The Fourth Ingredient

M.S. Brook
Translated from the Russian by V.A. Epshtein

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From the blurb:
A fascinating and easily understandable narrative is devoted to soil-exploring sciences and describes the history of soil science from ancient time up to present days. It discusses science problems occurring in the 19th century among chemists, agronomists, geologists and biologists.

The author expounds the soil's evolution version between “primitive” volcanic formations and present-day chernozen and podzol soils. Emphasis is on the role of flora and fauna and on the activities of microorganisms which converted lifeless lands into fertile ploughed fields.

Also discussed are issues dealing with melioration, chemization and cultivation of various land types.

Look Under Your Feet

(in lieu of a preface)

Today we often speak of saving the rivers and forests, pollution of air, lakes, seas and disappearance of the wild animals, every day we recall the word "ecology" and at the same time we hear rarely a word in defence of soil. Such an attitude to the fertile layer does not give rise to surprise: what is really the reason to be delighted with? What can happen with this layer?
The author tried to give an answer to these two questions in this book. Moreover, the author wanted to tell and show people, having no resemblance to their tribes, who saw not only simple amorphous lumps of dirt on the shoulder of the road but a wonderful creation nature - one of its kingdoms.

Then, the author had in mind another aim. It is not a secret that today a great number of people value the soil from the point of view of its fertility. If there is a good crop then the soil is rich. If there is lean soil it gives bad crop and therefore it is needless to protect it. Thus the main goal of the book, as the author wanted to show there are not bad and good soils in nature. Each type of the soil is a complex ecological system with major various laws. These systems connect plant kingdom with the animal one, land with ocean and minerals with life. At last, soil is habitat of a great number of living beings, the medium of complex chemical and biochemical reactions, and so on.

People must not live by means of their own interests, since they are only piece of nature.

It is impossible to study the objects and things that surround us every day without travelling into the history of our life, without changing people's attitude to fertile layer. It was not favourable at different times. Always the level of culture, the level of knowing the nature was principally important in handling with soil. Every cataclysm, degradation of morals and principles in a people society haven't bypassed our motherland. However, every person who will read this book, will see it.

Contents

Pre-Scientific “Science”

Whoever has read the book *The Golden Bough*, by James George Frazer, must remember his description of the wood-land lake Nemi surrounded by the green chain of the Alban Hills. "In antiquity this sylvan landscape was the scene of a strange and recurring tragedy. On the northern shore of the lake ... stood the sacred grove .... In this sacred grove there grew a certain tree round which at any time of the day, and probably far into the night, a grim figure might be seen to prowl. In his hand he carried a drawn sword, and he kept peering warily about him as if at every instant he expected to be set upon by an enemy. He was a priest and a murderer; and the man for whom he looked was sooner or later to murder him and hold the priesthood in his stead. Such was the rule of the sanctuary."

Whence this dismal figure and what does it have to do with the subject in hand? Alas, it has a great deal to do with it. "Why did the priest have to kill his predecessor?" the author asks himself in one of the closing chapters of his work. Here is his answer. "Now primitive peoples sometimes believe that their safety and even that of the world is bound up with the life of one of these god-men ... the fertility of men, of cattle, and of vegetation is believed to depend ... if the course of nature is dependent on the man-god's life, what catastrophes may not be expected from the gradual enfeeblement of his powers and their final extinction in death? ... The god-man must be killed ... and his soul, his divine spirit must be transferred to a vigorous successor before it has been seriously impaired by the threatened decay".

Thus here is the answer to the question. Back in Roman times the priest of Nemi symbolized inexhaustible fertility. Fertility of the earth? No. Fertility of nature. Hundreds of centuries ago a savage by his entire intuition, by his flair of a prehistoric hunter and gatherer - felt that there was some force which gave him his daily bread. Mentally, he endowed with this force in equal measure wild deer, bears, boars, trees and cereals. In those days man did not yet make a difference between the reproductive abilities of animals and plants. The soil simply did not fall into the scope of his primitive world perception. It represented a far too complex mechanism. Even when he ploughed up the land, threw seeds into it, and waited for the early sprouts and then the crops, man took some time to realize what force enabled the grains to produce hundreds of their likes. He must have thought that it all had been done by the seeds and ears as well as by water. And he proceeded to invoke rain, exorcise or protect the "grain spirit", worship the "mother of grain", etc.

That was how our distant ancestors formed the concept of fertility, which, millennia later, occupied the central place in soil science.

Another equally vital discovery was the calendar. As many as fifteen millennia ago and perhaps even earlier primitive hunters and gatherers noticed the cyclicity of natural phenomena. Plants wilted and revived and animals and man himself obeyed some "highest" rhythm. Man experiences everything - day and night, rain and dry seasons, cold and heat, good and hungry years. However, there was no need for exact chronology before the birth of agriculture. But already for the ancient ploughman the sequence of natural phenomena and correct time reckoning were of colossal importance. “The calendar” wrote the Soviet ethnographer Y. Knorozov, "became a powerful tool of the economy".

Possibly, the ancient agriculturists did not know even this state of the fertile layer. But they had the calendar painfully developed by the previous generations, which measured the course of time and contained a host of signs and beliefs. With their aid man corrected the timing of his agricultural operations - sowing, harvesting, etc. After all, weather is changeful, and rivers flood at different times.

However, man did not stay ignorant for long. A simple comparison of the size of crops on his own plot and on those of his neighbours and of the sowing times prompted to him that the seed fertility was related not only to the moisture, that there was also some other factor behind it.

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Thus, sunlight, water and plants .... What was the fourth component of fertility? Naturally it was the soil. By solving this problem, the agriculturist made another step along the path of the "Neolithic revolution". Regrettably, history does not - and cannot - make a reference to this quiet revolution in the world outlook of a "savage". After all, writing made its appearance much later.

True, there is indirect relevant evidence - data obtained by archaeologists. The early agriculturist settlements date back to the 9th and 8th millennia B.C. Finds made in the Cave of Ghosts in Thailand and in the Jordan Valley show that already in those times man knew many species of plants which are cultivated now. Furthermore, he had their cultivated varieties. What stood in the way of man's rapid enrichment, of the integration of scattered tribes into alliances and states and of the birth of great civilizations? Like those formed on the Nile, Euphrates and Indus three and four millennia later. Apparently, agriculture had not yet gained ground. The accumulation of the surplus product was a slow process. Knowledge was lacking. What knowledge? Wheat, barley, pumpkin, beans and other agricultural crops remained invariable for millennia, just as the basic labour tool - the hoe. Hence, the soil was the answer to the question.

When he recognized its ability to bear fruit man began to take a closer look at the choice of a plot of land for ploughing. By trial and error he established the first sign of the soil's high productive capacity - its colour. Excavations on the Deccan plateau in India showed that in the third millennium B.C. around the regurs - tropical black soils - had sprung up whole "urban agglomerations" each with a population of up to several thousand and with a lifeless desert spreading north of them.

In those days the banks of the Euphrates and Tigris were already the location of the mighty state of the Sumerians. Could it have flourished without fertile fields? Of course,' not. What gave them their strength? Above all, a powerful irrigation system. But how much water is required to ploughland? Won't it damage some lands and benefit others? Where will the use of watering be greater? After all, canal construction is a costly proposition. Whoever wants to create them should have· a good knowledge of soils.

And did the Sumerians and their heirs in Mesopotamia know much about soils?

To give an answer to this question let us look into one of the first calendars of agriculturists in history. "When you have begun to cultivate your field", teaches its author, "keep a sharp eye on the sluices and dam, the state of the ditches and weirs so that, when you have flooded the field, the watermark would not rise too high. When you have drained the water from the field see to it that the soaked earth should retain required fertility". Indeed, if the former advice is neglected the torrents of water will wash away the fertile layer, thus killing the sowings. Erosion did not spare the fields five thousand years ago any more than it does now.

The second precept is still more interesting. It discloses the Sumerian conceptions concerning soil fertility. Their "formula of well-being", on the face of it, looks simple - earth + water. But it is immediately provided with an explanation saying: "see to it that the earth should retain required fertility", i.e. don't miss the moment of soil "ripening".

Further, the calendar said: "Smooth over the field surface with little hoes which weigh two-thirds of a pound each". The hoe was then regarded as the agriculturist's main tool. But why should there be such an exact indication of its weight? There is only one answer to this question. In those days the Sumerians divided the soil not only by colour, but also by density, viscosity and other physical characteristics. This is confirmed by what is apparently one of the first poetic works written on the "production" subject. It is called *The Dispute between the Hoe and the Plough*:

> Take a look! Hoe, hoe, which bears a knot,
> Hoe made of mulberry, whose prongs are made of dogwood,
> Hoe made of tamarisk, whose prongs are made of "seawood"
> Hoe with two prongs, with four prongs ....

As the reader can see, this amounts to a large set for an agriculturist who practised many operations. The use of various hoe-marking materials was not a caprice, but a demand made by the soils on agricultural tools.

The texts of cuneiform tables also yield other information inviting reflection. One of them tells about the distribution of grain for sowing between fields. The amounts are not in proportion to the size of the plots. Why? The centuries-old experience is possible to give an answer of the number of grains that must be thrown into one or another soil. Even, with no exception that the Sumerians had a primitive cadastre of the arable land. But we can only conjecture what it was like.

It is possible that the denizens of Euphrates and Tigris were the first inhabitants who fought with wind erosion and desiccation of soil by means of forest plantations. According to a legend a Shukallituda guessed to plant trees on his land in such a way that a shadow ("karbaty") had never disappeared from the land. His estimation was right: the earth "sweats" weaker in the shadow and the soil pieces bound by moisture are better.

> "I studied the decrees of the gods.
> In the garden, in five to ten unapproachable places,
> In those places I planted one tree as a protecting cover.
> The tree's protecting cover - the sarbatu - tree of wide shade -
> Its shade below, dawn,
> Noon, and dusk, did not turn away."

The Sumerians were practical people. But then, this view is not shared by all. Another American archaeologist, Seton Lloyd, writes that present-day travellers in Iraq see consequences of impractical land use. Vast areas of land lie uncultivated being covered with one solid white crust - the result of overexploitation of the soils in the past.

Indeed, water in the local rivers and ground waters has an excess of salts. No wonder. The scorching sun drew them to the surface up the pores and the capillaries which thread the mass of the earth. Nevertheless, Lloyd jumped to conclusions. After all, the "salt smallpox" does tangible damage to agriculture to this day.

The leading Assyriologist Torkild Jakobsen also discovered in cuneiform texts direct references to the constant threat of salinization. He established that the worst damage had been done by salinization to the city-state of Lagash. Approximately 2500 years B.C. a white crust turned up on its ploughlands. It gradually robbed man of fertile plots and spread westwards. In a thousand years this "salt smallpox" crept up to the Babylonian fields.

So that was the reason for the rise and fall of the ancient Mesopotamian civilizations! However to recognize it means to agree that the creators of the greatest cultures were defeated by salt. A similar doubt was expressed by Jakobsen. This "epidemic" spread all too slowly in Mesopotamia! Only human resistance could account for this deliberateness. But complete confidence required relevant facts. Now, during excavations on the bank of the Diyala River, east of Baghdad, Jakobsen got hold of tablets with an unfamiliar cuneiform text. It has always been believed to be a futile occupation to search for a needle in a haystack, he wrote. What can be felt by a man who was lucky enough to drive a spade into earth and immediately to discover that he has found the missing "clay leaves" in the oldest guidebook on salt combating? he asked.

The Sumerians preferred to combat salt by water again. "Before you begin to cultivate your field," wrote an unknown land improver, "dig deep ditches around it. The deeper they are, the higher barley will grow. ... Set the fields at rest when you feel that they are tired and can no longer yield rich crops." Both methods are practised in our days. One of them is referred to as drainage, the other as fallowing.

