; they are also washed into bays from where they cannot get out. It is to this migration of rock-waste—sand, pebbles and boulders—that we must attribute the formation of sandbars and spits which gradually clog up the mouths of bays, transforming them into lagoons and, finally, into lakes isolated from the sea (Fig. 38).

Currents. In addition to the fickle waves of seas and large lakes caused by the force of the wind, there are currents—the constant migration of considerable masses of water in a particular direction. Currents originate at the mouths of rivers which empty into the sea their fresh and warm waters, which are lighter than sea water. This water flows in a certain direction above the sea water, gradually mixing with it and losing velocity.

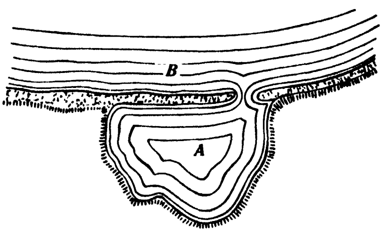

Fig. 38. Formation of a lagoon
A—gulf. B—spit making the gulf into a lagoon

Stronger currents are formed by the temperature fluctuations in various parts of the ocean and by the prevailing winds. For instance, the powerful warm Gulf Stream, which flows across the Atlantic to Europe and determines the mild climate of the latter, comes from the Caribbean Sea. A branch of this current deviates north of Scandinavia and even reaches the Barents Sea.

The cold waters of the Arctic Ocean flow mainly along the eastern shores of Greenland, forming an extremely cold current which reaches the eastern shores of North America, something that accounts for the cold climate of Canada and the United States. Weaker currents flow from the Arctic Ocean across Baffin Bay, west of Greenland, and across the Bering Straits, between Asia and America.

There are other cold and warm currents on which we cannot dwell. They pass so far from land that they are powerless to erode the shore but transport various materials. Some cold currents carry floes and icebergs with pebbles and boulders from the glaciers of Spitzbergen and from other islands, and when they melt the rock-waste sinks to the sea bottom. The Gulf Stream carries seaweed and plankton, i.e., various forms of drifting organic life, from warm seas to cold ones, where they serve as food for fish. The shallow shore currents transport along the coasts the fine sediment—sand and silt—which the rivers bring down to sea, and the sediment created by the surf.

Sedimentary Rock Formation. Now what happens to the sediment which the rivers empty into the lakes, seas and oceans and which the surf erodes on sea-shores?

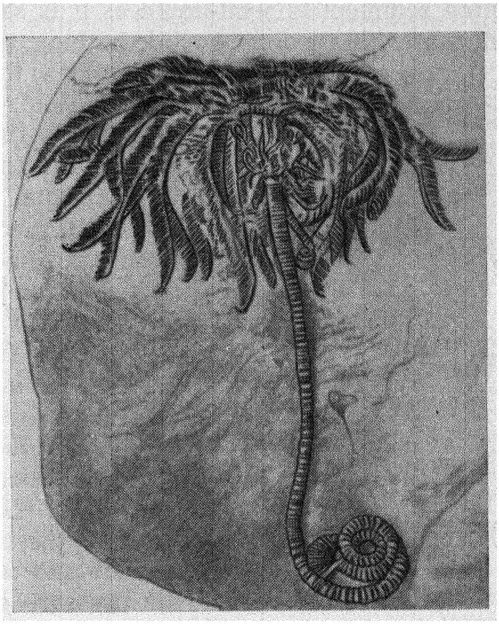

Fig. 39. Sea lily *Acanthocrinus rex.* Rare complete specimen. Found in Devonian slate in Hunsrück

The river silt settles gradually in the seas and lakes, the larger particles earlier, nearer the river mouth or coast, the smaller and lighter ones—later, farther from shore. In a large lake the finest particles settle only in its central part, while those in the sea are carried away by currents dozens and hundreds of kilometres from shore. And everywhere this sediment settles at the bottom of the sea, particle by particle, daily, yearly, during thousands of centuries.

This sedimentary matter accumulates layer by layer at the bottom of lakes and seas; the larger, sandy particles settle closer to shore, the grains of sand forming layers of sand; farther out to sea the smaller particles form layers of various clays: sandy clay layers accumulate in the vicinity of the region of deposition of sand particles where the finest grains settle together with the clay particles; the layers of pure clay take shape further away. Lime and mica particles often mix with the sand and clay. Recently deposited sediment is semi-liquid as it is saturated with water. We encounter this sediment while bathing, when our feet get stuck in the mud at the river bottom.

Fig. 40. Minute fauna and flora in sedimentary rock under microscope

But with the passage of time, with the piling up of deposits, the layers become firmer, their water is squeezed out, their particles compress, and if we pick up sediment a few metres from the basin bottom it will not be semi-liquid nor will it ooze through our fingers—it will be more solid, though still soft rock. Gradually, at great depths, these deposits become still firmer. Under the pressure of the upper layers, and the percolation of water, which contains various solutions of lime, silica and iron, the particles are cemented by these substances. In this manner rocks of different hardness are evolved—pure, clayey or limey *sandstone*, formed from sand, and *shaley clays* and *clayey shales*, from clays; *marl* is evolved if limey silt is deposited together with clay, and when limey silt predominates then clayey limestone is evolved.

It would be wrong to think that the bottom of seas and lakes is void of life. We find algae, sponges, sea lilies, and in warm seas—corals, molluscs living at the sea bottom, often forming colonies which spread over more or less extensive areas; here too crawl worms, starfish and sea-urchins. The remains of these plants, tests, shells, and the hard parts of animals are buried in the deposits separately or in layers, adding variety to the composition of the rock formations. In warm seas corals grow in enormous colonies, forming reefs. The surf erodes the decayed parts of the reefs, and transforms the polyp's matter into limey sand which settles at the sea bottom. In the sandstone, clayey shale, in the limestone and marl formed from sedimentary matter we encounter corals, shells, starfish and sea-urchins and even entire layers of their remains (Fig. 39).

Some algae extract lime (calcium carbonate) from the sea water and deposit it in their stalks. Whole layers of peculiar limestone are composed from the remains of these plants. Here also live drifting plants known as diatoms, which have shells formed from the silica they extract from the water. Then we also meet with minute animals known as radiolaria with silica skeletons and foraminifera with shells of lime. These plants and animals abound in the seas, forming with the various infusoria, jelly-fish, transparent molluscs and crustacea and the larvae of various sea animals called plankton, the community of creatures which swarm in the seas and serve as food for fish and the other denizens of the sea. When these creatures perish their skeletons and shells sink to the sea bottom and mix with inorganic sediment, and at vast depths, which inorganic sediment cannot reach because of the enormous distance from shore, these skeletons and shells form deposits of specific silt—essentially silicious (diatomaceous and radiolarian), or limey (foraminiferal)—which with the passage of time turns into hard rock known as tripolite (diatomite, infusorial earth), silicious shale and white chalk. The latter, with which readers are well acquainted, is composed of shells of foraminifera mixed with skeletons of diatoms and radiolaria. This can clearly be seen through the microscope (Fig. 40).

The enumerated rocks formed at the bottom of seas and lakes from inorganic and organic matter are called *sedimentary rocks*, since they settle in the water. Sandstone, sand, shingle and conglomerates of the latter (pebbles and boulders found in varying quantities in sandy, limey or clayey, i.e., finer, sediment known as cement, since it binds the coarser particles together), and also the various silts and clays and the shales formed by them are also called *clastic rocks* as they consist of rock fragments which have been eroded by water.

To sedimentary rocks also belong the layers of *gypsum*—calcium sulphate—and *rock salt*—sodium chloride, and other salts, which settle from brine at the bottom of seas, bays, lagoons and salt lakes, if the brine contains sufficient salt to precipitate part of it after the water has evaporated. This salt usually forms layers which alternate with layers of sand, clay and silt.

Stratification. Sedimentary matter does not settle in water continuously, and moreover, its quality and quantity may change.

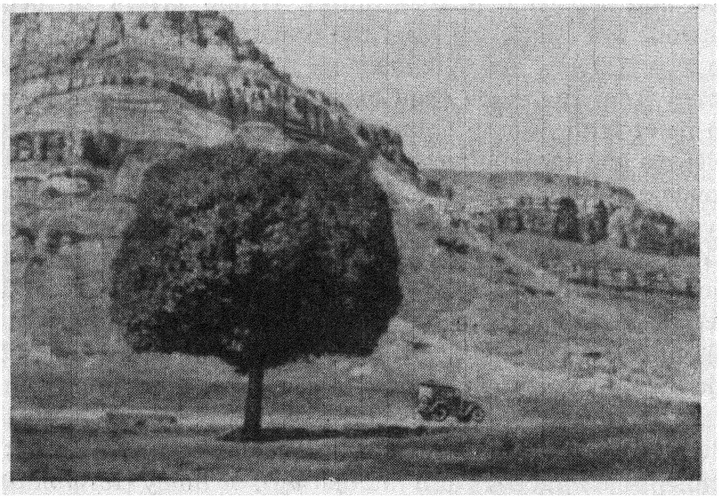

Fig. 41. Outcrop of Tertiary limestone beds, north-east Ferghana

When rivers are in spate and their flow is greater, they bring down to sea coarser sediment: sand and gravel, while the mountain rivers bring down pebbles and even boulders. When rivers are at low ebb no sediment, or only fine sediment, is transported. This is why sedimentary rocks are always deposited at basin bottoms in layers, varying in thickness, quality and colour. Each layer is the result of the steady deposition of one and the same sediment during a definite period, and it is separated from the upper and lower layers by a smooth surface which corresponds to the interval in the formation of the deposits known as the *bedding* or *stratification plane.*

This stratification is easily seen in precipices of sedimentary rock (Fig. 41). We see tiers of layers, like sheets of thick cardboard or boards. The precipice may entirely consist of thin or of thick layers, and sometimes of both. The thick layers are also called *beds* and the shortest distance between bedding planes, separating a bed from above and below, is called its *thickness* (Fig. 42, *T*).

The thickness of some beds remains constant for long stretches while that of others fluctuates, the bed may *thicken* (Fig. 42, *a*) or thin (Fig. 42, *b*). A bed can thin out quickly at both ends and disappear altogether when its upper and lower bedding planes merge. This is called a *lenticular* bed and its disappearance is known as wedging or *thinning out* (Fig. 42, *c*). The bed directly above the one that interests us, say of gypsum or coal, is called its *roof*, and the lower one its *floor* (Fig. 42, *d* and *e*). Rocks in precipices, on valley slopes and on shores which are bared of loose soil for some distance are known as *outcrops* (Figs. 43 and 44). Shore cliffs, rocks and often steep mountain slopes are more or less continuous outcrops.

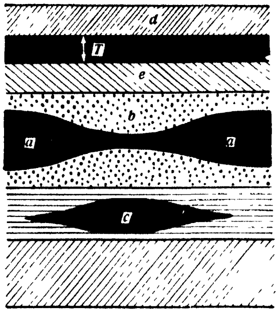

Fig. 42. Section of sedimentary rock thickness

a—thickenings. *b*—thinning of bed. *c*—a lens. *d*—hanging bed. *e*—bed floor. *T*—bed thickness

Fossils, as we know, are remains of animals or plants. They are often found in beds of sedimentary rock; they may have taken part in the formation of these rocks, or accidentally become embedded in the sand and silt which settled at the bottom of the basin. Fossils are remains of the hard parts of organisms: molluscs' shells, tests of crustacea and turtle, bones of vertebrates, trunks and boughs of trees. Imprints of soft parts: leaves, stalks, insects' wings, and jelly-fish bodies are sometimes found on rocks. These remains are important for identifying the age of the rocks and the conditions under which they were formed—at sea, in a lake or on land. We shall speak of them in detail in Chapter X. Here it is only necessary to remember that fossils are often found in outcrops of sedimentary rocks (Figs. 39 and 40).

Estuaries, Lagoons and Limans. In Chapter I we wrote of how the streams and rivers which flow into the seas or lakes build up deltas. But deltas can appear above water level only if the mainland does not subside or has not subsided fairly recently, otherwise they will be invisible, submerged. If the mainland has sub-

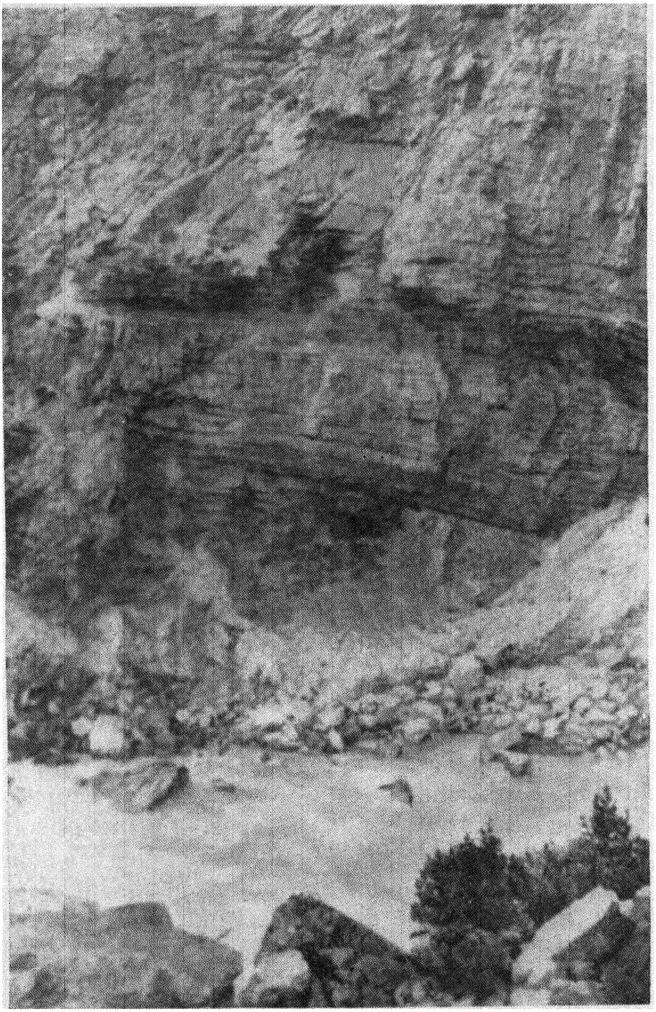

Fig. 43. Unconformable bedding of Upper Jurassic limestone on Middle Jurassic shale, Urukh River

sided recently, the rivers often have a narrow funnel-shaped mouth called an *estuary*. If you glance at the map of the Soviet Union, you will find these estuaries at the mouths of the Ob, Taz and Yenisei in Western Siberia.

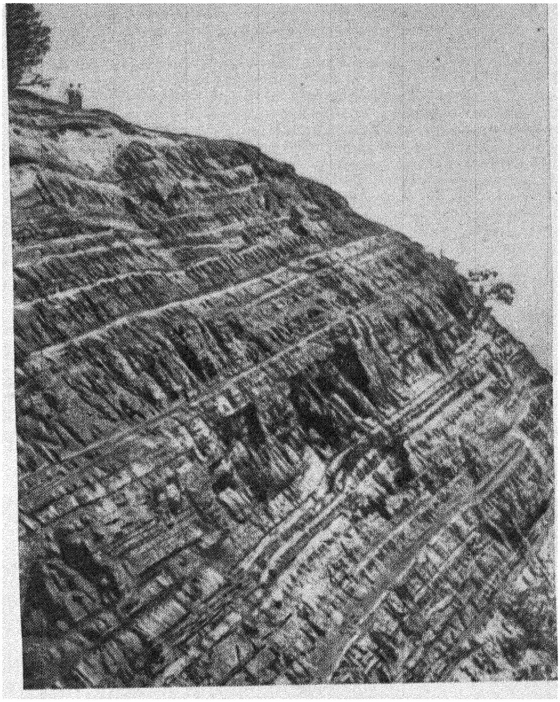

Fig. 44. Outcrop of Tertiary sandstone and argillaceous shale near Borzhomi, Caucasus

The rivers flowing south into the Black Sea—the Dnieper, Dniester, Bug and a number of smaller ones—also seem to have estuaries, but actually they are *limans* which differ from estuaries by spits which separate them from the sea, for after the land had subsided and evolved the funnel-shaped river mouths, it rose again, depriving the rivers of sufficient time to build up their deltas, so that the surf action alone washed up spits at the outlets of the shallow bays formed by their estuary funnels.

Lagoons. As stated above, lagoons can either be small or large bays separated from the sea by *spits* or *bars*. The spit can either be solid, completely isolating the former bay, or it may still have an outlet linking it with the sea. The Karabogaz Gulf on the eastern shore of the Caspian is actually an enormous lagoon. The loss of water caused by extensive evaporation is gradually compensated by sea water entering through a gap in the spit. The Karabogaz Gulf is, in essence, a huge frying pan in which the waters of the Caspian evaporate, forming a thick brine from which the salt precipitates. The Sivash, or the Putrid Sea, is a network of lagoons in the Azov Sea, in which the brine thickens and precipitates salt. But there are lagoons where salt is not precipitated because they receive the waters of large rivers and empty them into the sea. Lagoons of this kind are to be found on the south coast of the Baltic between Gdansk and Klaipeda—the Vistula and Kursky bays; an arm of the Vistula and the Pregel flow into the former—the Niemen flows into the latter (Fig. 45).

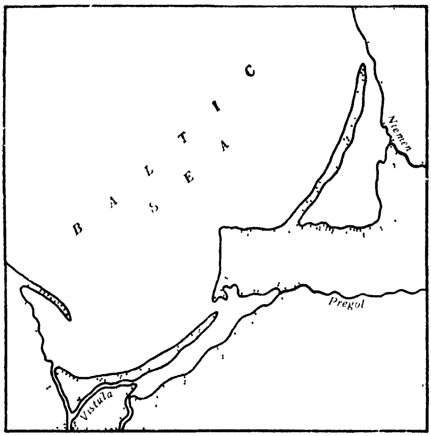

Fig. 45. Lagoons—the Vistula and Kursky bays on the Baltic Sea between Klaipeda and Gdansk

Limans, too, can turn into salt lakes and precipitate salt; take, for instance, the Tiligulsky, Khajibeisky and Kuyalnitsky limans near Odessa, situated at the mouths of streams which dry up in the summer. These limans precipitate salty mud which is used for medicinal purposes.

Lakes. In addition to limans and lagoons, which are lakes closely linked with the sea, there are many other lakes of highly diverse sizes and origin. They are divided into two main types—*dam* and *depression* lakes.

Lakes of the first type are formed when a valley becomes dammed by rock-waste which creates a backwater. Limans and lagoons belong to this type of lake—their spits serve as dams

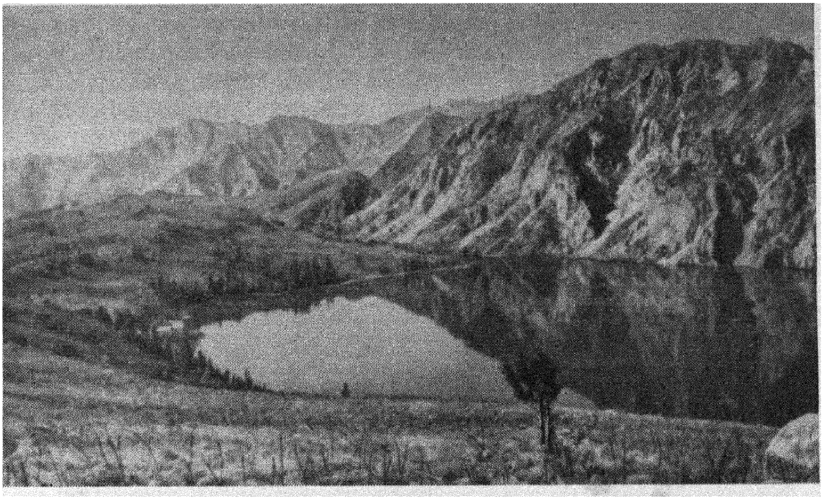

Fig. 46. Landslide dam which formed Lake Sari-Chilek in central Tien-Shan

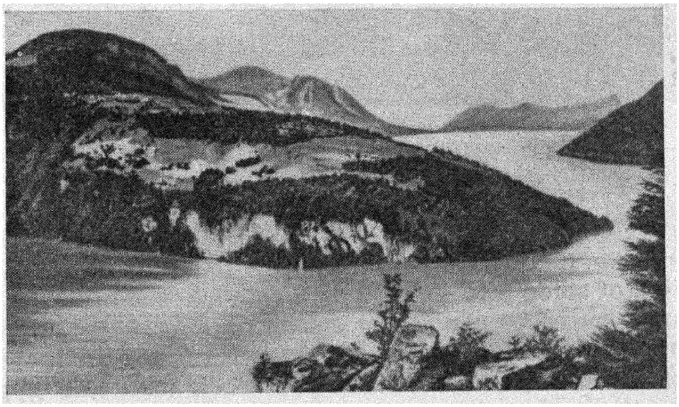

Fig. 47. Four Cantons Lake in Switzerland. Its depression was cut by a glacier

which cut them off from the sea. Dams can also be created by rock avalanches or landslides, glacial moraines, or by streams of lava. Oxbows also belong to this type of lake as they are created by the action of rivers. The dam lakes are, as a rule, not large (Fig. 46), although there are exceptions.

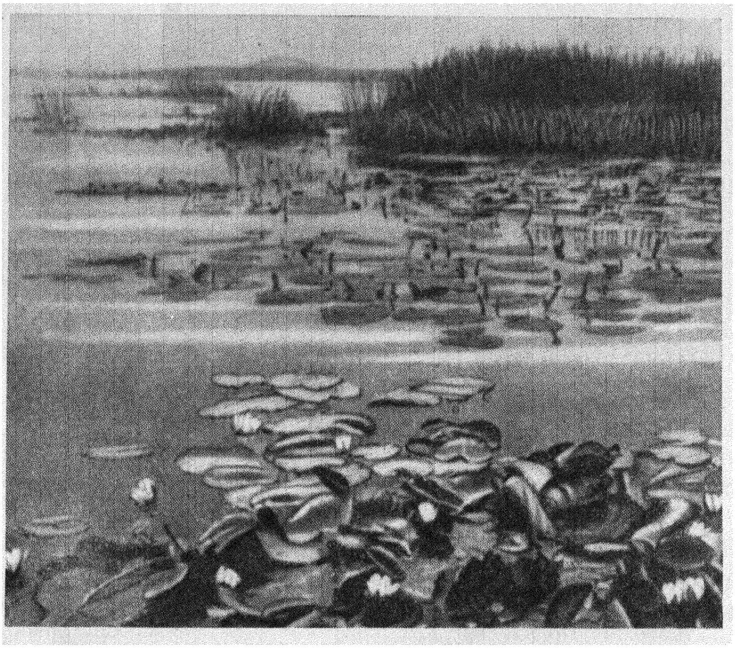

Fig. 48. Freshwater lagoon in north of Germany overgrown by vegetation. In foreground white lilies, further back, yellow lilies and in background—reeds

Depression lakes fill hollows on the Earth's surface caused by the action of some force of nature. These lakes are usually small. They are scoured by glaciers or cut by running water in a valley, or formed by the collapse or subsidence of surface layers into cavities caused by the dissolution of rock (salt and gypsum), by the action of underground waters (see Chapter III). These subsidence lakes are also small. They are many in Kirov Region and in the upper reaches of the Volga. Craters of extinct volcanoes, which are closed depressions, are often filled with water. The largest depression-type lakes were caused by the subsidence of considerable areas of the earth's crust during the process of mountain-building. Such are, for instance, Lake Issyk-Kul in Kazakhstan, Lake Baikal in Siberia, Kosso Gol Lake in Mongolia, Lake Tanganyika and others in Africa and the Dead Sea in Palestine.

In the Soviet Union some lakes are recently formed lagoons and limans, others, like the Elton and Baskunchak lakes, are ancient lagoons; then there are subsidence and moraine lakes (in the Altai, Tien-Shan and Sayan mountains), glacial lakes (such as Lake Teletskoye in the Altai), oxbow lakes and volcanic lakes (on Kamchatka).

A special branch of science known as *limnology* studies the physical phenomena of lakes.

III

HOW WATER WORKS UNDERGROUND

Ground Water. Springs. Wells and Artesian Wells. Karizes. Mineral Springs. Water as a Solvent. Sinks. Swallow Holes. Karst Topography. Underground Rivers. Caves. Cave Dwellers. Glacial Caves. Ground Water Deposits. Rock Avalanches and Landslides.

Not all the precipitated rain and snow take part in visible erosive and depository work. During a brief, drizzling rain we do not notice puddles or running water in hollows in the countryside. Only perhaps in town, where the paved streets prevent the rain from saturating into the ground, is it noticeable. And not all the water of a heavy rain runs off; some of it seeps into the ground; the looser the soil and the more gentle the incline, the more water it absorbs. Cultivated fields absorb far more water than roads do, sandy soil, more than clayey soil. Sand sucks in water continuously, while clay quickly wets, stops absorbing water and becomes *watertight*.

The water that seeps into the soil is called subsoil or *ground water*. In pervious ground the water, gradually seeping through the soil particles, percolates downwards until it meets a clayey bed, or solid uncracked rock, where it stops and accumulates. The rock saturated with water is called an *aquifer*, and it may lie at varying depths—from half a metre somewhere in a valley to dozens or even hundreds of metres deep. In marshes, where the watertight clay is close to the ground, the water collects in the gaps between the clods of earth. Here the aquifer lies at the very surface.

Water seeps into the ground not only from the surface as rain or melting snow. Part of the running water of rivers also seeps into river beds and banks and even ascends a little away from the river, slightly higher than its level, because of *capillary* creep, caused by the pulling power of the water's upper layer which wets the soil particles.

The phenomenon of capillarity can be easily observed. If you take a lump of sugar and a piece of filter paper and dip their edges into water the whole lump of sugar quickly becomes saturated while the filter paper—only up to a certain level. The water soaks the particles of the sugar and the paper and rises between their minute intervals. This is why at a valley bottom, some distance from the river proper, we can meet with ground water at a level higher than that of the river.

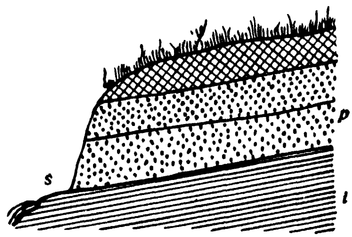

Fig. 49. A bed spring
p—pervious beds. i—impervious beds. s—spring

Springs and Wells. If the watertight layer on which an aquifer has been formed is graded in some direction, then the ground water will slowly flow in that direction. Let us suppose that this layer reaches the surface on a valley slope (Fig. 49). Then the water flowing along the layer will also reach the surface. This exit is called a *spring*, and its waters will be plentiful or negligible depending on the aquifer's area and its water supply.

But ground water can also be tapped on a plain, providing we bore the layers through which the water percolates and reach the aquifer. This is done by means of *wells*. Care must be taken, however, not to pierce the impervious bed beneath the aquifer, otherwise the water will escape to pervious beds lower down and the well may remain dry. The well's sides must be propped up by boards or matting to prevent the collapse of loose soil. The water will seep from all parts of the aquifer and collect in the well. The volume of the water depends on the aquifer's thickness and its degree of saturation. Some wells go dry very quickly, and it takes time for the water to accumulate again; this shows that a poor aquifer has been reached. There are often not one but several aquifers; beneath the top impervious bed there may be other pervious beds through which the water seeps to the next impervious bed, etc. Thus if the top aquifer has little water the well can be bored to the next one. When the water lies deep, *artesian* wells are bored, i.e., bore-holes, cylindrical shafts drilled into the ground and reinforced by cast-iron casing (Fig. 50). A hand pump pipe is lowered into this casing and the water is pumped to the surface.

In some artesian wells the water rises of its own accord and it may even overflow at the surface. This takes place when the locality in general is a flat depression and the tapped aquifer

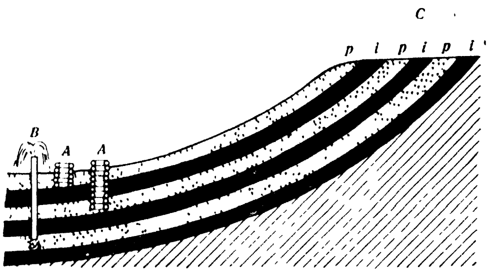

Fig. 50. Wells at various depths
A—ordinary wells. *B*—artesian well with overflow. *C*—catchment area *p*—pervious beds. *i*—impervious beds

reaches the surface somewhere in the neighbouring heights where the rain and snow water percolate downwards through the pervious beds and seep into it. The difference in height between the catchment area and the location of the well creates a pressure head which forces the water to ascend, and, when this difference is considerable, makes it gush out (Fig. 50).

An original method for tapping ground water for irrigation purposes is to drive a gallery called a *kariz* to the aquifer. These karizes are found in Azerbaijan, Central Asia and Iran—areas where the climate is very arid, rains rare and snow almost unknown. The waters of the streams and rivers flowing down from the mountainsides disappear rapidly by seeping into the thick layers of loose shingle and sand of the foothills. The peasants gradually drive a gallery (*k*) (Fig. 51), which starts at the fields far down the foothills, deeper and deeper into the deposits, retaining a slight gradient necessary for the flow of water. Pits (*w*) are dug at regular intervals to extract the soil from the gallery. Finally, nearer the hills, the gallery strikes an aquifer (*p*) which is fed by the water seeping down from the river. This water flows along the bottom of the gallery to the fields, orchards and kitchen gardens. Digging these karizes in loose soil is dangerous and laborious, for they often collapse; since it is very expensive to prop up the gallery's roof and walls they remain unpropped.

Not all springs are alike. The one depicted in Fig. 49, the most common kind, is called a *bed* spring. In other cases the impervious bed lies in the form of a flat depression and the spring flows out at the bed's lowest point which reaches the surface

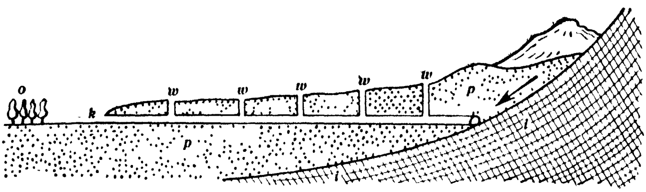

Fig. 51. Section of kariz

i—impervious thickness. p—pervious bed and aquifer. w—wells. k—exit of kariz o—oasis. Arrow shows river water seeping through mountain opening

(Fig. 52); this is known as a *pit* spring. In hard and solid rock the ground water percolates mainly through its fissures. The aquifer's fissures can reach the surface on the slopes of hills or valleys and the water flows out of them. This type is called a *fissure* spring (Fig. 53).

The waters of wells and springs are usually pure or, to be more precise, they contain such small amounts of dissolved salts that they are tasteless. Absolutely pure ground water does not exist, for during its slow percolation through pervious beds it gradually dissolves some of their salts. But in some places the water of springs and also of wells has a pronounced bitter-salty taste, which is sometimes so strong that not only people, but less exacting animals, even camels, refuse to drink it. Such wells and springs are encountered more frequently in desert and semi-desert land—in the Sahara, in Saudi Arabia, the Gobi and in our country—the Caspian steppe, Turkmenia. In these areas the climate is dry, with slight rainfall, and the surface beds through which the water percolates are rich in salts, especially in places which relatively recently were seas which left behind their salt-saturated deposits.

Mineral Springs. In addition to this water, in essence only slightly salty, found in countries with dry climates, in many other countries there are numerous mineral springs whose waters are charged with various salts and gases. The presence of the latter is clearly noticeable from the bubbles which rise to the surface—they can be seen even better in a glass of this water. These mineral waters may be either clear, quite transparent, yellowish, muddy or even milky-white. The quantity and quality of their salts differ greatly. Most readers have drunk the Borzhomi and Narzan mineral waters. These waters are charged with small amounts of salts and their gas, carbon dioxide, makes them very pleasant and refreshing to drink. But other mineral waters, the Batalinsk waters, for instance, are not pleasant to drink because of their bitter-salty taste, or their smell of bad eggs, as they are charged with a stinking gas, hydrogen sulphide, or because of their rusty taste owing to the presence of iron. Such waters are drunk only at the doctor's orders. Depending on their salt and gas content, mineral springs are classified into carbonaceous-alkaline, chalybeate, sulphureous, alkaline-earth, salty and other groups.

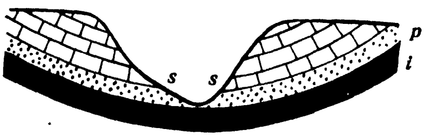

Fig. 52. Depression spring
p—pervious beds. i—impervious beds. s—spring on valley slopes

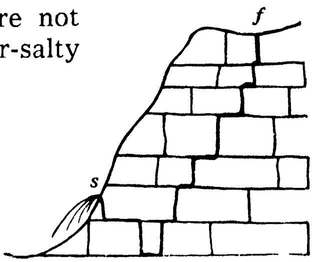

Fig. 53. Ascending fissure spring
f—upper inlet of fissure. s—outlet of water

Mineral waters are drunk and used for baths. The Narzan and Borzhomi waters are table waters—while the sulphureous waters of Pyatigorsk, Matsesta, Tskhaltubo, the salty waters of Staraya Russa, Slavyansk, Usolye are applied mainly for baths. Ordinary salt is also refined from salt springs.

Usually the temperature of the springs is not high, and it corresponds to the mean annual temperature of the locality, for the water, seeping slowly through the pervious beds near the surface, receives the annual temperature of the latter. In Siberia, where the mean temperature of many districts is below zero, the temperature of the springs is still one or two degrees above zero (otherwise the water could not flow out of the ground). But mineral springs have higher temperatures and can be warm, hot and very hot. For instance, the Borzhomi springs, the Pyatigorsk sulphureous springs, the salty springs of Staraya Russa and others are warm springs, while the temperature of the waters of many mineral springs on Kamchatka is very high, nearly reaching boiling point.

The high temperature of such springs indicates that the water rises from great depths, from the strata of the Earth's crust which are warmed by internal heat. These springs mainly belong to the fissure type and at the same time they are *ascending* springs (Fig. 54), as they have ascended from the depths, while cold fresh-water springs are chiefly *descending* springs as they contain waters which have percolated from the earth's surface downwards, and seeped along the slopes of the aquifers until their emergence. The waters of mineral springs, especially warm and hot ones, are also called *juvenile*, as they originate from the bowels of the Earth and appear on the surface for the first time; they are evolved from the cooling of the molten mass deep in the Earth and are, therefore, charged with mineral matter. In contrast to these juvenile waters, fresh cold springs are called *meteoric* or vadose, for their waters have repeatedly taken part in the cycle of surface water, evaporated, fallen to earth in the form of rain or snow, seeped into the ground, collected into streams, rivers and seas, and have again evaporated. Of course, there are exceptions. Ground water may percolate to considerable depths through rock fissures (to strata which are still warm), become heated and, retaining its warmth, rise to the surface again through different fissures at a lower level, and on its long journey even become somewhat charged with mineral matter. Hence, some warm mineral springs may be meteoric, and not juvenile. On the other hand, warm juvenile waters, ascending through fissures, mix with meteoric waters,

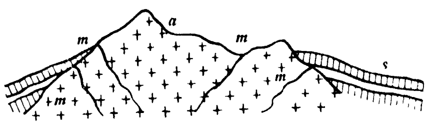

Fig. 54. Ascending fissure mineral springs *(m)* and sedimentary rock *(s)* on Zheleznaya Mountain *(a)*

become less charged with mineral matter, lose their warmth and emerge as descending cold springs.

Water as a Solvent. It is well known that water dissolves some substances; a spoonful of sugar, salt or soda can easily be dissolved in a glassful of even cold water. In warm water these substances are dissolved quicker. The salty waters of some springs and wells and the waters of all the mineral springs show that in nature water seeping through rocks dissolves matter on its way. But most rocks are not soluble, even in hot water, which can extract only separate, insignificant particles. However, such rocks as salt, gypsum and limestone are more or less soluble and the water seeping through them removes particle by particle, expands the fissures through which it flows and evolves cavities of varying dimensions. Limestone as a rock and lime as a component of other rocks is eroded more extensively if the water contains carbon dioxide, which it absorbs in small quantities from the atmosphere. Rock salt is easily dissolved in water, gypsum is far harder, but still easier than lime. The dissolubility of limestone can easily be proved by ascending a hill of this rock above the vegetation line where we find bare, slanted surfaces, down which rain and snow water stream, making the former smooth layer of limestone almost unrecognizable—cut up in zigzag fashion by deep ruts which stretch down the slope, divided by sharp jagged crests. Sometimes these ruts reach half a yard and more in depth. They have been made by the water streaming down the surface of the layers and gradually dissolving the limestone. These weird forms of erosion, called swallow holes, sometimes create entire stretches which, when the ruts and crests are very pronounced, are extremely difficult or simply impossible to traverse (Fig. 55).

These swallow holes tell us that water flowing underground through fissures of limestone, and especially through gypsum or rock salt, can corrode rocks and evolve caverns. If the caverns are large and have been formed near the surface, the upper strata may subside under the force of gravity, creating deep and wide sinks on hillsides or on valley floors (Figs. 56 and 57) indicating the activity of underground water. Where these sinks are numerous the area is very dangerous for construction work, say, for laying railways, because in time more sinks may easily be formed under the walls of buildings or under the permanent way, which may result in catastrophes.

Sinks are frequently found in gypsum rock districts. Take for instance the railway line descending from the Ufa plateau to the city of Ufa along the valley of the Belaya River. This line was built on gypsum layers and it demands considerable attention

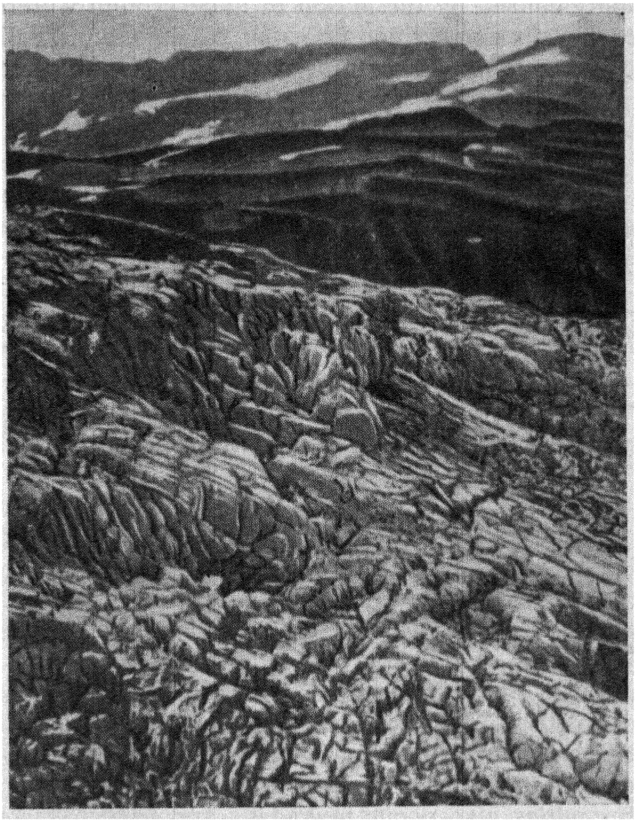

Fig. 55. Swallow hole area in limestone on Silberne Hills, Switzerland

and constant repair work. The railway engineers built this descent despite the warning by geologists of the danger of the gypsum layers.

In localities with humid climates, soil subsidences caused by the formation of underground caverns become filled with water and form small lakes of the subsidence type (Fig. 58) or swamps.

Sometimes streams disappear into sinks, leaving their beds dry; and sometimes ascending springs, fed by lost rivers, may flow out from sinks.

Karst Topography. In regions with drier climates, mainly in highlands composed chiefly of limestone, the so-called *karst topography* caused by the action of underground waters is pronounced. This is exemplified by sinks, cavings, blind valleys, the disappearance of streams, underground rivers, the absence of woods and the scarcity of hillside vegetation. This is the result of the rapid running off of rain waters through fissures into underground caverns, thus draining the soil which feeds the vegetation. Yet in the vicinity, strange as it may seem, there may be swampy blind valleys, formed on the sites of large sinks if the limestone surface is covered by a layer of clay remaining after the dissolution of the lime in clayey limestone.

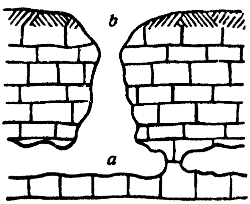

Fig. 56. Formation of sinks in dissolved rocks
a—swallow holes. *b*—sinks

The Crimea is typical for karst topography, but it is especially prevalent on the Karst Plateau (Yugoslavia) whence it derives its name. In more humid climates—on the Ufa Plateau, the Dvina-Onega watershed—where there are no mountains, karst topography is characterized by sinks, subsidence lakes, or *opadki* as they are called locally, which turn into marshes, in the disappearance and appearance of streams straight out of their river bed or from clefts in cliffs lower down. In Ivanovo Region, where there are large deposits of limestone close to the surface, there are many subsidence lakes which fill sinks from 20 to 65 metres deep.

Earth cavings also occur nowadays and they cause material damage. On May 18, 1937, for instance, in the village of Glubokovaya, Savin District, a sink suddenly appeared, 100 metres wide and over 20 metres deep, and it filled with water.

Caves. Usually caves are formed by the dissolution of rocks by underground waters. It is clear that districts with features of karst topography have a very large number of caves. But caves are often found in areas with non-karst topography, in limestone and gypsum rock areas, and, more rarely, in areas with other, less dissoluble rocks. The cave forms usually indicate how

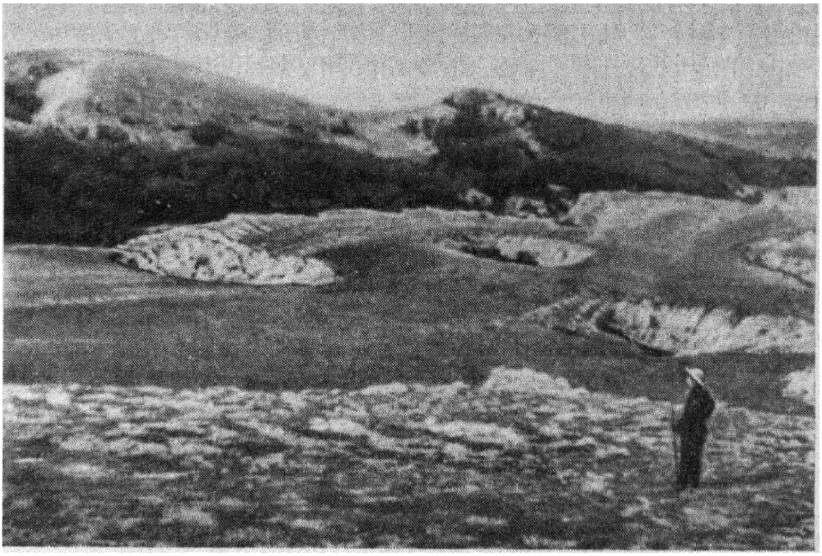

Fig. 57. Sinks in limestone on Yaila plateau near Ai-Petri Mountain

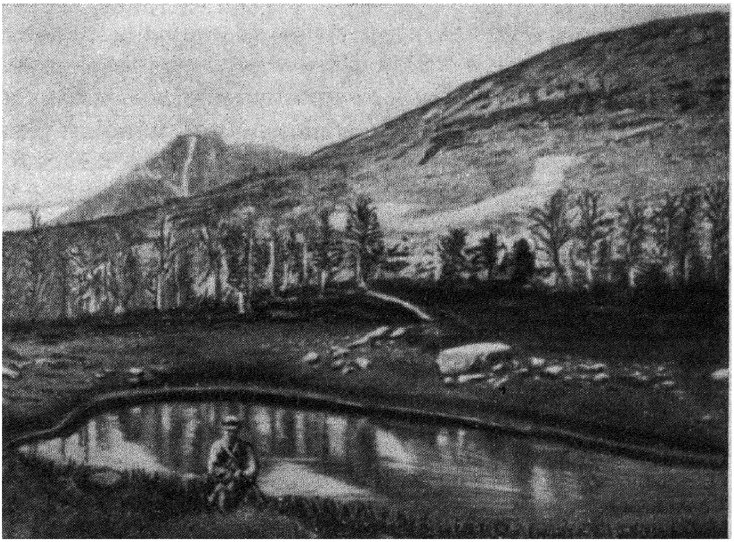

Fig. 58. Sink lake in karst landscape in the upper reaches of Yus-Kara-Tash, Kuznetsk Alatau

they were evolved. Mountain caves rarely have one cavern, they usually have a number of caverns or grottoes of various sizes, resembling chambers, with arch-shaped roofs, connected by narrow or low passages or by wide galleries. This system of passages and chambers may be on one level or slightly sloped or may have ledges at different levels, representing a system of fissures through which the underground water flows, eroding them more or less extensively, depending on the dissolubility of the rock. Underground streams and rivers still flow in some caves, while in others, small reservoirs with stagnant water lie at the bottom of the grottoes (Fig. 59).

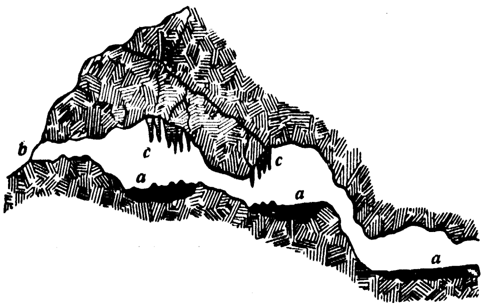

Fig. 59. Section of a cave
a—deposits on cave floor. b—entrance to cave. c—chambers with stalactites and stalagmites

Cave openings may be narrow or wide, they can be situated on mountain slopes or at varying heights in valleys, in sheer cliffs, and at sea level (sea-shore caves). Passing through the entrance, the tourist is immediately confronted with the first and sometimes the only chamber, or he may walk along a narrow and winding passage, leading upwards or downwards before he reaches the first widening. Some caves have additional exits in the shape of shafts rising from the chamber roofs. The number of chambers may differ greatly, from one near the surface to an entire labyrinth of chambers and passages. For instance, the Mammoth Cave in Kentucky, the United States, has 200 chambers, with a total length of more than 250 kilometres, forming a labyrinth of 16 kilometres in a straight line from mouth to exit. Its "big room" is over 30 metres high. Our Kungur Cave, the best explored one, is 2.5 kilometres long. We have caves in the Crimea, the Caucasus, the Urals, the Altai, in Transbaikal Region and in Eastern Sayan. But the majority of them have not yet been properly explored.

Cave floors are usually strewn with rock-waste which has fallen from the roofs, and become covered with dust. The rock-waste either lies directly on the solid bedrock or on a layer of sedimentary matter, deposited by flowing water or by blown-in dust. This sedimentary matter often contains bones and other remains of cave dwellers both of man and animal. These include the bones of beasts of prey, the permanent habitués of the caves —the lion, bear, tiger, hyena, wolf, jackal, fox and herbivorous rodents and birds which served the beasts as food. Other cave dwellers are bats, owls, eagle-owls and pigeons, whose bones are only found in caves near the surface. Primitive man who inhabited these caves has left his bones and those of the animals on which he fed, the fuel and ashes of his fires, the remains of articles of stone and bone and other implements, and on the cave walls—his drawings and inscriptions (Fig. 277). Many caves are, thus, of great scientific interest for the study of the fauna of ancient times and the history of primitive man. But the remains must be excavated in an orderly manner under the supervision of experts. Unsystematic excavations can but lead to the destruction of valuable material. Many cave deposits have been spoiled by amateurs and trove hunters. Only archaeologists are allowed to excavate caves in the U.S.S.R.

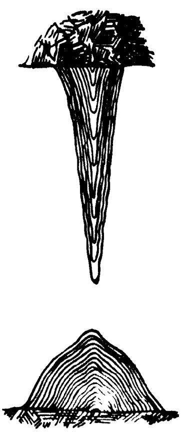

Fig. 60. Section of stalactite and stalagmite

Besides loose deposits, we find on the floors of many caves hard formations in the shape of hanging drops of lime, deposited by water dripping from the roofs. This water contains dissolved lime, part of which settles out while the drops are still hanging on the roof, the remainder—after the drops have fallen to the ground. Thus, little by little, long icicle-like pendants, called *stalactites*, grow downwards from the roofs, and others, called *stalagmites*, thicker and flatter, rise upwards from the floor. With the water dripping from several places, the stalagmites and stalactites gradually join and form pillars. These icicle-like pendants on the roofs and floors of the caves, depending on their evolution and combinations, are lovely to look at in artificial light but are of little scientific value (Fig. 60).

Even more beautiful is the light effect of the ice stalactites and stalagmites of the glacial caves, formed due to the low temperature of these caves, both in winter and in summer, from dripping water. Besides, on the walls and roofs where water does not drip, the humid air penetrating from without deposits moisture in the shape of hoarfrost, forming large and beautiful ice crystals, reflecting myriads of rays in the light of torch or candle.

We have glacial caves both in the Crimea, in the Chatyr Dag Mountains, in Orenburg Region (the Iletsk and Indersky caves), and in the Urals, the easily accessible Kungur Cave near the

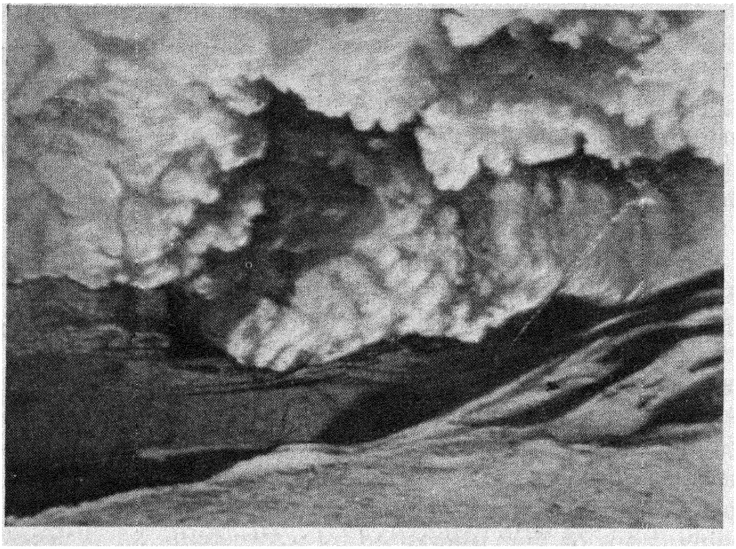

Fig. 61. Diamond Grotto with snow crystals on its roof in the Kungur glacial Cave, Urals

town of Kungur. The Kungur Cave has a number of chambers, each known by a different name, joined by passages which form a labyrinth nearly 2.5 kilometres long. The part of the cave nearest the surface is a glacial chamber covered with hoarfrost (Fig. 61) and hanging drops, while one chamber farther away, into which the cold air does not penetrate and whose mean temperature is above zero, has several small lakes which do not freeze (the largest one is six metres deep and covers an area of 750 square metres). Some chambers have vertical shafts reaching to the surface thanks to which the temperature of parts of the cave is below zero, owing to strong draughts of cold wind in the winter. In the summer the cold air, instead of leaving the chambers through the shafts, leaves through the entrance, a far slower process, which does not give the cave sufficient time to become warm. This cave was eroded by the underground Silva River which once flowed here through rocks of gypsum and limestone (Fig. 62).

Glacial caves are found all over Europe. Of special interest is the Dobshau Cave, Hungary, which has an ice-bound area of 7,171 square metres. Altogether its volume of ice comes to 120,000 cubic metres. Some of its ice walls are 15 metres high.

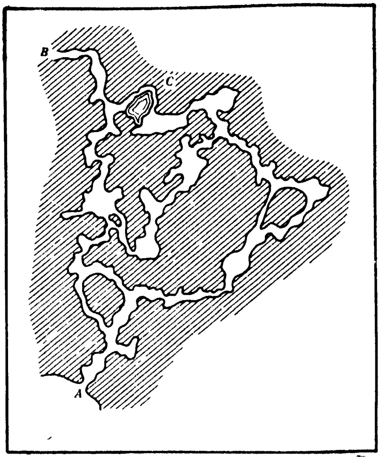

Fig. 62. Plan of Kungur Cave up to Ozerny Grotto *(B)*
A—entrance to cave. C—grotto of large lake

Ground Water Deposits. Besides the stalactites and stalagmites found in caves, ground water seeping or flowing through fissures of rocks deposits other minerals which fill up the fissures as streaks and veins. These deposits consist of lime in the form of lime-spar (calcite), silica in the shape of quartz and its varieties: rock crystal, chalcedony, opal, agate; more seldom of baryte (barium sulphate), fluorite (calcium fluoride), manganic spar, etc. Gold, silver, copper, iron, lead, zinc and other ores are disseminated in the veins and, if they are sufficiently rich, are mined.

An analysis of the water of mineral springs will show that the enumerated minerals and metals are contained in underground waters in certain quantities. Upon ascending to the surface, mineral waters also form deposits consisting either of lime in the form of *tufa* or *travertine*, silica as *silicious sinter* or *geyserite*, or ferric oxide in the form of *limonite*. An analysis of the tufa shows the presence of insignificant quantities of other minerals. The water in mains which we think to be pure sometimes deposits tufa which chokes up the main. Mineral matter is also deposited in the pipes which bring mineral waters to the surface to prevent them from mixing with the ground waters (the so-called "capping" of mineral springs), and these pipes have to be changed regularly.

Tufa and silicious sinter sometimes form very large deposits in the shape of several tiers of ledges with basins on hill or valley slopes or on flat ground around the outlets of the mineral springs

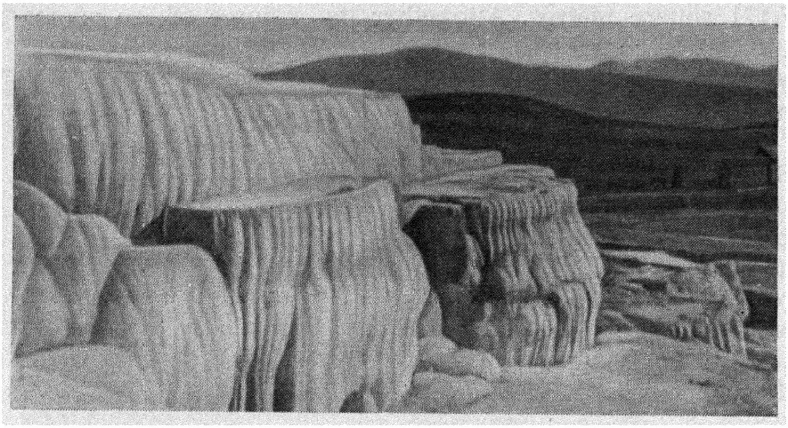

Fig. 63. The "White Terrace"—deposits of silicious sinter from hot springs, New Zealand

(Fig. 63). The water trickles down the ledges from one basin into another, leaving some sediment of its dissolved matter in each. Silicious sinter is deposited by hot springs, especially by geysers, of which we shall speak later. Tufa is deposited by cold springs and by some hot springs, for example, by the Karlovy Vary springs in Czechoslovakia. If we drop a flower or stick into the waters of a hot spring it becomes coated with a layer of tufa in the space of a few hours.

Rock *Avalanches and Landslides.* When ground waters reach the surface at some precipice or hillside, they may originate rock avalanches or landslides—the first being a rapid and the second, a slower displacement of huge masses of rock. During rock avalanches the mass of rock which separates from the cliff or hillside falls or hurtles down the slope, breaking up into large lumps, blocks and rock-waste which pile up in confusion partly at the foot of the hill and partly on the slope. Rock avalanches are also caused by erosion of cliffs by running water or the surf of sea or lake, by earthquakes or the careless work of man. And they often cause considerable damage, depending on the locality and the amount of fallen rock (Fig. 64).

Landslides occur on slopes when their layers are slightly tilted in the direction of the slope, if they have pervious (*p*) and

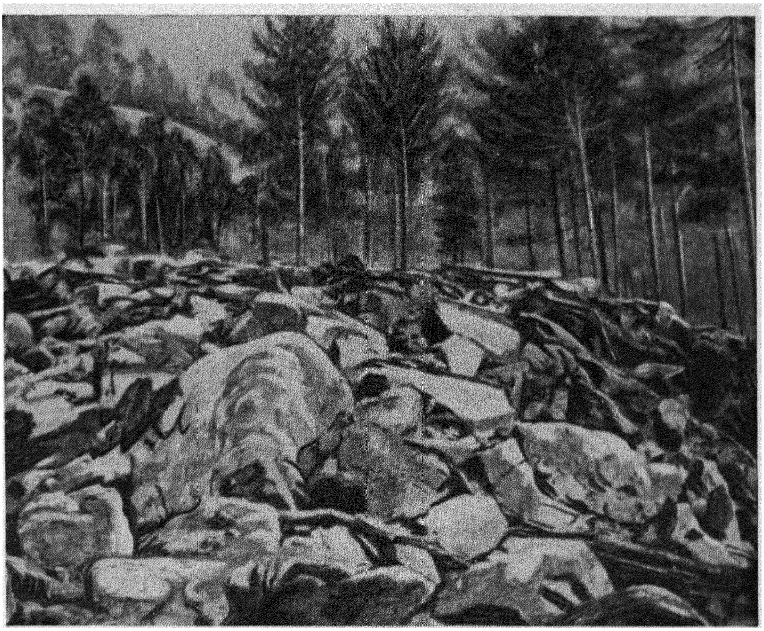

Fig. 64. Granite earth creep in Khamar-Daban, south shore of Lake Baikal

impervious (*i*) beds; the latter usually are of clay, whose surface becomes slippery when wet. The upper layer will sooner or later break away and slide down (Fig. 65). This movement can be caused by various agents: by an earthquake, heavy rains, which increase its weight, by the slope being eroded by a river or sea, or the careless work of man. In massive rock landslides can be started off, as in avalanches, along a fissure tilted in the direction of the slope or precipice which the water gradually expands. In the Soviet Union landslides cause grave damage to the

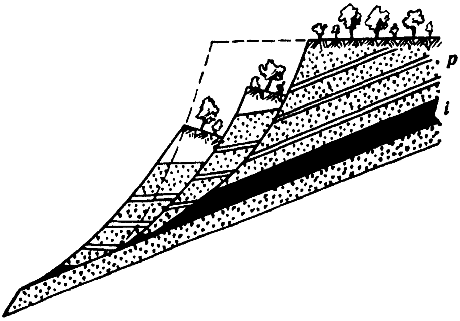

Fig. 65. Section of earth creep
p—pervious beds. *i*—impervious beds

banks of the Volga, on the Black Sea coast in the vicinity of Odessa, on the South Coast of the Crimea, on the Caucasian Black Sea coast between Tuapse and Sukhumi, and huge sums have to be spent on strengthening the shores. Some rock avalanches and landslides will be described below.

IV

ROCK WEATHERING

Rock Breakers: Sun and Frost, Atmosphere and Moisture, Plants and Animals. Weathering. Land Forms. Talus and Debris. Eluvium and Deluvium. Soil Formation. Soils and Climates. Soil Fertility.

Decayed Rocks. Let us examine a rock outcrop in a gully or on a mountain slope, a river bank or at the seaside. At first glance the rocks seem to be solid. But if we examine them closely we shall discover that they are ruptured, some—more, others—less. In places they crumble away simply from the impact of our fingers, and if we hit a rock with a hammer whole chunks collapse into screes of angular debris or sand. We see that the rocks are stained a rusty colour and dotted with small and large escarpment lichens. And our notion of their strength changes somewhat. The hard rock seems to have rotted away and heaps of fragments lie at its foot. The changes which cause the gradual destruction of rocks are known as *weathering*.

What are the forces which destroy such hard rocks as granite, quartzite and marble which are used in structures built for long life? Or are these calculations unfounded?

To a degree—yes. Buildings can be considered long-lived only when we compare them with the span of human life. Actually they, too, gradually wear away, for they are subjected to the influence of the same natural forces as those which destroy rocks.

Rock Breakers. We know these agents very well for we encounter them daily, but we haven't the slightest idea that they can destroy rocks. They are—the heat and frost, rain and snow, water and wind, and also modest plants and minute organisms. But how do they act?

On hot days the rocks are exposed to the blazing sunrays and they become intensely heated—you can verify this by touching one. At night they cool down. These temperature fluctuations from hot to cold and vice versa are especially pronounced in spring and autumn, when it is hot in the day and frosty at night.

When the rocks become heated they, like other bodies, expand and, when they cool, contract. These expansions and contractions are hardly noticeable, but when they are repeated day in and day out for hundreds and thousands of years, they ultimately make themselves felt; the adhesion of the rock particles (grains) gradually weakens; the coarser the particles, the more they weaken, because the coarser grains shrink and swell more than the finer ones. The rock's colour is also important: black, and in general dark-coloured, rocks become heated and, therefore, swell more than light-coloured ones, which reflect the sunrays better. You can prove this by placing a black stone and a white one next to one another in the sun and touching them after some time.

The colour of the rock's grains is also important. In rocks with grains of different colours, for instance white, red and black, like ordinary granite, grain adhesion weakens quicker than in rock of uniformly coloured grains, for instance black. Multi-coloured, coarse-grained rock offers the least resistance to temperature fluctuations.

The weakening of grain adhesion finally leads to the grains crumbling apart, the rock loses its strength and breaks up into its components—the solid rock crumbles into loose sand.

Water assists the temperature action. In rainy weather the cliffs become wet; porous, multi-cracked rock absorbs more moisture, solid rock less; then they dry again. This repeated wetting and drying is also harmful for the grain adhesion. Even more effective is the water which freezes in rock cracks and cavities (pores). This happens in the autumn when frost follows rain, or in spring, when on warm days the melt water seeps into the rock and freezes at night.

Water expands when it turns into ice. Everyone knows that if we leave a corked bottle full of water out in the frost the ice will burst it or expel the cork as it rises in the bottleneck. This expansion of freezing water in rock cracks and cavities widens them and weakens the grain adhesion, for the water seeps into tiny cracks invisible to the eye.

Moreover, the rain and melt water penetrating into rock are chemically active, as they carry gases absorbed from the atmosphere—oxygen and carbon dioxide. Oxygen is an active gas, present in the atmosphere. It maintains the burning of fuel,

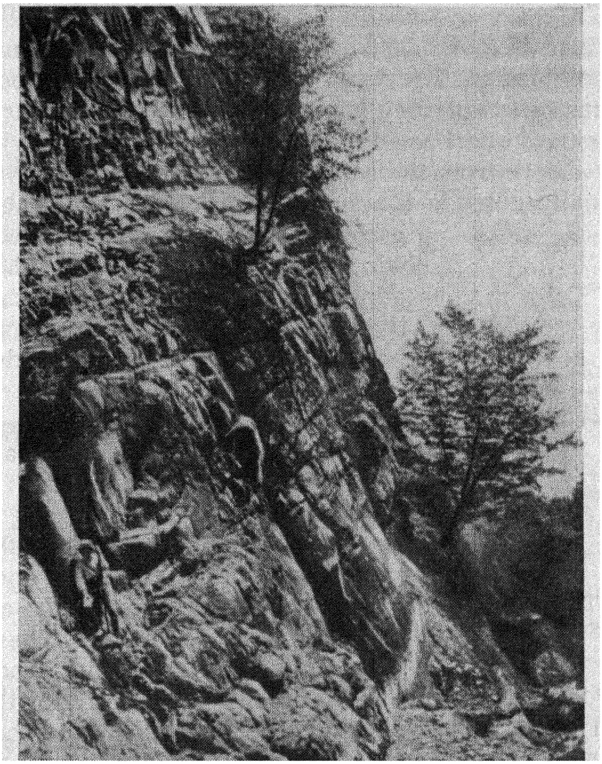

Fig. 66. Trees on precipice on bank of the Kura River, Borzhomi, Caucasus

causes oxidation of various substances, entering into combinations with them. Carbon dioxide is exhaled into the atmosphere by animals and plants; it is evolved during the burning of fuel in dwellings, fires, in car and aeroplane engines, in locomotive fireboxes, etc. Hence the water precipitated from the skies as rain and snow, which falls on the rock and seeps into the cracks is always charged with oxygen and carbon dioxide. This water exerts a more powerful effect on rock than the water in which these gases are absent. It dissolves particles of lime, decomposes the grains of felspar (found in many rocks) turning it into clay; it destroys the sparks of black mica, the grains of hornblende and magnetic iron ore, oxidizing their iron and turning them into ochre.

Plants also help in destroying rocks. Lichens colonize even very smooth rocks. The wind carries their minute spores into the tiniest cracks, or they stick to a rock's surface during rain; they germinate and become firmly lodged. Together with moisture they absorb from the rock the salts needed for their growth and gradually corrode the surface and widen the cracks. Fine grains of sand and dust carried by the wind or washed down from higher slopes adhere more easily to corroded rock and they fill the widened cracks. These particles of sand and dust gradually accumulate the soil necessary for the growth of other higher plants—grasses and flowers. Their seeds, too, are borne hither by the wind; they fall into the cracks and dust in the spaces between the lichen colonies lodged on the rocks and germinate. Grass tufts and flower stalks sprout from the chinks and soon grass smothers the lichens. These plants have long and tenacious root fibres which work down into the cracks and corrode the rock surface. The cracks widen and gather more dust and the humus of dead grass and their roots; and now a place has been prepared for the sprouting of shrubs and trees whose seeds are also transported by wind, water or insects. Their roots are perennial and stout and, working into the cracks and thickening as they grow, they act like wedges, widening the cracks more and more.

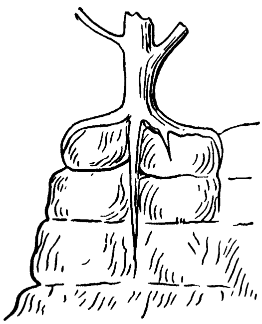

Fig. 67. Tree roots disintegrate rock

One often sees flourishing shrubs and trees peeping out of cracks on the sheer slopes of bare cliffs, and we wonder how they got there and how they manage to thrive (Fig. 66). The roots of the shrubs and trees reach deep into cracks which have become so wide that you can easily stick your hand into them. We see thick roots entwined around large blocks which they have already dislodged from the cliff (Fig. 67).

All plants injure rock because the carbon dioxide which they expel, when dissolved in rain and melt water, evolves carbonic acid which, as we have already mentioned, stimulates the corrosive action of the water. Then the dead parts of the plants—stalks, leaves, roots—rot and form other acids which also accumulate in the water and corrode the grains.

Thus, little by little, day by day, year by year, down the centuries, these negligible forces work at the destruction of the rock, at its *weathering*. How they work we cannot see, but the fruits of their labour are seen everywhere: continuous solid rock, which at first had only a few tiny cracks on its surface caused by temperature fluctuations or by the formation of folds (of which more anon), with weathering suffer more or less destruction, the initial cracks expand, and their number progressively increases, small and large fragments fall away from the corners and edges and pile up at the base or roll down the slopes, forming talus deposits. The smooth surface of rock becomes rough and corroded, lichens cluster in some places, dents and crevices appear at others and elsewhere we see black or rusty stains.

These forces—heat and frost, dew and melt water, water seeping into the rocks, and vegetation—do, as it were, not only their own work but also help other forces of nature—the rain and wind. Water cannot wash anything away, and the wind cannot blow anything away from a smooth, newly formed rock, for it is too hard for them, and the grain adhesion is too strong. But from a rock subjected to weathering, the rain washes away liberated grains. The rain, collecting in runnels, gradually wears away notches in the rock. The wind disperses liberated sand and dust particles and breaks off decayed corners and carries them away or hurls them down slopes. The wind blows harder on a mountain top than in a valley or on a plain, and the higher the mountain, the stronger it blows. It blows against the most rugged summits and crests, where aided by frost and heat it destroys the rock.

If we linger for some time near a larger rock, or sheer wall, or on a sharp crest high up in the mountains we can occasionally hear the loud reports of falling blocks, or the noise of boulders sliding down a slope. When the wind blows, or after a rain, or on a quiet frosty night, or in the spring, when the snow melts, this noise, which speaks clearly of the mountain's gradual and uninterrupted destruction, is heard more frequently.

Land Forms. Weathering forces not only accelerate and facilitate the action of flowing water, surf waves and wind but, as a rule, make this action possible. The combined activity of these and other geological agents evolves the majority of the diverse

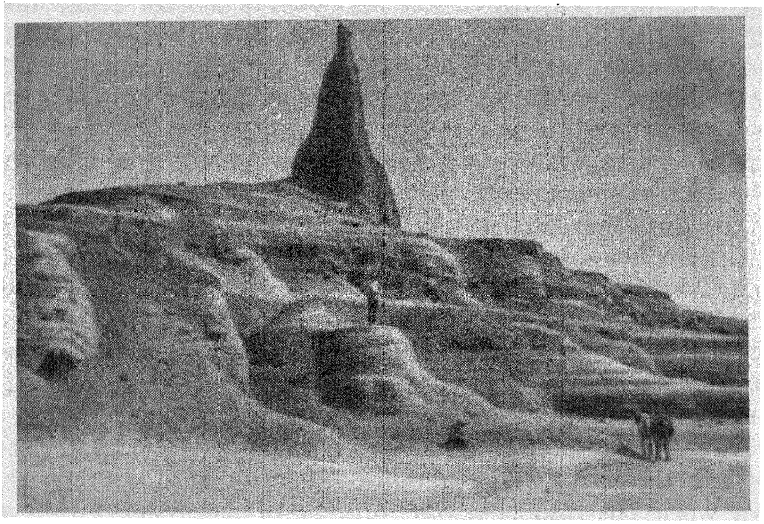

Fig. 68. Needle of soft sandstone and clay in "Eolian Town," Dyam River, Jungaria

forms of the Earth's surface which we see and whose beauty we admire, or whose uniqueness makes us wonder.

These forms can be divided into positive and negative, major and minor forms.

Mountain crests, summits and spurs constitute the large positive forms, and valleys, ravines and hollows, the large negative forms.

Among the minor forms with which we meet, isolated from or in conjunction with the major forms, which more strikingly display the variety of the latter, are such positive forms as towers, pillars, needles, tables, mushrooms, rocking stones, and negative forms: niches, pockets, pipes, honeycombs and cells. These minor forms give a clearer picture of the immense dimensions of the disintegration and erosion which caused their appearance. We are often able to measure these dimensions exactly. Minor forms are met with most frequently in deserts where they are extremely varied. Here the wind is chiefly responsible for their formation; in the desert the wind reaches maximum velocity because of the scarcity or absence of vegetation, which elsewhere protects the soil and slopes from its blasts. On mountain crests

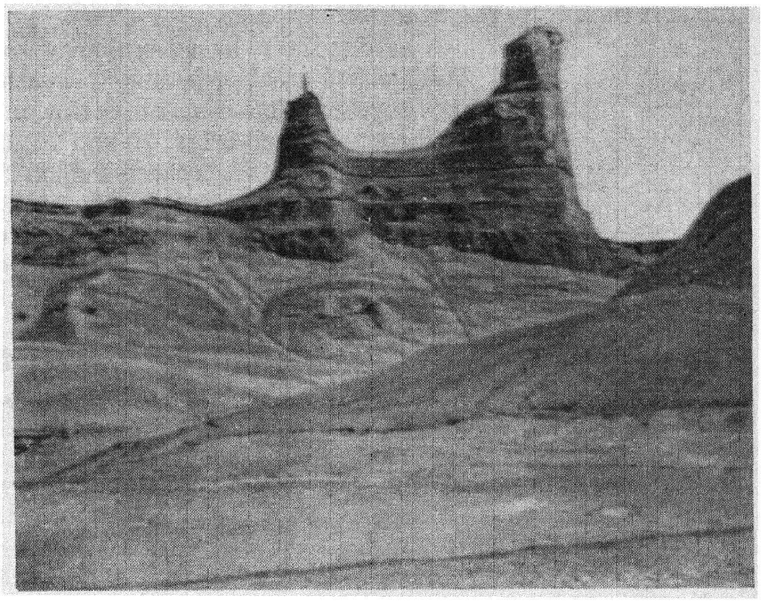

Fig. 69. Saddle of soft sandstone and clay in "Eolian Town"

and summits these forms are also frequent and varied; and here the wind, aided by frost and snow, is their main creator.

Take, for instance, the photograph of the needle (Fig. 68), which I took in the Jungaria desert on the banks of the Dyam River, where an extensive area is known as the "Eolian Town" for its collection of different-shaped forms resembling the ruins (walls, towers, streets) of a town, evolved mainly by the wind. The needle is of soft sandstone and sandy clay in undisturbed deposits. By measuring its height, about 20 metres, we can estimate that a 20-metre bed of sandstone once surrounded this needle. This is a residual deposit which has survived because of the numerous hard lime concretions in its upper part which strengthened it and protected its lower layers from the effects of weathering.

No less elevated and impressive is the saddle-shaped form with two towers in the same area (Fig. 69). The height of the man on the left tower gives an indication of the height of the tower and of the intensity of weathering that has taken place. The photographs show a total absence of vegetation—protection for the soft rock from the wind.

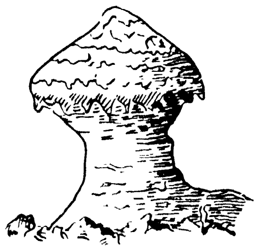

Fig. 70. Eolian mushroom in Vadi Tarfekh, Egypt

A harder layer, based on looser rock, which offers great resistance to weathering, is responsible for the evolution of mushroom-shaped (Figs. 70 and 73) and table-shaped forms. Sphere-shaped and lens-shaped concretions thanks to their hardness also create quaint forms, which travellers claim to have seen in the desert of the Mangyshlak Peninsula (Fig. 71).

On some mountain tops in the Northern Urals we meet with groups of lofty pillars of hard quartzite, which have survived the weathering of strata of this rock (Fig. 72). Similar pillars, but of granite, are found in Northern Siberia. An important part in their formation was played by fine snowflakes and dust, transported during winter snow-storms by violent winds blowing inland from the sea, which gradually sharpened their sides. Possibly these fine grinders also took part in evolving the pillars in the Urals. To the Yakuts of Northern Siberia these pillars are known as "kigilyakhi," i.e., "human"—they used to regard them as petrified human beings.

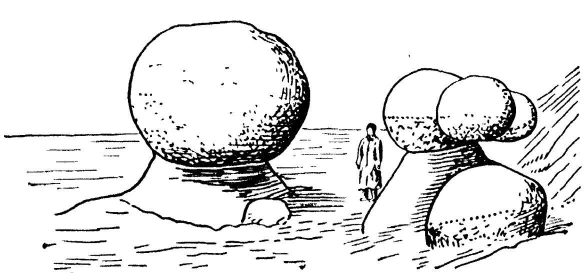

Fig. 71. Eolian spheres in desert of Mangyshlak Peninsula

No less quaint are the rocking stones—huge residual boulders, remains of the weathering of massive hard rock, similar to the one depicted in Fig. 77 (this rock rests on a small base and

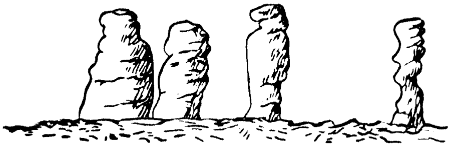

Fig. 72. Pillars of quartzite shales on summit of Bolvan-Iz, Northern Urals

rocks in the wind). Of interest are the rocks with several supports, for instance, the granite rock depicted in Fig. 78, located

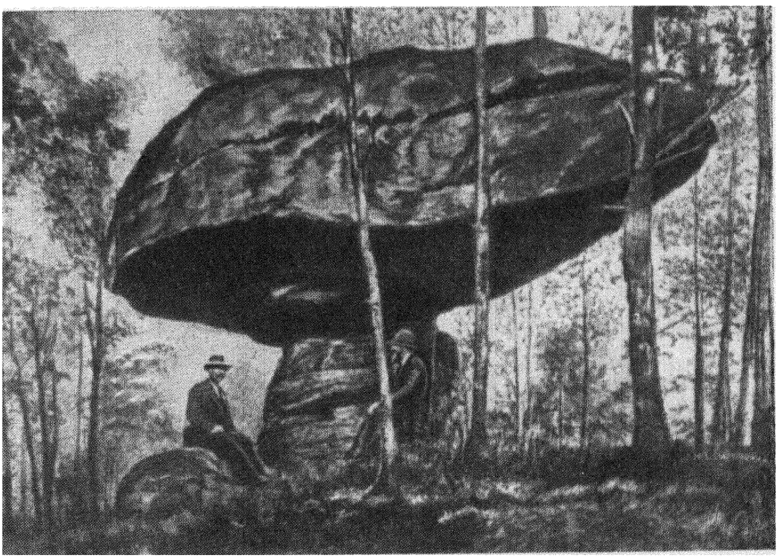

Fig. 73. Eolian mushroom of chalk sandstone near Schangnau, Saxon Switzerland

on the Kalbinsky Ridge in Eastern Kazakhstan, and also the rock in Jungaria (Fig. 79).

Massive rock of coarse-grained minerals, like granite, are subjected to a special kind of weathering distinguished as *spheroidal weathering*. The action of the frequent shrinking and swelling of the rock caused by temperature fluctuations does not penetrate deeply—rock is a poor conductor of heat. These surface fluctuations cause the upper layer to peel off in the form of

Fig. 74. Eolian pillar "Tower of Perfidy and Love" near Kislovodsk, Caucasus

a thick shell; it then breaks into fragments which pile up at the base of the outcrop. The granite is gradually destroyed, and a continuous outcrop may ultimately be transformed into a heap of rounded boulders (Fig. 80).

Massive rocks, formed from molten magma cooled in the bowels of the Earth, are always ruptured by the cracks formed while cooling. Deep down in the crust these cracks are minute,

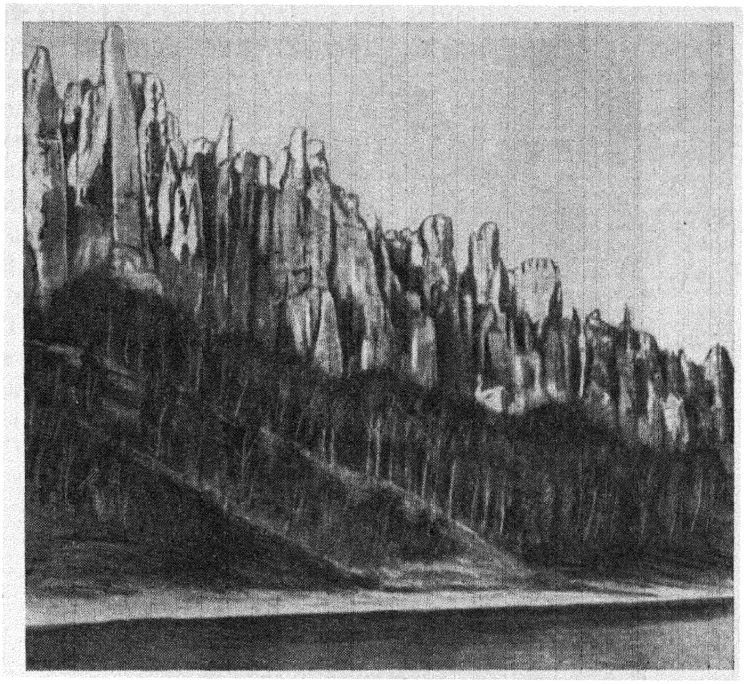

Fig. 75. Eolian pillars of Cambrian limestone on left bank of the Lena between Olekminsk and Yakutsk

almost invisible, but in time, when the rocks appear at the surface, they are widened by weathering, and they naturally disintegrate. These cracks are known as jointing.

Granite is especially subject to cracking; this cracking causes granite to break into flat-shaped bodies resembling mattresses or pillows and is called pillow-jointing. We see pillow-jointing granite on Fig. 81.

Granite and coarse sandstone often become covered with grooves which spread like ulcers and corrode their entire surface. These usually start as a crack in which snow or moisture collects; the grain adhesion is weakened and the separate grains fall apart, then they are blown away and hollows are evolved in the form of pockets or niches. The latter constantly collect moisture, and the process develops until the niche is corroded

Fig. 76. Perya (Feathers) cliff, one of granite pillars on right bank of the Yenisei at Krasnoyarsk

and becomes deeper and larger. Its roof, always shaded, is especially subject to corrosion and sometimes a hole is nibbled away in it. Neighbouring niches may merge and form a gallery of several niches, the intervals being marked on the surface by small pillars. Sometimes the galleries are roomy enough for a man to crawl through them, and at times, in sandstone, for instance, where stronger and weaker layers alternate, the latter develop numerous small niches and galleries, giving the rock surface a honeycomb or cell structure (Fig. 83). These forms can be observed not only in deserts, where they are especially frequent, they can also be seen, for instance, in the hills above Kislovodsk (Krasnoye Solnyshko and Rebrovaya Balka), in the Crimea, in the Southern Urals, in Kazakhstan and on the shore of Lake Kolyvanskoye (the Altai).