Now guides taking tourists around Babylonia frequently point to a bare hill without any sign of vegetation covered by brick and tile fragments. Over two millennia ago here hummed trees, murmured brooks and sang birds. And all these wonderful groves had been created for one person, the queen of Media. Her husband, King Nebuchadnezzar of Babylonia, ordered to construct four tiers and planting them to vegetation. Each tier of the structure rested on twenty-five pillars which had on their top lead sheets poured over with bitumen and earth. It is earth that is of particular interest here. The oaks and grasses brought from the north failed to take on on Mesopotamian grounds. If follows that the builders knew the secrets of soil manufacture and which of them suited particular plants. If old-time texts deciphered by Jakobsen are to be believed, each tier was intended to have its own earth. Artificial "black earths" obtained from a mixture of clays and silt and washed clean of salts were used for oak planting. For date-palms use was made of local material, whereas broad-leaved African plants required a special soil - red soil. It was delivered together with the trees covered by moist mats.

This miracle appeared to be fragile, in contrast to the pyramids. But man remembered about it for thousands of years. For "The Hanging Gardens of Babylon" or "Semiramis's Hanging Gardens", as they were dubbed much later, became a monument to human genius - the first successful attempt to transform nature. This monument was made of "living flesh" but not of clay and stone by the nature itself and thus was the most impressive.

About 500000 years ago the powerful Egypt state appeared in the Nile Valley, far in the west from the Mesopotamians. Egypt was then called "Ta Kemet" or "A Land of Black Earth". The river which crossed it was found to be a bottomless treasury filled with a priceless wealth - silt. The Nile annually discharged excellent fertilizers evenly spreading them over its banks. Up to eleven tons of dark, almost black liquid "gold" fell to the share of each hectare of its floodlands.

The Egyptians did more than use its gifts. They realized that the river performed a host of operations which in other conditions they would have had to perform themselves. The Nile simultaneously watered and fed the fields and washed away the salts accumulated in the dry period, i.e. carried out many reclamative and agrotechnical operations.

"Under the first pharaohs a strict cadaster, i.e. rating of lands by their acreage, fertility and profitability was used in Egypt," the well-known Soviet scientist Igor Krupennikov writes in his work *A History of Soil Science*. But then, the Mesopotamians also realized that there were different soils. They distinguished them by one or two criteria - colour, hardness, etc. The Egyptians rose a step higher in the study of the earth, giving it names. Among the variety of the soils which surrounded them they identified wheat, steppe, water-swamp, orchard and grape soils. The wheat soils were more than suited to grain cultivation, but to irrigated areas water was fed by a special sluice system. Their price was among the highest. The steppe soils, which were not flooded by the Nile cost several times cheaper. The Egyptians took a special attitude to the grape and orchard soils. It will be recalled that the first forests planted in Sumer were used for protecting fruit trees from dry winds. The same natural hedge in Egypt already surrounded wheat and barley fields, plantations of figs, apricots, etc. Tending the trees which comprised a forest strip, their watering and, finally, the water itself are not cheap even in our days. In those days such plots could be owned only by exceedingly rich people, but the water-swamp soils were within everybody's reach.

From X-VIII B.C. papyrus one can get to know that the Egyptians were not satisfied with such a crude division. They distinguished two varieties of soils among expensive soils: wheat - the soils near the river or black "nemhuna", distant from water, or grey earth "sheta-teni".

A papyrus kept in the Brooklyn Museum says: "Gold and fields were counted regularly." Besides the dull reports of harvests obtained from the given field the most unbelievable flights of imaginations were put down on the papyrus. The fertility of soil was in the interests of everybody: from pharaoh to ploughmen in Ancient Egypt. And the Egyptians, although they lauded the Nile, believed that some way up north there was a land far more fertile than theirs. A popular "political detective novel" of those days, *A Story of Senuhet*, discusses a pharaoh's favourite who ran away from a carnage to the land of King Amunenshi (the coast of modern Lebanon). The ruler, Amunenshi, met him benevolently and ....

"He gave me a chance to choose land in his country - the best there was to be had there... it was red earth, dubbed Iaa. On it grew figs and grapes... on the trees were all sorts of fruit; barley and wheat... "

Suffice it to look at the soil map of the Near East to notice a narrow red strip which stretches along the sea. It is subtropical red earths. In the Soviet Union similar soils occur in Adzharia. Are they really fabulously fertile? Not at all. The abundance of heat and moisture makes it possible to cultivate many crops in the subtropics, but red earths soon become depleted if left unfertilized. And, of course, they were less fertile than the soils of the Nile Valley.

Egypt and the Mesopotamian countries became the first cultural centres to carefully collect and store knowledge about the fertile layer. So far, it is difficult to tell what "heights" were attained by the ancients in the study of the soils. One thing is clear: questions of processing, protection and reclamation of ploughland arose and were adjusted already in those times. This is evidenced by agricultural calendars and manuals discussed earlier.

But let us continue our journey eastwards - to China. In the words of Vladimir Vernadsky, over 4000 years ago it already practised an intensive form of agriculture.

Some data about the soil science of the Celestial Empire are contained in the book *Agriculture in China*, by Nikita Bichurin, published in Russia in 1844. It saw light almost 150 years ago, when its author had already become a recognized Sinologist. It all began with a graduate of a seminary, who turned monk and adopted the name of Hyacinth, being appointed head of a religious mission to Peking. He saw what was a new world to him. Then Bichurin plunged head and shoulders into the study of this unfamiliar country where he lived for fourteen years. In these years he attained a good command of Chinese and collected exceedingly rich material about the culture of the Celestial Empire. But in 1823 came a high decree of the Synod, and Hyacinth, stripped of the title of archimandrite "for slovenliness in religious affairs", was sent to the Valaam Monastery. There, between fasts and prayers, he found time for processing the collected material. At the same time he began to write a book about agriculture, a work which he gave eighteen years of his life. His book opened with the following words: "Long before our era in China people, guided by annual observations, accumulated many data about the land. The government fixed to the people the ploughing time, means of fertilization and methods of sowing and harvesting."

Where did it all begin?

Bichurin established this as well: "In 2280 B.C. a great flood ravaged the Empire, bringing many troubles to the people. Then the government decided to end the riot of the elements. Emperor Yao ordered Prince Yu to build dams and weirs." Due to the titanic efforts of the Chinese agriculturists a host of lands were wrested from the water. This is one of the hymns collected in the Book of Songs *Shih Ching* marked this event:

> The flood waters spread wide, very wide.
> Yu began to bring his lands into order.
> The vast kingdoms which had previously lain outside
> Were included within the bounds of our increased country.

Incidentally, the "kingdoms" had not lain outside the Empire at all. They lay within it. But they were conquered only by harnessing the waters. After all, these were ordinary swamps.

The swamp harnessing was depicted by Bichurin as well: "In draining the swamps Yu carefully noticed the soil layers ... divided the lands by the properties of the soil and location (i.e. Relief - M.B.) into three categories - good, middling and poor.

Hence, Yu was the discoverer of one of the basic principles of modern soil science - the dependence of land properties on local relief.

In those times an accurate "calendar of an agriculturist" had already been used in China. In the *Song About the Seventh Lunar Month* an unknown author gave detailed explanations as to what should be done on each lunar month.

At times amazing observations occur in *Shih Ching*. The ode *Thanks for the Crops* contains the following lines:

> Bitter grasses rotted where they grew. Now
> Millet riotously and lushly grows in panicles.

These two poetic lines epitomize an entirely new conception of soil fertility. Let's remember the formula of "land + water". Here the field productivity is made dependent on organic fertilizers and the biological circulation of matter, i.e. on the vegetation-soil relationships. Some twenty years ago a documentary *Reminiscences about the Future* had run at the movie theatres. Its directors raised an absolutely serious question: Could a pyramid or a canal have been built by helpless (by the modern standards) people? And they cited "evidence" of visits of non-earthmen to the Earth. Central and South America figured particularly large as scenes of such visits. Let us try to look into the question. Perhaps visitors from outer space really did some work in the Western hemisphere?

In those years the Soviet archaeologist V. Gulayev published the book *The Early Civilization of Meso-America*. In this book, but already from entirely different positions, the author discussed the amazing structures of Mexico. He wrote: "The economic basis of the civilization of Teotihuacan (Central Mexico - M.B.), just as of other classical cultures of Meso-America, was formed by highly developed agriculture." Indeed, in all corners of the globe it was the principal basis for creating pyramids, and hanging gardens, and the Great Wall of China.

But the soil requires water, and the Central Mexico did not have the powerful Nile, the unruly Tigris or Euphrates, only shallow river San Juan Teotihuacan, which collects a host of streams and streamlets that disappear in the dry season. All this is true. But close by the ancient capital of aztecs is salt Lake Texcoco, surrounded by a whole system of natural reservoirs filled with fresh water. It was they which gave water for "chinamps" - long narrow strips of land surrounded on three or four sides by water. Sometimes the chinamps are made of reeds and other water plants, directly on water. Such an island is covered by a fertile silt layer on top obtained from the lake bottom or canal. Marl was added to it, and the field was ready.

In Mexico the first "floating" ploughs date approximately 2000 years back. Archaeologists say that about two or three centuries B.C. large-scale reclamation schemes got under way around Teotihuacan. The chinamps became the pinnacle of agricultural art. However, they were not the only finds of the Meso-Americans. The Mexican archaeologist E. Matoz Moctezuma, studying the "classical zones of agriculture", arrived at the conclusion that "in ancient times the people of the Mexico Valley and the adjacent areas knew how to use underground waters in irrigating their fields" (V. Gulayev). The moisture lifted from the deep layers was directed into canals which belted the fields based on the principle of the already familiar chinamps. That was how the "green zones" which are used by agriculturists to this day came into being.

Meso-America mothered yet another great civilization, which won fame with its temples, palaces and the world's most accurate calendar. The state of the Maya, in contrast to the Aztec Empire, lay in the zone of tropical forests on the Yucatan Peninsula. Its climate was extremely damp, its soils were waterlogged. In these conditions, too, man learned to manipulate the soil moisture, now draining, now feeding water to the fields.

The American scientists David Friedell and Vernon Scarborough, developing an interest in these man-made swamps and, conducting painstaking excavations in Belize, discovered remnants of a ramified network of canals found to be 2500 years old. As it turned out, these canals performed three functions: they collected rainwater, helped accumulate organic substances, and rapidly drained the earth. In the rain season they became filled with water, and the earth between them remained good for cultivation. In the dry season the water of the canal irrigated the fields.

Friedell assumes that the Maya perfectly realized that waterlogged soil grew like mushrooms. Its peat – organic - horizon increased by several centimetres in five to ten years. Instead of felling or burning trees, the Indians let the fatigued fields rest by waterlogging them. And they received up to 7.5 centners per hectare of maize from these fields.

The Meso-American Indians' "soil science" can best be judged on the basis of their deeds. The chinamps, canals built on swamps, the use of ground waters - all this necessitated knowledge or at least some conceptions about the physical properties of the soil - its density, porosity, mechanical composition, etc. The use of organic remains and marling were among the early reclamative devices.

Now it is difficult to re-create a full picture of the knowledge about the soil in the ancient world. After all, in those times a crumb of knowledge snowballed with a host of preposterous superstitions and delusions. Not without foundation, it is believed that this period was the longest in history but brought least results. But then, the first steps are always the most difficult.

Masters of Wisdom

"The science of nature" was born on the shores and islands of Aegean Sea. Here settled people endowed with amazing fantasy and temperament. They knew how to "learn the vicissitudes of the seasons, to mark the fleeting beauty of the damask rose, the transient glory of the golden corn, the passing splendour of the purple grapes. Year by year in the beautiful land the Greeks beheld, with natural regret, the bright pomp of summer fading into the gloom and stagnation of winter, and year by year they hailed with natural delight the outburst of fresh life in spring. Accustomed to personify the forces of nature, to tinge her cold abstractions with the warm hues of imagination, to clothe her naked realities with the gorgeous drapery of a mythic fancy, the Greek fashioned for himself a train of gods and goddesses, of spirits and elves, out of the shifting panorama of the seasons". No wonder the soil became one of the indispensable participants in Hellenic legends.