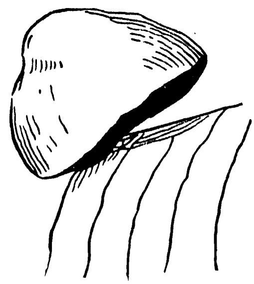

Fig. 77. Tandil rocking Rock, Buenos Aires, Argentina

The importance of temperature fluctuations in rock decomposition is exemplified by the large blocks and boulders

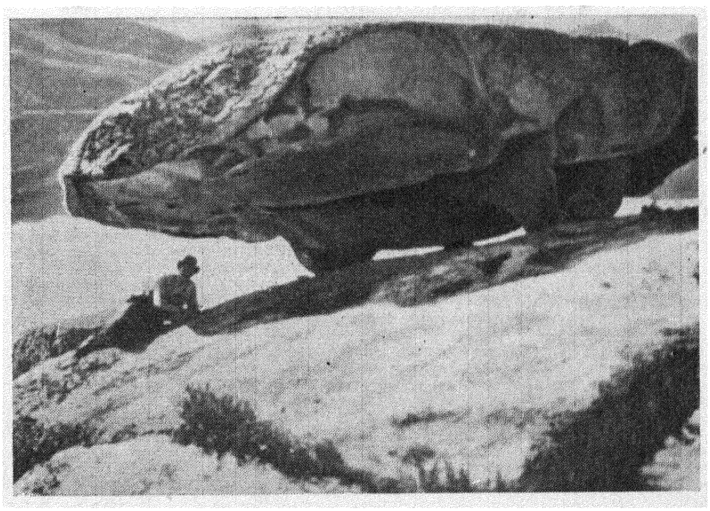

Fig. 78. Zhaba (Toad) granite Rock, Kalbinsky Ridge, Eastern Kazakhstan

ruptured by cracks but which still lie together so that their recent close relationship is easily established. Ruptured rocks are plentiful in deserts. Besides the large, conspicuous boulders, it is easy to discover smaller ones, the products of various stages of

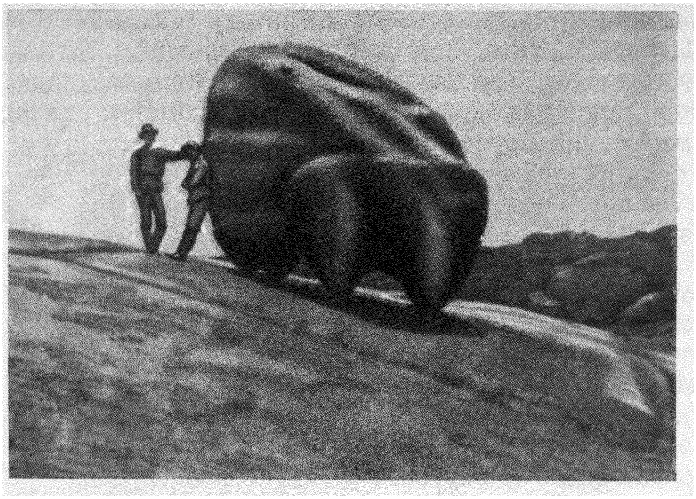

Fig. 79. Granite rock, Jair Ridge, Jungaria

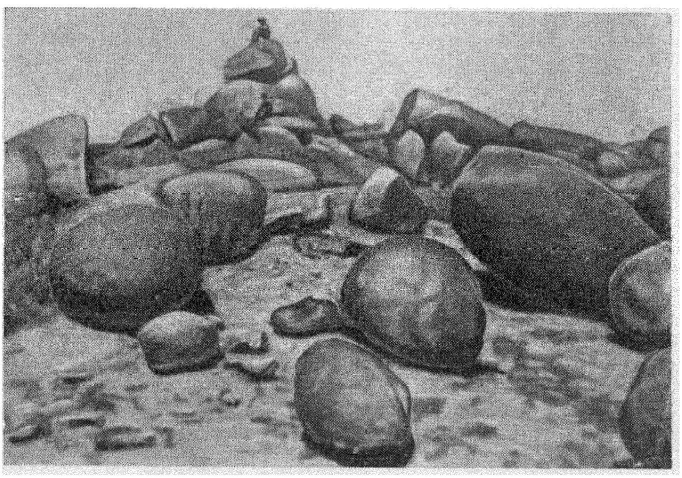

Fig. 80. Shaitan-Obo on the Jair Ridge, Jungaria. Granite outcrop disintegrated into boulders

disintegration caused by the continuous splitting up, which produces the small fragments of the selfsame rock.

Very peculiar are the brushes formed by the weathering of fine-textured slate rock in outcrops, which have split into layers

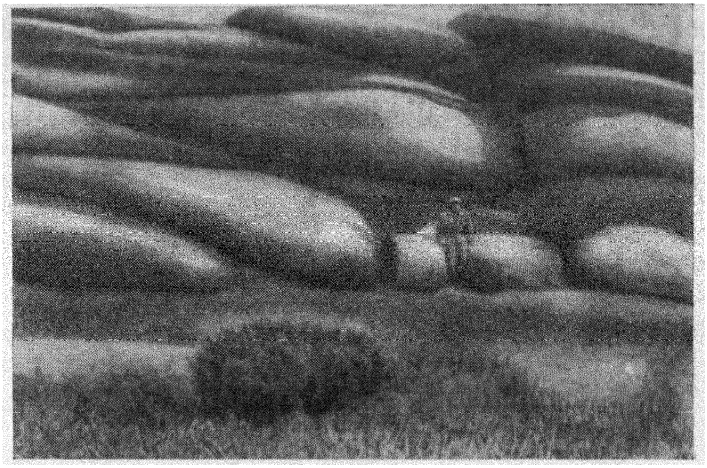

Fig. 81. Pillow-jointing granite in the Arkat Mountains, south of Semipalatinsk

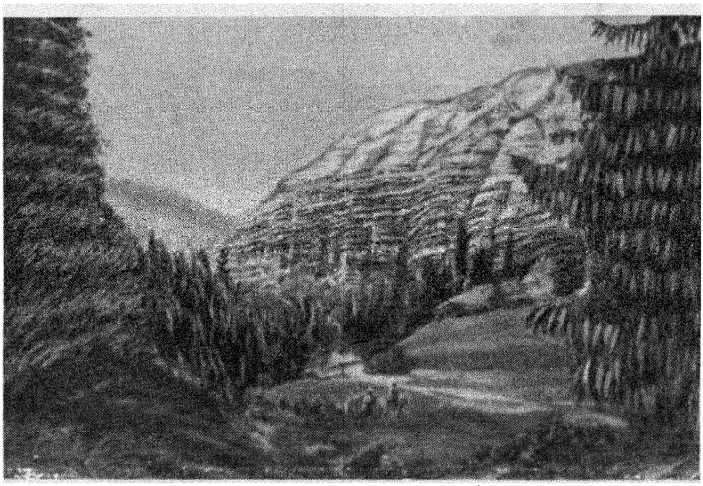

Fig. 82. Grooves and cornices in red sandstone caused by weathering in basin of the Jity-Oguz River, Tien-Shan

and spread out fan-wise at the rock surface, while deeper down they still touch one another.

Desert varnish is a singular product of weathering. It is an exceedingly thin film, hundredths of a millimetre thick, formed on the surface of rock, separate blocks and even on boulders and pebbles. It is of a dark brown or black colour and is more or less shiny, like a stone's coat of varnish. This film is composed of salts of iron, manganese and silica; a darker and more brilliant film is evolved on the hardest and finest-grained rocks which contain these elements; on coarse-grained granite

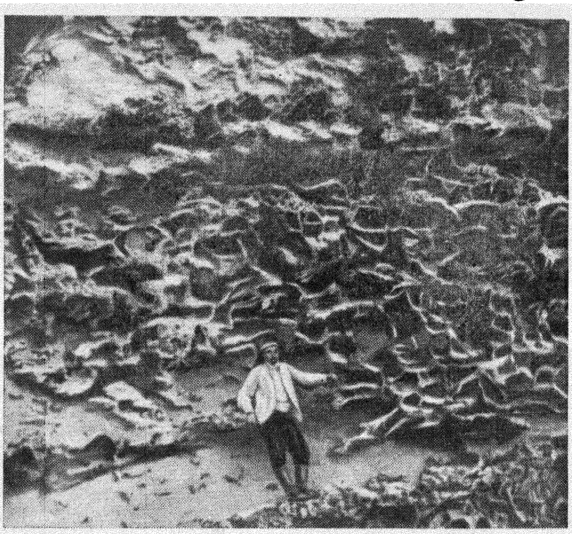

Fig. 83. Honeycomb weathering of chalk sandstone on the Alma River, Crimea

it forms brown spots, and on pure quartz—dull yellow-brownish spots. They appear only on the upper sides and are not found on the lower sides of the boulders or debris.

In the desert, where this varnish is widespread, a fantastic picture is produced: cliffs, rock fragments and boulders on level ground are painted black, and when the weather is overcast it is a miserable, depressing spectacle. But in fine weather the scene brightens up, the varnish reflects the sunrays like a mirror and tiny bluish lights sparkle everywhere—on the slopes, rocks and boulders. The origin of this varnish is not quite clear. It is presumed that it is chiefly caused by dew and the fine dust precipitated from the atmosphere; the dew derives the varnish salts from the rock itself and from the dust. The spheroidal granite, depicted in Fig. 80, is covered with this desert varnish, which is quite an obstacle to geological search because it conceals the rock's colour and grains.

Talus and Debris. Along with the minor positive and negative forms with which we have already become acquainted, weathering evolves larger forms. Rock-waste which crumbles and accumulates at the base forms extensive talus accumulations on slopes. They are often very mobile and difficult to traverse, consisting of large blocks or boulder flint which gives way under

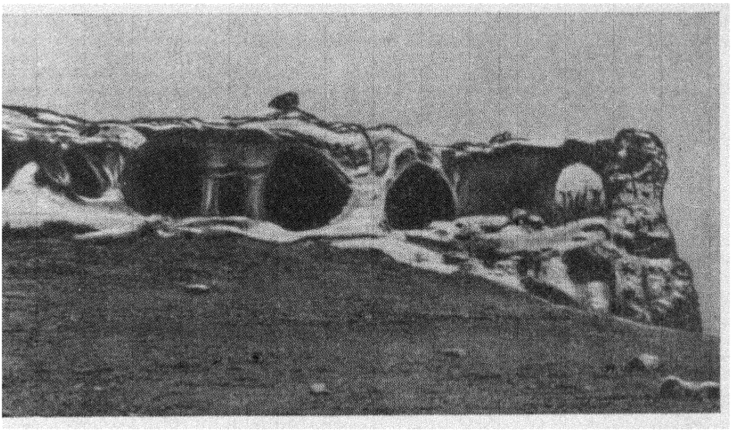

Fig. 84. Eolian niches in sandstone of Koltso Mountain on left bank of the Podkumok near Kislovodsk, Caucasus

the feet (Figs. 86 and 87). Heaps of talus deposits accumulate on level ground. Weathering causes outcrops of hard rock to crumble apart on the flat surfaces of mountain tops, turning them into stretches of debris fragments which spread out in all directions (Fig. 88). These debris are frequent in Siberia and in the Arctic, where they are evolved by the joint work of severe frosts and the moisture of fog, rain and melt water. But in the south, too, mountain tops rising above the snow-line, where the climate approaches that of the Arctic, are quickly destroyed by weathering and abundant talus and debris are produced in which the chief part is played by frost, from which it derives its name of *frost weathering.*

Eluvium and Deluvium. The products of weathering which remain at the place of their origin are called *eluvium.* Eluvium may consist of large fragments, like the debris already described, and of small fragments, the result of their further disintegration in which the main role is played by chemical agents. Thanks to the action of water charged with oxygen and carbon dioxide, all rocks ultimately turn into sand or sandy soil, or into loamy soil, or lime, depending on their composition. Quartzite, consisting of pure quartz, becomes pure sand, white or yellowish (if the quartz

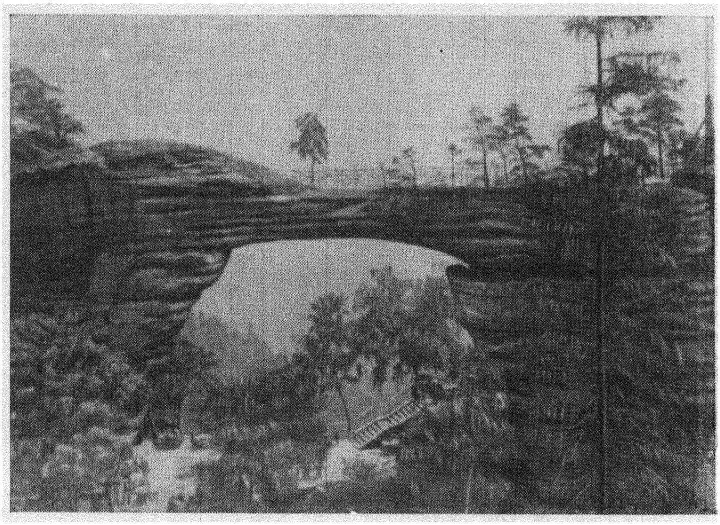

Fig. 85. Eolian Prebishtor Gate in chalk sandstone, Saxon Switzerland

contains ochre), sandstone produces clayey sand; granite at first turns into a loose mass of individual grains, and then into loam, clayey slate, clay. Limestone, usually impure, loses its lime, which is dissolved by water and carried away, leaving admixtures in the form of pure or sandy clay. These final products of weathering are mixed with boulder flint and fragments undergoing different stages of disintegration.

The products of weathering on slopes and in valleys are known as *deluvium* which differs from eluvium only by the components having migrated from their place of origin by sliding or falling down slopes due to gravity. Talus deposits at the base of rocks represent the most coarse deluvium. All slopes, with the exception of rocks and cliffs, are covered with a more or less thick layer of deluvium in which the coarse and fine materials intermingle. Aided by the lubricating action of water, the deluvium moves and slides down slopes sometimes very slowly, impercep-

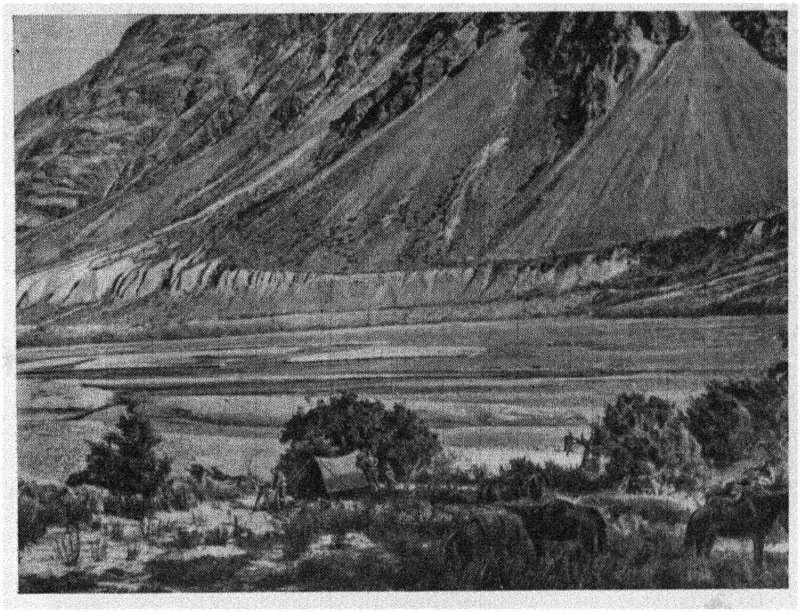

Fig. 86. Talus deposits on mountain slopes. The river Muk-su valley, north-western Pamirs

tibly, and at times rapidly. When thoroughly water-logged, it turns into a thick mud which flows downwards, cutting and tearing away the turf cover, uprooting shrubs and even trees on its way. These mud torrents, sometimes very long and wide, occur in many countries. They halt at valley bottoms, forming fields of thick mud mixed with turf, uprooted shrubs and trees.

Soil Formation. The gradual transition from hard rock to eluvium and deluvium can be noticed in the steep lower part of slopes, especially the parts exposed by the building of roads and railways. In the lower part of the precipice one may see hard

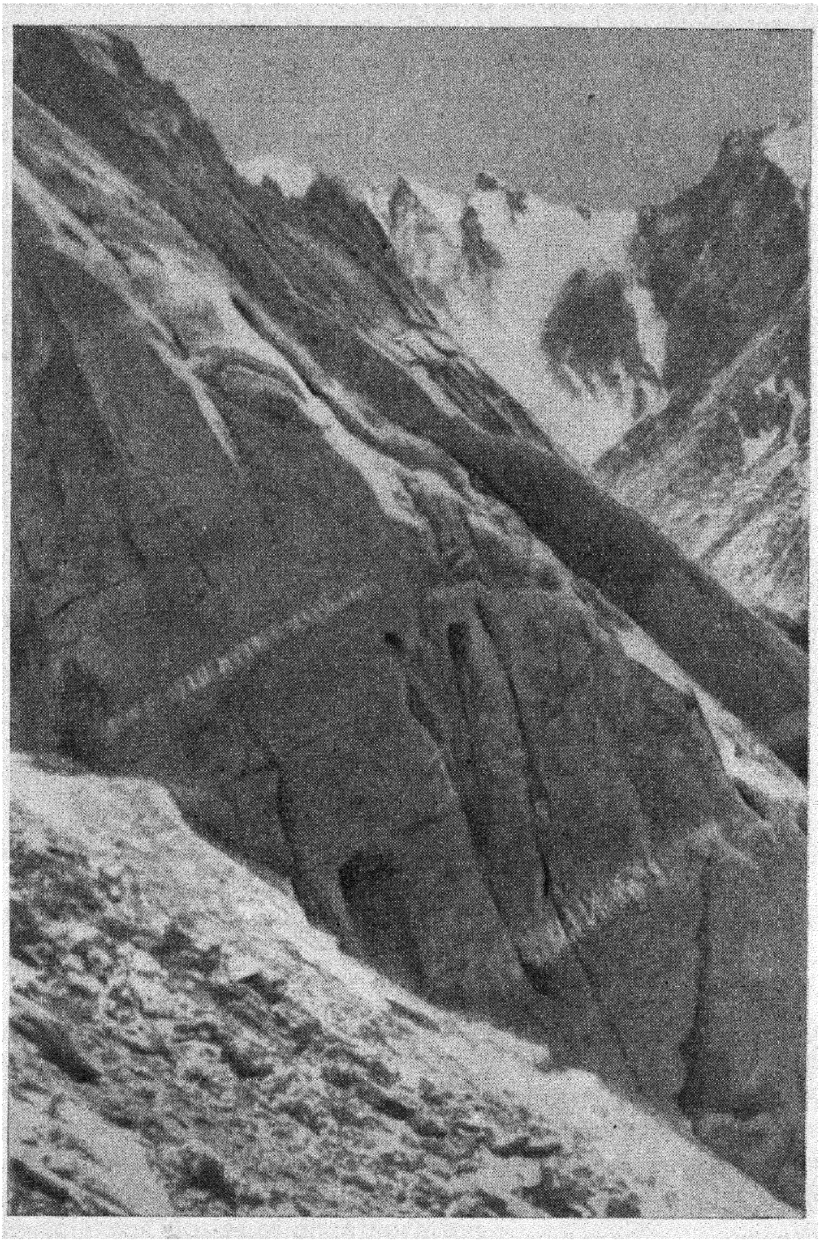

Fig. 87. Pegmatite veins cutting across solid granite, Turkestan Ridge

rock ruptured only by a few cracks, a little higher up the cracks become more numerous, the rock is cut into blocks and fragments, still higher up these fragments are mixed with sand, loam or clay—deluvium—and the precipice is covered by a layer of dark or black earth, pierced by plant roots and known as *vegetation soil* or simply *soil* (Fig. 89). This transition from hard rock to soil forms the weathering rind.

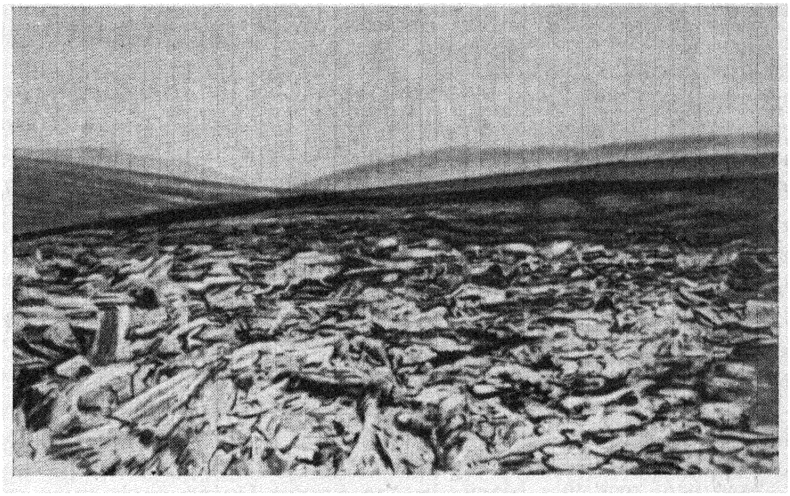

Fig. 88. Bedrock debris on hill tops in Bodaibo Region, Eastern Siberia

In addition to the part played by weathering agents—heat, frost and water charged with oxygen and carbon dioxide—an important role in the formation of the layer of soil on the surface of eluvium and deluvium is also played by roots and dead and decaying parts of plants—leaves, stalks and microscopic organisms—bacteria. Soils are very diverse; they depend not only on their original matter, i.e., on the rock from which the deluvium and eluvium were formed, but also on the climate, which defines the role of any weathering agent, and on the type of vegetation. The rock which weathering has turned into soil is called the *parent* rock. Given different climatic conditions, different products of weathering are formed from the same parent rock; some of these are residual and enter into the soil's composition, others are transported to deeper parts of the weathering rind, while yet others are carried away by ground water. The influence of the climate creates the zonality of the soil, i.e., its distribution in accordance with the world's climatic zones; tropical climates create one soil type, temperate climates, another, while frigid climates evolve a third type. The influence of the parent rock is expressed in a more or less pronounced deviation of the soil type from the one typical for a definite climatic zone.

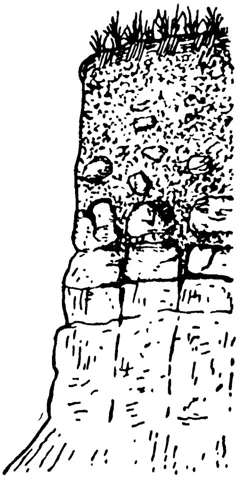

Fig. 89. Transition from hard rock to loose soil

Soil experts divide soil formation into the following types:

Lateritic, typical for the tropics and part of the subtropics. The soils are of a red or yellow-red colour, depending on the deposits of ferric oxide in the upper stratum of the weathering rind. In the U.S.S.R. such soils, called red soils, are found in Transcaucasia, partly on the South Coast of the Crimea and in Central Asia. They are developed in hot and rather humid climates.

The *steppe* type is formed in hot and arid climates. In arid steppes these soils have a chestnut or brown colour, and in regions with abundant atmospheric precipitation—black. In the Soviet Union such soils are found in the Ukraine, the Crimea, in the Caucasian foothills, in Central Asia, South Siberia and in the black-earth regions of the R.S.F.S.R. They are very fertile for, thanks to the arid climate, the easily dissolved salts, needed by plants for their growth, have not been extracted from the upper stratum of the weathering rind. The colour of the black soil is due to the high content of the accumulated vegetation humus, which serves as the soil's natural fertilizer.

The *podzol* soil type is typical for cool and moist climates. The abundance of moisture brings in its train the sinking of the dissolved salts into the deeper stratum of the weathering rind, while the upper stratum, within reach of the plants' roots, lacks these salts and is, therefore, not very fertile. These soils are ash-coloured or yellow-greyish, covered by a thin black layer containing humus. In the U.S.S.R. they are found all over the north, and to the south they gradually give way to steppe soils.

Swampy, saline and *saliniferous* soils are typical for all climatic zones with specific local features. The swamp-type soil is found in areas where the ground water rises practically to the surface, i.e., in depressions and swamps. The saline and saliniferous soil types are typical for an abundance of sodium chloride, which is injurious to most plants, and they develop in specific conditions, which further the accumulation of these salts in the upper stratum of the weathering rind. The saline soil type is found in the zone of podzol soils, and the saliniferous type in the zone of steppe soils.

The process of the development and transformation of soils is highly complicated and one must be well versed in chemistry to understand it. Hence we shall confine ourselves to the foregoing which provides us with at least a general idea of the soil types and their distribution according to climatic zones. We should also note that, upon ascending mountains, the climate changes in respect to the quantity of heat and moisture, with the result that the soils on the slopes also reveal climatic zonality, i.e., they correspond to definite climatic conditions (in a vertical direction). High up in the mountains and in the Arctic, where the soil temperature during a larger part of the year is below zero, and where chemical processes are very weak, with mechanical ones dominating (the simple disintegration of the parent rock into large and small fragments), *skeleton* soils are evolved, representing a simple mixture of this rock-waste subjected only to slight chemical change. Skeleton soils are also found in deserts where the lack of moisture likewise retards chemical processes, while the sharp temperature fluctuations aid the mechanical disintegration of the parent rock.

The fertility of the soil depends on the composition of the easily dissolved salts, which the plants assimilate, on the distribution of these salts in the weathering rind and the structure of the soil. If the soil is very compact and slender roots barely penetrate it, even given ample quantities of salts, it will be less fertile than porous soils into which roots and also air penetrate more easily. Air is necessary both for oxidation processes and the breeding of bacteria, which decompose vegetation remains in the soil and also help to evolve and accumulate the nitrogen needed by the plants. The main significance of organic fertilizers for raising soil fertility is in introducing nitrogen combinations into the soil. Burrowing animals such as moles, insects and worms assist in loosening the soil, in shifting components from one layer to another, in breaking up and changing the soil.

Wild plants, which extract from the soil the substances needed for maturing, return these substances to the soil after withering in the form of vegetable humus, to which are added the carbon dioxide and nitrogen they have extracted from the atmosphere. Cultivated plants are used by man fully or partly (the tops of cereals and roots of many vegetables). These plants increasingly exhaust the soil, and their cultivation necessitates annual fertilizing to return to the soil the substances needed for their growth.

V

WIND ACTION

Dust-Storms. Simooms. Transportation of Sand and Dust. Dunes. Barkhan Sands. Shifting Sands and Their Control. Sand Heaps. Dust Sources. Exodus of Desert Dust. Loess. Types of Deserts.

A long spell of dry warm weather is inevitably associated with dust. The soil of unpaved roads, of freshly ploughed fields, and slopes unprotected by vegetation becomes parched and crumbles into fine particles which the wind lifts and carries away. Even paved or asphalted roads are dusty and need watering. Gusts of wind raise clouds of dust from the roads and, in the spring, from ploughed fields. The air, clogged with dust, becomes hazy, the horizon is obscured. Areas with loose sand become very dusty, although the wind constantly winnows the sand, every gale discovers fresh fine material, as the process of weathering continues to grind down sand grains.

Dust-Storms. Real dust-storms occur at times, especially in the southern part of the Soviet Union in early spring, when the fields are not yet protected by green sprouts, and in April and May when there is insufficient rain. During these dust-storms the sky becomes quite dark, the red disc of the sun is faintly seen, the dust penetrates into houses even through closed windows and doors. In the street it gets into one's eyes and teeth, making it difficult to breathe.

In Africa, in the vicinity of sand deserts, the dust-storms are called simooms, but actually they are sand-storms as the wind carries clouds of sand grains. Dust-storms also rage in North China and in South Mongolia, where they are called "hei-fengs" (black winds) and "huang-fengs" (yellow winds), depending on the colour of the dust, and elsewhere, for instance, in Australia (Fig. 90).

Dust is raised even in calm weather. On hot days we can see pillars of dust suddenly rising from roads or fields, rolling and whirling about, and, as abruptly, thinning out and vanishing. This is a dust-storm or *whirlwind,* caused by the spiral motion of

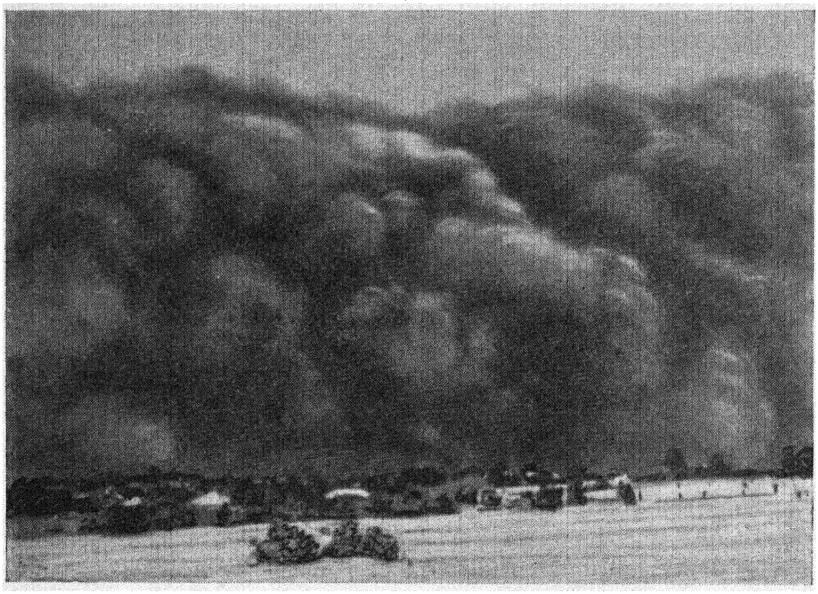

Fig. 90. Dust-storm brewing in Western Australia

the air. Bits of paper, straws, twigs, leaves are tossed high into the air and drop back to earth.

Dust-storms are frequent in deserts and in steppes, where they keep the atmosphere constantly charged, sucking up the fine dust from the ground. The dust saturates the atmosphere for days, until rain beats it back to earth.

Carried by the wind for long distances sand and dust particles form peculiar deposits with which we should become acquainted, because while some of them are harmful, others are beneficial.

Sand Deposits. Let us go to a flat sea-shore or to the flat shore of a large lake built up by the sand which has been washed up by the surf waves. This sand is loose and uncemented and when it dries it is a convenient material for transportation by the wind. Coastal winds often blow with great force. They lift the sand grains into the air or bowl them along the ground until the grains meet an obstacle which stops their further movement. This obstacle can be a shrub growing on a beach. The shrub's branches weaken the current of air and the sand grains drop to earth beyond the shrub. A sand heap is gradually built up behind the shrub in the shape of a longish spit which gradually thins out (Fig. 91, *a*).

A boulder exerts a different influence—being a solid obstacle and not a screen like the shrub which weakens the current of air

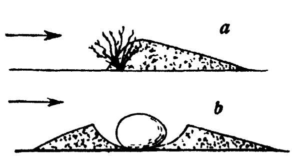

Fig. 91. Formation of spit-swells *(a)* behind bush, and in front of and behind stone *(b)*

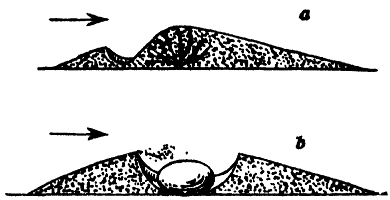

Fig. 92. Small spit-swell grows *(a)* and covers obstacle *(b)*

but lets it through. The lower layer of air is repelled by the boulder, it loses velocity and drops the sand grains in front of the boulder in the form of a shorter spit, directed windward (Fig. 91, *b*). But some wind streams over the boulder's top and round its sides and drops sand grains on its sheltered side. Thus a solid obstacle builds up two sand spits, but shorter ones, in front and behind. The shrub and boulder, however, are temporary obstacles. When the shrub is fully buried in sand it turns into a solid obstacle, and the sand begins to accumulate on its windward side (Fig. 92, *a*). When the spits next to the boulder reach its height, the role of the latter changes; the ruts between it and the two spits begin to fill up, they disappear, and a solid two-sided spit is formed similar to the shrub's spit (Fig. 92, *b*).

The further build-up of sand proceeds alike in both cases. The double-sided spit grows mainly windward, where the sand grains accumulate, but the wind drops grains on the summit and these slide down leeward. Thus, little by little, a typical sharp-crested mound is formed with a gentle windward and steep leeward slope (Fig. 93). But the sand grains carried to the lower part of the windward slope overtake those that rise to the crest, they are carried further, forming small spits which trail behind the leeward slope. Seen from above, the mound is a hollow with two spurs on the leeward side (Fig. 94). This typical picture of a sand mound formed at an obstacle is shaped like a horse's hoof.

In this manner desert sand accumulates at obstacles, and the typical mound described here is called a *barkhan* (Fig. 95).

Dunes. Sand mounds on a sea coast cannot exist by themselves for long. The sea continuously washes sand ashore and the wind blows it further inland. Since the sand meets obstacles the separate mounds begin to merge with their right and left neighbours. A chain of mounds is thus formed parallel to the shore at some distance from the water's edge. This chain is called a *dune*. Crosswise, facing the sea, it has a gentle slope, on which sand grains are continuously winnowed, and a steeper leeward slope, down which slides the sand from the summit. Lengthwise it has flat summits, corresponding to the original mounds, and flat saddles, corresponding to the places where the mounds merged (Figs. 96 and 97).

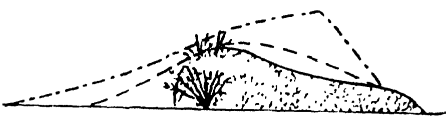

Fig. 93. Swell turns into barkhan

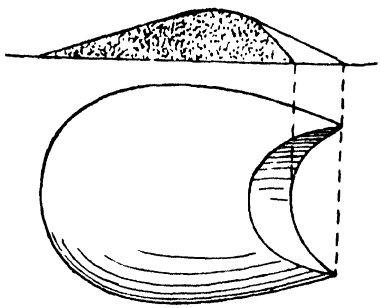

Fig. 94. Section and top view of separate barkhan

Dune Migration. The dune nearest the water is called the advanced dune. It is not immobile; sand continuously shifts from the windward to the leeward slope, and very slowly, over the decades, the dune moves inland. When it has migrated some distance inland, a new dune takes shape on its former site. The first dune continues its migration inland, followed by its successor. And so in the course of centuries several chains of dunes—five, ten and more—are formed parallel to the coastline.

Their height and number depend on the abundance of the sand washed ashore and on the force and constancy of the winds.

They vary in height from 20 to 30 metres on the Baltic Sea shore, to 50-100 metres on France's Atlantic shores, and to 155-200 metres on the shores of the Mediterranean. The rate of drift of small dunes in stormy weather is 2 to 3 metres a day, while large dunes drift from 1 to 20 metres a year. During their advance they sometimes obliterate woods, meadows, pastures, villages on the way. With the passage of time, after the dunes have drifted further on, the buried dead woods and the ruined

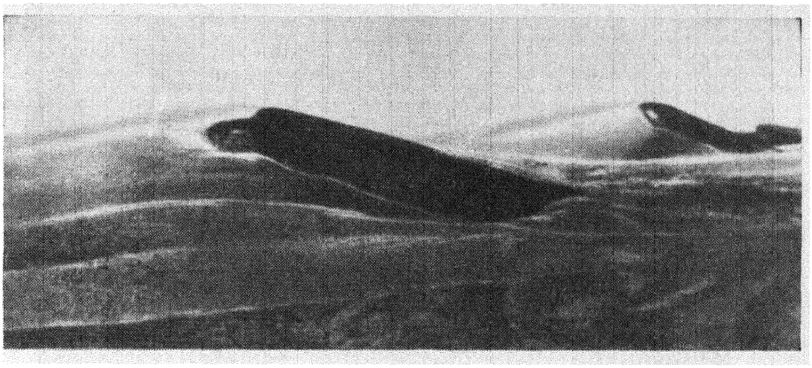

Fig. 95. Large barkhans of loose sand near Chingpien, South Ordos, China

villages reappear. Many of such ruined woods and houses are seen on the shores of the Baltic and North seas and along the Atlantic coast. This is why measures are taken to halt the migration of dunes. Grass and shrubs are planted on unflooded beaches and on the windward slopes of the advanced dune. The crest and leeward slope of the advanced dune and of the dunes of the subsequent chains are protected by planting grass, and then trees, chiefly conifers, which thrive on sandy soils. Gradually, the dune chains can be turned into stretches of woods, and their drift stopped altogether. Only on beaches and on the windward slope of the advanced dune does man continue his fight against the forces of nature. In stormy weather the waves wash away the growths, and the wind uproots and blows them away, and the coast has to be constantly reinforced (Figs. 97 and 99).

Drifting dunes often bar rivers flowing to the sea, turning them into lakes and marshes, as illustrated by the Cazau dunes in France, depicted in Fig. 100.

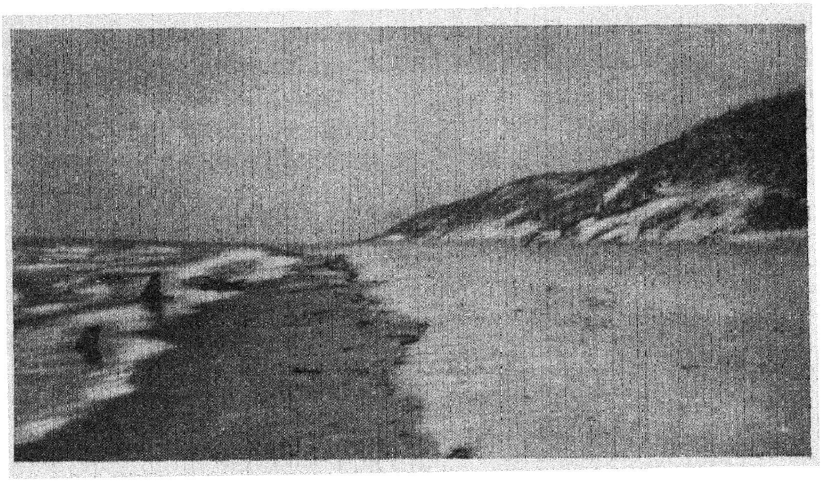

Fig. 96. Beach on the Baltic Sea at Svetlogorsk. Windward slope of advanced dune

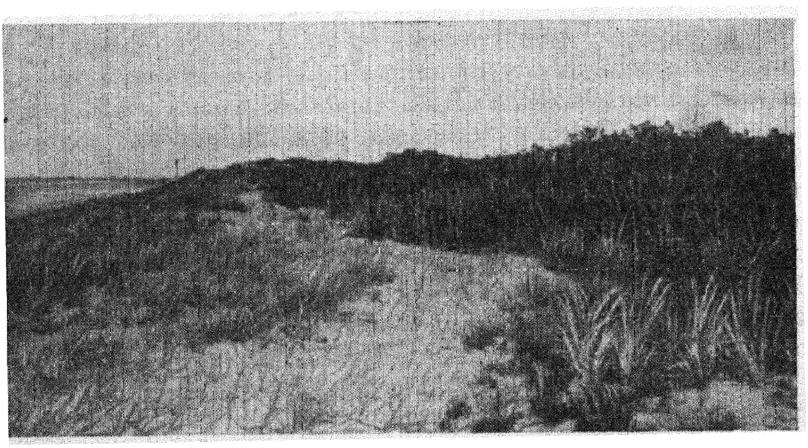

Fig. 97. Crest of advanced dune planted with vegetation. Svetlogorsk

Lake and River Dunes. Dunes also form at large lakes with considerable expanses of flat shore and where the prevailing winds blow inland. But lake dunes do not reach the height of coastal ones, and they attract vegetation more easily. Separate dunes or chains of dunes are also formed by winds on the flat banks and arms of rivers, where in low water extensive areas of

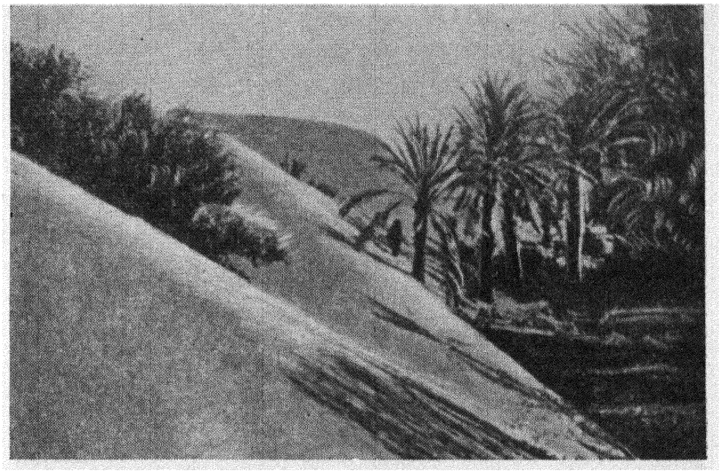

Fig. 98. Drift of barkhan sands at border of Dakhla Oasis, Sahara

deposited sand and silt are stranded high and dry. These dunes also drift in the direction of the wind, and smother woods, fields and villages. They are combated by the systematic planting of vegetation. In the European part of the Soviet Union river dunes are found in the lower reaches of the Dnieper, Volga, Ural, and in Siberia along the banks of the Irtysh, Ob, Selenga, Chikoi and Lena.

Barkhan Sands. The wind discovers other material in the desert for evolving loose sand. It is supplied by the weathering of such sedimentary rock as various sandstones, and by such widespread igneous rock as granite. During the process of weathering this rock disintegrates into separate minerals and sand. Besides, vast quantities of loose alluvium and proluvium are available in the desert from river beds which have dried up after floods and from deposits of short-lived upland torrents which bring down sand and silt, pebbles and rock-waste to the lowlands, where the deposits dry quickly.

In the desert the wind is not a casual guest but lord of the manor. Usually a breeze rises at dawn, gathers force in the morning, reaches peak in the afternoon, loses velocity towards eve-

Fig. 99. Advanced dune covered with trees, west of the Narva River, Gulf of Finland

ning and subsides for the night. Besides these regular winds there are gales which sometimes rage days on end, rising suddenly and ceasing just as suddenly.

On areas with large quantities of loose rock unprotected by a covering of vegetation, the wind sweeps up and carries off sand grains to the first obstacles, which, as on the sea-shore, are shrubs, boulders and rocks, hills and mountain ranges. Behind the shrubs, and in front of and behind the boulders, the wind-borne sand forms spits similar to the coastal ones. These spits also develop into the typical two-spurred mounds with gentle windward and steep leeward slopes (Figs. 93 and 94). The Turkic-speaking desert tribes call the mounds (Fig. 95) barkhans, a term which has entered the scientific vocabulary. Barkhan sands are deposits of loose sand formed in the desert from the products of weathering, in distinction to the dunes made up of sand brought by the waters of seas, lakes and rivers.

With insufficient material for forming barkhans isolated mounds are developed which quickly drift in the direction of the prevailing winds. With adequate supplies of sand the bar-

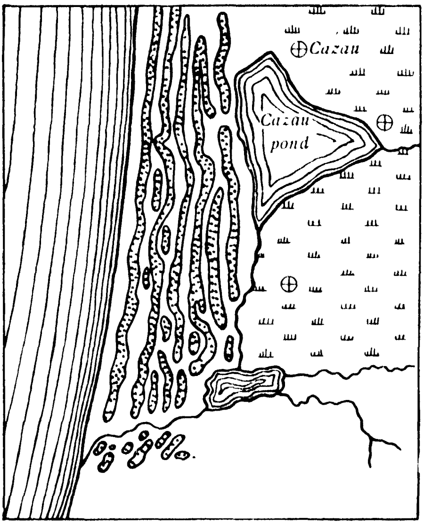

Fig. 100. Plan of Cazau dunes on western coast of France

khans which form at obstacles grow and merge like the dunes, forming barkhan chains.

Their ridges always undulate in the horizontal and vertical directions; the height of their separate summits corresponds to that of the original separate barkhans, and their depressions—the saddles, which usually protrude forward compared with their heights—correspond to the spurs of the neighbouring merged barkhans.

Barkhan desert sands cover considerable areas, running into hundreds and thousands of square kilometres, the chains stretching one after another with crosswise links, so that the gaps dividing them have turned into chains of troughs. This picture can be seen in the Kara-Kum and Kyzil-Kum deserts, the Tarim Basin and in many other areas of Central Asia, in Alashan, Eastern Mongolia, the Sahara, the Arabian Desert, the deserts of Australia, etc.

Barkhans vary in height, usually 15-20 metres, but in some areas, depending on specific conditions—the abundance of sand material and its age-old piling up at high obstacles—they reach

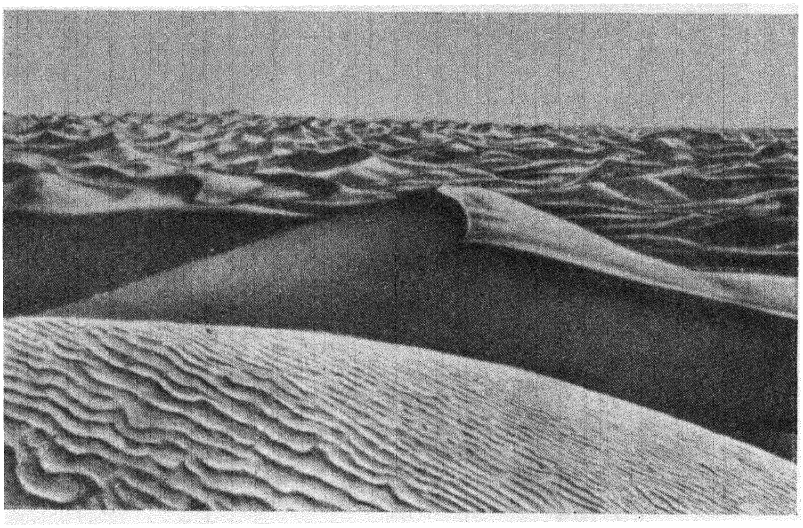

Fig. 101. Barkhans in Sahara near Egypt. In foreground ripples on barkhan slope

heights from 100 to 200 metres, forming regular hills. Such are the sands of the vast Takla-Makan Desert in Chinese Turkestan, and the Kum-Tag sands in the southern foothills of Eastern Tien-Shan, between the towns of Lyukchun and Pichan, and in various parts of the Sahara (Fig. 101).

Obstacles, such as groups and chains of hills and mountains, cause the irregular piling up of barkhan sands in the form of separate barkhans and chains of various sizes and shapes which stretch along valleys and depressions, border slopes, mount their sides and cross their saddles.

Isolated barkhans, especially small ones, quickly drift in the direction of the prevailing wind, the smaller ones, hundreds of metres, the larger ones, about 30-40 metres a year. Barkhan sands advance very slowly, they send separate scout barkhans ahead, which develop in front of the sand areas. These scout barkhans increase in number, merge in twos and threes, and gradually seize new territory, while the main body of sand slowly advances behind.

These onslaughts on formerly sandless steppeland, cultivated fields and villages are made in Turkmenia, Uzbekistan, Kara-Kalpakia, Kazakhstan, the Tarim Basin, and on the borders of the loose sand area in Ordos, Central Asia.

This menace cannot be coped with by individual peasants. The sands can be one kilometre away from his fields, orchard or home. During a gale the wind-borne sand gradually collects at obstacles: small spits appear behind shrubs, on field furrows, in road ditches, under hedges. With each strong wind the spits grow in number and size; the soil becomes increasingly sandy. After a few years the spits turn into mounds and then into barkhans; the fields yield less. Another decade passes and the sands lay siege to the peasant's home, his fields have practically disappeared under a mantle of sand, the barkhans have already penetrated into the orchards, crept along fences, crossed them, crowded into the yard and climbed up the walls to the roof of his house. And the peasant is obliged to forsake his farmstead. Only collective effort and state aid can halt this offensive. And this is done by the extensive planting of vegetation.

It would be wrong to think that barkhan sands are completely devoid of vegetation. There are very few such sand deserts; these are the sands of the Sahara, of the Arabian and Takla-Makan deserts and certain areas of the Kara-Kum and Kyzil-Kum deserts. In most cases some grass grows and shrubs nestle at the bottom of the troughs between the barkhans and sometimes they appear on the slopes. With an abundance of vegetation the barkhans smooth out—their crests round off, the steep leeward slopes become less steep for vegetation protects their surface and detains the sand. These sands are called mound sands from their mound-like shape, unlike the barkhans.

People who cut out shrubs for fuel, and cattle which eat and trample the grass are the chief saboteurs of sand vegetation for they help the sands to return or to conquer fresh areas. The mound sands in the vicinity of the camping sites of the former nomad cattle-breeding tribes were especially desolate and they turned into barkhans. Other saboteurs of sand vegetation are rodents—the suslik and sand rat—which are found in large numbers in some troughs; they injure roots by burrowing and provide loose material for wind action. Troughs colonized by these animals are distinguished for their barrenness and withering vegetation.

Ripples. The sand's surface on the windward slopes of barkhans and dunes is always slightly uneven, with tiny crests or small flat swells with grooves in between, which, in their entirety, form ripples. These ripples are caused by breezes which carry the sand grains for short distances. If we look closer we see that the swells consist chiefly of smaller grains, while in the

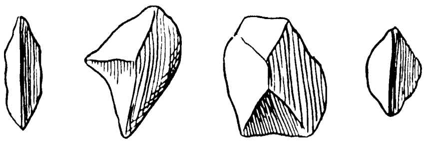

Fig. 102. Pebbles ground and polished by sand

grooves the grains are larger. Hence the wind grades the grains. Actually the swells are dune and barkhan chains in miniature. The positions of the swells and grooves change with every change of wind, taking up a position perpendicular to its direction (Fig. 101).

Polished Stones. The numerous wind-borne grains consist mainly of hard quartz. Striking and streaming over the surfaces of rock-waste, pebbles and rocks the grains sharpen and polish them. The results of this work—the rock-waste and pebbles—can be seen everywhere where there is rock in the vicinity of sandy expanses.

The sand which abrades the rock does this work with varying degrees of success, depending on the latter's hardness; the softer the rock, the quicker it is abraded, while very hard rock is mostly ground and polished. The surface of rock with grains or sections of different degrees of hardness becomes uneven, the harder parts protrude like crests or mounds, the softer parts correspond to hollows and grooves. Rock-waste which has lain on the sand in the same position for long receives an all-round sharpening, but in varying degrees, depending on the frequency and force of the wind. In this manner interesting three- and four-faceted highly polished stones with relatively sharp edges are evolved from hard rock. These stones can be collected in the desert (Fig. 102).

Sand Heaps. In places where sand is lacking for the speedy formation of barkhans and where vegetation is abundant, the sand slowly accumulates under the protection of this vegetation, which successfully holds up its advance. Special forms of sand accumulation are evolved—heaps and mounds of various sizes—called sand heaps. Their shape and size depend on the kind of vegetation growing in the area. Small shrubs with few thin branches pile up sand heaps like grave mounds from half a metre to a metre high. Thick shrubs like the tamarisk, which often grows in clusters, raise sand heaps, like small knolls resembling burial mounds 3-5 metres high. Under the protection of reeds near springs the sand is heaped up like flat knolls. The needle grass plant, with its thick, sheaf-like tufts, builds up small mounds (Figs. 103 and 104).

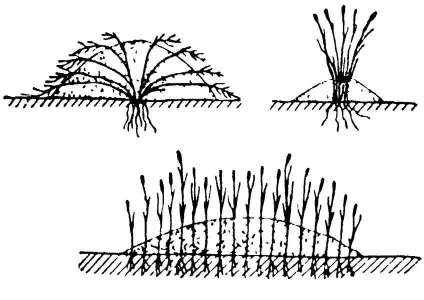

Fig. 103. Types of sand heaps at a bush, a cluster of needle grass and at reeds

Vegetation can withstand the piling up of sand to a certain point. When the sand deposit becomes too high the plants begin to die—their roots no longer reach the ground water. The shrubs dry up, the wind breaks off and carries away withered leaves and twigs and then branches. The sand heap, deprived of its support, is gradually blown away. The wind carries the sand to the live shrubs. Thus there is a limit to the height the sand can pile up for each plant. Tamarisk sands, typical for saliniferous soil and river banks, disappear when the river changes its course. The water bypasses the sands, the tamarisk perishes and the sand heaps are blown away (Fig. 105).

Dust Sources. Now we have learned that in deserts loose sand is heaped up in places where weathering provides sufficient wind-borne material in the shape of decayed bedrock and dried-up deposits of rivers and brief torrents. But besides the sand accumulated in these deposits, weathering provides a still finer material—specks of dust. We also know of dust-storms, which take place not only in deserts, and of dust "devils" or vortexes, which on hot days whirl over steppeland and fields, along roads, raising pillars of dust. What happens to this dust? Had it remained permanently in the atmosphere the latter would long since have lost its transparency, and we would have existed in a dense fog of dust.

Fig. 104. Sand mound overgrown with tamarisk, Jungarian Gate Desert

Dust specks are the finest particles of rock weathering. They float in the air for relatively long periods and are carried over great distances. But finally they settle on the ground, mainly with the aid of rain and snow; raindrops and snow-flakes falling from the clouds collect the floating dust specks and beat them down to earth. You have, of course, noticed how pure and transparent the air is after rain or snowfall. One can see farther and better. This is because it has been cleansed of the dust, which, while imperceptible to the human eye, reduces the transparency of the air (of which we can judge by seeing distant objects).

Every day we observe the settling of dust in our room, both in town and country. It penetrates into the house together with the outer air, from the streets, and settles on all objects. If we do not dust our rooms regularly the layer of dust thickens and becomes so noticeable that we cannot take up any article without soiling our hands. But this dust, which settles everywhere, both on land and water, merges with the soil, is transported by water, and settles jointly with other materials without forming independent deposits.

Given certain conditions wind-borne dust (loess) accumulates on the ground. The desert, where due to lack of vegetation and sharp temperature fluctuations weathering takes place much more vigorously, is in essence a factory for the manufacture of vast quantities of fine products—grains of sand and specks of dust. It is also notable for the velocity of its winds. Absolutely calm days are rare. We have already mentioned this and also noted the frequency of sand-storms which occur even on calm days, sucking up and raising the ground dust aloft. Because of this desert air is less transparent than in more humid regions with abundant vegetation, which protects the topsoil from the wind's action.

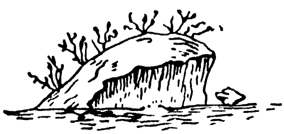

Fig. 105. A tamarisk sand mound being blown away

Desert winds are usually directed centrifugally, i.e., from internal areas to its borders. They cleanse the desert, tidy it up and sweep the weathering products away to its borders. If not for the wind all the desert mounds and hills would have long ago been buried under a mantle of bedrock weathering. Yet travellers in the desert meet with far more bedrock outcrops than in humid areas. These outcrops can be seen everywhere, on mound and hill slopes, often even on depression and valley floors. True, they are ruptured, demolished and have often turned into disintegrated fragments, boulders and rock-waste, but they lack the layer of soft soil that in humid areas usually covers the bedrock, which is rarely exposed, and then mainly in the lower part of slopes eroded by running water. Eluvium in deserts is either absent or forms a thin layer of coarse deposits, while deluvium accumulates only on the lower parts of slopes.

We already know that barkhan sands are the product of desert weathering. But these sands by no means cover all the desert's expanses. They accumulate mainly at its borders and seldom in its centre, usually at places where weathering creates especially abundant material or where there are especially large obstacles which stop the further migration of material. The bulk of the grains of sand and specks of dust is blown from the middle of the desert to its borders where the larger grains settle and, gradually accumulating, form vast areas of barkhan sands. The finer specks of dust are borne still farther, beyond the desert borders, to the region of vegetation where the climate is more humid, with rainfalls, where the desert winds meet winds blowing from other quarters, and, finally, they lose their velocity and deposit their fine material.

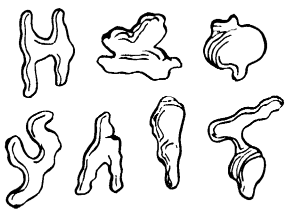

Fig. 106. Loess dolls

Loess Formation. This wind-borne desert dust gradually accumulates and forms deposits of specific soil of varying thickness called *yellow soil* or *loess*.

Loess has a greyish-yellow or brownish-yellow colour, cuts easily with a knife, is easily crushed between one's fingers, and yet is so tough and has such high resistance that it forms sheer precipices several yards and, sometimes, 10-20 metres high. It has many minute cavities. This can be illustrated by putting a bit of loess into a glass of water: the loess will expel air bubbles, which the water forces out. Besides the minute pores, imperceptible to the eye, we can see narrow vertical cavities—tubes—left over from plant roots. Loess consists of fine sand and dust—grains of quartz, felspar, clay, limestone and minute sparkles of mica all packed closely together. In water it forms a sticky mud, and on roads under the wheels of vehicles and horses' hoofs it is ground into a fine dust. This is why the roads running through loess are very dusty in dry weather—clouds of dust rise from under the feet, and in rainy weather they turn into mire—a thick mud sticks to one's boots.

A study of the composition of loess shows that it consists of fine sand and dust. Typical also of loess is the absence of stratification; it forms a solid body, and is not divided into thin layers like the sedimentary rock that is deposited in water. The content

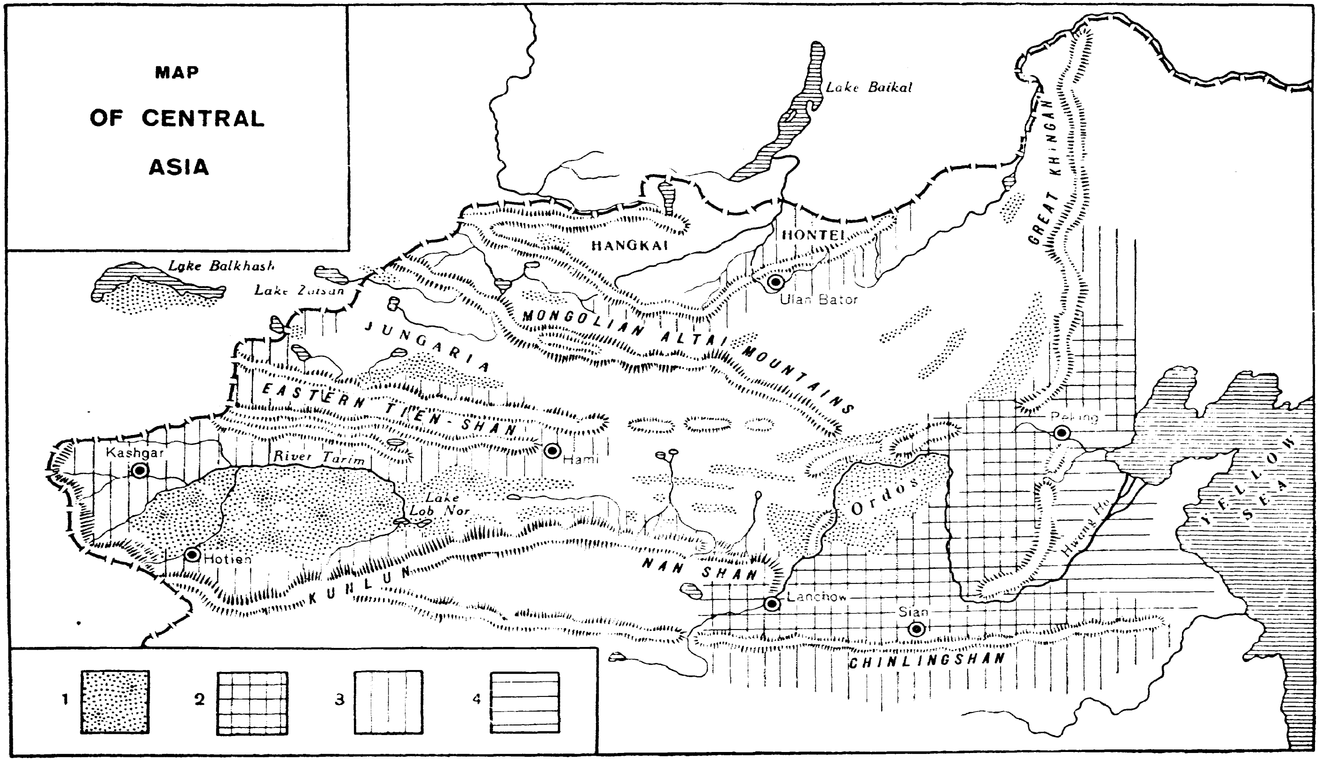

Fig. 107. Map of Central Asia. Areas of loose sand and loess

1. Sands. *2.* Very thick loess. *3.* Thin loess. *4.* Layers of loess redeposited by rivers with layers of unstratified loess of lime in loess is seen in the frequent presence of lime concretions in loess precipices in the shape of round or elongated stones (like the roots of horse-radish) known as "dolls," either ingrained in the loess separately or forming entire levels (Fig. 106).

The characteristics of loess are explained by it originating from slowly accumulated wind-borne desert dust. The dust settles on the steppeland which borders deserts. The steppes are covered with more or less abundant grass and dwarf wormwood shrubs on which the dust settles and coats their stems and leaves. When walking in such a steppe one's boots become covered with a yellowish dust. The wind and rain beat the dust to the ground; it adheres permanently to the earth and, in this manner, very slowly, little by little, the dust soil is built up, perhaps at a rate of only 1-2 millimetres a year, but in the course of thousands of years it forms layers of 10, 20, and even 100 metres thick and over, providing the conditions remain the same (Fig. 110).

Characteristic of loess is its negligible humus content, due to the dry climate of the steppe where it accumulates. Some parts of perished plants are not interred in the soil, but gradually fall to dust, which is blown away, leaving their roots rotting in the ground. Yet loess is highly fertile, thanks to its porosity which permits air to reach the root fibres, and to its high content of dissolved salts, which plants need for their growth.

China—Land of Loess. Loess is evolved at present in those countries where conditions favour it—ample expanses of desert for a "dust factory," bordered by grassland capable of accumulating it. The best modern example of this "dust factory" is Central Asia, and for accumulating loess—Northern China.

A glance at the map of Central Asia (Fig. 107) will show that considerable areas are covered with deserts—the Gobi Desert in Eastern and Central Mongolia, which in the west merges into the Khamiisk Desert (Bei Shan), which lies south of the Eastern Tien-Shan mountain range, and into the Jungaria Desert, to its north. These are the "factories" from which sand and dust are blown outwards to the borders. The sands form extensive areas: to the east—along the foothills of Great Khingan, to the south in Ordos, along the banks of the Hwang Ho River and in Alashan, to the south-west—in the Tarim Basin (Takla-Makan) and in the north-west, the Kobbe sands. Besides these vast areas there are some lesser ones within Gobi itself, but still the concentration of loose sands along the borders, especially in the south-east, south and south-west is quite pronounced. Beyond the sand areas lie the loess areas; the largest of these are situated in Northern China—the Hopei, Shanhsi, Shenhsi and Kansu provinces—where the mountains, plateaus and valleys are covered with a solid loess blanket not less than 100 and, in places, 200-300 metres thick. China is a typical loess country, where the parent bedrock is exposed from its covering only on the crests and slopes of the

Fig. 108. Man-made terraces in loess. Shanhsi Province, Northern China

higher mountain ranges and, in places, at the bottom of the larger deeply cut river valleys, especially in the Hwang Ho basin. Serious incursions have been made into the loess by numerous gullies and valleys (Fig. 108), but the same loess of deeper strata is visible on their slopes. The entire life of the population bears the unmistakable loess hall-mark. Houses are made of loess (from baked or raw bricks), cave dwellings and entire villages are dug in loess precipices (Fig. 109), for loess caves, because of the softness of the soil, can be dug easily; then they are warmer in winter and cooler in summer than ordinary houses; all cereals and vegetables are loess-grown, all roads cut through loess. Yellow is the dominating colour both on earth and in the air, with its abundant loess dust—and it was China's "sacred" colour.

This chief loess area directly borders on the sands of Alashan, Ordos, the Hwang Ho and Eastern Mongolia; in the direction of these sands the loess becomes increasingly sandy. In this arid steppe area settles the dust blown south-east from the desert by the prevailing winds. Loess is also advancing up the northern ridge of the mountain chain of Eastern Kunlun, which terminates the loess area of the south. Beyond this mountain chain, in Southern China, the climate is already different—it is very humid—and the soil is different. The vast lowlands of the Great China Plain to the east are also covered with loess, but this loess has simply been redistributed by the Hwang Ho and other rivers flowing down from the loess highlands, from the region where they erode it.

To the west the foothills and northern ridge of the Nan Shan and Western Kunlun Mountains, the eastern slopes of the Pamirs, and the southern slopes of Eastern Tien-Shan are also mantled by loess. The loess area here is smaller and so is its thickness. It has had no stretches of grassland for depositing the loess (unlike Northern China), and it has settled on mountain slopes from where it was often washed away. But here too the loess areas directly border the extensive Takla-Makan sands. Its vastness, and the height of its massive barkhans, which reach 200 metres, are due to the area—Chinese Turkestan—being encircled in the south, west and north by mountains, and it represents a huge sack into which the eastern winds blew sand and dust, accumulating vast quantities of sand.

There are few sands on the northern borders of Central Asia, but they too have a thin layer of loess. This area is void of extensive arid steppes for here rise the wooded Hangkai and the Hontei highlands which change the local conditions. Moreover, winds rarely blow north from Central Asia. It is only in Jungaria that we again find sands—the extensive Kobbe sands, and beyond them, on the mountains near the Soviet frontier, thin layers of loess. The winds carry dust over enormous distances in this direction and distribute it over large areas.

Hence, in general we have a regular combination of the desert as a sand and dust "factory," with areas of loose sand, and loess accumulation areas. All the peculiarities, all the differences observed along the borders of Central Asia in the occurrence of sand and dust and the thickness of their layers, are explained by the local climatic and vegetation conditions, by its relief and direction of the winds.

Today Central Asia continues to be a sand and dust "factory," and its borders—accumulation areas. But in the recent past, in the first half of the current geological period, the necessary conditions for forming and depositing sand and dust were more pronounced thanks to the climate of the ice periods, of which we shall learn in the next chapter.

Deserts in other parts of the world are also sand and dust "factories," but the regularity of the occurrence of their out-

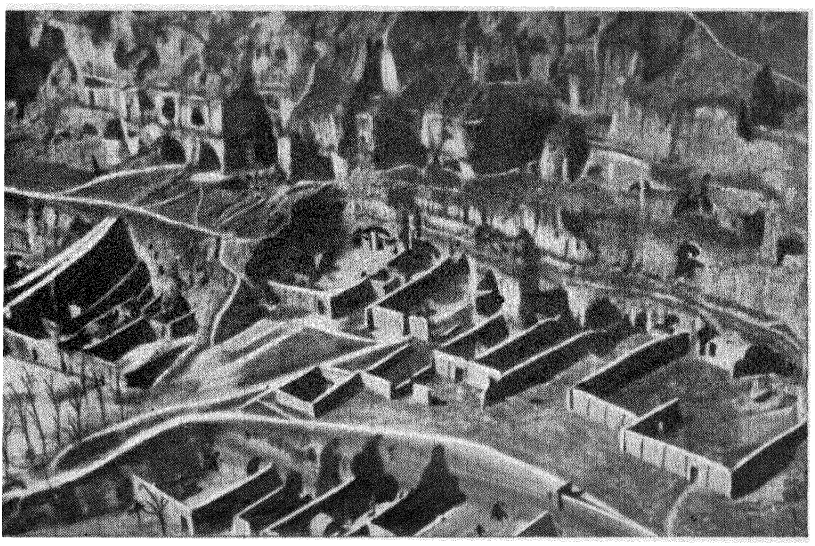

Fig. 109. Loess precipices with cave dwellings. Shanhsi Province, Northern China

cropping and deposition areas is not so pronounced since their climate and location are different. Asia alone has deserts situated in the heartland of a vast continent, and the influence of the oceans and their winds is less than in Africa and Arabia.

Ukrainian Loess. The reader knows that a large part of Ukrainian soil is loess, and he may ask where is the dust "factory" which evolved it. Or, perhaps, it originated otherwise than the loess of Asia? No, it also is made of dust, but its desert "factory" has disappeared. The sole difference between the loess of China and that of the Ukraine is that the first is a contemporary dust soil, while the second is an earlier-evolved mineral, now covered with contemporary soil in the form of chernozem. The next chapter will tell of the location of the desert which created the Ukrainian loess and why it disappeared.

Hence, deserts, as dust "factories" which manufacture fertile soils, play an important part in nature, a part beneficial for man. On the other hand, we know that these sand "factories" accumulate vast quantities of sand on desert borders, whence they mount offensives against steppes, cultivated land and the habitations of man. Deserts, therefore, also cause great harm. But if we strike a balance to see what is more—the bad, expressed in a narrow stretch of sand on the outer borders of deserts, or the good—seen in the fertility of extensive loess steppes, then it is obvious that the good greatly outweighs the bad. We can combat the sand nuisance by planting trees and turning the sands into arable land.

Types of Deserts. We have spoken a lot about deserts as "factories" of dust and sand, as cradles of centrifugal winds, but we have not dealt with their other aspects. Since physical geography deals with the description of the deserts of the world, we shall limit ourselves to a brief outline of their main types.

According to their surface forms and soil composition, deserts are divided into the following types: 1) rocky deserts, 2) stony deserts, 3) sandy deserts, 4) clayey deserts.

Rocky deserts have uneven topography, alternating between mountain ridges and groups of usually small hills, which turn into hillocks with more or less wide valleys and depressions (Fig. 111). The mountain ridges have rugged summits and crests, steep slopes with numerous precipices and outcrops of bedrock. Because of mechanical weathering the latter are severely ruptured by fissures and can easily be broken by hand; the coarse-grained rocks often have hollows shaped like the pockets, niches, galleries, combs and cells of which we have written in Chapter IV. Sometimes entire hillsides of granite or sandstone are full of these hollows, resembling tree trunks pitted by insects, or a porous cheese.

Often parts of hillsides are completely covered with the rock-waste and boulders of bedrock which has crumbled on the spot. These talus and scree debris are numerous on hillsides, i.e., on the less high relief forms which sometimes have no outcrops of bedrock whatever—for they have disintegrated and crumbled away, while outcrops dominate, or at least abound, on mountain

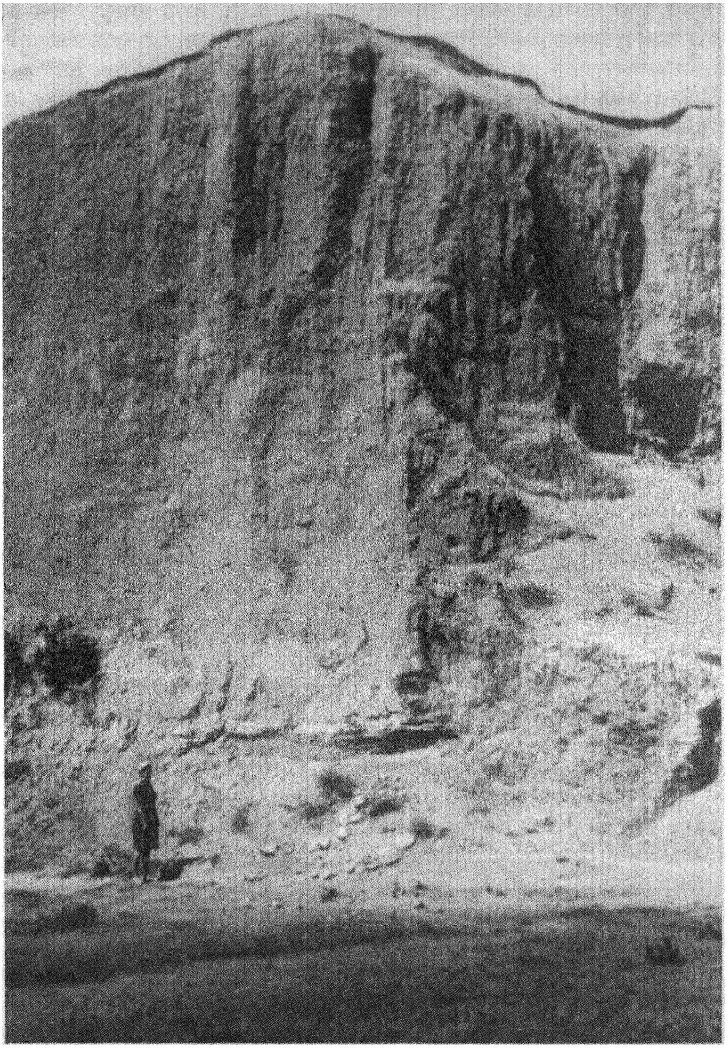

Fig. 110. Loess precipice in valley of the Angren River

slopes. Under specific conditions both the outcrops and the talus are coated with a layer of desert varnish, and they look as if they have been cast from sparkling pig-iron or consist of its fragments.

Numerous valleys and depressions, and sometimes entire labyrinths of depressions, joined by short valleys or saddles are cut into the chains and groups of hills and hillocks. Their floors

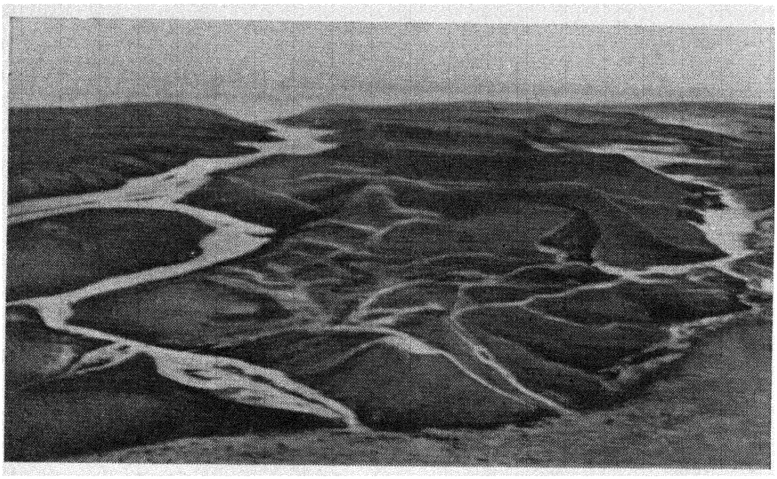

Fig. 111. Mountainous desert of Eocene limestone bordering on Nile valley near Helwan. Dried-up beds are visible

are covered with the coarse or fine alluvium of rock-waste, sand and clay, and contain the deposits of short-lived torrents, which, in rare cases, after heavy rains, sweep this sediment down from the uplands to the surrounding plains or the main valleys. The winds constantly blow fine sediment from the hill slopes and cliffs and, like the rain, assist in preventing the desert hills from becoming buried in the products of their own disintegration.

The chains and groups of mountains usually rise above a flat, wide pedestal which slopes gently on all sides to the surrounding plains or valleys. These pedestals are composed of the coarse and fine products of rock weathering washed down from the valleys and gullies by torrents. Torrential rain descending on bare slopes instantly produces sheets of water that rush through the valleys carrying sand, clay, rock-waste and rolling huge blocks along their beds. Deluges of water from the valleys overrun the pedestal. Here the water with its mass of stone and sand quickly runs off the flat surface, loses its carrying force and drops the matter, the proluvium, it has transported. This proluvium gradually accumulates and forms the pedestal. The mountains rise immediately and sharply above the pedestal (Fig. 112, *a*), while in humid regions this mountain angle is smoothed over by deluvium deposits (Fig. 112, *b*).

It cannot be said that all rocky deserts are completely devoid of vegetation. One can always see isolated small and large shrubs on the lower parts of slopes, in valleys and depressions and even trees growing in dry river beds. The abundance and forms of vegetation in these deserts vary, some having more vegetation, others less or none at all.

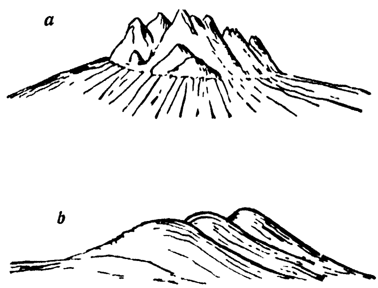

Fig. 112. Pedestal of mountain chain *(a)* in desert, and *(b)* in locality with humid climate

The broad valleys or depressions between chains and groups of mountains and hills in rocky deserts are more or less covered by thick layers of loose deposits, rock-waste, sand and clay brought down from the uplands, forming stony, clayey and sandy deserts. But sometimes outcrops of bedrock are also met in these valleys and depressions. They appear as isolated, highly smoothed exposures or as small cliffs and even as hillocks, which proves that the thickness of the deposits in these depressions is not so great.

Water in rocky deserts is met with in the shape of springs which sometimes appear on valley floors with more rich vegetation in their vicinity; the water flows for a certain distance as a stream and then disappears into the deposits.

Stony deserts are completely flat or gently undulated areas whose sandy-clayey soil is more or less densely strewn with rock-waste, i.e., with sharp-edged rock fragments or pebbles. Desert varnish often covers the rock-waste and pebbles and, with no vegetation and water, these deserts are a most depressing sight to behold. They cover extensive areas in the Sahara and in Arabia. The Arabs call the deserts covered with rock-waste *hammada* and those with pebbles—*serir* (Figs. 113 and 114). But in both types of desert the abundance of rock-waste or pebbles is caused by the wind blowing away and transporting all the finer matter, thus enriching the surface with coarse matter. If we dig into the soil of these deserts we shall discover that it consists of clayey sand containing rock-waste or pebbles. The hammada and serir types of desert are also found in Central

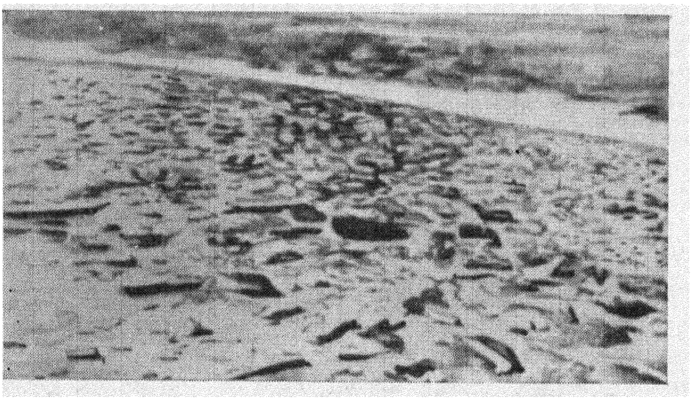

Fig. 113. Stony desert of the hammada type strewn with coarse rock-waste. Azlef, Western Sahara

Asia, but they cover smaller areas, the floors of large depressions or the foothills of rocky deserts, thus making perfectly clear their close connection with the latter, and they consist of proluvium—the products of torrents (Fig. 114).

Sandy deserts are areas of loose sand which forms hillocks in the shape of barkhans or dunes. Barkhan and dune sands can be classified as deserts only if they are devoid of vegetation or if it is scanty—with abundant vegetation they can be steppes or even forests, if they are covered with pines (dunes) or groves of saksaul—the peculiar tree of the desert.

Sandy deserts have uneven surfaces of undulating chains of dunes or barkhans, isolated by short valleys or hollows through whose floors peep clayey soil or bedrock outcrops. Vegetation is found mainly in these hollows.

Sandy deserts devoid of vegetation present a dismal picture. If you ascend a high barkhan and look around you will get a view of endless yellow barkhan chains stretching to the horizon, resembling sea waves during a gale suddenly frozen stiff. There are no vestiges of life. If grass and shrubs do grow, they are invisible, hidden at the bottom of the hollows. The Takla-Makan Desert is an even more dreary place. Its barkhans reach a height of 200 metres, and no blade of grass gladdens the eye. This is a panorama not of stormy waves but of huge ocean billows turned to stone.

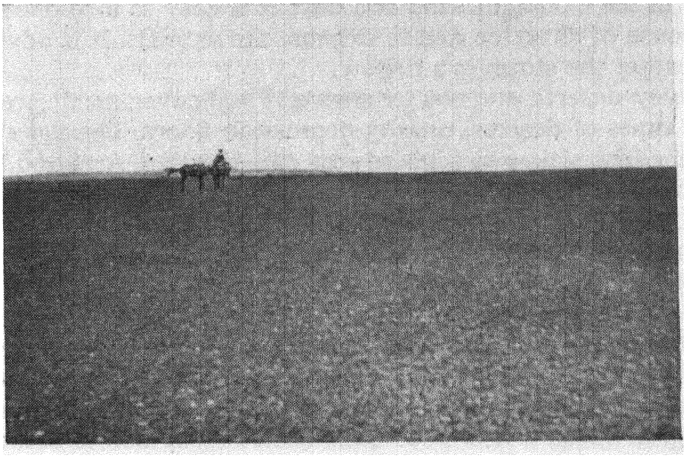

Fig. 114. Stony desert of the serir type through which runs the Dyam River, Jungaria

It is difficult to walk straight across or slantwise to the barkhan chains; one has continuously to climb crests and descend into hollows; if one's path lies in the teeth of the prevailing wind it is necessary to climb very steep and loose leeward slopes, the animals stick in the soft sand and quickly become exhausted. It is easier to walk aided by the wind, for on the windward slopes the sand is packed hard and the going is good, and the descent of the leeward slope with its loose sand is fairly easy. Best of all is when our path lies parallel to the barkhan chains, for then we mainly traverse the hollows and cross the low bars which divide them. In hot weather the sand's bare surface becomes baked and it blazes like a furnace. Then it is difficult to walk in any direction.

But with a strong wind this petrified yellow sea quickly awakens. The barkhans begin to "smoke," wisps of sand curl on every crest, the air fills with sand which gets into your eyes and teeth. On the windward slopes the wind whips the sand into snake-like motion and everything comes alive. The wind blows sand from the crests, scattering some on the leeward slopes. The sultry air is laden with dust. Like a dull-red disc faintly shines the sun and the horizon disappears in the haze. Even on horse-back one needs special glasses, so strongly do the grains strike the face. In sand-storms the traveller may get lost and perish, since in the clouds of sand and dust it is easy to lose one's way and sense of direction and to exhaust the animals. It is advisable to weather the storm in a hollow.

Clayey deserts are not extensive. They cover small areas of other types of deserts, usually depression floors. The flat shores of some large lakes and inland seas (the Caspian, Aral and Mediterranean seas) are, in places, clayey deserts. Their surface is level, clayey, usually cracked into polygonal sections, which are so hard that horses' hoofs leave no imprint. Vegetation is either completely absent, or grows sparsely in cracks. In Central Asia these clayey deserts are known as *takyrs*. Their soil is of fine silt, deposited on the floors of flat depressions, which are flooded with muddy water in spring or after heavy rainfalls, and which dry up in a few days or weeks. Some clayey deserts are made up of solid or loose saliniferous soil. Their clayey soil is saturated with salts. In these deserts, usually on flat mounds, grow salsola shrubs, while kharmyk shrubs grow on higher mounds and tamarisks, on the highest mounds.

VI

TRAVELLING STONES

History of a Boulder on a Farm. Accumulation of Snow in the Mountains. Névé. Glacier Formation and Flowage. Crevasses. Moraines. Glacial Melting. Glacial Retreat and Advance. Types of Glaciers. Great Glaciation and Its Products. Hall-Marks of Glaciation. Recurrence and Causes of Glaciation.

Let us take a walk through the fields of some collective farm in the northern half of the European part of the U.S.S.R. or in the environs of Leningrad, Kalinin, Vologda or Pskov. We shall probably notice a large round stone weighing a ton or even two tons on the grey soil of the field, the green of the pasture or meadow, or in the wood. We should probably see many small stones were it not for the fact that in the forest they are hidden in the grass and bushes, while on the farms and meadows they have long since been piled out of the way because they interfered with the field work. Only the big stones which man could not remove have remained. The soil around them is soft and loose; there are no outcrops of hard rock near by; these we shall find only on the banks of deeper river valleys.

We wonder where these stones have come from, what force has brought and strewn them over the fields and woods. Could not a big river possibly have flown through these places in time immemorial or could they have dropped from the sky?

No, they have not dropped from the sky; stones, called meteorites, sometimes fall on the Earth from world space, but these have an entirely different appearance and composition, which we shall learn in due time. Nor has a river brought them, but another and much greater force that can transport stones weighing dozens and even hundreds of tons over thousands of kilometres, something no river can do. This force is ice, and it has brought the stones from the far north—from Finland, Karelia and the Kola Peninsula. And strange as it may seem, but at one time—though compared with the history of the Earth it was not so long ago—when primitive man already lived on

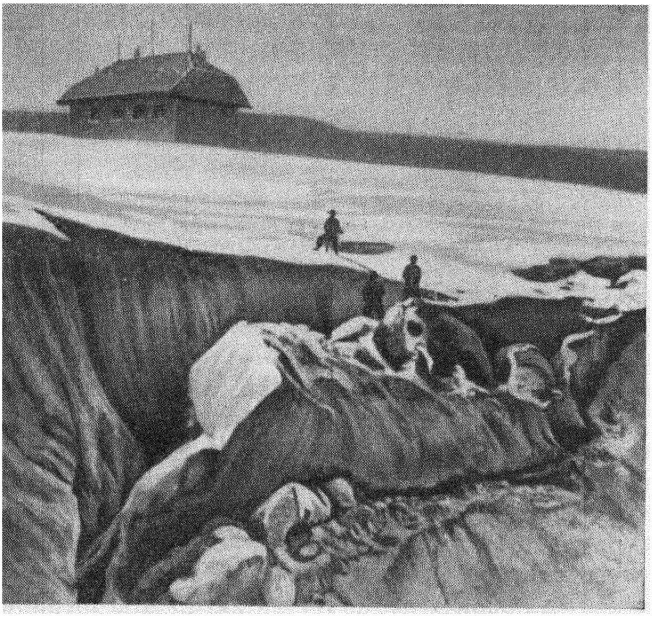

Fig. 115. Accumulation of snow (névé) on Mt. Feldberg (1,492 metres), Schwarzwald. View in the beginning of summer

the Earth the entire north of Europe, Asia and North America was covered with ice and looked like present-day Greenland or Franz Joseph Land located in the Arctic near the North Pole. At that time the Earth was going through the ice age. To understand how this enormous northern ice sheet moved and worked we must acquaint ourselves with the modern glaciers found in the mountains of the Caucasus, the Altai, the Alps and other parts of the world.

We all know that in the atmosphere which surrounds our Earth it is very cold even in summer. The flyers, who went up in the air in planes, and scientists, who flew in balloons, convinced themselves that at an altitude of several thousand metres the temperature of the air was several degrees below the freezing-point even in summer, whereas at altitudes of eight to ten kilometres the temperature dropped to 30 or even 40 below.

Temperature measurements during ascents in stratostats have shown that at altitudes of 15 to 20 kilometres 70° frosts obtain all year round. But it has long been known that it is also cold on the peaks of high mountains, that the snow therefore lies there and never melts and that there is a snowfall there each time it is inclement weather.

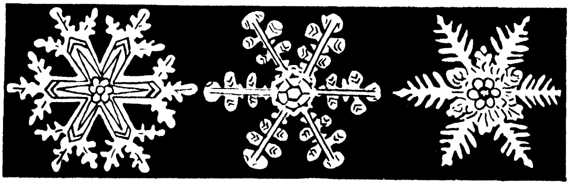

Fig. 116. Snow-flakes

Snow cannot accumulate in large masses on the sharp peaks and ridges of mountains or on their steep slopes: the wind sweeps it away; the fresh loose snow rolls down in rills, the larger masses break off from time to time and go avalanching down. Only somewhat lower, where the snow mass rests on the floor of some hollow or depression in the slope can it grow deeper, but not indefinitely. The upper layers press on the lower ones and force them to move slowly down. Under this pressure the snow is transformed little by little into ice, though the temperature does not rise above zero. The snow-flakes (Fig. 116) adhere to each other and change to fine grains of ice. We can also see such granular snow down on the plains after the thaw or during melting in spring. In the mountains it is called névé. This névé accumulates in large masses on mountain slopes, in all ruts, ravines and valleys between the mountain ridges and keeps slowly but stubbornly creeping down, the small ice grains freezing together and becoming larger.

These mountain valleys and depressions always have an exit to a larger valley cutting through one of the mountain ridges. This is where the névé creeps down to from all sides, and the

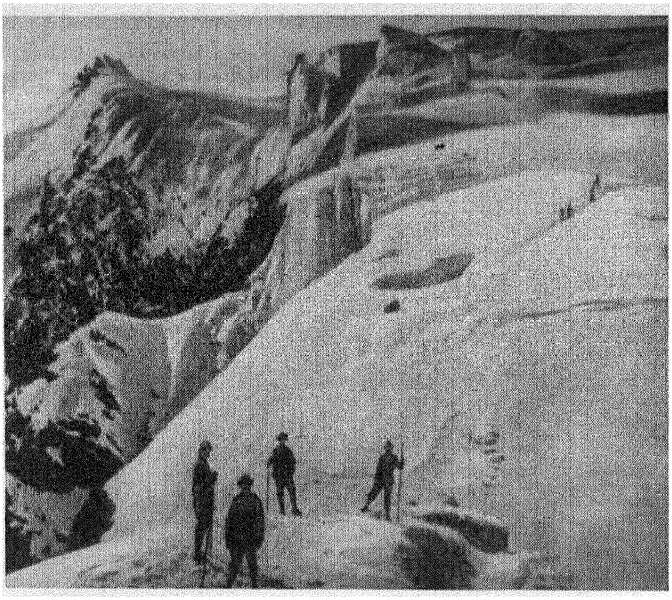

Fig. 117. Névé line of the Ortler Glacier, Tyrol. Stratification, crevasses and névé subsidence

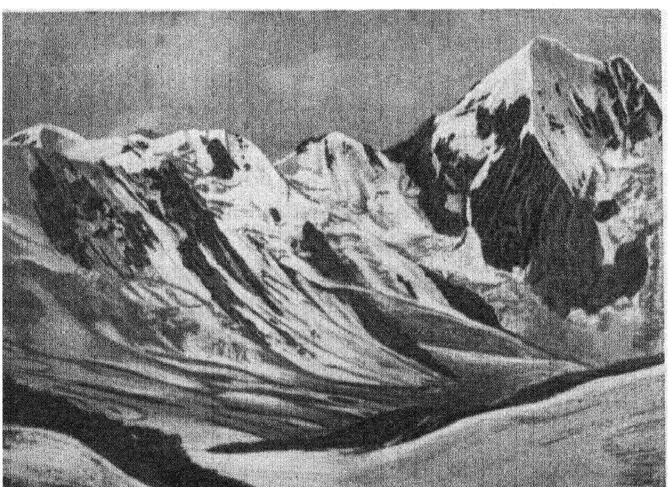

Fig. 118. Névé basin, glaciers with ice-falls and moraines. Königskreuz Peak, Tyrol

glacier begins. The entire area from which the névé creeps down into one glacier is known as its névé basin; this is the region of its nourishment; its size and altitude, and, of course, the amount of snow falling out in the mountains determine the size of the glacier (Figs. 117 and 118).

The glacier pressed from all sides by the névé that feeds it creeps down the valley. But how can hard ice creep? Is it not fragile? the reader will ask. If you hit it with an axe or a hammer will it not break into fragments? This is true, but the ice which is fragile under the temporary action of a force becomes plastic if acted upon by the same force for a very long time. We can easily show that by a simple test. Let us put a hammer on an ice block and we shall see several days later that it has made a little dent in the ice; the latter has yielded to the pressure of this weak force—the weight of the hammer. If we place the ends of a flat block of ice on two supports it will cave in in the middle within a few days.

The ice of which the glacier consists is not a continuous transparent mass like river or lake ice; it consists of separate grains, like the névé, but larger ones, and this facilitates its movement. Slowly, very slowly, it flows down the valley adapting itself to the accidents of its floor. In a day, as observations have shown, a mountain glacier moves from three to 40 centimetres, rarely from one to four metres, its movement depending on its thickness, and on the width and gradient of the valley. Large ice sheets travel faster; for example, the Greenland glaciers cover from 10 to 40 metres a day.

Crevasses. And still a glacier is not so plastic as wax or pitch with which it is often compared. This is demonstrated by its numerous crevasses. Some of them are formed along the margins of the ice stream because here the movement of the ice is retarded by friction against the sides; the marginal parts lag behind those of the centre and are cleaved by crevasses, usually short and shallow, and running from the margins to the middle. Many more crevasses are formed across the entire glacier where the gradient of its bed, i.e., the floor of the valley, suddenly becomes steeper (Fig. 120). Here the plasticity of the ice yields because it cannot keep pace with the accelerating movement, and the glacier breaks up into separate vertical slabs or even blocks. On steeper slopes this results in an almost impassable chaos of ice blocks. These places are called ice-falls.

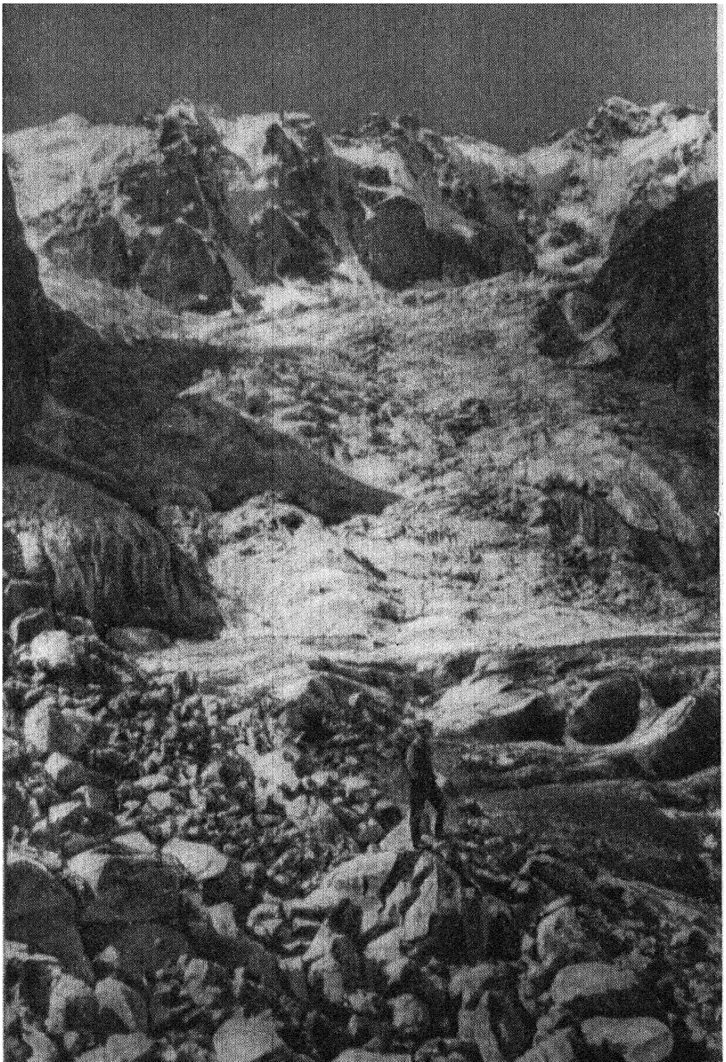

Fig. 119. Moraines and ice-fall on the Sanguti-Dan Glacier

Below the ice-fall where the gradient is gentler again the crevasses gradually join, the slabs and blocks unite and the glacier becomes smoother again.

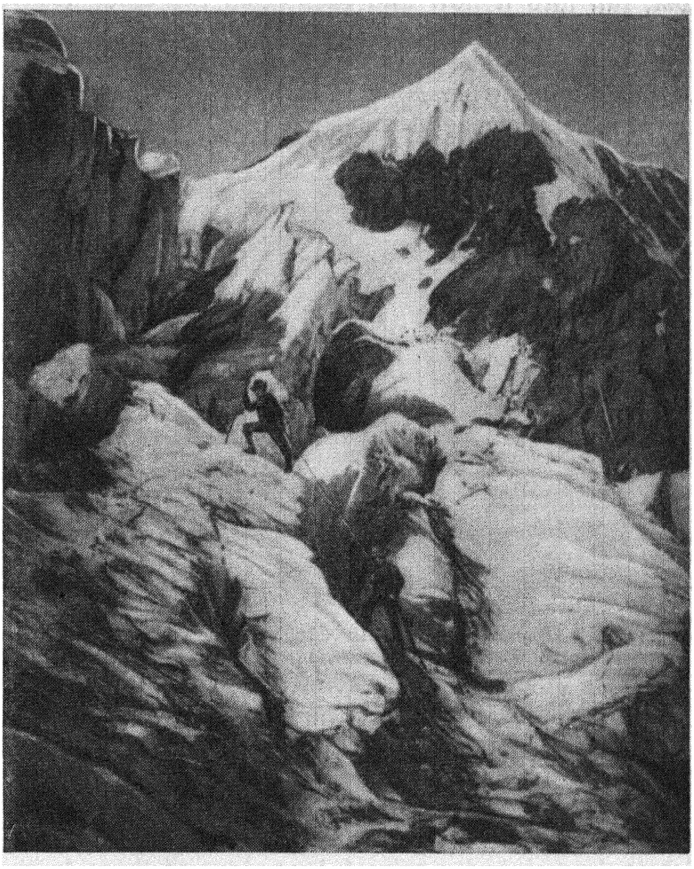

Fig. 120. Crevasses in the Sulden Glacier. Königs-spitze Peak, Tyrol

The glacier crevasses are dangerous to the traveller when concealed by fresh-fallen snow since many of them are from one to two metres wide and sometimes run through the entire thickness of the ice which may reach 50, 100 and even 200 metres. Deeper down most crevasses taper and, finally, close up or are filled with snow. At any rate, falling into a crevasse does not always end safely.

Moraines. In the névé basin the surface of the névé is always clean and white. Though gravel and fragments of rock, shattered by frost, fall into it now and then from the cliffs, protruding here and there from under the snow on the slopes, they are soon covered up by fresh snow. The surface of the glacier at its head is also clean, but further down it often loses its whiteness, and *moraines* make their appearance on it. The farther down the

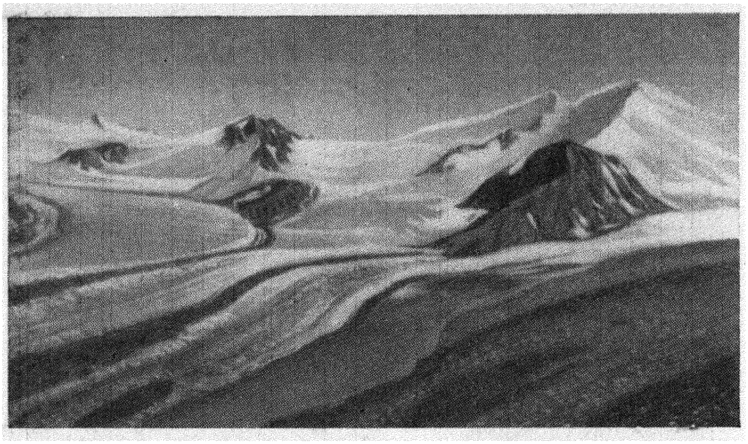

Fig. 121. The Bolshoi Taldur Glacier, South-Chu Belki, Altai. Formation of two medial moraines running from nunataks

sides of the valley, along which the glacier travels, the less they are covered with snow and the more rock protrudes from them in the form of cliffs and precipices from which gravel and fragments fall on to the surface of the ice. The glacier carries them farther, a new clean part of the glacier comes to the same spot and debris drops into it again. A long ridge of these fragments, small and large, of a height and width depending on the composition and steepness of the slopes, thus forms along the sides of the glacier. The steeper the slopes and the easier the rock breaks up, the higher and wider is this ridge known as a lateral moraine (Fig. 122).

Many glaciers are formed by the coalescence of several glaciers flowing out of various névé basins. At the confluence of two glaciers the right lateral moraine of one glacier and the left lateral moraine of the other join and below the place of junction we shall see besides the lateral moraines one more, which runs along its middle and is called a medial moraine. The glacier formed by the coalescence of several glaciers may also have several medial moraines (Fig. 121).

All these moraines lying on the surface of the ice are known as *surface* moraines. But the glaciers also have englacial moraines. As crevasses are formed part of the surface moraine materials fall in and continue their movement inside the ice.

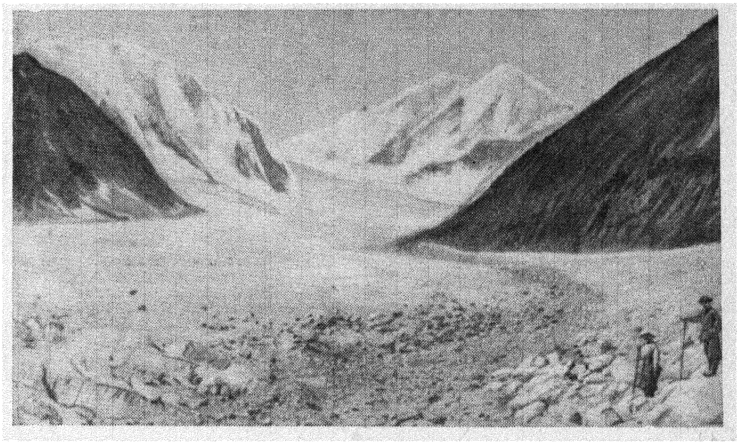

Fig. 122. Myon-su Glacier, Mt. Belukha, Altai. Lateral and coastal moraines (front, right)

All the fragments that fell on the névé in the névé basin and were covered up with snow also travel inside the ice.

Like flowing water, the heavy mass of ice creeping along its rocky bed erodes this bed. Little by little it wears it down and takes up the small fragments and large chunks separated from the bed by fissures. These are joined by the fragments that have fallen into the deep crevasses which reached to the bottom of the glacier. Freezing into the ice all this material moves along with it and partly accumulates in the dents and cavities of the bed. If the glacier disappears we often find its bed partly covered with this material and forming the *ground* moraine. It differs from the material of the surface moraines in that the various rocks in it are more or less rounded and made smooth by friction against each other, the ice and the bed, whereas in the surface and englacial moraines all the fragments are angular and rough.

On these boulders we often see surfaces polished by the ice friction and covered with thin scratches or rough grooves made by the sharp edge of some other rock frozen into the ice. These scratches and grooves are known as *glacier scars*. They can also be found on the surface of the glacier's rocky bed polished and scratched by the ice and rocks frozen into it.

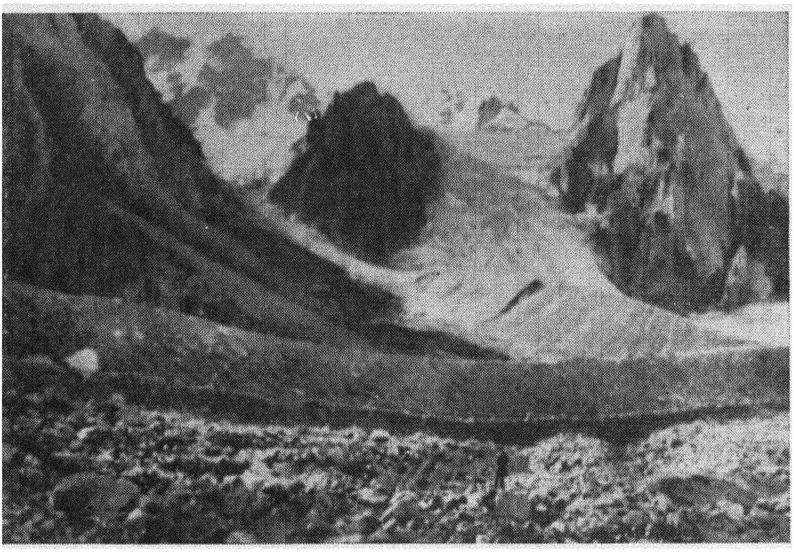

Fig. 123. Right side of the Sanguti-Dan Glacier. Lateral moraine. Nunataks in the background

The glaciers in the mountains move for some distance down the valleys, but always lower than the line of the permanent snow-field, i.e., the border below which the temperature in summer is above zero and the snow melts. Below this border the glacier begins to melt, shrinks and finally disappears, while all the rocky debris on the ice and inside it is liberated and, dumped in piles or ridges, forms one more type of moraine called *terminal* moraine (Figs. 124 and 125). In these moraines we shall therefore find a motley blend of fragments of all rocks making up the slopes of the névé basin and the glacier valley, of angular, slightly smoothed and quite rounded forms and various sizes.

Fig. 124. Terminal moraine of the Myon-su Glacier on Mt. Belukha, Altai

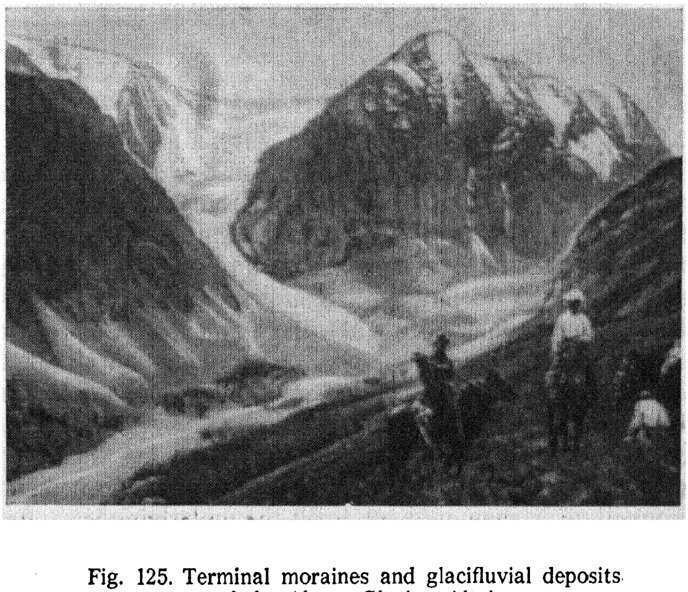

Fig. 125. Terminal moraines and glacifluvial deposits of the Ak-tru Glacier, Altai

The glacier has carried all this out and has dumped it into a single heap.

Glacial Melting. As before stated, below the edge of the permanent snow-field the surface of the glacier begins to melt; the farther down the valley, the more it melts; the mass of ice diminishes and gives rise to interesting phenomena on the surface of the glacier.

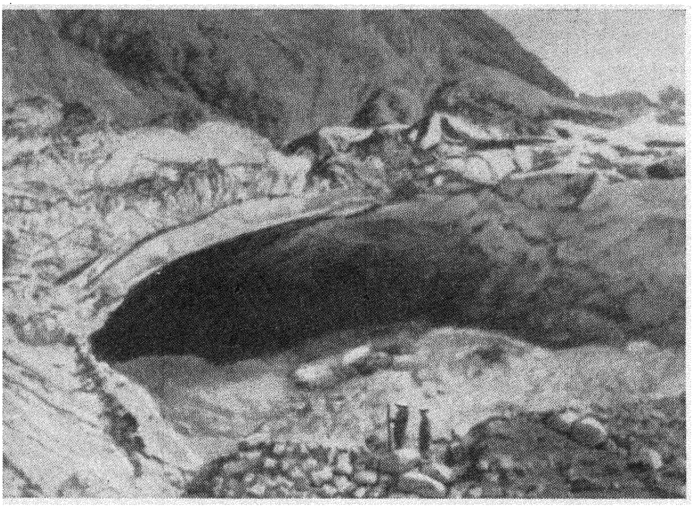

Fig. 126. Glacial grotto. End of the Myon-su Glacier, Mt. Belukha, Altai

Some large, flat slab that has tumbled down from the slope and has lain on the surface of the ice protects the ice beneath it from melting, while all around it the ice melts and its level drops. Some time later this block carried farther down the valley together with the ice turns out to be perched on an ice support. This is a *glacier table* (Fig. 127). But fanned by warm air this support continues to melt, grows thinner and the slab finally loses its balance, falls on the ice and may form a new table.

The small rocks lying on the surface of the glacier behave differently. They are heated by the sun and having greater thermal capacity, i.e., being capable of absorbing more heat than the surrounding ice, they gradually melt the underlying ice and cutting into it little by little find themselves on the bottom of a small vertical tube. These are the *ice cups* (Fig. 128).

In the névé basin snow does not fall continuously, the snowfalls alternate with clear days during which the wind brings to the surface of the snow fine dust from the rocks protruding on the slopes. This is why the névé in the basin is stratified rather than even. The same is true of the snow in the plains. After each snowfall the wind brings to the surface of the snow dust, leaves, rubbish from the nearby road and village streets, as well

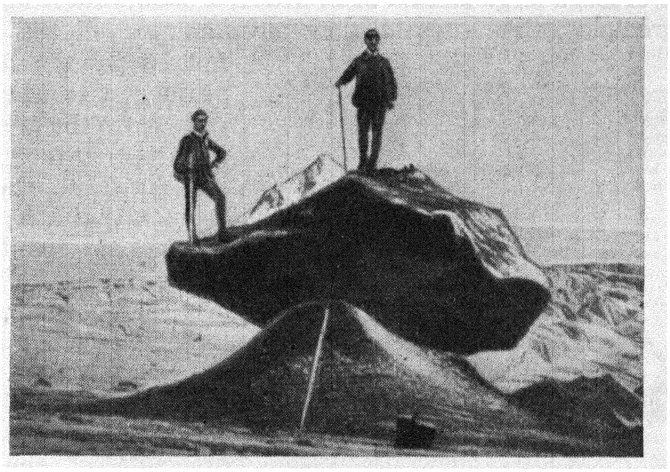

Fig. 127. Glacier table. Mer-de-Glace Glacier, Switzerland

as particles of soot emitted from the chimneys, especially in the environs of cities and factories. The snow of each snowfall is therefore separated from the overlying snow by a thin layer of dust.

In the névé basin the layers of snow covered with ever new snow are compacted and become thinner as they are transformed into the névé. The stratified névé finally changes to *ice* which is therefore also stratified (this can be seen in the walls of the crevasses); but where the glacier is already melting heavily the layers also come out to the surface in the form of curved lines, frequently quaintly twisted.

If the glacier has many surface moraines in its lower end, called the tongue, the ice is often entirely covered by them. The observer sees haphazardly-heaped small and large rocks of the coalesced lateral and medial moraines and may not even suspect any ice under them. Only after going farther up the glacier will he see ice in some places.

Depending on the thickness of the ice and the abundance of moraines the terminal front appears to the observer in different shapes. If the ice is very thick and there are but few surface moraines we shall see an ice precipice shattered by crevasses with sometimes broken-off and fallen-down large and small blocks of ice; a large stream or even a river shoots out from under this precipice, this river having accumulated all the water formed by the melting of the glacier. The water runs down the crevasses from the surface of the ice (Fig. 129). The river frequently issues from a beautiful ice tunnel. Near by are the ridges and piles of the moraine that has melted out of the ice (Fig. 126). If the glacier has a lot of rocky debris the ice precipice of the front is more or less covered with them, sometimes to the point of complete disappearance of the ice.

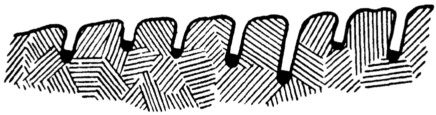

Fig. 128. Ice cups

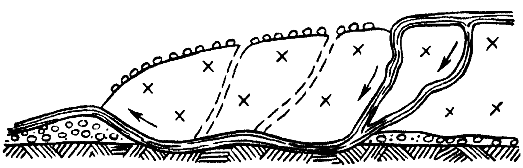

Fig. 129. Cross-section of glacier tongue. Crevasses, along which water runs from the surface of the glacier under the ice, and deposits of the ground and terminal moraines

A river issuing from under a glacier always has dirty water because it carries away all the dust melted out of the ice, as well as the sand and silt formed on the rocky glacier bed, worn down by the ice, and on the moraines shattered by the frost. The river carries away the pebbles and boulders melted out of the englacial moraine or washed out of the ground moraine. Breaking out of the ice the river also erodes the terminal moraine and carries away from it all it can. But its ability to do so varies: in winter, when the glacier does not melt, the river is very small; in spring and autumn, when the melting is weak, it is a bit bigger but in the summer, at the height of melting, the river swells up and works especially zealously.

Below the terminal front, sometimes for several kilometres, up to the line of vegetation, the floor of the valley is bare, covered with sand, pebbles and boulders brought by the river. The river meanders in one or several beds on these deposits called *glacifluvial* (Fig. 125).

Glacial Retreat and Advance. The terminal front, does not always remain in the same place, but shifts up or down the valley because the mass of the glacier varies with the changes

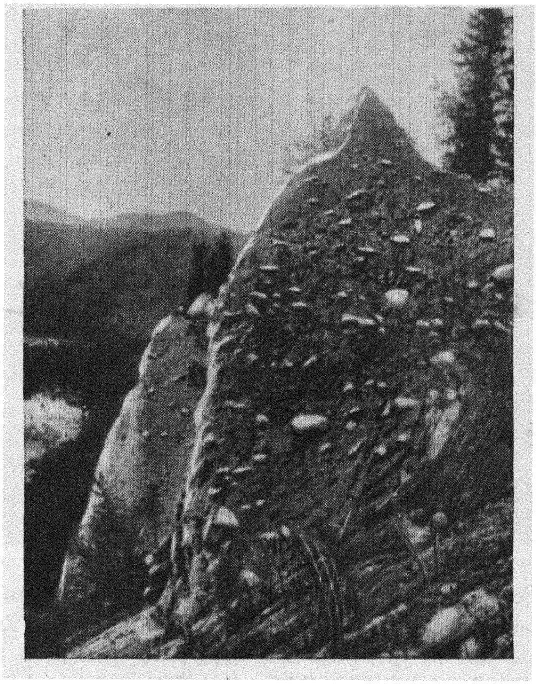

Fig. 130. Ancient moraine (eroded) on right bank of the Katun River, Altai

in the climate. These changes are either casual and transient or perennial. There are years of abundant atmospheric precipitations and years when there is little precipitation. During the former the névé basin receives more snow, the mass of the glacier increases and its tongue moves downward—the glacier advances. During the years with little precipitation the mass of the glacier diminishes and its tongue shifts upward—the glacier recedes. Owing to the sluggish ice movement these variations in the nourishment of the glacier take a few years to affect its tongue.

The climate of a country may change for a long time in a definite direction; for example, in consequence of a felling of forests and draining of lakes it will become dryer; this will cause all the country's glaciers to recede with each passing year. It is

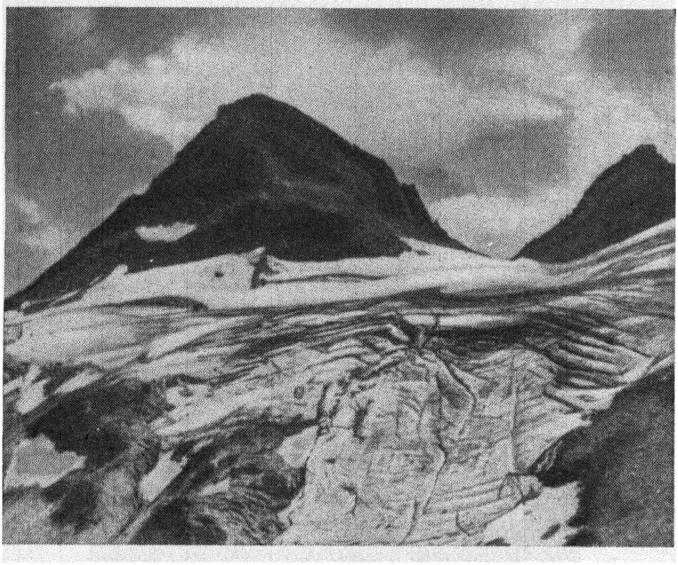

Fig. 131. Hanging glacier on Mt. Tauernkopf, Austrian Alps

now occurring in the Swiss Alps, the Caucasus, Altai and Tien-Shan.

Types of Glaciers. Glaciers may differ in size and may occupy various positions depending on the relief of the country, its altitude above sea level and the amount of atmospheric precipitations. In the mountains, which are not very high, only the tallest ridges and peaks rise above the line of the permanent snow-field. The snow-covered area is small, as are also the névé basins. The glaciers receive but scanty nourishment, do not descend very low and end either at the mouth of the névé basin or even on the slope of a ridge. The former are known as *corrie glaciers*, the latter are referred to as *hanging glaciers* since they seem to be hanging from the ridge where they are fed by a small névé area (Fig. 131). The corrie glaciers are nourished by the névé which fills the *corries*—large circular hollows cut into the ridge of a mountain range with very steep rocky slopes and a flat bottom. A corrie may be likened to a giant's armchair with straight arms and back and an indented seat (Figs. 132 and 133). The névé basin of an individual corrie is small and the glacier hardly emerges from its mouth on to the slope. We can find corries in many mountains, but if the mountains rise higher a number of adjoining corries and the floor of the valley into which they open form a common névé basin and can then jointly feed a large glacier.

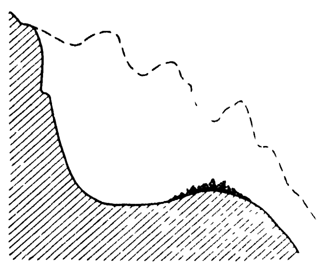

Fig. 132. Longitudinal section of a glacier corrie

The glacier occupying a mountain valley is called a *valley glacier*. With heavy mountain glaciation a valley glacier may creep out of the mountain valley into the surrounding lowland; several such glaciers joining on the lowland form a *piedmont glacier*. Such glaciers are known in South Alaska. In piedmont glaciers the ice fans out in the plain, but its power, naturally, wanes. On the mountainous Arctic islands, on Novaya Zemlya, Spitzbergen and Franz-Joseph Land many glaciers emerge from the mountain valleys and descend into the sea. Large masses of ice break off now and then from the front ends of these glaciers, are carried away by currents and floating in the sea form icebergs of various sizes. These glaciers have no visible terminal moraines and the rocky debris melted out of them drops in the water.

Types of Glaciation. A highland carrying glaciers presents three types of glaciation according to its relief and the thickness of the ice. If we see valley glaciers in a highland divided by valleys into separate mountain ranges and frequent rocky cliffs rising above them it is an *Alpine* type named after the Swiss Alps where it is well developed. If the highland presents more or less broad plateaus at the valley heads and these plateaus are all covered with snow and serve as névé fields feeding glaciers, it is the *Scandinavian* type, because it is now well developed in

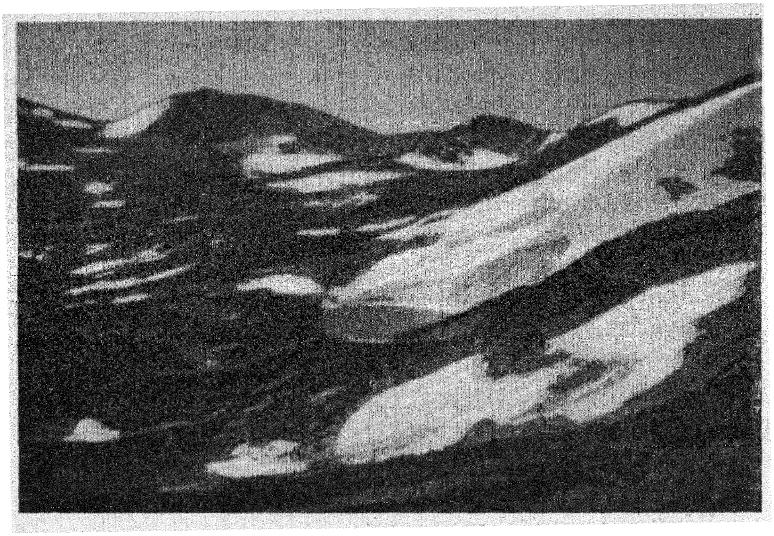

Fig. 133. Snowdrifts in ancient corries and corrie lakes on the Chebal-Taskyl bald Mountain, Kuznetsk Alatau

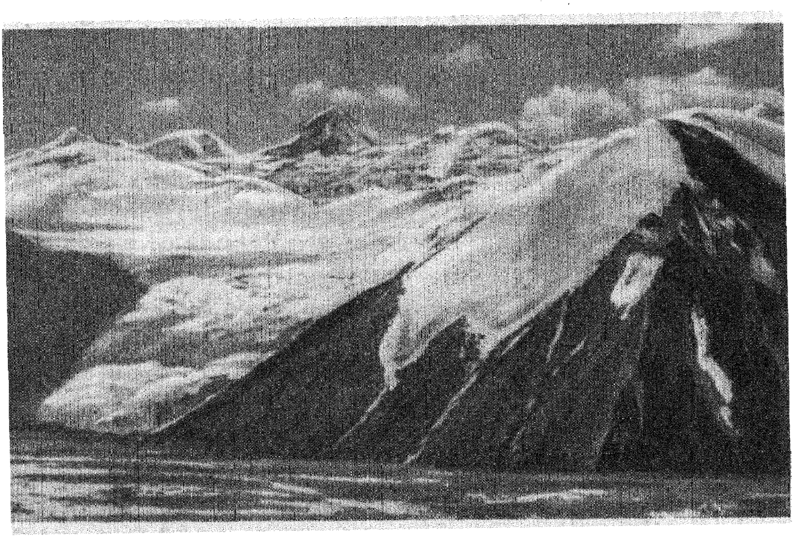

Fig. 134. Khan-Tengri, one of the highest Tien-Shan peaks. Névé basin on the northern slope. Surface of large glacier covered with moraines in the foreground

the north of Scandinavia. But if a vast plateau is completely covered with ice or a highland carries such powerful glaciers that they hide even the slopes with only separate peaks rising here and there over the ice it is the *ice sheet* type. We now find this type in Greenland, on Franz-Joseph Land and in the Antarctica (Figs. 135 and 136).

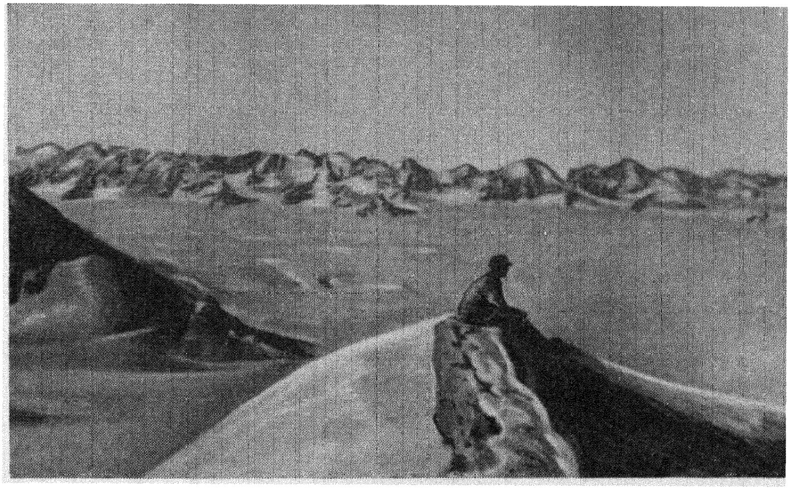

Fig. 135. Margin of continuous ice sheet. Greenland

At one time glaciers of this ice sheet type covered the entire north of Europe, Asia and North America. Our Earth was then going through the ice age, or four glacial phases. An ice sheet attaining various sizes developed during each of these phases, then it greatly diminished or disappeared altogether to extend again some time later. The three intervals between the ice phases are known as interglacial stages. The time following the last glacial phase is referred to as the post-glacial stage which essentially continues today since we can still see the remains of the last glaciation in the Arctic, the north of Europe, the Alps, the Caucasus, the Altai and other mountains, in the form of modern glaciers.

During the glacial phases the climate in the Northern Hemisphere was much more rigorous than it is today; there were more atmospheric precipitations which fell mainly as snow; all this snow could not possibly melt during the short, cool summers. We still find such remains of last year's snow in the higher mountains of the Northern Urals and Siberia as separate fields on the northern slopes and in hollows. They are called snow patches and the mountains in which the snow stays long are

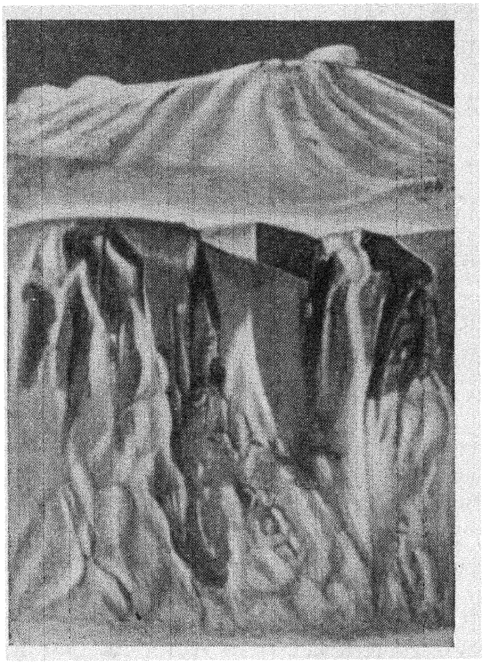

Fig. 136. Precipitous slope of the Antarctic ice sheet near Mt. Erebus

referred to as *belki*. In the beginning of each glacial phase the climate changed for the worse, and these snow patches appeared in the north—Scandinavia, Finland, Canada and Siberia—increasing with each passing year and occupying ever larger areas. Then, very many years later (since the climate changes very slowly), these snow patches merged into a continuous sheet on all elevations, while the valleys and plains were still free from them. On the elevations the snow accumulated from year to year, but since the mass of snow cannot increase indefinitely, it turned into a névé, crept in the form of glaciers down the slopes and filled the valleys.

The vast areas covered with snow, névé and ice served to make the climate still worse; the period of melting became increasingly shorter, the precipitations fell during the greater part of the year in the form of snow, and the sheet grew thicker. In connection with the fall of the temperature, regions more to the

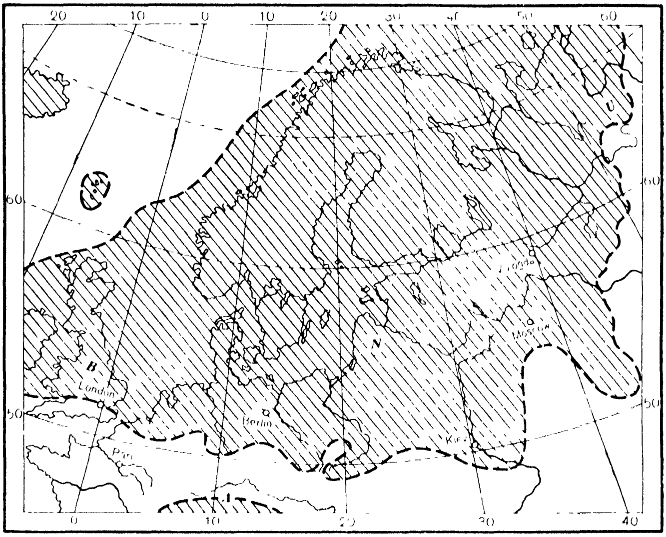

Fig. 137. Map of greatest European glaciation.
Glaciers: *A*—Alpine; *B*—British; *N*—Northern; *U*—Urals

south also began to be covered with snow patches and then with a continuous sheet, ever new areas disappearing under it, while the glaciers crept down into all valleys and grew longer and thicker. When this sheet had spread all over Finland, Karelia and Northern Scandinavia because these areas had more mountains, the glaciers began creeping into the plains farther down in the south. Separate glaciers merged with each other like the modern piedmont glaciers and then began their very slow southward advance. This advance lasted for centuries and the glaciers moved farther and farther and seized ever new areas (Figs. 137 and 138).

At its southern edge the ice, naturally, melted and gave rise to rivers, which flowed to the south, and to lakes in all depressions that could hold water. But the melting during the short summers could not counterbalance the increase in the snow that fell in the course of long winters, while farther north, where there was a continuous sheet, the precipitations fell as snow even in summer. The ice mass increased, and the glacier had to move ever farther south. The thickness of the ice sheet in the highlands, which served as the centres of glaciation, is estimated at 2,000 metres judging by that of the modern sheet covering Greenland and the Antarctica. It is even hard to believe that Finland, Kola Peninsula, Northern Scandinavia, Canada and Northern Siberia were ever covered by continuous ice 2,000 metres thick. But this is undoubtedly true, because the ice sheet could never have moved so far south if the ice were only some 200 or 300 metres thick in the centres of glaciation. As a matter of fact, in Europe the ice reached not only Moscow, but even Kursk, Kiev, Warsaw and Berlin. To make the ice travel so far the centres had to exert very high pressure. Of course, the farther south, the thinner the ice. Moving along the earth's surface and pressing against all its accidents this gigantic glacier, like the modern mountain glaciers, plucked off small fragments and large blocks of rock, gravel, sand and clay, and carried them away. It rubbed down, polished, grooved and scratched the protruding rock. Since there were no high mountains in its way and the ice was enormously thick in the centres of glaciation the ice sheet had only englacial moraines made up of the debris taken from the bed.

But what was going on at the southern edge of the glacier? There the climate was already sufficiently warm, the ice melted very heavily, unloaded the rocky debris it had brought along and built terminal moraines. Numerous creeks and rivers of melt water issued from under the ice, washed away silt, sand and pebbles, and gradually deposited them as glacifluvial sediments. Their level varied, the highest being in the summer, at the height of melting; it was lower in spring and autumn and lowest in winter. These rivers overflowed, flooded large areas in the summer, and ran in a narrow bed in winter. Some rivers at first flowed for a long distance under the ice or in an ice tunnel and made their deposits in the form of long and narrow ridges.

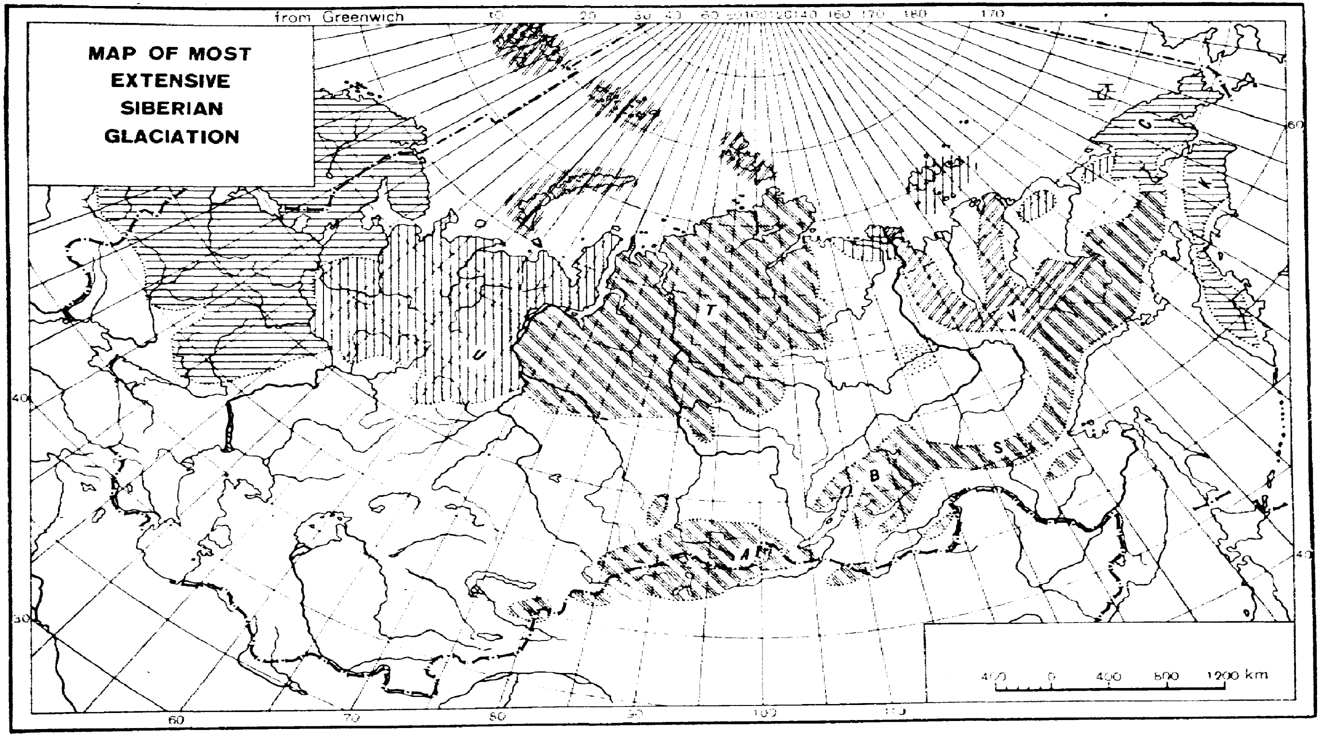

Fig. 138. Map of most extensive Siberian glaciation

Glaciers: *U*—Urals; *T*—Taimyr; *V*—Verkhoyansk; *C*—Chukotka; *K*—Koryak-Kamchatka; *A*—Altai-Sayan; *B*—Baikal; *S*—Stanovoi

Gradually moving south and covering ever new areas the enormous northern ice sheet, finally, stopped its advance because its gains from the snowfalls on its surface were balanced by the losses over the entire melting area. This state of equilibrium probably continued for hundreds and even thousands of years. Then the losses began to exceed the gains and the glacier started

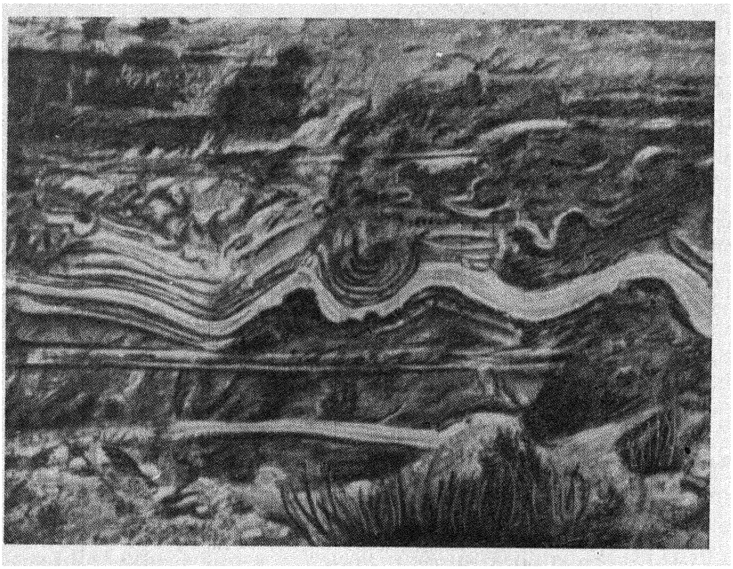

Fig. 139. Varved clays crumpled by underwater earth creep. River Chornaya (Black) near Posolodino, Leningrad Region

shrinking, i.e., its southern end began to withdraw northward clearing the territory that had long been under ice. This territory was, of course, nothing but a desert, its surface covered with a layer of ground morainic debris consisting of clay or loam and containing small and large boulders. In the depressions, i.e., the former valleys, the layer of this moraine was heavier and on elevations it was thinner. The debris of the englacial moraines consisting of various-sized boulders melted out of the ice and was scattered on the earth's surface. Deposits of subglacial rivers, known as *eskers,* stretched here and there as long narrow ridges resembling railway embankments. In other places subglacial rivers washed out a lot of sand and deposited it at the end of the glacier as fields with an uneven surface. These sandy areas are called *outwash plains*.

Of course, the terminal moraines could accumulate only now and then when the glacier stopped retreating for a long time. Due to increased melting more water issued from under the glacier than when it advanced or was in a state of equilibrium.

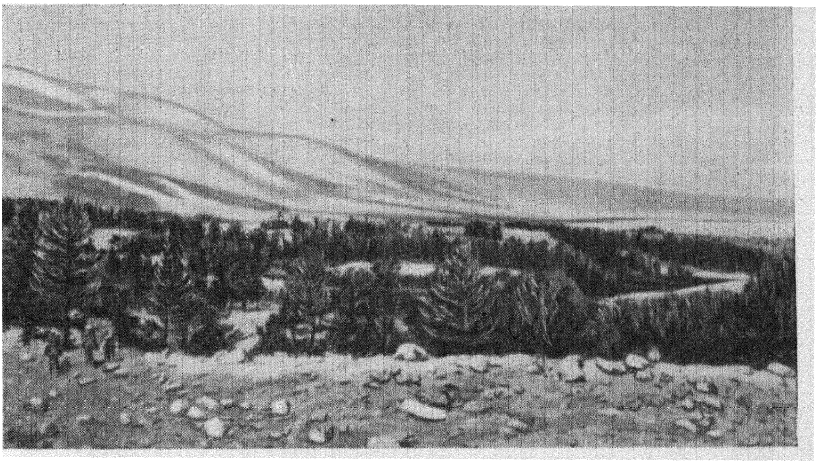

Fig. 140. Morainic landscape near Lake Dain-Gol, Mongolian Altai

These streams and rivers brought out their material from under the ice, but also washed out the ground moraine along which they ran, overflowed in high water, shrank in winter and deposited glacifluvial pebbles, sands and clays. In many places small and large lakes formed in hollows at the end of the glacier and the material brought from under the ice settled down in them. Small lakes filled up and disappeared rapidly, large ones persisted; fine sand, silt and clay and loams were deposited in them as varved clays. These deposits clearly show alternating, one- to two-millimetre thin layers of different colour and composition. This alternation can be accounted for by the fact that at the height of melting in summer the subglacial waters falling into the lake brought larger particles and in greater amounts than they did in winter, when the melting was weak, their amounts decreased, the force of transportation waned and they brought to the lake only the finest loess in the form of silt or clay. By counting the number of these annual layers in the sediments of some lake we can find out how long it had existed before it was filled with sedimentation (Fig. 139).

De Geer, Swedish scientist, undertook to count the layers of varved clays in a number of former lakes in Southern Sweden and found that it required 2,000 years for the Northern Glacier to recede

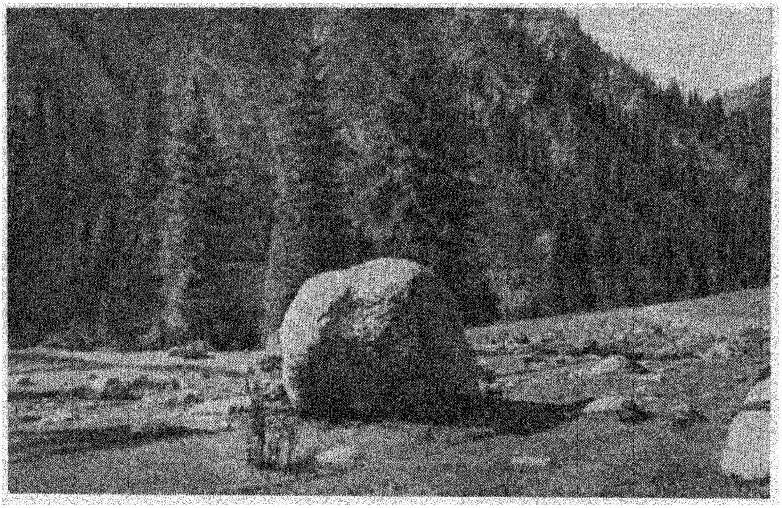

Fig. 141. Erratic boulder. Valley of the Jety-Oguz River, Kirghiz S.S.R.

from the southern end of Sweden to Stockholm—a distance of 400 to 450 kilometres or an annual retreat of 200 to 225 metres.

Thus it took many thousands of years for the glacier to retreat from Kursk to Moscow, then to Leningrad and Petrozavodsk, then to withdraw from Finland and Scandinavia and finally to disappear. And the farther up north, the later did the ice withdraw from the area and the clearer and more distinct are the traces left by the ice sheet because running water worked a shorter time in destroying these traces. It therefore seems to the observer in the north—in Finland and on Kola Peninsula—that the ice has left these places but very recently. He sees ridges and heaps of the terminal moraines and though they are already covered with grass, bushes and trees, and are ploughed up or built up, they are still very characteristic as to their relief, i.e., hummocky surface with numerous hollows containing small lakes or marshes (Fig. 140). In other places he sees long eskers (some of them run through Finland for dozens of kilometres) or areas of ground moraines or sand fields of outwash plains. Everywhere on the surface are scattered large and

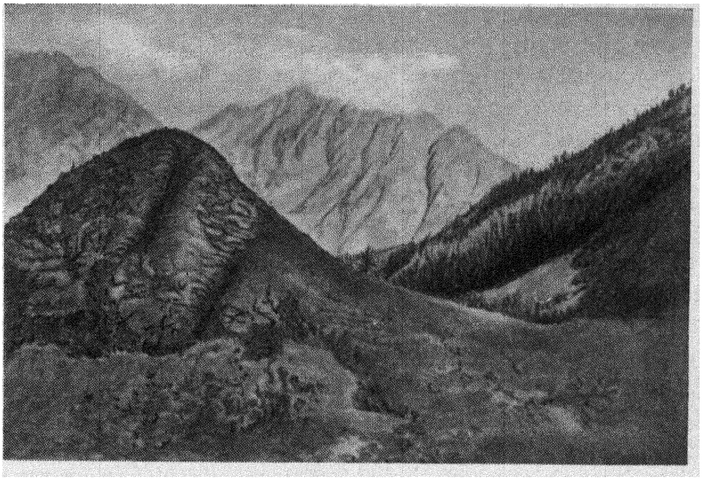

Fig. 142. Roche moutonnée—enormous cliff smoothed out by ice at the valley mouth of the Iedygem River falling into the valley of the Argut River, Altai

small boulders left by the glacier, and these boulders still retain the scars and grooves and even the polished surfaces made by the ice. The large blocks of rock left by the ice are referred to as *erratics*, i.e., wanderers (Fig. 141).

Where hard rock comes directly to the surface we can see how it was worked up by the glacier: all the corners and protrusions have been smoothed and rounded out, and the outcrop presents the so-called *roches moutonnées* with rounded protuberances and flat depressions between them (Fig. 142). Individual roches moutonnées have a characteristic appearance: on one side from which the ice came they are well rounded, covered with scars, polished and slope gently, whereas on the other side, where the ice flowed down, they were worked up less, are rougher and slope steeply. These individual knolls are known as *crag and tail.*

The aggregate of these forms—moraines, hollows in them and between them, eskers, roches moutonnées, crag and tails, and erratics—present the characteristic *glacial* or morainic *landscape* which clearly shows that the area was formerly covered with ice. We find this landscape in our northern plains and in the mountains where there were glaciers before—in the Northern Urals, the Caucasus, the Carpathians and many mountains in Siberia.

Now we know how the boulders dispersed in such large numbers over our plains came to be there. These boulders get in the way of ploughing and mowing, but are used for paving the streets in our North and in the Central Zone—Leningrad, Novgorod, Kalinin, Vologda and Moscow regions, and in Byelorussia, all the way to the Northern Ukraine, where hard rocks do not come out to the surface so frequently and those that do are usually unsuitable for this purpose (they are either too soft and wear too fast or are very hard and are difficult to work up). The erratics scattered all over the fields and finding their way into the beds of many rivers during the denudation in post-glacial time offer ready material for pavements. They must only be picked to match in size since they are all of good quality: they are mostly pretty hard Finnish rock. Were it not for this material, which had to be collected and transported, all the towns in the North and the Central Zone of the U.S.S.R. would either be buried in dirt or would have to content themselves with expensive and insecure wooden pavements. The cobbles have only recently disappeared from the main streets of large cities yielding to the more perfect asphalt pavements, but are becoming widespread in collective farm settlements and small towns. The larger boulders, too large for pavements, have long been used in building highways.

These boulders are collected in the fields, transported to roads and crushed to gravel to fill the highways.

We can thus be thankful to the Great Northern Glacier for bringing us so much good and cheap material from Finland and the Kola Peninsula and scattering it all over.

The Northern Glacier has brought us not only boulders for our pavements. The loess and yellow earth of the Ukraine are also products of glaciation. Both during its advance and recession the glacier set up ahead of its front a desert in the form of moraines, outwash sands and glacifluvial sediments unprotected by vegetation from dispersal. The winds blowing from the ice sheet dispersed these loose sediments and carried sand and dust southward; the sand formed barkhans while still in the desert, and the dust was carried farther and deposited on the steppes, which covered the southern part of the Russian Plain, gradually accumulating and turning to loess. After the disappearance of the glacier the climate changed, becoming more humid. The former

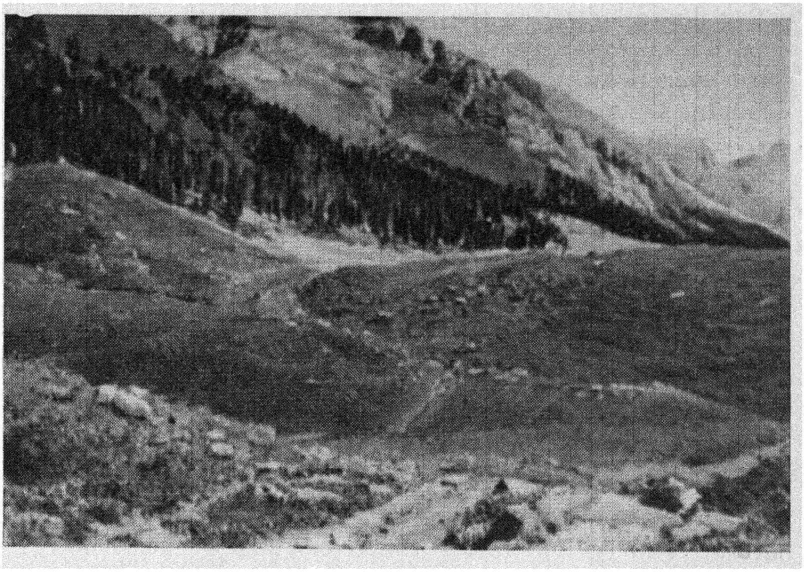

Fig. 143. Morainic landscape at the head of the Turgen River valley, Terskei-Alatau

desert of the north was overgrown with forests, but sands can be found in many places under them, for example, in Polesye or in the environs of Moscow. Luxuriant grasses developed in the arid southern steppes and an accumulation of humus began, the humus changing into chernozem covering the loess and gradually turning into the latter. It follows that the loess of the Ukraine is a product of the former desert formed along the southern edge of the ice sheet and, of course, disappearing together with the latter.

Hall-Marks of Glaciation. At the time when nearly two-thirds of the European part of the U.S.S.R. were covered with ice there were glaciers also in the Northern and Central Urals, where there are none today, save a few small ones in the north. There are still many glaciers in the Caucasus, though there were many more before; they had even moved from the mountains into the neighbouring plains. In the mountains we can also judge about former glaciation by the characteristic morainic landscape. If we go to the mountains where there are no glaciers today, but where they were before, we shall first find terminal moraines on valley floors indicating the place reached by the glacier at the time of its greatest development. These moraines, of course long since overgrown, present one or several ridges of hills nearly damming the valley and only leaving enough place for the bed of a river which gradually eroded the moraines. Between the hills there are small depressions which, like the haphazard distribution of the hills in the common ridge, show what we are dealing

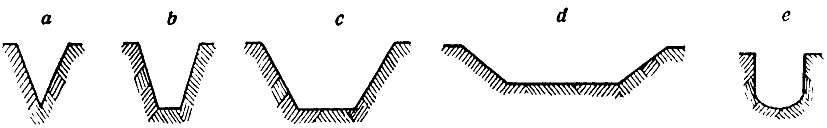

Fig. 144. Cross-sections of valleys of fluvial (*a*, *b*, *c*, *d*) and glacial (*e*) origin

with. A little digging in the slope of the hill (if there is no natural open section facing the river) and we shall find it to consist of boulders of different sizes haphazardly dispersed in sand, loam or clay; some boulders have retained the glacial polish and scratches.

Higher up the valley we can discover one or several more of these terminal moraines formed where the glacier stopped for a long time during its retreat. In the intervals we shall probably find boulders of different sizes, sometimes very high up on the slope, and in this case we can even determine the thickness attained by the glacier. In addition to the terminal moraines we shall also discover lateral moraines left on the sides of the valley during the shrinkage of the glacier, but these were smoothed out or even eroded by the water running down the slopes and therefore obtain more rarely or are less conspicuous than the terminal moraines. Sometimes we can also discern a crag and tail, and on a rocky protuberance of the valley floor some roches moutonnées.

Coming closer to the head of the valley we shall encounter even clearer traces of glaciation—more frequent and better preserved terminal moraines which sometimes dam the valley and serve as dikes for the lakes. The lateral moraines are better preserved here, while the crag and tails and the roches moutonnées are found more often. We shall see, too, that the valleys end in more or less steep slopes of a cirque which served as a névé basin; on the slopes under the mountain ridges we shall discern corries—semi-cirques with flat bottoms and steep sides cut into the slopes; in some cases there are small lakes on their floors, the lakes being separated by a terminal moraine or stone threshold in the mouth of the corrie. Small glaciers were cooped up in these corries long after the diminution of glaciation (Fig. 133).

The cross-section of the valley along which the glacier moved is also quite distinctive. In its upper reaches, in the region of erosion, the valley washed out by a river has a V-shaped cross-section (Fig. 144, *a*), i.e., a narrow floor occupied by the bed and more or less steep slopes. Lower down, in the region of lateral erosion, the valley widens and its cross-section looks like a trapeze (Fig. 144, *b*), while still lower, in the region of sedimentation, the floor is still wider and the slopes are gentler (Fig. 144, *c* and *d*). The valley which accommodated a glacier has a U-shaped cross-section (Fig. 144, *e*)—a wider, but concave floor, ground by the ice, and steeper slopes which the glacier gradually wore down carrying away also the products of weathering that tumbled down from the slopes (Fig. 145). This debris evens out the gradient of the slopes in a river valley by accumulating as deluvium in their lower parts (Fig. 146).

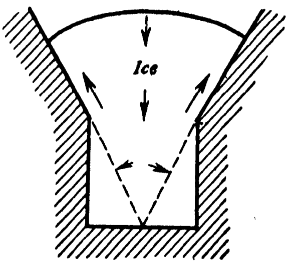

Fig. 145. Transformation of a fluvial valley into a glacial

The totality of the aforementioned hall-marks enables the observer not only to say confidently that there was a glacier in this valley not so long ago, but even to determine its length by the very lowest of the terminal moraines, the thickness of the ice by the boulders perched on the slopes, and approximately the line of the permanent snow-field during glaciation by the floors of the corries which are usually located on a height corresponding to this line. The observer can also say how many times and in what parts of the valley the glacier stopped during its retreat —precisely where there are terminal moraines—and by the size of the latter he can judge whether the stops were long or short (Fig. 147). There are even signs which make it possible to as-

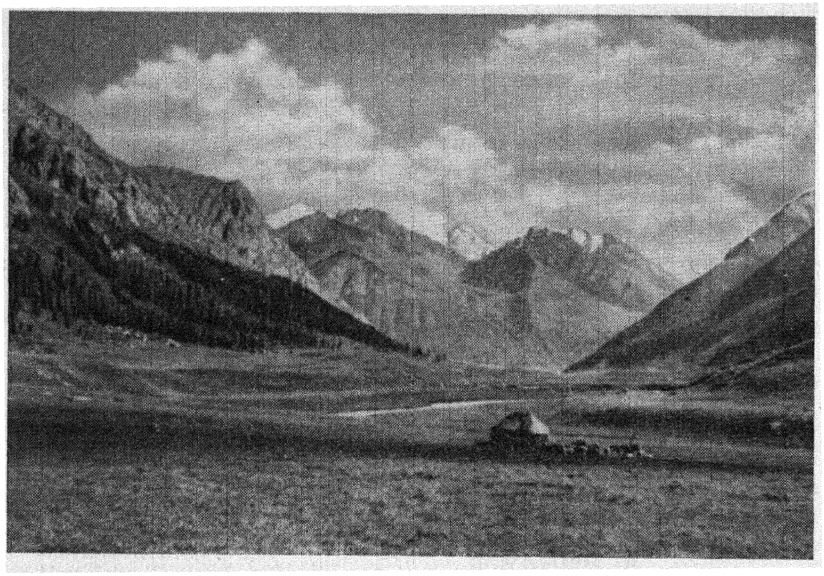

Fig. 146. Trough valley of the Turgen River on the northern slope of Terskei-Alatau

certain whether there was one or multiple glaciations. This is the question we shall now consider.

Recurrence of Glaciation. After the scientists had traced the signs of the vast former glaciation in Europe they proved, little by little, that this glaciation had not been an accidental phenomenon and that it recurred several times not only during the modern geological period, measured by the appearance of man on the Earth, but also during preceding, even most remote periods.

During the modern period glaciation recurred in Europe four times. The glaciers appeared each time in the north of Scandinavia; they grew, covered Scandinavia and Finland, passed over to Northern Germany, Poland, Lithuania, Latvia, Estonia and the northern part of the R.S.F.S.R., attained their greatest development, stopped at a certain line, then began to retreat, continued receding and finally disappeared for a long time—till the next phase of glaciation. Four phases of glaciation are therefore distinguished in Europe; beginning with the most ancient phase

Fig. 147. Old terminal moraine in the valley of the Kara-Airy River, **Altai**

they are referred to as *Günz*, *Mindel*, *Riss* and *Würm*. The intervals between the glacial phases are known as interglacial stages, while the period following the last glacial phase is called the post-glacial period.

Not during all the glacial phases did the ice sheet reach the same extent. The glacier of the Mindel phase is believed to have been the biggest, those of the Günz and Riss phases somewhat smaller, and the one of the Würm phase the smallest. On the Russian Plain the glacier of the Mindel phase reached Kiev, Poltava and Kursk in the south, the glacier of the Riss phase ended south of Moscow, while the glacier of the Würm phase stopped at the Moscow latitude.

It stands to reason that the traces left by the older phases have not been so well preserved as those of the most recent one because they were gradually smoothed out, washed out and even destroyed not only by the rains and rivers of the interglacial stages, but also by the glaciers of the following phases which again smoothed them out, covered them over with their own moraines and washed them out with their melt waters. To find the lines reached by the older glaciers required painstaking research; contrariwise, the traces left by the Würm glacier were easy to find because they are quite well preserved. Its terminal and ground moraines, eskers and erratics are clearly traced on the Russian Plain north of Moscow, in Finland and Karelia.

Scientists made attempts at estimating the durations of the glacial and interglacial stages and have obtained the following figures, tentative of course, but giving us an idea of how long these stages lasted.

Duration of Glacial Phases (in years)

Post-glacial Period	10,000 to 20,000
Glaciation of the 4th (Würm) Phase	52,000
3rd Interglacial Stage	65,000
Glaciation of the 3rd (Riss) Phase	53,000
2nd Interglacial Stage	183,000
Glaciation of the 2nd (Mindel) Phase	49,000
Ist Interglacial Stage	65,000
Glaciation of the 1st (Günz) Phase	49,000
Total about	600,000

The glacial phases were not continuous but showed considerable climatic fluctuations; the ice sheet now greatly receded (but did not completely disappear), now extended and advanced, i.e., was interrupted by incomplete interglacial stages; that is why stages of advance and recession are additionally distinguished in each glacial phase. The Günz and Mindel phases number two stages of advance and one of recession each, the Riss phase—three stages of advance and two of recession, and the Würm phase—four stages of advance and three of recession. These heavy fluctuations of the ice sheet are, of course, most clearly traced in the last phase (Würm).

Causes of Glaciation. About 100 years ago, when the erratics dispersed over the fields of Germany, Denmark, Holland and England were first noticed and it was found that they were composed of rock forming Scandinavia and were entirely absent from the countries where they were discovered (this is the reason they were named erratics), scientists believed they had been brought there by floating ice. They thought that in the beginning of our modern period the aforesaid countries had been flooded by the sea, that the currents had brought icebergs from the north and that these icebergs containing morainic debris had broken off from the Scandinavian glaciers. In the warmer, southern part of the sea the icebergs melted and the boulders they carried dropped to the bottom.

This hypothesis of drifting, i.e., floating, ice persisted in science until the sixties or seventies of last century when some scientists, including Kropotkin, Russian geographer and revolutionary, advanced the hypothesis of continental glaciation. At first this hypothesis appeared monstrous because it was hard to conceive that all of Europe, down to London and Berlin, had formerly been covered with ice. But gradually such facts as moraines, outwash plains, eskers, crag and tails, and roches moutonnées, which the hypothesis of drifting could not explain, compelled everybody to accept the hypothesis of glaciation.

Subsequent detailed observations all over Europe and North America fully confirmed it and from a hypothesis it became a theory. But for a long time yet, almost up to the time of the October Socialist Revolution, while recognizing the glaciation of all of Europe and North America, scientists denied glaciation of the north of Asia (Siberia), believing that its climate was too continental for it, i.e., poor in atmospheric precipitations. But already 70 years ago the same Kropotkin discovered signs of glaciation in several places in Siberia and assumed that the north of Asia had also gone through an ice age. Only the observations accumulated little by little forced everybody to recognize that Siberia, too, had been under an ice sheet.

But the causes of glaciation are still explained differently by various scientists. We cannot expose or consider in detail the different explanations in this chapter and shall confine ourselves to but few.

Some explanations are based on the assumption that Gulfstream, the warm current that brings Europe heat from the tropics, did not exist or had a different direction; others account for glaciation by the former greater height of the northern countries by virtue of which the precipitations fell there only in the form of snow. Attempts were made to explain the lesser solar heating of the earth's surface, by a periodical increase in the carbon dioxide content of the air due to intense volcanic activity. Some scientists, on the contrary, ascribed glaciation to a lack of carbon dioxide because it had been absorbed by the luxuriant vegetation of the Carboniferous and Tertiary periods, which conserved a lot of carbon in the layers of coal. Absorption of solar heat and weakened heating of the Earth was also ascribed to the volcanic dust ejected in large quantities into the upper layers of the atmosphere.

All these hypotheses are easily disproved.

The hypotheses that seek an explanation in the data of astronomy have more basis in fact. Thus a coincidence of the greatest inclination of the Earth's axis and the greatest eccentricity of the Earth's orbit may create for one of the hemispheres (where winter occurs when the Earth is in aphelion, i.e., farthest removed from the Sun) conditions favouring glaciation—drop in annual temperature and prevalence of snow. According to other assumptions a change in the position of the poles, i.e., geographical latitudes, may cause glaciation around each of the poles, as is the case today in the Arctic and Antarctic. Moreover, glaciation may be explained by periodical weakening of the Sun's radiation in connection with the special development of the sun spots. It has been found that the latter influence the climate of the Earth. Lastly, it is thought that in moving through space our solar system periodically goes through regions filled with cosmic dust, owing to which the Earth receives less heat from the Sun.

All these hypotheses have their adherents and adversaries, but not one of them can be considered proved, while some of them, especially the development of sun spots or the passing through clouds of cosmic dust, can neither be demonstrated nor refuted.

The Earth went through phases of glaciation not only during the modern, so-called Quaternary, geological period, but also in more remote times. Some of them have been firmly established by the glacial deposits discovered in such warm countries as South Africa, India and Australia, which were not subjected to glaciation during the Quaternary period. This renders the problem of the causes of glaciation even more complicated because it disproves the very widespread opinion that in former geological periods the Earth received much more heat from the Sun, that it had a uniform climate from the poles to the equator and that the climate, only gradually growing increasingly worse, led to the glacial stages.

Let us hope that in time science will manage to solve the great riddle of the causes of glaciation as it has already solved many other riddles relating to the history of the Earth.

To be sure, the time in which we are living also deserves to be called, in a certain measure, a glacial phase, especially if we compare it with some phases of the Tertiary period which preceded the modern; the more so, since today in the Arctic, i.e., around the North Pole, and in the Antarctic, around the South Pole, vast spaces are covered with ice and offer a sufficiently clear picture of what Europe looked like during the glacial phases.