In the myth about Demeter and Percephone the infuriated goddess deprives the earth of its main property - fertility. The bullocks drew ploughs along the brown furrow and the sower threw barley grains there in vain. Nothing sprouted on the desiccated lumpy soil.

In the parable about Alcmaeon the hero grows insane. The earth takes revenge on him for murdering his mother. Following long travellings he gets on an island formed in the mouth of Akheloos and calms down there. For, according to a prediction of the Delphic oracle, Alcmaeon could gain a lucid mind only on the land which did not exist at the moment of the murder.

Finally, the gold seal from the album of the French Archaeologist Louis Dussane referred to in Krupennikov's book. "In front of a branchy tree sits a goddess holding in her hand a symbol of fertility - a bundle of wet leaves. In front of the goddess from the loosened soil rises the figure of a girl with a sheaf of ears. The girl is portrayed without her feet, whereby is emphasized her emergence from the ground. Above her is a hoe-shaped pole-axe whose blow exposed the fertile soil and helped the girl with the ears to rise to the surface."

At first glance, these three subjects have scant connection. But each of them includes the same personage - a woman-mother. She symbolizes the earth and its chief property - to give life to plants and animals?! Precisely to animals.

One of the fathers of Greek "science of nature", Anaximander, was absolutely convinced that all living beings had emerged from mud, silt and the original soil which had covered our planet.

The myth about Alcmaeon is more than a tragedy. Behind its vivid, image-filled events stand the Hellenic conceptions about the earth. It turns out that it can be "old" and "young", accumulate information and remember things. Of course, these are mere parallels, the humanization of the soil's abilities. The surprising thing is something else. Among the multitude of "talents" bestowed on man by nature the Greeks chose precisely these. And they were right. Modern scientists have increasingly often been combining the words "soil and memory", "ripe soil", "soil at the stage of climax", etc.

Greek epos played a colossal role in the formation of rational - hence, scientific - thinking. This period of Hellenic history is also referred to as the era of Hesiod and Homer. They undoubtedly were not researchers but they collected in their poems the wisdom of the many-century folk experience and cast a bridge "from the myth to logos".

In Hesiod's poem *Opera et dies* (The Works and Days) one can find data about fat and lean soils. Greece was not pampered with rains. All its agriculture was based on the saving of the soil moisture:

> Improve the season: to the plough apply
> Both thou and thine, and toil in wet and dry ...
> In spring upturn the glebe; nor spare the toil
> In summer days to break afresh the soil;
> It shall not mock the hopes; then freely sow
> The fallow field, whilst light the mould below;
> The fallow field bids muttered curses flee,
> And gathers happy children round thy knee.

And man did not always succeed in saving moisture. There were no rivers like the Nile and Euphrates in the south of the Balkan Peninsula. Therefore neither Hesiod nor Homer ever referred to irrigation canals. All man could do there was to "toil in wet and dry". Especially since only 15 to 18 per cent of the territory of mainland Greece and still less on the islands were good for agriculture.

The scantiness of the soil resources became the key factor behind the migration of the Hellenes to the coasts of Asia Minor, the Ister (Danube), the Black Sea, etc. But the peaceful colonization of new lands did not always proceed smoothly.

In *Ilias* Homer created pictures of military valour, but it was the earth that endowed his heroes with strength and smartness, slyness and intrepidity.

His observation about "thrice-ploughed fallow land" is not to be found even in Hesiod's poems, still less so, in the Egyptian or Mesopotamian writings.

Incidentally, at the Trojan walls the Acheans also saw "water-rich fields". "Forty wellsprings" spouted there, the reference to which in *Ilias* helped Heinrich Schliemann to find legendary "Priam's great city". Furthermore he set therein the demesneland of a king .... Also he set therein a vineyard teeming plenteously with clusters wrought fair in gold; black were the grapes."

However, it is time to recall "logos". A work by an unknown author whom the Russian soil scientist A. Yarilov calls "the first pedologist of the ancient world" contains the following speculation. The soil functions as the mother's organism with respect to the vegetable embryo, giving it warmth and moisture. For all that grows on Earth lives by the Earth's moisture and the amount of moisture contained in it equals the amount of moisture contained in the plants. The soil constantly contains now more, now less water.

"The first pedologist of the ancient world" discloses the secrets of the heat-moisture relations. In summer the Earth is "more loose", ha says, "and light, for the sun is hotter, attracting the moisture from it". In the cold season the "water which falls from the air" makes the soil thicker, "since the moisture is very heavy". Observing the fertile layer, this unknown author arrives at the conclusion that "in summer the inside of the Earth is cold, in winter it is warm, while the reverse is true with respect to the surface layer". In our days such discoveries would not surprise anyone but at the boundary of the 5th and 4th centuries B.C. man first noticed such problems, "detached" from practical needs. He gave thought to the path which is annually traversed by water and to the nature and destiny of rain. He discovered the laws which formed the basis of a theory of soil moisture created by the outstanding Soviet scientists N. Kachinsky and A. Rode.

True, that came 2500 years later. Meanwhile, let us continue our journey through Hellenes and meet "pedologist number two", Theophrastus of Eresos. This scientist was born slightly later than his unnamed colleague - the only reason why the author places him second. But his training (he was a pupil of Aristotle!) and especially his successes in the study of plants, agronomy and the fertile layer were far superior to those of all his predecessors combined.

Theophrastus shared all aspects of the Aristotelian teaching but never missed the chance to "rummage in the wisdom of the ancients". He frequently cited in his works Hesiod, sympathized with Empedocles, and simply went to agriculturists and woodcutters in order to pick up some fresh data about plants and soils. In his book *On the History of Plants* he writes: "All... vegetation owes its emergence to the changes which took place in the soils; perhaps the soil itself reaches an appropriate state. The latter explanation is hardly absurd: after all, the Earth also contains moisture." It should be observed that, according to Theophrastus, the soil is the source of plant nutrition. He says that the Earth is not a manlike being but a quite independent organism, which obeys its own laws.

On the History of Plants is a botanical work. But, just as plants are inconceivable without earth, botany is inconceivable without the knowledge of the soils. The alliance of these sciences was recognized by Theophrastus. His work does not contain a simple enumeration of grasses, shrubs and trees, but it is keynoted by the idea that the "specificity of vegetation is created by the difference in place". The "place" was another discovery of this Graeco-Roman scientist. Simultaneously Theophrastus had in mind the climate, and the soils, and the relief, more exactly, landscapes, or facies, as elementary natural complexes are referred to now. This is not a far-fetched interpretation. In discussing the growth, fruit bearing and quality of the plant fruit, Theophrastus observed: "The place is a factor of greater importance than the processing and culture". Indeed, a "place" on a swamp or in a desert is much less fertile than in a black-earth steppe. Sands, scorching heat and salt ground waters will not create "comfortable conditions" for the life of any variety of wheat or any other farm crop known today, however carefully the land is cultivated.

Theophrastus's work makes it clear that plants find vital the physical nature of the soils. In many places he writes about clay, sandy, stony, stratified, dry, moist and other soils. His conversations with land tillers yielded him quite a bit of information about the connection between soil fertility and climate. This led him to conceive yet another interesting thought: "Light soil requires frequent but short rains; fat soil sustains showers and dry periods." A modern soil scientist will effortlessly explain such differences. He will be able to tell a story about the absorbability of the geoderm and the role of humus in the accumulation of nutritive substances and moisture.

But two thousand years ago nobody suspected all this. Nevertheless, the questions as to "what generates the Earth's thirst and what gives it the strength to combat dryness" were as acute as now. How did the Graeco-Roman scientists answer these questions? What helped them find metaphoric and exact definitions? Above all, it was their amazing gift of observation. No detail of the plant-soil relationships eluded the sharp eye of Theophrastus. "Sowing should be thick or sparse depending on the soil", he wrote. "Wheat depletes the soil more than barley, therefore it requires a better soil. Beans are not a burden on the earth and, apparently, even fertilize it since they are loose and soon begin to rot." Possibly, he was the first to express these assumptions. At any rate, no such observations are encountered among the Mesopotamians, the Egyptians and the Chinese or even among his own colleagues.

However, nature contemplation did not always bring fruit. Sometimes the Hellenes' sharp eye was helpless and could not penetrate into the essence of a phenomenon and prompt answers to hundreds of questions they may have had. Then help came from the imagination. And everything fell into place. "Wheat by its very nature is a hot plant." Therefore it necessitates abundant "manuring and a moist soil". "Beans come tasty on ... light and warm soils ... chick pea ... likes fat black earth ... a date palm prefers salt soil."

Light, warm, salt and hot soils, love and hate, addictions and foibles, great and little passions among soils and plants all, on the face of it, should be studied by historians of science. But let us open a modern soil map, and you will see the soils of humid subtropics, dry savannas, fat black earths, etc. Works by Alexander Fersman and Vladimir Volobuev, devoted to the energy problems of soil formation, discuss the same feelings, old as the world, which are exhibited by plants for soil combinations and chemical elements. What is it, an anachronism? Not in the least. Scientists have on many occasions tried to get rid of obsolete terminology, to cast off the "inconcrete" notions of "love", "hate", etc. But each time they got back to them again.

However crude, wrote John Bernal, these notions and terms were not substantially perfected in the next two millenia. "The Romans, the thinkers of the Middle Ages and even of the Renaissance," Krupennikov continued Bernal's thought, "did not surpass Theophrastus in their statements about the soil."

The Greeks - precisely because they did not go as far as to analyse nature - viewed it as a single whole. The universal connection between phenomena was not proved in detail. The Hellenic science of nature was cohesive. Special disciplines like botany only began to make their appearance but they already bore knowledge of the soil. Another science which exhibited an interest in the fertile layer was geography. Its founder was the Greek Herodotus of Asia Minor, more exactly, of Halicarnassus. His entire life and his observations are presented in *Historiarum libre IX* (History in Nine Books). Herodotus did a lot of travelling. He visited Italy, rounded the Pontus Euxinus (the Black Sea), went to Egypt and saw the Nile. But then, what is so surprising about it? Any traveller to Egypt saw this great river. But Herodotus was not just "any traveller". His gift of observation, which distinguished him even among his compatriots, prompted to him that the soil which fed the Egyptians was a gift of this great river. "If one casts the lead across a distance of one day's sailing from the seashore," he wrote, "it will pick silt from a depth of eleven sagenes. It follows that the earth has been washed away and taken to the sea by the river"! With the foresight of a real naturalist Herodotus assumed that not very long before Lower Egypt had been covered by sea. But the silt which was brought by the river gradually filled the expanse between Thebes and Memphis. Modern research has shown that not only the low-lying places, but also the high grounds in the Nile Valley are strongly salinated and covered with sea shells, i.e. has proved that Herodotus was absolutely right.

But then, this far-sighted Greek also happened to make errors. Rounding the Black Sea and landing in Scythia, he was surprised to see well-irrigated grass-rich plains. Their "fat layer is so thick that it crops out on the surface", he wrote. Here it should be specified that the Hellenes divided the fertile layer into strata: first came the "upper" stratum, good for ploughing, it was followed by a "smaller" stratum, which fed the cereals and grasses, below it lay the "ligneous" stratum, which fed the trees. The fourth horizon was the "fat stratum", which gave food to the plants. Of course, it was a mistake. But the Greeks had heard so much about the black earths of Egypt that they believed as if their soils must have contained this nutritive stratum. And they found it, more exactly, they dug it up. The point is that the Balkan Peninsula is dominated by brown and cinnamonic soils, which in their lower part of the profile have dark-red horizons. When Herodotus saw our black earths he decided that "these immensely rich earths are also a gift of the River Borysthenes (Dnieper), or the bottom of a dried sea". But the Dnieper is much less powerful than the Nile, and the sea had nothing to do with it either. But another thing is vital here. This Graeco-Roman thinker, who undoubtedly believed in the power of Zeus and other Olympus denizens, wrote that a whole country had been created by the work of rivers and the sea, and not by some divine intervention. Only Lyell proposed a similar idea many centuries later.