In the Arctic an enormous ice sheet conceals almost all of Greenland, save a narrow coastal strip of this large island. Spitzbergen, Franz-Joseph Land, Bennett Island, the islands of Severnaya Zemlya, the northern island of Novaya Zemlya and the North American Archipelago are also covered with large glaciers, many of them reaching the sea-shore and giving rise to icebergs. These glaciers move like those in the mountain valleys discussed in this book because they are nourished by the snow that falls on their surface nearly all year round. The tongue of the glacier descends into the sea, and from time to time large blocks of ice break off. These are the icebergs. Winds and sea currents carry them away and they melt very slowly until they get into warmer seas.

Antarctica is a whole continent covered by a single very thick sheet of ice, and only sharp peaks of separate mountains or mountain ridges rise here and there above the ice. In many places the ice descends into the sea as a high and sheer wall and gives rise to numerous icebergs which not infrequently present table-shaped mountains. The icebergs are carried by currents far away to the north.

At the same time remains of plants of the Tertiary period are found in various places on the northern islands, which proves that at that time the islands were not only ice-free, but were covered by forests of trees like those now growing in the warm climate of Southern Europe.

VII

PRODUCTS OF THE EARTH'S ENTRAILS

Heat of the Earth's Crust. Igneous Rocks. Magma. Volcanoes. Eruption and Its Products. Types of Volcanic Eruptions. Distribution of Volcanoes on the Earth. Ancient Volcanic Regions. Fumaroles and Geysers. Eruptions in the Interior. Types of Igneous Rocks. Harm and Usefulness of Volcanoes.

Primitive man knew that in many places fire came out of holes in the ground or in the mountains and attributed this phenomenon to some mighty or evil beings in the interior of the Earth. The ancient civilized peoples believed the entrails of the Earth to be the abode of the souls of the deceased. They considered it an underground kingdom; the Hebrews and Christians named it hell, the place of suffering of the sinners. The Romans who called the ruler of the underworld Pluto, and the Greeks Hades, at first regarded him as an enemy of everything living. The Romans, who knew about the eruptions of volcanoes on the Lipari Islands, Etna in Sicily, etc., believed these volcanoes to be pipes of the underground smithies of Vulcan, the god of fire, smithing, smelting and conflagrations, and therefore built his temples outside city limits. The mountains expelling fire, smoke and small fragments of rock, and effusing lava—molten rock—were therefore given the name of volcanoes.

These mountains prove that in the interior of the earth's crust the temperature is so high that the rocks there are molten.

Observations in mines and boreholes have also shown that the deeper we penetrate into the earth's crust, the more noticeably the temperature rises. In some places the rise is faster than in others; it has been found to average one degree per 33 metres.

The depth at which the temperature in the earth's crust increases by one degree is referred to as a *geothermal gradient.*

Given 33 metres as the mean value we can easily estimate that at a depth of 10 kilometres the temperature must be 300°C higher than on the surface, and at a depth of 40 kilometres it must reach 1,200°C, i.e., most of the rocks must be molten. Incidentally, it is believed that deeper into the interior the value of the geothermal gradient must increase, i.e., the temperature of rock-melting can be reached only much deeper. In addition, the greatly increased pressure also raises the melting-point of rocks. It is therefore probable that the rocks are not molten even at great depths, though they have a higher-than-melting temperature. A sharp weakening of the pressure, however, and these rocks may immediately melt. As vents connecting the earth's interior with its surface, volcanoes may so weaken this pressure in the interior as to cause the rocks to melt.

Igneous Rocks. Magma. The study of rocks which formerly lay deep in the interior of the Earth but are now on the surface shows that some of them were undoubtedly molten before and then solidified. All such rocks are described as *igneous* because they were erupted at one time or another, *massive* because they are not stratified like sedimentary rocks, and *magmatic* because they owe their origin to *magma.* The Greek word *magma* means dough and is used to designate the molten rocks in the interior of the Earth.

Magma contains not only mineral matter, but also water in the form of steam, and various gases. This is evident from direct observations of active volcanoes and analyses of their emanations, as well as from the studies of igneous rocks of different ages in which analyses also reveal the presence of water and various gases, while the microscope shows vesicles containing water and gases inside the grains of minerals.

Volcanoes. Volcanic eruptions are one of the most redoubtable and majestic natural phenomena which man can as yet neither prevent, regulate or render harmless. Not all volcanoes erupt alike for observations have shown several principal types of eruption. We shall first consider the most widespread type.

Volcanoes are divided into *active, extinct* and *ancient.* Active volcanoes are those which suffer eruptions in our days or suffered them in historical time, while those of whose activity no information has come down to us are considered extinct. It would be more fitting to call them dormant or temporarily extinct because we know of several cases in which volcanoes thought extinct suddenly came to life, as did Vesuvius in 79 A.D. and Mont Pelée on Martinique in 1902. Only volcanoes greatly destroyed or eroded, and inactive over many thousands of years,

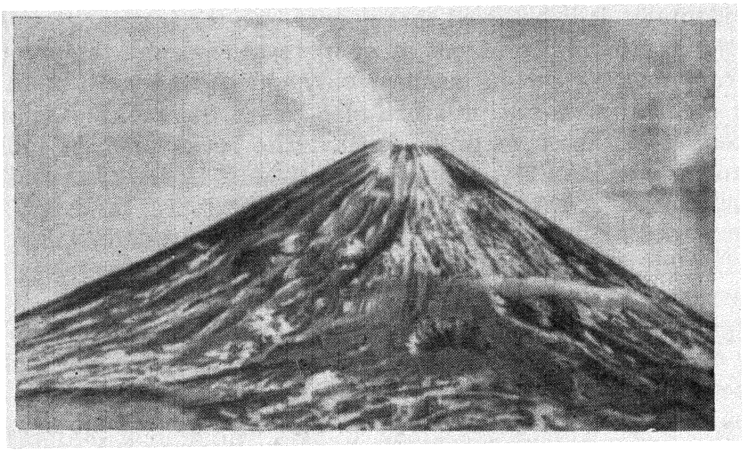

Fig. 148. Mt. Klyuchevskaya Volcano, Kamchatka

may be regarded as totally extinct. These volcanoes are also referred to as ancient.

Volcanic Forms. Most volcanoes are individual mountains with truncated summits or cones (Figs. 148 and 149). The top of the cone has a more or less deep depression known as the crater; the latter is oval or round and has a diameter ranging from a few score metres to two or three and even more kilometres. The crater walls run steeply or sheerly into the interior of the volcano. One or more openings can be distinguished in its floor; these are the vents of the feeding-channels which connect the entrails of the volcano with the crater (Fig. 153) and are more or less choked with indurated lava. A crater not infrequently even turns into a lake. A volcanic mountain is usually built wholly of extruded materials. Hardened streams of lava of different ages and sometimes secondary, smaller craters, which also erupted and are known as parasitic, can frequently be seen on its slopes. Some volcanoes rise singly and far apart, while others form chains or groups in the same area, the individual volcanoes, chains or groups being active at different times and with varying force, others long since being inactive.

Eruption. Active volcanoes do not always erupt with equal force. Each volcano has its own peculiarities, but its general

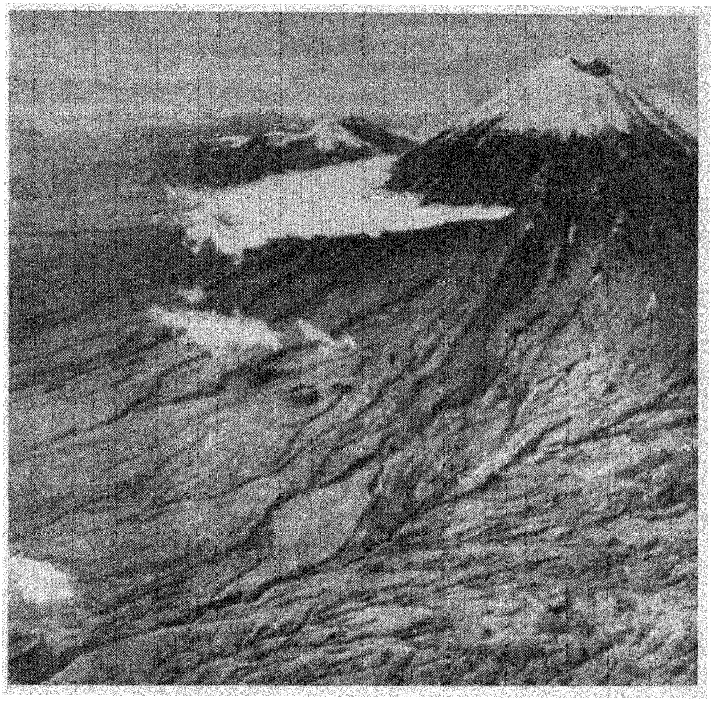

Fig. 149. Mt. Klyuchevskaya. Formation of lateral cones—most typical form of this volcano's eruptions in our time. Panorama of Kamchatka volcanoes in the background. Aerial photograph

activity now wanes and now grows more vigorous so that it is possible to speak of paroxysms, i.e., outbursts of activity which may be of different character and varying duration in the very same volcano. In the intervals between the paroxysms, which may last from several days to several centuries, some volcanoes come almost completely to rest and appear extinct, others barely smoke, still others regularly emit a lot of smoke and from time to time expel stones and ash, which must be regarded as weak paroxysms, while still others quietly exude lava.

A paroxysmal eruption begins with the appearance of smoke in totally inactive volcanoes or the emission of greater amounts

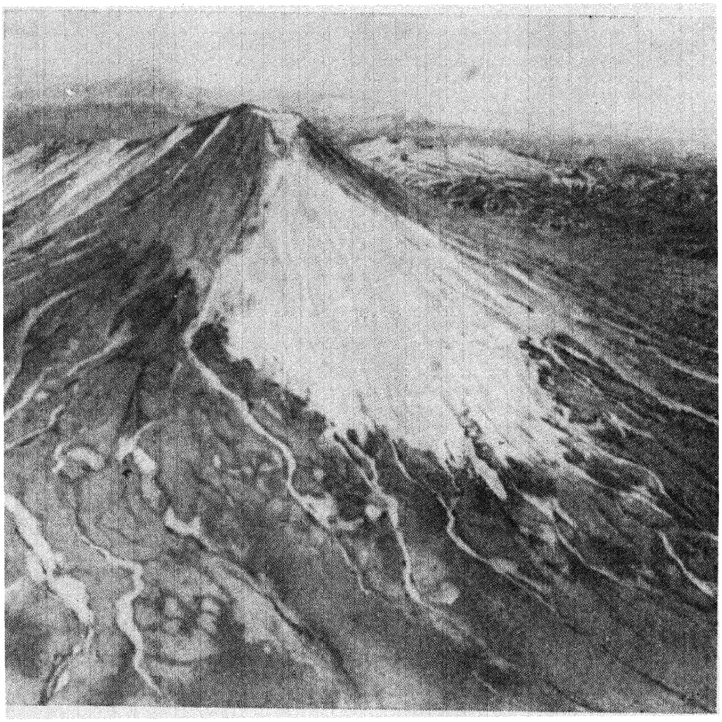

Fig. 150. Mt. Kambalnaya (2,160 metres), southern view. The volcano has smooth, barely eroded slopes; there is a vast lava plateau on the slope. Aerial photograph

of smoke in others. It is preceded or accompanied by more or less perceptible earthquakes, i.e., tremors of the earth in the closest proximity to the volcano, the disappearance of the sources of water or the diminution of their debit in the surrounding country, or yet a change in their composition. These quakes show that layers of the earth's crust are shifting deep under the volcano and that new fissures are being formed or the old ones restored under the pressure of the accumulated gases and vapours which seek an outlet to the surface.

The smoke rises from the crater in a more or less heavy pillar and depending on the weather is either immediately carried away and transformed into clouds or reaches a height of several kilometres and then spreads in every direction; this pillar is shaped like an Italian pine and is therefore described as a pine-tree cloud (Fig. 151). It consists of black smoke and white vapours with either the smoke or the vapours predominating. The smoke consists of minute particles of rock which under the pressure of vapours and gases break away from the lava while still in the interior of the volcano and quickly cool. It is these particles that make up the *volcanic ash* which settles on the slopes of the volcano or its environs from the smoke cloud depending on the direction in which it is carried by the wind. The ash in the form of fine black, grey or white sand sometimes falls in so thick a layer that it not only breaks leaves and branches off trees, but also caves in house roofs and destroys orchards and vegetable gardens.

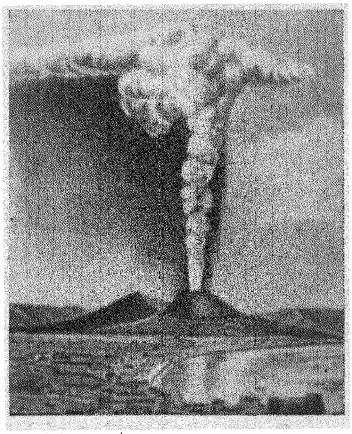

Fig. 151. Eruption of Vesuvius with a pine-tree cloud (1822)

Collecting in clouds over the volcano the water vapours finally break out in rain-storms (because in moving through the air the particles of ash are charged with positive electricity, while the drops of water acquire a negative charge). The rain cleans the air from the ash and running down the slopes of the volcano also takes along the ash that fell before; then it continues in streams of dirty water or even mud, to be exact, filled with gravel and boulders which were washed down the slopes of the volcano. These streams play havoc on their way. Their precipitate run makes them even more dangerous than streams of lava.

Coarser materials—volcanic *sand*, *lapilli* and *bombs*—are ejected in addition to the ash, especially when large quantities of smoke are emitted. The lapilli are small pieces of lava, the size of a walnut, consolidated in the air; larger clots of lava are referred to as bombs. Severed from the lava while hot the bombs in flight acquire twisted forms sometimes resembling heavy rope. Sand, lapilli, bombs and fragments of more ancient rocks, broken away from the walls of the channel, shower down

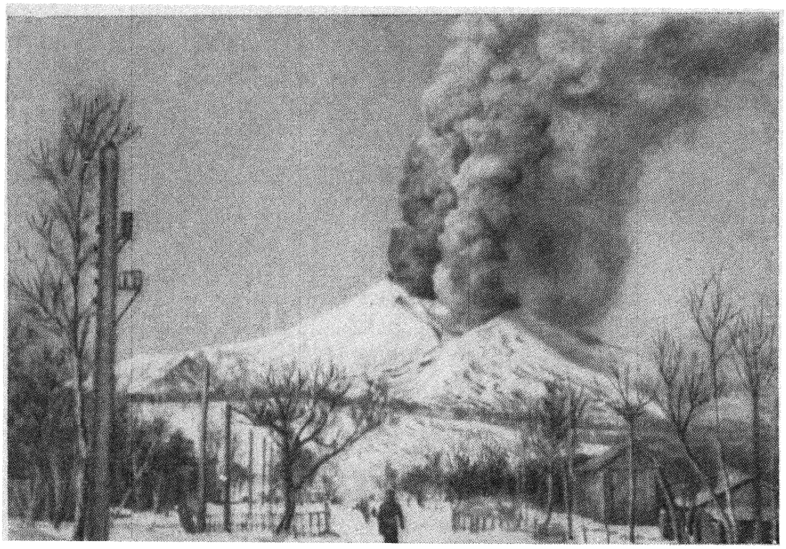

Fig. 152. Eruption of Mt. Avachinskaya on February 25, 1945. Formation of dense clouds of steam as the hot material falling on the slope melts the snow

on the slopes of the volcano in greater or lesser quantities; they constitute the main danger to those who would like to ascend the volcano during its eruption.

The effusions from the crater keep increasing and finally—sometimes with a great explosion—lava rises in the crater, fills it, overflows its lowest upper rim and forms a stream which runs slowly down the slope of the volcano reaching its foot or coming to rest on the slope, depending on the amount and composition of the lava.

The extrusion of lava usually brings the paroxysm to an end. The emission of smoke and gases quickly or gradually diminishes, and the volcano returns to its former state, i.e., either dies down altogether or continues to smoke.

The *products of eruption* are gaseous, liquid or solid. In addition to steam, which constitutes an essential part of the gases liberated by the volcano, analyses have shown these gases to

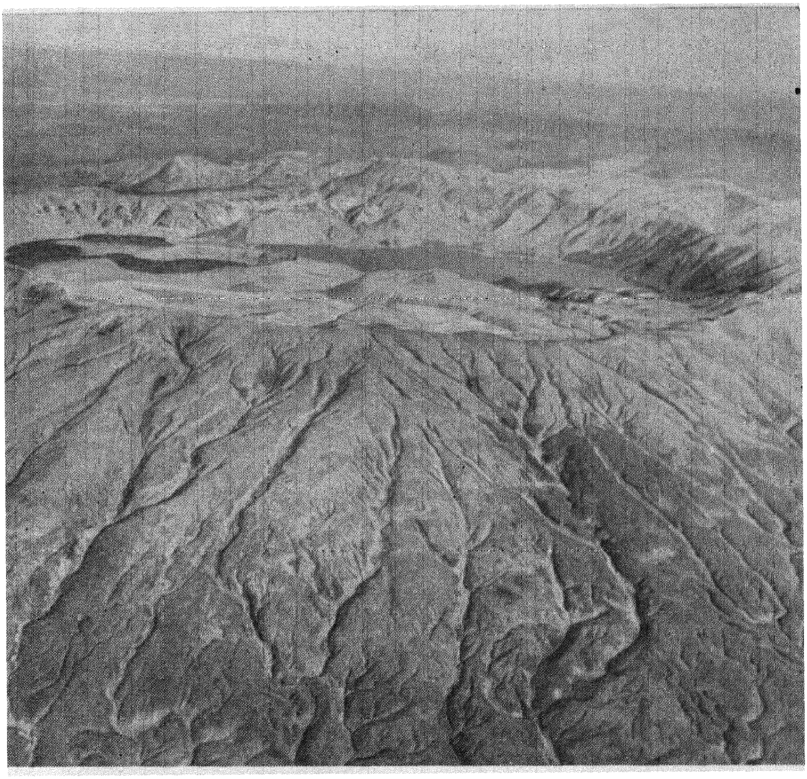

Fig. 153. Keudach Volcano (Stübel's) (893 metres), Komchatka; the round caldera bowl with a diameter of seven kilometres was formed in place of the peak of an enormous volcano, the diameter of the peak exceeding 20 kilometres. Aerial photograph

include hydrogen, chlorine, sulphur, nitrogen, oxygen and carbon. The carbon is present in the form of carbon dioxide, carbon monoxide and methane (hydrocarbon), the other gases in their elementary state or as compounds of hydrogen chloride, hydrogen sulphide, sulphuric and sulphurous acid (anhydrous), ammonia, ammonium chloride and ammonium carbonate. The steam and gases are liberated not only from the crater of the volcano, but also from its slopes and the freshly effused lava in the form of so-called *fumaroles* which escape with a hiss and

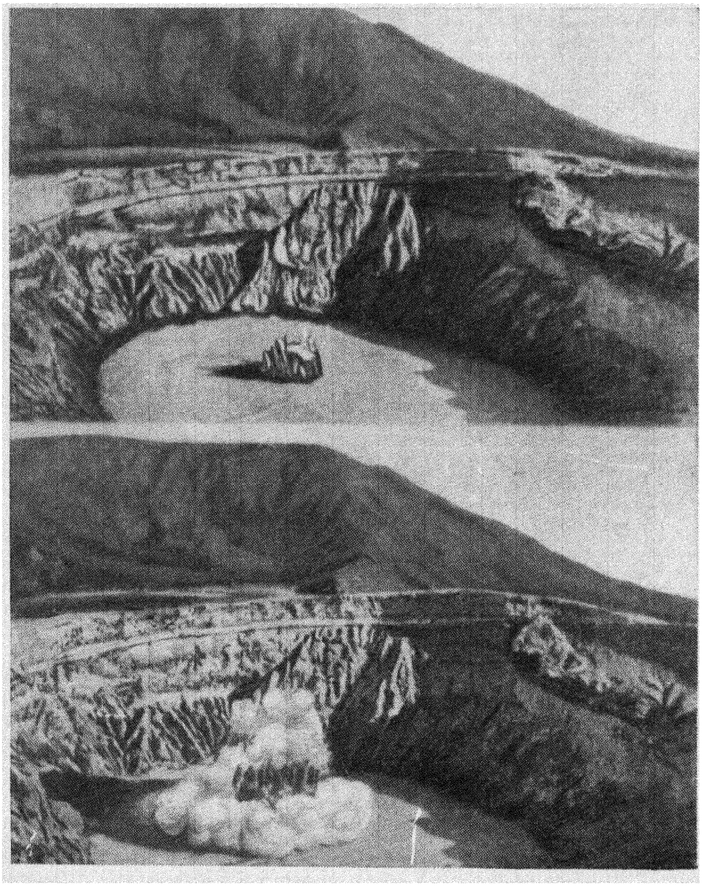

Fig. 154. Crater of the Poas Volcano with a geyser-like eruption, Costa Rica, Central America

noise as clouds of steam from the fissures and openings and spread a stifling odour of chlorine, sulphur and ammonia.

Fumaroles are also liberated in the craters and on the slopes of volcanoes in the intervals between the eruptions, and only for a short time from the streams of lava, before the latter has cooled.

Ash, sand, lapilli and bombs are the solid products of eruption; they consist either of various minerals forming part of the lava (ash and sand) and representing the result of the dispersal

Fig. 155. Krasheninnikov's Volcano (Kamchatka), composed of two volcanoes (Northern and Southern). A young volcano is rising from the summit of the Northern Volcano

of lava by the pressure of the gases and vapours, or of large and small clots of lava broken off by this pressure and solidified in their flight through the air (lapilli and bombs). The composition of these solid materials is the same as that of the lava of the given eruption. Part of the solid materials may consist of the rocks forming the walls of the channel leading to the vent of the volcano and severed by gases and vapours.

Lava exuding from a volcano is a liquid, but it is not a necessary product of all eruptions which sometimes expel nothing but solid and gaseous material. Lava may be more viscous, i.e., containing more silica, or more fluid, i.e., having less silica. Owing to its viscosity the former moves slower and forms shorter and heavier streams on the slopes; while still moving these streams solidify on the surface, the crust breaking up into blocks of different sizes. This lava is called *block* lava. The lava

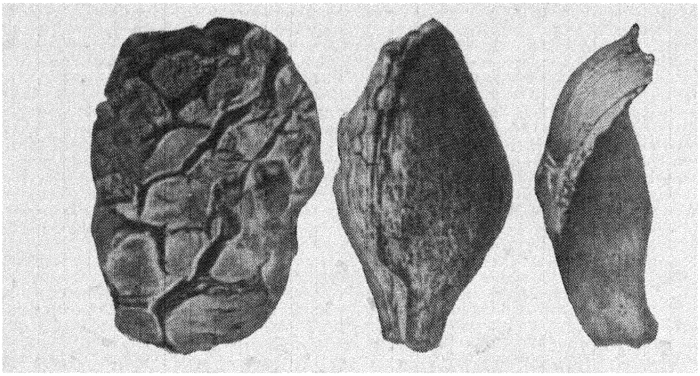

Fig. 156. Bombs—bread-crust, pear-shaped and twisted. The one on the left is from Mt. Pelée

containing less silica is more fluid, flows faster and congeals in overlapping waves. This lava is referred to as *ropy* lava.

It will be noted that in its different eruptions the same volcano may extrude lava of varying composition, i.e., ropy or block lava; this does not happen very often, however. Some volcanoes never change the composition of their lava.

The ash and sand deposited by the volcano on its slopes and in its environs at first form a loose mass, then become compacted and transformed into hard rock known as volcanic tuff. If the ash falls into a lake or sea, its particles mix with those of sand, clay and lime silt brought to the same basin, and form *tuffite,* i.e., rock of a mixed volcanic and sedimentary composition. Tuff formed on the slopes of a volcano or in the closest proximity not infrequently includes extruded lapilli or bombs; if there are many of these coarser constituents the tuff passes into volcanic *breccia.*

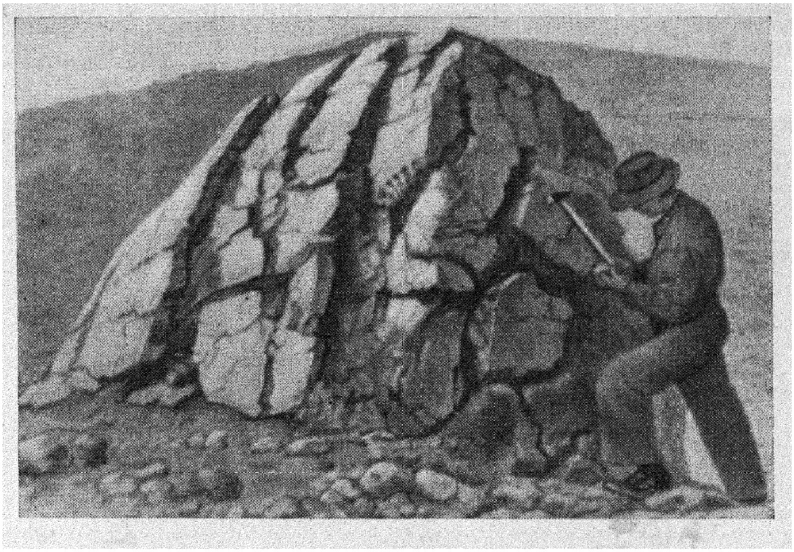

Fig. 157. Gigantic bomb of the bread-crust type on the slope of the Ebeko cone, Paramoshiri Island, Kuriles

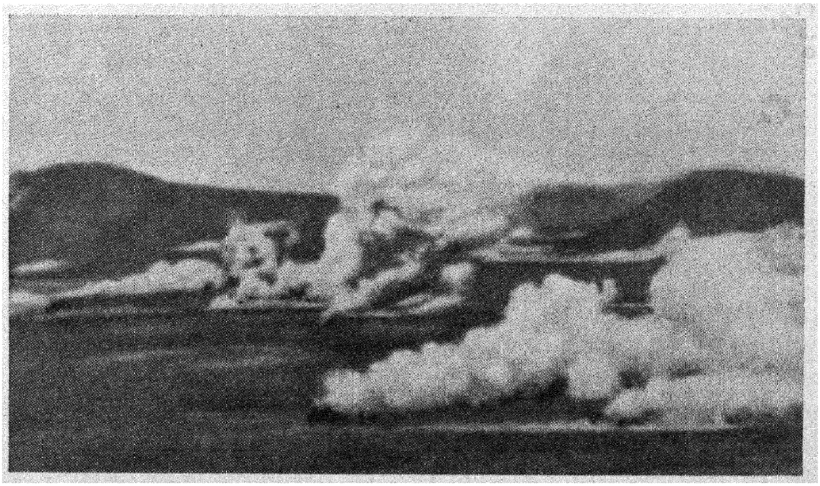

Fig. 158. Part of the Valley of Ten Thousand Smokes in Alaska

Types of Eruptions. We have already mentioned that not all volcanoes erupt alike. Observations have made it possible to distinguish the following principal types of eruptions:

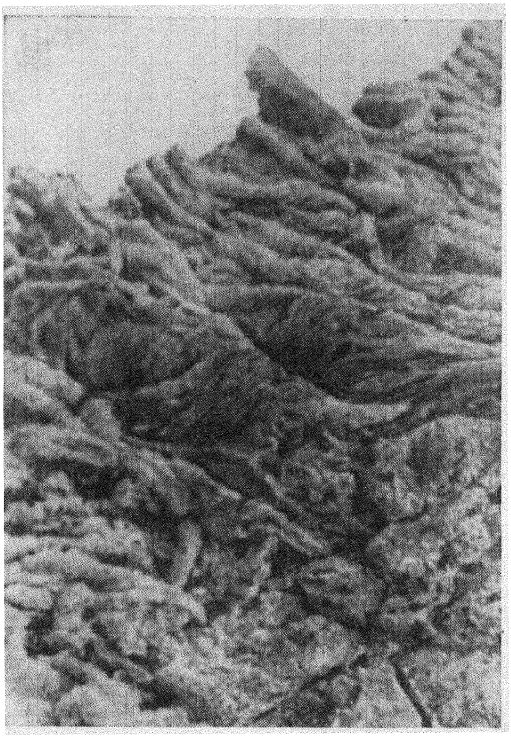

Fig. 159. Ropy lava, Kamchatka

1. *Hawaiian Type.* This type is conspicuous for its scanty emanations of gases and vapours and hence of ash, lapilli and bombs. The lava is very thin and is effused more or less continuously and quietly with hardly any explosions. This type of eruption is characteristic of the volcanoes of the Hawaiian Islands in the Pacific, especially, the Kilauea. The latter has an enormous flat crater forming a lake of fluid lava which liberates small amounts of vapours and gases that produce lava fountains. The lava is ropy.

2. *Strombolian Type.* The volcanoes of this type also erupt thin lava, but the gases they liberate cause violent explosions that throw out bombs but no ash. The bombs are twisted or pear-shaped. The lava is ropy. Stromboli, the volcano in the

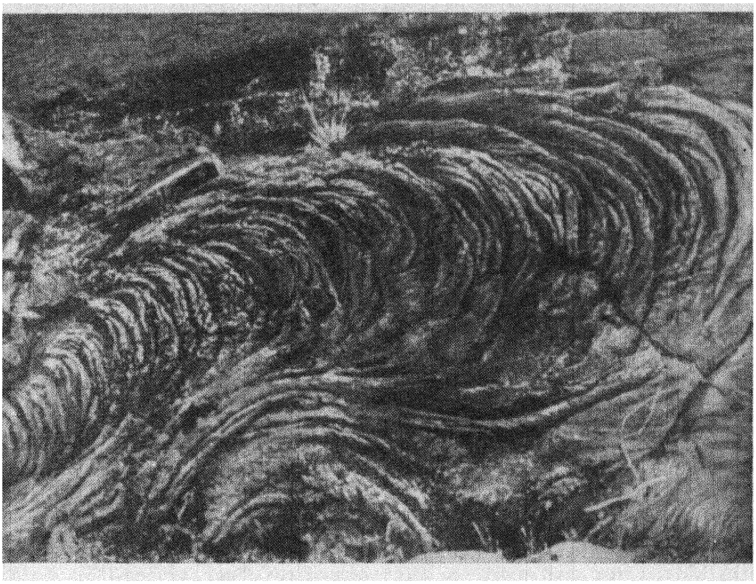

Fig. 160. Surface of a ropy lava sheet of the Tolbachik Volcano, Kamchatka

Mediterranean, after which these volcanoes were named, is a typical representative.

3. *Vulcanian Type.* The lava is more viscous and therefore often chokes up the vent with the result that the pent-up gases and vapours give rise to explosions during the eruptions and throw out a lot of ash, lapilli and bombs. Since the lava is viscous the latter are not twisted, but are of the "bread-crust" type, i.e., they are blocks with a cracked crust like that of a loaf of bread. The streams of lava are rare, scant and do not spread wide. The lava is of the block type. This type of eruption is characteristic of the Vulcano volcanoes in the Mediterranean and partly of Vesuvius in Italy.

4. *Peléan Type.* The lava is very viscous and prevents the escape of gases and vapours; gathering strength the latter produce

violent explosions and spurt out in an enormous cloud of greatly compressed incandescent gases, vapours, ash, lapilli and blocks which sweep down the slope of the volcano at a terrific speed destroying all life on their way. The cloud grows upward into an immense curly pillar referred to as a *nuée ardente*. Under the pressure of gases the hardened but still incandescent lava shoots out of the crater like a plug and forms a spine which very rapidly breaks up into fragments and founders into the crater. This type was first observed during the eruption of Mt. Pelée on Martinique; it took but a few minutes for the nuée ardente to wipe out the town of St. Pierre with its 26,000 inhabitants.

5. *Bandai-san Type*. Very viscous lava prevents the escape of gases and vapours whose pressure finally explodes the whole volcano and throws out masses of old, long-since-solidified lava. Fresh lava does not rise to the surface. This type was first observed during the eruption of Bandai-san in Japan which destroyed the greater part of itself. The terrible eruption of Krakatao near the Island of Java in 1883, when half the volcano foundered into the sea, probably belonged to the same type.

A volcano does not always erupt according to the same type; only the extreme types—the Hawaiian and Bandai-san—are apparently constant for certain volcanoes, whereas eruptions of the three intermediate types may occur in the same volcano. Thus, Vesuvius suffered its last eruption first according to the Strombolian type, then according to the Vulcanian type, and finally threw out a nuée ardente of the Peléan type. The eruption of Vesuvius which destroyed Pompeii in a short time in 79 A.D. probably belonged to the Peléan type. This change in type is, apparently, due to changes in the lava composition, which in the course of time are likely to occur in the same volcano.

The active volcanoes on Kamchatka and the Kurile Islands, the only ones in the U.S.S.R., belong, as far as we know, to the Strombolian and Vulcanian types.

All these types of volcanic eruptions are characteristic of volcanoes which have a channel for the gases and magma to reach the surface, i.e., a certain centre. This is why they are called *central*, as distinct from the *fissure* type eruptions in which the gases and lava pour out of more or less long and very deep fissures in the earth's crust. Fissure outpourings were observed in Iceland from the fissures of Laki, Aeldgia and others; these fissures 30 to 40 kilometres long produced prodigious volumes of lava which spread over the surrounding country.

In connection with fissure effusions a few words should be said about lava *sheets*. The lava issuing from a crater is rarely thin and mobile enough to reach the horizontal plane at the foot of the volcano where it must spread in all directions. The lava flows down the slope and forms a hardening *stream* sometimes several kilometres long, rarely longer than 10 or 15, but only a few dozen metres wide and seldom more than 20 metres thick. On a more gently sloping surface the stream reaches a width of one kilometre or more. On a horizontal surface thin lava spreads in all directions and forms a sheet which may occupy a very large area and grow very thick as is evidenced by some ancient volcanic regions where lava poured mainly out of fissures.

The *amount of extruded materials* varies greatly for the same volcano at different times of its activity. It has been estimated that the greatest amounts are produced by volcanoes which erupt very rarely, whereas the volcanoes which act frequently yield but little material. To give the reader an idea of this we shall cite several figures:

Amount of Extruded Materials (in cubic kilometres)

Volcano	Year	Amount of Lava
Laki Fissure in Iceland	1783	12.5
Etna in Sicily	1669	0.98
Etna in Sicily	1879	0.57
Mauna Loa, Hawaiian Islands	1880	0.45
Mauna Loa, Hawaiian Islands	1907	0.15
		Amount of Loose Material
Tambora on the Island of Sumbawa	1915	30
Santa Maria, Guatemala	1902	more than 4
Laki Fissure in Iceland	1783	2 to 3

It is generally considered that since 1500 all the volcanoes on Earth have extruded close to 300 cubic kilometres of loose material and only about 50 cubic kilometres of lava.

The lava streams are usually unevenly distributed on the slopes of the volcano and depend on the state of the crater's walls and the position of its lowest rim over which the lava pours out. This hollow may persist for years and the lava will invariably stream out on the same part of the slope. A violent explosion may, in ejecting loose materials, instantly form a new hollow and the lava will then flow to another part of the slope. Besides, not infrequently lava exudes from a parasitic crater on a slope rather than from the main crater. In this case the stream may reach inhabited localities and cultivated areas at the foot of the volcano, which are rarely reached by the streams from the

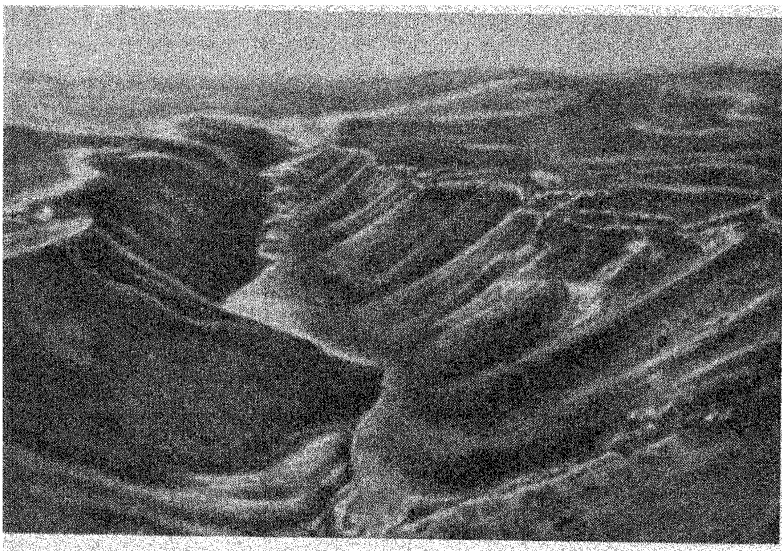

Fig. 161. Aeldgia Fissure, Iceland

main crater since they solidify while still on the slope. Thus, during the Etna eruption in 1928 the lava from a parasitic crater on the eastern slope crossed a railway at the foot of the volcano and overran the streets, houses and orchards of two villages.

The *composition of the volcanic cone* depends on the extruded materials. The volcanoes of the Hawaiian type which pour out only lava are built exclusively of stratified streams of lava of different ages. Most volcanoes, however, are made up of alternating strata of lava and layers of tuff and breccia formed by the loose debris (Fig. 162). Volcanoes ejecting only loose material mould their cones out of tuff and breccia.

Volcanoes are unevenly distributed over the Earth, and vast areas, even continents, have no active volcanoes at all. There are no volcanoes in Australia; in Asia they are concentrated in Kamchatka and are not found anywhere else save the group in North-East China (Tung-pei); the only European volcano is in Italy; Africa has a few, but most volcanoes are found in the Americas, on the islands in the Pacific and in the Indian Ocean, part of the Atlantic and the Mediterranean. On the other hand, if we consider the now extinct volcanoes and the regions of more ancient vulcanism, the distribution of volcanoes on the Earth no longer appears uneven because we find no appreciable area totally devoid of at least ancient volcanoes.

Most of the active volcanoes are in the Pacific; they are located along the coast of the Americas, passing from Alaska over the Aleutian Islands to Kamchatka and from the latter along the Kuriles to Japan; they are dispersed over the islands of the Sunda Isles, and are known in New Zealand and on the southern continent—Antarctica. Some of the islands, for example the Hawaiian and Samoa, have active volcanoes. The Pacific is girded with a fiery belt; if we add to it the neighbouring volcanoes of the Sunda Isles in the Indian Ocean the number of active volcanoes in this belt will exceed 400.

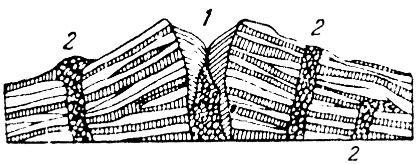

Fig. 162. Section of a volcanic cone built of tuff beds and sheets of lava pierced by the channels of the main (*1*) and parasitic (*2*) craters

The Atlantic Ocean with the Caribbean and Mediterranean seas may be regarded as occupying second place. Here the volcanoes are scattered in groups or singly rather than in chains as in the fiery belt. They are found in Iceland, on the Azores, the Canaries, the Cape Verde Islands, the Lesser Antilles in the Caribbean, in Sicily, on the Lipari Islands, in Italy and on the Greek Archipelago in the Mediterranean. There are several dozen active volcanoes in this area.

Africa occupies third place with its solitary volcano on the west coast and several in the interior along the chain of large lakes.

According to the latest estimates, of the 486 volcanoes active since 1500, 403 are located in the Pacific half of the Earth and 83 in the half of the Atlantic and Indian oceans. If the more ancient known eruptions are taken into account, however, we get a total of 522 volcanoes.

Studies of the structure of the earth's crust have led scientists to the inference that volcanoes occur in regions of the greatest disturbance of the strata forming the crust. These disturbances consist, as we shall learn in the next chapter, primarily in a powerful *compression* of the strata resulting in *folds* like those

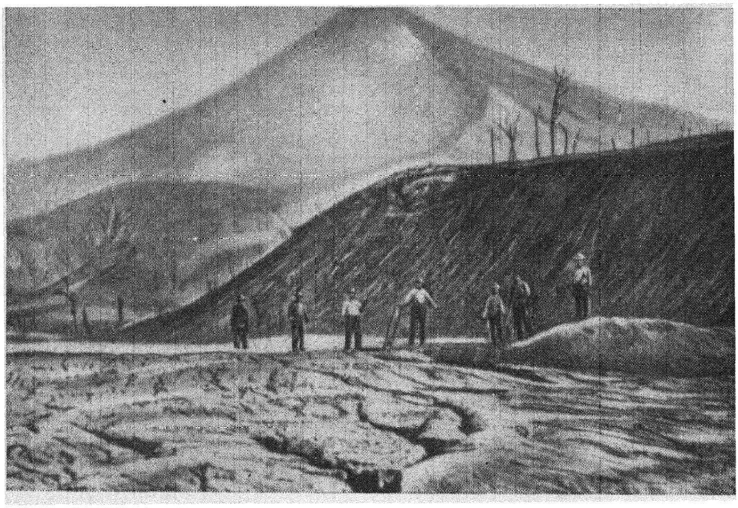

Fig. 163. Santa-Maria Volcano with the stratum of ash ejected during the eruption of 1902, Guatemala, Central America

we see in a table-cloth when we crumple one end of it with our hands, and secondly, in *fractures* of these strata by the fissures formed when the layers are pulled apart by excessive tension. Active volcanoes are found mainly in places where the earth's crust recently experienced particularly violent folding or great fractures. Not infrequently both disturbances occur in combination. Thus, the young folding on the Pacific coasts was accompanied in many places by large fractures, and in the neighbourhood of the folded mountain ranges along the coast we find the greatest depths of the ocean in the long narrow depressions. The volcanoes of the Mediterranean and Caribbean seas are also located in regions of late folding accompanied by fractures. The volcanoes in the interior of Africa occur in the long belt of young fractures ending in the Red Sea and the gap of the Dead Sea and the Jordan Valley in the north. The laws governing the distribution of the volcanoes in the Atlantic are less clear; these volcanoes are assumed to be a result of a crossing of ancient and recent belts of folding and fractures. Also vague is the origin of the volcanoes on the Hawaiian Islands in the Pacific too far removed from the coastal belts of folds and fractures.

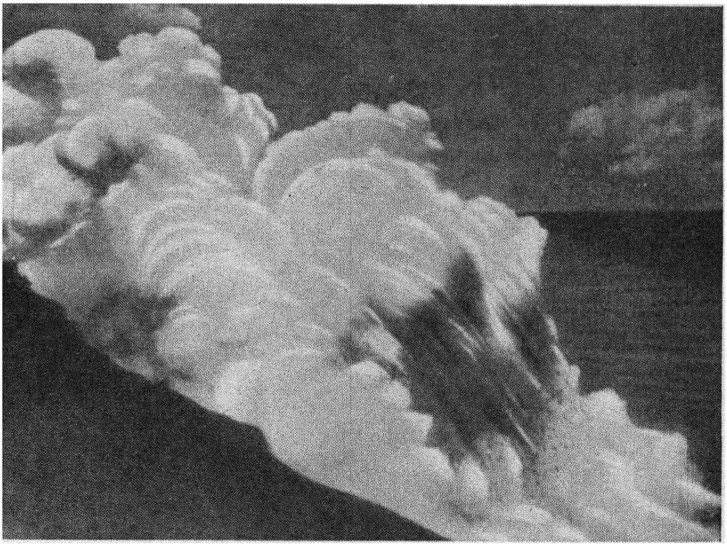

Fig. 164. Stream of lava pouring into the sea. Matawanu Volcano, Savaii Island, Pacific

The *ancient volcanic regions* confirm the aforesaid natural distribution of volcanoes. These regions are of different age. Some have volcanoes which were active as late as the beginning of the modern geological period, and were, probably, even witnessed by primitive man. The youngest of the ancient volcanoes have retained the characteristic forms of conical mountains with the crater at the summit, frequently containing a lake, and the lava streams effused from the crater. Such are the highest peaks in the Caucasus—Kazbek, Elbrus and some others—Ararat in Turkey, Alagez, etc., in Armenia, Demavend in Iran, the small volcanoes of Lopatin, Mushketov and Obruchev on the Vitim Plateau, and the Peretolchin and Kropotkin volcanoes in Eastern

Sayan. Auvergne in France, Monte Nuovo and the Phlegraean Fields in Italy, Drachenfels on the Rhine and the Eifel Maars in Germany are also among the youngest (of the ancient) volcanic areas. We shall also find them in the Mongolian People's Republic (for example, the volcanoes in Darigan Region and Clements' Volcano in the Hang-hai uplands), in Southern China, Northern India, Australia, Asia Minor, etc. In Tung-pei, in the Uyun-

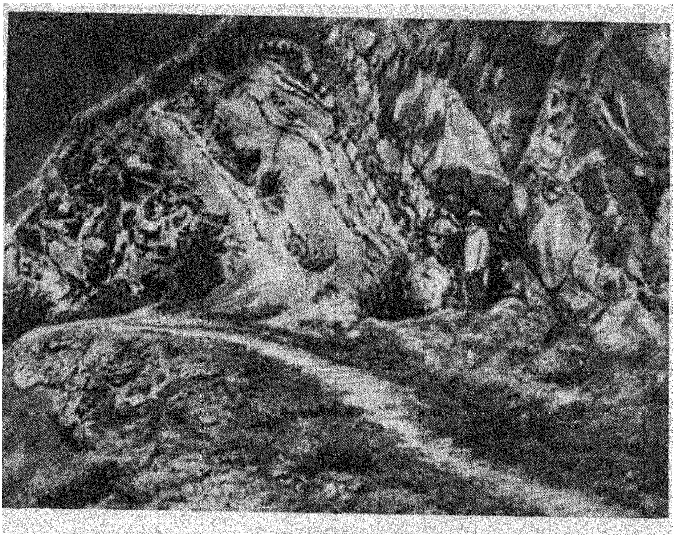

Fig. 165. Sheets of lava interbedded with strata of tuffs, Borzhomi, Caucasus

Kholdongi group there was an eruption in the vicinity of the city of Mergen as late as 1724 A.D. (according to Chinese annals).

Older volcanic districts are unevenly scattered through all the continents, the forms of the volcanoes strongly affected by weathering and erosion and retaining only ruins of volcanic mountains and remains of lava streams and sheets (Fig. 165). There are still older remains in which we find only the innermost parts of the volcanoes and the channels filled with magma. These remains are known in the Urals, the Donets Basin, Volhynia, the Pyatigorsk area in the North Caucasus, the Alps and Carpathians, the Balkans, Tibet, Altai, Sayans, Transbaikal, Chukotka Peninsula, on the Amur and along the entire coast from Vladivostok to the Anadyr River. An enormous sheet of lava, which poured out mainly through fissures, lies in Central Siberia between the Yenisei and Lena rivers in the northern part of the Tunguska Basin; a vast area south and east of this lava sheet is covered by the tuff ejected by many volcanoes and explosive vents. The Deccan Plateau in India with its lava sheets is another ancient volcanic region. The Arctic islands—Spitzbergen, Franz-Joseph Land and Greenland—also abound in ancient lava

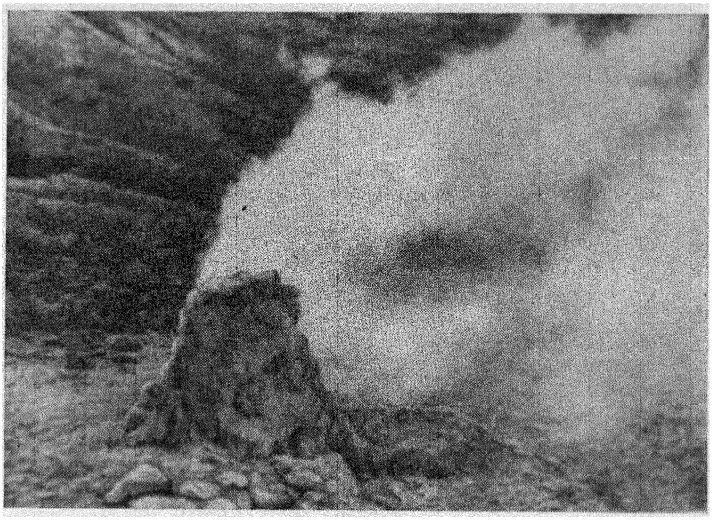

Fig. 166. Solfataras in the crater of the Ebeko Volcano, Paramoshiri Island, Kuriles

sheets which cover the layers of sedimentary rock and partly alternate with them.

All these ancient volcanic areas reveal a clear dependence on the belts of intensive folding or fracturing of the earth's crust. Chains of active volcanoes arose or fissure lava outpourings occurred along these fractures. In some of these areas, especially the younger ones, the last repercussions of volcanic activity still manifest themselves in the form of hot springs showing that the volcanic focus, the reservoir of magma, in the interior has not cooled yet and continues to liberate juvenile water. The hot springs on the shores of Lake Baikal and in the Barguzin taiga, Karlovy Vary in Czechoslovakia, Pyatigorsk and Borzhomi in the Caucasus, Kissingen in Germany, Auvergne in France, and Demavend in Iran show signs of extinct vulcanism. Not only the warm, but in many cases also the cold mineral springs are the last repercussions of former volcanic activity.

Observations of modern volcanoes have shown that when a volcano becomes extinct after vigorous eruptions and its fuma-

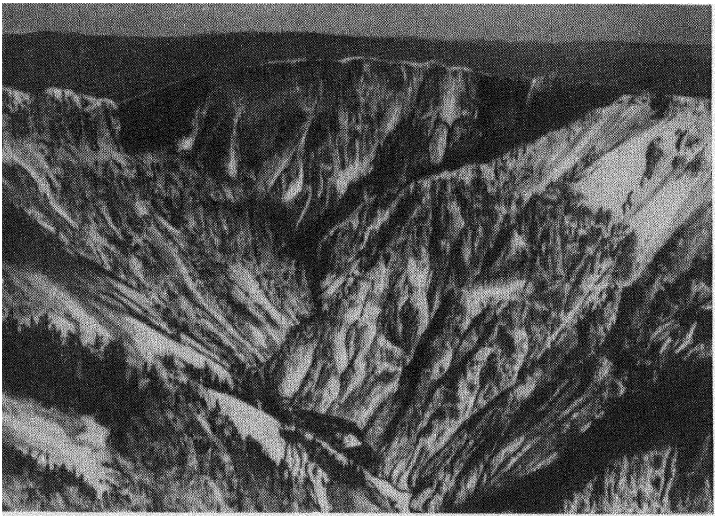

Fig. 167. Canyon of the Yellowstone River, U.S.A., burrowed into the strata of tuffs and lavas to a depth of 360 metres

roles cool down the variety of gases in them diminishes and even the main centre liberates only sulphurous and carbonic gases and steam. In this state the volcanoes are referred to as *solfataras* (Fig. 166). At a later stage of extinction volcanoes emit only carbonic gas and hydrocarbons in a form known as *moffettes*. In the ancient volcanic regions the warm and cold mineral springs may be regarded as juvenile waters of volcanic origin, rather than vadose heated and mineralized in the interior of the earth's crust.

One of the most remarkable and relatively young volcanic regions is the Yellowstone National Park in the Rocky Mountains (the United States). The Yellowstone River has cut a canyon through enormously thick lava and tuffs of former eruptions (Fig. 167) in which remains of trees are buried on 15 levels. A large forest with age-old trees grew in this area 15 times and 15 times the neighbouring volcano buried the new forest in ash and lava. Many trees were petrified standing and have come down to us in a vertical position as stumps, others as felled trunks. This shows that catastrophic volcanic eruptions occurred there 15 times and that centuries elapsed before another forest grew on the new surface (Fig. 168).

In the National Park we also find other proofs of recent volcanic activity in the form of abundant geysers.

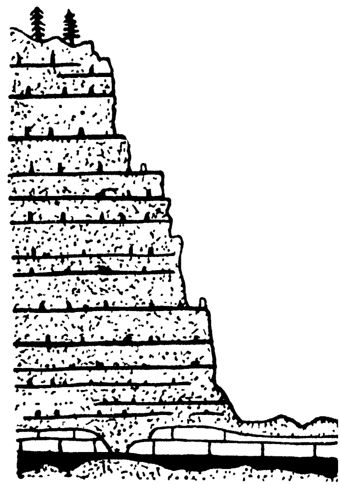

Fig. 168. Section of strata of tuffs and lava with 15 levels of buried forests, Yellowstone National Park, U.S.A.

Geysers are hot springs erupting periodically as more or less high fountains. They are known only in volcanic regions, modern—Kamchatka, Iceland and New Zealand, and older—Yellowstone Park. Some geysers issue from openings in the floor of a small basin, others from orifices amid layers of silicious tuff which are depositions of hot water. They discharge their water at various intervals constant for each of them; some spout every 10 or 20 minutes, others every few hours, still others once a day. The eruption is preceded by underground shocks and boiling of the water in the basin; then a fountain of water is hurled into the air; this, too, lasts for different periods of time and then ceases. The temperature of the geyser water ranges between 60° and 99° C; it contains in solution mainly silica which, when liberated, builds up irregular small cones or basins around the openings surrounded by terraces; it runs down the terraces which gradually grow larger. The Great Geyser in Iceland suffers eruption every 24 to 30 hours; in New Zealand dozens of them spout in the Waikato Valley around Lake Rotomahama, the largest—Tetarata—has formed a series of snow-white terraces of silicious tuff. In Yellowstone Park there are several dozen geysers of different sizes (Fig. 169). In the neighbourhood of some geysers part of the forest flooded by mineral water gradually perishes: the trees impregnated with silica petrify.

More than 20 large geysers were discovered in Kamchatka near the Kikhpinych Volcano in the valley of the Geyser River in 1941. The largest known as the "Giant" spouts a stream of

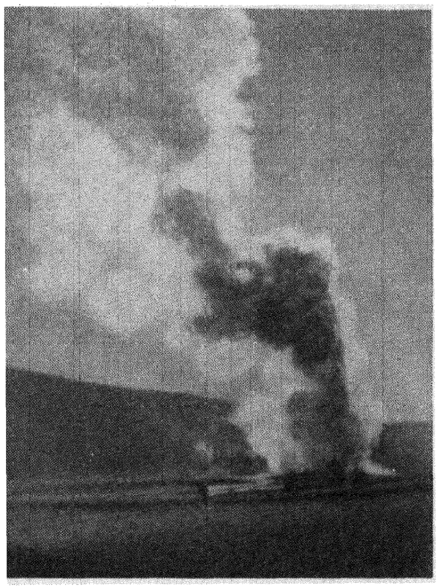

Fig. 169. Old Faithful Geyser, Yellowstone National Park, U.S.A. Spouts every 70 minutes to a height of 40 metres

water up to three metres in diameter at the point of emergence to a height of 40 metres, while the steam rises at times to 500 metres.

The regime of the Kamchatka geysers varies. Some are noted for long quiescence, others, on the contrary, for prolonged eruption and brief quiescence.

The duration of a complete cycle, i.e., eruption and quiescence, of the Kamchatka geysers varies from 2.5 minutes to five hours. The eruption of water and steam lasts from one to 12 minutes. The discharged stream is from one to 40 metres high. The water temperature ranges between 94° and 99° C.

Most of the geysers erupt irregularly. In Kamchatka they act with an accuracy of only 20 to 40 per cent, but compared with the other world's geysers they are more regular.

In the course of time the regime of the geysers changes, the periods of their activity usually growing longer.

Intrusions. The magma rising from the entrails of the earth does not always reach the surface to create volcanoes and their

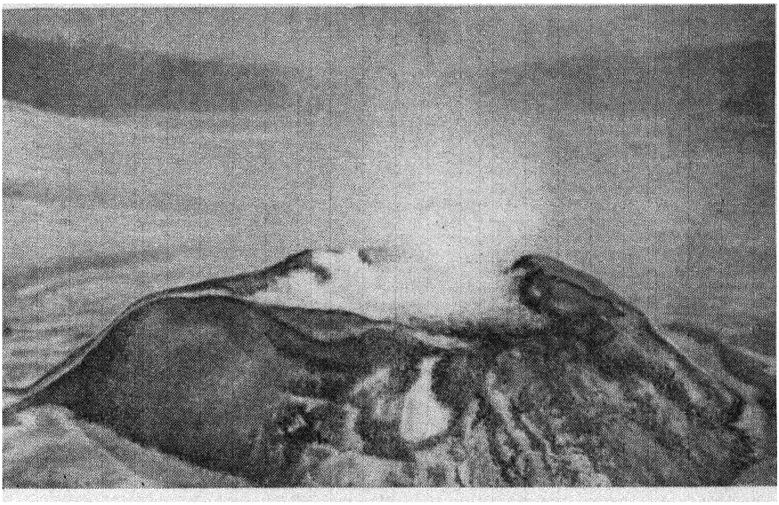

Fig. 170. Basin of the "Sponge" boiling spring, Yellowstone National Park, U.S.A.

eruptions. Of much greater importance, judging by the masses of rock formed from magma, are the eruptions remaining in the crust and referred to as *intrusions*, because magma invades the layers of the earth's crust sometimes using the available cavities, but more frequently making a place for itself by raising and parting the layers and melting them with its heat.

The intrusions differ in shape and extent. The largest, covering areas ranging from a few dozen to several hundred square kilometres (and having a corresponding volume) are known as *batholiths*; they are elongated or rounded and have branches and hollows; their upper surface is irregular and has protrusions (domes). Sections or separate blocks of sedimentary rock forming the roof of the batholith invaded by magma are severed from the latter and submerged in its mass in the form of *xenoliths*. Small batholiths covering an area of hundreds or thousands of square metres are referred to as *stocks*.

Magma frequently arches up the layers of the earth's crust into domes and hardens in the form resembling a loaf of bread and known as a *laccolith*; the latter always has a channel, along

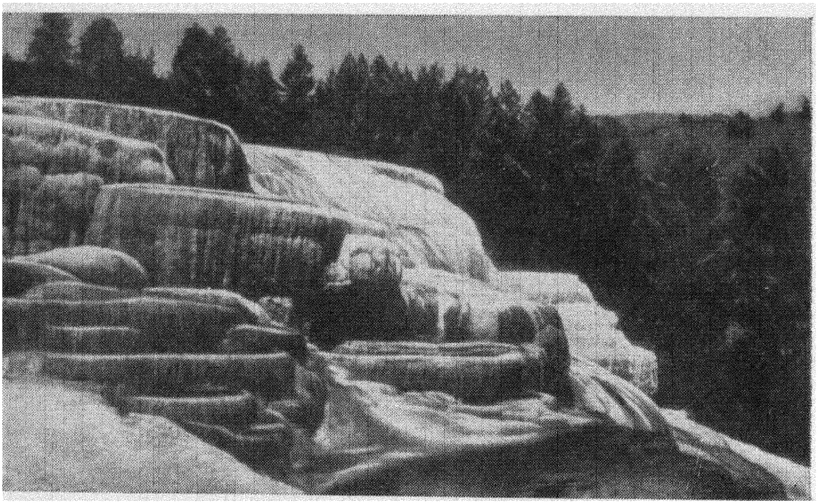

Fig. 171. Cleopatra's Terraces of silicious tuff deposits with red, orange and brown algae, Yellowstone, U.S.A.

which the magma rose, under its floor. Laccoliths can form only near the earth's surface amid horizontal or slightly tilted layers which can rise under pressure. In the roof of the laccolith, if it consists of thinner rock strata, one can see the invasion of magma between the layers, i.e., along the planes of stratification, sometimes over a considerable area. A laccolith may be regarded as a miscarried volcano—the magma failed to break through to the surface; on the other hand, it is possible that at some depth under the active volcano there is a laccolith in the form of a reservoir of magma producing the eruptions. Figure 181 shows a laccolith (Ayu-Dag Mountain) exposed by erosion.

The Mineralniye Vody area in the Caucasus where we see a number of individual mountains (a total of 17) offers an instructive example of laccoliths. Some of them are already eroded laccoliths, as for example Beshtau, Zmiyevka, Razvalka, Zheleznaya Gora, Verblyud and Byk, where the intruded rocks come to the surface, while others, like Mashuk, Lysaya, Yutsa and Svistun, are laccoliths still hidden under a shell of dome-shaped sedimentary rocks. Figure 174 represents a cross-section of the Beshtau (1), Zheleznaya (2) and Razvalka (3) mountains showing that in laccolith invasion the layers sometimes turn up or even over. Zheleznaya and Razvalka have a common laccolith with two peaks—the remnant of the roof between them. Apparently, invasion does not occur so quietly as is shown in the ideal cross-section (Fig. 173). The hot and cold mineral springs of

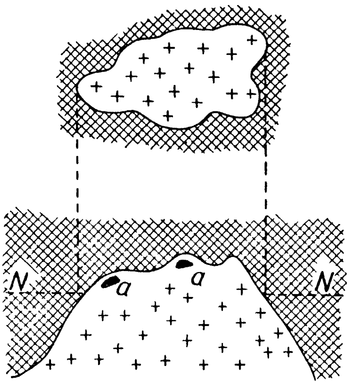

Fig. 172. Sections of batholith: vertical (below) and horizontal on the level of line *NN* (above), *a*—xenoliths

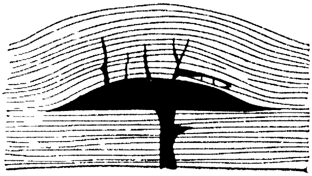

Fig. 173. Ideal section of a laccolith with cross and sill veins in the roof

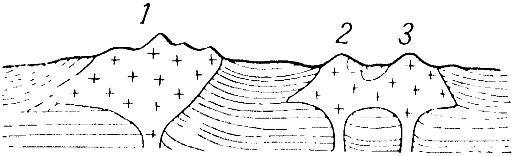

Fig. 174. Section of laccoliths (*1*, *2*, *3*) of Beshtau, Zheleznaya and Razvalka mountains exposed by erosion, Caucasian Mineralniye Vody

various composition for which this area is known are the last repercussions of the intrusion which has long since died down and produced no volcanoes. But not so far south of here we find

Elbrus which is an enormous volcano that was apparently active within the memory of man judging by the legend about Prometheus who stole light from the sun and whom the gods punished by chaining him to the peak of this mountain.

In addition to batholiths and laccoliths the intrusions build up other forms, both more complex and simple; of these we shall

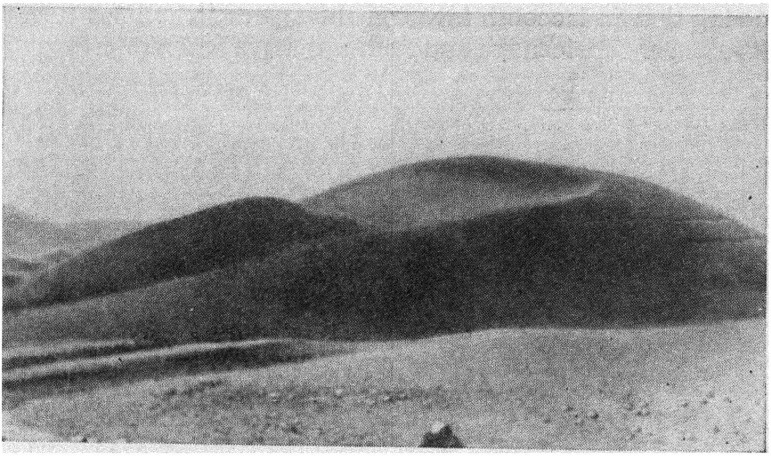

Fig. 175. Lower Quaternary slag volcano on the Kyzyl-Juk Plateau (Armenian Upland) with a secondary cone in the crater

consider only *veins* as occurring the most frequently; the veins either cross the layers of sedimentary rocks in different directions and are referred to as *discordant* or make their way along the planes of stratification and are said to be *concordant* or *sills* (Fig. 177). A hanging wall (*H*), a lying wall (*R*) and a thickness are distinguished in veins. The thickness, determined perpendicularly to both walls, varies from a centimetre to scores and even hundreds of metres. Some veins are short, others run for hundreds of metres or several kilometres.

The veins often grow thicker or thinner. They issue both from batholiths and laccoliths, as well as from volcanoes, namely, from their channels, and are magmatic fillings of fissures (discordant) or magmatic invasions along the planes of stratification.

Types of Igneous Rock. It was pointed out in the beginning of this chapter that magma solidified in batholiths, laccoliths, veins

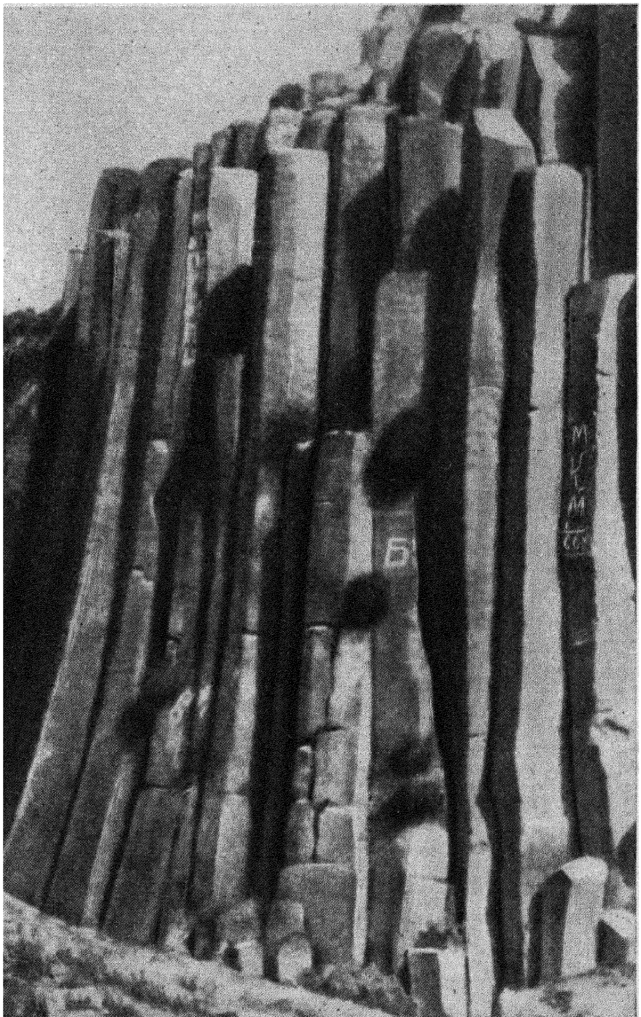

Fig. 176. Basaltic pillars in the environs of Yerevan.
Quaternary cover

and streams, and that sheets of lava formed rocks known as igneous or magmatic, which greatly varied in composition and structure. These and the sedimentary rocks are studied by *petrography*, a major branch of geology; here we can offer only a most general idea of their composition and structure.

Igneous rocks are divided primarily according to their content of silica into *acid* (containing more than 65 per cent of silicon oxide), *intermediate* (52 to 65 per cent), *basic* (42 to 52 per cent) and *ultrabasic* (less than 42 per cent).

According to their mode of occurrence we distinguish among igneous rocks: a) *intrusive* or *plutonic* which hardened in the earth's crust and accordingly acquired a granular structure; b) *effusive* or *extrusive* (also volcanic) which broke through to the earth's surface along the channels of volcanoes or fissures and solidified under atmospheric pressure; c) *lode* rock, i.e., magma consolidated at various depths in fissures of the earth's crust.

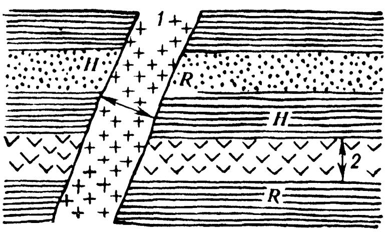

Fig. 177. Discordant (1) and concordant (2) veins; *H*—hanging wall; *R*—recumbent wall

The following rocks are distinguished according to structure:

1. *Coarse-grained* rocks, formed when the magma solidified very slowly in the earth's crust and all the minerals included in the composition of the rock had enough time to separate in the form of crystals or grains of about the same size. The following rocks may be mentioned by way of example: acid rocks—granite, intermediate—diorite and syenite, basic—gabbro, and ultrabasic—peridotite.

Granite is composed of quartz, felspars and mica with hornblende, and rarely augite along with or in place of the mica.

Diorite and syenite consist of felspars and mica (or hornblende, augite); the difference between them depends on the composition of the felspar—potassic (in syenite) and calcareous-sodium (in diorite).

Gabbro is made up of calcareous-sodium felspar, pyroxene (diallage, augite, hypersthene) and olivine.

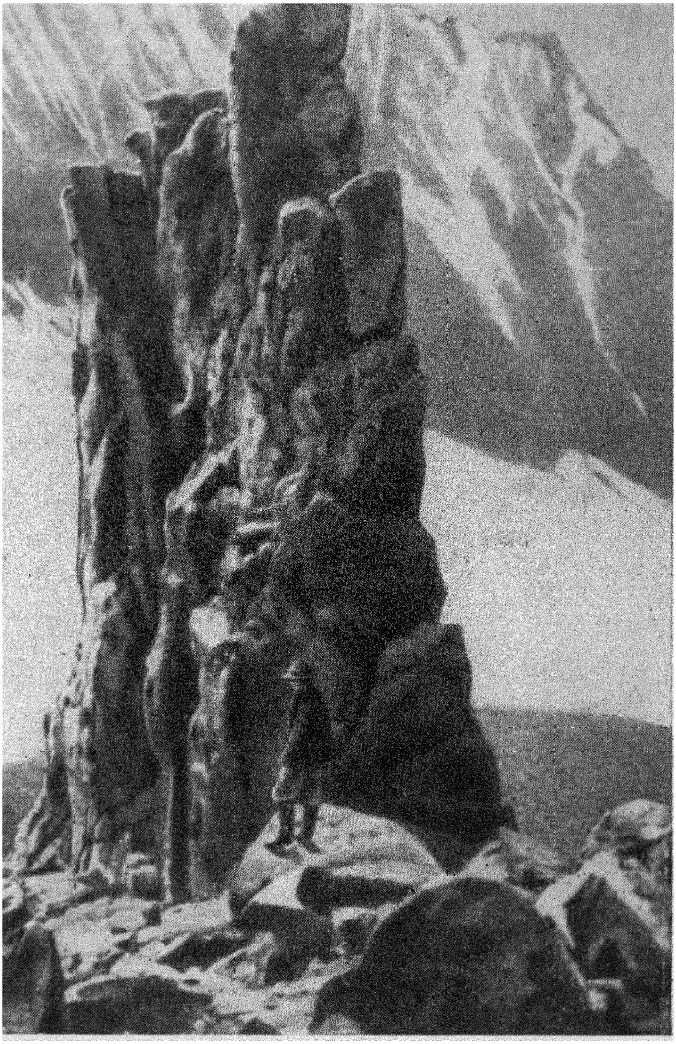

Fig. 178. Pegmatitic vein exposed by weathering of the slates that surrounded it, Turkestan Range

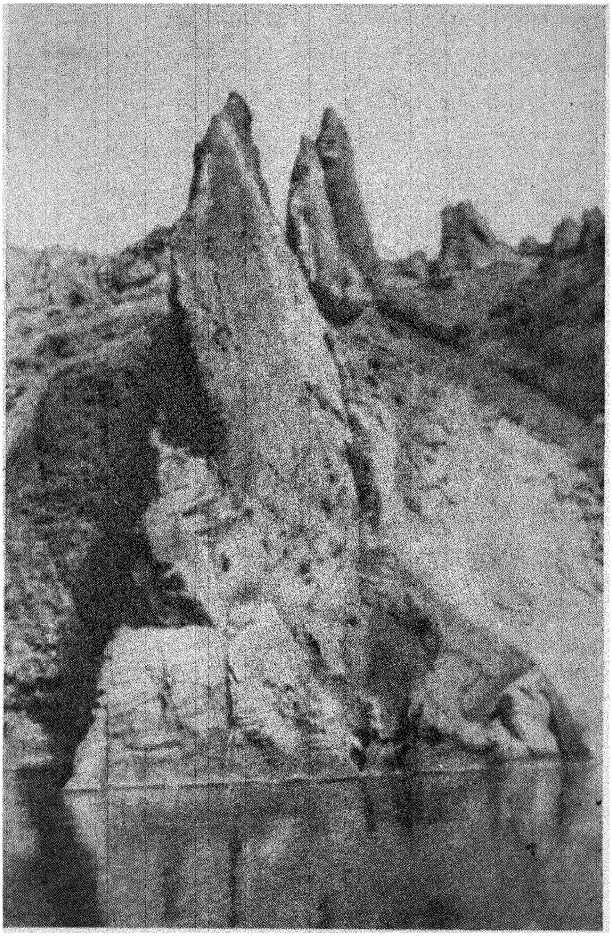

Fig. 179. Vein of effusive rock, Kara-Dag, Crimea

Peridotite is composed of olivine and augite with sometimes an admixture of hornblende and mica.

2. *Porphyritic* rocks are formed when the magma consolidates more rapidly on or near the surface and are distinguished for the fact that part of the minerals had enough time to separate in the form of grains or crystals of appreciable size, while the rest cooled as a very fine-grained mass often additionally con-

taining glass. When lava hardens so fast that no minerals have time to separate volcanic glass is formed, which is a translucent mass of different colours and resembles artificial glass.

The following examples of porphyritic rocks may be named: acid—quartz porphyry and liparite; intermediate—dacite and trachyte; basic—porphyrite, andesite and basalt; ultrabasic—picrite-porphyrite. These rocks are of the same composition as

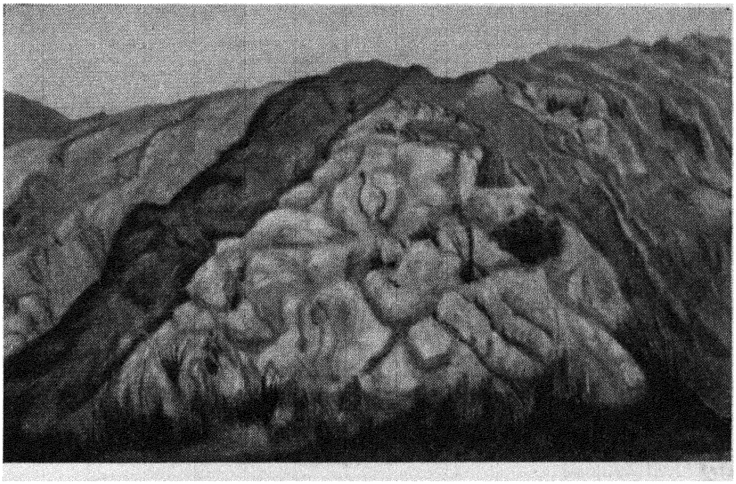

Fig. 180. Diorite vein in white granite which broke through grey gneisses (right). Depression of the Lobachen Spring, Pei-Shan Desert, Central Asia

the aforementioned coarse-grained rocks (for example, quartz porphyry and liparite correspond to granite, trachyte to syenite, porphyrite and andesite to diorite, etc.), but of a different structure due to other conditions of solidification.

3. *Glassy* rocks are either made up completely of glass or contain in the glass certain minerals which have had time to become isolated. Vitrophyre (glass porphyry), vitrobasalt (glassy basalt), obsidian, pumice and pitchstone (continuous glass of the liparite and dacite composition) are some examples.

Distinction is also made of *bubble-rocks*, as a variety of porphyritic and glassy rocks, abounding in cavities of different sizes left by the gases liberated from the lava. According to the size and shape of the voids the texture is said to be spongy, frothy, coarse and fine-grained, which is generally common to the rocks extruded to the surface of the earth.

The reader may ask why the porphyritic rocks, which correspond to granite in composition, are called quartz-porphyry and liparite, and what the difference between them is. The thing is that older and younger, or more altered and fresher, varieties

Fig. 181. Laccolith exposed by erosion, Mt. Ayu-Dag in the background. South Coast of the Crimea

are distinguished among the porphyritic rocks; the former include quartz-porphyries and porphyrites, the latter—liparites, trachytes, dacites, andesites and basalts.

The older rocks are noted for their greater compactness, since they have already suffered various changes under the action of chemical and physical agents; the fine pores left by the gases liberated from the magma, as the latter cooled, have disappeared from them. Some juvenile rocks have isolated a glassy felspar (sanidine) which is not found in old rocks. In the latter the glass has essentially decrystallized. In most cases it is not difficult to distinguish old porphyritic rock from young.

A few words should be said about *metamorphic* rocks formed in the earth's crust from sedimentary rocks as the latter come into contact with intrusions. The heat liberated by the intrusions as they cool, as well as their vapours and gases, produce more or less appreciable changes ranging from the appearance of various new minerals to a complete recrystallization of the sedimentary rock, i.e., to changing it into a crystalline rock. The considerable pressure prevailing in the interior and developing during mountain-building, high temperature and the solutions circulating through the rocks are agents of metamorphism.

Gneisses, crystalline slates, quartzites and marbles are examples of metamorphic rocks. The gneiss of granitic composition is formed either of fully recrystallized sedimentary rocks and is then said to be a *paragneiss*, or the intrusive mass consolidating under pressure during mountain-building receives a slaty texture and is transformed into *orthogneiss*. Marble is built up from limestones and dolomites; crystalline, hornblende, micaceous, chloritic and other slates are formed by various sedimentary rocks.

The *study of volcanoes* is an important and in some respects particularly difficult task. To study the ancient, long extinct and deeply eroded volcanoes is, of course, not any harder than to study the outcrops of any other rocks; in this manner it is possible to get an idea of the volcano's interior, its composition and structure, the form and method in which its channel was filled, the relationships of the various rocks and the sequence of stratification in the volcanic cone.

The batholiths and laccoliths more or less deeply exposed by erosion make it possible to study the composition and structure of these underground manifestations of vulcanism and to reveal the process of their invasion of the layers of the earth's crust, their hardening and influence on the surrounding rocks. But the very process of vulcanism in its various manifestations on the earth's surface and in all phases of its development can be studied only on active volcanoes, and in this case the study is rendered very difficult by the asphyxiating or poison gases, hot water vapours, nuées ardentes and ejected burning hot bombs.

Considerable progress in studying active volcanoes has been made since the beginning of the twentieth century. At first American scientists penetrated into the spacious crater of the Kilauea Volcano in Hawaii and at the peril of their lives measured the temperature of molten lava, took samples of it and collected gaseous emanations. This made it possible to solve the complicated problem of the composition of gases, especially the participation of water vapours which many had disputed. Later scientists began to descend into the craters of Vesuvius and Stromboli; the scientist Mercalli lost his life in the former, and Kerner descended on a rope to a depth of 250 metres in the latter. A Japanese geologist and a journalist descended into the crater of the active Miharayama Volcano near the city of Yokohama. A steel gondola equipped with an artificial cooling system was used in the descent. Both observers wore asbestos suits and gas masks. It was clear vision down to a depth of 150 metres so that they were able to observe the extrusion of the lava and explosions of gases, and to take photographs. Another 30 metres and visibility grew so poor that they could move only at random. At a depth of 370 metres the gondola began to be thrown about by the explosions of gases so violently that further descent was rendered unsafe and they had to signal for ascent. Samples of gases and several hundred photographs were the scientific results of their descent into the crater.

After several unsuccessful attempts a descent was recently made into the crater of the Klyuchevskaya Volcano in Kamchatka; the volcano is very high and the climb to its summit alone requires a great deal of effort. Members of a Kamchatka expedition—geologist Kulakov, chemist Trotsky, worker Mikulin and mountain-climber Koptelov—went down into the crater in 1935, collected gases and observed the liberation of smoke and ejection of lapilli and bombs.

The Americans have long since organized a special observation post on the Kilauea Volcano and the Italians on the Vesuvius.

The vulcanological station of the U.S.S.R. Academy of Sciences built in 1935 near the Klyuchevskoi Volcano—the most active Kamchatka volcano—is studying volcanic activity in its various manifestations, i.e., the mechanism of eruptions, the state of the volcano in the intervals between the eruptions, its fumarolic and solfataric activity, the geysers and hot springs.

Special studies are made of the signs of impending eruptions for the purpose of warning the population.

Since the existence of the station the Shiveluch, Klyuchevskaya, Tolbachik, Maly Semyachik, Karymsky, Zhupanovsky, Avachi, Mutnovsky, Sarychev and Krenitsyn's Peak have suffered eruption and have been in some measure observed and studied.

The volcanic products (the lavas and other volcanic rocks, minerals, sublimates and volcanic, mainly fumarolic, gases), volcanic forms and other objects are also being studied. These observations and studies have so far been published in 23 issues of the *Bulletin of the Kamchatka Volcanological Station* and in

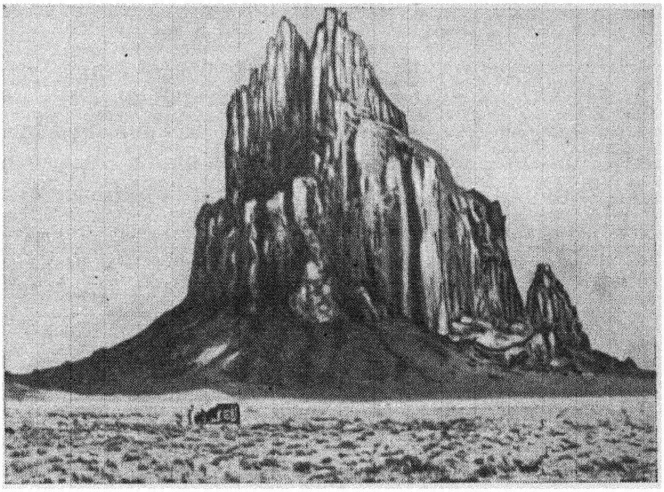

Fig. 182. Shiprock Cliff—remnant of ancient volcanic vent built of lava and tuff breccia. Navaho Country, Arizona, U.S.A.

nine volumes of the *Transactions of the Kamchatka Volcanological Station.*

Harm and Usefulness of Volcanoes. It has long been known that upon weathering and decomposing volcanic rocks yield very fertile soil. If the climate is suitable the slopes and surrounding country are densely populated and the soil is tilled despite the continuous danger of recurring eruptions. The ash thrown out by volcanoes serves as fertilizer for the fields and orchards if it does not fall in amounts that bury and destroy the vegetation.

The deposits of sal-ammoniac and especially sulphur in the craters of some volcanoes are exploited sometimes at the peril of the workers' lives.

The mineral springs connected with volcanoes, both active and extinct, have long since been used by man for medicinal purposes. The beautiful sight of the periodically erupting geysers attracts tourists.

In some places the liberated carbon dioxide is caught for production of carbonic acid. The boric acid collected in the Vulcano Volcano, until its last eruption destroyed all the

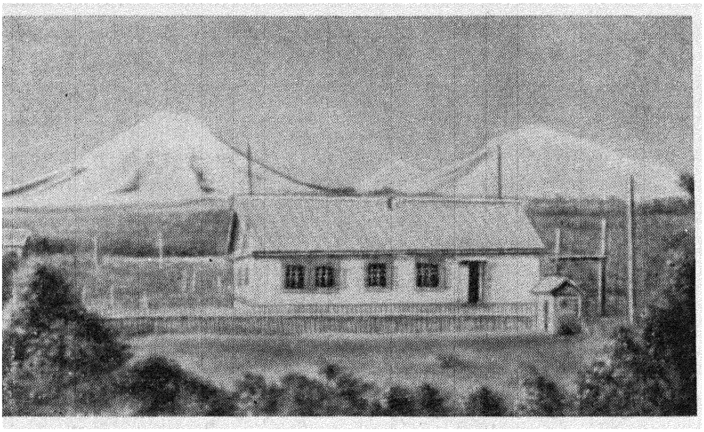

Fig. 183. Kamchatka Volcanological Station of the U.S.S.R. Academy of Sciences against the background of the Klyuchevskaya group of volcanoes. Left to right—Klyuchevskoi, Sredny and Plosky volcanoes

apparatus, was very valuable. Of great importance are the hot fumaroles and Soffioni springs in Toscana, Italy, containing boric acid; they were used as early as 1818. The thermal energy of the fumaroles has begun to be used of late not only for extraction of boric acid, but also for production of mechanical and electric power. By means of boreholes from 60 to 1,561 metres deep close to 3,000 tons of steam with a temperature ranging between 100° and 240° C is caught per hour. The steam contains up to six per cent gases, mainly carbon dioxide (90 per cent), hydrogen sulphide, methane, ammonia, nitrogen, argon and helium. The works produces boric acid, borax, sodium and ammonium carbonates, and a lot of electric power used by the neighbouring towns.

The success of this undertaking has given rise to the idea of utilizing the fumaroles in Southern Italy, California, Indonesia, Chile and Bolivia. But the tremendous quantities of ash and gases liberated during the short time of volcanic eruptions are not utilized by man as yet because the inconstancy of these phenomena and the enormous risk it entails for all the machinery and its operators render mastery of the volcanic forces a very difficult task.

The volcanoes do a lot of harm, but less than earthquakes. They cause losses in life and property in connection with the following phenomena conditioned by vulcanism: 1) the earthquakes preceding and attending the eruptions destroy buildings and roads and deflect springs; 2) mud streams ruin fields and orchards, damage roads and buildings; 3) extensive fall of ash and bombs inflicts similar damage; 4) the lava overruns cultivated lands, roads and streets and destroys houses; 5) the nuées ardentes exterminate not only all vegetation, but also all life on their way, as was shown by the eruption of Mt. Pelée which wiped out the town of St. Pierre and annihilated its 26,000 population; 6) the waves arising during underwater eruptions devastate the neighbouring coasts.

All these phenomena involve the loss of human life; according to available figures, close to 190,000 people have lost their lives in connection with volcanic eruptions since the year 1500. Compared with the number of earthquake, flood and typhoon (hurricane) victims this number is not so high.

VIII

BUILDING AND DESTRUCTION OF MOUNTAINS

Main Features of the Surface Relief. Folding and Faulting Dislocations. Shapes of Folds and Faults. Joints. Shapes of Mountains. Dislocational and Volcanic Mountains. Types of Dislocation Mountains. Destruction and Eradication of Mountains. Rejuvenation of Mountains. Geosynclines and Platforms. Orogenesis and Epeirogenesis. Causes of Dislocation.

We all know that the surface of the land consists of lowlands and elevations. The lowlands are mainly plains, but their level surface is sometimes broken by low hills, for example, dunes or barkhans made up of alluvial sand, or by hills composed of country rocks evened out by weathering or marine erosion. The relief of the elevations varies to a greater extent and shows isolated mountains, plateaus, various mountain ranges, highlands and uplands. We have already considered volcanoes which are individual mountains or groups and small chains of similar mountains, and we know that they are built of the materials of eruptions—lavas and tuffs.

Most elevations, however, are of a different origin, though they frequently contain igneous rocks. They have been created by *movements* which disturbed the structure of the earth's crust and caused its strata to become displaced, i.e., upset their initial mode of occurrence. In these movements the layers of rocks formed on the floors of seas or lakes, or on land in a horizontal or slightly inclined attitude (when the floor of the basin or the surface of the land are somewhat inclined) are brought out of their initial position, rise, drop, tilt, fold like paper or a fabric, fracture, slide over each other and even turn over. These displacements build most of the elevations on Earth and by their nature are divided into two basic types—*folding* and *faulting*.

Shapes of Folds. If we trace one layer of rock in a fold we shall see that it rises, gradually bends over, forming a vault, and then goes down. All the over- and underlying strata repeat the same bend (Fig. 184). The fold arching upward is referred to as an *anticline* (because the bed inclines away from the crest on either side). A fold with its crest pointed downward is said to be a syncline (because the beds on either side incline towards the keel) (Figs. 185 and 186).

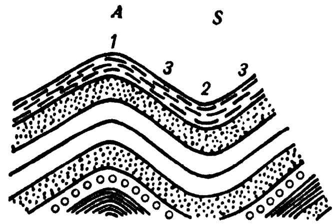

Fig. 184. Fold
A—anticline; *S*—syncline; *1*—vault or col; *2*—downfold; *3*—limbs

The neighbouring anticline and syncline together form a complete fold. The parts of the bed in the intervals between the crests are described as the *limbs* of the fold. The latter is rarely isolated; one fold usually follows another, etc., like the wrinkles on a baked apple. The folds also vary in shape: they may be either flat or round, have gentle bends or sharp fractures.

When both limbs have the same inclination the fold is called *symmetrical*; if one limb is inclined steeper than the other the fold is *oblique*; with the vault thrust over one of the limbs the fold is said to be an *overfold*; lastly, there are folds in which the crest is arched neither up nor down, but to a side, and both limbs lie flat; these folds are referred to as *recumbent*. These different shapes of folds depend on the force of compression: when the pressure is weak the folds are flat and symmetrical; when it is stronger the folds become steeper and steeper, warp, turn over, lie down and even thrust over each other, their limbs bend over in their turn and form secondary folds resulting in complex folding which can be seen in mountains (Figs. 188 and 189). It shows that in this place the earth's crust was strongly compressed.

The reader may mistrustfully say: this cannot be! The beds of such hard rocks as sandstones, limestones and slates are not paper or cloth, nor rubber or leather which you can bend as you please. At one time these objections were also raised by scientists who therefore thought the folds to have been made when the rocks were still soft and consisted of sand, clay and silt. But the studies of mountains have shown that the rocks were really bent when they were *hard* because their beds suffered a lot in the process—they are torn by fine cracks, in some places they are even shattered and the beds are often displaced in relation to each other. However, these fractures are not enough to ex-

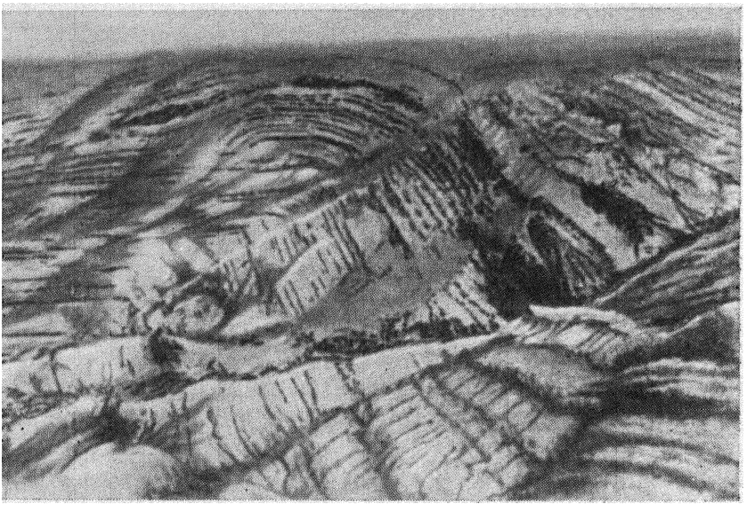

Fig. 185. Flat-folding Jurassic carbon-bearing deposits at the foothills of Jair Range, Jungaria

plain the intense and composite folding. To understand it we must recall that the layers now found high in the mountains and coming out to the surface were formerly deep in the earth's crust and sustained the pressure of all the overlying beds. Under such pressure even solid bodies tend to change their shape without fractures. Scientists have demonstrated this with various experiments. For example, under pressure lead runs in a stream through a narrow opening, while big machines bend sheets of iron, copper and steel like sheets of paper. Glass is very fragile, but it can also be bent cold if the force is applied very slowly and gradually. Besides, deep in the earth's crust the rocks were much hotter and more humid than on the surface, and this contributed to their pliancy. Miners know by experience that blocks of hard rock just broken away from a continuous bed in a mine or quarry are easier to hew than after they have been exposed for some time to the air. In a word, rocks in the earth's crust could suffer intensive bending, and fracture but insignificantly, especially since folding occurred very slowly.

Shapes of Faults. But this capacity of rocks to bend has its limits. When the pressure went beyond these limits the fold

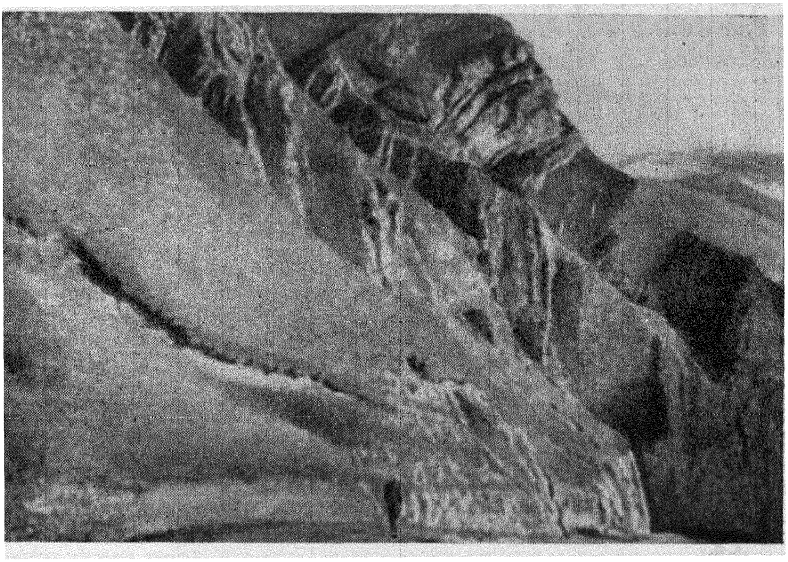

Fig. 186. Limb of an anticlinal fold. Ossetian Military Highway, Caucasus

fractured either along its axis or along one of its limbs and parts of it thrust over each other (Fig. 190). The fractured folds can also be seen in mountains where the overthrusts are sometimes of tremendous dimensions. The plicative form not infrequently passes into this fractured and overthrust fold which now assumes the form of a disjunctive or faulting displacement, and is known as a *fold-fault* (Fig. 191).

Some folds are one-sided, i.e., they have only one limb and form a knee-like bend of the strata (Fig. 192, *a*) referred to as a *flexure* or *monoclinal fold* (inclined to one side). In this type of bending the beds frequently fail to sustain the pressure, and fracture, the fold passing into a normal *fault* (Fig. 192, *b*), the most widespread form of disjunctive displacement also encountered irrespective of folding in vertical slips in the earth's crust (Figs. 193, *a* and 194). The reverse faults or *thrusts* also occur irrespective of folding (Fig. 193, *b*).

The fissure which severed the beds is called a *fault crevice*; if it is not vertical, but inclined, which occurs in most cases, the overlying beds are described as the *hanging wall* and the underlying beds are referred to as the *footwall*.

The difference between normal and reverse faults is that in the former the hanging wall drops and in the latter it rises in

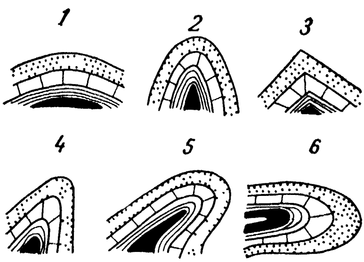

Fig. 187. Folds
1, 2, 3—symmetrical; *1*—flat; *2*—steep; *3*—with break in the col; *4*—oblique; *5*—overturned; *6*—recumbent

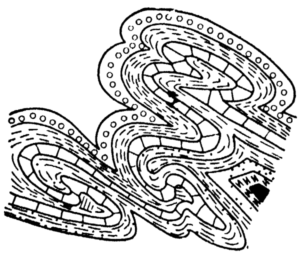

Fig. 188. Complex (secondary) folding

relation to the footwall. The layer ends broken by the fracture and rubbing against one another slightly bend along the fracture and it is easy to determine by these bends whether this was a normal fault or a reverse fault as the comparison of both parts will show (Fig. 193).

In a fracture the strata are sometimes displaced along the fissure not upward or downward, but sideward, i.e., in a horizontal direction. This form of displacement is called a *horizontal fault*; it can be pictured only in plan rather than in a vertical section as the other forms (Fig. 195). In the displacement of the beds along the fracture the vertical movement is not infrequently combined with a horizontal movement and as a result the displacement is inclined; this displacement is known as a *strike-slip fault*.

All miners have had bitter experience with faults and overthrusts. Upon encountering a fissure along which a displacement occurred in the earth's crust the miner sees that the coal bed or ore vein, which he has been working, suddenly vanish as though cut off and the stope, i.e., the working end of the excavation, has run into dirt. The continuation of the coal bed or ore vein must be searched by turning the mine working to the right or left, upward or downward. To avoid any guesswork and to find the

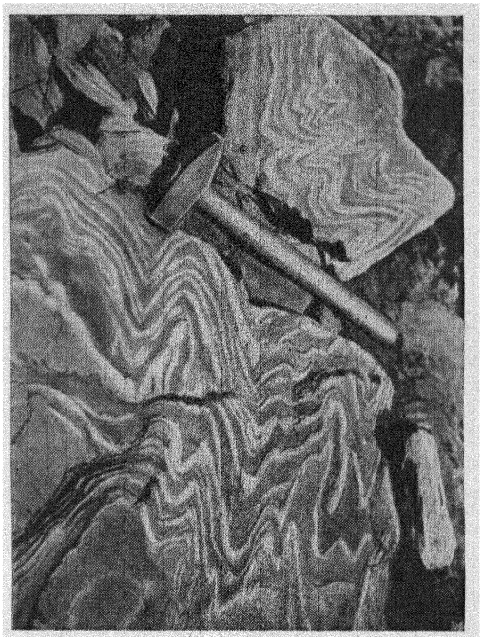

Fig. 189. Complex (secondary) folding of gneiss in Northern Mongolia, Hontei Mountain Range

proper direction the miner goes by the signs he sees which tell him whether the displacement was a normal fault, a reverse fault or a shift fault.

A few words must be said about the mode of occurrence of the beds which has to be determined in the study of displacements.

If we draw a horizontal line *AB* through an inclined bed the line will show the direction of the bed and will be known as the *strike line*. A perpendicular dropped to this line in the bedding plane *CD* is referred to as the *dip line* because it corresponds to the maximum slope of this plane. The direction of these lines is determined by a compass, while the angle of dip is measured by a clinometer. All these bearings are best taken by a special, so-called dip compass which also has a clinometer. The strike of the fold is determined by measuring the strike of the beds at different points of the limbs along the length of the fold; it may change according to the bends of the fold. The dip of the limbs is measured on the limbs; it also changes from the anticline downward, growing steeper or gentler in the secondary bends. In normal and reverse faults it is necessary to measure the strike and dip of the fault crevice plane and of the beds in the hanging wall and footwall, which makes it possible to determine the type of displacement; in connection with studying the other signs it will permit to determine the direction of the displacement and in some cases even its dimensions, i.e., the amplitude of the normal or reverse fault.

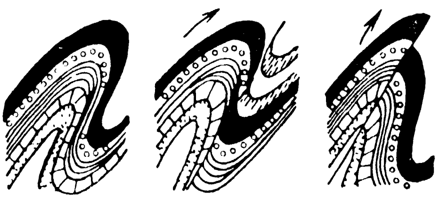

Fig. 190. Transformation of an overfold into a fold-fault owing to a fracture of the extended limb and a fracture along the axis of the fold

In large normal and reverse faults big sections of the earth's crust are displaced as wedges and blocks relative to each other creating elevations and depressions, but of a type, as we shall learn later, which differs from that formed in folding movements. These fractures run deep into the earth's crust and the magma uses them as the easiest way to rise to the surface. The fracture crevices serve as channels for the laccoliths and volcanoes; when filled with magma they become discordant veins of igneous rock. But, of course, not all the fissures formed in disjunctive displacements become veins. Most of them remain empty or fill with fragments of the rock from the hanging walls and footwalls sheared off during the slips and forming *fault breccia* (Fig. 199).

In addition to these fissures connected with folding displacements and faults we find in rocks even more crevices of another origin. The molten masses extruded to the surface or indurated in the earth's crust were originally continuous, but as they cooled they contracted and were therefore fractured by fissures in different directions, some into large blocks, others into columns, still others into thick or thin slabs. The sedimentary rocks, after their deposition in the form of thick or thin beds, also suffered changes; we know they have hardened; in addition,

Fig. 191. **Recumbent and reversely faulted folds of ancient slates.** Kadali River, Bodaibo District, Eastern Siberia

they have also contracted and cracked as they dried after coming out of the water. These cracks formed in massive rocks as a result of cooling and in stratified rocks as a result of drying are described as *joints* to distinguish them from the fissures produced by pressure during the formation of folds, normal and thrust faults. In the mountains we often find both types of fissures side by side.

In granite solidified in the earth's crust we see characteristic joints described as *pillow jointing* because they break up the granite into parts shaped like pillows. Figure 176 shows fine *columnar* jointing common to basaltic lava, i.e., rock extruded to the surface. Besides these two forms of joints there are also *parallelepipedal* joints in which the rocks are divided by three systems of crevices into parallelepipeds of different shapes, *bedding* or *slab* joints in which the rock is broken up

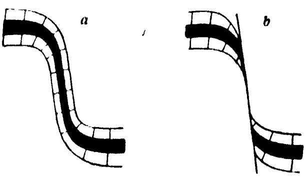

Fig. 192. Flexure (*a*) transformed into a fault (*b*)

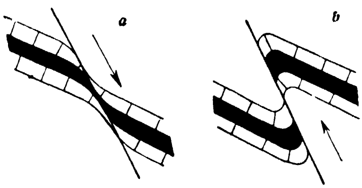

Fig. 193. Normal fault (*a*) and reverse fault (*b*) with ends of layers curved

by one system of fissures into layers or slags, and *spheroidal* in which the rock breaks up into spheres of the same diameter.

In steep river banks, sea coasts and mountain slopes one can observe enormous folds in which the same layer rises in the anticline for hundreds of metres. In other folds one can see how surprisingly the strata are crumpled, twisted, serpentined and thrust over each other. Observations of faults have shown that the displacement of the beds in the hanging wall relative to the same beds (i.e., their former continuation) in the footwall also reaches hundreds of metres. Having thus studied the various forms of displacement and their amplitude, i.e., the magnitude of the throw, we shall inevitably arrive at the conclusion that it must have been a tremendous force to cause all these disturbances of the originally horizontal or slightly inclined attitude of the strata in the earth's crust on the floor of a water basin. It stands to reason that we want to know what brought this force about, i.e., the cause of the displacements, these grandiose disturbances of the structure of the earth's crust. We shall dwell on this question later because we must first learn about the main forms of elevations created by the displacements on the earth's surface.

Mountains greatly vary in *shape*. In some places the force of underground movements has barely uplifted the layers and thrust them out as a long, wide swell or several such swells separated by intervals representing valleys between these swells.

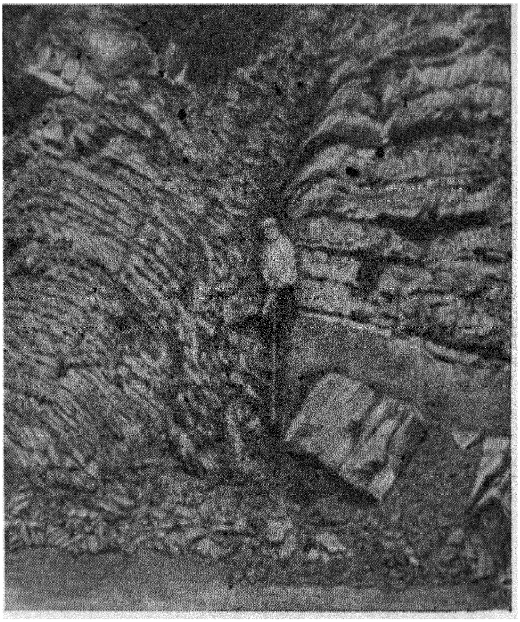

Fig. 194. Fault with curved ends of layers in Tertiary beds. Right bank of the Kura River, Borzhomi, Caucasus

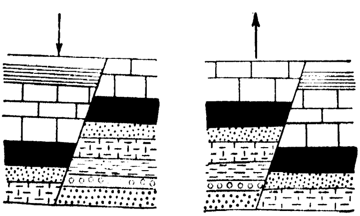

Fig. 195. Shift faults (in plan)

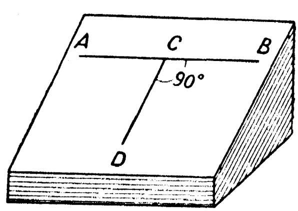

Fig. 196. Strike *AB* and dip *CD* of layer

In other places this force acted over a longer period, the swells grew higher, their slopes steeper. But more often than not, it did not stop at creating these even and quiet folds, a fine example of which is offered by the Jura Mountains in Switzerland.

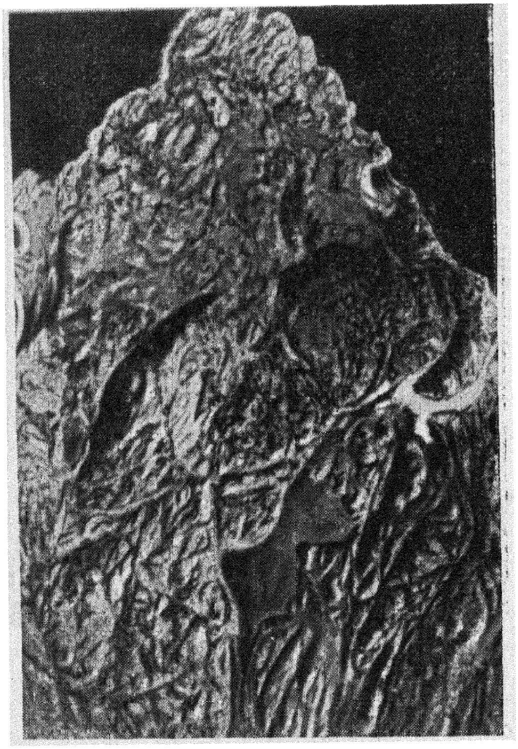

Fig. 197. Fracture fissures in ancient foundation of Southern Sweden clearly reflected in the relief. Aerial photograph

The pressure was strong, the folds rose increasingly higher, thrust over each other, turned over and fractured, while along the fissures molten masses rose from the entrails of the Earth, filled the cavities frequently remaining in the cores of the folds, cooled in them or broke out to the surface creating volcanoes and lava sheets.

It is because of these various manifestations of mountain-building forces on our Earth that we find different shapes of mountain ranges from the simplest to the most complex. The simplest shape is a wide, flat bank representing a single fold and looking like a more or less long swell or hill on the earth's surface. If we trace this swell along its entire extent we shall find

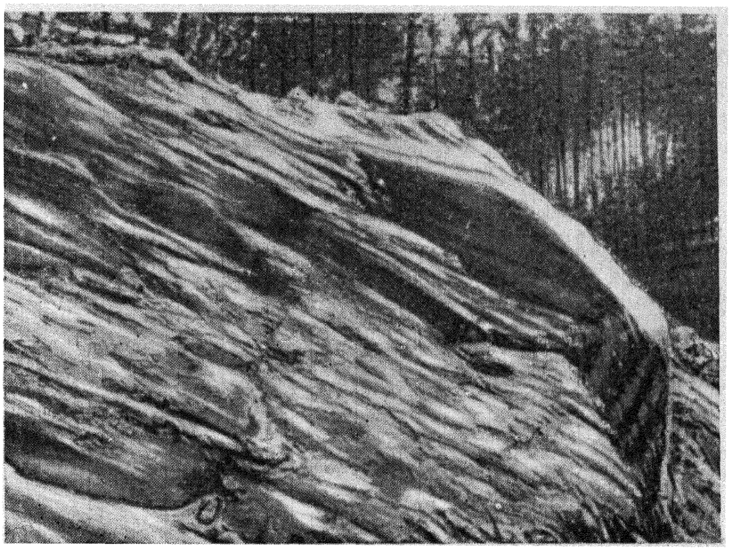

Fig. 198. Polished surface of overthrust on sandstone, Lausitz, Hohenstein, Germany

that it grows lower towards both ends and little by little merges with the surrounding plain, its greatest height being in the middle. Moreover, we shall notice that the longer swells rarely run straight, but their ends more frequently arch to one side thus representing a flat arc. This is a common property of folds: in the middle where pressure was the highest the fold rose higher and at the same time its forward movement in the direction of the pressure was the greatest, while the ends, where the pressure was weaker, lagged in this movement. The arched shape of the folds therefore shows where the force acted, i.e., precisely on the concave side of the arc (Fig. 200). The older folds meander in plan, curving now to one side and now to another.

If the pressure does not cease after the first fold has formed, it is followed by a second, third and fourth folds. The next shape of the mountains will therefore be several swells, more or less high and steep-flanked, running next to each other and slightly arched. It is in highlands that we frequently see not one but several mountain ranges, one behind the other, the highest being either in the middle or on the margin. Valleys, said to be *longitudinal*, stretch between them.

When the pressure is very high and the folds thrust over each other these various ranges may in some places merge and it becomes more difficult to discriminate between them, especially if fractures and outcrops of effusive rocks are added. The fractures and effusions occur more often on the concave side of the arc of the marginal fold, whereas on the convex side we can see more frequently overthrust folds, recumbent folds and even enormous overthrusts.

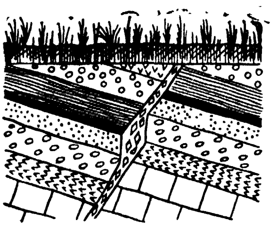

Fig. 199. Fault crevice breccia

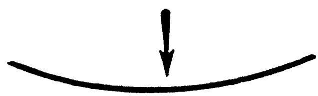

Fig. 200. Arched fold (in plan)

Thus we can now distinguish: 1) *simple mountain ranges* or ridges composed of one fold; 2) *complex mountain ranges* of several folds more or less divided by longitudinal valleys, and 3) *highlands* in which the folds hug each other closely, the total width of all the folds being only slightly less than the length, whereas in mountain ranges the length is always many times that of the width (Fig. 201).

Most of the mountains on Earth represent either complex ranges or highlands. Such are the Urals, the Caucasus, Altai, Tien-Shan, the Swiss Alps, the Himalayas, the Andes in South America and the Cordilleras in North America. Take a look at the map and you will see that many of them stretch over hundreds of kilometres across continents and all are somewhat arched. The concave side of the Alps faces the south—Italy, that of the Carpathians faces west—Hungary; Altai, Tien-Shan and the Himalayas have their concave side towards the north, while the Caucasus, the Urals and the Andes have a double curve. It is clear that the force that created these mountains acted in different directions in the various countries. We shall also see on the map that many mountains merge into long ranges: the Cordilleras join the Andes and run through two continents; the Alps are connected with the Carpathians and Balkans, on one side, and the Apennines, on the other; Tien-Shan adjoins the Altai in the north, the Pamirs in the south, and is linked through the latter with the Himalayas and the mountains of Iran and China. We shall see that the principal, longest and highest mountain ranges are not individual and casual swellings on the earth's surface, but that in their distribution they are governed by some general law and that they form long belts.

In addition, we also see isolated mountains, separate elevations, short mountain ranges and small highlands; such, for

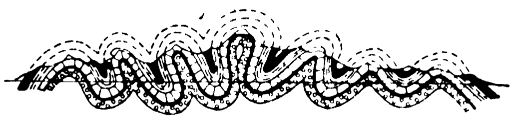

Fig. 201. Section of a folded highland after erosion. Dotted lines indicate air saddles, i.e., eroded parts of the saddles

example, are the mountains of England, France and Germany in Europe, the mountains of Northern Siberia, Arabia and India in Asia, the mountains in Africa and in Brazil (South America), the Alleghenies in North America, and the mountains in Australia.

Studies of these separate mountains show that some of them are remains of former very ancient long mountain ranges broken up and partly eradicated; thus the mountains of England were at one time connected with those of Belgium, France and Germany, while the mountains of Novaya Zemlya formed a continuation of the Arctic Urals.

Other mountains are representatives of a volcanic or faulting and not of a folding type; the mountains of India and Siberia between the Yenisei and Lena rivers, and some mountains in Africa are built of sheets of lava which effused from fissures and flooded large areas. They generally have a level surface and are referred to as *plateaus*.

Large fractures of the earth's crust accompanied by faults with sinking or uplifting of large areas in between the crevices also create plateaus, more or less high table elevations of various length and width. One margin of such an area at times rises higher than the other and the plateau is then tilted, inclined to one side or the other. Neighbouring areas divided by crevices are sometimes lifted to different heights, and the plateau then consists of several scarps resembling steps of a giant staircase. In Africa we find examples of large and small plateaus created by faults and consisting of horizontal or slightly inclined beds.

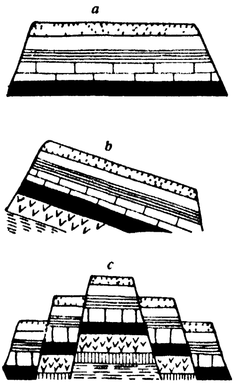

Fig. 202.
Plateau-horsts
a—straight; *b*—oblique; *c*—stepped

These flat elevations raised between two fractures are called *horsts*, while the hollows, the valleys formed by the sinking of a stretch of the earth's surface between two fractures, are known as *fault troughs*. As before stated, a horst may be tilted or even one-sided if the fracture runs on one side; it may also be stepped if several fractures and sections of the earth's crust were raised to different heights (Fig. 202). The horst edges have already suffered from erosion and have ravines and even gorges, while the old horsts are broken up into mountains all through their mass.

Large fractures of the earth's crust frequently occur where the folding displacements had already built mountain ranges or whole highlands which, as we shall learn, were later destroyed by erosion. In this case the separate areas between the crevices do not consist of the layers in their initial, i.e., horizontal plane as in the preceding example, but are of a complex structure composed of the original folds of different types—symmetrical, oblique and overturned—running in different directions.

As a result we have plateaus and highlands in the shape of horsts of a complex nature. There are very many of these mountains on Earth. The Urals, Tien-Shan, Altai and the Sayans in the U.S.S.R., the Rocky Mountains in North America and others are of this type (Fig. 203).

But in the folded mountains proper the disjunctive displacements developing simultaneously with the folds or after them are a widespread phenomenon. We have already learned about the individual reverse fold-fault; in some mountain ranges these faults no longer cut across individual folds, but series of folds, displacing them in relation to each other. The Caucasus, part of which is shown in cross-section in Fig. 204, is an example of these mountains with a prevailing folded type, but strongly developed reverse faults.

It stands to reason that in the initial attitude of the layers the younger ones are on top, the older ones underneath. But in folding the situation is not infrequently the reverse: in an overturned or recumbent fold the strata constituting its inner part, i.e., the core, are, of course, older than the layers in the limbs, though they happen to lie higher than the beds in the overturned limb. If the upper limb is destroyed by erosion we shall see an abnormal relationship of layers in the exposure, i.e., the older ones (*A*) on top and the younger ones (*B*) underlying them (Fig. 205). Still more complicated derangements may come to

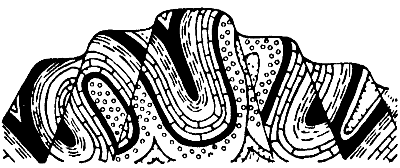

Fig. 203. Section of block-folded mountains representing a stephorst

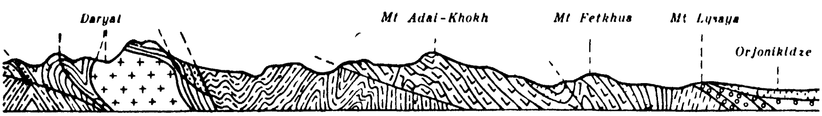

Fig. 204. Section of the northern slope of the Main Caucasian Range from the Daryal Gorge to the city of Orjonikidze

pass in greatly overturned (to a recumbent attitude) folds under further mountain-building pressure. This fold continues its forward movement; pressed by the whole mass of the anticline against the underlying syncline the layers in the overturned limb increasingly stretch and, finally, fracture, the anticline deprived of the overturned limb being able to slide more freely inside the syncline. As a result the upper limb of the anticline forms an overthrust in which the oldest rocks of the anticlinal core (*1*) lie on the youngest synclinal core (2) (Fig. 206). Such overthrusts have been found in the Swiss Alps, in Scandinavia, Scotland and elsewhere. The severed upper part of the recumbent fold may have been displaced for several and, according to some scientists, even dozens of kilometres.

Thus, according to the method by which they were built, the mountains on Earth are of two basic types: a) mountains built by *displacement* and b) mountains of *volcanic* origin. It must not be thought, however, that there are no igneous rocks in the mountains of the former type. Magma invades the core of the forming folds in all of the more intensive displacements and igneous rocks are therefore represented in the mountains of this

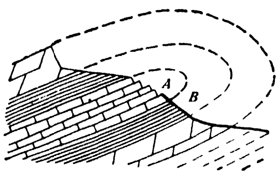

Fig. 205. Eroded recumbent fold

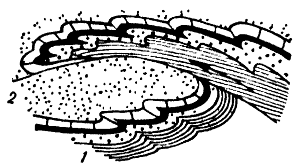

Fig. 206. Development of overthrust folding from a recumbent fold

type, especially in the deeply eroded ones. After the formation of folds volcanic eruptions not infrequently begin in these mountains because magma breaks out of the interior of the crust, and both intrusive and effusive rocks are therefore often found in considerable quantities in mountains of the displacement type. Volcanic mountains, however, consist wholly of effusive rocks—lava and tuffs.

The displacement mountains may be divided into the following types according to the form of displacement:

1. *Folded mountains*, built mainly of folds, compared with which faults and thrusts play an unimportant part, though they are nearly always present. The Jura Mountains in Switzerland offer an example of the simplest folded mountains (see Fig. 201).

2. *Overthrust mountains*, in which the folds were greatly complicated by simultaneous and later thrusts and overthrusts. This type is widespread; the Urals and the Caucasus are mountains of this type in the Soviet Union (see Fig. 204).

3. *Nappe mountains*, consisting mainly of recumbent folds transformed into nappes de chariage. The Swiss Alps are considered the best example of this type.

4. *Block mountains*, built only by faults which have divided the crust into separate blocks; in the blocks the layers are horizontal or gently tilted to one side. These are usually plateaus and are particularly widespread in Africa. The Ust-Urt Plateau between the Caspian and Aral seas, and the Ufa Plateau in the Urals (see Fig. 202) belong to this type in the U.S.S.R.

5. *Fault-folded mountains* mainly built also by fractures, but the individual blocks are slightly folded or arched; the folds were fractured during their formation. Such mountains are found in Central and North-Western Germany.

6. *Block-folded mountains* are noted for the fact that after more or less intensive folding, which included even thrusts, they were deeply eroded; following this fractures and faults broke them up into separate blocks, the latter retaining the initial folding. Such are the mountains in Asia—the Altai, Sayans, Tien-Shan, Stanovoi Range (see Fig. 203).

All these types are interrelated by transitional forms.

Destruction and Eradication of Mountains. A person who does not know any elements of geology is justified in asking: can mountains consisting of hard rocks be destroyed? Are they not supposed to stand up for thousands or even hundreds of thousands of years as they were fashioned by the forces of nature? Don't we see ruins of ancient castles and towers on mountain peaks and separate cliffs? These structures put up by man many centuries ago have come to ruin, but the underlying rock is intact; it was there before man put up his building, it is there now, and why should it not be there, as the saying goes, "to the end of time"?

But mountains are destroyed just the same and to the very rock bottom at that. Where there were high mountains at one time we now often see knolls or even a plane surface. There were formerly high mountains in the Ukraine—Krivoi Rog and the Donets Basin—but today we see only an undulating plain and flat mounds. The plains and small hills of Kazakhstan are all that is left of the rows of mountain ranges that were there at one time. In its time the Urals was much higher and consisted all through its width of mountain ranges that ran in several rows from the Arctic almost to the Caspian; now it consists of low ridges and knolls east of the watershed and imperceptibly passes into the West-Siberian Lowland.

After reading the first chapters of this book the reader will no longer doubt that mountains are destroyed. He already knows about the work that is tirelessly done by running water, how this water erodes the layers of the earth's crust, how it is helped by ground water, how glaciers creeping down valleys wear out their beds and carry away the fragments that fall off the slopes where weathering never ceases to destroy rocks. All these geological agents work day and night to eradicate all the accidents of the earth's surface which they aim eventually to transform into a plain barely lifted above sea level so that rain water will stay in one place, rather than roll down, because as long as there is a drain water must work.

Each fold of rock formed by lateral pressure was originally a flat and wide or steep and high swell hunching over the surface of the Earth. Longitudinal fractures could have occurred in the steeper, especially overturned, folds along the crest of this swell if the upper layers could not withstand the pressure and broke up. The plateaus built by faults were originally wide or narrow, high or low steep-flanked masses with a level surface, often with scarps on one or both sides. The plateaus built by volcanic fissure eruptions, i.e., sheets, had the same appearance. Hence, no mountains, as they were built by the orogenic forces, showed any variety of contour and their monotonous heavy forms must have appeared tiresome to the eye of the observer. Only the volcanoes heaped up by the streams of lava, fragments and ash could have somewhat relieved the monotony of contour prevailing in the mountainous parts of the earth's surface.

All of the beauty and variety of mountain views are created by the destructive forces whose work we have already discussed. These forces began functioning when the creative powers had already been at work because the folds and faults were made very slowly. As soon as a fold or an edge of a fault showed themselves the least little bit over the plain they were immediately acted upon by heat and cold, rain and snow, wind and vegetation. From day to day, from year to year, and so for centuries on end, these forces gnawed, bored, ground, and ate away the flat crests of the folds and the precipices of the faults, while the winds blew off and the rains eroded everything that their assistants had prepared. Little by little the sides of the folds and the precipices of the faults were cut up by furrows; these widened and deepened into ruts, the ruts enlarged into ravines, the ravines grew, branched out and turned into valleys or canyons. The crests of the folds and the edges of the faults became jagged, and various cliffs, towers, walls and screes made their appearance.

The fact that not all rocks equally resist weathering greatly contributes to the variety of forms. Of course, the forces of destruction do a better and faster job in weaker rocks which more easily break up into their particles or dissolve in water. Having attacked one of these beds or suite of such beds, the destructive forces cut into them with particular speed, while the stronger neighbouring rocks remain standing as walls, towers and cliffs which also disintegrate, but slower.

In the high mountains, whose peaks and crests rise above the line of vegetation, the destructive work of the water is favoured by frost weathering, snow and ice. The cliffs and crests break up into fragments and metal, the force of gravity and winter avalanches throw them down and the glaciers carry them away.

Thus do various forces work to destroy the mountains, and after many and many thousands of years of this work the monotonous and unsightly original folds and level plateaus are transformed into beautiful and greatly diversified highlands with chains of jagged peaks, picturesque cliffs, sheer rocks, steep slopes, screes and fields of blocks and metal, wide and narrow valleys, gorges, waterfalls, rapid rivers and glaciers. This beauty and endless variety of the nature of mountains have been achieved by the slow but untiring work of invisible forces; the higher the mountain folds or plateaus rose at one time, the steeper their slopes were and the greater the diversity of the rocks of which they were built, the greater the variety of contours and colours we see in them today. The flat and low folds were diversified less and the monotonous rocks have also yielded monotonous forms.

The beauty and variety of the mountains also partly depend on whether they are in the northern cold belt or the southern warm belt of the globe since the work of the destructive forces itself depends on the country's climate, i.e., on the amount of precipitation and its distribution, the number of warm and cold days, the extent of heat and cold, cloudiness, etc.

There is less beauty in the northern mountains in which the winter reigns too long and the summer is too short and humid; in winter the destructive forces slumber under the heavy coat of snow and only individual cliffs protruding from under the snow are open to weathering; but water, one of the major agents of destruction, is inactive many months of the year and does but little work in the river beds under the ice. Because of the abundance of moisture the mountain slopes are covered with dense forests and moss carpets which also retard the work of a part of the destructive forces. The valleys are very marshy or are overgrown with shrubbery and the rivers receive little material to carry down. The entire course of weathering is retarded, there are but few cliffs and rocks, and there is hardly anything to do for the wind, sun and frost.

Only in the Far North, within the Arctic Circle, where there is hardly any vegetation, are the mountains beautiful again, but their beauty is rather monotonous. Not infrequently sharp ridges and cliffs jut out from under the thick coat of snow and ice, and sheer slopes that can hold no snow loom black. Frost and wind work alternately on these ridges, cliffs and slopes all through the long winter, spring and autumn; the sun and water work during the short summer, and only snow and ice are active on the rest of the area. These mountains of the Far North can be compared with the uppermost parts of the high mountains rising in the realm of eternal winter in the other zones of the Earth. Both here and there the destructive forces are the same and they act similarly.

In the south where the foothills are in a warm and humid climate and the peaks are crowned with snow the beauty and variety of the mountains manifest themselves with particular force because all the destructive powers work most successfully.

But the tall mountains of the deserts are also beautiful, though theirs is a special beauty. Here, almost from top to bottom, is the kingdom of bare rock; everywhere there are bare cliffs, ridges and screes; the gentler slopes are covered with scant wisps of grass or small bushes, while the floors of valleys along rare springs give asylum to small groves of trees and shrubs, and small overgrowths of reed which offer shelter to the traveller and food to his animals. But these mountains very greatly vary in form and are thoroughly and deeply disjointed; here the forces of destruction work diligently, but not all alike. Here there is too little moisture and too little vegetation, and the weathering conditioned by vegetation and the water that seeps

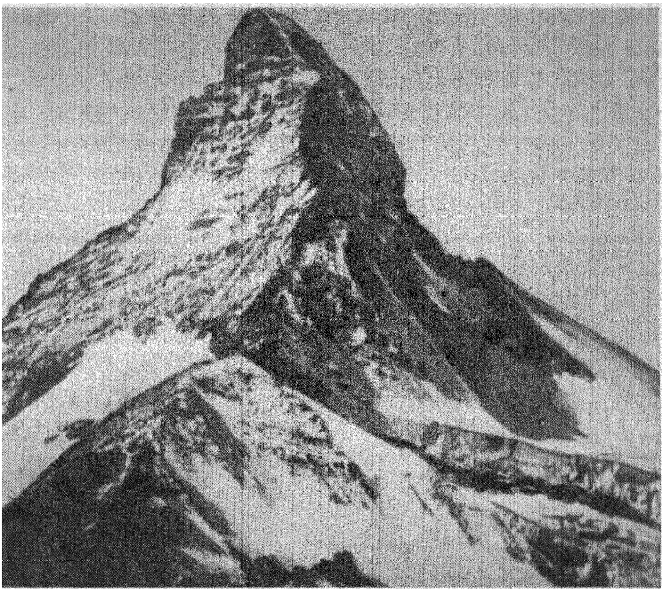

Fig. 207. Alpine-type forms in moderate climate.
Mt. Matterhorn, Swiss Alps

Fig. 208. Alpine relief. Belukha Peak and morainic
lake on the Berelsky Pass, Altai

into the ground is therefore very weak. But then the heat and frost, as also the wind that blows particularly often in the desert, find plenty of work on the slopes almost completely bare from top to bottom. The wind wakes up with the first ray of the sun and blows, growing stronger and stronger, all day long, and dying away only after sunset. It sweeps away everything that the heat prepares for it on the bare cliffs during the day and the cold during the night. Here it rains seldom, but once it starts it is usually a downpour. From the bare cliffs and the slopes hardly reinforced by vegetation it washes down all that the wind had no time to or could not pick up. Furious streams of dirty water rush through ravines and valleys which usually have not a drop of water for months on end; they move stones, uproot bushes and deposit it all on the plain at the foothills where the water spreads about and loses its force.

In the sultry and humid climate of the tropical countries the mountains look different again. They are covered with dense woods from top to bottom and it is impossible to make one's way through them without an axe. Rocks and cliffs are rare and are buried in thickets; the rocks are hidden from heat and cold, but the plants and abundant moisture work the more zealously; the ground is saturated with moisture to the extent that for many feet in depth the rocks are totally disintegrated and transformed into laterite, a red argillaceous rock abounding in iron and aluminium hydroxides.

Thus, the work of the destructive forces of nature varies with the climate in which the mountains are located. But there is no place on Earth where these forces fail to undermine the mountains.

It is clear then that from the monotonous mountain folds, level surfaces of faults and volcanic structures the destructive forces of nature create the multiform and beautiful mountains. But their work does not include the creation of the beauties of nature: the beauty of mountains is incidental and transitory.

The objective of the destructive forces is complete eradication of the mountains. They aim to raze all these jagged ridges, sharp peaks and steep cliffs, to level them out and wipe them off the face of the Earth. And they cannot come to rest so long as even a single hill remains or one rock juts out. They must destroy everything so that the rays of the sun do not fall on a single cliff, that the rain does not wash off a single grain of sand and that the wind may roam about unimpeded. And sooner or later, depending on the height of the mountains and the hardness of the rocks, the destroyers achieve their aim and the beautiful mountains vanish from the face of the Earth.

If we compare the different mountain ranges on our Earth with each other we shall find that not all of them by far have the same height or similar contours. In some places we see

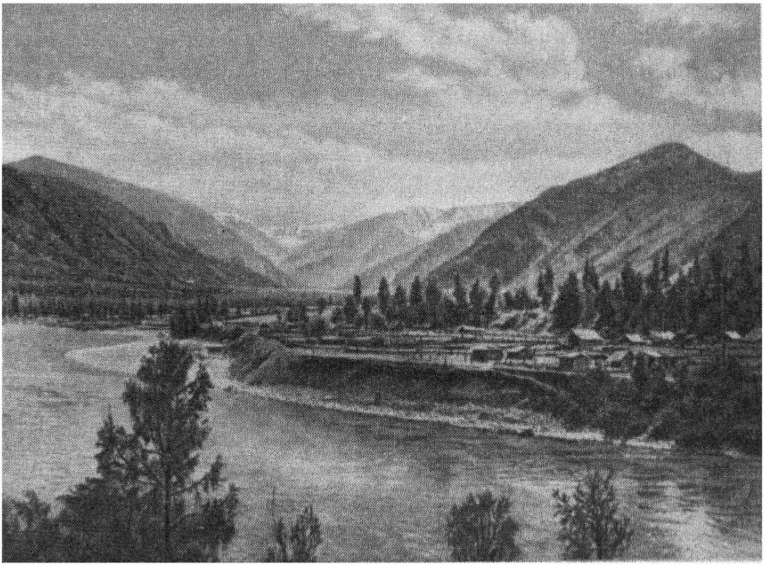

Fig. 209. Mountains of medium height. Valley of the Yenisei River below the Bolshoi (Grand) Rapid

such high and beautiful mountains as the Altai, the Caucasus or the Swiss Alps with their deep and narrow gorges, sharp peaks and ridges, and steep and rocky slopes; in a word mountains that are generally referred to as *Alps* or *Alpine* (Figs. 207 and 208) because of their resemblance to the Swiss Alps which were the first to be well studied and therefore serve as a criterion. In other places we see mountains that are not so tall and not so beautiful, with rounded, dome-like peaks, straight or undulating wide ridges, gentler slopes and fewer cliffs, precipices and canyons. Such are the mountains of the Central Urals and many areas in Siberia (Fig. 209) and South Germany. These are *mountains of medium height.*

Elsewhere we see still lower mountains in the form of wide and flat ridges without or with barely perceptible peaks, gentle slopes and broad valleys almost totally devoid of the main beauty—cliffs, gorges, precipices and waterfalls. Such are the mountains of Timan, Pai-Hou, Mugojary and Guberlin of the South Urals and the mountains in North Germany. In still other places we find mountains or rather hills scattered individually,

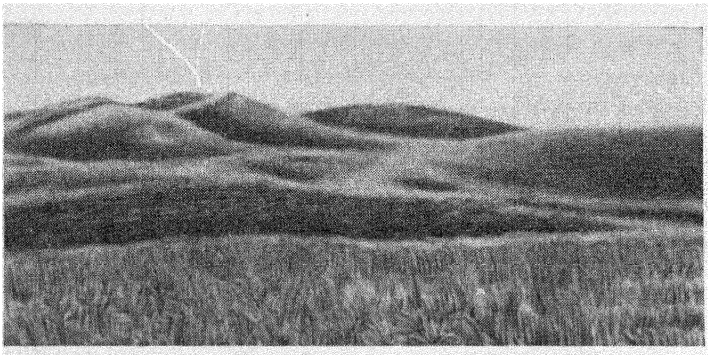

Fig. 210. Dwarf hills of Kazakhstan. Karagalinsky Mountains

in rows or groups, amid a steppe or separated by valleys and hollows several kilometres wide—mountains nearly totally devoid of vivifying rivers or creeks and tiresomely monotonous of contour as if they were all fashioned after a single model. Such are the mountains of Kazakhstan scornfully called *dwarf hills*; individual rocky peaks or small jagged ridges rise only here and there, and let the eye rest after the dozens of kilometres of boresome monotony (Fig. 210).

Lastly, there are such places where only separate little hills or outcrops of different rocks forming the remains of folds amid a level dry steppe, desert or northern tundra suggest that here, too, at one time mountains rose, ridges loomed blue and rivers gurgled. Such are the areas along the eastern foothills of the Urals, in many parts of the vast Gobi Desert in Mongolia and in the north of Kola Peninsula.

All these mountains bearing but little resemblance to each other vividly show us the various stages of destruction. They prove that hard rocks are not at all eternal, that they also change and in time disappear like everything else on our Earth with the sole difference that it takes scores and even hundreds of thousands of years to destroy mountains.

The destructive forces work in the mountains imperceptibly but tirelessly, now slower and now faster, according to the time of the year, weather and region. The beautiful cliff that we admire and the sharp peak cutting into the blue of the sky appear immutable and eternal to us, but if we could accurately measure and photograph them, then come back a couple of hundred years later and measure and photograph them again we would find both the cliff and the peak to have changed in shape and height. As a result of the untiring work of the destructive forces the mountain ridges and summits grow lower, the cliffs change their contours, disappear in one place and arise in another, the slopes now becoming steeper and now gentler.

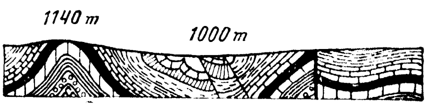

Fig. 211. Section of a peneplain formed in place of ancient folded mountains

Millions of years will elapse and if we could come back to life and look at some very familiar mountains we should be amazed at the difference. In place of the Alpine mountains we should find undulating ground; the sharp snow-covered peaks now rising above the clouds will break no more; the glaciers will have disappeared, the jagged ridges will be levelled out, the valleys widened, and the slopes will have grown gentle; there will be no cliffs, precipices or canyons. Instead of the rapid streams roaring over boulders on valley floors a quiet river will be flowing amid overgrowths of bushes.

And if we come to the same place many more centuries after that we will see flat hills, wide level swells or even a real plain.

Compare the pictures shown in Figs. 207-210 and you will get a clear idea of these changes.

Mountains are thus gradually destroyed, but the more advanced the destruction, the slower it is. The taller the mountains, the steeper the slopes and the more jagged the ridges, cliffs and gorges of these mountains, the more concerted and successful is the work of the destructive forces. As the ridges round out, the cliffs disappear and the slopes become gentler, the destruction slows down. A heavy layer of eluvium and deluvium covers the country rocks and protects them against wide temperature variations, rain and wind; only ground water continues its work in the earth's crust. Little by little the rain and melt waters wash the soft soil off the surface and carry it down into valleys, but new soil appears in its place. That is why low, greatly levelled mountains last longer than tall mountains. Nor can they escape the inevitable end—transformation into

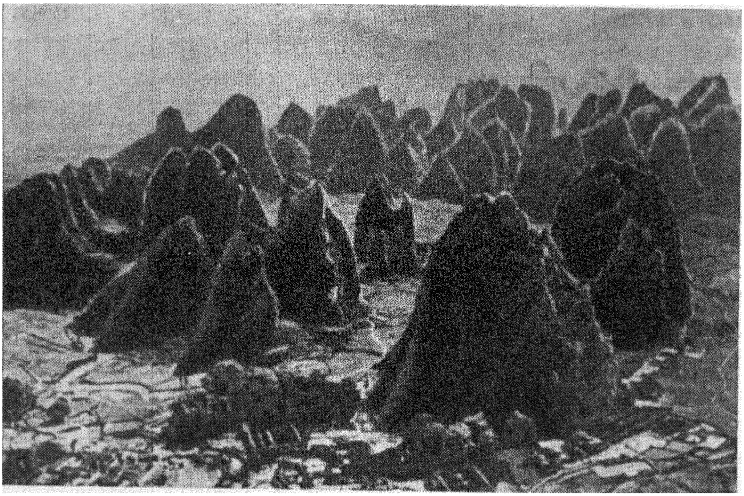

Fig. 212. Rock pillars of limestone mountains in subtropical climate. Kwangsi Province, South China

plains with only a flat hill or swell, the remains of the former peaks and ridges, rising here and there. Plains remaining in places of mountains are known as *peneplains* (Fig. 211); the ridges, swells and hills rising amid them are referred to as *rock pillars* (Fig. 212). Figures 213-214 show different types of residual mountains resulting from the destruction of mountains; figures 215 and 216 show an erosional valley and a fault-line valley.

Rejuvenation of Mountains. Now we know that mountains disappear. Working tirelessly, imperceptible but mighty forces have ground up and eaten away the enormous bulks of the mountains that rose above the clouds, while the water of streams and rivers, and the wind carried them apart grain by grain, in the true sense of the word, all over the surrounding country and into the nearest lakes and seas. New sedimentary rocks—sandstones, sands, clays, slates, whole layers of deposits—were formed in the beds of rivers and on the floors of lakes and seas from the fragments of the different rocks of which the vanished mountains had been built.

More centuries will pass and in the places of these lakes and seas the mountain-building forces will erect the folds of new mountains composed mainly of the materials belonging to these

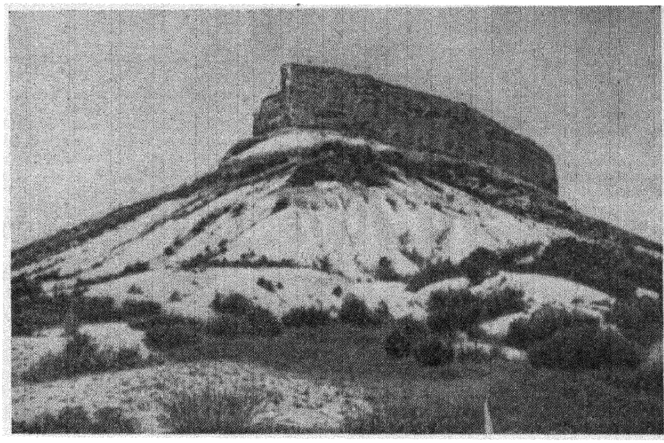

Fig. 213. Rock pillar in moderate climate (Tertiary limestones). Mt. Tepe-Kermen, Crimea

formerly existing but vanished mountains. Mountains are also frequently rejuvenated in their old places.

A peneplain created on the territory of a highland is cleaved by fissures of large fractures which disrupt the earth's crust to a great depth. Under the pressure of mountain-building forces long stretches of the peneplain are uplifted, some more, others less, as wedge-shaped blocks of the earth's crust, and the plain is transformed into a scarped plateau (see Fig. 203). The destructive forces which have grown weak on the peneplain they had levelled out go to work again as soon as large accidents in the relief make their appearance: cutting of the scarp edges, deepening of gorges and valleys, and dissection of the plateau scarps are resumed; ridges, peaks and saddles appear, and the plateau is transformed into a highland of a block-folded type.

We can find these rejuvenated mountains in various countries. For example, at one time, very long ago, Altai was a folded highland which the destructive forces have reduced to a peneplain. Then, much closer to our time, the peneplain was broken up, uplifted and transformed into a scarped plateau from which the awakened destructive forces have created the modern Altai with the remains of the peneplain retained at different heights

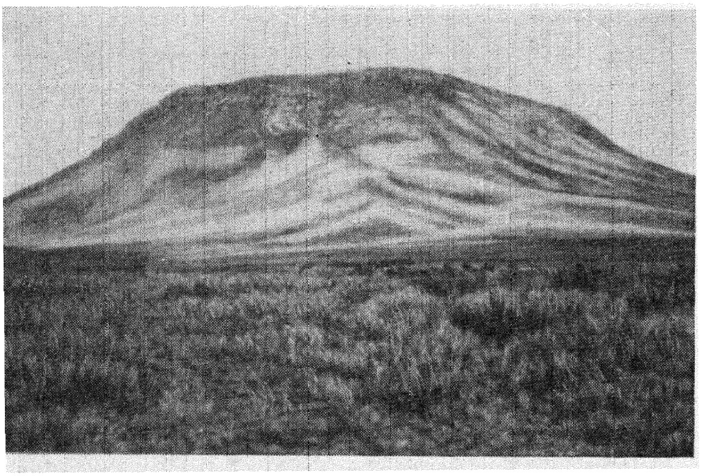

Fig. 214. Remnant of ancient volcano. Mt. Kalmyk-Tologoi built of porphyrite and its tuffs. Kalbinsky Range, Kazakhstan

as levelled-out areas; at the same time the layers of rock everywhere form steep and complex folds whose direction does not always correspond to that of the present-day ranges and ridges. This indicates that the modern shapes of these mountains do not conform to their inner structure and shows us their ancient shapes. But the same fate is awaiting the new Altai in the distant future; it will be similarly destroyed and transformed into a peneplain for the second time.

Geosynclines and Platforms. The particularly mobile belts of the earth's crust in which dislocations give rise to folded mountain ranges are called *geosynclines*, i.e., synclines (subsidences) of the Earth.

In these belts the earth's crust forms a depression in most cases flooded by the sea. The products of erosion are carried down to the geosyncline from the surrounding land and layers of sedimentary rocks—sandstones, slates and limestones—are deposited. In a short time these layers must, of course, fill the geosyncline, but because of its mobility the latter continues to subside and the depression is periodically renewed so that in the long run enormous strata of sediments accumulate in the geosyncline.

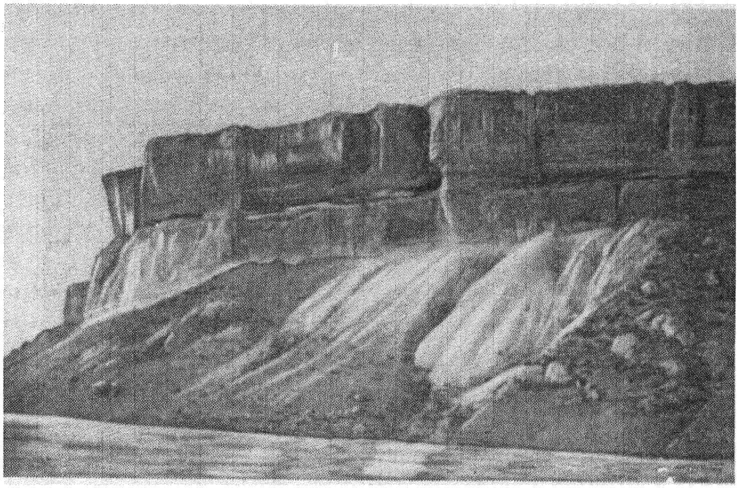

Fig. 215. Erosional valley in gently sloping layers. Kacha River, Crimea, near Bakhchisarai

But sooner or later the reverse movement begins—not subsidence but uplifting—and the mountain-building forces create in the geosyncline folded mountain ranges which rise above the sea level.

It is believed that a geosyncline may remain unflooded forming a depression within the limits of the continent and the materials in the form of continental deposits will be carried to this depression from the neighbouring uplands; heavy layers of sedimentary rocks may accumulate in this geosyncline and finally give rise to folded mountains. The valley of the Ganges, along the foothills of the Himalayas, is pointed out as such a geosyncline; the very thick layers of sediments accumulated in it and discovered in boreholes prove the slow subsidence of this area.

Platforms are contrasted with geosynclines as the stablest areas of the earth's crust in the particular geological epoch.

Orogenesis and Epeirogenesis. Dislocation processes which build mountains of any type are referred to as orogenic (mountain-generating); it is believed that they are relatively short-lived and represent episodes in the history of the earth's crust comparable to the revolutions in the history of mankind during

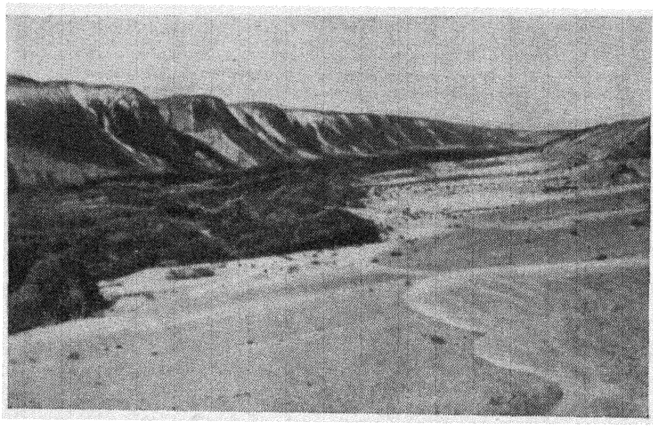

Fig. 216. Erosional valley along fault crevice in steeply sloping layers. Darbuty River in Jair Range, Jungaria

which the latent and long suppressed forces of the popular masses come into play and radically change the existing social system. The brief orogenic epochs similarly derange and change the structure of the earth's crust which remains relatively quiescent during the longer intermediate epochs. But only relatively and not absolutely. It is thought that during these epochs, too, the earth's crust suffers movements and displacements, but very slow ones compared with the fast orogenic movements; these movements do not change the structure of the earth's crust and are likened to evolutions. They are described as *epeirogenic* (continent-generating, *epeiros* meaning continent in Greek) because they manifest themselves in rises or drops of vast areas or whole continents, as flat uplifts or broad depressions. They are proved by the slow recession of the coastline observed in the old coastal swells and terraces, the formation of lagoons, the transformation of islands into peninsulas, etc., or by the advance of the sea and the flooding of the coasts. These movements are also called slow oscillations of the earth's crust.

Incidentally, some scientists have lately concluded that the orogenic processes are also very slow, which is proved by the fact that many rivers burrow not only through separate mountain ranges, but through whole highlands, and this can be accounted for only by supposing that these rivers are older than the mountains; the mountain folds arose so slowly that the rivers had enough time to erode these accretions and retain their directions. The existence of quiescent epochs in the intervals between the orogenic ones is also doubted, and it is assumed that the earth's crust always moves slowly, and that there is no essential difference between oro- and epeirogenesis. Slow displacements of the coastlines in one direction or the other, the subsidence of land and dislocations of the youngest deposits have been observed in many countries, and evidence is accumulating that recently, during the modern geological epoch, there were uplifts on all continents, these uplifts amounting to even several hundred metres and expressing themselves in increased erosion in the highlands due to the increased gradient of the river beds. Thus, even the modern epoch formerly considered quiescent is also orogenic.

Causes of Dislocations. Scientists have already made many different assumptions relating to the causes of crustal dislocations, but these are still only assumptions, i.e., hypotheses, because we can observe only the results of these processes since the latter being abyssal cannot be observed.

The *contraction* hypothesis, i.e., the hypothesis of compression of the earth's crust put forward in the middle of last century, was formerly the most widespread. Laplace's hypothesis assumes that the Earth was originally a molten body gradually cooling and developing a hard crust. But the hot core of the Earth continues to lose heat by radiation into world space. Observations in mines and boreholes prove that the deeper we penetrate into the earth's crust, the hotter layers we encounter, while volcanic eruptions confirm the presence of high temperatures and molten masses in the interior. Hence, the entrails of the Earth are losing heat and must therefore contract as any other body does in cooling; the earth's crust becomes too spacious for the contracted core and must shrink like the skin of an apple or potato when they dry, i.e., when they lose water and diminish in volume. The shrinkage of the earth's crust expresses itself in its dislocations, the folds of the rocks being the wrinkles. This process must repeat periodically. Heat is lost continuously, but for dislocations, i.e., for the overcoming of the resistance to crumbling by the rocks it is necessary that the tension gradually developing in the earth's crust grow to a considerable force, in other words, that it accumulate. This is why dislocations occur periodically, in certain epochs separated by long epochs of quiescence, and spread simultaneously over the entire globe.

Other greatly differing hypotheses have been proposed, but we cannot consider or criticize them here. Suffice it to say that most of them are based on considerations of various processes operating very deep under the hard crust, as, for example, currents arising in the magma, differentiation, i.e., break-up of the magma into parts of different composition before hardening, radioactive decay (which compensates for the loss of heat even with an excess, i.e., expanding the core instead of compressing it), drifting of light continents on a heavy underlying bed and their lagging during the rotation of the Earth, etc. Unfortunately we do not as yet have any positive knowledge concerning part of these processes; we do not even know if they occur in the earth's crust at all, so that these hypotheses are built on very shaky foundations which admit of most diverse interpretations. On the other hand, the contraction hypothesis is based on direct observation and incontestable facts. We see the eruptions of volcanoes which eject into the atmosphere a lot of heat in the form of hot gases and vapours; we see cooling streams of lava and numerous hot springs which also liberate heat. Geological research has shown that volcanic eruptions have occurred since the formation of the earth's crust, and that in other epochs these eruptions took place on a much greater scale than today. The lavas, gases and vapours of the volcanoes, and the water and salts of the mineral springs (which were also active in all geological epochs) represent not only a loss of heat from the interior of the crust, but also a tremendous loss of substance transferred from the entrails to the uppermost crustal layers in the form of enormous intrusions of effusive rocks, and to the surface as lavas, waters and gases.

We shall not dwell on the core of the Earth since we know too little about its composition and the processes operating in it. But the foregoing considerations concerning the loss of heat and substance from the peripheral layers of this core or the lower layers of the earth's crust irrefutably denote that these layers are contracting, while the surface layers which receive substance in the form of intrusions, effusions and spring depositions are increasing in volume, i.e., are becoming too spacious in relation to the underlying layers and must adjust themselves to them by contraction.

It is an incontestable fact that these surface layers are contracting; the numerous folds clearly reduce the area which these layers have covered before; the reverse faults and overthrusts are also contractions and only the normal faults denote a certain expansion. The geosyncline—mobile belt in the earth's crust—after changing to a folded mountain range or a highland undoubtedly also contracts. The vast Canadian, Brazilian, Baltic and Aldan shields in which strongly folded very ancient layers of the earth's crust are prominent occupy smaller areas than they did before folding.

It is during this contraction that high tension, mainly tangential and acting in a horizontal direction, develops. This tension must cause the soft and still plastic layers of sedimentary rocks in the orogenic belts, the geosynclines, to fold. In the stable areas or platforms which do not form a single, continuous, monolithic whole, as some people believe, but consist of parts of different sizes, different composition, and different rigidity and were formed at different times, i.e., are composed of a coarse mosaic, the tension is discharged in lifting various sections to different heights even with possible subsidence of others, in thrusting their edges over each other accompanied by shearing and displacement of whole layers, which slide over one another, and in crumpling the young surface strata of sedimentary rocks into folds.

If we relinquish the supposition that dislocations occur rapidly and only during certain brief epochs separated by epochs of quiescence, and assume that they are slow and continuous we shall rid ourselves of one of the essential objections to the contraction hypothesis, namely, that the layers of the earth's crust cannot accumulate and then communicate over considerable distances the tangential tension they develop. We must take it that dislocations occur very slowly and wherever layers or sections of the earth's crust can react to the tension by some displacement or other, i.e., by changes in the mode of their occurrence. Their friction against each other and the law of inertia frequently prevent these layers or sections from immediately submitting to the tension and require a certain accumulation of energy. The latter, therefore, sometimes resolves itself in separate shocks, rapid displacements of strata, contortions and faults which shake the layers over long distances. These sharp dislocations are essentially quite small, but on the surface they produce more or less intense, even catastrophic earthquakes which we shall consider in the next chapter.

Precision instruments now record earthquakes at many stations and it appears that the earth's crust vibrates lightly and imperceptibly to man, but almost continuously now here and now there, thus proving the continuity and slowness of the dislocations. This does not mean, however, that the intensity of the dislocations is always and everywhere the same. It undoubtedly increases during the epochs of the geological revolutions and then diminishes. The intensification in some countries may not exactly coincide with that in others; it may either be ahead or lag behind, according to the variety of local conditions on which the nature of the dislocations essentially depends.

The contraction hypothesis which takes into consideration only compression as the force that determines all dislocations is one-sided and fails to account for many facts. The recently proposed hypothesis referred to as the pulsation hypothesis introduces serious amendments into the contraction hypothesis by accounting not only for the processes of compression, but also for those of expansion.

As a luminous body the Earth, like the other cosmic bodies, served as an arena for the struggle between the forces of attraction and repulsion. The attraction conditioned the reduction in volume and the distribution of matter according to specific gravity from the centre to the periphery. The repulsion created radiation and ejection of matter into world space after the manner of the protuberances observed on the Sun.

It should not be thought that this struggle between the antagonistic forces ceased after the formation of the earth's hard crust; it must continue in other forms. The forces of attraction express themselves in the compression of the earth's crust; the forces of repulsion cause its expansion. These forces struggle incessantly, but the resistance the crustal layers offer to various displacements necessitates a periodical accumulation of energy to overcome this resistance. All dislocations therefore occur in leaps which correspond to the epochs of energy discharge and are separated from each other by longer and more quiescent epochs of energy accumulation.

The crustal contraction manifests itself in the following essentially tangential movements: in the mobile belts of the crust, i.e., the geosynclines, more or less filled with juvenile deposits, the latter contract into folds of various complexity and the geosynclines narrow down under lateral pressure. On the stable rigid platforms and shields the compression complicates the folding of their foundations consisting of older, already folded deposits, bends these foundations into swells and crests, crumples the superficial, younger and as yet indisplaced deposits into broad folds, and displaces large wedges of the earth's crust as thrusts and overthrusts along the fracture crevices; the area of these stable platforms is thus also reduced.

The expansion of the earth's crust is evinced in the following essentially radial movements: in the mobile geosynclines the belts of the folds created during the contraction jut out and rise as mountain ranges and systems above the former level, while new depressions, i.e., geosynclines, form next to them during the expansion. Crevices—fractures—appear on the platforms and shields which also rise and expand, and stretches of the earth's crust in the form of horsts and fault troughs are displaced along these crevices. The expansion is additionally accompanied by magmatic activity: magma invades the uplifted geosynclines from the interior and forms intrusions and effusions of igneous rocks, while on the platforms it is extruded along the fissures in the form of sheets and also builds chains of volcanoes.

This hypothesis assumes that the struggle between the forces of attraction and repulsion persists also after the formation of the earth's hard crust, that the Earth develops in leaps, that opposites replace each other and that quantity changes into quality and therefore best conforms to the teachings of dialectical materialism; after additional elaboration it should become the most acceptable hypothesis offering the best explanation of the complex structure of the earth's crust. It is not one-sided as are all the other hypotheses so far proposed, and can also account for the movements and transformations of the magma in the entrails of the Earth, the radioactive processes, the influence of the rotation of the Earth and the other phenomena which in any way affect the struggle between the forces of attraction and repulsion.

The structure of the earth's crust created by various displacements and the intrusions and effusions connected with them is referred to as *tectonic* (*tektos* being the Greek word for structure).

The idea of mountain rejuvenation occurred to geologists only in the beginning of the twentieth century. It was formerly believed that mountain-building on Earth had been fully completed as early as the Tertiary period which preceded the modern Quaternary period. The Tertiary period was considered the youngest as regards mountain-building. It is the period when all the Earth's mountain systems crowned with the highest peaks came into being; on these summits we see accumulations of snow and ice all year round; these accumulations give rise to glaciers that descend into the surrounding valleys. Such are the Alps and Carpathians in Europe, the Cordilleras and Andes in the two Americas, some ranges in Africa, Tien-Shan, Nan-Shan, Himalayas and other mountains in Asia.

But closer geological studies of the mountain systems of Europe and Asia have revealed that mountains were also built in various places at the end of the Tertiary and even in the beginning of the Quaternary periods, that side by side with the old mountain ranges already in a certain measure levelled and lowered by processes of erosion and weathering others came into being, and that in these not only the Tertiary but also the Quaternary deposits were dislocated forming folds, even overfolds and overthrusts. Thus, while studying the Kalbinsky Range which is a continuation of the Altai Mountains on the left bank of the Irtysh I noticed in 1911 that its western end near Semipalatinsk was greatly lowered and had old levelled forms, whereas stretching eastward it gradually acquired sharper and more disjointed forms, though it ran along the Irtysh in both places and should have had the same forms of relief. My observation led me to the assumption that this range running from west to east came close to the Altai located on the right bank of the Irtysh and, consequently, the Altai might also have rejuvenated forms. I did not find any confirmation of my assumption in the literature on Altai then available and therefore made up my mind to go there and solve the problem myself. I was able to do it only in 1914 and my assumption that the Altai was also a greatly rejuvenated mountain range was confirmed.

Similar assumptions of the recency of the last mountain-building movements were also voiced by some foreign geologists at the end of the nineteenth century and these views gradually came to be dominant. In my brief report made in 1948 I proposed to designate these most recent movements of the end of the Tertiary and the beginning of the Quaternary periods by the term *neotectonics* which has since become current among Soviet geologists.* The mountains that have recently come into being in place of the older and greatly levelled ones or beside them may be referred to as *rejuvenated* mountains.

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* *The Main Features of Neotectonic Kinetics and Plastics*, "News of the Academy of Sciences," Geological Series, 1948, No. 5, pp. 13-24. Russ. Ed.

IX

WHY THE EARTH SHAKES NOW HERE AND NOW THERE

Effect of Earthquakes on Man. Focus and Epicentre. Isoseismal and Homoseismal Lines. Period of Earthquakes. Recording. Seismometers. Depth of Origin. Intensity of Earthquakes. Causes of Earthquakes. Area of Distribution of Earthquakes. Portents. Results of Earthquakes. Seaquakes. Types of Earthquakes. Correlations with Other Natural Phenomena. Safeguards.

We have grown accustomed to regard the earth, the solid ground under our feet, as something stable and unshakable. We build our heaviest structures on it and only sink our foundations the deeper, the heavier these structures are. That is why when the earth begins to quake under our feet so that it is impossible to stand up, when large trees sway, and strong buildings that have stood up for decades crack and collapse before our eyes, when fissures disrupt the ground and we hear a roar and rumble from its interior as if the very entrails of the Earth were foundering we are gripped by terror, lose our heads, and do not know where to run for safety.

But, as we noted in the preceding chapter, our Earth vibrates continuously. Precision instruments have revealed that there are annually between eight and ten thousand earthquakes, i.e., approximately one earthquake every hour; actually there are many more, because two-thirds of the earth's surface is covered with water on which there are no stations to record all, including the weak, earthquakes and, besides, large areas on the continents also have no such stations. Fortunately, most of the earthquakes are so weak that they pass unnoticed. Man begins to take notice of them only when the things in his home start crackling or knocking against each other; but these earthquakes are still inoffensive. Somewhat more intensive are those in which the dishes clink, hanging lamps and wall pictures swing, and the window panes jar; these earthquakes are enough to sorry us. But when the plaster begins to flake off, various things drop, clock pendulums stop, the doors slam and cracks appear in the walls, people involuntarily run out into the streets because they

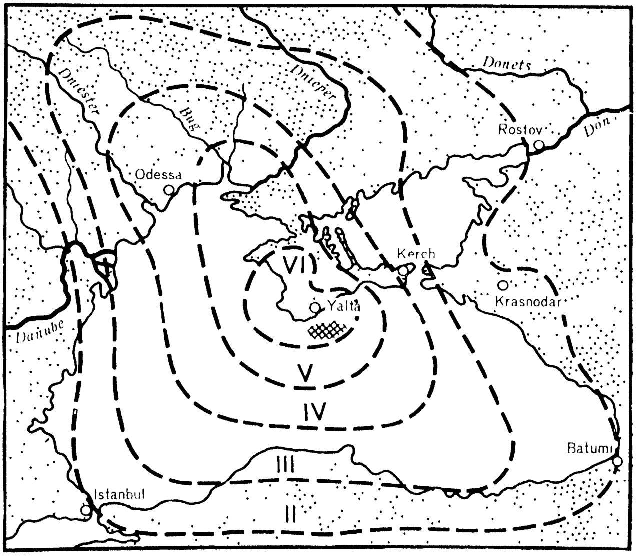

Fig. 217. Epicentres and isoseismal lines of the 1927 earthquakes in the Crimea. Shading in the sea near Yalta indicates the epicentres. Roman numerals show force of shocks

feel much safer outdoors than in, since houses are now more like mousetraps. There are several dozen of these earthquakes every year, but still stronger ones that destroy cities and annihilate thousands of people are a rare occurrence. Still less frequent are the catastrophic earthquakes during which more people lose their lives in a few seconds than do in epidemics or battles.

An earthquake manifests itself on the surface, but its *focus*, i.e., the region in which it originates, is in the entrails of the Earth and is concentrated within the limits of a plane or some area with unknown boundaries.

To simplify the calculations the focus is taken as a point called the *hypocentre*. The shock wave arises at this point, spreads in all directions and sets all the particles into resilient vibration, which gradually dies down along with the wave farther away from the hypocentre. On the earth's surface the shaking is the strongest in the area immediately above the focus; this area is called the epicentral area and the point above the hypocentre is described as the *epicentre* (Fig. 220).