Hellas was rightly considered to be the homeland of "men of wisdom". Their thoughts formed the foundation of the edifice of modern science. By now the Pythagorean conjectures that man lives in a world of numerical relationships or a "natural harmony of numbers" have been embodied in exact formulae based on measurement. This search has not bypassed the fertile layer either. Numbers and measures describe its basic properties and the energy fluxes which it exchanges with the plants and the atmosphere. Correlations of various figures represent the soil in computer programmes.

Fertility Formula

The picture of the Graeco-Roman world is motley and contradictory. Peloponnesus was a reign of logic and "pure science", the Apennines and Rome saw the meaning of life exclusively in bringing practical benefit, in Carthage only the ability to buy and sell goods at a profit was prized. Which of them was right? Naturally, the winner.

The rivalry between the giants of the Mediterranean lasted for centuries. First, success attended the Hellenes, then the Carthaginians, but the crucial battle of history was won by the Romans. In 146 B.C. their legions laid siege to the "accursed city" of Carthage. Its walls appeared to be impregnable. Bold attacks and ingenious designs ended in failures. Here Scipio, the commander-in-chief, noticed the fields which surrounded the fortress. A chain of trees formed a double ring around it. The first row was formed by date-palms. They hid olives, which yielded shadow to ripening grains and vegetables. Each "cell" of the field was watered by a spring.

This Roman general had a reputation for being a slow-witted person. But when his patrols reported that at night the people of this besieged city restocked their food and water precisely in these fields he issued an immediate order to cut all the trees. And Carthage fell. True, soon the Roman army found nothing to eat either. The wind which blew from the Sahara buried the sowings and springs with sand, changing this flowering area into a desert.

If Scipio had known what a subtle mechanism he had destroyed! Not only sowings and trees were destroyed at Carthage, but the first artificial biogeocenoses in history. The date-palms in them blocked the way to the wind and sand. These trees were seasoned fighters and did not fear the heat of the desert and the salt of the ground waters. The olives not only covered the ground from the scorching sunrays, but also filled the air with phytoncides, which scared off the field pests. The alliance of earth and vegetation, of trees and cereals - this is what heights were attained by the agriculture of the peoples which lived on the coast of Northern Africa at the end of the last millennium of the past era.

However, the Romans mastered this art, too. They waged a no less fierce battle in their homeland than abroad. Here their enemy number one was "motley earth". As he ploughed up the mountainsides, the river valleys and draining the swamps on the Apennines the agriculturist constantly handled one problem - what is favoured by what earth.

Marcus Porcius Cato Elder, a fairly well known politician and a sword enemy of Carthage, who opened each session of the Senate by saying: "Carthage must be destroyed", became also known as the author of the popular treatise *De re rustica* ("About Agriculture"). One of the chapters of his work opens on the following warning: "Don't touch motley earth." The book also contained brief clear advice: "Lupine will come good on red earth, and on loose, dark, heavy, gravelly earth where there is no moisture. On white clay and on red viscous soil... it is best to sow spelt. In unshadowed dry places sow wheat." Cato issued sound recommendations as to how to buy an estate: "The climate should be good and not stormy, the soil good and having its own strength." He set much store by the earth's "own strength", but he also knew methods of raising it. Here from advice he went over to precepts: "What is good soil cultivation?" asked Cato. And himself explained: "It means good ploughing. And second? Ploughing again. And third? Manuring it." Cato was one of the first to analyse details of the problem of organic fertilizers which are little known even now: "Pigeon droppings should be scattered over the meadow, vegetable garden or field. Meticulously preserve the manure of goats, sheep, cows and any other manure." But it was found in short supply even in those times. Then Cato raised the questions: "What will you obtain manure from?" And again he went over to precepts: "Straw, lupine, beanstalks, chaff, holly and oak leaves. In the field tear danewort and hemlock... tall grass and sedge. Use it as a litter for sheep and bullocks.” This is already a guide for compost making. Cato was convinced that all organic substances were good for the earth: "If a grape vine is barren cut its branches and plough immediately."

All Roman was “measured” in quinaries and digits, in feet and inches. Many of them were alien to works by Aristotle, Pythagoras an Plato, difficult for understanding. They preferred popular encyclopaedias which contained a host of widely varied useful advice.

These handbooks were written and rewritten by a host of authors. Cato himself was “updated” on dozens of occasions. But a really new agricultural encyclopaedia was only created a century later. Its author, Marcus Terentius Varro, had a reputation for being the most educated man of his time. On an assignment of Julius Caesar he established a public library in Rome, for a long time lived in Athens, had an excellent knowledge of Greek source of materials, including works by Herodotus, Theophrastus, Empedocles, etc. "Agriculture," wrote Varro, “is a great and necessary science. It teaches us what and how should be sown on the field so that the earth would bring the highest crops.” His formula of fertility had little difference from Cato's including the same precepts for soil fertilization, specifying that “some plants should be sown not so much for the sake of higher crops as for sake of the crops awaited next year," i.e. required crop rotations.

Before Varro the Greeks and Romans had a fairly chaotic register of soil resources. In the main these were descriptions of various areas of the world they knew. And Varro decided to bring it into order. As the first, keeping in mind Theophrastus's percepts, he divided the earths into localities. Next, he divided each of them into at least twenty-seven types - “three by degree of moisture... into lean, fat and medium. Further one soil contains many stones, another a moderate number, a third is almost stones”. As a result, Varro obtained almost 300 varieties of the fertile layer. But he assumed that they were not enough for "practical purposes".

The interest in soils was so universal that one architect wrote that a knowledge of the earth and its properties was as important for designing and constructing buildings as astronomy, geometry, history, jurisprudence, medicine, optics and philosophy. This "eccentric" was Marcus Pollius Vitruvius. His impractical approach to construction did not bring him fame in the Eternal City. But this did not upset Vitruvius. He spoke of himself in exclusively flattering terms: "As regards the field of my art and all theories it encompasses ... I can ... present this in my books ... not only to builders, but also to all enlightened people."

This ambitious author gained recognition only in 1500 years. During the Renaissance he became one of the most widely read Graeco-Roman thinkers. His books had great impact on Bramante, Michelangelo and Vignola. To soil scientists Vitruvius left his theory of the Earth-atmosphere moisture exchange: "When the rising sun suddenly shines on the earth circle cooled during the night or when a breath of wind rises in the darkness the clouds from raw localities soar skywards and the air, heated by the sunrays, draws the evaporations from the earth ... ". Vitruvius's circulation model is simple. Possibly, he picked it up from one of the Roman baths where heated water evaporated and the rising steam formed drops on the ceiling and then fell back on the washers again. This "bath" analogy survived only until the 10th century. His classification of soil-grounds by the properties of the water which occurs in them served man for a much longer time. Clay grounds also contain poor water in small amounts, while loose and coarse sand soils are short of moisture, but it has a better quality. The most valuable liquid is included in dark-coloured grounds. It has an excellent taste, but it is represented in small amounts.

As an architect, Vitruvius was interested in the depth of occurrence of moisture. Without a knowledge of this there was no designing of buildings and no driving in of piles. Therefore he developed an entirely new method of establishing the depth of groundwaters. It is very simple: to dig pits and measure the levels at which opens up a "water vein" or "lens". Soil scientists are well familiar with its modern modification - meliorative land survey. Today settlements and cities are not founded and fields are not ploughed without such surveys.

Vitruvius did not take care of his works' style. He was obviously not an admirer of the Muses. Small wonder his advice to "find out soil moisture, which he promptly called theories, dimmed in the rays of fame won by the poem of "divine" Virgil, Georgicia, which celebrated the work of agriculturists. Virgil recalled it the "golden age", when man's favourite occupation had been the cultivation of fields and the growing of grains, when “agriculturists became the most courageous men and the most efficient warriors”. However, nostalgia for the bygone times did not dominate his works at all. It only looked through the lines which, in the words of the French historian Billiard epitomized the entire wisdom of Roman agronomy:

> "See, too, that your arable lies fallow in due rotation,
> And leave the idle field alone to recoup its strength:
> Or else, changing the seasons, put down to yellow spelt
> A field where before you raised the bean with its rattling pods
>
> On the small-seeded vetch.
> Or the brittle stalk and rustling haulm of the bitter lupine
> For a crop of flax burns up a field and so does an oat-crop,
> And poppies drenched in oblivion burn up its energy.
> Still, by rotation of crops you lighten your labour, only
> Scruple not to enrich the dried-up soil with dung

And scatter filthy ashes on fields that are exhausted.
So, too, are the fields rested by rotation of crops."

This fragment, as is easy to see, discusses crop rotations, fallows and fertilizers and cites a list of farm crops that are light and "burdensome” to the land.

Virgil does not attempt to strike the reader with the novelty of his advice. He honestly confesses that

" ... But plough not an unknown plain:
First you must learn the winds and changeable ways of its weather,
The land's peculiar cultivation and character,
The different crops that different parts of it or yield not."

Indeed, these truths were known back in the Cato times. But did many Romans read the treatise *De re rustica*? On the other hand, were there many people who did not know Virgil's poem? But then, the poet also recommends entirely new methods of study:

"Now let me tell you how to distinguish the various soils.
If you wish to know whether soil is loose or uncommonly stiff
For corn requires the one and vineyards thrive on the other.
First mark a place with your eye and have a pit sunk deep
In the solid ground, then put all the earth back again
And stamp it level on top:
If it fails to fill up the cavity, that soil is loose and fitted
For pasture and generous vines; but if you cannot replace
It all, and earth is left over after you're filled the pit,
That land is of close texture ... ".

It is the "pit method" of soil evaluation employed back in the 18th-19th centuries. And here is a "method" familiar to all students of soil science at Moscow University, prospectors and scientists:

"Further, soil that is fat and rich will answer briefly
To the following test: when tossed in the hand it never crumbles
But adheres to the fingers, like pitch growing stickier in the handling."

Of course, it has been slightly perfected in the intervening two thousand years. Now a soil sample is twisted into a "band" and squeezed with the fingers to see whether the stamp has come clear. However, Virgil may have dropped some details which overburdened the content and defied the smoothness of the poetic line.

But, however hard Virgil tried to attract his fellowzens to the earth, nothing came of it. The possessions of the Eternal City spread from the Pyrenees to the Euphrates. Streams of gold and grain flowed to it from all parts of the world. Cato's precept saying: "The agriculturist makes the surest income" already raised smiles. The harvests were diminishing. Droughts befell the Apennines more and more frequently. Then Gaius Plinius Elder said: "There is no more losing game than the best field cultivations. Soil should be cultivated in the cheapest ways." And the cheapest way was slave labour, indifferent to the earth, stimulated by the stick, and hated.

There is no saying that all Roman thinkers showed "sympathy" for Pliny's "appeals". True, among his supporters were Seneca and Marcus Aurelius. But there was also an opposition, led by Lucius

Junius Columella. His treatise *De re rustica* was the best answer to the "Malthuses" of all times and peoples. "I hear," he wrote, "how frequently the first men in our state accuse ... the earth of barrenness ... Some even, as it were, ease these complaints by references to a certain law: in their opinion, the earth, fatigued and depleted by the excellent crops of the old times, is powerless to bring people food with farmer generosity. I am positive ... that these causes stand far removed from life. It is impious to assume that nature which the father of the world has endowed with eternal fertility, has been affected with barrenness as it would be by a disease, and a reasonable person will not believe that the earth, which has been graced by divine eternal youth and which is called universal mother, because it gives birth to everything and will continue to do so, has grown old as man." And Columella added: "We assign agriculture to the worst of our slaves as we would to a hangman for execution".