The farther away in all directions from the epicentre, the less are the tremors felt until the point is reached when they are no longer felt by man, but only recorded by precise instruments.

The earthquakes are studied by a special branch of geology known as *seismology* (from the Greek word *seismos* meaning earthquake). The vibrations felt by man are referred to as macroseisms and those detected only by instruments are called microseisms.

Earthquakes are most intensely felt in the epicentre; at some distance from it in all directions we shall find a series of points at which earthquakes manifest themselves with equal force. By drawing a line through them we shall obtain the *isoseismal line*, i.e., the line of equal force. The isoseismal lines will not be true concentric circles around the epicentre, but distorted, because the manifestation of the force largely depends on the composition and structure of the earth's crust which vary very widely (Fig. 217). In addition to the isoseismal lines we can also draw a line through the points at which an earthquake is felt at the same time; this will give us the lines known as *homoseismal lines*; these lines will also be distorted because the velocity with which the shock wave is propagated depends on the composition and structure of the rocks through which it travels.

Weak or medium earthquakes frequently consist of only one shock which lasts a few seconds or even a fraction of a second, though it seems much longer to man. Strong earthquakes usually begin with one or several weak shocks followed after some interval by one or a few main shocks, the latter being the most destructive; these shocks gradually die down and then change from macroseismic to microseismic. An earthquake may generally last from a few hours to a whole day. Sometimes certain regions of the Earth suffer vibrations of varying intensity for a period of several days, weeks or even months. These long-continued tremors are said to be *periods of earthquakes*. Separate shocks or series of shocks are divided by intervals during which only weak or very weak tremors occur. Nearly every earthquake is accompanied by noises which create a strong impression and inspire man with awe. The underground rumbling now resembles hollow peals of thunder, now the bubbling of boiling water, now it sounds like the roar of a heavy train or a landslide, and now it is like the singing of the wind, the screeching of a shell or the crash of an explosion. The sounds sometimes run ahead of the earthquake wave and sometimes lag behind it. The intensity of an earthquake cannot be judged by the strength of the sounds; long-continued underground rumbling is sometimes unaccompanied by any earthquake or is attended by a very weak one.

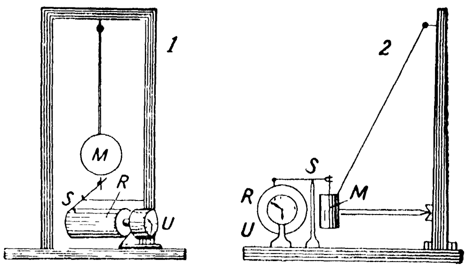

Fig. 218. Diagrams of seismographs with vertical (*1*) and horizontal (*2*) pendulums
M—pendulum; *S*—recording lever; *R*—drum with paper; *U*—clock

Recording Earthquakes. The study of earthquakes requires instruments which record the time, intensity and direction of each individual shock. The simple instruments mark only the time of the first shock; somewhat more complex instruments also indicate its direction. But these simple instruments called *seismoscopes* have long since been replaced by very complicated *seismographs*. Fig. 218 schematically shows two types of seismographs. Their most important part is the heavy pendulum *M* which swings either in a horizontal or vertical plane. In the absence of tremors it is motionless, but the very first shock makes it swing and at the same time starts clock *U* running; the latter marks the time of the beginning of the earthquake and turns drum *R* covered with a paper on which recording lever *S* traces a fine line showing all the oscillations of the pendulum.

This curve is known as a *seismogram* on which it is possible to discern all the individual shocks and to determine their time and force (Fig. 219) because the drum turns at a definite rate, while the sizes of the notches on the line correspond to the swings of the pendulum which depend on the strength of the shocks. Microseismic vibrations are shown by fine notches.

Good seismographs record not only the earthquakes occurring in the area where the instrument is installed, i.e., where the seismic station is located, or in close proximity, but also the most remote ones, and make it possible to determine their distance from the station and their power.

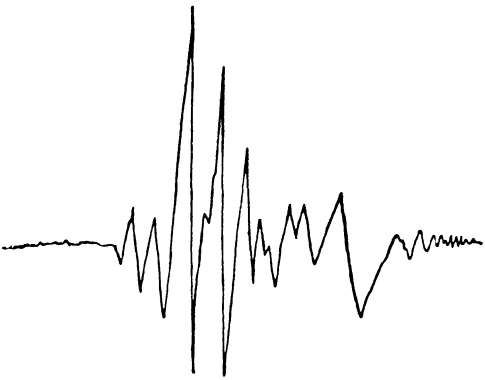

Fig. 219. Seismogram of an earthquake

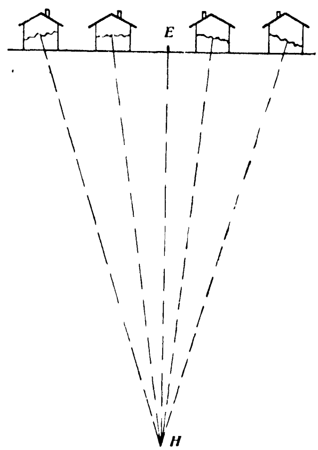

Fig. 220. Determining the depth of origin of an earthquake.
E—epicentre; *H*—hypocentre (focus)

Depth of Origin. The interesting problem of the depth at which an earthquake originates is solved by calculations based on the seismograms. Measurements of cracks in the walls of buildings offer a rough but clear method (Fig. 220). By determining the pitch of the cracks relative to the earth's surface and by drawing perpendiculars to them we shall find the focus in the interior at the intersection of the perpendiculars with the vertical line drawn through the epicentre or at their intersection with each other.

Observations have shown most of the earthquakes to originate at a depth of up to 50 kilometres, few of them at a depth of from 50 to 100 kilometres and only single earthquakes to occur at depths ranging between 300 and 700 kilometres. The region which has suffered from earthquakes the most is located around the epicentre and is called the *pleistoseistic* region. Its extent depends not only on the force of the shock, but also on the depth of the origin. A strong earthquake with a small pleistoseistic area has a very shallow focus. A large area always indicates a great force and a deep origin. The terrible Lisbon earthquake of 1755 spread over an area four times the size of Europe. The 1881 earthquake on the Island of Ischia (in the Mediterranean) which destroyed the town of Casamicciola had an area of only 55 square kilometres and a very shallow focus.

The *intensities of earthquakes* are gauged by their effects; the scale adopted in the U.S.S.R. distinguishes 12 degrees of earthquakes:

I—imperceptible; the microseismic vibrations are detected only by instruments;

II—very feeble; noticed by few sensitive people at rest;

III—slight; felt by few people as jolts caused by a rapidly passing carriage;

IV—moderate; felt by few people outdoors and by many indoors; slight clinking of dishes and jarring of window panes, creaking of doors and floors;

V—rather strong; felt by most people in motion and at work; shaking of buldings as if by heavy objects falling indoors; vibration of chairs and beds;

VI—strong; felt by everybody; very many people run outdoors; falling of pictures and books, breaking of dishes, appearance of fine cracks in the plaster;

VII—very strong; furniture falling indoors, light cracks in the walls, parts of plaster, of stucco moulding, and of chimneys falling; some of the weaker buildings collapse;

VIII—destructive; great damage to buildings, large cracks in the walls, some walls and all chimneys and towers collapse;

IX—devastating; great damage to stone buildings; some collapse;

X—disastrous; landslides and landslips, crevices in the earth's crust; most of the stone and lighter buildings destroyed;

XI—catastrophic; wide fissures in the earth's crust, numerous landslides and landslips; most bridges and frame buildings destroyed;

XII—extremely catastrophic; enormous changes in the earth's crust; total destruction.

There are three *causes of earthquakes*. First: the cavities created by the ground waters in the soluble rocks of the earth's crust cause earthquakes due to the sudden collapse of the roofs of these cavities. These *collapse earthquakes* have a very small region of propagation, an insignificant pleistoseistic area and a shallow focus, but can be very destructive.

Second: volcanic eruptions are often preceded and sometimes accompanied by more or less strong earthquakes resulting from the sudden drop in the pressure of the gases in the channel of the volcano as the lava plug is ejected from the vent, and also from the cave-in of the roofs of the cavities formed after the outflow of the lava. These *volcanic earthquakes* are sometimes very destructive; the areas of their dispersal and their pleistoseistic regions are small and their foci shallow.

Third: all the slow crustal displacements—folds, faults, thrusts and overthrusts—are frequently accompanied by earthquakes. These *tectonic* earthquakes are the most widespread and not infrequently the most destructive; the areas of their dispersal and their pleistoseistic regions may greatly vary in size and their foci may be located at different depths.

Portents of Earthquakes. The slight ground vibrations recorded by seismographs and partly noticed by people several hours before the destructive earthquake are its portents, but not always; a strong earthquake may occur without these portents or the latter may precede the earthquake so directly as to be of no significance as a warning. Sometimes the whole thing may confine itself to these feeble vibrations.

Animals are the most sensitive as regards impending earthquakes. Domestic animals—chickens, pigs, and donkeys—become restless and noisy. Wild animals run into the forest and howl, crocodiles come out of the water; on the island of Cuba tame grass-snakes leave houses and crawl away to fields for safety.

Before the eruption of Mont Pelée which began with a strong earthquake in the beginning of May 1902 the domestic animals became very restless already at the end of April: cows mooed, dogs howled and hugged closer to people; wild animals left the vicinity of the volcano, birds deserted the forests and large numbers of snakes came crawling to the houses. This was due to the spread of sulphurous gas from the newly formed fissures

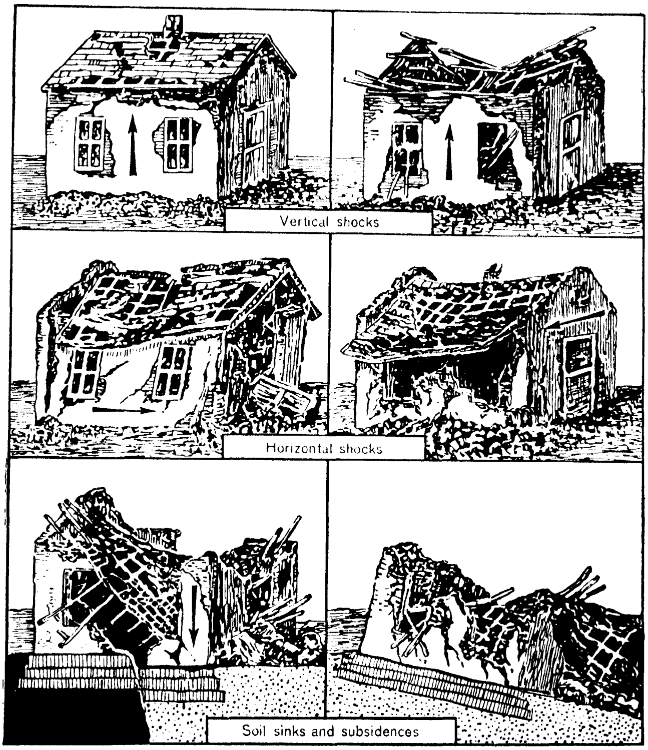

Fig. 221. Dependence of damage on direction of shocks

and to the underground rumbling always heard before the awakening of a volcano; by pressing the ear to the ground it is possible to distinguish the separate shocks and the peals of thunder caused by the increasing pressure of gases and vapours. It stands to reason that the animals who have much better hearing than man and whose ears are closer to the ground, especially those that crawl and live in burrows, hear these sounds ahead of man and instinctively feel the danger.

The *results of earthquakes* manifest themselves in damage to man-made structures to the point of their complete destruction, in fissures, thrusts and overthrusts in the earth's crust, landslides and landslips in the mountains, appearance and disappearance of springs, and drainage and flooding of coasts.

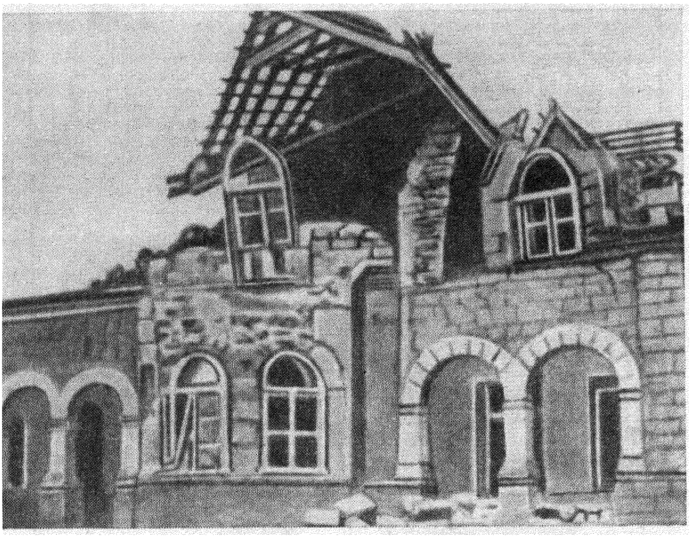

Fig. 222. Damage due to poor building material. Balaklava, Crimea, 1927

The extent of the damage to the structures depends on the quality of the construction, the composition of the soil, the nature and strength of the shock and the angle of its emergence (Fig. 221). The vertical shocks observed in the epicentre and in close proximity to it are less harmful than the wave-like vibrations characteristic of the surrounding country. The earthquake waves travelling in the ground inflict heavy damage on buildings, especially their walls, if the latter happen to be parallel to the waves. They not only rise on the waves, but are also bent by them. It is well known that the greatest damage is inflicted by shocks with a 45° to 55° angle of emergence.

The composition of the ground is of some significance: it affects the rate of propagation of an earthquake, the latter spreading much faster in hard than in loose rocks. In thick layers of loose rock, for instance in deposits (the alluvium of valleys), the wave wanes and may even die down altogether; but a thin stratum lying on hard country rocks has not enough time to absorb the shock and is thrown up on its bedding. Under these conditions the destruction will be greater. The structure of the country rocks has the following effect: the wave travels faster along the strike of the faults and layers than across them. The most dangerous grounds are generally the screes and rock debris (especially on hillsides), thin layers of alluvium on valley floors, marshes, overgrown lakes and peat bogs; dry grounds are less dangerous than those saturated with water.

The damage to buildings begins with a destruction of chimneys, plaster flaking off from the ceilings, falling of cornices and appearance of cracks in the walls. In stronger shocks corners or even whole walls of buildings cave in, the roof also suffering some damage. The severest shocks reduce buildings to a heap of ruins. The quality of the materials also plays an important part: the walls built of brick and good mortar will suffer much less than those built of boulders and clay; several earthquakes in the Transcaucasia and the 1927 earthquake in the Crimea have shown that many buildings were destroyed only because of the poor quality of the construction (Fig. 222).

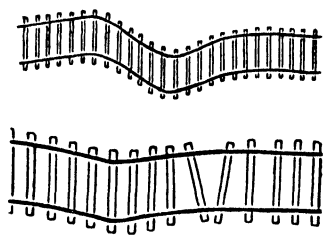

Fig. 223. Distortion of railway tracks during earthquake

The destruction of buildings is often accompanied by fires because the broken hearths, overturned lamps and severed electric wires give rise to fires, while the damage to the water-mains and the streets obstructed with debris hinder fire-fighting in towns. Thus, during the earthquake of September 1, 1923, in Japan fires broke out in Tokyo in 76 places after the first shock with the result that in 48 hours three-quarters of the city was reduced to ashes.

Heavy damage to buildings, especially during night earthquakes, inevitably entails loss of life—people buried under the ruins; the general panic, the fires and encumbered streets prevent the timely digging out of the living. That is why severe earthquakes victimize so many people. Thus, the 1908 Messina (Sicily) earthquake killed 83,000 people; the 1920 earthquake in Kansu Province (China) entailed the loss of nearly 200,000 lives, most of them buried in the loess cave dwellings destroyed by the shock. The 1934 earthquake in India involved 12 towns and many villages leaving 500,000 people shelterless and killing 10,000. More than 100,000 people were lost and 521,000 buildings

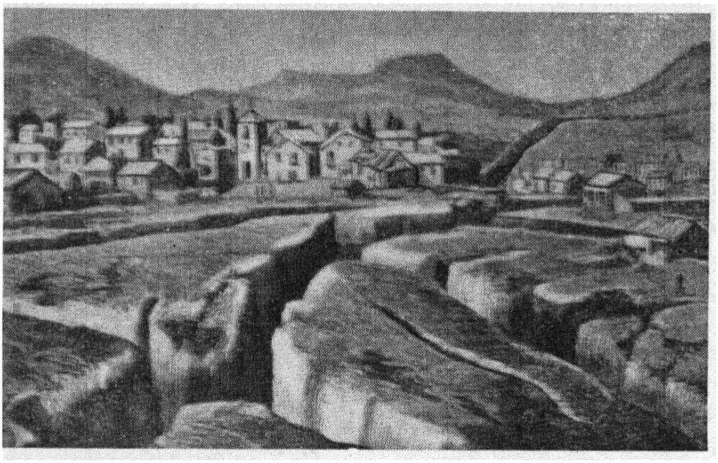

Fig. 224. Fissures in Andalusia (Spain) formed during the earthquake of December 22, 1884

were destroyed in Japan between 1604 and 1914. The Tokyo earthquake of September 1, 1923, annihilated 96,000 people and reduced 412,000 buildings to ashes.

Besides buildings, underground structures—sewers, gas and water-mains, lighting and telephone cables—stone and iron bridges (in the latter trusses come off their supports), and railway tracks (both the permanent way and the rails are distorted, Fig. 223) also suffer from earthquakes.

Earthquakes produce *fissures* in the earth's crust (Fig. 224), mostly in the region of the epicentre; sometimes they radiate in all directions from some centre, but are more frequently arranged haphazardly in various directions, usually running along mountain slopes or along coasts; they range in width from 20 to 50 centimetres, reach a depth of 10-15 metres, and are sometimes many kilometres long. Buildings, people and animals fall into these fissures. The fissures formed during the first shock sometimes close up during the subsequent shocks, but often close up very slowly or remain open.

If the fissure runs along alluvium on the floor of a valley or plain and there is a quick ground or water-bearing layer underneath, water and mud, and sometimes gases are ejected from

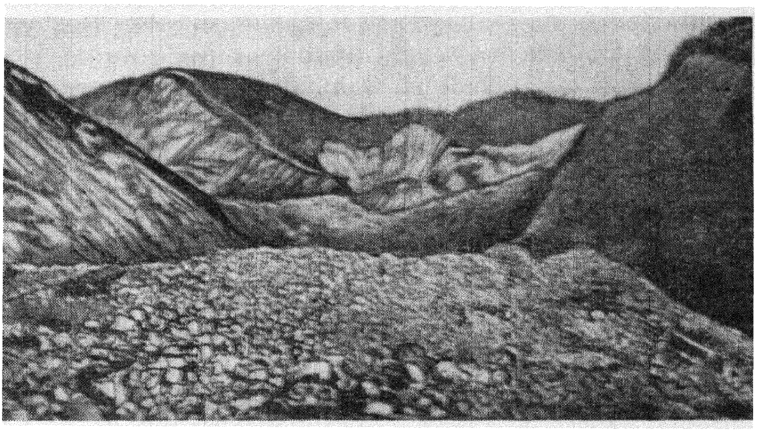

Fig. 225. Landslide in the valley of Ak-Jar (Transili Alatau) during the 1887 earthquake

the fissure, the gases igniting in the air. So much water and mud is sometimes ejected that they flood the surrounding country.

Larger areas also *subside* or *sink* during very severe earthquakes (this was observed in Italy, Asia Minor, India, on the shores of Lake Issyk-Kul in Central Asia, etc.) sometimes to a depth of 60 metres; this is likewise accompanied by eruptions of water and mud. The embankment with a mass of promenaders sank in Lisbon during the 1755 earthquake; ground subsidence was observed both on land and on the sea floor in Messina and Tokyo. During the earthquake of 1861 in the delta of the Selenga River on Lake Baikal an area of about 260 square kilometres, the mass weighing approximately 1,300 million tons, subsided with all the dwellings and herds on an average of 2.9 metres below the lake level.

Faults, *thrusts* and *folds* also occur during earthquakes. Folds were observed in the alluvium on the shore of Lake Issyk-Kul both in the subsided areas and next to them. Faults and thrusts happen very frequently, when fissures are formed, and sometimes stretch for kilometres on end. Especially characteristic was the thrust that disrupted several country roads on the floor of a broad valley in Japan during the earthquake of 1891 (Fig. 226). A tremendous fault occurred during the California earthquake of 1906; it ran for hundreds of kilometres along the coast and had 1.3-metre vertical and 7-metre horizontal displacements. The city of San Francisco suffered greatly during this earthquake, and though it was not in the way of the main line of the fault the secondary line with a 3-metre horizontal displacement cut across the city.

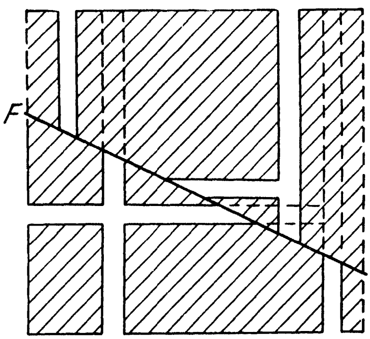

Fig. 226. Displacement of country roads during the 1891 earthquake in Japan
FF—crevice in ground; dotted lines show location of the roads before the displacement

The earthquake of December 20, 1932, in North America involved an area of about 500,000 square kilometres in the State of Nevada and some of the neighbouring states; judging by the fissures the earthquake displaced the eastern part of the area in relation to its western part.

Landslides, landslips and *solifluction* occur during earthquakes in highlands. During the earthquakes of 1887 and 1911 in the city of Verny (now Alma-Ata) there were numerous landslides in the adjacent mountains of Tien-Shan; the volume of the 1887 landslides is estimated at 440 million cubic metres, some of these masses being two kilometres long, 200 metres wide and 100 metres thick. Similar landslides happened in Assam, Japan, the Rockies (U.S.A.) and Alaska.

The *dislocations of ground waters* during earthquakes are quite understandable. Crustal displacements may close up the crevices along which water emerged or open up new ones, i.e., the disappearance of springs in some places and their appearance in others may be the result of strong shocks. Landslides and landslips may also create new vents for ground water or plug up the old ones. A watertight bed underlying a water-bearing layer may be disrupted by fissures along which the water will escape into the interior, and as a result groups of wells will be deprived of water.

Seaquakes (Tsunamis). If the focus of an earthquake is located somewhere under the floor of an ocean or of a large sea the shake is transmitted through the entire thickness of water and is felt on the ships sailing the sea at this time. In a vertical shock, i.e., over the epicentre, the ship is suddenly raised and then lowered, and a swelling-up of the water is observed. In lateral shocks the ship is jolted as though it has run into an underwater cliff, floating timber or an iceberg; unfastened objects fall, people barely stand up and the rudder is shaken up with particular force. The shock is often accompanied by a hollow rumble passing from the water into the atmosphere.

The seaquakes are more destructive when the epicentre is near the coast. In this case the sea frequently withdraws from a large area during the first shock, then returns as an enormously powerful wave, comes down upon the coast and sweeps everything off. In the Lisbon earthquake of 1755 the wave was 26 metres high and rolling for 15 kilometres inland annihilated some 60,000 people. In 1923 the waves transported ice for a distance of half a kilometre from the shore line in Kamchatka and buried several buildings; the tundra was flooded for several kilometres. The shallow coastal part of the sea is often covered with disorderly raging waves. The waves raised by an earthquake near the coast then spread over large distances across the oceans, erode the coasts and flood the coastal towns and villages.

The *distribution of earthquakes* on the earth's surface shows that they are closely linked with regions of dislocations and vulcanism. Statistics indicate that 40 per cent of the earthquakes occurs on the Pacific coast, from the Strait of Magellan across the Aleutian Islands to New Zealand which, as we know, also abound in volcanoes. Here we find mountain ranges running along the borders of the continents and near by the deepest depressions in the ocean floors along the coasts, i.e., the sharpest breaks in relief. About 50 per cent of the earthquakes happens in the so-called "zone of fracture" which runs from Mexico in the Western Hemisphere across the Atlantic, and along the Mediterranean to the Caspian and India; this zone is noted for its young folded mountains, large subsidences—depressions, and active volcanoes. Only 10 per cent of the earthquakes falls to the other main masses of continents, the seismic areas being: 1) the zone of fracture along the African lakes, the Red and Dead seas; 2) the mountain ranges of Tien-Shan and the Pamirs, and 3) the southern part of Lake Baikal with the surrounding country.

Thus the most seismic areas are those of the young folded mountains, young faults and subsidences, i.e., the young orogens in general; the least seismic regions are those of the oldest structures, long since consolidated, i.e., the old platforms.

The seismic areas in the Soviet Union are: 1) the Transcaucasia, belonging to the Mediterranean zone, and the Crimea (earthquake of 1927); 2) Tien-Shan, especially the northern foothills (earthquakes of 1887 and 1911 in Alma-Ata), Ferghana and the Pamirs as a region of young fold-thrust and fold-block mountains; 3) the southern part of Lake Baikal with the adjacent areas east and west of the lake—an ancient platform, but with young subsidences (only relatively seismic); and 4) Kamchatka and Primorye from the Anadyr River to Vladivostok, belonging to the Pacific belt (also less seismic in this part).

The Russian and Siberian platforms with their little disturbed structure, and the Urals, as very ancient mountains, contrariwise have rare and weak earthquakes; there are somewhat more earthquakes in the region of Altai in connection with the recent movements in these fold-block mountains.

Types of Earthquakes. Earthquakes, as we already know, are divided by origin into subsidence, volcanic and dislocation (or tectonic). The first are the rarest, the second occur more often, and the last are the most numerous. Among all these categories distinction is also made according to type, *central* earthquakes having a focus of dimensions limited in all directions, and *linear* earthquakes with the origin considerably elongated in one direction. The subsidence and volcanic earthquakes mostly belong to the central type, while the dislocation earthquakes are more frequently linear because their origin (hypocentre) is more or less elongated along the folds and crevices of the fractures (faults, thrusts and shift faults).

Correlation Between Earthquakes and Other Natural Phenomena. Man has long tried to find out if earthquakes occurred mainly at certain times of the year, the lunar month, and hours of the day. Statistics has shown earthquakes actually to happen: 1) more often in autumn and winter than in spring and summer

(4:3 ratio); 2) more frequently during the new moon and full moon; 3) more often during the perigee, i.e., when the Moon is closest to the Earth; 4) the shocks are more frequent and stronger when the Moon is in the meridian of the given place.

Certain correlations are also observed with the winds, precipitations and changes in atmospheric pressure. Thus, strong winds themselves cause microseismic vibrations. Earthquakes are observed somewhat more often after the period of abundant precipitations. A sharp drop or rise in the air pressure may serve as a trigger for the discharge of the tension in the folds or fractures in the form of a displacement of the strata which will in its turn cause an earthquake. A similar influence may be exerted by an increase of the load on the earth's crust due to abundant precipitations in winter and autumn, wind pressure and strengthening of the tides according to the position of the Moon.

Safeguards. Man is unable to prevent earthquakes; all he can do is to issue due warnings so that people may find safety; man can also build structures capable of withstanding strong earthquakes.

Seismic stations equipped with precise and sensitive seismographs are set up in seismic areas for purposes of warning the population of coming earthquakes; the seismographs must record not only the strong vibrations, but also the microseismic waves; by studying these the stations must ascertain if possible the movements that presage destructive earthquakes. This has not been achieved as yet.

The safeguards adopted in the countries greatly suffering from earthquakes consist of certain building rules. They come essentially to an enlargement of the foundation, use of metal ties in the brickwork, special strength of vaults and straight arches, a clearance between the roofs and chimneys, prohibition of heavy cornices and stucco moulding, and use of quality building materials. The buildings put up according to these rules are called *antiseismic*; they must guarantee safety to the tenants.

X

BRIEF HISTORY OF OUR EARTH

Earth's Early Youth. Formation of Continents and Seas. Origin of Life. Fossils and Their Significance. Transformation of the Face of the Earth. Cycles of Dislocations and Erosions. Transgressions and Regressions. Geological Chronology. Archaeozoic, Proterozoic, Palaeozoic, Mesozoic and Cainozoic Eras. Chronological Table. How the Age of the Earth is Determined. Continental Drift.

Nobody can tell us exactly how our Earth was made because not a single scientist was in a position to observe it himself. Only more or less plausible assumptions in the form of hypotheses are therefore enunciated. Several, as we know today, perfectly fantastic hypotheses were proposed in the civilized Mediterranean countries of antiquity according to the knowledge then current. The first scientific cosmogonic hypothesis based on facts established by science was proposed in the eighteenth century by Kant and Laplace. These scientists believed the Sun and all the planets revolving around it to have formed by condensation of one primary incandescent nebula which rotated even before the origin of the Sun. This nebula was bigger than the entire planetary system and somewhat flattened in form. Under the influence of cooling and attraction to the centre the nebula contracted and its rotation caused a ring of matter to break away at the equator; this ring broke up and was transformed into a sphere which continued to rotate. Since the contraction persisted, several rings broke off and were transformed into spheres, all the planets being finally formed and revolving each in its own orbit around the Sun. The central part of the nebula was changed into a star which continued to burn, lighting and heating the planets revolving around it. The planets' satellites originated in like manner—by rings breaking away from the planets because of their fast rotation.

The Kant-Laplace hypothesis was long thought appropriately to explain the formation of the Earth, but the rapid development of astronomy, geophysics and geology in the nineteenth century made it possible to reveal several errors in this hypothesis, and new explanations appeared. For example, the scientist Chamberlain thought that the little Earth, formed in the manner proposed by Kant and Laplace, gradually grew larger by the addition of meteorites—similar condensations of nebular substance—which fell on it from cosmic space. The astronomer Jeans believed the Solar System to have formed as a result of the passage of another star very close to the Sun, the attraction of this star causing a sharp disturbance in the balance of the internal layers of the Sun and the ejection from it of an enormous stream of matter which later by division and subsequent condensation gave rise to all the planets of the Solar System. For a number of years this hypothesis was thought very adequate, but was then disproved because the passage of one star so close to another that it may cause the supposed ejections of material is a very rare phenomenon and unlikely to explain the formation of the planets revolving around the Sun. Several serious errors were discovered in this hypothesis chiefly by Soviet scientists.

More than 10 years ago Academician O. Schmidt put forward a new hypothesis of the formation of our Earth and the other planets revolving around the Sun. He assumed that moving in the Galaxy through the dust and gases which form the interstellar matter the Sun attracted part of them and came out surrounded by a cloud of this substance. According to the law of gravity this cloud revolved around the Sun, the particles composing the cloud moving in it in all directions, colliding with each other, sometimes breaking up, but more frequently uniting, the smaller particles joining the larger ones; the planets were thus gradually formed in the cloud. The part of the cloud closer to the Sun was heated more intensely, and the nearest planets Mercury, Venus, the Earth and Mars are therefore small and consist of dense matter, rock and metal, and little gaseous remains, whereas Jupiter, Saturn, Uranus and Neptune, the more distant planets, are of enormous size and consist of gaseous and volatile substances. The bodies that failed to join the solid inner planets form comets and asteroids.

Schmidt originally thought that the meteorites forming part of the primary cloud had played an important part in the making of the planets; later he relinquished this idea and believed the gas-dust mass to have been the initial material for the creation of the planets.

Schmidt's hypothesis successfully explains a great deal in the formation of the planets, but it is not devoid of serious shortcomings, as was pointed out at the very first conference on problems of cosmogony.* The hypothesis considers the formation of the planets of the Solar System, but leaves out the Sun; it offers a good explanation of the origin of the terrestrial type planets, but the large planets with their physical properties do not fit into it. Schmidt did not study the evolution of the Sun or the problem of the origin and evolution of the stars and did not utilize the rich material of modern astrophysics. All this shows that Schmidt's hypothesis is as yet unable to explain the formation of all the heavenly bodies and is inadequate in its present form.

Most of the Soviet scientists studying problems of astronomy and geophysics believe that the Earth and the other planets of the Solar System were formed not of substance brought from without, but of the gaseous or gas-dust matter existing within the limits of this system.

Schmidt's and several other hypotheses assume that the Earth and other planets of this type formed of the gas-dust substance were originally cold. Subsequently, the substance was divided according to its specific gravity by means of gravitational differentiation and the globe was stratified into geospheres of different densities as a result of the rise of the lighter particles to the outer shells of the Earth.

The mean density of the globe is 5.5, while the mean density of the outermost part of the earth's crust which we can study on the surface, in mines and boreholes does not exceed 2.5 to 3.0. The density of the earth's core is very high, from 8 to 11.

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* O. Schmidt, *Four Lectures on the Theory of the Origin of the Earth*, Moscow, 1950; and *Transactions of the First Conference on Problems of Cosmogony*, April 16-19, 1951, Moscow, 1951. Russ. Ed.

Some scientists suppose that the earth's core consists of nickel and iron; others explain the physical state of the core by saying that owing to a colossal pressure the substance of the core is in a special "metallized" condition and that the structure of the atoms of this substance differs from that in the earth's crust, namely, that the outer electrons are displaced in each atom.

According to the Kant-Laplace hypothesis the molten globe of the Earth gradually cooled from the surface inward and was covered with a crust which was at first very thin and was often disrupted under the pressure of gases and incandescent masses. Subsequently, this crust grew heavier and stronger, but beneath it, at a depth of 50 to 100 kilometres, a zone (geosphere) of molten magma was retained just the same.

The discovery of deep-focus earthquakes originating at a depth of more than 600 kilometres has persuaded some geologists that the outer shell of the Earth consists of solid substance to a depth of at least 800 kilometres. This structure of the earth's crust conforms to the assumption of the origin of a "cold" Earth from cosmic dust better than to the hypothesis of a fiery-liquid Earth.

According to Schmidt's hypothesis the originally "cold" Earth had in its composition radioactive elements which by disintegrating served as the source of energy, and the Earth gradually melted, only the outer shell of the Earth—the crust—remaining hard. On the other hand, as A. Vinogradov points out, if we take the meteorites to be fragments of planets (this is now believed firmly established) we must also admit that these planets went through the stage of complete melting. Thus, the Earth, whose internal geospheres have, according to modern assumptions, a structure analogous to that of different types of meteorites, must, as a whole, have gone through the stages of a molten body in which the processes of liquid differentiation, liquation and stratification occurred. In Vinogradov's opinion the Earth began to cool from the inside and long retained a molten shell.

If we summarize the discussions of Schmidt's hypothesis at the First Cosmogonic Conference we shall see that the problem of the origin of the Earth and planets, the problem of whether the energy produced by the decay of radioactive elements is alone enough to heat and melt the globe, and the problems of the further differentiation of the Earth's substances and the process of the Earth's cooling have as yet been inadequately elaborated and that astronomers, geophysicists and geologists have come to no agreement.

In his work *Dialectics of Nature* F. Engels pointed out that on our Earth, as on all the other cosmic bodies, there is a continuous struggle between the forces of attraction and repulsion and that since the hard crust was formed the forces of attraction have gained an upper hand. "Owing to its decisive superiority over repulsion on our present-day Earth, attraction has, on the contrary, become *entirely passive*: we owe all the active movement to the influx of repulsion which comes from the Sun."* This amendment to the hypotheses of the Earth's formation was of great significance because without the alternation in the activity of the forces of attraction and repulsion it is impossible to explain the structure of the earth's crust in which we observe the results of strong attraction as fold-forming contractions as well as the results of repulsion which has replaced the epoch of attraction. Expansion leads to formation of fractures, faults with downward and upward displacements of whole layers, gaping fissures and sinking of small and large stretches of the earth's crust in the form of so-called fault troughs. The amendment made by Engels must be accepted since the structure of the earth's crust cannot be understood or explained without it. It was proposed by some geologists, who evolved the pulsation hypothesis according to which the development of the earth's hard crust after its formation represented an alternation of epochs or periods in the activity of the forces of attraction which caused compression of the crustal layers and the forces of repulsion which produced its expansion, fractures, faults and fault troughs (for details see Chapter VIII).

By assuming that the Earth was originally either a molten sphere or, having formed as a cold body, later changed to a molten sphere by internal melting, we can draw for ourselves the following picture of the subsequent transformation of the earth's crust.

The molten sphere of the Earth gradually cooled from the surface inward and the liquid had to pass into a solid state and cover itself with a crust consisting of compounds of lighter elements. This crust was at first very thin and broke here and there

* F. Engels, *Dialectics of Nature,* State Publishers of Political Literature, 1955, p. 53. Russ. ed.

under the pressure of gases and vapours liberated from the molten mass. But it gradually became stronger growing from below by the hardening of the deeper layers and from above by the cooling of the lava poured out on to the surface through the ruptures in the crust.

The fractures now occurred less frequently and only in separate weaker places, but then grew more catastrophic because they were followed by eruptions and effusions much more powerful than those occurring in modern times. Under the pressure of gases and vapours the crust rose in bubbles and broke up with a terrible explosion throwing about enormous fragments and letting the lava emerge; it is possible, however, that the latter sometimes poured out of the fissures in the crust more quietly.

Since these processes did not operate uniformly over the entire surface the crust gradually had to grow uneven and cover itself with protrusions of various sizes in the form of fields of extruded lava separated by hollows. Thus were the primary continents and oceans outlined, though there was no water on the Earth as yet; at that time the temperature of the crust was still higher than the boiling-point of water and all the water then existed as steam in a dense atmosphere.

The cooling continued, the steam in the atmosphere condensed and returned to the Earth in the form of terrible downpours which on the hot crust quickly changed to steam again. The air was saturated with electricity, and it is hard to conceive the awful thunders that roared over the Earth and the lightning that cleaved the dense air; there was no quiet either day or night, and since the Earth was enveloped in continuous heavy clouds the rays of the Sun did not penetrate to the surface of the Earth which was being born in storm and tempest.

Then, watered and cooled by downpours the crust cooled on the surface to the extent that the water falling on it did not evaporate at once, but began to fill the depressions. At first the water in these primary seas boiled and curtains of steam hung over them; later the boiling stopped, but the seas long remained hot. It is to be supposed that the water in them was already salty because the gases liberated from the magma included constituents of various salts. The crust was still insufficiently strong, broke here and there, and the lava pouring in heavy streams over the continents often reached the sea-shores, tremendous explosions and clouds of steam attending the contact between the lava and the water. There were probably no volcanoes like the modern ones as yet; the crust was still thin and easily broke, the gases, vapours and lava breaking out more freely (Fig. 227).

This primeval state of the Earth lasted very long, perhaps much longer than all the subsequent periods put together. It was as yet impossible to live on the Earth. The continents represented fields of solidified lava with a very uneven surface; vapours escaped with a hiss and gases, including asphyxiating

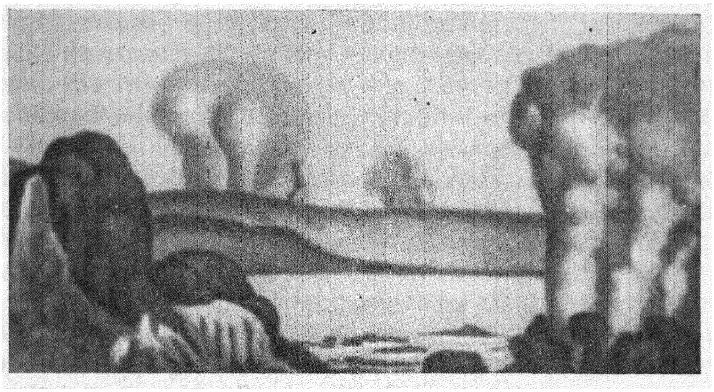

Fig. 227. Earth's surface after formation of the first seas, but before the appearance of life

and poison varieties, were liberated in different places from the fissures; the water was still hot in the seas and the latter smoked like cauldrons. The air was heavy and saturated with vapours; dark clouds covered the sky and obscured the Sun; frequent flashes of lightning illumined dark days and black nights; terrible downpours broke out here and there, and torrents of water ran down the continents beginning their work of erosion, transport and deposition of sand and silt of which the first sedimentary rocks were built.

But little by little the conditions improved, the Sun peeped out more often, storms broke out less frequently, the water basins cooled and the first forms of life appeared in them.

The *origin of life* is the second riddle still unsolved by science (the first riddle is the formation of the Earth), and all that is being said about it is merely so many hypotheses. All religious teachings take advantage of this by proposing in some form or other an omnipotent creator of the Earth and life. This is no answer, however, but an avoidance of the problem because the eternal existence of some creator assumed by the religions, as well as his omnipotence, are still greater riddles than the origin of life in the Universe.

The most probable thing is that life originated by itself in the warm primordial ocean abounding in various salts; the discharges of electricity in the form of lightning may have ionized the water and created an impulse for the first accumulations of protoplasm, lumps of jelly-like protein substance representing the first organisms; all life—plant and animal—has developed from them by an interminably long and complicated evolution.

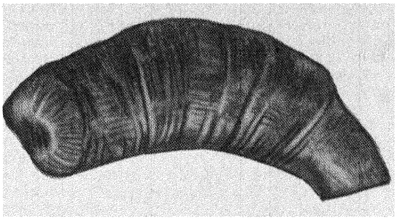

Fig. 228. Coral *Cyathophyllum heterphyllum* from Devonian deposits

Have we any data to judge about the ancient forms of life on the Earth? Yes, we have.

Fossils. We know very well that various animals—fish, crayfish, frogs, mussels, leeches, etc.—live in the water of rivers and lakes, and that algae, water lilies and reeds grow there. In the seas the animal kingdom is still richer; there in addition to fish and various molluscs, we find sea-urchins, stars, lilies, corals, worms, sponges and different seaweeds. The corpses of these animals and the stalks and leaves of the plants often drop to the floor of reservoirs and are gradually buried in the layer of sand, silt or clay that is at that time precipitated from the water. The soft parts of the animals' bodies—the flesh, viscera, etc.—decay or are consumed by other animals before they are completely covered up by the sediment, while the hard parts—the bones, teeth and scales of fish, the testae of lobsters, sea-urchins and stars, shells, etc.—remain. In the layers of sand, clay and chalk they are preserved for thousands of years and gradually petrify, the remains of plants changing to coal. In time, when the river changes its bed, the lake dries up or the sea recedes, these remains may be exposed and found in dry places, even on steep mountain slopes.

These petrified or carbonized remains of animals and plants are referred to as *fossils* (Figs. 228-231). They frequently occur in stratified rocks and are of great importance to science because it is only by these fossils that we can find out what animals and plants lived on our Earth in times long gone by. By comparing the fossils found in different layers we can learn how the animal and vegetable kingdoms changed on the Earth. Studies of fossils have shown that the creatures inhabiting the Earth in days of

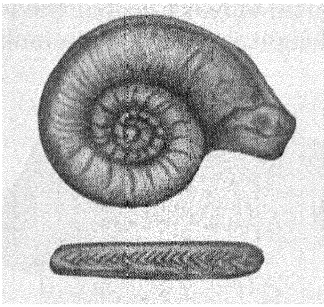

Fig. 229. Ammonite *Mimoceras gracile* from Devonian deposits (top and side views)

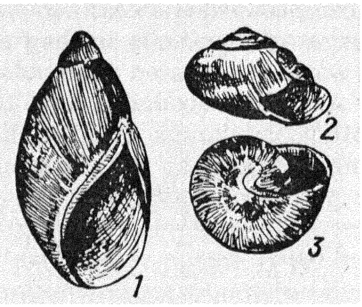

Fig. 230. Shells of gastropoda molluscs *Physa gigantea* (*1*) and *Helix sp.* (*2* and *3*) from Tertiary deposits

yore greatly differed from those we see today, and the longer the time that has elapsed since they lived, the greater is the difference between them and the animals of today. We can therefore judge by the fossils which rock layers were formed earlier and which later, and can distinguish the sedimentary rocks according to their age. From the fossils and the rocks that compose the earth's crust we can therefore make out the entire history of our Earth since the most ancient times when there was no man as yet and, consequently, no legends or annals by which scientists form their ideas about past life and its events.

It is not only the animals and plants which had lived in water that we find fossilized. The corpses of animals and parts of plants living on land also frequently get into the water. The wind blows the branches and leaves of the trees and bushes growing on the banks and shores into the water of the rivers and lakes on the floors of which they are buried together with the algae. Whole trunks of trees are brought into the water by currents or tides. Rains erode and carry into rivers, lakes and seas leaves and twigs, insects and land molluscs, small birds and animals who even live far from the water. Large animals sometimes drown in floods or when swimming across rivers, or sink in marshes, and their bones are buried along with the remains of fish and shell-fish.

During volcanic eruptions the remains of plants and small animals get into layers of tuffs formed on the land and in

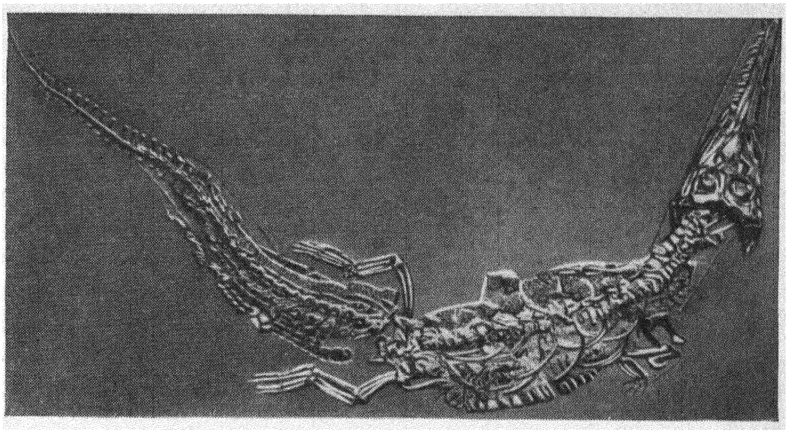

Fig. 231. Skeleton of ichtyosaur, marine reptile of the Lower Jurassic period, on a slab of lithographic slate from Solenhofen (Bavaria). The skeleton is 3.9 metres long

reservoirs. In the layers of stratified rocks we can therefore find fossils of land plants and various land animals.

The large quantities of plant remains—trunks, stalks, leaves and mosses—accumulating on floors of lakes or in marshes are gradually transformed into layers of peat, brown and anthracite coal. The bones of animals sometimes accumulate in layers of so-called bone breccias.

Transformations of the Face of the Earth. As soon as the surface of the Earth, depending on the non-uniform consolidation of the crust and the breaks-through of the magma, was covered with elevated areas which constituted the continents, and with depressions with accumulations of water which created the seas, the geological agents, already familiar to us, went to work on transforming this surface named the "face of the Earth" by the famous geologist Suess.

The work of these geological agents does not cease for a single moment, though it fluctuates considerably, increasing in some parts of the Earth and waning in others.

Not all these agents work incessantly, nor does each of them always work with the same intensity; the work may, in fact, temporarily die down. Thus, for example, in countries with a moderate or cold climate the chemical and organic weathering ceases in winter, while physical weathering increases. On quiet days the work of the wind wanes, but while it is quiet in one country a hurricane may rage in another. Some volcanoes are constantly but feebly active, others temporarily die down and then display vigorous or even catastrophic activity. The earth's crust shakes continuously, but strong earthquakes are not so frequent. Dislocations are created slowly and ceaselessly, but judging by strong earthquakes sharp displacements occur only from time to time. Running water works day and night, but during the spring flood-time and after strong rains its work gains in intensity, while in winter it wanes. In highlands its work is vigorous, on plains it is barely perceptible, and in deserts it manifests itself very rarely but with double force. The work of the surf is connected with the inconstancy of the winds.

The most uniform work is generally done by glaciers, but they work with different vigour in different parts of their beds, while over long periods of time their work is also subject to considerable fluctuations.

This lack of uniformity in the work of the geological agents, the more or less sharp fluctuations in the intensity of this work, enable geologists to speak of *stages*, *phases* and *cycles* in the development of geological processes on the Earth, implying longer periods of time by cycles and shorter ones by phases and stages. These periods may vary not only for the different processes, but also for the same process in different parts of the Earth and in different historical times. The vigorous activity of some volcano may thus be called a cycle or period in which phases or rather stages of awakening, eruption of loose material, effusion of lava, and dying down are distinguished. In one volcano this cycle lasts several days, in another—years or decades; the same volcano may in different epochs greatly change the duration of the cycle, as well as of the individual phases.

Of the greatest interest in the history of the Earth are the cycles of dislocations, erosion and glaciations. We have already considered the latter in Chapter VI and shall now dwell on the former.

Tectonic Cycles. Though dislocations—the crustal movements that change the structure of the crust and the interrelations between the layers of rocks—occur, as it is now believed, incessantly, the varying intensity of these movements can hardly be doubted. The history of the Earth confirms that certain intervals of time characterized by mountain-building are followed by periods during which the formerly created mountain ranges are subjected to intensive erosion; of course, the latter also took place during the mountain-building, but it later became dominant. We are therefore justified in speaking of cycles of dislocations followed by cycles of erosion or denudation, implying by the word denudation the totality of the processes of weathering and erosion (denudation means exposure).

To understand the terms used below and define the time of the cycles take a look at the table of geological chronology given on page 285. The following cycles of dislocations (tectonic) are distinguished in the history of the Earth: several most ancient ones that came to pass during the Archaeozoic and Proterozoic eras; the *Caledonian* characterizing the first half of the Palaeozoic era; the *Variscian* (or *Hercynian*)—second half of that era; the *Alpine*—Mesozoic and Cainozoic eras. It is now considered proper to divide the latter into the *Pacific*, embracing the Mesozoic era and the *Alpine* proper, encompassing the Cainozoic era. Each of these cycles is in its turn divided into several phases separated from each other by longer or shorter periods of waning or, at any rate, weakening mountain-building movements.

Cycles of Erosion. This concept, elaborated by the American scientist Davis, helped to understand the development of the forms of the earth's surface. Each cycle is divided into stages.* After a mountain fold is formed as a long or short swelling of the earth's surface running water begins to cut hollows in the limbs of the folds and changes the latter to

* Phases imply the totality of processes leading to a certain result and then ceasing, i.e., the phases are divided by intervals, whereas the stages imperceptibly merge into one another.

ravines and then to valleys; but the area is still weakly disjointed and the valleys have gentle sides. The numerous streams of water are not yet united into complicated systems, but frequently end in small lakes; the main rivers proceed along the natural inclines of the region. This is the *stage of childhood.*

The erosion gradually grows stronger, the valleys become increasingly deeper and the sides steep; sharp ridges are formed developing peaks and saddles. Individual streams unite into systems and some lakes disappear. The relief is strongly diversified. Erosion prevails everywhere. This is the *stage of youth.*

The development continues. The valleys widen because of lateral erosion; the rivers form meanders and islands and divide into distributaries. Under the action of denudation the sides become gentler, the ridges and summits round out, and the watersheds grow lower. The streams unite into complex systems. The relief is strongly diversified, but its forms are already softened. The erosion weakens. This is the *stage of maturity.*

The watersheds keep growing lower and the ridges and peaks rounder, the slopes become very gentle, the rivers in broad valleys greatly meander forming numerous oxbows and swamps. The transport of material by rivers slows down considerably and deposition dominates. The relief grows flat. This is the *stage of old age.*

Finally, the lowering of the divides, the gentleness of the slopes and the disappearance of all the unevennesses of the relief reach their maximum. The work of the water entirely wanes, the greatly meandering rivers barely flow, many valleys are drained. The country is so levelled out that it approximates to a plain and the relief is referred to as a peneplain. This is the *stage of senility.*

It will be observed that the farther the cycle of erosion progresses, the longer the individual stages become. During the stages of youth and maturity this is determined by the extent of the deepening and disjunction which the erosion must effect, while during the stages of old age and senility it is conditioned by the weakening of the erosion due to the negligible gradients of the beds and the gentleness of the sides.

The following areas now at various stages of the erosion cycle may be mentioned by way of example: North Kazakhstan and Finland offer good examples of the stage of old age and senility, the Eastern Urals is at the stage of old age, the watershed and western slope of the Urals and many Siberian mountains exhibit the stage of maturity. The Caucasus represents the stage of youth.

Rejuvenation of the Cycle of Erosion. The cycle of erosion may quietly go through all its stages only on the condition that the earth's crust in the given area is entirely undisturbed because the slow movements which increase the folds and, especially, the sharp changes in the relief manifesting themselves as faults, thrusts and flexures must inevitably greatly derange it. The history of the Earth offers quite a few examples of these derangements. Let us imagine a peneplain or an area in the stage of old age rapidly raised in the form of a plateau between two faults, i.e., an ordinary horst. Running water will immediately set to work cutting hollows in its edges where the gradient has sharply altered. The hollows will then change to ravines and gorges whose heads will increasingly recede into the horst. The latter will go through the stages of childhood, youth and maturity again and after a long time may return to the stage of old age; the cycle of erosion recurred in it, i.e., was rejuvenated.

This rejuvenation will be even more complex if the peneplain is broken up by several faults into separate stretches or wedges raised to different heights; the erosion will resume its work along the edges and will transform the steps of the complex horst into disjointed mountain ranges.

Many countries offer examples of this rejuvenation. Mention can be made of the Altai which was once a folded highland, later eroded and levelled to the state of a peneplain, broken up by faults into wedges variously uplifted and already transformed by a new cycle of erosion into diversified mountain ranges. But in some places their surface still shows even sections of the former peneplain. These sections in aggregate with the complex structure of the ranges and their failure to coincide with the direction of the strike of the former folds definitely suggest that the Altai is, as we have already pointed out, a block-folded range and that its rejuvenation as a highland was conditioned by the rejuvenation of the cycle of erosion.

The rejuvenation of other Siberian mountains is evidenced by the steepness of the slopes or the gorges in the valleys of the middle and lower reaches of many rivers; they are results of the swift flow of these rivers, the rapids and even waterfalls which testify to the vigorous erosion and the stage of youth. At the same time we find in the upper reaches of these rivers flat marshy valleys, gentle slopes, levelled divides and weak, slow streams which clearly denote the stage of old age. The combination of these signs proves the recent uplift of the highland responsible for the rejuvenation of erosion in the middle and lower reaches of the rivers, though this rejuvenation has not had enough time to spread to their upper reaches which are still at the stage of old age. It is even possible to determine the time

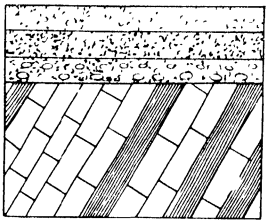

Fig. 232. Transgression with abrasion in a sharp angular unconformity of layers

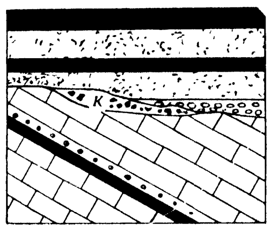

Fig. 233. Transgression on the surface of denudation with a remnant of the crust of weathering (*K*)

of the last uplift: the river gorges cut into the trough valleys formed during the last glacial epoch, hence, the uplift occurred after the end of the epoch.

The first glaciation developed in the country with a flat relief and, consequently, the new uplift occurred in a not very distant past, but rather close to the beginning of the last glacial stage because the erosion has not had time enough deeply to disjoint the uplifted peneplain.

Transgressions and Regressions. In the history of the Earth we have to assume repeated advances of the sea covering more or less considerable land areas and, on the other hand, retreats of the sea and increases in land areas. The former is called transgression, the latter—regression. In some cases both phenomena occurred simultaneously, i.e., the transgressions in some parts of the earth's surface concurred with the regressions in other parts, whereas in certain epochs either the transgressions prevailed, generally reducing the land area, or the regressions were dominant; the latter are usually connected with mountain-building phases.

During the transgression the sea may advance against a highland gradually destroying its folds and creating in their place a wave-built terrace shifting inland. This process is called marine *abrasion* and the marine sediments are deposited unconformably on the formerly dislocated older layers (Fig. 232). If the sea advances against a peneplain created by erosion and denudation the marine sediments will also be deposited unconformably on the older strata which are located differently, but remains of the crust of weathering will be seen in the intervals between them (Fig. 233). The sea may also advance against a plain built of older and as yet undisplaced beds; in this case its sediments will be deposited on ancient layers seemingly conformably, though they are separated from them by a rather long period of time. This relationship will constitute a concealed unconformity, and a careful study will reveal traces of erosion or weathering on the surface of ancient layers and fragments of ancient rocks in the lowest of the young beds (Fig. 234).

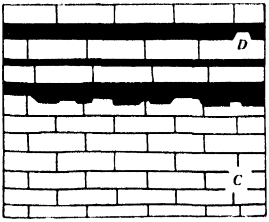

Fig. 234. Concealed unconformity with a long interval in the formation of the strata

C—Cambrian; D—Devonian

Geological cronology, i.e., the scheme of the sequence of events in the history of the Earth, is based on a study of the cycles of dislocations, erosion, vulcanism, transgressions, regressions and, mainly, of the fossils. But the sediments of the oldest epochs in the history of the Earth contain no fossils because the first creatures to come into being on the Earth had no skeletons or hard shells capable of preservation in the deposited sediments. Under the action of the heat, gases and vapours of the abundant intrusions or by finding themselves at a great depth under layers of younger deposits and also under the influence of heat these sediments completely changed their original composition, took on a new appearance and were transformed into rocks called *metamorphic*.

The oldest epochs lasted very long, but only at their end, when life had already developed and had become more diversified, did the first fossils appear in the sedimentary strata; these were chiefly various algae which formed whole layers, imprints of medusas and sponges, as well as forms defined as the first crustacea, primitive corals and traces left by the crawling of worms. Life was still cooped up in the water, the land being an absolute desert.

These oldest times in the history of the Earth beginning with the formation of the first sedimentary rocks are referred to as the *Archaeozoic* era. An era implies an extraordinarily long period of time, in this case hundreds of millions of years. The formations of the Archaeozoic era contain no fossils as yet, but the presence of carbon in the form of graphite and thick layers of limestones most probably formed of organic calcareous silt warrants the assumption that life had already made its appearance in the upper half of this era. Archaeozoic means primeval life (*archaeos*—primeval, *zoe*—life).

During this era the sedimentary rocks formed are not so strongly altered as the Archaean and are often hardly distinguishable by the extent of alteration from the later normal rocks. The next period of time is known as the *Proterozoic* era, i.e., the era of earlier (*proteros*) life, the rocks containing obvious remains of plants and animals.

Both these eras are sometimes combined into one and called Archaean or Pre-Cambrian, but this is wrong because each of these stages is too long. Moreover, the Proterozoic era is separated from the Archaeozoic by a long interval during which the Archaean rocks suffered dislocation with extensive intrusions, following which the folded mountains created by this dislocation were deeply eroded before the deposition of the Proterozoic sediments began. These long and characteristic intervals serve as the best signs to distinguish the eras from each other. These intervals noted for phenomena of dislocation and erosion, rather than deposition of sediments, naturally have no fossils which renders determination of their duration difficult. Chronologically they are associated with the preceding era which they terminate.

The Proterozoic era is also brought to an end by a similar interval after which the *Palaeozoic* era, i.e., the era of ancient life (*palaios*—ancient), begins; this era already contains numerous remains of multiform and rapidly developing life. They make it possible to divide this era into periods, i.e., shorter spaces of time, namely, the Cambrian, Silurian, Devonian, Carboniferous and Permian periods. The era is generally noted for the prevalence of the lowest classes of animals and plants, appearance of land animals and tremendous development of land

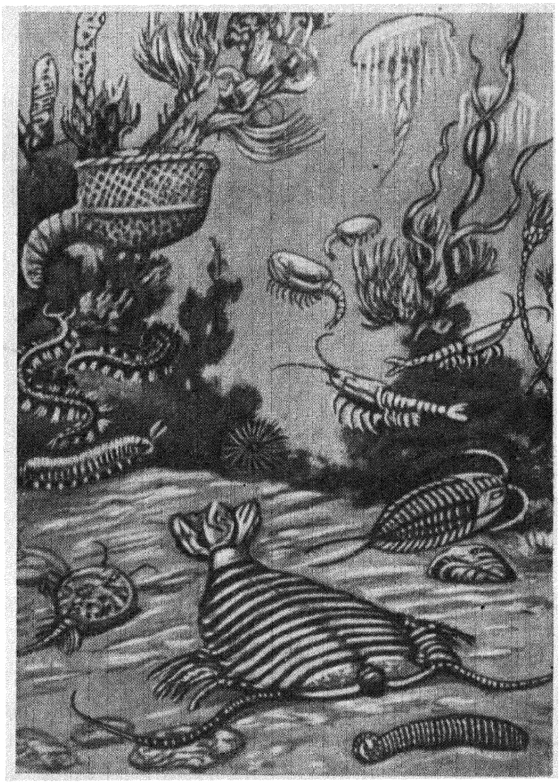

Fig. 235. Life on the floor of a Cambrian sea: trilobites of several genera, worms and starfish in the foreground; seaweeds, sponges, swimming crustaceans and medusas in the background

plants. Two cycles of dislocations—Caledonian and Variscian—each with several stages, several cycles of erosion and vulcanism, two or three considerable transgressions, an extensive regression and a glaciation at the end, are observed during this era.

During the *Cambrian* period life was still concentrated in the water, while the land presented deserts. There were already large numbers of crustaceans (trilobites), original archaeocyatha (something between sponges and corals), the first brachiopods and gastropods (Fig. 235); as for plants, algae predominated. In the beginning of the middle epoch a vast marine transgression occurred in Siberia, while the beginning of the upper epoch was

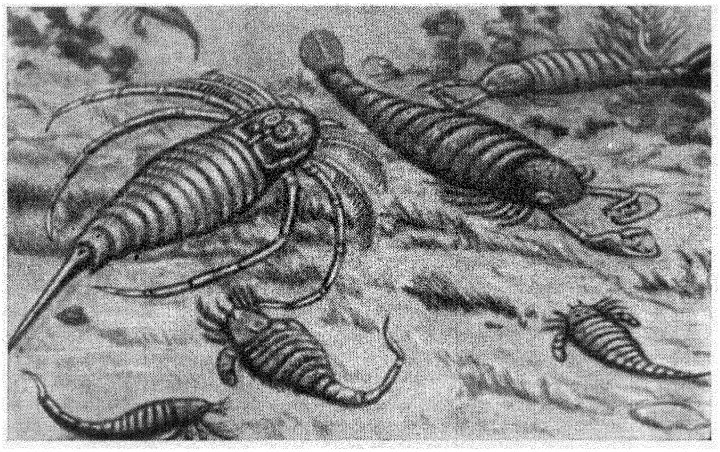

Fig. 236. Life on the floor of a Silurian sea: various eurypterids amid seaweeds

marked by the first phase of the Caledonian cycle and an intensification of vulcanism.

The *Silurian* period terminates the domination of marine life because at the end of it the first land animals (scorpions) and plants (psilophytons) made their appearance. Crustaceans and brachiopods dominated in the sea, but cephalopods, graptolites, corals and the first fishes also appeared (Fig. 236). The archaeocyatha vanished. Two phases of the Caledonian tectonic cycle developed in the middle and the end of the period giving rise to regressions of the sea and intensification of vulcanism.

The *Devonian* period is distinguished for its considerable spread of land plants. The fishes, mainly the testaceous forms, achieved extensive development; they lived not only in the sea, but also in the mouths of rivers and in lagoons, and probably tried to crawl out on land because some of them were dipnoian (Fig. 237); traces of the first land amphibians are also found. Brachiopods, various orders of molluscs, corals and giant crustaceans greatly multiplied in the seas, whereas graptolites disappeared and trilobites decreased. The last phase of the Caledonian cycle in the beginning of the period provoked an extensive

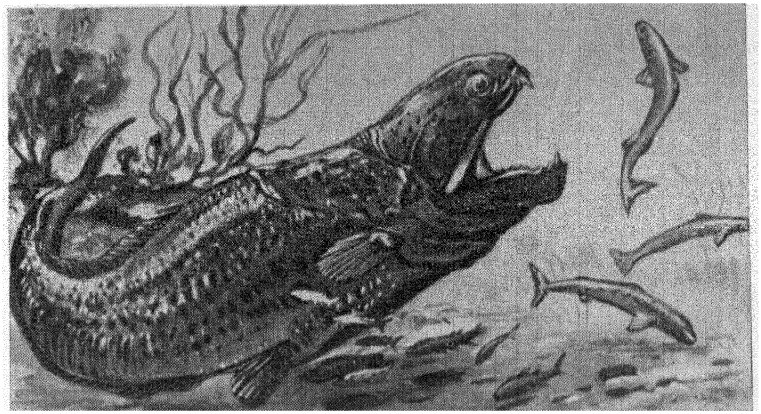

Fig. 237. Life in a Devonian sea: several genera of testaceous fish, including an enormous Dinichthys

regression which was followed by a transgression in the middle of the period; the Variscian tectonic cycle started at the end of the period. Vulcanism was very intense, especially during the first and last epochs of the Devonian period.

The *Carboniferous* period is noted for its unusual spread and variety of the flora of land cryptogamic plants which formed vast forests on the marshy shores of seas and created thick and numerous beds of coal known in many countries (Figs. 238 and 239). Various amphibians inhabited the forests, reptiles made their appearance and large insects (dragon-flies, beetles and butterflies) soared in the air. Trilobites were dying out in the seas, corals, brachiopods, various molluscs and large rhizopods developed abundantly; as for vertebrates the leading part was played by sharks. Several phases of the Variscian cycle provoked marine regressions and outbursts of vulcanism.

The *Permian* period is, unlike the Carboniferous, characterized by a dry and cold climate which caused extensive glaciation in the Southern Hemisphere, development of deserts, diminution of the seas and formation of thick layers of salts in their lagoons in the Northern Hemisphere.

These processes were connected with several phases of the Variscian cycle of dislocations which built mountain ranges and

Fig. 238. Swampy forest of horse-tails and ferns of the Carboniferous period

provoked regressions; vulcanism was greatly intensified. Various carnivorous and herbivorous reptiles made their appearance on land (Fig. 240), while many representatives of the Carboniferous flora became extinct and new forms appeared in the forests; layers of coal were also formed in various places. The trilobites died out in the seas, whereas the cephalopods, especially the ammonites, greatly developed.

The *Mesozoic* era, or the era of middle life (*mesos*—middle) is divided into the Triassic, Jurassic and Cretaceous periods. It is noted for the intensive development of reptiles, molluscs—belemnites and ammonites, and more highly organized sago and coniferous plants. Several cycles of erosion and vulcanism, and a number of phases of the Pacific cycle of dislocations caused transgressions and regressions and changed the face of the Earth.

The *Triassic* period was a time of relative quiescence of the earth's crust. The extensive regression in the middle epoch and

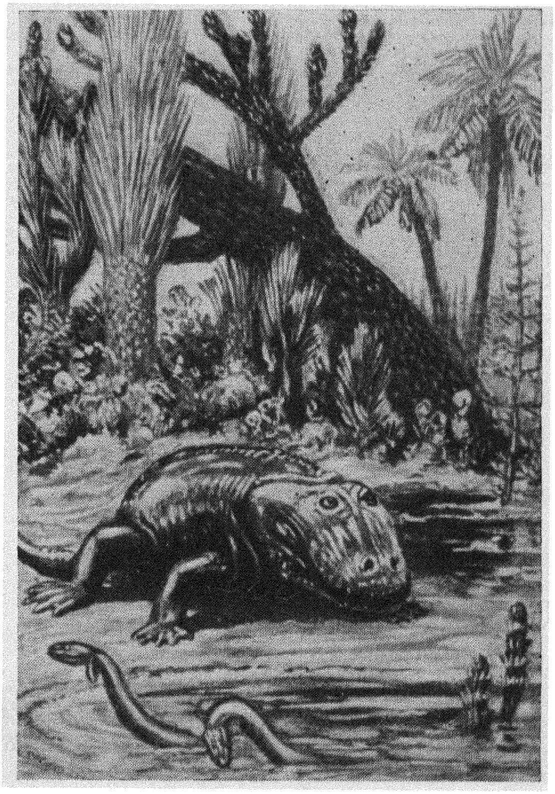

Fig. 239. Forest of the Carboniferous period: horse-tails and ferns, amphibian Eryops and snake-shaped amphibians

the transgression during the upper epoch were conditioned rather by smooth uplifts and subsidences than mountain-building. Reptiles represented by all the principal groups dominated on land; the first mammals appeared at the end of the period. Various ammonites and marine reptiles lived in the sea.

The *Jurassic* period is characterized by a development of mountain-building movements, regressions of seas, and spread of land flora which created a series of coal basins; in coal resources it is second only to the Carboniferous period. The reptiles at-

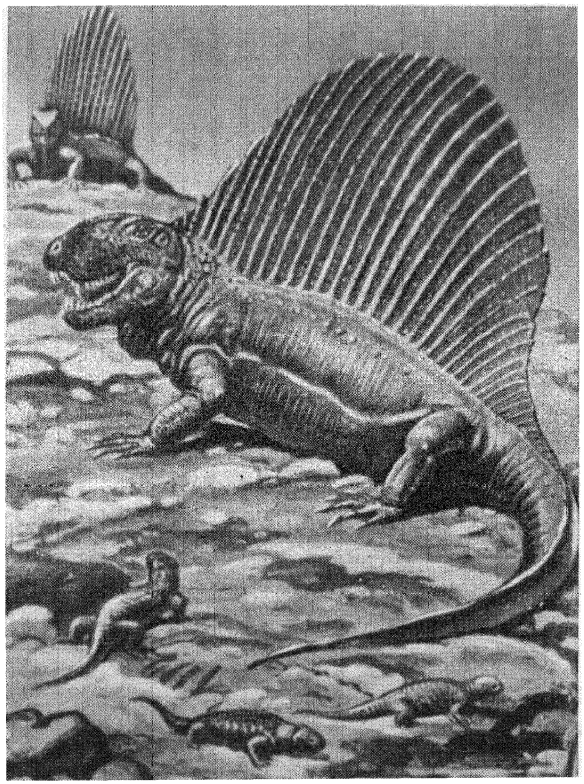

Fig. 240. Desert landscape of the Permian period: pangolin naosaurs in the background; dimetrodon and other small pangolins without ridges on their backs in the foreground

taining domination on land and in the seas are represented still more abundantly; in addition to ammonites, belemnites, new forms of bivalves, reef corals and sea-urchins develop plentifully in the seas. The first birds appear and compete with the flying reptiles (Fig. 241). Vulcanism increased at the end of the period.

The *Cretaceous* period is distinguished by intense mountain-building, extensive regression in the beginning and transgression

Fig. 241. Flying reptiles of the Jurassic period: nude pterodactyl and feathered archaeopteryx, progenitor of birds

at the end, and revival of vulcanism. The first broad-leaved trees and angiosperms make their appearance. The fauna exhibits the same features as in the Jurassic period (Fig. 242); the appearance of large rhizopods and various sponges, as well as depositions of strata of white chalk are characteristic. Extinction of ammonites

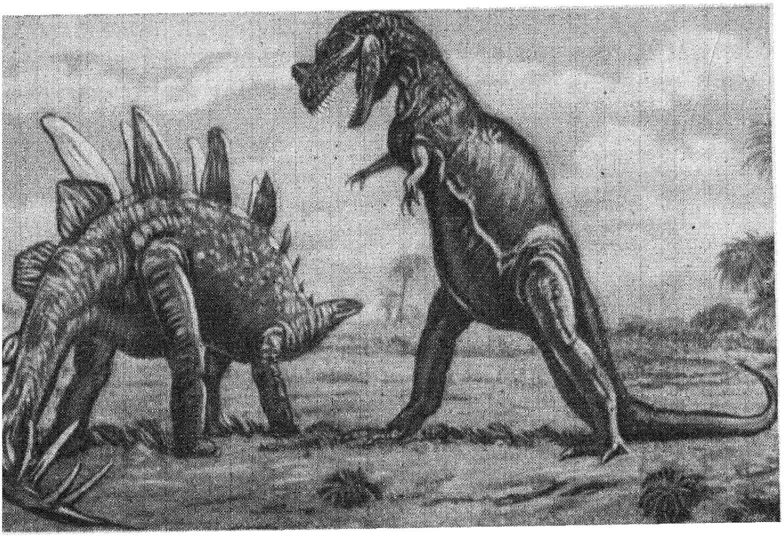

Fig. 242. Reptiles of the Cretaceous period: herbivorous stegosaur with two rows of bony plates extending along the back and predatory ceratosaur

Fig. 243. Tertiary landscape: arsinoitherium, rhinoceros-like mammal, attacked by predatory hyaenodons

and development of gigantic bivalves begin. Birds are represented by dentigerous forms.

The *Cainozoic* era, or era of recent life (*kainos*—recent) is divided into Tertiary and Quaternary periods. After a series of transformations taking place during this era the earth's surface and the distribution of continents, oceans, highlands and lowlands reached their modern state. The place of the reptiles dom-

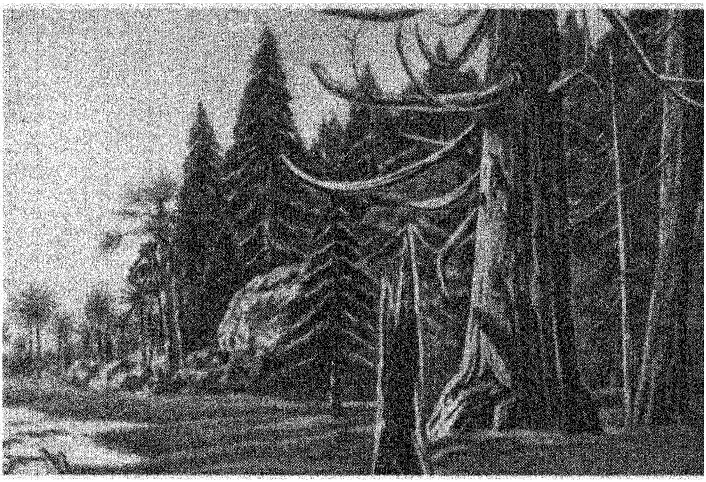

Fig. 244. Forest in the second half of the Tertiary period which gave rise to layers of brown coal. Palms and conifers

inating during the Mesozoic era was wrested by mammals and birds; man made his appearance at the end of the era and subsequently became master of the Earth. Foliage trees and cereals assumed predominant importance in the world of plants. The part of the era closer to modern times was characterized by an intense cooling of the climate and a development of several glacial epochs.

The *Tertiary* period was noted for its manifestation of several phases of the Alpine cycle of dislocations which took in the geosynclines of the Mesozoic era and the border regions of the Pacific gradually bringing the relief of the Earth and the distribution of land and sea to their present state. These strong movements served to activate vulcanism extraordinarily and to build the Pacific belt of volcanoes and earthquakes.

Rapidly multiplying mammals (Fig. 243) and birds, foliage trees (Fig. 244) and cereals dominated on land, while mammals (cetaceans and pinnipeds) began to play an important part in the seas; large rhizopods (nummulites), bivalves and gastropods formed thick strata, whereas the ammonites and belemnites dis-

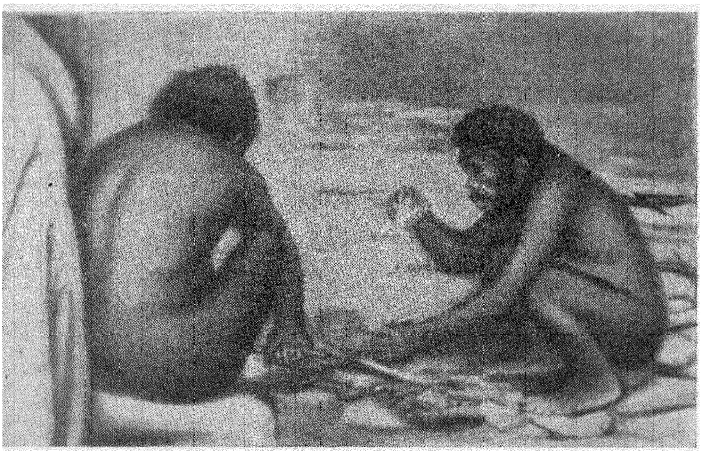

Fig. 245. Early man chipping flints to make primitive tools

appeared. Towards the end of the period the climate grew much colder and the first glacial stage known as the Günz phase is believed to belong to that time.

The *Quaternary* period which is still on and is also referred to as the anthropogen in view of the domination of man runs through the last phases of the Alpine cycle to the present state of the Earth. The alternations of cold and warm climates were responsible for three glacial phases—Mindel, Riss and Würm—separated by interglacial stages. A migration of faunas takes place in the regions affected by glaciation, the arctic forms moving southward and supplanting the warmth-loving animals which either die out or move still farther south. During the interglacial stages the ocean level rises because the melted ice increases the mass of water; transgressions (and during the glacial phases regressions) of seas occur. In the middle of the

Quaternary period man makes his appearance (Fig. 245) in different places, judging by the various remains of tools, though he developed from an ape-like animal before then. A series of slow land uplifts is marked by marine and river terraces, the last uplift—by a rejuvenation of erosion.

On the other hand, there are subsidences, and the water invades the former land in the eastern part of the Mediterranean, the southern part of the Black Sea, and the north and east of Siberia where Sakhalin is divided from the continent; sinks are created—the chains of lakes in Africa, the fault troughs of the Red and Dead seas and Lake Baikal. Compared with the Tertiary period vulcanism gradually wanes, though in the beginning of the period volcanoes still smoke and lava pours out in the Caucasus and Eastern Siberia.

Let us now make a chronological table of the Earth's history for the sake of convenience, taking note of the fact that the intervals of time correspond to certain thicknesses of sedimentary rocks the totality of which is designated by certain terms. Thus the interval of time referred to as "era" corresponds to the division of strata known as a "group"; "period" corresponds to "system", "epoch" to "series" and "age" to "formation."

Eras (Groups)	Periods (Systems)
1. Archaeozoic	
2. Proterozoic	
3. Palaeozoic	Cambrian Silurian Devonian Carboniferous Permian
4. Mesozoic	Triassic Jurassic Cretaceous
5. Cainozoic	Tertiary Quaternary

Today most geologists divide the Silurian period into two, referring to the lower as *Ordovician* and the upper as *Silurian* or *Gothlandian.*

Age of the Earth. Our chronological table gives us only an idea of the sequence of the various intervals of time established for the history of the Earth. It shows that the Cambrian period precedes the Silurian and by its age is the first in the Palaeozoic era which is brought to an end by the Permian period; it indicates that the period in which we live is the tenth of those more accurately determined by the study of fossils buried in the strata of the earth's crust and that these ten periods were preceded by two very long eras during which life had already made its appearance. But this table does not give the age expressed in years, i.e., the unit of time we use for the history of man. At the same time it would be very interesting to know the duration of each of these periods and the age of the Earth in general.

This problem has, naturally, long agitated the scientists, especially since science rejected the truthfulness of biblical chronology which estimates the age of the Earth since its creation by an "omnipotent maker." According to the Anglican Church, the Earth is now 5,962 years old, whereas according to the old Russian chronology it is 7,467 years old. The figures cited in Chapter VI are alone enough to disprove these for they show that it required about 2,000 years for the northern glacier to retreat from Southern Sweden a mere 400 kilometres; this interval. of time is only a small part of the last glacial phase which lasted, as it is believed, more than 50,000 years, while all this phase is only a small part of the Quaternary period.

It is interesting to note that the biblical chronology does not agree even with the annals and legends of other peoples. Thus, the annals of ancient Babylon read that after the creation of the world the forefathers of the Babylonians ruled the country for several hundred thousand years. Japanese legends tell us that the Japanese islands have been inhabited by man for several million years. The ancient Chinese annalists believed that 3,266,000 years divided into 10 periods had elapsed before the beginning of Patriarch Yao's rule in 2357 B.C. Other Chinese sources offer an estimate of two million years. The Chinese and Japanese figures must, of course, be regarded as exaggerated because the entire duration of the Quaternary period is now estimated, as we shall see below, at one million years, and this period encompasses all of man's history, including the ancient stone age of which no legends could have come down to our time.

Various methods have been used in attempts to estimate the age of the Earth. The time required for the formation of the Nile delta was calculated on the basis of its area, the thickness of the layers and the rate at which they are deposited by the

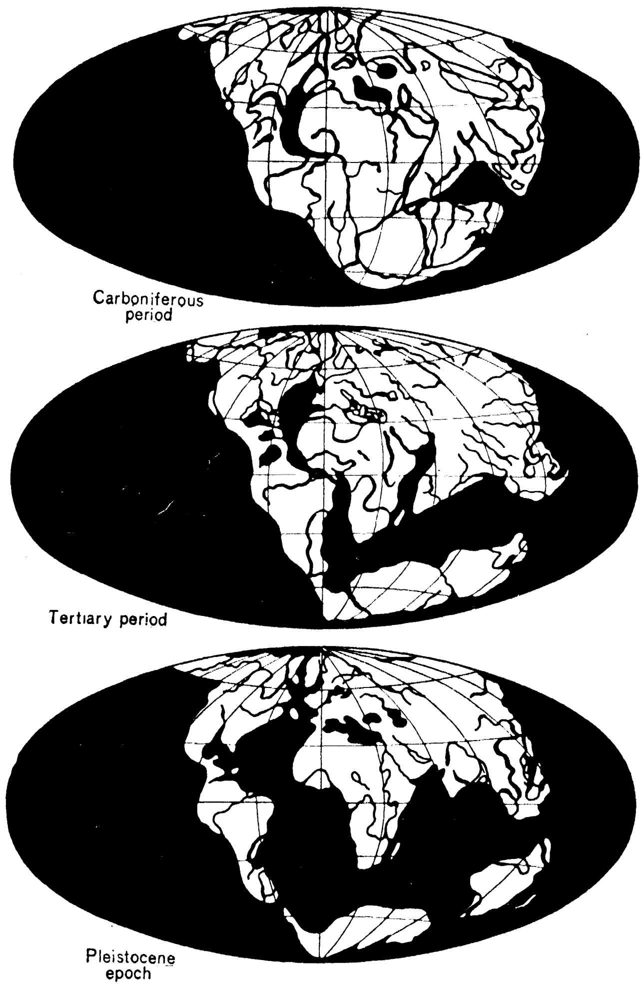

Fig. 246. Break-up of the primary land into modern continents after Wegener

river. Attempts were made to determine the number of years it had taken for the sedimentary rocks of all periods, beginning with the Palaeozoic era, to form in the seas on the basis of their total thickness and the rate of land erosion with due allowance for the area of the latter and the area of sedimentation. The geothermal gradient was used to estimate the time it took the Earth to cool to its present state. The theory of evolution was applied in an endeavour to compute the time since the origin of organic life. Astronomic data—changes in the eccentricity of the Earth, periods of the perihelion and aphelion, shifts of the Solar System within the Milky Way, eccentricity of Mercury, hypothesis of the tidal origin of the Moon—were also made use of in calculating the age of the Earth. The accumulation of salts in the oceans has made it possible to figure up the time that has elapsed since they began to be formed. But all these methods yielded greatly varying and unreliable results, the age of the Earth ranging from 20 million to 5,000 million years, because they were all based either on the assumption that the processes of erosion and sedimentation, as well as the accumulation of salts, operated with the same intensity during the former periods as they do now, or on the hypothesis of the constancy of astronomical data which is also doubtful.

Much better results were obtained with the methods based on the transformation of some elements into others discovered in the twentieth century. All the substances containing radium form two series of changing elements gradually passing into each other; one series begins with thorium, the other with uranium, both ending in lead; radium is one of the intermediate members of the uranium-lead series. In this series the closer it is to the end, the faster is the change of one element into another.

If we, therefore, take a mineral containing uranium and lead or thorium and lead and determine the amount of both we shall be able to compute the time that has elapsed since the formation of this mineral, and insofar as such minerals can be found among the sediments of various periods we shall determine by this method the age of each of them.

The second method consists in determining the amount of helium liberated during the intermediate transformations of uranium and thorium; the age of the rock is determined by the ratio between uranium or thorium, on the one hand, and helium, on the other.

The third method is based on radioactive decay of potassium which leads to the formation of argon. Since potassium occurs very widely it is possible to find out the absolute age of many rocks by determining the potassium-argon ratio. There are several more methods based on radioactive decay of other elements. The lead method is the most precise, while the helium and argon methods sometimes still result in big errors.

The age of many rocks and minerals of various geological periods has been estimated by these methods and the following figures showing the duration of eras and periods in millions of years (after the 1950 table of Marbly and Holmes) have been obtained:

Periods

Quaternary	1
Tertiary	59
Cretaceous	70
Jurassic	25
Triassic	30
Permian	25
Carboniferous	55
Devonian	55
Silurian	120
Cambrian	80
Total	520

The duration of the eras thus constitutes (in millions of years):

Cainozoic	60
Mesozoic	125
Palaeozoic	335

These figures are not very accurate because determinations sometimes yield discrepancies of several million years. In time when many determinations are made in different countries and of different epochs of the same period these discrepancies will increasingly diminish. The accuracy to within one million years that may be attained will be quite adequate because considering the enormous time with which we generally deal one million years is a small value.

On the whole this chronology shows that the duration of the eras greatly increases with their antiquity. This also corresponds to other data based on the transformations of the earth's surface, on thickness determinations of the strata referred to the corresponding time and on the development of organic life.

The durations of the Proterozoic and Archaeozoic eras have not yet been precisely determined owing to the uncertainty about the exact beginning of each of them.

It is believed that both these eras together lasted at least 1,500 million years of which 500 million or 600 million years fall to the Proterozoic era. The age of the Earth since the formation of the first continents and oceans may generally and with sufficient reason be set at 2,000 million years.

Continental Drift. A hypothesis that was recently enunciated by the German scientist Wegener (1912) and the American scientist Taylor in 1910 (elaborated in lesser detail) offers a different explanation for the formation of the modern seas. These scientists believe that the various original protrusions of the earth's crust gathered in one place in the manner small bubbles on the surface of water are attracted to each other and unite into large ones. Thus the first large continent Pangaea, the mother continent, was formed uniting all the modern continents, including Antarctica. Then, during the Carboniferous period Pangaea began to break up into parts, Australia and Antarctica drifting southward and America westward.

This fragmentation continued over scores of millions of years and the hollow of the Atlantic which has separated the two Americas from Europe and Africa was formed only during the Tertiary period and took its final shape during the Quaternary (see Fig. 246). The idea of the former union of the continents arose as a result of an examination of the map: the contours of the eastern and western coasts of the Atlantic really coincide, especially those of Africa and South America; brought close to each other across the ocean the coasts will touch nearly all along, the small gaps being easily explained by erosion. Of Russian scientists this was noticed in 1877 by Y. Bykhanov.

But the question is, why did the continents first unite and then drift apart again?

Wegener believes that the break-up of Pangaea was due to the rotation of the Earth. The Earth rotates on its axis from west to east and the western part of Pangaea gradually had to lag behind in this motion and break away from the eastern part by force of inertia, i.e., the tendency of the masses to remain in the place which opposes the force of motion eastward developed on the surface of the Earth during its rotation. Precise determinations of the position of the Atlantic coasts are now being made in order to find out whether the continents had drifted apart or not.

But you will, of course, ask how the enormous masses of the continents can move, even though very slowly, along the surface of the Earth.

You are familiar with the force of gravity conditioned by the attraction of the Earth. It is by virtue of this force that we keep on the earth's surface despite the rapid rotation of the Earth; it is because of this force that a ball or stone thrown high up in the air falls down again. It is due to the same force that the globe consists of layers of different composition; when it was in a molten state the heaviest substances—iron, lead and other metals—gathered in large masses closer to the centre of the globe while the lighter ones remained on its surface and in cooling formed the crust. Wegener, therefore, came to the conclusion that the continents composed of lighter rocks floated on a heavier internal basaltic layer like icebergs float on water. And if they float they are likely to shift, very slowly, of course, since the basaltic layer is much more viscous than water.

The upper layer composed of rocks in which silica and aluminium prevail is referred to as "sial" (by combining the first syllables of the words "silicon" and "aluminium"), while the underlying heavier layer on which the sial floats is called "sima" because in addition to silica it contains a lot of magnesium.

Wegener's hypothesis explains the formation of the high mountain ranges of the Cordilleras and Andes bordering the coast of the two Americas by the fact that during the shift of this continent westward the sedimentary strata near the west coast were strongly crumpled by the resistance offered by the layer "sima" to the pressure produced by the layer "sial" in the westerly direction.

At first winning over many scientists Wegener's hypothesis now arouses serious objections because the distribution of the various mountain ranges on the earth's surface does not agree with it and even contradicts it. Europe and Africa which must also press westward in connection with the eastward rotation of the Earth have no mountain ranges along the western shores, whereas in Asia the mountain ranges are located along the eastern coast which, according to this hypothesis, is not subject to pressure by the layer "sima."

Today geologists regard the hypothesis of continental drift as unable to explain the changes on the face of the Earth.

XI

CATASTROPHES IN THE HISTORY OF THE EARTH

What a Catastrophe Is. Floods. Sills. Landslides, Earth Creeps and Sinks. Hurricanes—Simooms, Typhoons. Avalanches. Volcanic Eruptions—Vesuvius, Mont Pelée, Bandaisan, Krakatao, Santa-Maria. Earthquakes—Lisbon, Messina, Crimea, Alma-Ata, Caucasus, America, New Zealand, Japan. Catastrophes of the Past. Sodom and Gomorrah. Atlantis. Transgressions and Regressions. Glaciations. Extinction of Faunas and Floras. Cemeteries. The Deluge.

A sudden event lasting a relatively short time and involving a loss of human life and property is said to be a catastrophe. A railway, plane or automobile accident, a collapse of a house and fires are all short-lived catastrophes. The catastrophes conditioned by natural forces are frequently also sudden and of short duration, or they may last hours, days and even weeks. The former include landslides, avalanches and earthquakes, the latter—floods, earth creeps and volcanic eruptions. These latter catastrophes can be foreseen and safety measures can be taken; they are not sudden or fortuitous, though they are also called catastrophes. Epidemics, famine and wars may thus also be referred to as catastrophes, i.e., events which unsettle the normal course of life.

In geology the sudden destructive phenomena were formerly called cataclysms. In the infancy of this science they were ascribed a universal nature and, using the Deluge as incontestable proof, scientists explained geological periods by them. In the eighteenth century the prominent French geologist Buffon maintained in his famous ten-volume work *Epochs of Nature* that at the end of each of the epochs established by him immense cataclysms in the form of eruptions, earthquakes and floods entirely transformed the face of the Earth and destroyed all life which was re-created in the beginning of the following epoch by a new act of creation in a more perfect form. This theory of periodic catastrophes won wide recognition and dominated until the thirties of the nineteenth century when Lyell showed that the history of the Earth was a continuous transformation of its face by the same natural forces that we observe today, while catastrophes were a fortuitous phenomenon. Later Darwin demonstrated that the organic world was also governed by the same law of continuous and slow development and transformation, rather than of periodic destruction and rebirth.

Though Buffon's theory has now been rejected, since it was proved that catastrophes did not play a dominating part in transforming life and the face of the Earth, they must be regarded as quite important just the same. This holds especially true of catastrophes of a longer duration since they are responsible for great destruction and renewal. We therefore devote a whole chapter to these events in the history of the Earth.

* * *

Are we not justified in regarding the first centuries of the Earth's history, described in the preceding chapter, as catastrophic despite their enormous duration? The earth's crust had hardly formed when it broke up here and there and streams of lava poured out onto the surface or were hurled out as fiery fountains during the sudden liberation of gases. Powerful electrical discharges in the form of lightning smote the cliffs in the terribly dense atmosphere saturated with vapours and gases. Later, when the seas began to be formed, the crustal tremors and ruptures continued, the volcanic eruptions were perhaps even more intense, and frightful rain-storms accompanied by thunder and lightning beat down upon the land and sea. These daily and protracted catastrophes only gradually changed into transitory and casual, making possible the origin and development of life which would have been immediately destroyed during the first epochs.

Let us now return to modern times and consider their various catastrophes.

Floods. Let us start with the activity of running water. This agent works continuously and uniformly, but from time to time streams and rivers overflow their banks and flood the surrounding country causing damage. Every spring high water may turn into a flood if the snow-rich winter and the vigorous thaw in the spring produce more water than the rivers can hold. In warm-winter countries floods frequently occur in autumn or winter because of the abundant and, mainly, incessant rainfall responsible for an excessive rise in water. Southern France, Spain and Italy often suffer from these floods. In other countries the floods happen in summer-time when there is a lot of rain. These include the Transbaikal areas, especially Amur Region and Primorye, the spring high water being relatively safe because there is but little snow there in winter.

It is not rain, but wind that is responsible for the floods from which Leningrad suffers mainly in autumn: the winds blowing from the west, from the Gulf of Finland, drive water into the mouth of the Neva, impede drainage, raise the level of the Neva, force it out of its banks and make it flood the streets of the city located in the flat delta. The water not infrequently rises in autumn, but catastrophic floods happen only once in a hundred years, the last two occurring in 1824 and 1924. Similar floods conditioned by sea-storms are characteristic of the lowlands in the mouths of the Indus, Ganges, Huang Ho and Yangtze rivers whose drainage is obstructed by the sea waves. Low-lying river banks even away from estuaries may also be flooded when very strong winds blow from the sea; this was observed in Germany, Holland and England during very big storms in the Baltic and North seas.

A river that overflows its banks erodes roads, spoils pavements (especially those made of wood blocks because the latter come to the surface and are carried away), covers the fields and meadows with sand and silt, undermines stone houses and easily washes away frame buildings severed from their foundations. In houses remaining intact it inundates the basements and lower floors which stay damp long after the flood has subsided. Firewood and lumber yards on the banks may be completely carried away. The foodstuffs and other goods stored in flooded buildings spoil, and machines rust.

The following are two examples of floods.

Because of the silting of its bed with deposits of loess which it erodes in the mountainous parts of China the Huang Ho River in its lower reaches on the Great Chinese Plain flows in some places between artificial earth dikes above the level of the plain. Every spring these dikes are eroded here and there and the river floods more or less large areas, their villages, fields and orchards. The population has always struggled against these breaches in the dams and called the river "China's misfortune." Only since the liberation of China has the Government of the Chinese People's Republic undertaken extensive hydrotechnical construction which now prevents the possibility of dam breaches, the surplus of the Huang Ho waters being diverted into irrigation systems and navigable canals.

During the second half of January 1937 long-continued downpours alternating with snowfalls caused an unprecedented flood in the United States of America. All of the Mississippi tributaries, especially the Ohio, the Arkansas and the Red River began to rise and by January 25 constituted a flood menace. More than a million people had already been affected in the Ohio Valley by that time, while on January 27 it was necessary to evacuate the population of the entire Mississippi Valley from the Ohio down to the mouth of the Mississippi, the zone being 80 kilometres wide along both banks, because this part of the valley was in danger of being inundated. The Ohio River alone poured out 135,000 centilitres per minute and it was clear that the dams along the Mississippi constructed for protection against floods providing for a water discharge of about 108,000 centilitres would not withstand the pressure. For the evacuation of the population 35,000 motor vehicles were delivered the very first day, but many were unable to leave the threatened zone. Downstream the water flooded ever new towns and in most cases the houses, especially those made of concrete, collapsed within a few hours; the people who sought safety on the upper floors when the flood began went down together with the houses. The current developed the enormous velocity of 56 kilometres an hour and the river washed away all the structures. Three-fourths of all the houses were destroyed in some towns in the course of one day, and most of the people were left shelterless; the destruction of the petrol tanks in the high part of Louisville spared by the flood caused fires. Instead of helping the victims gangs of robbers who arrived in motor boats indulged in plunder. The continuing rains and cold aggravated the calamity. The damages were estimated at between 2,000 million and 3,000 million dollars.

In countries with a dry climate accidental downpours producing furious torrents, known as *sills*, also cause catastrophes. For example, on July 8, 1921, a rain-storm broke out in the city of Alma-Ata in the afternoon and lasted for four hours. In the evening the Malaya Almaatinka River overflowed its banks and rushed into the city in waves reaching from 1 to 2 metres in height and carrying large firs uprooted in the Tien-Shan Mountains, and logs and boards from the country-houses destroyed by the river in the mountain valley. The main stream went down the central street carrying away small frame buildings with all their inhabitants, the water also flooding the side streets and yards and playing havoc everywhere. Many adobe houses were damaged and large frame buildings were dislodged. The torrent brought along a lot of gravel, pebbles and boulders, the latter weighing several tons each, and deposited all this in a layer up to 1.5 metres thick. A rut 2 metres deep was cut by the water in the upper part of the main street and the boulders weighing up to 25 tons each got stuck in the rut. Many people were caught by the torrent and drowned, the dead estimated at 500. By midnight the torrent stopped. According to a rough estimate it had brought 3.6 million tons of solid material to the city and since it had worked for a period of five hours it had deposited 200 tons a second. Destructive mountain torrents—sills—were observed the same day for a distance of 25 kilometres west and 60 kilometres east of Alma-Ata. The main mass of precipitations fell in the mountains, whereas in Alma-Ata there was only 27 mm of rain that day.

A catastrophic downpour occurred in the Khamar-Daban Mountains on the southern shore of Lake Baikal near Slyudyanka railway station on June 29, 1934. Previous to that it had rained in the mountains incessantly for three days and saturated the soil with water; the last day torrents ran down the smallest valleys which had always been waterless before then; down the slopes the water flowed in a continuous sheet. On the night of June 28 the Slyudyanka River overflowed its banks, rushed towards the station in an enormous stream, flooded the station settlement, carried away eight houses, smashed the concrete dam of the reservoir into fragments transporting some of them into Lake Baikal. All the vegetable gardens were ruined, their area transformed into a field covered with large boulders up to 1.5 metres in diameter each, while all the tracks of the station were covered with a layer of sand and silt about one metre thick. Several trains were stuck up to the top of their wheels in sediments. The sand and silt deposited on the roadway was estimated at 153,000 cubic metres. In some places the river

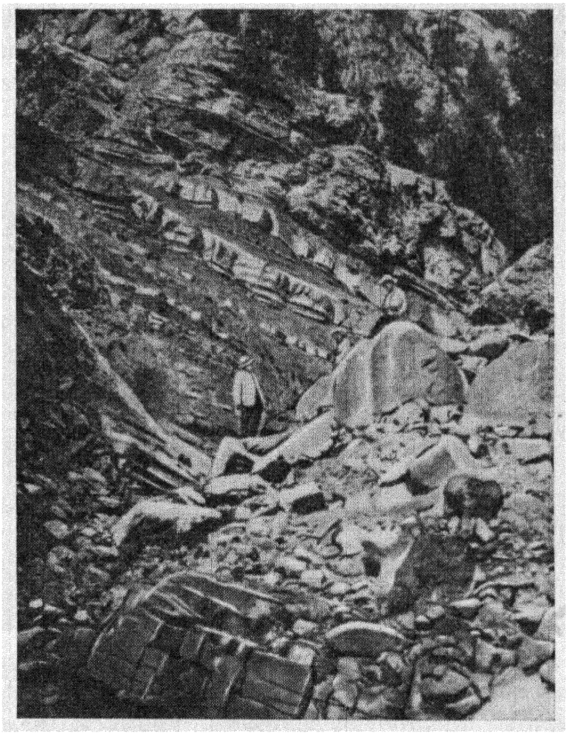

Fig. 247. Mouth of Beshenaya Balka on the left side of the Kura River valley in Borzhomi after torrent in the beginning of August 1912

had cut a new bed six metres deep for itself and carried numerous trees into Lake Baikal. In the mountains the loose soil crept down the slopes and avalanched en masse. In the Slyudyanka Valley, several kilometres above the settlement, near the quarry, there had been from time immemorial a large boulder the size of a man; after the sill it disappeared. Only 50 mm. of rain fell in the settlement during those three days, whereas in the mountains there must have been at least between 500 and 600 mm.

In August 1912 I witnessed a redoubtable sill in Borzhomi, Transcaucasia. After a short and heavy downpour the Beshenaya Balka on the left side of the Kura River valley discharged into this valley an enormous mass of rock, sand and silt that covered the highway with a layer two metres thick which required a few days to clear away. This gorge was named Beshenaya (Furious)

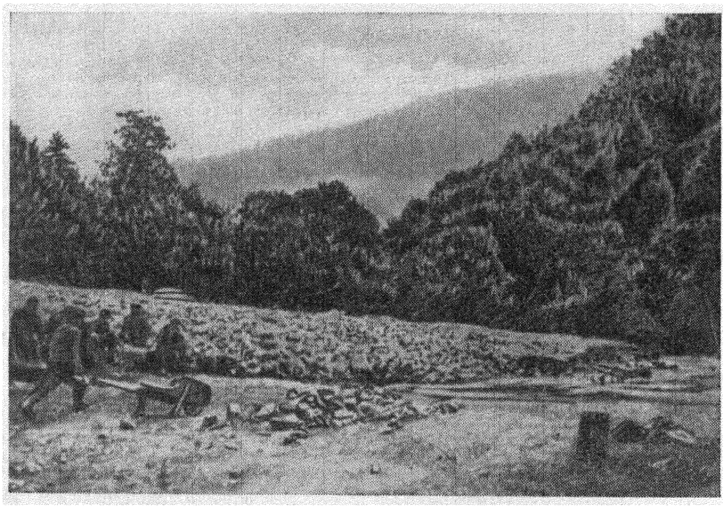

Fig. 248. Deposits made by the torrent of Beshenaya Balka buried the highway on the left bank of the Kura River in Borzhomi, August 1912

precisely because it gives rise to such torrents after every rainstorm. The gorge is short but ramified and its steep sides are almost bare; the water rapidly washes a mass of material off the sides and turns into a furious torrent laden with stones and mud on the floor of the gorge (Figs. 247 and 248).

Landslides are not infrequently catastrophes caused by processes of weathering and undermining, earthquakes and man's careless work.

Breaking loose from steep slopes masses of rock cover up roads, ruin forests and orchards, demolish buildings and kill people. Thus a rock of more than three metres in diameter broke loose from the Koshka Cliff on the South Coast of the Crimea in the winter of 1923 and in falling demolished half of the house at the foothill. We shall now describe several large landslides which caused heavy damages.

In 1881 the slope of a hill near the village of Elm in Switzerland collapsed as a result of careless work in the quarry. A mass of 10 million cubic metres of rock broke off from a slope 70° steep and plunged down with such force that many fragments went up 100 metres into the air on the opposite side of the valley, while others were scattered in every direction to a distance of 1,500 metres. The landslide buried an area of 89 hectares, destroyed 83 buildings and killed 115 people, all in less than two minutes (Fig. 249).

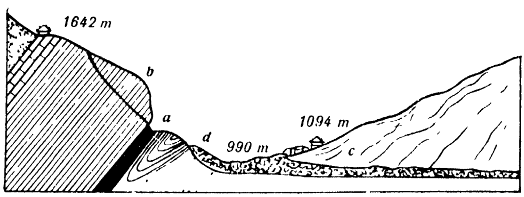

Fig. 249. Landslide near the village of Elm in Switzerland

a—quarry; *b*—severed mass of slates; *c*—area covered by fragments; *d*—site of buried village

In 1911, as a result of an earthquake, a mass of 2,200 million cubic metres of rock broke loose from a steep side of the valley of the Bartang River near the village of Serez in the Pamirs, buried the entire valley, including the village, dammed up the river and created a big lake. This excited apprehensions lest the drainage of the lake erodes the loose thickness of the landslide and the enormous mass of water breaks through and causes a devastating flood lower down the rather densely populated and fertile valley. But the mass of the landslide constituting about 6,000 million tons has proved so strong and its erosion so slow that the lake is still in existence today (Fig. 250).

During the earthquake of 1887 in the town of Verny (Alma-Ata) a landslide occurred in the Ak-Jar Valley of the Transili Alatau Mountain Range from a height of 300 metres and an area of 2.8 million square metres. Immense blocks of granite, diorite and slates weighing up to 500 tons each filled the entire valley and formed a rock screes reducing the flourishing forested valley to a total desert. The screes was two kilometres long, 200 metres wide and 100 metres thick; it had a volume of at least 40 million cubic metres. During this earthquake, as also during the next one in 1911, there were many landslides in the mountains which buried the yurtas of the Kazakhs. The total mass of landslides in this area in 1887 was estimated at 440 million cubic metres; these landslides had done enormous mechanical work.

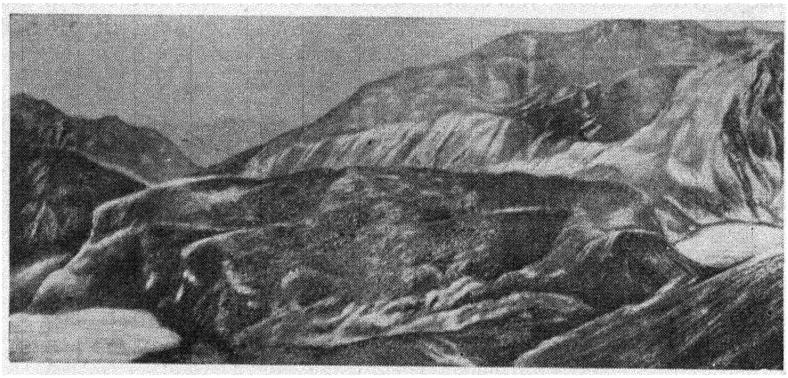

Fig. 250. Usoi landslide in the Pamirs: mass of the landslide in the foreground; right and left: lakes Shadau-Kul and Serez formed above the landslide

A collapse of a mountain in the Dalsk Gorge of the Kodor River (near Sukhumi, the Caucasus) in 1898 built a dike 150 metres high with a large lake above, which existed several weeks. In the eighteenth century a tremendous fall of limestones from the Yaila Ridge near the village of Kuchuk-Koi on the South Coast of the Crimea buried many houses and orchards and pushed some houses into the sea. The description of large landslides in the recent centuries alone could fill a whole book.

Earth creeps must also be regarded as geological catastrophes though they occur much slower than landslides and represent displacements of more or less large masses creeping down a slope over a period of minutes, hours and even days. They are produced by the activity of ground waters, but are frequently caused by earthquakes, or result from the lower part of the slope being undermined by running water and the surf, or by the slope being cut off during excavations and loaded with buildings.

The description of catastrophic earth creeps would also fill many pages, but we can offer only a few examples here.

The earth creep on the sea-shore near Lime Ridges in England is very typical. The shore is built of white chalk, sandstones with flints and loose sand of the Cretaceous system resting on a bed of watertight Jurassic clay. The layers dip towards the sea and the ground water runs down the clay forming numerous springs and creating conditions for the creep of the overlying strata. After the rainy weather of 1839 which saturated these strata with water and thus increased their weight the entire shore started moving on December 24, broke up into enormous blocks divided by crevices and ravines, and crept towards the sea. The pressure of the masses of rock raised from the sea floor a ridge one kilometre long and 12 metres high consisting of severed blocks covered with algae, shells, starfishes, etc., and now forming several cliffs.

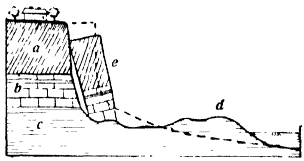

Fig. 251. Section of earth creeps near Odessa

a—clay; *b*—limestone; *c*—blue clay; *d*—raised sea floor; *e*—slipped mass. Dotted line shows the profile of the shore before the earth creep

Near Odessa the sea-shore consists of Tertiary clays resting on a bed of limestone with blue clay underlying the latter; the ground waters run down the blue clay to the sea and cause periodical earth creeps (Fig. 251). Large blocks break away from the shore, creep and turn over; the entire coast is disrupted by crevices and ravines with sand banks rising from the sea bed. These earth creeps systematically reduce the area of Odessa's countryside, ruining the orchards and destroying the buildings. The earth creeps have increased since limestone began to be quarried here for the city's structures and the vast quarries exposed the lower clay to the atmospheric precipitations.

The South Coast of the Crimea suffers from earth creeps almost along its entire extent. Here on the surface of strongly folded slates and sandstones of the Triassic and Lower Jurassic periods lies a thick layer of coarse deluvium built by the destruction and collapses of the thick overlying limestones of the Upper Jurassic period forming the slopes of the Yaila. Atmospheric precipitations and springs of the Yaila penetrate into this diluvium and the latter creeps down the steep slate slopes together with the buildings and orchards, fracturing and demolishing buildings. The Black Sea Coast from Tuapse to Sukhumi is also unstable; the undermining of the coast by the surf and its cutting off by railway and highway construction are frequently the main causes of the earth creeps.

The right bank of the Volga frequently creeps in different places—Ulyanovsk, Volsk, Saratov, Syzran, Batraki, etc.—because it consists of watertight and water-bearing layers and is inclined towards the river. The natural conditions fostering creeps are aggravated by the carelessness of man who cuts off the lower part of the slope to build streets and roadways to the piers and loads the overlying slope with buildings which in time are infallibly destroyed. The absence of sewerage in the towns formerly increased the amount of water penetrating to the water-bearing layers.

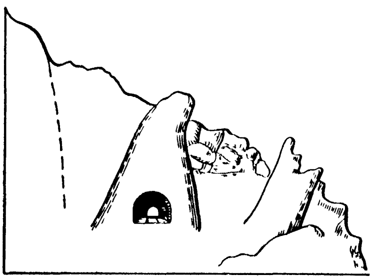

Fig. 252. Cape "Second Pillars" on Lake Baikal with the fault crevices on both sides of the tunnel

The western shore of Lake Baikal from the source of the Angara River to station Kultuk is the result of a large fault which created the deep depression of the lake. This was not taken into consideration when the railway was built; numerous tunnels and cuttings cross the extremities of the promontories between the valleys too close to the steep shore slopes where the hard rocks are disrupted by fissures which run parallel to the main fault and are therefore unstable. As a result of the continuing small movements near the fault, the walls of the cuttings cave in, the tracks bend and blocks fall out of the tunnel vaults (Fig. 252).

In Chapter III we described soil *sinks* caused by the dissolving action of ground waters in gypsum and limestones and by the formation of cavities whose vaults collapse. They are catastrophic when whole buildings cave in. Man provokes these sinks by pumping the water out of artesian wells (if the pumping produces cavities) and by removing the water with the sand from a floating layer or a lenticular deposit.

This is the explanation given to the collapse of St. Mark's belfry in Venice and the destruction of 14 houses around the square in the town of Pila (Poland) where there was a borehole from which water issued together with sand.

Hurricanes not infrequently create great catastrophes. The sand-storms in Africa are typical of the Sahara Desert where they are called *hamsins*; similar winds in Arabia are referred to as *simooms*. As long as an hour before the beginning of a simoom one can see heavy yellow clouds in the south, the air becomes stuffy, the people grow anxious and even camels become restless. Some people are stunned by sand-storms and there are cases of death apparently due to heat stroke. Toxic properties were therefore ascribed to simooms. From the friction which occurs during simooms the sand grains are electrified and woollen clothes may give off sparks. Simooms are most dangerous in areas of shifting sands where the barkhans turn into a moving sand sea. If a simoom overtakes a caravan the camels are made to lie down with their backs to the wind, while the people, using them as shelter, lie down beside them and cover themselves with blankets; the ears and noses have to be stopped up with cotton and the breath withheld to prevent the lungs from filling with sandy dust. When the simoom is over, the camels have to be dug out of the sand. A simoom usually lasts only a few hours, but when it lasts much longer the caravan is inevitably lost.

The invasion of fields, orchards, villages and towns by dune and barkhan sands may also be regarded as catastrophes though these invasions develop slowly, taking months and even years. There have been cases of oases buried by sand in a short time, but these are very rare.

Much more redoubtable are the hurricanes that sometimes rage along the eastern coasts of Asia and North America. In Asia they are called typhoons (in Chinese *tai* means big and *phyn*—wind); they originate under the Tropic of Cancer and sweep northward along the coast of China and along the Philippines and Japan. In America they rise in the Caribbean Sea and take in the south and east coasts of the U.S.A. These hurricanes come on with a terrific force, uproot trees, fell telegraph

Fig. 253. Earth creeps of Tertiary and Quaternary deposits on the Tom River above the city of Tomsk

Fig. 254. Defence wall on Uzedom Island (Baltic) destroyed during hurricane in December 1913-January 1914

poles, blow off roofs and tear down light buildings; they are accompanied by torrential rains; along the coasts the surf floods the land. Typhoons always cause material damage and take a toll of human and animal life lost in the ruins and by drowning.

Hurricanes sometimes also happen in other places, but they rarely develop the force of typhoons. Mention should be made of the spring dust-storms in the Ukraine which carry away layers of earth from sown fields and expose the seeds or even

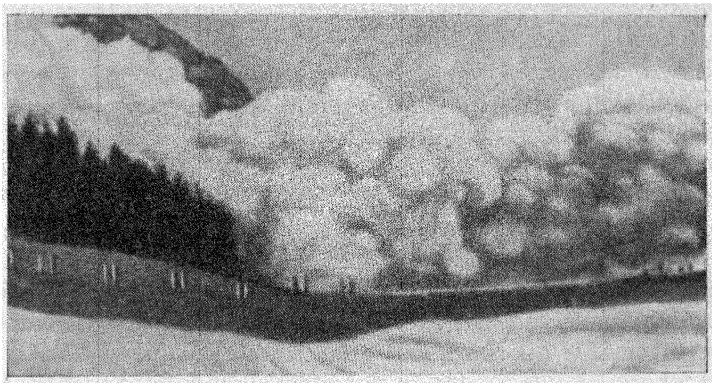

Fig. 255. Powdered dry avalanche in the Swiss Alps

the roots of the winter crops; of the dry winds east of the Volga which blow from the deserts of Central Asia and destroy the vegetation; and of the Novorossiisk bora, the hurricane that covers the houses, streets and ships in the harbour with a crust of ice and causes extensive damage.

In the highlands *avalanches* are annual catastrophes. Large masses of snow may accumulate on the steep lee slopes of mountains, then break off, roll down as avalanches or snow slides and cause damage.

Three types of avalanches are distinguished: dry, wet and glacial.

Dry avalanches occur in winter when snowdrifts on the ridges and steep slopes grow so large after heavy snowfalls without thawing that any vibration of the air, a shot or even a loud call cause them to break off. This is facilitated if the fresh snow falls on the smooth surface of the old snow frozen after a thaw. These avalanches come down, simultaneously filling the air with snow-dust which forms a veritable cloud (Fig. 255).

Wet avalanches occur in winter, after heavy snowfalls, during intensive thawing and also during spring thawing; they consist of more or less sticky, water-logged snow. The masses of snow in the snowdrifts grow heavy during thawing, while the underlying surface becomes slippery from being moistened by the melt water; the snow finally breaks away and slides down taking along the snow lying on its way on the lower slope; individual blocks roll down with snow adhering to them on their way. These avalanches have a very uneven surface and produce no snow cloud as they come down (Fig. 256).

Glacial avalanches are the terminal parts of hanging glaciers sometimes breaking away from the main mass and rolling down to the foot of the slope as a chaos of fragments. As the name indicates these avalanches consist of ice.

In the highlands avalanches cause great damage: they destroy forests that lie across their tracks, block up river valleys, railways and other roads thus interrupting communication, bury houses and outbuildings together with the people and cattle in them, often tear off roofs and break in walls and windows. The snow where the avalanche has stopped is not infrequently from 10 to 20 metres deep so that trenches must be dug to clear the houses, clean the roads and save the people and animals. The following statistics offers an idea of the damages caused by avalanches in a single Swiss area in the beginning of February 1689 when there was an exceptionally heavy snowfall:

Human lives lost	120
People saved	180
Houses destroyed	119
Barns and haylofts destroyed	629
Cattle killed	326
Goats and sheep killed	584
Trees broken	1,830

This was an unprecedented catastrophe; lesser ones occur quite often and small ones take place annually in the Swiss, French and Italian Alps.

In the U.S.S.R. many areas suffer from avalanches in the Caucasus. Annual avalanches on the Georgian Military Highway sometimes disrupt communication for days on end. In the Altai, Tien-Shan and the Pamirs avalanches are also not infrequent.

But because of the relatively sparse population in these mountains they do not cause much damage. On Kola Peninsula, in the Khibiny massif, avalanches have begun to harm the buildings and people of the apatite mines and of the city of Kirovsk;

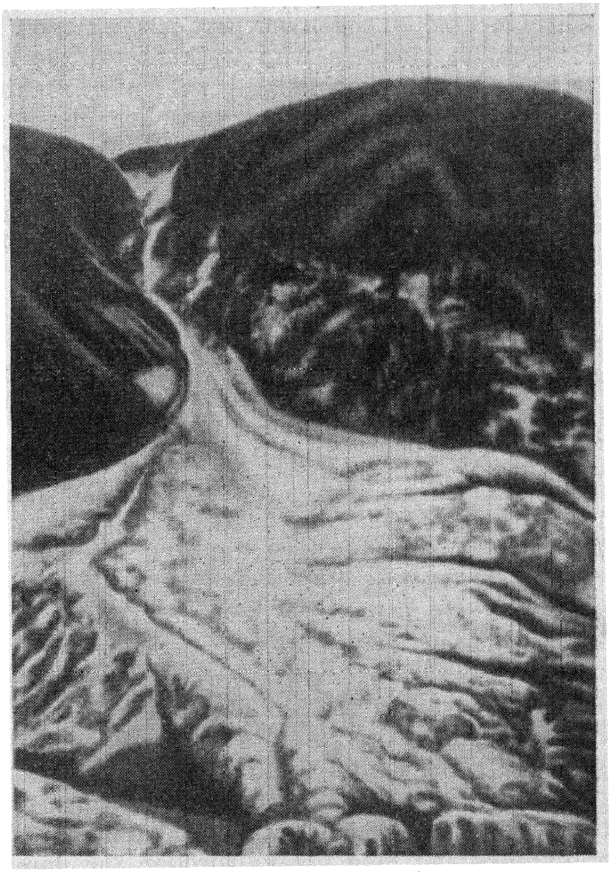

Fig. 256. Wet avalanche in the Swiss Alps

several buildings and their occupants were buried in February 1938. Avalanche protection structures have been built on the slopes of the Khibiny.

In the mountains snowdrifts accumulate annually in certain places which favour their formation and then give rise to considerable avalanches depending on the amount of snow, the number of days of continuous snowfall and sudden thawing. The paths travelled by these avalanches are known and the people put up no buildings on them. The main damage is caused by avalanches occurring under extraordinary circumstances in unusual places; they destroy entire forest zones and bury buildings located on the lower part of the slopes. Even experienced mountain climbers who walk the slopes along the snowdrifts or below them sometimes meet with accidents.

The protection against these catastrophes consists in the following. The steep slopes on which snowdrifts are formed are broken up into steps, or a series of stone walls is built along the slopes (Fig. 257); both keep the snow from breaking off. Below the forest line the same part is played by trees planted on the steep slope. Roads are protected by wooden tunnels. Thus, the parts of the Georgian Military Highway, where avalanches occur every year, run through tunnels for hundreds of metres. Glacial avalanches are comparatively rare and occur periodically when the ice breaks off from glaciers that terminate on the slopes. During its periodical advance the Devdorak Glacier on Kazbek, in the Caucasus, sometimes blocks up the valley of the Terek River and the Georgian Military Highway. The last large obstruction in 1832 involved 12.8 million cubic metres of ice and stones that came down the gorge of the Amalishka River into the valley of the Terek with a speed of 2.5 kilometres a minute. As the glacier advances it builds an ice wall across the narrow part of the gorge of the Amalishka and dams up the water; the latter accumulates and then breaks through the dam carrying a mass of ice and stones down the gorge.

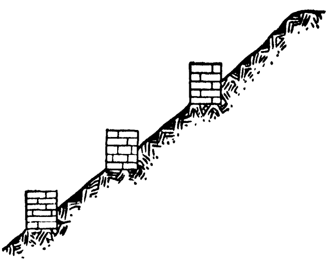

Fig. 257. Avalanche defences

A similar catastrophe was wrought by the Saniban Glacier in 1902 when it dammed up by an avalanche the Genal-don River and buried about 100 people who were taking treatments at the Karmadon Hot Springs; the avalanche was caused by an earthquake.

Catastrophes resulting from the damming up of water by the front of an advancing glacier or by its accumulation in glacial caves occurred several times in the Swiss and the Savoian Alps.

Volcanic eruptions are not infrequently accompanied by considerable catastrophes the description of which would fill a book. Of the older ones we are familiar with the destruction of Herculaneum and Pompeii in 79 A.D. at the foot of Vesuvius which was considered an extinct volcano. Its crater was even overgrown with a forest in which Spartacus, leader of the slaves who revolted, found asylum; its fertile slopes were covered with vegetation, and numerous prosperous villages were located at its foot. Judging by the description of Pliny the Younger, who was an eyewitness, the eruption started suddenly without preliminary signs; Pliny the Elder, naturalist and uncle of the former, was killed in the catastrophe. Pliny's description is the oldest vulcanological document.

Vesuvius began its activity with a terrific explosion which destroyed the plug in the vent and hurled it out in a shower of rocks; then it threw out an enormous mass of white pumice which buried Pompeii; this was followed by darker pumice, then still darker slags and during the main phase by tremendous masses of ash which obscured the sun in the surrounding country. Strong earthquakes that accompanied the eruption devastated the country; rains fell on the slopes of the volcano and mixing with the ash formed a muddy mass which streamed down and flooded Herculaneum. Lava in the form of the Castello di Cisterna sheet probably broke out at the end and poured into the uninhabited marshes at the foot of the northern slope. Such was the catastrophe that befell the two cities and annihilated 25,000 people who were buried in the ash or drowned in the mud, as revealed by the excavations which have unearthed buildings, streets, all the household goods and remains of the people overtaken by death in various postures in the streets and at home.

A similar catastrophe occurred before our eyes in 1902 on the Island of Martinique, one of the Lesser Antilles, when the volcano of Mont Pelée awakened. It was also believed extinct and the population had no legends relating to its activity. Its slopes were covered with a forest, there was a small lake amid a forest in its crater inhabited by birds and animals.

The volcano began to show signs of life at the end of April by light tremors of the ground and by liberating from its crater smoke and vapours with ashes, and from its fissures sulphurous gases, which poisoned many birds. The animals started an exodus from the forest, but the people who lived on the numerous farms on the slopes and in the town of St. Pierre were

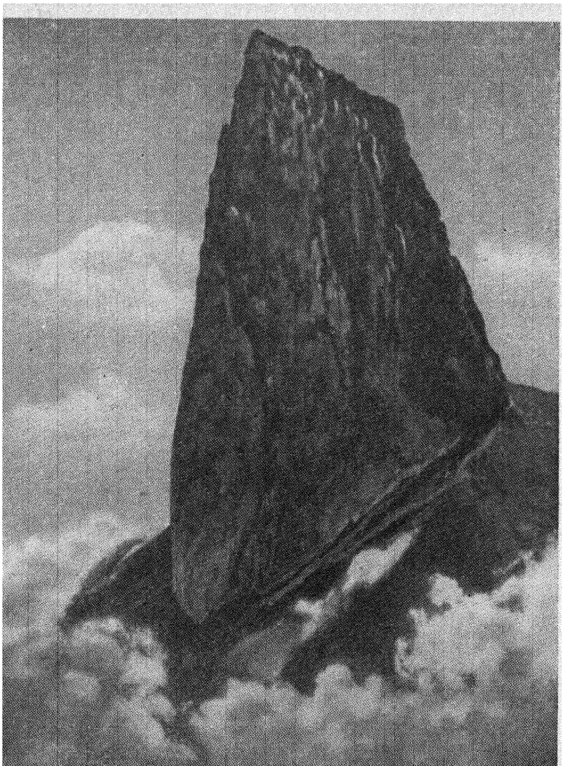

Fig. 258. Spine on Mont Pelée (Martinique) ejected from crater in an incandescent state during the 1902 eruption

afraid to leave their property to the mercy of fate and remained. On May 5 a mud stream destroyed the factory on the slope; it seems the lake in the crater was ejected by the explosion. On May 7 dense ash and incandescent bombs fell again and heavy rain-storms produced mud streams. Finally, an immense cloud broke out of the crater with an explosion on May 8 and rushed with the speed of an express train down the slope at the same time growing upward and sideways and changing to a gigantic pillar of dense curling and whirling blackish-lilac clouds incessantly cleaved by lightning.

The pillar grew to a height of several kilometres and destroyed everything on its way to the sea-shore. Several minutes after the explosion the town of St. Pierre located eight kilometres in a straight line from the crater was reduced to ruins and its 26,000 population was annihilated. The nuée ardente burned tree leaves and branches, grass and shrubbery, blew off the roofs, demolished walls of buildings, and choked and burned people with incandescent gases mixed with ashes. Even outside the path travelled by the cloud, but near by, people choked and the vegetation dried up.

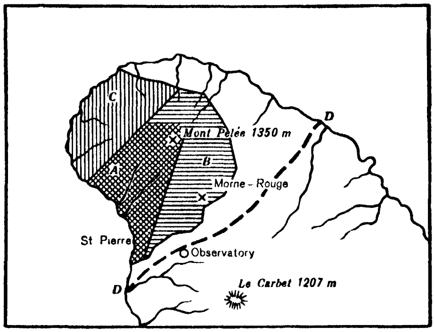

Fig. 259. Map of the northern part of Martinique

A—area devastated by the nuée ardente on May 8, 1902; *B*—increase in this area during the eruption of August 30; *C*—area abundantly covered with ash; *D*—boundaries of the ash-covered area

Fires broke out and there were casualties on the ships in the St. Pierre roadstead. During the explosion very viscous lava rose in the form of a heavy incandescent column from the crater and formed the "spine" of Mont Pelée about 140 metres high which was gradually destroyed by breaking up into blocks (Fig. 258). It was a long time before the volcano grew quiescent; it kept emitting similar nuées ardentes, but they chose another path to the sea along the valleys of the Blanche and Seche rivers. Investigations have shown that masses of ash, small and large bombs, and blocks the size of a two-storied house brought by the nuée ardente were deposited on this path. This terrible catastrophe enabled the scientists to study a new and formerly unknown type of eruption, since then given the name of Peléan. The map of the northern part of Martinique shows the areas devastated by the nuées ardentes and the intense ashfall (Fig. 259).

The eruption of the Bandaisan Volcano in Japan on July 15, 1888, was of a different nature. A rumble was heard at seven o'clock in the morning; this was followed by shocks half an hour later, and soon a column of vapours and dust rose almost 1,300 metres in the air. Then came from 15 to 20 explosions which threw out masses of hard rocks in an almost horizontal direction. The column rose to a height of nearly 6,000 metres, the hot ashes plunged the area in total darkness; one of the explosions blew out a horseshoe-shaped crater in the volcano two kilometres in diameter and all of the material of the explosion was ejected horizontally in the form of a hot avalanche; it was preceded by a hurricane with a velocity of 40 metres a second, which felled trees. An area of 71 square kilometres was covered with debris and 400 human lives were lost. The entire eruption lasted only two hours, but the darkness continued for eight hours. This volcano had been inactive for 1,000 years; its awakening almost destroyed the old cone which was 670 metres high.

The eruption of Krakatao, a volcano in the Sunda Isles, on August 26 and 27, 1883, was an unusual catastrophe; it was accompanied by such explosions and shocks resembling artillery firing that they were heard in India, Australia, the New Guinea and the Philippines, i.e., 3,600 to 4,800 kilometres away. The air blasts caused by the explosions shook up buildings for a distance of 850 kilometres. Half the volcano which was an island between Sumatra and Java partly disappeared under the waves and partly was transformed into debris and ash. The latter created such darkness that a ship overtaken in the Java Sea had to stop; a rain of ash, thin mud and pieces of pumice fell on the deck; the people choked with sulphurous gas; pieces as large as a human head fell 20 kilometres away from the volcano and those the size of a fist were carried for 40 kilometres; they were discharged with the speed of cannon balls. The sea waves produced by the collapse of the volcano constituted the chief menace; near the shores of Java and Sumatra they reached a height of 20 to 35 metres, flooded the coast, swept off villages and took a toll of 35,000 lives. These waves travelled as far as India, South Africa and the coast of North America between Panama and Alaska. The layer of ash around Krakatao was up to 16 metres thick and on Sumatra up to one metre. Fine ash obscured the sun in Japan and other places more than 3,000 kilometres away. This ash floated in the atmosphere for a long time and lent a bluish shade to the light of the sun and moon in Africa, America and the Pacific islands; it was also responsible for the remarkable red sunsets observed all over the world at the end of 1883 and in the beginning of 1884.

We shall also briefly mention the eruption of the Santa-Maria Volcano in Guatemala (Central America) that occurred on October 24, 1902, after a period of total quiescence. It began with an earthquake after which a cloud of rocks and ash was thrown up to a height of 10,000 metres; the ejection of ash and pumice continued for 18 hours; debris fell at a distance of 14 kilometres from the volcano. The eruption came to an end on October 26; it had yielded 5.5 cubic kilometres of loose material which covered the surrounding country with a layer ranging from one to three and more metres thick and destroyed numerous plantations. A new crater 600 metres deep and one kilometre in diameter was formed on the slope of the volcano and continued weakly to emit vapours and ash. At the end of the year it began to fill with water; in 1906 explosions from time to time hurled this water skyward like geysers.

No lava was poured out during the eruptions of the Bandaisan, Krakatao and Santa-Maria volcanoes and it is generally not lava, but the gaseous and loose materials of the eruptions that are mainly responsible for the toll of human life, as was also shown by the eruption of Vesuvius in 79 and that of Mont Pelée in 1902.

Owing to the heating of the air during the eruption of the Tambora Volcano on Java (April 10, 1815) a terrific wind-spout arose and swept away whole villages and forests, lifting trees, houses and cattle into the air and whirling them until its force waned one hour later; many of the things thus lifted fell into the sea. More than 56,000 people were killed during this eruption.

The very incomplete figures of human lives lost in 57 volcanic eruptions since the year 1500 run into 190,000; of these 93 per cent falls to the Pacific Hemisphere and only seven per cent to the Atlantic where the main losses were suffered by Italy, Sicily and Iceland. The damages caused by the loss of cattle, destruction of buildings and ruin of plantations are incalculable. The chief causes of the catastrophes are the nuées ardentes, ash, bombs, hot gases, air blasts and sea waves, lava being the least important. The forest and field fires, as well as the epizootics are also regarded as results of eruptions.

As for their effects on man *earthquakes* lead the catastrophes in the history of the Earth. Their description would also fill a book, but we can describe only a few of them. In the catastrophes of this type human lives are lost mainly through destruction of buildings and attendant fires; an important part is also played by sea waves resulting from the shocks and flooding the shores; landslides and earth creeps in the mountains and sinks of

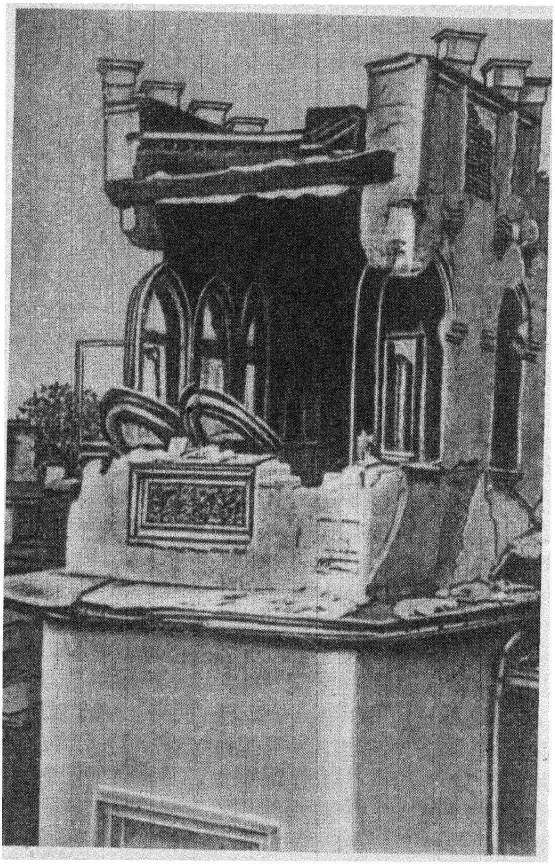

Fig. 260. Demolition of the upper story of a house. Yalta. Earthquake of 1927

land form the third most important cause. The material damages are also determined mainly by destruction of buildings and other structures; comparatively little cultivated land comes to be ruined. But earthquakes have the advantage that it is possible largely to prevent their pernicious effects by putting up anti-seismic structures, whereas man is loath to take the only rational measure as regards volcanic catastrophes, i.e., abandon the environs of active or suspicious volcanoes. Incidentally, as the foregoing should make it clear, this measure does not provide a full guarantee either.

The earthquake of 526 A.D. which involved the Mediterranean coast took a toll of human life estimated between 100,000 and 200,000. The 1693 earthquake on the Island of Sicily killed 60,000 people. The Lisbon earthquake of 1755 was felt over an area four times as large as Europe; most towns in Portugal were destroyed and some cities in Spain—Madrid, Seville, Cadiz—were also affected. The number of people killed by demolished buildings ran into 32,000, while 60,000 more were drowned in the sea which at first retreated and then returned as a huge wave. In Lisbon this wave reached a height of 26 metres; it swept into the sea a mass of people who sought safety on the embankment. In Cadiz it rose to a height of 20 metres, in Morocco and Madeira of five to six metres.

The 1908 Messina earthquake which took in both shores of the fault trough between Sicily and Italy killed 83,000 people and destroyed most of the towns on the shores; crevices were formed and whole strips of land (including the embankment in Messina) were submerged. The extensive destruction of buildings was in considerable measure due to the poor building materials —boulders instead of brick and clay in place of cement. The same factors augmented the catastrophe during the 1927 Crimean earthquake. Most of the structures built of good materials stood up, while those built of poor materials collapsed (Fig. 260). During this earthquake many people feared lest the Crimea fall into the Black Sea as it happened at one time to the southern continuation of the Taurus Mountains now lying on the floor of the deep southern part of the sea. But determinations of the epicentres of this and subsequent earthquakes have shown them to be located on the sea floor 30 kilometres from the Crimean coast and apparently to correspond to the line of the fracture that divides the lowered part of the land from the raised part, the latter being the Crimean Peninsula. Earthquakes indicate that displacements still occur periodically and it is most probable that the southern limb of this fault continues to sink and the northern limb to rise. The latter is confirmed by the displacement of the zero line at seismic stations, the line inclining seaward. It is therefore more probable that during the future earthquakes the Crimea will continue to rise, i.e., it is not in any danger of sinking.

The 1887 earthquake in the town of Verny (Alma-Ata) destroyed 1,500 buildings, but killed no more than 330 people, including those in the surrounding country. This is accounted for by the fact that the residential buildings were mostly one-

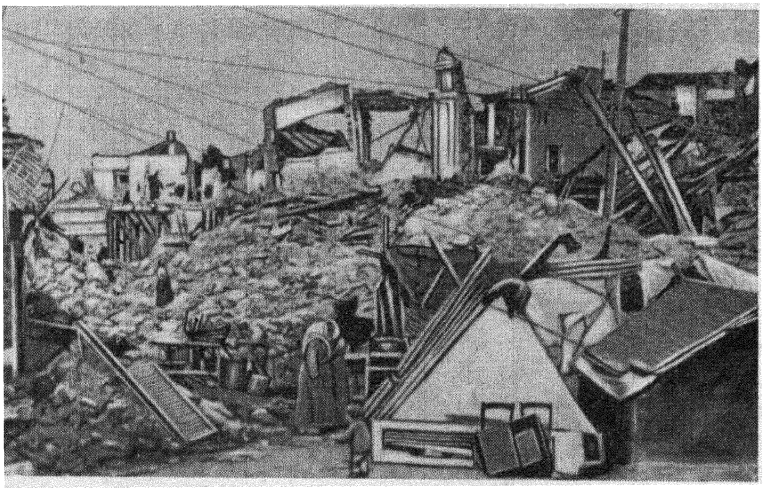

Fig. 261. Extensive destruction in the city of San Giovanni. Messina earthquake, December 28, 1908

storied, the streets were wide, the houses were far apart and the area was generally sparsely populated.

The areas most affected by earthquakes in the Caucasus are the southern foothills of the Greater Caucasus in the region of the towns of Shemakha and Nukha, and the Minor Caucasus on the territory of Armenia. The 1902 earthquake in Shemakha destroyed 9,500 houses and damaged 4,000, killing 86 people and injuring 60, and killing 400 head of cattle. Here, too, the few casualties were due to the fact that the houses were mostly one-storied and the earthquake happened in the daytime. Much more destructive were the earthquakes the same year in Andizhan and Ferghana; these occurred at night and killed 4,500 people and 7,000 animals.

On the American coast of the Pacific it is South and Central America that particularly suffer from earthquakes. Four-fifths of the town of Riobamba was destroyed and close to 40,000 people were killed in 1797; the little neighbouring town of Latacunga is destroyed almost every ten years. It took just 30 seconds to destroy the city of Caracas in 1812; since then every house has had a safe wall near which the fragile things are kept;

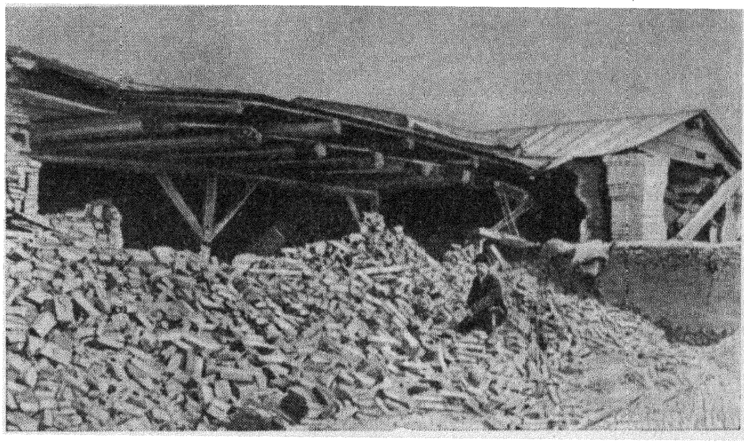

Fig. 262. Baths in Alma-Ata after earthquake in the beginning of January 1911

this side of the buildings (northern) was chosen because the destructive shocks travel mostly from west to east.

New Zealand is also affected by earthquakes. In 1931, the catastrophe befell the town of Napier on the eastern shore of the northern island; all the stone buildings were destroyed and all the oil tanks caught fire; there was no water to extinguish the fires and they continued to rage in the centre of the town for seven hours after the first shock. The port quarter was razed to the ground by burning gasoline. In the region of Hawke's Bay five towns were destroyed; these towns were on fire as long as the shocks continued. Earth creeps and crevices up to 30 metres long were formed along the sea-shore for a distance of 120 kilometres; rivers changed their mouths and the entire sewerage was demolished; in some places the coast rose and the sea receded; geysers gushed in the region of the earthquake at first spouting water and then mud which dammed up the river and caused a flood.

On the west coast of the Pacific Japan is the country that suffers from earthquakes most. From 1604 to 1914, 103,189 people met their death and 521,000 buildings were destroyed there. The most disastrous was the earthquake of September 1, 1923, that

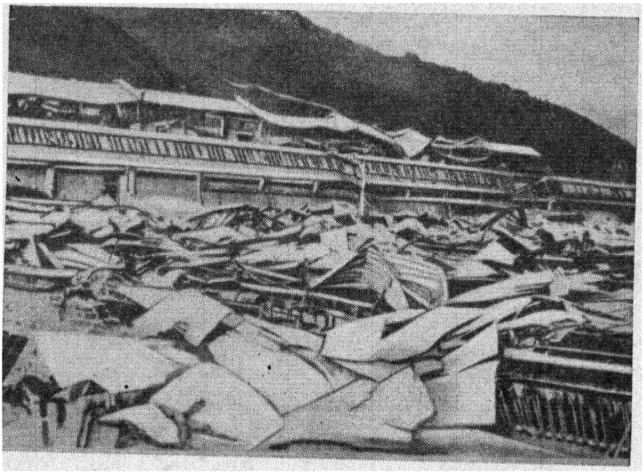

Fig. 263. Japanese earthquake of September 1, 1923. Ruins of a textile mill and neighbouring houses in Tokyo

affected the eastern shore of the main Island of Honshu. Tokyo, Japan's capital, and its large cities Yokohama and Yokosuka were destroyed in two days by an earthquake and fire; eight smaller cities were utterly destroyed and 11 were heavily damaged. This earthquake destroyed 653,000 buildings and affected 3,060,000 people, 42,000 people were reported missing. The damage was estimated at 10,000 million yen. In Tokyo fires broke out in 76 places right after the first shock; disruption of the water supply, the blocked-up streets, the strong wind and the size of the area affected by the fires rendered fire-fighting impossible and three-fourths of the city was reduced to ashes as a result. Oil and kerosene stores caught fire in Yokohama. Burning oil spread over the water in the bay and set fire to wooden ships. Thousands of people were killed by fire and smoke. A sea wave caused by the earthquake demolished the shore and swept off more than 500 houses; 356 shocks were recorded during September 1 and 2 (Fig. 263).

All in all only the seven stronger earthquakes that occurred between 1755 and 1915 took a toll of 300,000 lives, while the 1923 Japanese earthquake killed 142,000 people. According to old annals 1,415,000 people died in earthquakes in China between 1038 and 1850, and 200,000 were additionally killed in 1920. These large numbers are accounted for by the fact that many people lost their lives in the loess caves in which a considerable part of the population of Northern China formerly lived. This very incomplete statistics proves that earthquakes cause a much greater loss of life and damage to property than do any other catastrophes.

Catastrophes of the Past. All the catastrophes described happened either before our eyes or in the very recent past, in the last millenniums. No doubt there had also been catastrophes in antiquity, and some of them perhaps very extensive. We may regard as such catastrophes the biblical legend about Sodom and Gomorrah which were swallowed up by the ground presumably for the sins of their inhabitants. These towns were located on the territory now occupied by the Dead Sea, while the latter, as geology has demonstrated, is located in a fault trough, i.e., in a sink hole that terminates a large zone of subsidences and sinks running from the centre of Africa along large lakes and then representing the depression of the Red Sea and the valley of the Dead Sea and Jordan. It is therefore quite possible that the Bible describes in a distorted form an actual event that took place in ancient times, i.e., the sinking of two towns during an earthquake.

Even more stupendous was the catastrophe that destroyed the Atlantis, as the state located on the large islands in the Atlantic west of Gibraltar was called. According to *Timaeus* and *Critias*, two of Plato's dialogues, 8,000 years before the time of Solon numerous troops of the king of Atlantis conquered the entire area of the Mediterranean and only Athens successfully resisted, but it, too, would have been subdued were it not for the terrible earthquake during which Atlantis was submerged in one night, while the waves caused by the earthquake devastated the Mediterranean coasts. The legend sounds plausible because all the islands in the East Atlantic are volcanic and some geological and zoological data imply the former existence of extensive land between Europe and America.

The catastrophe by which the Aegean Sea was formed probably occurred in a similar manner as a sink in the beginning of Quaternary period and gave the waters of the Mediterranean access to the Black Sea.

All the aforementioned catastrophes are natural components of volcanic eruptions, earthquakes and other natural forces, but are territorially limited. But are there not in the history of the Earth some proofs of great catastrophes simultaneously involving large areas of land and therefore capable of exerting an essential influence on the organic world?

We already know about *transgressions*, i.e., advances of the sea which involved vast territories; we also know about the epochs of *glaciation* in which even greater areas were covered by an ice sheet. In the history of the Earth both these phenomena have the right to be considered catastrophes though they did not come about suddenly and did not last a short time, but developed very gradually and persisted for tens of thousands of years.

Both regressions, i.e., retreats, and transgressions of the sea took place during each geological period. Some of them were confined to one continent, others affected more or less simultaneously all the continents. The living conditions had to change both on land and in the sea during the transgressions and regressions alike; during regressions the climate grew drier and more continental, and during transgressions it was more humid and showed lesser temperature variations. The neritic zone of the sea, i.e., the area of small depths (up to 200 metres) in which the most diverse and abundant organic life is concentrated, greatly increased during the transgressions thus setting up optimal conditions for the development of this life and for the rise of new varieties, species and genera. During regressions this zone of the sea greatly contracted; in its drained area all the permanent marine part of the population perished, whereas in the section that was retained a cruel struggle for existence began for the organisms not confined to the floor, and all those that could not adapt themselves to the new conditions also died out.

Glaciations also radically changed the living conditions on the Earth. Seizing large areas the ice destroyed all life on them; the climate of the territory bordering the ice sheet altered; it grew cold and the forest supplanted the steppe and was in its turn replaced by the tundra; the warmth-loving forms of animals and plants perished or slowly migrated south, while their place was taken by forms adapted to cold and humidity. Some forms died out, others were modified. During the retreat of the ice sheet the fauna and flora moved in the reverse direction, but no longer in their former composition since some of the older forms died out and new ones appeared. The climate also changed outside the areas involved in glaciation. It is believed that during the glacial epochs in the moderate regions zones of a pluvial climate, i.e., abounding in rain, were formed much farther south.

Thus, transgressions and regressions, as well as glaciations may with certain justification be regarded as catastrophic phenomena. But it may be urged that since the entire history of the Earth essentially consists of transgressions and regressions it therefore all consists of catastrophes. The answer to this is "yes" or "no." Yes, because the difference between these prolonged and other catastrophes is only in time, in the duration of the phenomenon, which is a very conditional feature. No, because in the intervals between the transgressions and regressions and between the glaciations the conditions of existence remained approximately the same for a more or less long time. At any rate these protracted catastrophes do not resemble those assumed by Buffon in his *Theory of the Earth* during which all life was totally destroyed at the end of each epoch. Long-continued catastrophes resulted in a slow extinction of some forms, transformation of others and appearance of still others.

Extinction of Faunas and Floras. The history of life on the Earth really shows that during certain periods of time some genera, families, orders and classes of animals and plants came into being, attained their greatest development and distribution and then died out or considerably diminished.

Thus, the archaeocyatha, organisms intermediate between sponges and corals, appeared, reached unusual development and became extinct all during the Cambrian period alone. Ammonites, cephalopod molluscs with a spiral shell, appeared in the Palaeozoic era, developed an enormous diversity of species and genera during the Mesozoic era and died out towards the beginning of the Tertiary period. The reptiles made their appearance at the end of the Palaeozoic era, became the kings of nature on land, in the air and in water during the Mesozoic era and receded into the background during the Tertiary period by ceding their place to the mammals; the latter dominated during the Miocene and Pliocene periods and have now yielded the primacy to one of their genera—man, who developed during the Quaternary period. The trilobites, quaint crustaceans which became extremely diversified during the Cambrian and Silurian periods and held first place in the marine fauna, lost it with the appearance of cephalopods, the most dangerous and wildest of the marine predatory invertebrates.

Owing to the hot and humid climate during the Carboniferous period cryptogamous plants—ferns, horse-tails and lycopodia—attained unusual development and formed vast forests on marshes. During the Permian period with its drier and colder climate many of their species and genera disappeared and were replaced by gymnosperms, cycadophyta and coniferous plants fertilized with the aid of the wind and better adapted to the dry climate; they dominated during the Mesozoic era, while during the Tertiary period they were supplanted by angiosperms better adjusted to considerable climatic variations.

Many more of these examples could be cited. The leading part was played by climatic changes connected with the transgressions and regressions of the sea, the epochs of mountain-building and glacial phases.

But in addition to these slow transformations of the fauna and flora connected with climatic changes, which can be regarded as catastrophes only with the aforementioned reservations, we find in annals of the Earth proofs of real catastrophes which in a short time exterminated large numbers of animals and plants. Their remains form whole strata of the earth's crust and may be called fossil *cemeteries* or fields of corpses.

We have already made mention of the fact that in Yellowstone Park (U.S.A.) the side of the river gorge reveals 15 levels of petrified trees interbedded with volcanic tuffs. Age-old forests grew up there 15 times and were then ruined by volcanic eruptions. The layers of coal which in many places of the Earth are imbedded with strata of sandstones, clays and limestones are essentially also cemeteries of trees which existed under favourable conditions as forests for some time and were then rapidly destroyed by a transgression of a lake or sea or by a river flood.

Cemeteries of reptile corpses of Cretaceous age are known in North America and East Africa. In Mongolia recent expeditions of the Palaeontological Institute of the U.S.S.R. Academy of

Sciences have also discovered in various places accumulations of bones of Cretaceous pangolins and even their nests with eggs, and in other places accumulations of remains of Tertiary mammals. Similar cemeteries of Permian reptiles and amphibians are known in South America and in Germany. Accumulations of remains of Tertiary mammals are also found in the U.S.S.R.—Bessarabia, the Taman Peninsula and in Western Siberia near Lake Chelkar-Tengiz, in the basin of the Turgai River and near Pavlodar on the Irtysh River. Such cemeteries were recently discovered in the lower layers of the Tertiary conglomerates and sands in the lower reaches of the Chu River, in the Ketmen Ridge near Tashkent, and in the sands of the Kyzyl-Kum. Here the bones of the Cretaceous pangolins, the scutes of turtles and the trunks of trees are badly chipped, rounded and mixed with pebbles representing remains of a vast cemetery of animals and plants of the end of the Cretaceous period which existed in this area and were eroded probably by torrents in the beginning of the Tertiary period.

The cemetery of Permian and Triassic herbivorous and carnivorous amphibians and reptiles discovered by Professor Amalitsky on the Northern Dvina has been known for a long time; the skeletons of these animals have formed a whole gallery, part of which is now on exhibition at the Palaeontological Museum of the Academy of Sciences in Moscow. This cemetery runs from the Unzha River across the Northern Dvina almost to the Kama River and the bones are found in a bed of sandstone with pebbles and sand from 20 centimetres to three metres thick, above and beneath which are mixed marls entirely devoid of remains. A regression of the sea had apparently set up favourable conditions in the form of vast marshes and river floods for the existence of great numbers of these animals in this area, and then a rapid transgression buried their remains.

The asphalt deposit in the Rancho la Brea near Los Angeles, California, is famous for its bones of Quaternary mammals and birds. Today it is a large hollow formed as a result of hard-asphalt quarrying; on the floor of the hollow amid reeds and shrubbery there are puddles of water from which here and there large bubbles of combustible gas escape; the water is dark brown, dirty and smells of oil. It is rain water accumulated above heavy viscous oil, liquid asphalt, which makes up the entire floor of the hollow. Woe unto the animal that attracted by the water steps on the edge of a puddle or to the bird that alights on it: they will inevitably sink. This place is a gigantic trap in which mammals and birds perished for hundreds and thousands of years, their bones being preserved in the asphalt. They were found during the quarrying of hard asphalt, but were thrown out by the hundreds until scientists noticed

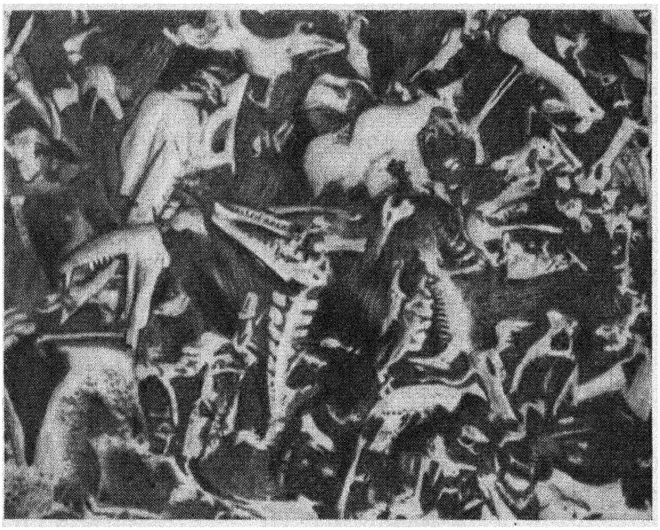

Fig. 264. Slab of bone-bearing layer from Carnegie Hill, Nebraska, U.S.A.

that these bones belonged to animals of the glacial epoch and began proper excavation. Many thousands of skulls and bones of the sabre-toothed tiger (more than 3,000), various wolves, lions, pumas, bobcats, martens, skunks, foxes, bears, eagles, vultures, kites, condors, falcons, hawks and owls have been extracted and now adorn U.S. museums. The herbivorous animals found include camels, deer, antelopes, bisons, boars, horses, tapirs, mastodons, Imperial Mammoths, bats and moles; rodents—gophers, rabbits, hares and mice—were also found.

The formation of this vast cemetery may be conceived as follows: herbivores and rodents came to water or accidentally found themselves on the shores of this treacherous swamp and began to sink; their death cries and parts of corpses still showing above water attracted predatory mammals and birds who also sank and perished as soon as they alighted beside the corpses or fell on the surface of the swamp during the fighting for the food. Interestingly enough the greater part of the bones belongs to young animals who are apparently less careful than the old ones. The complete mixture of bones and separation of skeletons are accounted for by the fact that the mass of liquid

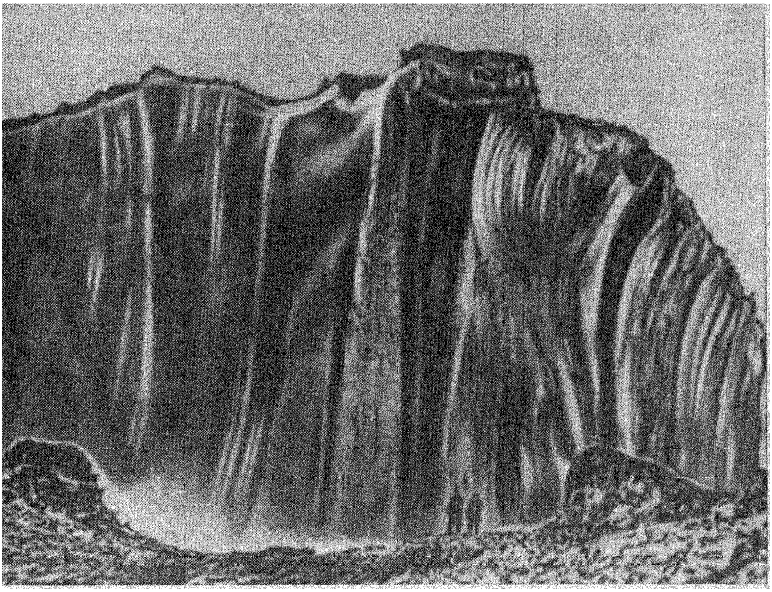

Fig. 265. Exposure of underground ice on the coastal precipice of Bolshoi Lyakhov Island. Cemetery of mammoths

asphalt is in motion, owing to the gases liberated from it, and therefore keeps mixing.

An even greater cemetery, but of the Tertiary period, was discovered in Carnegie Hill and University Hill in the State of Nebraska. Scores of thousands of skeletons of Rhinoceratidae—Diceras, Moropus and Dinoceras, are buried here in a layer only 15-65 centimetres thick. A slab cut out of this layer and measuring 1.65×2 m. (part of this slab is shown in Fig. 264) contains 22 skulls of Diceras and an enormous mass of its bones in a chaotic mixture. According to available figures 164,000 bones belonging to 820 skeletons of rhinoceroses have already been extracted, most of these bones from skeletons of Diceras. Numerous skeletons of a small antelope-like camel were found in two layers of a neighbouring hill. All the bones are very well preserved and exhibit no marks of teeth of predatory animals or rodents. This shows that the corpses did not stay on the surface very long and were buried very soon. So extensive an accumulation of remains of herbivorous animals of few species in one place can be explained only by a catastrophe which rapidly destroyed whole herds of them. It is believed that a terrible drought forced these herds to accumulate in search of water in the dry bed of a river where they all died of thirst. Similar cases in which cattle was destroyed during a drought happened, according to Darwin's description, in Argentina in 1827 and 1830. But the absence of tooth-marks on the bones suggests that the corpses were soon buried under the sediments brought by a torrential stream resulting from a terrible downpour which ended the drought. The sands containing the bone-bearing layer are of a fluvial origin. It is also conceivable that the animals perished from a sudden epizootic.

The Bolshoi Lyakhov Island, the southernmost of the Novosibirskiye Islands, is essentially a cemetery of mammoths. Mammoth tusks and sometimes whole corpses of mammoths and other mammals were buried in great numbers in the Quaternary sediments; they have been preserved by the permafrost of the soil. In the coastal slopes washed by the surf the tusks thaw out in summer and fall on to the beach; in the past they were annually gathered in by traders who came from the continent (Fig. 265). These abundant remains of large animals on a relatively small island which was unable to provide food for them is accounted for by the fact that as late as the beginning of the Quaternary period the land of Siberia reached much farther north and at the end of the last glacial epoch was broken up, large areas sinking into the sea. The herds of mammoths living on this land sought safety on the areas which remained intact. The Bolshoi Lyakhov Island was one of the asylums where the animals accumulated in large numbers. But it had already been separated from the continent by a wide strait and so became a cemetery for the animals who rapidly starved to death. This was a real catastrophe. Bones are also found on other islands, but in lesser amounts. Instinct drove the animals south, towards the continent, and that is why the greatest numbers of them accumulated on the southernmost island. Fig. 266 shows a reconstructed mammoth.

The Deluge is the only world-wide catastrophe related by the Bible as taking place since the existence of man. Geology has not discovered any proof of anything like it in the strata of the Quaternary period which should have contained the remains of

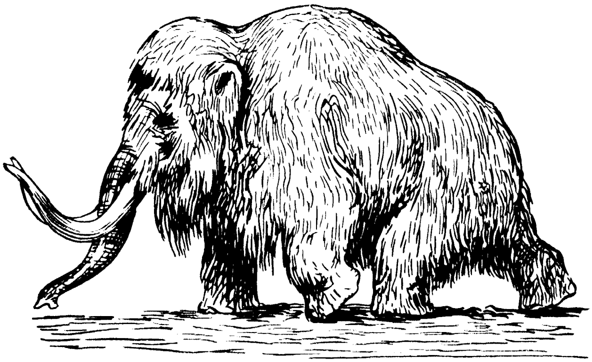

Fig. 266. Mammoth

the extinguished animals and plants everywhere on the same level. But many peoples on all the continents have legends about a deluge, the story greatly varying according to local conditions. Thus some peoples in the Arctic think that the Deluge resulted from sudden snow-melting, while the coastal peoples speak mostly about the land being flooded by sea waves or about its sinking into the sea.

This is due to the fact that the myth is based on a real happening, on a catastrophe which occurred at different times and in different forms of floods and overtook most of the peoples on Earth. The Austrian geologist Suess has found the biblical version of the myth to be very close to the description of the flood contained in the grand epos about the deeds of Isdubar discovered in the excerpts of the annals of the Babylonian priest Berozus (in cuneiform tablets). By studying the description of the events Suess arrived at the conclusion that the enormous flood in the lowland of the Euphrates on which the biblical legend is based actually did take place and was caused by a strong earthquake in the region of the Persian Gulf; the earthquake forced the sea to recede which then returned as a tremendous tidal wave augmented by a terrible cyclone coming on from the south; the wave flooded the entire lowland of Mesopotamia. But the Babylonian annals do not say it was a worldwide flood; they describe a purely local event. There had been similar floods giving food for myths in other countries, but their causes may have differed very widely—unusual overflows of rivers after rains, sudden snow-melting, typhoons on sea-shores, tidal waves of earthquakes or intense volcanic eruptions (like the 1883 eruption of Krakatao). That is why the myths of different peoples assumed different forms; based on real happenings they were in some measure or other embellished by fantasy.

XII

WHAT RICHES THE EARTH CONTAINS

Minerals and Their Properties. Relationship between Minerals and Rocks. Formation of Rocks and Minerals. Endogenous and Exogenous, Primary and Secondary Deposits. Natural Distribution of Minerals. Mosaics of the Earth's Crust—Geosynclines, Shields and Plates. Distribution of Minerals over the Territory of the U.S.S.R. Objectives of Geochemistry.

The earth's crust contains various minerals required by civilized man; these minerals have to be dug out, extracted from different layers of the earth. Even primitive man made use of these minerals in the form of chips of flint and other hard rocks in order better to defend himself from predatory animals, to procure animal food and to fight his fellow-men, i.e., to wage war in its elementary form. The higher man rose in his development the more extensive and varied use he made of minerals. Modern engineering is absolutely impossible without their wide employment; only coarse food and clothes and simple dwellings, like nomadic tents and huts, can be procured and made from vegetable and animal products without using any minerals.