Words even the most convincing, always remain words if they are denied support by actions. Columella was perfectly aware of this but he was in no hurry to "take up the plough". After all, the question as to what is preferred by what earth had no definite answer yet. And how many "earths" were in existence? Varro proposed 300 varieties of soils. Julius Grecin drew up a long list of earths suited for vineyard cultivation. But, apart from these well known scientists, the fertile layer was described and "systematized" by hundreds of other unknown authors. Columella refused to "get lost amidst the innumerable soil types", preferring "to deal with series which are easy to embrace with thought and word. Handling a small set of signs, he devised a logical system which was easy to remember. Among the most important properties Columella named moisture, fatness, density, colour and stoniness. Such a scheme made it easy to compare the earths of different plots and estates, to evaluate them in simpler ways and to propose necessary improvements.

As soon as order and logic triumphed in theory he proceeded to experiment. Here he discovered how imperfect his classification was. Being self-critical, Columella realized that "no one can grasp all soil varieties. Some soils delude one with their colour, others with their properties. In some countries there is good black earth ... in others smearing fat soil is better ... in Africa loose sands surpass the strongest soils with their fertility".

Columella had every reason to hate little wooden ploughs and ploughshares. In his opinion, they did not overturn, but "bit the soil". He advocated deep ploughing, which “benefits each growth best", assuming that only fertilizers could restore the soil strength. Here his passion for systematization showed itself with renewed vigour. He divided the earth food into five categories: manure, mineral fertilizers, green fertilizers, compost, and fertilization of earth with earth. Here the scientist recalled his uncle Marcus, who "took clay on sandy places and sand on clay ones and not only obtained generous grain crops, but also grew excellent vineyards". These manipulations with earth maddened his opponent Pliny. "To improve earth with earth is sheer madness!" he exclaimed. But Columella was deaf to such criticism. He continued his experiments, specified the rates and doses and improved the method of introducing "manures". "Soil fertilization should be more frequent than excessive." Such was his basic principle.

Columella, Varro, Cato and other Ancient Roman Scientists offered agriculturists a host of all possible instructions and practical advice. But in their treatises seldom occurred abstract speculations and logical constructions, in other words, pure science". The exception is formed by perhaps Titus Lucretius Carrus. As he observed natural phenomena he created what in those days was an amazing poem, *De Rerum Natura* (On the Nature of Things) - a story of the evolution of vegetation, animals and the soil. Here are two lines from this poem:

"And one state after another overtakes the earth, so that it cannot bear

What It did, but can bear what it did not of old."

Does it have to be said that their graceful form is matched by their exceedingly clear content? It took Carrus only nineteen words to present the law illustrating it with a relevant example.

But then, Roman literary achievements have never been contested. However, Roman agricultural progress for a long time was denied recognition. The main objection was Rome's weak productive forces. Poems were written by free citizens whereas the land was cultivated by slaves. It was this unjust division of labour that raised doubts But they were dispelled by Romans themselves. Works of Varro and Columella not only describe agricultural practices, but also contain harvest reports by individual years. For instance, at the beginning of our era the Empire fields yielded up to 15 centners of wheat per hectare - approximately as much as was produced in the 19th century Europe. The Apennine Peninsula resembled a fruit orchard, and no wheat, wine and olive oil in the world could surpass Italian. Nevertheless, Rome was heading for a decline. More and more estates became ruined, less and less arable land remained, and the decor of the patrician villas grew more and more luxurious.

Heirs to the “Eternal City”

At the close of the fourth century A.D. waves of an invasion of the Germanic tribes, which had long been attacking the borders of the Roman Empire, broke inside it and flooded its territory. In 410 Alaric's Visigoths ravaged the "Eternal City". They were followed by the Vandals, Suevians, Burgundians, and Franks. From 476 B.C. the West Roman Empire did not more exist.

Now Europe was divided between the barbarians and Byzantium. To Constantinople, the capital of the empire of the Romans, as the Byzantines styled themselves, flowed creations of the great Romans. Among them were the famous treatises of Columella, Varro, Vitruvius and poems by Virgil and Carrus. But the Byzantines had their own authorities as well. Already in the 4th century the Greek Theophrastus created the first East-Roman encyclopaedia of soils and minerals! His treatise contained few new and surprising observations for the ancient world. Another thing was surprising about it. The soil was found to "neighbour" on minerals rather than plants, the plough and fertilizers. There is no telling whether Theophrastus was aware that he was the first to see the kinship between the fertile layer and the stone. Most probably, he was not. After all, geology was not then in existence, any more than soil science.

His author Cassian Bass called it "Selections about Agriculture". But these "selections" were not an ordinary rewrite or imitation of Western authors. They discussed Byzantine soil. And the nature of the Empire of the Romans bore no resemblance to Italian.

When the encyclopaedia was already published in the 10th century the northern borders of Byzantium passed along the Danube. Byzantium possessed the extremely fertile valleys of Thracia. Here lay silty lands formed by river loads like Egyptian, smolnitzes and black earths. With regard to the latter Cassian wrote: "They do not fear either rain or drought. On them grow tall succulent grass and thick forests in the gullies. . . A piece of earth dipped into water does not make it taste bitter." But then the author of *Geoponics* gives "compliments" to other, less "worthy" soils for instance, red earths. His classification resembles a "menu", bristling with "sweet", “salt”, “hot”, and "cold" earths.

True, salt soils were not at all a figment of Bass Scholastic's mind. To Byzantium they were as great a plague as motley fields to the people of the Apennine Peninsula. “Salt earth should be avoided", warned Cassian. But if this is impossible it should be improved. Here the author of the encyclopaedia proposes nothing short of a culinary recipe: to fertilize salt soils with sweet! But how? Alas, he says nothing about it. Apparently, he left it to the future generations to develop relevant proportions and the techniques of the salt combating method he had discovered.

Geoponics also contains other curious passages. Together With the descriptions of soils and vegetation it carries astrological information. Since the times of Julius Caesar the Romans had largely relied on heavenly bodies. That was how another branch of agronomy – stellar - came into being. But then, the author does not insist on his recipes, but proposes that the reader should choose recommendations which suit him best.

Despite Cassian's delusions his *Geoponics* was a great scientific treatise, which not only preserved for the coming generations knowledge accumulated by the Romans and Byzantines, but also showed how man can use it in other natural conditions.

In the west Byzantium bordered on barbaric states. In the 6th-7th centuries these "ephemeral" kingdoms became a focus of glaring ignorance. Only a few of their monks read works of Romans and Romaioi. As regards their own leading lights, the Europeans did not know them at all. But they existed, creating immortal works in their quiet little cells and delighting by them the ears and eyes of their relatives and friends. One of such hermit scientists was Isidorus Hispalensis. This bishop, like all dignitaries of the early medieval church, gave major attention to agriculture and managed vast estates.

The great connoisseur of the ancient world he collected a large library where there were a great number of works written by Roman and Greeks. "As we are taught by Varro, a field can be sown on four occasions," he wrote. "There are fields where man sows .... Alluvious, or alluvial fields gradually created by rivers.” At first glance, things are not so bad. But, still more importantly, a bishop, a servant of God, wrote about river work. But then, a minister of the cult who read Latin texts was one thing and the totally illiterate human mass was another.

Across the Pyrenees spread Gaul, a land of "the most fertile soil where all land is cultivated except thickets and swamps", once wrote Strabo. But already in the 6th century *Historia francorum* of St. Gregory of Tours presented an entirely different picture: "They do not plant fruit trees, do not divide the meadows ... all they demand of the earth is grain sowing." Small wonder such soil treatment rapidly robs it of its strength. Now is the time to think of composts, ashes and manure. But the Franks, Burgundians and other Germans had never heard about them. Enlightened Isidorus himself knew only manure. Following Pliny, he said that fertilizer “cheered the embryo" of a grain. But even this sound idea did not occur to the northerners. They had contempt for manure. At best, they used it to warm their house walls. "Apparently," says the Soviet scholar Valerian Bakhtin, "the Europe of the 6th-7th centuries still had little appreciation for the 'joy of sprouts' and, using it as a hot-water bottle and for symbolic slaps in the face of visitors and relatives, insufficiently spread it in the fields. Only ... more cultivated people, who remembered Roman behests and the more depleted areas such as the Spain of the Isidorus era were an exception."

Not only knowledge about the land and the methods of its fertilization were lost. None of the source materials of that period speaks of the sowing deadlines. The Romans had had a more distinct "schedule". "Sow wheat on September 1 and oats on March 21," wrote Pliny. Even the Sumerians, Egyptians and Chinese had had an agricultural millenia before.

Already the 8th century introduced a slow agricultural upsurge. New laws and edicts ordered the peasants to take marl and manure to the fields. Man gave thought to what soil is all about. In the *Conversations Between Alcuin and Pupil Pipinus* the land is described in Christian terms: "The mother of those who are born, the feeder of those who live, a cell of life and the devourer of everything." But this fairly accurate definition was again only a spark which lighted the night of medievalism".

In the 10^{th} century Britain stole a march on the other medieval countries. The islanders already realized that their allotments were not enough for them. And they ploughed up half a million hectares of virgin, waste and swamp land. In the 13^{th} century Walter Henley wrote the first English agronomical treatise *Hosebondrie*. In contrast to Isidorus and other predecessors, he makes no references to Romans. And in those days their prestige was held to be indisputable. It follows that he was simply unfamiliar with their writings. But this gap in his education did not prevent him from issuing very sound advice. For instance, as to how to drain land. Calcareous and sandy soils, he wrote, should not be sown early ... they should not be overturned while they are very moist... After the sowing, in swampy and moist earth dig ditches so that water would stream into them and the earth would get rid of the water, warned Henley. He was one of the first Europeans to propose the use of straw as a fertilizer. Don't sell straw and don't remove it from the field he warned. If you remove it you will lose more than you will gain.

At the time the level of practical knowledge in Britain was high, but it had no science of the soil and plants. On the continent the situation was entirely different. The 13^{th} century put an end to the fierce battle of Rome with the German emperors. Victory went to papal authority. But the battles continued also on another ground - between “white” and “black” sciences, between secular and church scientists. Both sides promoted its ablest people to the front ranks. It would be an error to assume that some of them strove for the truth and the others for hiding it from the people. The paradox was in the fact that both warring groupings frequently made their way to the same aim. The most famous among them was Albert von Bollstadt, or Albert the Great. A monk, theologian and the founder of a scholastic school, the teacher of Thomas Aquinas and other "fathers of the church", he could not stand hermitage. Travelling, the study of nature, history and agriculture in near and distant countries were his passion. If von Bollstadt had turned up in the camp of "white" science instead of the leading church scholast history would have had another hero and martyr of his convictions at the hands of the Inquisition.

Albert the Great brought within the reach of his contemporaries the heritage of Aristotle and all Graeco-Roman science, but he did not become its blind admirer. Amazingly for his time, he exhibited a creative attitude to the authorities of the ancient world. "Furthermore," he wrote in his *Introduction* to the works of this great Greek, "we will make digressions which will explain difficult places." Albert the Great's book *De vegetabilibus* became precisely such a digression. It collected the author's numerous observations. The soil, in his words, is a "synthesis of cold and dryness" "enlivened" by warmth and moisture. The "source of life” is humours, or juices. Von Bollstadt did a lot of travelling in Germany and France and visited Italy. Naturally, he attached colossal importance to the "joy of plants", manure. But this was not simply practical advice, but a scientific recommendation accompanied by a detailed explanation. Having no belly, the plant uses the soil instead. This makes it important that in the earth "around the plant there should lie rotting food. We have already shown,” he continued, "that all decay, in keeping with nature, forms ashes, just as rapidly as all animal manure."

For Albert the Great nature was various "sources" tied with each other by commitments. Water and the soil, plants and fertilizers, "humours" and moisture ... He did not see the end of such a chain himself but he fearlessly took up the study of its accessible parts. In his view, moisture is not always a benefit for the soil, for running water can do harm on the slopes: "by its flow it washes away all it finds earthy ... nutritive around the roots".

Another question faced him, too: why should man plough the land? And von Bollstadt pointed out four benefits of ploughing - opening, levelling, mixing, and loosening. Indeed, thick soil is harmful to plants. Furthermore, Graeco-Roman authors had claimed that at a depth of two or three feet a fat stratum lay in the soil. Nutritive juices seep with the water there. Therefore the lower layers should be lifted higher and the upper deepened by ploughing ... so that the force of the earth would be evened and united into one common force moving and fertilizing the plant roots.

Albert the Great had an amazing feeling for nature. He issued no out-of-hand recommendations but proposed "above all, examining the earth". If it is bad it should be healed. To cold soil should be added dug-up clay to thick soil sand. "Salt and bitter soil will never accept doctoring". Here, in contrast to Cassian Bass, Albert the Great did not set his hopes on "sweet earth".

In the 13th century, the fields left fallow were an ordinary rural scene. The agriculturists realized that the soil needed rest. In a year or two it restored its fertility. But how did the soil regain it? Von Bollstadt provided an answer to this question as well. "A bared field on the third or some other year was left exposed to sunrays from whose heat and light it took in the power to fruit ... To one field it is restored sooner, to another later, in keeping with the greater or smaller fertility, heat, moisture, fatness, porosity and softness of the soil." The sun and fertility! Wasn't it a guess of a genius? Could this medieval monk see in the soil a powerful energy accumulator? Of course, not! In those times such a conclusion was traditional. Nobody gave thought to the complexity of the transfer of solar heat, still less so, energy, to the Earth. Such a concept simply did not exist. And the "softness porosity and fatness" appeared to have been derived from a modern research account. Neither Varro nor Columella spoke with such definiteness about the physical nature of the soil and its connection with fertility.

However much we are amazed at the "discoveries" of Albert the Great, seven centuries ago they failed to earn him popularity even among the "experts". His treatise *About Plants* contains many extensive speculations. And in the 13th century agriculturists did not shine with education. They needed a manual filled with brief and clear advice. And the work of this scholarly monk required what we would now call popularization.

And, by the irony of fate, popularization of the agricultural works of this scholast and theologian was undertaken by his potential opponent, a secular scientist, Pietro Crescenzi. He received what was then a brilliant education, which helped him to become a senator in the small Italian city of Bologna. Crescenzi, of course, did not have Bollstadt's erudition. But he had a perfect command of the art of compilation and knew how to find the rational element in the most tangled reasonings. All "principles" were dumped along with the long speculations about "solar heat" and "earthly cold". All that remained was practical advice. In an effort to lend them greater weight, Crescenzi referred to Roman authors and simply forgot to make a reference to von Bollstadt, whose treatise he had so mercilessly reworked. His new essay, *Liber ruralium commodorum*, rather had the appearance of an explanatory dictionary, containing a succession of chapters. *About Rye, About Barley, About Wheat*, etc. Briefly and clearly, this Bologna senator tells about the types of plant, their benefit to man and the conditions necessary for their raising. He saw the success of all agricultural schemes in a "correct choice of soils". At the end of the book Crescenzi cited an agricultural calendar saying what can be done in the estate each month.

Rus on the Advance

While in Western Europe fields were ploughed "enthe spec" and in Byzantium the emergence of *Geoponics* was still two centuries away a young Slavic state came into being in the Dnieper steppes. Rus, as it came to be called, imperceptibly grew and gained in strength in the shadow of the Empire of the Romaioi. There is no saying that it had a serene infancy. Its legends about those troubled times speak of knights, battles and the cunning and treachery of the enemies. Amazingly, however, whenever a warrior clashed with a ploughman his valour and strength were eclipsed by the undefeatable power of these people. Svyatogor, a knight among knights, cannot lift a bag dropped on the road by a peasant called Mikula:

> "Svyatogor strained all his efforts.
> So hard did he flex his muscles that scarlet blood streamed down his white face,
> But he lifted the bag only by a hair's breadth ... ".

What was the matter? Whence such a "weight of the bag"? It came from "raw mother earth". No wonder the people, who put the land tiller's work first, had great respect and understanding for the soil.

Already in the 7th-8th centuries the people of Rus cultivated a fairly long list of farm crops - rye, wheat, barley, oats, millet, buckwheat, peas, hemp, and flax. The list can be made longer, but another thing is of importance: such a "specialization" would have been impossible without a knowledge about the fertile layer. In those times Western Europe was dominated by rye, oats and barley - little demanding plants. But even these "Spartans" of the fields did not bring high crops. Where under Roman rule up to fifteen centners per hectare were obtained, now the figure dwindled to one or two.

Although the author failed to discover data on crops in Rus, it is known full well that Russian grain was unrivalled in the Byzantine markets. And it should be observed that grain was yielded not by the rich steppes, which were ploughed occasionally, but by the northern Vladimir and Suzdal principalities. Their lands were not too fat. A case in point is a legend about the ploughman Mikula Selyaninovich:

> "The ploughman's plough creaks,
> The ploughshares strike against stones ...
> The plough tears out stones and roots."

That was the kind of the ploughland that had to be handled by the Slavs. And some of the "stones" could not be moved even by two bullocks.

Regrettably, in Rus earth sciences was conveyed by word of mouth from father to son. And we can judge about what our ancestors knew and what they did not know about the soil only on the basis of the evidence left by government officials and a few codes included in the Russian Law.

There are no indications that *Geoponics* was translated into Russian. However, much of what it contains was known to the agriculturists of the Kievan, Vladimir and Suzdal principalities. Already at the boundary of the last millennium they left fields for fallow and alternated on them "burdensome" and "unburdensome" crops with a view to future harvests. "It is not the wide strip, but a long one that feeds man," goes a proverb of those years.

At the boundary of the 14th and 15th centuries the princes took tax on plough. The outdated tax on plough was replaced by the registration of ploughland, meadows, forests and hayfields. At first, they were measured only by special "strings ... which bore the stamp of the Great Czar". While in

England, with its "model agriculture", trust was still placed on polls which were tested "by eye". But then, in Rus trust in "measuring strings" was not contented with for long. Shortly, the scribes were assigned the more complex task of determining by "calculating and asking in what villages, clearings, wastelands, dwelling sites, large areas which sometimes became flooded and on faraway ploughlands the land was good, indifferent or bad". True, there were also fairly poor, or very poor lands but the officials took little interest in it. Incidentally, even such simple classification does not occur in the treatises of Albert the Great or Crescenzi.

It may be asked, how were the soils divided? The answer poses quite a problem. In those days the scribes had a reputation for being educated people although they did not learn their craft. Their sharp well-trained eye noticed a great deal in landlord estates and peasant holdings. Some things they wrote down in their Cadastral Records, others they just remembered. They did not share their art of land evaluation. That was their secret of the trade.

The scribes had to argue with the owner of each holding. And, according to the officials themselves, the peasants knew how to "analyse the properties of poor and good fields and were great ones for dividing lands and never made mistakes". Therefore, in an effort to reduce the influx of complaints and petitions, *Harvest Books* were introduced. They registered control crops, which scribes determined in the presence of witnesses.

It would appear that there was nothing to analyse here. It was the north, with its expanses of swamps and forests. The land here, compared to that of Central and Western Europe, was scant. Nevertheless, a detailed classification was conceived here. In Rus's various volosts, in addition to the official division into "good" and "poor", the soil was divided into "poor, stony and sandy", "wettish", "swampy", "swamp", "pine forest places" (sandy podzol), "wet earth", and "rusty earth" (podzols). Now a soil scientist will easily identify them as moraine, gleyed, peaty, peat, podzol, gley and even eroded podzols.

The names alone make it easy to see that the northerners were real scholars of the fertile layer. Around Arkhangelsk and along the Dvina not only ploughlands, but also meadows and forests were rated high. Here ideas were conceived of soil erosion and the role of the forest in combating it. Under Ivan the Terrible a decree was published saying: "The forest on top of the island and on the Dvina banks should not be felled for wood or bast. Otherwise the water and ice will destroy the trees, and then the fields will be damaged." The word "erosion" did not exist in Rus, but there was the excellent realization that a green barrier was a saving to the fertile ploughland layer. In 400 years an attempt was made to stem the erosion and steppe drought by forest plantings. Then they were "ostracized" and "exonerated" again.

With every year Rus grew rich and Siberia was of importance here. Thence came furs and gold along with amazing stories about rich new lands. Not all of them were true, but sometimes reality was found to be more amazing than the most incredible yarn. But, as is known, one picture is better than a thousand words. And the trail-blazers proceeded to compile maps of their journeys, marking on them roads, villages, swamps, forests, rivers and, naturally, lands. All this information flowed to Tobolsk and stirred the imagination of its inhabitants. In the 17^{th} century this city became the base of innumerable expeditions, which were fitted out for gems, gold and fur. Here gathered people of various kinds, but among them educated people occurred as well. The first among them was Pyotr Godunov, a voivode and rich courtier. This man appeared to have been born for travelling in unknown lands. According to his contemporaries, he had a tough temper but "loved justice in everything" and was an "excellent draftsman". His first major work was a *Draft of Siberia*, which was "put together in Tobolsk on the basis of evidence of people of all possible ranks, who had been to various Siberian cities and fortresses and had a perfectly good knowledge of places, and roads, and lands". And although the *Draft* was based on data obtained from military men, and not on his own observations, the map came sufficiently accurate considering the times. Pyotr Godunov treated the poll materials with great judiciousness. He soon saw "who was a liar and who was a truthful man". The soils were not specially identified in the *Draft*. They could be judged about from notes and recordings appended to the map. "The earth is saline with no forest on it." This stood for forests with patches of solonchaks. "The ploughlands abound in grain, with blackness of two cubits." This implied black earths, etc.

In Tobolsk Godunov organized a "course" in which many officials learned to grasp the secrets of Siberian nature. This course was frequently recalled by Godunov's successor, Semyon Remezov, the author of the atlas *A Draft Book of Siberia*. "My search was partly a success," he wrote, "due to Godunov's pupils, dutiful workers with a good knowledge of the land."

And Remezov's "search" spread as far as the "Chinese state" and Eastern India, where the "sand desert" of the Amur has grain-rich arable steppeland fields whose "black earth is as deep as the human height".

Not all explorers went to Siberia of their own accord. Yuri Krizanic had to "make a trip to Tobolsk" on a czar's order. This educated Croatian, living in Moscow, showed himself to be an all too zealous Catholic and was deported. But when he saw forests and steppes which were as large as the sea he forgot the trouble which had befallen him and gave all his strength to the study of the "new world". "Siberia consists of three belts", he wrote. "The first is washed by the Arctic Sea. Neither fruit nor vegetables grow here." Naturally, Yuri meant the tundra. But the "second belt ... is rich in the growths of earth ... the soil does not need manure fertilization". This can be easily identified as Siberia's black-earth steppes. The "third - climate", said Krizanic, encompassed "the vast steppes"; which stretched from Astrakhan to China. "These steppes are arid since their soil is sandy and alkaline."

Undoubtedly, Krizanic's "climates", or "belts", which succeeded each other from north to south, were natural zones. Hence, the law of zonality, discovered and explained in another 200 years, was already known to this exiled Croatian? Of course. And not to him alone. Spafary Milescu, a man in the government service, has left a still more detailed description of the "Siberian kingdom", pointing out such belts in the Upper Irtysh mountains. Furthermore, all trail-blazers noticed a change of forest by steppe and of steppe by "sandy desert". But only V.V. Dokuchaev sorted out the reasons for this change.

The Hour Has Struck

Even the longest journey sooner or later draws to a close. In 1676 Krizanic's exile ended. This Croatian turned Siberian packed what little he had and left inhospitable Russia for Europe, where two centuries before had begun and was still raging a revolution known as Renaissance.