Some of these minerals can be used in the form in which they are extracted from the ground, as for example, coal, lignite, peat, clay, sand and quarrystone. Others require a simple processing such as cleaning, cutting, hewing, sorting, grinding and concentrating; these include mica, asbestos, amber, phosphorites, rock salt, salt brines, placer gold, facing and precious stones. Still others need more or less complicated factory operations to yield the useful product; among these we find all the ores, i.e., compounds of metals with oxygen, sulphur, arsenic, etc., as well as oil; the latter may incidentally be used in its raw state as a fuel.

The conspicuous feature of the minerals which distinguishes them from the other natural resources such as animals and plants, white coal (water power), yellow coal (solar energy) and blue coal (wind power), is their scantiness and impossibility of renewal. The resources created by the natural processes during the long centuries of the Earth's history are limited and are not renewed on a scale necessary for their practical utilization. This should impel man to use them sparingly; on the other hand, the increase in population, development of industry and exhaustion of the worked deposits drive man to search for new ones and for methods of their more economical utilization, force man to work the poor deposits and to employ various substitutes.

Most important in the search for new mineral deposits is the knowledge of the geological processes which created these deposits during the past periods in the life of the Earth; these processes are still creating them today, but so slowly that in most cases their products cannot be regarded as industrial reserves. The studies of geological processes help us explain the origin of minerals and the laws of their distribution; consequently, they help us expediently and most successfully to direct the search for new and as yet unknown deposits, as well as correctly to estimate their reserves and practical importance.

Mineral deposits consist of an accumulation of one or several varieties of minerals and are, therefore, formed by the same processes which generally create minerals. Rocks are the largest accumulations of minerals, while the accumulations that form useful deposits are generally private cases of rock formation depending on some special conditions which create a concentration of these minerals large enough to be profitably exploited. These are determined by the value of the mineral and may therefore greatly differ from very thick layers or large stocks to thin veins or even separate disseminations. Only such minerals as brick clay, sand and various building stones represent the layers or series of the rocks themselves.

We already know that rocks are formed in three ways. Some are formed by the hardening of magma, i.e., molten masses rising to the surface from the entrails of the Earth. These are *igneous* rocks which are in their turn divided into *intrusive* or *plutonic* rocks that solidified at some depth, and *volcanic* or *effusive* rocks that consolidated on the surface. Other rocks are created as chemical or mechanical deposits in water basins precipitating out of the solution or from the suspension and are therefore referred to as *sedimentary* or *fragmental* rocks. Still others were originally either igneous or sedimentary rocks, but were later in one way or another altered—by pressure during mountain-building, by remelting or intensive heating, by impregnation with hot gases or vapours in sinking to a great depth, or by contact with newly extruded magma. These rocks are known as *metamorphic*.

It follows that the mineral deposits as private cases of mountain-building processes represent the same three main categories. Those connected with the formation of igneous rocks are called *magmatic* or *endogenous*, i.e., created by depth processes. The deposits formed in water basins or by weathering processes on land are said to be *sedimentary*, *weathered* or *exogenous* deposits, i.e., created by processes on the surface. The deposits formed or transformed during the processes of rock alteration are called *metamorphic*.

But the primary source of all minerals that form the earth's crust and, consequently, the mineral deposits is the magma. Analyses show that igneous rocks contain in some measure or other all the chemical elements known on the Earth. The substances found in the exogenous deposits were originally found in some form in igneous rocks and were liberated from them by weathering and erosion; later they got into water solutions or weathering residues and accumulated into deposits again which are therefore generally *secondary*, whereas the deposits connected with igneous rocks are essentially the only *primary* deposits. Even the most ancient sedimentary rocks are products of disintegration of the primary earth's crust so that the oldest exogenous mineral deposits are secondary. In later periods of the Earth's history magmatic extrusions from the depths created ever new primary deposits, while the processes of weathering and erosion formed from them and from the very igneous rocks and ancient secondary deposits new secondary deposits. The processes of rock alteration simultaneously created metamorphic deposits. All three processes are still operating today.

Let us now briefly consider the processes by which mineral deposits are formed.

The magma of the earth's interior contains various chemical elements necessary for mineral formation. Minerals begin to be liberated from the magma just as the latter starts cooling, during the crystallization of the melt. The compounds of heavy metals, mainly iron of which the magma contains the greatest amounts, form accumulations referred to as ore pockets. The process during which they are liberated is called *crystallization differentiation*, i.e., disjunction and disintegration of the magma.

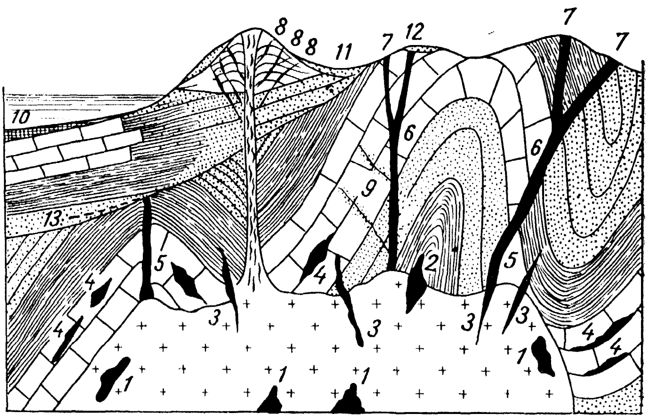

Fig. 267. Diagram of origin of ore deposits

1—segregated; *2*—injected; *3*—pneumatolytic; *4*—contact; *5*, *6* and *7*—hydrothermal—deep, medium and shallow; *8*—volcanic; *9*—replacement; *10*—sedimentary, modern on floor of water basin; *11*—weathered (alluvial); *12*—the same (but eluvial); *13*—ancient placers

In other cases the melt breaks up into parts of different composition while still in a liquid state; some parts contain many compounds of heavy metals, especially with sulphur; in hardening these parts of the magma will also yield ore accumulations. This process is known as *liquation differentiation*.

In both cases we obtain more or less large accumulations of some ores—magnetic, titanic and chromic iron and various pyrites—in the very igneous rock as *segregated* or *liquation* deposits. The molten ore substance sometimes breaks through with the other molten magma to the shell of the intrusive rock and forms a deposit amid sedimentary rocks, then said to be an *injected* deposit. These three types form the magmatic deposits proper (Fig. 267).

All volcanic eruptions show that solidifying magma liberates large amounts of gases and steam known as *emanations*. They consist not only of gaseous substances, such as oxides of carbon and sulphur, and compounds of fluorine and chlorine with hydrogen, but also of compounds of light and heavy metals with sulphur, chlorine, phosphorus, fluorine, etc. During volcanic eruptions the greater part of these emanations is lost, dispersed in the atmosphere, but some of them are deposited in the fissures and on the walls of the crater just the same and form layers of sulphur, sal ammoniac, iron glance, arsenic sulphide, etc. As the magma cools in the interior in the form of intrusions the emanations are deposited in the surrounding rocks and form accumulations as layers, veins or streaks of various minerals.

Among these *emanation* deposits we distinguish:

1. *Contact* deposits formed in the very beginning of hardening and consisting mainly of compounds of iron, more rarely of copper and still more rarely of other metals.

2. *Pneumatolytic* deposits laid down somewhat later not only outside the intrusive body, but also in its already hardened surface layers. These deposits consist of oxidized ores of tin, tungsten and iron accompanied by sulphurous compounds of iron, bismuth, molybdenum, etc.

3. Still later, when the hardening has gone very deep, the liquid remains of the magma rich in silica and volatile compounds break through the fissures of the intrusive body and its shell and harden in them as *pegmatites* forming irregular veins and containing but little heavy metals and many compounds of rare elements which were concentrated in the magmatic remains deep in the magma source. Pegmatites abound in quartz, felspars, micas, apatite, precious stones and other rare minerals.

The formation of pegmatites does not terminate the solidification and cooling of the intrusive body. The process drags on for many thousands of years depending on the size of this body and the depth at which it is located.

Gases and water vapours continue to be liberated from the depth of the body, but in the shell which cools sooner they pass into a liquid state and are transformed into solutions containing compounds of various elements which also include heavy metals. These solutions rise along fissures to the earth's surface and as the temperature and pressure drop they deposit on their long way various minerals, thus creating deposits in the form of veins of different thickness and content referred to as *hydrothermal* deposits. Among these we distinguish *deep-seated* deposits consisting mainly of gold, copper and partly of iron, tin, tungsten and molybdenum ores which pass from the pneumatolytic deposits; deposits of *medium depth* rich in silver, lead, zinc and to some extent gold, iron and copper ores; and *shallow* deposits characterized by mercury and antimony ores with some silver, lead and zinc. Quartz is a satellite of the ores that form the main mass of the veins; barite, calcite and dolomite are also satellitic ores at lesser depths.

The hydrothermal deposits formed during volcanic eruptions compose a special group. Though many emanations are lost in the atmosphere in this case, the magma feeding the volcano in the interior also liberates gases and water vapours while hardening and gives rise to solutions which deposit in the volcano's body and beneath it veins of minerals. We find the same minerals in their composition as we do in the hydrothermal deposits of an intrusive origin, but less regularly distributed as to depth; these are gold together with silver and tin, copper, lead, zinc, etc.

Hydrothermal solutions rising from the depths also come out to the earth's surface as hot and cold mineral springs which we already know as juvenile water. They contain gases—carbon dioxide and hydrogen sulphide—and compounds of metals, both light and heavy; the main part is played by easily soluble compounds of potassium, sodium, calcium and magnesium—carbonates, sulphides and chlorides—whereas the compounds of heavy metals dissolving with greater difficulty have already mostly fallen out on their long way to the earth's surface. But in some cases the hot springs bring out to the surface so many compounds of heavy metals that they deposit them right there and then; thus, the hot springs of California bring out and deposit cinnabar—mercuric sulphide. This content of metals in the water of mineral springs explains the process by which the ore-bearing veins are formed.

We shall now consider the *secondary* or *exogenous* deposits. The processes of weathering and erosion destroy the primary deposits which as a result of mountain-building and denudation have found themselves at the earth's surface. Their mineral material breaks up into two parts: the part that dissolves with difficulty remains in the form of residues of the primary deposit or is mechanically transported for some distance by water, wind or ice and is redeposited. Thus deposits called *placers* consisting of very stable and hard-to-dissolve metals and their compounds are formed; these include native gold, platinum, tin ore, wolframite, magnetic iron ore and insoluble minerals—diamond, garnet, ruby, emerald and monazite. Owing to their great stability and great weight placers frequently contain more of these minerals and metals than do primary deposits because the lighter and less stable soluble compounds are carried away in greater proportion, i.e., being transformed into a placer the deposit is enriched by chemical and mechanical means.

The dissolved part of a primary deposit is transported by rivers to water basins—lakes and seas, where under conditions of considerable concentration or due to the activity of lower animals and plants, compounds of heavy metals precipitate out of the solution and form deposits of marsh, lake and marine iron and manganese ores, and disseminations of copper ores in sandstones and slates; deposits of lake-salts of various composition are formed in lakes and lagoons owing to the intensive evaporation of water. These mineral deposits are said to be *sedimentary*.

But the same dissolved parts of the primary deposits also find their way into ground water and settle down in loose surface alluvions not infrequently accumulating and forming profitable deposits in the form of kidneys, nests and lentils of iron and manganese ores, disseminations of copper ores, concretions of sulphur pyrite, and cobalt and nickel ores. These deposits are called *concretionary*.

Exogenous deposits, but only non-metallic, also include *primary* deposits built by the activity of plants and animals from the material taken in the air, i.e., carbon which forms part of carbon dioxide. These are deposits of peat, lignite, coal and oil formed in marshes on land, on the shores of lakes and seas, and in the littoral shallow parts of the sea. The vital processes conditioned by the energy of the Sun create a gradual accumulation of material remaining from the extinct lower and higher plants, as peat and coals, and from the seaweeds and lower animals in the form of oil.

The deposits of phosphorites and guano are also primary exogenous deposits produced by the activity of the higher animals who concentrate phosphorus out of their food and void it with their excrements.

Mineral springs may also be regarded as mineral resources, the juvenile springs being the same products of eruptions (both intrusions and effusions) as various ores so that they may be considered primary deposits, while the vadose springs which borrow their mineral composition of one sort or another from the sedimentary rocks created earlier are, as, for example, salt springs, of course, secondary.

Natural Distribution of Minerals. Now we know that mineral deposits are created by processes operating both in the interior of the earth's crust and on its surface, i.e., by the activity of internal and external geological forces. But the activity of the same forces also determines the composition and structure of the earth's surface and the relief of the face of the Earth. It follows that there must be a certain regularity in the distribution of the useful deposits over the different parts of the earth's surface. It is interesting and necessary that we ascertain these regularities to learn what deposits we may encounter in an area of a certain composition and structure and how we may most expediently direct the search for them.

The relief of the earth's surface varies, as we know, very widely. The continents represent an aggregate of Alpine mountain ranges, plateaus, medium-height highlands, hilly areas and level lowlands of most diverse dimensions. These combinations of various forms have been created by the aggregate activity of the internal and external forces.

Crustal movements build mountain ranges and plateaus, slowly raise or lower vast areas. Rising during these movements the magma of the interior invades the strata of the earth's crust and forms intrusive bodies of various sizes and networks of veins connected with them. It frequently breaks through to the surface and builds volcanoes, sheets and streams of lava, and strata of tuffs.

All these unevennesses created by the internal forces are disjointed, transformed and, finally, smoothed out by the external forces, i.e., the work of weathering, of running and standing water and glaciers. These forces work tirelessly, destroying the unevennesses of the relief and building from their material new rocks—various alluvions on land, strata of sand, clay, silt and pebbles, and limestone in lakes and seas. We already know that this activity of the external and internal forces creates, transforms, destroys and gives rise to new forms of useful deposits. The study of the composition of the earth's crust and of a country's history makes it possible to determine the deposits it may have, as well as where and how they are distributed.

Mosaic of the Earth's Crust. Mountain ranges consisting of folds of rock are formed mainly in *geosynclines*, i.e., long and more or less wide depressions located amidst the land or along the margins of continents. These depressions whose floors periodically subside gradually accumulate thick strata of sediments from the materials brought down by rivers from the neighbouring land and by the surf from the shores. When the depression is more or less filled with sediments it gives rise to mountain-building, the reasons for which are not yet clear and excite discussion. But it cannot be doubted that the strata of sedimentary rocks accumulated in such depressions rise from them in the form of more or less complicated folds which build mountain ranges. At the same time, since the floor of the depression in its downward flexing sank deep into the earth's crust and reached the layers with high temperature, the lower layers of the depression were already able to melt and the magma during the formation of the folds invaded the sedimentary strata in the form of massifs of different size and numerous veins, even breaking through to the surface and building volcanoes.

The studies of mountain ranges have shown the formation of folds usually to be accompanied by an intrusion of magma. And since magma is the primary source of all ores, mountain-building is ordinarily attended by various types of ore deposition, from magmatic to hydrothermal, i.e., by a formation of primary ore deposits of a deep-seated origin.

What minerals can we expect to find in a highland raised from a geosyncline? The answer will depend on the age of the country. If it is young and but recently uplifted we can expect to find shallow hydrothermal, as well as volcanic, deposits provided there are any volcanoes thereabout. The other deposits are still hidden at great depths and are inaccessible. If the highland is a bit older the external forces have already been able to cut deeper into the folds and we can then find, in addition to the aforesaid (which may have been partly destroyed), also deposits of medium depth. Lastly, in an old and greatly eroded highland we should find near the surface not only deep-seated deposits but also pneumatolytic, contact and magmatic deposits in different combinations varying with the extent of the erosion. Besides these endogenous deposits, highlands of different ages may reveal exogenous deposits—sedimentary iron and copper ores, layers of coal and phosphorites, provided favourable conditions for their formation were set up in some places of the geosyncline.

The history of the Earth shows that the folded highlands were built successively in different parts of most continents because in the course of time the geosynclines shifted. The uplifted mountain ranges gradually aged, were eroded, became lower, were transformed into mountains of medium height, then into hilly country and, finally, into peneplains. And in the neighbourhood, either on one side or the other, the earth's crust flexed again, a new geosyncline was formed and was again filled with sediments giving rise to a new mountain range subject to the same fate.

We thus see in the north of Europe remains of the oldest Archaean and Proterozoic mountains in the form of the Baltic Shield transformed into a peneplain. This is the most ancient Europe or Arch-Europe. In the west it adjoins a highland built by folds of the Caledonian cycle in the first half of the Palaeozoic era; this highland encompasses the west of Scandinavia, Great Britain, and the north of France and Germany. This is Palaeo-Europe. Farther south from Poland to France and Spain run the mountain folds of the Variscian cycle of the second half of the Palaeozoic era which form Meso-Europe. Lastly, in the south, along the Mediterranean, we find the mountain ranges of Asia Minor, the Caucasus, Balkans, Carpathians, Alps, Pyrenees, Apennines and Atlas built during the Alpine cycle of the Mesozoic and Cainozoic eras and forming Neo-Europe.

Thus, the mountain-building in the geosynclines creating the modern face of Europe shifted from north to south and with it shifted the magmatic activity, which has created the ore deposits, as well as the activity of the external forces which exposed ever deeper layers in the mountain folds gradually destroying the deposits of the upper horizons and creating secondary deposits from their materials.

But mountain-building is not confined, as we know, to geosynclines. The pressure developing in the earth's crust and raising the strata of sediments accumulated in the geosynclines (the most mobile zones of the earth's crust) also acts on other regions, on areas of former geosynclines already transformed into highlands more or less eroded and levelled out. These areas show little mobility and are rigid because of the former folding and of the invasions of magma which have pierced them as igneous rocks. Here new folds form but weakly, and fractures and ruptures prevail; considerable series of strata shift, thrust themselves over each other, whole stretches of the earth's crust are uplifted, some more, others less, and form horsts and fault troughs. Ejected by the pressure from the depths magma also rises and forms new intrusions in the strata of rocks and the networks of veins, and breaking through to the surface builds volcanoes or sheets of effusive lava. This magmatic activity is also connected with the formation of primary mineral deposits, whereas sedimentary and weathered deposits are formed in lakes, swamps and on the surface of these rigid areas.

The oldest areas of the earth's crust that suffered mountain-building as early as the Pre-Cambrian eras and were never again subjected to intensive folding are known as ancient *platforms*. In the platforms distinction is made of *shields*—sections which since the last stage of folding have been characterized by a stable uplift and have never been covered by the sea. But larger areas of the platforms periodically sank and rose and were seized by the sea; they are overlain by a rather thick cover of sedimentary rocks which is not crumpled by intensive folding and has almost horizontal layers. Such sections of platforms are called *plates*.

Platforms constitute the central part of the continents: in Eurasia it is the Russian platform with the Baltic and Ukrainian shields, the Siberian platform with the Anabar and Aldan shields and the projections of the ancient foundation on the edge of the platform in the Yenisei Mountain Ridge, the Eastern Sayans and the Baikal upland, the Sinian platform (Northern China) with small shields, and the Arabian and Hindustani shields. In North America it is the North American platform with the Canadian Shield, and in South America the South American platform with the Brazilian Shield. Nearly all of Africa presents a platform with several shields, as also does Australia with a large shield in the east. Almost the entire Antarctica constitutes a platform and a large ancient shield.

Deeply eroded shields may contain primary deposits of the greatest depth—magmatic proper, emanation and rather rarely very deep hydrothermal. Metamorphic deposits created in Pre-Cambrian time frequently occur on the shields. The occurrence of various kinds of secondary deposits is also possible; these were created on the surface of the shield from the products of destruction of the primary deposits in the form of placers, lake and swamp iron ores, as well as coal seams in the depositions of lakes of different ages. When the shield was pierced by effusive rocks the latter could bring along volcanic-type minerals.

The platforms in which the ancient foundation is overlain by strata of sedimentary deposits of different ages never subjected to intensive folding may contain secondary deposits built from the products of destruction of the primary deposits included in the ancient foundation, but more frequently sedimentary deposits of coal, iron ores, phosphorites, various salts and oil formed in the seas, which flooded the platform, and in their lagoons, as well as in lakes and on land during the regressions of the sea and drainage of the platform. In some sections of the ancient foundation projecting from the platforms the minerals may be the same as on the shields.

The modern continents thus present a mosaic of areas of different geological histories and therefore different composition. Side by side with the stable deeply eroded ancient shields we see less stable platforms covered with but little disturbed sedimentary rocks of different ages and the most unstable geosynclines transformed into highlands of various ages and, consequently, of varying depth of erosion and the latest very complicated transformation. The deposits of various minerals are distributed in the mosaic according to the different compositions and different histories of these areas. With the knowledge of the geological structure of a country we can therefore tell what minerals can be found in its various parts.

Distribution of Minerals over the Territory of the U.S.S.R. Covering one-sixth of the earth's surface and stretching across two continents the Soviet Union naturally includes areas with varying geological histories and different structures and therefore with varying combinations of mineral deposits. Let us briefly trace the distribution of the latter over its territory (Fig. 268).

We find the eastern and northern margins of the ancient Baltic Shield in the European part of the country (Karelia and Kola Peninsula); most of the territory is occupied by the vast Russian platform in the southern part of which the Ukrainian Pre-Cambrian massif comes to the fore; it would be more appropriate not to call it a shield, but a section of the ancient foundation of a plate exposed as a result of an uplift and erosion, because it is overlain by Tertiary and partly Mesozoic and, at its western end, in Volhynia, by Palaeozoic marine sediments which have suffered only weak and local folding dislocation. Side by side with it is the Donets Basin, a Palaeozoic geosyncline strongly folded and at one time forming a real highland. In the east the plate is bordered by the mountain system of the Urals, also a Palaeozoic geosyncline whose mountain ranges are deeply eroded. In the extreme south we see the Crimean and the Caucasian mountains taking their final origin in a Tertiary geosyncline with Alpine forms of relief.

The minerals are generally distributed over the aforementioned areas of varying structures as follows:

On the deeply eroded margins of the *Baltic Shield* we find only magmatic proper, pegmatitic and metamorphic deposits; iron ores (iron quartzites and hematites) of metamorphosed sedimentary formation, pyrites (pyrrhotite with copper, nickel and zinc) in the form of deep veins; micas and felspar in pegmatitic veins, garnets in Archaean slates. In the Khibiny Massif near the town of Kirovsk tremendous deposits of apatites and various rare minerals are found in the younger Palaeozoic intrusion. The marshes and lakes also contain iron ores of the latest eroded-type formation, while the Karelian shungite is an ancient metamorphosed bed of coal.

The *Russian platform* covered with sedimentary rocks of different ages, only slightly dislocated and unpierced by intrusions, contains no deep-seated ore formations. The following numerous deposits are found: coal—Moscow and Pechora basins; iron ores—sedimentary and weathered—Kirov, Tula and Lipetsk regions, lake—Novgorod Region; oil—various parts of the Western Urals—from the Kama to the Lower Volga—Emba District at the Caspian Sea, and the North Caucasus—Grozny and Maikop; rock salt and other salts—Solikamsk, Bakhmut, Iletskaya Zashchita, etc.; bauxite (aluminium ore)—Tikhvin; lake-salt—lakes in the area east of the lower Volga and Sivash; phospho-

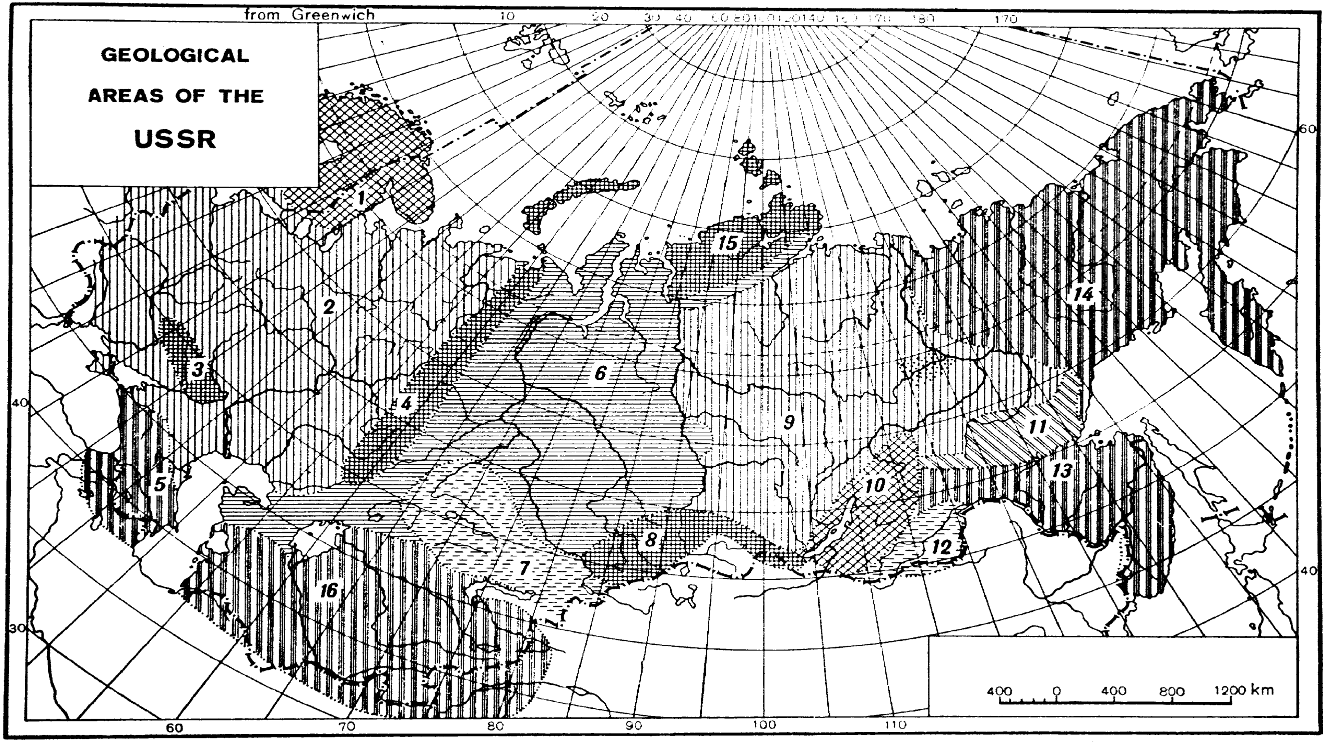

Fig. 268. Geological areas in the U.S.S.R.

1—Baltic Shield; *2*—Russian platform; *3*—Donets Basin; *4*—Urals; *5*—Caucasus; *6*—West-Siberian Lowland; *7*—Kazakh Dwarf Hills; *8*—Altai-Sayan area; *9*—Siberian platform; *10*—Baikal Highlands; *11*—Aldan Shield; *12*—Eastern Transbaikal area; *13*—Amur-Ussuri territory; *14*—North-Eastern area; *15*—Taimyr; *16*—Central Asia rites—deposits of different ages. Large deposits of metamorphic iron ores have been discovered under strata of sedimentary rocks in the Pre-Cambrian foundation of the platform in Kursk Region. Similar deposits come to the surface in the Pre-Cambrian rocks of the Krivoi Rog area in the Ukraine; the same zone of Pre-Cambrian formations has mica, felspars in pegmatites, deposits of graphite, and layers of brown coal and sedimentary manganese ores in the overlying Tertiary deposits near Nikopol.

The eroded geosyncline of the *Donets Basin* contains numerous layers of coal in the strata of the Carboniferous sedimentary rocks, while in the overlying Cretaceous and Tertiary sediments we find deposits of white chalk, cement marls and tripolites. The silver and lead veins of the Nagolny Ridge and the mercury deposit of Nikitovka are connected with but few intrusions.

The deeply eroded geosyncline of the *Urals* in which numerous and various intrusions occurred is rich in magmatic proper, pegmatitic, emanation and deep hydrothermal ore deposits; these include native and placer deposits of gold and platinum, magnetic, titanic and chromic iron ores, tungsten and nickel ores, copper and copper-containing pyrites, pegmatites with mica and emeralds, magnesite and asbestos. There are also sedimentary and weathered iron and aluminium ores, while on the slopes where we find younger strata there are layers of coal and sedimentary iron and manganese ores.

The young mountain ranges of the *Caucasus* abounding in various intrusions contain hydrothermal deposits of different depths yielding gold, copper, silver-lead-zinc, molybdenum and tungsten, as well as contact deposits of iron ores. Large deposits of oil are known in Azerbaijan (Baku); Western Georgia possesses sedimentary deposits of coal and manganese.

In Siberia we find a vast lowland west of the *Ob* composed of the most recent sedimentary formations which overlie older layers probably dislocated and pierced by intrusions, but so far known only by the data obtained from boreholes and as yet inaccessible. The surface deposits contain nothing but peat, sands and clays.

Farther south, in the northern part of Kazakhstan are the *Kazakh Dwarf Hills*; their structure is very complicated. After the Pre-Cambrian cycles this was apparently an ancient Palaeozoic geosyncline transformed by the Caledonian cycle into a folded highland, later eroded. A new subsidence created in the same place an Upper Palaeozoic geosyncline, very wide but shallow and with numerous islands—remains of Caledonian mountains. The Variscian cycle transformed it into a folded highland which was also eroded; during the Mesozoic era there were lakes on its surface, while in the beginning of the Tertiary period the steppe was flooded by the sea. The Alpine cycle affected it with fractures and overthrusts insufficient to change it to a block-folded highland except the eastern part where the Kalbinsky, Saur and Tarbagatai ranges were uplifted as horsts. Erosion was therefore able extensively to level out the relief of the greater part of the country. This former geosynclinal area widely pierced by intrusions possesses rich ore formations of almost all types, from the magmatic to the medium-depth hydrothermal: ore and placer gold, tin, tungsten, copper, silver-lead-zinc in the form of vein deposits, contact-metamorphic iron ores, various types of disseminated copper ores, corundum deposits, coal layers of Carboniferous and Jurassic ages, lake-salt, gypsum and weathered aluminium ores.

The *Altai-Sayan Highland* adjoining the steppe in the east and running across South Siberia to Lake Baikal represents block-folded mountains which arose on the site of older folded mountains—Caledonian and in the western part also Variscian—uplifted from geosynclines. The endogenous ore formation is abundant and diversified: ore and placer gold, tungsten, molybdenum, copper, silver-lead-zinc in the form of vein deposits, Pre-Cambrian iron quartzites, asbestos, graphite, nephrite, contact iron and copper ores, copper pyrites, beryl, weathered aluminium ores, and here and there Tertiary coal. The deep Kuznetsk and Minusinsk depressions—fault troughs cut into this highland—contain Carboniferous, Permian and Jurassic coal; the Minusinsk depression also has lake-salt and in the outcrops of Palaeozoic rocks it contains iron and copper ores.

The *Siberian platform* differs from the Russian in that it does not have part of the Mesozoic and Tertiary marine deposits, in the prevalence of ancient Palaeozoic and vast intrusions and outwellings of igneous rock—the Siberian trap. The latter is connected with deposits of iron ores and copper pyrite containing nickel and platinum, marine sediments of the ancient Palaeozoic era—salt springs, rock salt and signs of oil, while the beds of coal (and graphite in the Permian deposits of the Tunguska Basin) and Jurassic combustible shales of the Irkutsk and Vilyui basins are linked with the Permian and Jurassic lake sediments. The outshots of the Pre-Cambrian foundation in the form of the Yenisei Ridge and Anabar Shield contain ore and placer gold.

The *Baikal Highland* which encompasses the areas west of Lake Baikal, the shores of the lake and the Patomsk-Vitim Highlands is a deeply eroded Pre-Cambrian folded mountainous country pierced by enormous ancient intrusions and in its southern part by later effusions of igneous rocks along the crevices of the fractures responsible for the horsts and fault troughs; the latter contained Jurassic lakes. Its ancient ore formations consist of ore and placer gold, contact and metamorphic iron ores, here and there copper ores, mica, and felspar in pegmatites. The Jurassic and Tertiary sediments contain coal. Ore formations of tungsten, tin, molybdenum, gold and silver-lead have been found at its southern margin where it adjoins Palaeozoic folded mountains.

The *Aldan Shield* adjoining the highlands in the east is a peneplain on the site of Archaean folds overridden by a transgression of the Cambrian sea and sediments of Jurassic lakes; the shield was later pierced by young intrusions and effusions which resulted in gold-ore formation; we also see ore formation of gold and iron and deposits of mica, corundum and rock crystal in the Archaean foundation, and coal seams in the Jurassic sediments.

The *Eastern Transbaikal Area* has a complex structure. After the erosion of the Pre-Cambrian mountains it presented Palaeozoic geosynclines in which Caledonian and Variscian folds occurred; a depression was formed in their place in the beginning of the Mesozoic era; the sea penetrated into this depression in the form of a long gulf which was transformed into lakes at the end of the Jurassic period. The movements of the Pacific cycle built new folded mountains formed of blocks of Pre-Cambrian and Palaeozoic sediments and folds of the Triassic and Jurassic periods.

All of the folding cycles were accompanied by intrusions, the last cycle including effusions which continued through the Tertiary and Quaternary periods.

This complicated history resulted in abundant and diversified ore formation. We see contact iron ores, pegmatites and pneumatolytic veins with mica, precious stones, fluorite, tin, tungsten and molybdenum, as well as hydrothermal veins of various depths with gold, copper, silver, lead, zinc, even antimony and mercury; the Jurassic and Cretaceous lake sediments contain coal; the weathered deposits represent placers of gold, tungsten and tin.

The history of *Amur Region* and *the north-east of Siberia* is also very complicated. The Pre-Cambrian folded foundation is often overlain by Palaeozoic, Mesozoic and, on the eastern mar-

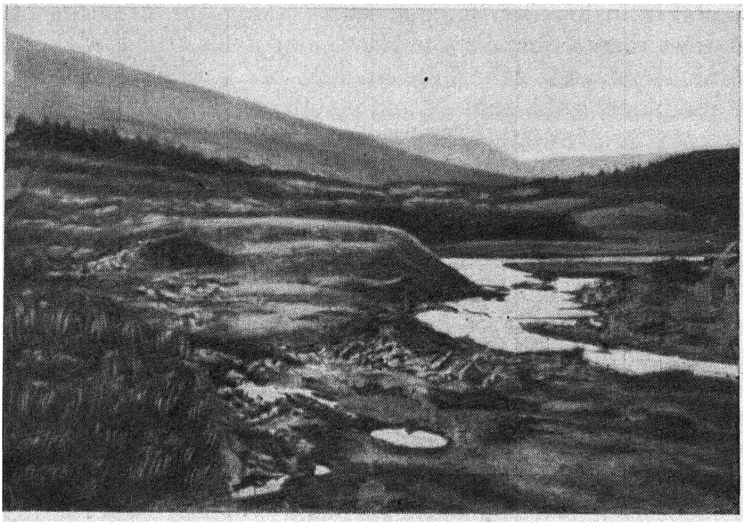

Fig. 269. Gold-bearing valley of the Nygri River, Bodaibo District. Old cut and dumps of washed gold-bearing layer

gin, Tertiary marine sediments which have gone through all the cycles of folding accompanied by intrusions and effusions. Here we therefore find ore formations of different ages and types: Pre-Cambrian, Palaeozoic, Mesozoic and Tertiary ore gold, Pre-Cambrian iron quartzites and graphite; Tertiary contact iron ores; Mesozoic and partly Tertiary tin, tungsten, molybdenum, copper, silver-lead-zinc and antimony; the continental sediments contain Mesozoic and Tertiary coal, the littoral—oil.

Central Asia presents two areas with different histories and different combinations of mineral resources. West of the Amu-Darya River we have the plains of Turkmenia bordering in the south on the young Kopet-Dag Mountains which constitute a continuation of the Caucasus, and in the north on the Ust-Urt

Plateau. These areas are known to contain the following deposits: oil in Nebit-Dag (Oil Mountain), oil and ozokerite on Cheleken Peninsula, deposits of thenardite (sodium sulphate) in the valley of Kopet-Dag, sulphur in the sands of the Kara-Kum, beds of coal, phosphorites and veins of copper ores in the

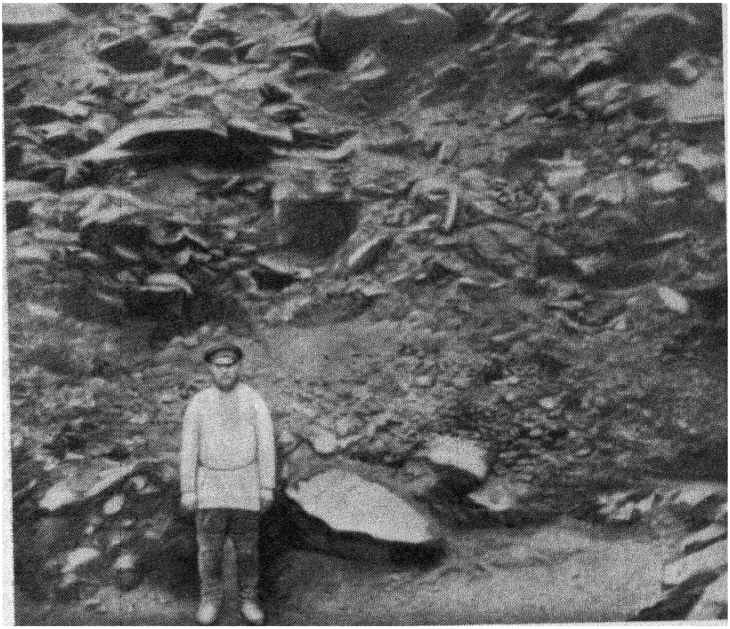

Fig. 270. Cut of gold-bearing alluvium along the Nakatami River, Bodaibo District; bottom—layer of small pebbles and gold; top—coarse deposits of glacial ground moraine

mountains of Mangyshlak Peninsula. All in all these resources except the veins are of a sedimentary origin.

The mountain ranges of Tien-Shan and the Pamirs-Alai built by folding of the Caledonian and Variscian cycles and rejuvenated during the Mesozoic and Cainozoic eras run east of the Amu-Darya. The Pamirs were also subjected to folding during the Alpine cycle. Plutonic intrusions of different ages created deposits which we now find side by side with sedimentary and secondary deposits. The mountain ranges contain deposits of gold, tin, tungsten, copper and silver-lead-zinc, i.e., hydrothermal deposits of various depths, and contact deposits of iron ores, quartz-tourmaline with magnetite, tungsten, arsenopyrite, and pegmatites with mica and felspar. Sedimentary deposits of coal and iron ores are known in the foothills. In the vast Ferghana depression we find deposits of Jurassic coal and oil, and in the belt of fracture shallow hydrothermal deposits of antimony and mercury. Lake rock salt, sulphur, alum, phosphorites, asbestos and graphite complete the variety of this area's

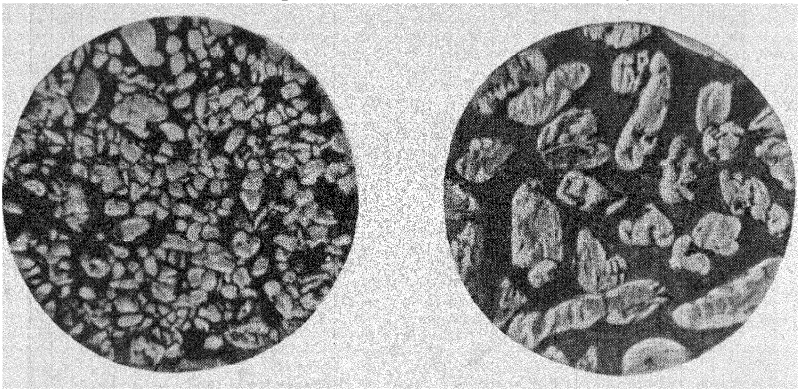

Fig. 271. Fine and coarse placer gold from the fields of the Bodaibo River basin, Bodaibo District. Magnified threefold

resources which have been discovered or properly appraised only by the explorations conducted since the Great October Socialist Revolution.

Objectives of Geochemistry. Studies of the geological composition and structure of a country revealing the history of its development to the present state enable us to judge of the mineral deposits that *may* be found within its confines. But these data are not enough to determine the deposits that *must* necessarily exist in the country in question. To solve this important problem, to render the predictions precise requires a deeper study of the mineral-forming processes which is the province of *geochemistry*, the young science that has branched off from geology and combines methods of mineralogical and chemical research with those of geology.

The thing is that the mineral-forming processes operating in the earth's crust at various depths and under widely differing conditions are very complicated and can be only partly reproduced and studied in laboratories. Rising from the interior, containing various elements and forming the primary ore deposits on which the formation of the secondary ore deposits depends, the magma may have a varying chemical composition to begin with. Invading the crustal strata during the formation of the intrusive body it dissolves by its contact some rocks or others—limestones, slates, sandstones, marls or more ancient igneous rocks—and must change its composition as a result of enriching itself with the water that impregnates the rocks, as well as with silica, alumina, lime and compounds of alkalis, according to the composition of the pierced rocks. The composition of the magma, the mode of its occurrence and solidification at a particular depth are responsible for the process of its differentiation, i.e., division into partial magmas of some composition or other, and the process of emanations and composition of the latter, and consequently the nature of the ore formation. The nature of the country rocks, their composition, mode of occurrence and jointing are also important. For example, some rocks, especially those that contain lime, yield more easily to ore formation than do others; the mode of occurrence, hardness, stratification and jointing of the rocks in some cases facilitate ore formation and in others render it difficult; they also affect the form of the deposits.

That is why, despite the general similarity of the various types of ore formation—magmatic, emanation and hydrothermal—we also observe wide local differences, i.e., prevalence of some ores and infrequency or absence of others. For example, sometimes it is the magmatic deposits proper that are absent, sometimes it is the pegmatites or the contact deposits. The composition of magma which gives rise to pegmatites is especially reflected in the latter; the pegmatites produced by acid rocks differ from those formed by basic rocks; they also differ in mineralization. Some igneous massifs have conditioned poor or monotonous ore formation, others rich and diversified.

All these different conditions observed in nature necessitate a deep study of the magmatic rocks and the entire mode of ore formation in the given area to ascertain all the circumstances and to come closer to the solution of the problem of the deposits that should be found there, naturally also taking the history of this area into consideration. This is the principal aim of geochemistry.

Our cursory review has shown the various mineral resources of the U.S.S.R. The country has all the varieties of metals needed for industry, as well as the so-called non-metallic minerals such as coal, oil, peat, various salts, asbestos, graphite, magnesite and different building materials. These resources are not only diverse, but also extensive, i.e., their reserves ensure industrial development for many decades.

Suffice it to say that the U.S.S.R. holds one of the world's leading places in the most important mineral reserves. Only the United States of America can in any way compare with us in the diversity and extent of the mineral resources.

The resources of all the other countries are very uneven. For example, Germany has a lot of coal and salt, but little iron, copper and other ores and hardly any oil. There is but little oil, coal and iron ores in Japan and Italy. Spain abounds in iron, copper and mercurial ores, but is poor in coal and oil. Switzerland, a country of continuous mountains, is very poor in minerals, except building materials.

The shortage of the most important ores and fuel was one of the causes of aggressive wars and the striving to seize colonies on other continents. Spain conquered Mexico and South America because they had rich silver deposits, England subdued the Transvaal Republic because the latter had rich gold resources. One of the important causes of modern imperialist wars is the struggle for minerals—ore, coal and oil. During the Second World War Germany and Japan primarily strove to conquer the countries that supplied them with the minerals which their own territories either lacked or had in insufficient quantities.

XIII

THE YOUNG PATHFINDER

What the Traces on Snow, Sand, Mud and Stone Tell Us. Fossil Traces: Raindrops, Ripples, Molehills and Mollusc Pits. Archive of Manuscripts and the Archive of the Earth. Examples of Trace Studies. Studies of Outcrops, Relief and Minerals. Fossils, Their Collection and Preservation. Pathfinder's Equipment.

If you ever go skiing out of town, not where hundreds of skiers have furrowed the snow in every direction but farther out where the surface of the recently fallen snow is intact, see if you can find tracks of animals and try to tell whom they belong to. Learn to distinguish the tracks left by a hare, a fox, a dog, a wolf, a crow, a sparrow or other small birds.

You can tell bird tracks by their form and the fact that they end abruptly; besides, near the footprints you can always see traces left by the birds' wings as they take off.

It is also interesting to observe the tracks on the surface of quicksands away from wells where they have not been trampled down by the cattle going to water. There you can see tracks of a hare, a fox, a gopher, a lizard, various birds, beetles and even snakes. If you spend a few hours hiding in the bushes to check on your conjectures you may see some of the creatures who have left the tracks.

In the moist sand or silt of the flat shores of lakes and seas or in the sticky clay of *takyr* freed of water you can also observe traces of various animals, but these will live longer than the tracks on the snow or sand. The latter will be destroyed by the next snowfall or wind, whereas the traces in the clay will dry together with the clay and will be preserved till the next inundation which will not destroy them, but will cover them over with a new layer of clay, i.e., will fossilize them (Fig. 272).

Many years later when the sea recedes or the modern littoral deposits are raised the processes of weathering or erosion will destroy the clay that has covered up the traces and some investigator will notice and describe them.

Such fossilized traces have already come to the notice of scientists of different countries and have been described by them. They are traces of large and small reptiles, who roamed along the moist shores of lakes or seas (Fig. 273) deeply pressing in the soft soil with their weight, and tracks left by worms and crustaceans creeping in the soft coastal silt. They were covered over by a new sediment during inundation and were preserved.

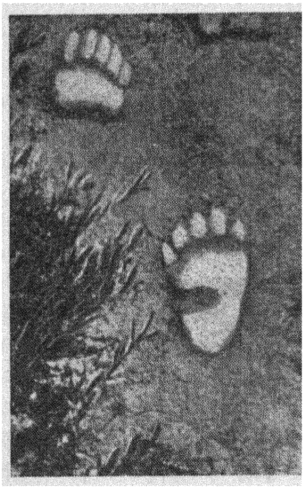

Fig. 272. Bear tracks on argillaceous soil of a mountain slope, Kamchatka

We have thus accidentally learned that there are not only fossil animals and plants, but even preserved fossil traces; they are the ephemeral, i.e., short-lived, imprints of the feet of a running animal or of the body of a creeping creature. We shall now no longer be surprised to find that even the imprints of separate *raindrops* are preserved as fossils; these at one time fell on a dried-out shore of a lake or sea and now appear as flat and round dents of various diameters surrounded by a barely perceptible swelling, the dents being made by the drops in the surface of silt or clay (Fig. 274).

There are also traces of the billowy motion of water in the form of so-called *wave ripple marks* and ripples of currents, i.e., the unevennesses formed on the surface of a sand or clay floor by the light agitation of the water in a lake or sea or by the flow of a river (Fig. 275). These traces consist of flat crests separated from each other by grooves, i.e., flat indentations resembling the ripples caused by the wind on the surface of sand (as we have learned in Chapter V). They are frequently incorrectly referred to as wave-cut marks, i.e., they are connected with the crests formed on the shore; the latter occur much more rarely and have other contours (Fig. 276). By a careful study of their structure, the shape of the crests and the size of the grains on the crests and in the grooves, it is possible to determine whether these ripples were made by the wind on land or by the current or the waves underwater, and to ascertain the direction of the current, the waves or the wind.

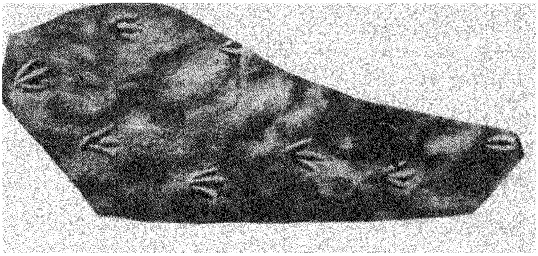

Fig. 273. Tracks of a tridactylus reptile walking from the beach into shallow water found on a sandstone slab in the Lily Pond layers, Massachusetts, U.S.A.

On the steep bank of a river or in the side of a ravine, in the wall of a hole in which sand or brick clay is dug you can see under a layer of dark vegetable earth or black earth, in the yellow subsoil grey and black, round or irregular spots of various sizes. These are fossil *molehills* or animal burrows filled in from above; in these we find the bones of the animals or the remains of their food. On blocks of some rocks, especially limestones, on the sea-shore above its present-day level we often find many strange deep pockets. These are holes drilled by bivalved molluscs which stayed in these pockets when the water level was higher and covered them. Even the valves are found in the holes. They prove that the shore has risen, the sea receded or its floor has sunk.

All these traces are documents which enable us to judge of the distant past of our Earth. They are like the manuscripts kept in archives by which a historian judges of the past events in the life of a given country. The historian studies not only the content of the manuscript, but also the print, the representation of the different letters which changed as time wore on; he studies the colour and quality of the paper and the colour of the ink in which the manuscript was written. More ancient documents were written on parchment made of skin or on papyrus made of the lotus.

Still older documents were not written in ink, but were cut out on wooden tablets or pressed on clay tablets which were then baked. Still older ones, i.e., documents of the times when man

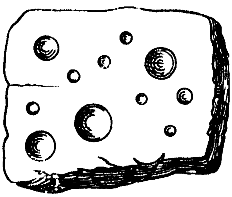

Fig. 274. Raindrop imprints on a stone slab

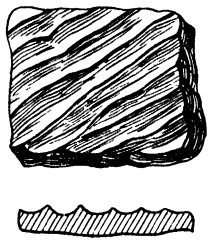

Fig. 275. Ripples on a slab of stone; below—section of the slab across the crests

had not yet invented characters to depict the words of his speech, but had already learned to draw the animals which he hunted or which he fought for his life, are pictures made in red or black paint on the walls of caves and on smooth surfaces of cliffs or hewn on them by a chisel. The historians, archaeologists and anthropologists need all these documents to ascertain the history of man.

But geologists are also interested in the drawings of ancient man because they give them an idea of the animals that existed in his time. Thus, the picture of the mammoth (Fig. 277) despite its crudity correctly conveys the general shape of the body, the position of the tusks and especially the hairiness which suggests that the animal lived in a cold climate. In this connection it is worth while comparing this ancient picture with the reconstruction of the mammoth made by modern scientists on the basis of the corpses of this animal found in the ever-frozen soil of Northern Siberia (see Fig. 266).

The history of the Earth is also studied from documents, i.e., the traces which we have pointed out and the still more numerous ones left by all the geological processes as the latter form and change the face of the Earth. The totality of these traces represents an enormous geological archive which the geologist must learn to read and interpret, as the historian reads and interprets the manuscripts of a state archive.

The geologist follows these traces step by step carefully studying them, comparing them with each other and combining

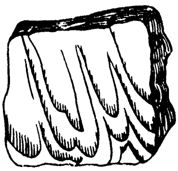

Fig. 276. Wave-cut imprints on a stone slab

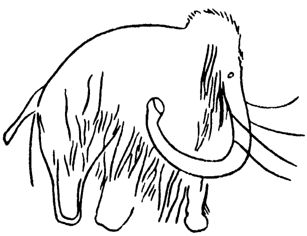

Fig. 277. Drawing of a mammoth made by primitive man

his observations in order to arrive at definite conclusions. The geologist is essentially a pathfinder.

Studies of Outcrops. In the preceding chapters we have described the various geological processes and their results, i.e., the traces they have left. We shall now give several examples to show how these documents of the Earth archive are to be interpreted.

We are studying a mountain valley cut into folded strata of sedimentary rocks—limestones, sandstones and shales—and find in the bed of the river and in the sides of the valley boulders of granite, a rock that does not occur anywhere within the confines of this valley. Where have they come from? We shall say: they are probably erratic boulders brought by a glacier which at one time flowed over into this valley from the neighbouring valley. By carefully studying the shape of the valley we shall notice that in its cross-section it is neither triangular nor trapezoidal, but trough-like, i.e., it is shaped like the valleys along which glaciers moved (see illustrations in Chapter VI).

On the floor of the valley we shall run into a barely perceptible cross swell or group of hills with closed depressions in between; in the outcrop we shall find the swell or the hills to be built of boulders of different sizes bound by clay and some of them to be polished and covered with scars. It is clear that this is an old terminal moraine. The erratic boulders, the shape of the valley

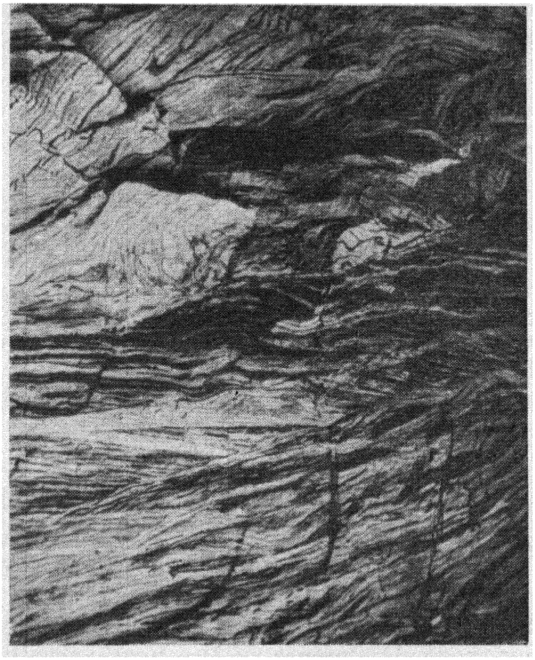

Fig. 278. Oblique stratification in Devonian sandstones. Salair Mountain Range, Western Siberia

and the terminal moraine prove that the valley in question was at one time occupied by a glacier which has left these documents. By combining our observations made in different parts of the valley we shall come to the conclusion that will elucidate a whole page in the history of this area, a page that suggests its former glaciation.

In a steep bank we saw a thick series of layers of loose sandstone, almost sand, in which the stratification, i.e., the occurrence of the various thin layers, is not parallel to the upper and lower surfaces which delimit each layer, but runs obliquely now to the right and now to the left and is tipped at different angles. This stratification is known as *cross lamination* (Fig. 278) and is characteristic of the depositions in a medium in which the

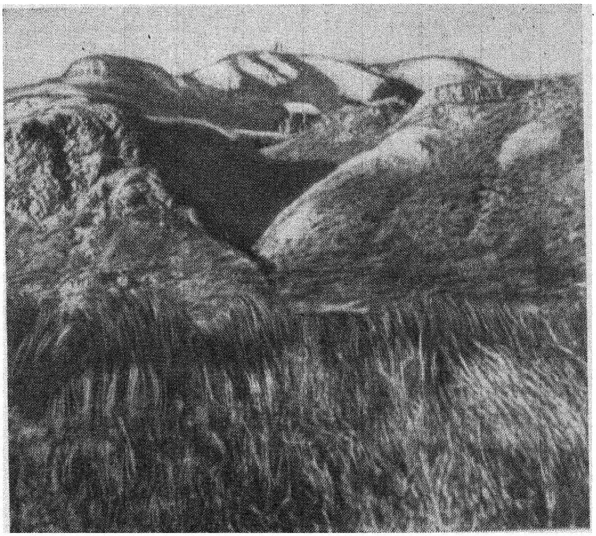

Fig. 279. Transgression of Lower Tertiary deposits (white hills in the background) on greatly deranged coal layers (grey hills in the foreground). Tuzdy-Jelanchik, Turgai Depression, Kazakhstan

direction of the current frequently changes as, for example, in a river bed, near a flat sea or lake shore, and in quicksands on land.

The geologist can decide by a number of fine marks in what medium—on land in the form of dunes and barkhans, in a river or in standing water—this thick bed of sand was deposited.

In the side of a ravine or on the bank of a river we have found a precipice at the bottom of which there are layers of sedimentary rocks (for example, shales) steeply inclined to the right (Fig. 280). They appear to be cut off in the middle and are covered with a layer of a conglomerate gently sloping in the same direction; we shall examine the pebbles of the conglomerate and note that part of it is the same shale that occurs below, the other part being composed of other rocks. Upward along the layer the amount of pebbles diminishes and the conglomerate passes into sand. In the latter we have found imprints of Jurassic plants and in the shales, shells of Lower Jurassic ammonites.

This outcrop has told us a long story: judging by the shales which at one time constituted fine silt deposited far from shores and by the ammonites which swam in the open sea, during the Lower Jurassic epoch this area was covered by an open sea.

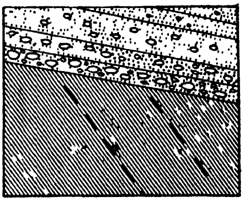

Fig. 280. Conglomerate transgression over the heads of older slates

Then intense dislocations occurred: the shales were folded, the folds at one time forming part of a highland, which was later deeply eroded, and a conglomerate was deposited on the heads of the shales as early as the Jurassic epoch.

But the subsequent history is unclear: in the sandstone we have found only imprints of plants and we cannot say whether this was a transgression of the sea which advanced on the highland, or the conglomerate was deposited by a river which eroded a valley in the mountains or on the shore of a lake; it is also unclear when this happened because the plants have enabled us to determine their Jurassic age only in a general way. The documents in this outcrop are thus incomplete, and to clear up a number of questions we must look for other outcrops in the same area. We often encounter such gaps in the history of the Earth and they are filled but very slowly by the detailed studies of the country conducted by many investigators.

Not only the composition, but also the colour of the sedimentary rocks and their grain size are important for the pathfinder's inferences. Red colour shows that the land from which the material of sandstones, marls and clays was carried off had a hot but sufficiently humid climate in which low-hydration red iron oxide is formed, whereas in a moderate and humid climate this oxide is yellow and highly hydrated. The green colour is most frequently due to iron oxide compounds and indicates that on the floor of the basin in which the green sedimentary rocks were deposited the water contained insufficient oxygen to oxidize the protoxide, or else there were conditions that fostered deoxidation of the oxide with a change of the red or yellow colours into green. The very fine grain of sedimentary rocks possessed by slates and pure clays proves that they were deposited from the finest suspension in the sea far from the shore or in land basins where only such suspension found its way. Layers of pure clay are often interbedded with strata of sandy clay or clayey sandstone which indicates that the conditions under which these materials were transported periodically changed. For example, very thin layers of pure and sandy clays are interbedded in the glacial clays; the former were deposited in winter when glacial melting diminished and the weakened subglacial waters brought only the finest particles, whereas in the summer the more abundant waters also brought fine sand. These are varved clays and the number of their layers has enabled the scientists to determine how many thousands of years the retreat of the ice sheet in Scandinavia lasted, as was pointed out in Chapter VI.

The first task of the geologist-pathfinder is thus to *study the outcrops*, i.e., the natural outbreaks of the rocks wherever they are found in the investigated area. He must determine what rocks form the outcrop, the order in which they lie on each other, their composition and colour, their horizontal or dislocated position and their conformity or unconformity. He must also measure the strike and dip of the beds, if they are disturbed, and trace the fissures if the latter form regular systems and cross all the beds.

If the outcrop consists of igneous rock the pathfinder's objectives somewhat differ. The intrusive rock will present either a uniform mass in which he will have to measure the fissures and the arrangement of the crystals by which it is possible to trace the direction of the magma flow, or he may be able to observe *inclusions* of some other rocks seized during the invasion, or *pockets*, i.e., accumulations of one of the minerals of which the rock is composed (dark, for example, black mica, and more rarely light—felspar and quartz).

Volcanic rocks may reveal lamination, i.e., interbedding of lava sheets of different composition and structure, or interbedding of lava and tuff. In this case the pathfinder must find out their mode of occurrence.

The presence of both igneous and sedimentary rocks in the same outcrop complicates the pathfinder's tasks. We have found, for example, that granite adjoins a bed of sedimentary rock consisting of sandstone (Fig. 281). A careful study of the boundary between them, the *contact*, will show that the sandstone near the granite is not normal but modified, metamorphosed, and that here and there thin veins issue from the granite and cut into the layers of sandstone. This is enough to say that the granite is younger than the sandstone, while the fossils in the

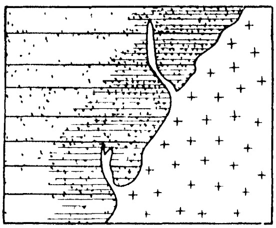

Fig. 281. Contact between young granite and older sandstone

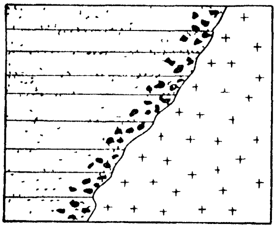

Fig. 282. Contact between ancient granite and younger sandstone

(sandstone on the left, granite on the right)

latter will help to estimate the age of the granite; for example, if they are Upper Devonian the granite is younger than Devonian.

In another outcrop of the same area we will find the same granite adjoining a bed of sandstone which at first sight is like the one in the preceding case (Fig. 282); but a study of the contact will show that there are no veins of granite in the sandstone and that the sandstone is not modified but contains small fragments and individual grains of granite near the contact. This proves that the granite is older: it has not only hardened, but because of the erosion had even come out to the surface and sandstone was deposited on its eroded slope (Fig. 283).

If we find fossils, say, of Lower Permian age in the latter we shall infer that the granite is older than Permian, and by combining both outcrops we shall establish the intrusion of granite to have occurred during the Carboniferous period and rather in the beginning than at the end, since the erosion of the intrusion must be given sufficient time.

Studies of the Relief. The second task of the geologist-pathfinder carried out parallel with the first is the study of the territory's relief whose relation to the composition and structure of the earth's crust he must know in order to ascertain the history of this area. He must find out if it is part of a highland, plateau or plain, or a combination of these forms, if the highland

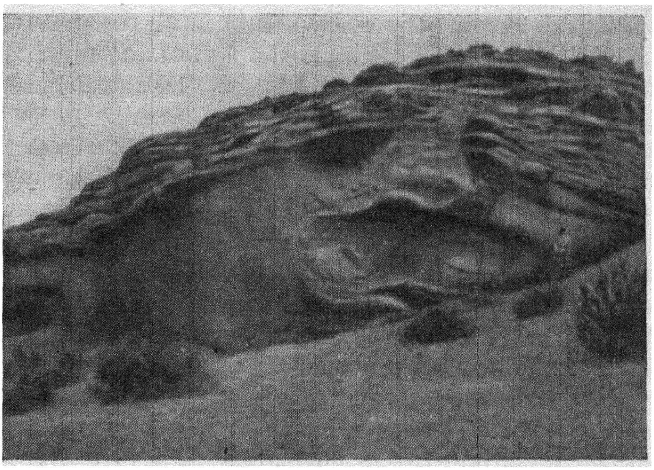

Fig. 283. Jurassic sandstone bedded on older granite. Kok-Tal at the northern foot of the Jair Mountain Range, Jungaria

has sharp so-called Alpine forms or more rounded and smoothed and therefore called mountains of medium height, or if they are perchance wide swells or chains and groups of hills. The forms of the elevations, the nature of the sides of the river valleys and their width, the presence or absence of river terraces, the specific features of the stream beds and lines, etc., will enable him to determine the stage of the erosion cycle at which the investigated area is. The age, composition and mode of occurrence of the rocks in the outcrop in aggregate with the relief will help him to ascertain in some detail its history, but this will in turn depend on how good or bad the outcrop is, the thoroughness of the study and the experience and diligence of the pathfinder.

By way of example let us take a peneplain, the stage of senility in the erosion cycle. Flat hills or so-called residual mountains or rock pillars rise on it here and there; in some places we find a ridge of hard rocks, a smooth granite outcrop protruding from the grass or its gruss covering the soil amid the grass; in a ravine we see outcrops of several destroyed layers of sandstone, limestone or slate. The geologist-pathfinder will study all these documents, which at first sight appear to be of little importance, will measure the position of the layers, their strike and dip, will determine the composition of all the outcrops, will find fossils in them, will estimate the age of the layers and the sequence of the past events, will plot his observations on a map of the area and will tell his unlearned companion (who is helping him in his work) the entire history of this country: the mountains that at one time rose on the site of this plain, the rocks of which they were composed and the direction of the mountain folds; he will also tell him if these mountains had any volcanoes or igneous massifs in their depths, when they were built and when destroyed. In studying the traces—the documents of the former events—the geologist-pathfinder divines the history of the area through which his companion walked for many years ignorant of the fact that he was trampling the last remains of Alpine mountains, the area in which he unnoticeably crosses former high mountain ridges and calmly sits in the grass on a site at one time covered with the seething lava of a volcano.

The third task of the geologist-pathfinder, carried out simultaneously with the former two, is to find and study the various types of *minerals* which may occur amid the rocks in the area explored. He must determine their quality and mode of occurrence and on the basis of these data ascertain if the discovered deposit is worthy of any reconnaissance without which it is in many cases impossible to decide whether or not there is sufficient mineral in the various outcrops, i.e., whether it is of any practical importance. If it is a good outcrop it is possible roughly to estimate the probable amount of mineral by local observation and by a laboratory study; the analysis will establish the percentage of ore or other mineral in the vein, deposit or rock. If the outcropping is inadequate it requires prospecting—deepening of prospect pits, digging of more or less deep ditches on the sides or on the plain and boring of holes. This constitutes the tasks of reconnaissance in which the invention of precision instruments has made it possible to use *geophysical* methods in recent years; these methods are based on a determination of magnetism, electrical conductivity, gravity and propagation of seismic waves produced by explosions in various rocks and minerals.

In his search for minerals the pathfinder must take notice of the remains of ancient ore workings—funnel-shaped holes, crevice-like excavations, filled-in mines and adits, accumulations of ancient slags and foundry forms, etc.; deposits from which ore was mined in prehistoric times may be found near these old mines.

Fossils, Their Collection and Preservation. We already know that the remains of the formerly existing animals and plants buried in the layers of sedimentary rocks are of great importance for determining the relative age of the thicknesses in which they are found. They indicate not only the age, but also the environment in which the given organisms existed. Thus the remains of algae show that the rocks were deposited in water, while remains of land plants suggest deposits in lakes, swamps or seas but close to the shore (if the layers that contain them are interbedded with strata containing marine organisms).

The bones of land mammals are found in land or lake deposits. Shells with thick valves live in a shallow sea where the waves go down to the bottom, whereas shells with thin valves live at great depths. Fossil corals suggest warm sea water, certain molluscs—cold water. Shark teeth are found only in marine deposits, while testae of Palaeozoic fish are encountered in deposits at the mouths of rivers, lagoons and shallow seas. Imprints of insects are known exclusively in continental deposits.

Marine deposits, especially in shallow water, contain more fossils than do continental deposits, and their fauna is of greater diversity; they abound in sponges, corals, sea lilies, brachiopods and crustaceans. Only the lowest forms—various foraminifers, radiolarians and diatoms can be found in the deepest water deposits.

In continental deposits the remains of plants occur more frequently than those of animals, though in some places the latter are plentiful and the bones of vertebrates form continuous layers as, for example, in the Permian deposits along the North Dvina, the Triassic deposits of Kirov Region, and the Cretaceous and Tertiary deposits of North America, Mongolia and Kazakhstan.

The sedimentary rocks that most frequently contain fossils are marls, bituminous and argillaceous limestones, calcareous and glauconitic sands, and not infrequently also sandstones and argillaceous shales. Quartzites and quartz sandstones are usually very poor in organic remains; the conglomerates may contain only large and hard remains which endured friction and shocks of pebbles and boulders in the zone of the surf or in the stream bed as, for example, the bones and teeth of vertebrates, thick valves of shells and stems of plants. The organic remains, especially of animals, are frequently responsible for the formation of lime-rich concretions totally enveloping the fossil which is discovered when the concretions are broken up. The latter contain ammonites and other molluscs, fish, bones of vertebrates, even whole skeletons around which the concretions gradually formed. The concretions in the layers of sedimentary rocks must therefore be broken up to see if they contain any fossils. There are, of course, no organic remains in intrusive rocks; they are extremely rare in volcanic rocks, but in tuffs, especially fine-grained and clearly stratified, we sometimes find very good imprints, particularly of plants.

Fossils occur in rock either separately (singly) or may be plentiful and even form continuous layers. Such layers are built, for example, of corals, algae, brachiopods, molluscs, and bones and their fragments. Corals form whole fossil reefs, algae—thick strata, and shells—shell banks. Plants most frequently form imprints in thin layers of rock which may abound in them all along its surface. Beds and veins of coal consist wholly of vegetable material, which has been transformed into a continuous mass; individual forms (leaves and stems) are rarely distinguishable, though good imprints often occur in the soil or the roof of a coal bed.

The remains of invertebrates present the hard parts of their bodies—shells of molluscs and brachiopods, stems and arms of sea lilies, testae and needles of echinoderms, shells of foraminifers and testae of crustaceans, the original material being replaced by lime carbonate, more rarely by silica and sometimes by sulphur pyrites; the place formerly occupied by the soft body parts are also filled with rock.

Separate bones or whole skeletons, horns and teeth of mammals, scutes of testaceous fish, reptiles and amphibians, as well as their teeth and needles, are also preserved. Only in exceptional cases, in the ever-frozen soil of Siberia and in asphalt are the soft body parts, viscera and skin preserved.

These finds are of particularly great scientific importance. They have made it possible to reconstruct the exact likeness of the hairy rhinoceros and mammoth, whereas the numerous reconstructions of other higher animals made by different scientists are not so reliable; they were made on the basis of skeletons, often very incomplete and without any data pertaining to the nature and colour of the cutaneous covering.

It is always easiest to discover remains of animals on the weathered surface of rocks, in outcrops and screes at foothills because they are of a different composition, sometimes harder than the rocks that contain them and therefore somewhat jut out during weathering and free themselves during the destruction of rock. That is why the geologist-pathfinder first of all carefully examines the small products of weathering in the screes, on the surfaces of blocks at the foothills and on the surface of the outcrop itself. If the rock contains any fauna the latter will always show itself during such examination. But the fossils collected in screes and separate blocks must not be confused with those obtained in the outcrop itself because they could have fallen out of different horizons of the latter. During geological studies each outcrop receives a separate number in the description and on the map, while the layers of the different rocks of which it is composed are designated by individual letters under the same number. The fauna obtained in the outcrop itself will therefore have a number with a letter corresponding to the layer from which it was taken, whereas the fauna collected in the scree will have only a number.

The pebbles in the bed of a stream or river are not infrequently rounded fossils and serve as a clue in the search for the outcrop of a corresponding rock higher upstream.

After the discovery of organic remains in an outcrop the former are extracted with the aid of a hammer and chisel, an attempt being made to obtain a large piece containing the remains so that this piece may later be carefully cleaved into layers or chipped off on the edges if the rock is not stratified. Of course, one should never strike with a hammer the fossil itself. A piece containing a lot of remains should best be taken home as it is in order that it may be thoroughly attended to at leisure. If the rock is soft the fossils are cautiously extracted together with the enveloping rock with the aid of a chisel. The fossils taken from different layers of one outcrop, and naturally those obtained from different outcrops, must not be mixed. The memory should not be relied upon; each sample must immediately be given its number and letter, inscribed in indelible pencil on the sample or a tag, and must be wrapped in paper.

Vegetable imprints on the bedding plain of shales or sandstones for the most part consist of a thin film of coal which easily breaks off. For transportation they must therefore be covered with a pad of cotton and then wrapped in paper. Cotton is also used to protect fragile shells, small bones, imprints of insects, etc. Small shells and other remains are best stored in boxes or tin cans; they must be interlaid with cotton and contain tags indicating the outcrops and layers. The fossils wrapped in paper are taken home (or the pathfinder's camp) in a knapsack or kit-bag (or an ordinary bag or basket), re-examined, supplied with accurate tags showing where obtained and then stored in boxes. To avoid confusion during the examination and comparison each sample should have its number and letter inscribed in indelible pencil. If the samples are to be mailed to another city they must be wrapped in cotton and paper and tightly crated.

The concretions in which fossils are suspected are best placed in a small fire, well heated (not incandesced, however) and then either put in or under water as a result of which they break up splitting along the surface of the fossil and freeing the latter. The bones of vertebrates are often contained in enormous concretions which can be extracted only by special excavations and experienced people. If the pathfinder discovers such concretions he should only record them and note their exact location on the map in order to report them to the Academy of Sciences or a university which may arrange for excavations. In some cases such bones may be contained in clay, loam, sand or sandstone but in so decayed a state that they easily crumble when attempts are made to extract them; an inexperienced pathfinder must not endeavour to extract them, but make note of them and mark them on the map and then report them where necessary because the extraction of such remains requires special methods and experience (Fig. 284).

Pathfinder's Equipment. Here we shall not describe the equipment of an expert geologist going on an expedition because this is dealt with in corresponding manuals. We can only suggest the equipment of an amateur who wants to learn the methods of field work and study the geology of the area in which he lives.

The equipment of a geologist-pathfinder consists of a hammer, chisel, miner's compass, notebook, magnifying glass, bag or net and a small stock of wrapping paper and cotton.

Hammer (if obtainable)—so-called geological, one end of the head blunt and the other sharpened as a wedge crosswise to the handle or pyramidally as a hack; the latter is convenient for

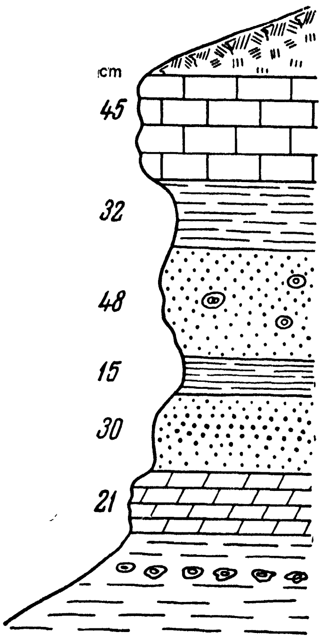

Fig. 284. Sample of sketching and recording the outcrops of rocks in the geologist's notebook

work in loose rock, the former in hard rock. It should be of average size, its head weighing about 500 grammes. If no geological hammer is available a forge or upholstering hammer will do but the hammer must not be too soft for work in hard rocks or it will flatten out from the shocks and will soon become worthless.

The *chisel* is a band of steel, 5 to 6 inches long and weighing between 250 and 500 grammes, elongated at one end having a round or rectangular cross-section; it should have some steel welded at the sharp end which is required for knocking out the minerals and fossils and for chipping off pieces of rock; for work the sharp end is put into the fissure and the blunt end is hit with the hammer.

The *miner's compass* differs from the ordinary pocket compass in that the case with the limb and magnetic needle is fastened to a brass or aluminium, square or rectangular plate and that the points E and W, i.e., east and west, are interchanged. The limb is graded counter-clockwise from 0 to 360°. In addition, a small weight with a pointer is suspended under the needle on its pin and graduations from 0 to 90° are made on the limb on both sides of the letter E to measure the dip of the beds. When buying the compass make sure the needle has a clamp in the form of screw outside the case (it must press the needle to the glass while the compass is in the pocket), and see that it works freely and that the needle swings well, the swings gradually diminishing. The compass case must have a brass or aluminium lid. It is advisable to have a leather or strong cloth case for the compass. Compasses made of plastics are now available.

A pocket *magnifying glass* is required for examining fine-grained rocks, fossils and minerals; magnifying glasses come in metal, horn and bone rims. A five-fold magnification is desirable.

A *notebook* and pencil are needed for recording the observations; checked paper for sketching the outcrops is preferable.

A *bag* is necessary for carrying the collected samples, food for long trips and a stock of paper and cotton. A knapsack is spacious and no hindrance in work, though it has to be taken off the back for anything to be put in or taken out. The nets used by hunters for the game and field bags suspended from a strap are also good for the purpose.

Paper and *cotton* are needed for wrapping the samples of rocks and fossils provided with tags and numbers so that the latter may not be mixed up in transportation.

The pathfinder should have several small bags for loose and crumbling rocks; these are easily made of paper. It would be still better to have about 20 to 30 little bags (15-16 centimetres long and 10 centimetres wide) made of canvas or coarse calico with strings attached and numbered in indelible pencil; the collected samples of rocks are best put in these bags in the order of their collection, the pathfinder marking in his notebook only the number of the bag with the sample of a given outcrop. This makes the wrapping of the sample in paper and writing out the tag in the field unnecessary. All these operations are then performed at home during the sorting of the collection, the bags being freed for the next excursion.

The pathfinder will do well to keep a *diary* recording in detail (in ink) all the observations made during the excursion. In the field the observations may be written down in the notebook hastily and concisely during the sketching of the outcrops. At home, while the memory is still fresh, the details are recorded and the drawing made accurately with the aid of crayons.

The *sizes of the samples* differ and are from 3×5 to 7×10 cm. (width and length; the thickness depends on the quality of the rock, but in general should not exceed the width). A young pathfinder does not need large ones. The samples should be chipped off on several sides so that they have fresh fractures rather than a weathered surface. Fossils must naturally not be chipped. The collections should be kept in little flat cartons the size of the samples.

The pathfinder should have a *penknife* for sharpening pencils and testing the hardness of minerals and rocks. It is good to have a *tape-measure* at least one metre long for measuring the thickness of the layers and veins.

If possible the pathfinder should have a good *topographic map* of the area; it will prove very useful for his orientation, the choice of routes and recording the examined outcrops. The map should be cut into pocket-size parts and pasted on canvas or calico because a paper map folded to this size soon wears out in the folds if carried in the pocket. The map must be carefully guarded against moisture and if it gets wet it must be cautiously dried and smoothed out.

It is good to have a portable *camera* to photograph the relief of the terrain and the outcrops in addition to describing them.

We shall point out in conclusion how the mode of occurrence of the strata of sedimentary rocks is to be determined with the aid of a compass. In its inclined position each layer has a certain strike and dip at some angle to one side or another; the measurements of the line of strike, direction and angle of dip determine the mode of occurrence. Choose a level ground on the stratification plane of one of the layers in the outcrop and place the compass on it with the long side of its plate in a *horizontal* position; by drawing a pencil line along the edge of the plate you will obtain the strike AB. Release the clamp of the compass needle, wait till it stops and record the reading of one of its ends. Let us assume that one end reads NE 40° and the other SW 220°. The strike consequently has an azimuth NE 40° or SW 220°; a record of the northern points is preferred for the sake of uniformity. Now turn the compass plate 90°, i.e., place its narrow side against the strike but so that the *northern* end of the plate, i.e., the part of the limb with point N, is in the direction of the tilt of the layer. Record the reading only of the *northern* and not the southern end. Suppose it is NW 310°; the

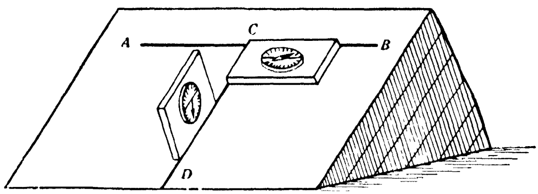

Fig. 285. Measuring the strike and dip of the beds

layer with a south-west to north-east strike has a north-western dip. The azimuth of dip must always differ from the azimuth of strike by 90° because the line of dip is always perpendicular to the line of strike (Fig. 285).

Now turn the plate of the compass on the side and place it vertically, long side on the CD dip line; the weight rotating on the pin of the needle will show the angle of tilt, i.e., the dip of the layer to be, say, 32°. The results of the measurements will be recorded thus:

Strike NE 40°; dip NW<32°.

We do not record the azimuth of dip because it differs from the azimuth of strike by 90°. The record can therefore be limited to the dip alone, but this requires the record of its azimuth, i.e., NW310°<32°. This record fully determines the strike to be NE 40°.

If the pathfinder has only an ordinary pocket compass in a round case he will be able to determine the strike and dip only approximately, by sight, comparing the direction in which the line of strike deviates from the north-south line of the compass, to which the needle must correspond, with the direction in which the layer is tilted. The angle of dip will also be estimated by sight.

The strike and dip of veins and joints are measured the same way as the layers on a level ground. If there is no such ground the measurement is made by sight in the air and is, of course, not so accurate.

* * *

We are finishing our book in which we have endeavoured to instil in the reader an interest for the science about the Earth and its practical importance, as well as to explain what can be observed and how on the vast territory of the U.S.S.R. with a modicum of training and the simplest instruments. The natural conditions in the Soviet Union are so diverse that the young pathfinder will find sufficient material for observation of the composition and structure of the Earth and its relation to its present relief wherever he lives. He may discover and collect fossils, describe interesting outcrops, find signs of minerals and become a connoisseur of the surrounding country. It has been the aim of this book to acquaint him with the fundamentals of geology and to help him in this work.

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