Krizanic discovered much for himself in works of the great Leonardo da Vinci, Bernard Palissy and Francis Bacon. These three men evoked particular admiration in him. Much of what he had seen in Russia presented itself to him in a different light. While in southern Siberia he had on many occasions observed how lush steppe vegetation opened out in spring and faded with autumn colds. But Leonardo had taken a different view of this ordinary phenomenon. "You will see," he wrote, "that the grasses, on producing their seeds, dried up and, falling on the ground, shortly changed into the ground themselves, augmenting it. Then you will see that the newly born seeds will perform the same circle and you will always see how these seeds, performing their only circle, will augment the earth as they die and decay." "What a clear and simple thought!" Krizanic exulted. "And Woodward even in our days writes that black soil had been created by God?" Indeed, two hundred years after da Vinci enlightened Europe still saw the creations of nature as God's handiwork. Woodward was convinced that the fertile black layer had evenly covered our planet during the making of the world, but the picture had been changed only by the Flood, which had shifted and mixed everything.

But then, Woodward more than compensated for his theoretical errors by brilliant experiments. However this will be discussed slightly later. Now, taking Krizanic's advice, he introduced himself to the "thoughts and deeds" of Bernard Palissy. In 1580 this French Huguenot published a work whose name in those times could set an example of brevity: "Miraculous Dissertations about the Nature of Waters and Natural and Artificial Springs, Metals, Salts, Stone, Fire and Earths with Many Other Secrets of Objects Which Occur in Nature and with a Treatise about Earth's Fertilizers Appended." In this treatise he set forth what was then a "crazy" idea: plants needed earth. And not that they just needed earth, but that it fed them with "soil salts". "When a plant burns," he wrote, "it changes into a saltish ash which pharmacists and philosophers call alkali. Ashes contain the salt which straw has taken from the soil. If the salt returns the soil improves. The straw, on burning in the field, forms a fertilizer because it restores to the soil the substances which were taken from it." The book was written in French, whereas the scholars of the day wrote in Latin. Therefore it failed to attract the attention it merited. But in 1588 during a civil war between the Catholics and the Protestants his treatise figured as one of the main charges in a trial. And if not for the intervention of the connetable of France, de Montmorency, Palissy would no doubt have been executed.

Then it was earnestly believed that the earth only kept the stalks upright, protecting the plant from cold and heat and furthering its "more cheerful growth". And such conclusions were made not by some successful charlatan, but by the great Francis Bacon. He assumed that a plant extracted very little from the soil and that the basis of its nutrition was formed by water and some "specific juice" - a "subtle part of saltpetre". The "father of new philosophy" advocated the all-round use of experiments. This basically sound approach to the study of nature was what let him down. Bacon placed trust in the famous "Brussels experiment" of Van Helmont.

But then, let the author outline his experiment himself: "I put 200 pounds of oven-dried earth into a clay vessel. Then I wetted the earth with rainwater and planted a willow branch, which weighed five pounds. In exactly five years it grew into a tree, which weighed 169 pounds and three ounces. The vessel never had anything put into it except rain or distilled water to wet the earth... and in five years it remained filled with the earth, which grew still thicker. To keep the dust from getting into the soil, the vessel was covered with a sheet of tin riddled with holes. I did not weigh the leaves which fell in autumn. On completing the experiment I dried the earth again and obtained the same 200 pounds I had had at the beginning of the experiment minus approximately two ounces. Consequently, 164 pounds of wood, bark and roots grew out of water alone."

The English physicist Robert Boyle repeated Van Helmont's experiment, replacing the willow branch by Indian gourds. When it ripened he did not put it up for all to see as added evidence of the correctness of the “theory of water nutrition of plants", but exposed it to dry distillation. The results were staggering. It was discovered that water could yield not only a gourd, but also "salt, alcohol, earth and even oil". Here Boyle misrepresented the picture. By speculating with such uncompromisingness, it is easy to arrive at the conclusion that in the grass-cow-milk chain the cow is a needless stage and that hay can be changed into sour milk, butter and cottage cheese.

What is the matter? It turns out that it was mere trifles. Both experimenters neglected the "two ounces of soil" which were missing by the end of the experiment. The amount was really negligible. And what was the caloric value of this "subtle substance"? Perhaps the 57 grams of the substance absorbed by the willow contained far more nutrients than the mass of the products consumed by man in his lifetime. Furthermore, neither Van Helmont nor Boyle considered the influence of the air. But that was already not their fault: in the 17^{th} century man did not have the slightest suspicion of the "air nutrition of plants". The well-known British soil scientist E. Russell wrote that in the experiments with plants and the soil it was easy to overlook vital phenomena and to make from good experiments a conclusion that would appear to be absolutely sound but would in effect be absolutely misguided.

One way or the other, the "water theory" existed for almost 200 years. Only afterwards did the aforementioned John Woodward recall the work of the "heretic" Palissy. What hurt this Englishman worst was that his great compatriot Francis Bacon, familiar with the Frenchman's *Miraculous Speculations*, had failed to appreciate them at their true worth.

And Woodward corrected the error of the Lord of Verulamium. For an experiment he planted four mint shrubs. One of them was exposed to pure rainwater, another two were fed with the water of the Thames and a water supply system which stretched from Hyde Park, and the fourth was trusted to the earth. What were the results? The mint grown on the soil was found to be fed best. The shrub left in the care of rain had scarcely gained any weight. And the water from water-supply exhibited amazing fertility. The plant trusted to it, of course, came smaller than that which had grown in the soil but left behind the other rivals. True, such a "discovery" could stir only London's sanitary inspectorate. Especially since it did not exist in those days.

However, the main thing was proved: plants were fed not by water, but by some special substance. What? Woodward assumed that it is the "earthy substance of the earth", which deserved concern. For "the soil can be made to yield new crops of the same plants, but only after it is provided with a new stock of a substance like that which it contained at the outset; the stock can be created both by leaving the soil to lie fallow ... and by fertilization". That was a good practical recommendation. True, it was by no means new but it was scientifically substantiated.

The same view was held by Jetro Toole, a practical minded Oxonian who believed that plants' real food was the tiniest particles of earth chewed and swallowed by the microscopic jaws located at the tips of the plant roots. Toole even attributed the need for loosening ploughland to the fact that in the course of the loosening formed little clots capable of satisfying the appetite of the grasses and trees.

But what were these "particles of earth" like? After all, plants do not eat just anything. Do they have to have some taste, after all? Another Scotsman, Francis Home, decided to sort out the problem. He made experiments with grasses and cereals in vessels. As he added to the soil saltpetre, salts of magnesium and potassium, it occurred to him that the plants' menu consisted not of one substance, but at least of six - air, water, earth, salts, oil, and fire. Oh, if not for the fire! Home would have gone down in history as the discoverer of a more or less correct set of "products" consumed in the plant kingdom. But for "fire in a fixed state" he was declared a visionary and for a long time his name was forgotten.

Now, what do plants eat, after all? An attempt to obtain an answer to this question was made in France. Under Louis XV the country had a number of lean years. Afterwards the fields did not please their owners either. Then the Bordeaux Academy announced a competition for the best treatise about soil fertility. Its winner - and its only participant - was Johann Adam Kuelbel, a "physician of the Polish king", who had a good knowledge of agronomy, which did not prevent him from treating the king. "The theory of water nutrition of plants failed. But what has been proposed instead?" he reasoned. "The vague substances of Woodward, the toothed plants of Toole, and the 'fire' of that eccentric Home - not much for our progressive 17th century." And "physician Johann" decided to get back to the sources. "What do we have?" he wrote. "The earth, whose fertility is diverse. But even the richest soil does not produce anything if it does not rain in time. It follows that those who hold water to be necessary to plants are right. But water only drinks plants, and their food is the nutritive juice which forms when it fuses with the earth".

"Juice", "nutritive juice", "special juice" all are different notions. To this day newspapers write about the "earth's juices" but each epoch gave them its own meaning. Kuelbel definitely pointed to its origin. It becomes born when water gets into the soil. However, he did not attempt to make out the composition of the "nutritive juices". This was done for him by Johann Vallerius. That was when a new theory - the humus theory - made its appearance. What is humus? In Latin it stood for "earth"! Now, what was new about it? It turns out that humus is not just earth, that it "results from the destruction of vegetation", is black, vital to plant development and stimulates the adsorption and retention of "fatness".

That was how one of the main crises in agronomy was solved. This was followed by almost a century's serene development. Everything appeared to have fallen into place. The scientists, equipped with the results of chemical analyses, took an entirely new approach to what had been known already to the Sumerians and Egyptians. Again "black earth" gained its lost fame. Again it became the ideal of "enlightened agriculturists", more precisely, landowners. Its cultivators had not the slightest idea of the difficult position of the scientists.

This new theory was also supported by news from Russia, where black earths had been ploughed for centuries already and where the steppe landowner was styled a "Russian Rothschild". But the 18th century is rightly regarded as the Age of Enlightenment. Words and empty speculations were believed less and less, reliance being increasingly placed on experiment.

In 1786 Franz Achard, using an alkali, extracted some brown substance from a peat sample. Operated on by an acid, it formed a black sediment. The experiment was fairly simple. The scientist decided that something like it occurred in nature as well. And "this substance is like the soil juice". "Of course" , the Swiss physiologist Nicolas Saussure exclaimed in another fifteen years, "the humus extraction is precisely what is absorbed by plants!" And he had every reason to make this conclusion. Experimenting with the soil, Saussure separated from it "that dark-brown, almost black substance". But he did more than that. He desired to find out what it consisted of. And he made a discovery! The precipitated black powder contained not only carbon, as had been believed before, but also nitrogen, phosphorus, sulphur, and oxygen. So that was what plants "ate"!

The longest resistance to the "temptation" of acknowledging humus as the only "feeder of grasses and trees" was put up by Albrecht Daniel Thaer, a professor at Berlin University. "The Achard substance and the Saussure discovery undoubtedly confirm some of my thoughts but they do not furnish a direct answer to the question as to what humus is and what is its difference, for instance from the black earths of the Danube area and the Ukraine," he wrote. Thaer understood that humus is not earth and is so called for its powdery state. Humus is the product of an organic force".

However, the temptation was found to be too great, and he not only yielded to it, but also became an enthusiastic exponent of this new theory. His credo was as follows: "Humus is a product of life. . . it is also its condition, it gives food to organic bodies. . . Thus, death and destruction are necessary for the reproduction of new life." Who would dare challenge it? No one. That was the trouble. This categorical declaration had a flaw. "Great Albrecht" made things look as if the organic world by its very nature had performed its circulation from the living to the dead and back. And as if the mineral world, the dead world, had existed separately. But then, Thaer realized that "the soil is made up of a mixture of a wide variety of substances. . . The main components of this mixture are silica, alumina, lime, and sometimes magnesium, which at times are accompanied by a bit of iron and other elementary substances. But. . . fertile. . . soil, good for the production of useful plants, also contains a fairly complex substance. . . namely. . . humus".

But the soil is not a mixture. And mineral substances also take part in plant nutrition, but this was understood only a century later.

However, despite the entire inertia of the "humus" adherents, its research opened agriculture's doors for chemistry. That was a major achievement. Fashion for "miracles obtained by reagents" carried away the whole of Europe. A host of new data about the properties of soils made their appearance, followed by critical notes, and then by the collapse of the humus theory.

“On the Earth's Strata”

A good deal is said and still more is written about M. V. Lomonosov, the great Russian scientist. But, apparently, no book has encompassed, or will ever encompass, all his thoughts and deeds, his entire contribution to science.

The Lomonosov phenomenon is the more amazing since until the mid – 17^{th} - century Russia did not have a single university and works by foreign scientists made their way here half a century after their publication. The very list of scientific treatises left much to be desired. For instance, in 1739, with the approval of the St. Petersburg Academy *Geography* by Georg Kraft saw light which plainly said that the Earth was created by God 5688 years ago and which recognized the Flood as the only reason for the diversity of the Earth's soil, vegetation and animal world.

By the 1750s Russia's scientific scene had changed. A major factor behind this change had been the advent of Lomonosov to the St. Petersburg Academy. Behind Lomonosov rallied a large group of progressive scientists Timofei Klingstadt, Johann Lehmann, Johann Hebenstreit, etc. Incidentally, "an inquisitive professor of botany and natural philosophy", Hebenstreit was the only 18^{th}-century scientist to visit the Ukrainian steppes ("the lands are endowed with such great fertility that they yield crops even to the laziest"). On September 6,1756 he addressed the Academy with a Speech on the Fertility of Land. His speech contained many interesting observations made during the journey. "Black earth is a natural formation which comes from the rotten particles of animals and plants," he said. But the scientist immediately added: "The globe has been covered with such fertile earth since the creation of the world." Alas, even some scientists of Lomonosov's group shared the views of John Woodward.

This creates the impression that it was precisely these vexing errors in his contemporaries' views that made Lomonosov take up the "burning of metals in closed vessels", and compile *Russian Grammar*, and suddenly lay aside all his other preoccupations in order to study the "Earth's strata". Each of his schemes brought him invariable success. In 1756 experiments confirmed the law of conservation of substance in chemical reactions which be had formulated eight years before. And 1763 saw release of his work *On the Earth's Strata*, in which he immediately raised the question: "What is the soil?" The answer was as follows: "It is not the original or pristine matter. . . but a body made up of rocks formed by wind, and the natural kingdom of animals and plants. . . and the long time."

Let us stop! We will neither admire the brevity, nor the exactness of definition and let us carefully read into the beginning and end of this remarkably brief and accurate definition. To Lomonosov the soil was not created "by nature" in an instant (however long it may have been), but was borne by a "length of time". His was a genetic idea, which presupposed a law - governed change of natural bodies and phenomena in the course of time. He made this discovery independently of another brilliant 18th-century mind, Georges Buffon.

In his work *Kant and Natural Science* published in 1904 Vladimir Vernadsky wrote: "The historical principle, which played such a minor role in the philosophical ideas of the 17th century, was extended by Buffon to the entire field of natural science, to all visible nature. . . The few millennia which, under the influence of the Bible and the chronicled legends of political history, the educated men of that time were used to reckon with, faded, taking second place to the hundreds of thousands of years which had inevitably covered the phenomena whose results were discovered in surrounding nature by reconstructions or the inevitable premises ... of natural history." These words apply to Lomonosov's book *On the Earth's Strata*.

The interest of this "titan of Russia" in soils was not accidental. Lomonosov saw in them a reflection of the "material properties of the Earth's exterior". This furnishes added evidence of the breadth of his view of nature. Speaking of dry land, Lomonosov observed: "A great part of it is occupied by black earth."

Today any soil scientist, hearing such a remark, will exclaim: "But black earth is the steppe soil!" It most certainly is. Lomonosov did not deny that steppes are a place "where grass grows on black earths". But he gave the same name to humus, whose origin "is not mineral, but is recognized by everyone as coming from two... kingdoms of nature, animal and vegetable". And it was not an error, not a confusion of notions, but a recognition of the multifaceted nature of the accumulation of organic matter in our planet's top geological tier ranging from the thinnest layer in the tundra to the thick layer in the steppe.

The thoughts expressed in Lomonosov's book *On the Earth's Strata* exhibit amazing clarity and run far ahead of their time. In 1900 Dokuchaev, known from Vernadsky about this work, exclaimed: "Lomonosov had long presented in his works the theory the advocacy of which had earned me my doctorate, and I must say, he presented it more broadly and at a higher level of generalization!'· Here the founder of genetic soil science obviously played down his own merits. But his surprise can well be understood. 200 years ago, without having a tiny portion of the materials which were at Dokuchaev's disposal, Lomonosov put forward conjectures of a genius. The first and most important of these conjectures was concerned with the soil, more exactly, with the special "Earth's stratum" (it should be observed that it was no longer the Thaer "mixture"). Another was concerned with the zonality of nature.

Lomonosov knew about the observations of Russian trail blazers and highly appraised their courage but the materials they had gathered did not suit him at all. Therefore in "correcting the Russian atlas" he circulated to the gubernias a special questionnaire he had compiled. It embraced about thirty questions. The answers did not keep themselves waiting. Lomonosov "processed" the answers he had received and offered his own description of the "strips" of European Russia. He also identified three belts. But he described them far more accurately than Krizanic or Spafary Milescu: "The tundras, overgrown with mosses, have a thin layer of fine earth and are rich in peats ... the deciduous forests with soils richer in humus, the coniferous forests, poor in humus, the steppes, where the grass grows on black earth." His "strips" stand out not only in terms of climate, vegetation and soils, but also in terms of the conditions of economic activity.

The "corrected" atlas had a great advantage over the old. One of Lomonosov's pupils recalled: "The new maps were very accurate, and their colours reflected where what lands lay, below them in columns was appended a list of gubernia farmlands. Good ploughlands were also marked ... their earth was described, where the black earths are friable and where they are intensely mixed with silt." These lines belong to the Russian agronomist Andrei Bolotov. He lived a long life, participated in the establishment of a Free Economic Society and wrote 350 "ordinary-format" books on agronomy.

Whereas Lomonosov liked "with a broad look to embrace the entire earth, furnish an explanation for everything ... and take a cohesive view of things", Bolotov preferred to rummage in "particulars". He compiled a detailed description of the Kashira uyezd lands, divided the steppe black earths into "different kinds", published Russia's first manual of crop rotations and wrote what was nothing short of a novel- about agronomy - *The Life and Adventures of Andrei Bolotov*. To this day it is debated what dominates this four-volume work - data about the earth and plants or biographical information. But the best answer to the question is furnished by the author himself (also the novel's protagonist). "I did not set out to write a scientific treatise. I have published many such treatises. I attempted to present the development of science through the prism of human fates in an entertaining and edifying manner."

And Bolotov succeeded. The book is entertaining and can be read by whoever can read. It was not dull but contained a host of useful advice and information. For instance, about the "soil clots". The earth, divided into small and big shapeless blocks, appears, to be an ordinary thing. But Bolotov took a different view of them. "They are not shapeless at all, but, on the contrary, have a structure definitely given to them by nature. Some are clots, others are layers, still others have acute angles", he wrote.

As the reader can see, it is a question of the soil structure, i.e. of the particles into which falls any piece of clay or loam overturned by a plough on ploughland. By now it has been established that field fertility depends above all on the shape and number of these "clots".

Another surprise in the "novel" is speculations about plant nutrition (the 18th century was undividedly dominated by the "humus theory"). Even Lomonosov tried to avoid this "slippery ground". But Bolotov challenged the "taboo". He clearly wrote that the "food of the grasses and trees" is water and some "specific earthy or even mineral particles". Consequently, "this earth must have these things in fairly sufficient quantities". True, he failed to formulate a new theory of plant nutrition. This was done in another seventy years by the German chemist Justus Liebig.

Salt Instead of Oil

Presenting to the St. Petersburg Academy his *Introduction to True Physical Chemistry*, Lomonosov observed: "Instead of the roar of wild beasts our expanse will be filled with the voice of rollicking mankind and instead of thorns it will be covered with wheat. But then don't forget to thank this great participant in your population, chemistry."

Indeed, in the 19th century it was believed that precisely this science would become a panacea for all agricultural troubles. But, apart from outstanding discoveries, 19th-century chemists made errors, one of which was the humus theory. The scientists' delusion also stemmed from their poor knowledge of surrounding nature. After all, the aim of their work at times was reduced to bringing out the composition of the substance in the flask. And the early-19th-century chemical methods were none too accurate. That was when the English scientist Humphrey Davy proposed feeding up plants with oil!

The analyses carried out by scientists showed humus to contain hydrogen, carbon and oxygen. No nitrogen was discovered. It followed that the good growth of farm crops necessitated substances of composition akin to theirs - fats. That was a blinding delusion. Otherwise there is no explaining why manure and composts were prized due to their high fat content - oiliness. As regards the mineral particles they were assigned the role of stimulators. In the agronomists' opinion, they ensured a "more brisk plant growth".

But experiments not only create theories. They also destroy them. The first mine under the theory of humus nutrition of plants was laid by the aforementioned Humphrey Davy. He did not question the correctness of the Thaer theory. But sometimes he observed that the soils which had the greatest alumina and carbonate of lime content were those which at the same time, had the greatest energy of fertilizer preservation. Hence, alumina detains organic substance. The only way to achieve it is by forming compounds with it. Is such a relationship possible? Of course, it is. Now such substances are referred to as organomineral. Their discoverer was a man who sacredly believed in the closed circulation of organic compounds - from the soil to the plants and back. Thus, the first assumption was made: the mineral world and the animate world were not isolated, but maintained connection and interaction.

Nevertheless, it was too early to exult. And Davy continued his search. He calcined various "minerals and earths" on fire. The samples changed from dark to white, became bleached and cracked when poured water on. The experiments are extremely simple. But Davy studied how various rocks developed into sand, clay, crushed stone, i.e. the mineral basis of the soil. But what heats and destroys rocks in the natural conditions? Of course, the sun and water. And if the latter contains carbon dioxide the decomposition proceeds faster. But Humphrey knew that nature had equally powerful destroyers such as primitive mosses and lichens. Thus, another assumption was that living organisms were capable of reconstructing the world of minerals, of changing it into the soil, which became so improved that even higher plants could vegetate in it. Another effort could prove that humus was not the only "feeder" of the grasses and trees. But the Thaer theory remained corrected, but not disproved.

It is difficult to tell how long it would have taken chemists to overcome the "humus delusion". Following Davy, many well-known chemists experimented with organic substances - Johann Berzelius, Gerardus Mulder, Karl Sprengel. But none of them so much as suspected that, apart from already known hydrogen and carbon, this substance contained nitrogen compounds.

Suddenly, this theory, which gave no doubt for 150 years, collapsed. All relevant treatises sank into oblivion. Scientists and agriculturists extolled a new agronomical "gospel" - *Chemistry as Applied to Agriculture and Physiology*. Now they "prayed to a new god" - Justus Liebig. He was a man of sharp judgements and bold conclusions, an excellent orator and populariser. His book could be read by everyone.

"Liebig," wrote Academician Dmitri Pryanishnikov, "having concluded his experiments connected with the basic questions of chemistry, became an agricultural thinker, but did not work with plants. Predominantly, he proceeded along deductive lines basing himself on the general laws of chemistry and already known facts. He brilliantly compared them. He wrote for the general public, in a popular and frequently acutely polemical form, and soon won broad renown ... but himself ... not infrequently made errors by prematurely introducing into practice what was not yet sufficiently cleared up by the light of scientific experiment."

Leibig's arguments were simple. If a plant "eats" humus the latter should be dissolved in water. "Suppose," he wrote, "all precipitation water goes to plants without being spent on direct evaporation from the earth's surface, seeping into the ground," etc. It turns out that all this water is clearly insufficient for extracting even a modicum of the carbon which is so vital to plants. Here are relevant proofs. All experiments chronologically ranging from Saussure to Sprangel confirm that only hundredth fractions of organic matter become dissolved in water. Where can the missing carbon be taken? Of course, from the air. But this suggests that humus is not the only plant "feeder"! "Furthermore," exulted Liebig, "the early plants ate only atmospheric carbon since humus is a product of plant decomposition." Consequently, humus is needed neither to the grasses nor to the trees? Liebig was positive that "inorganic nature gives plants their primary food". To humus "furious Justus" assigned the fairly modest role of provider of carbon dioxide for the destruction of minerals. Thus, the first conclusion was "salts" instead of "oil" .

This conclusion was followed by another: crop monotony depletes the soil. Here it should be observed that the defeated humus theory exponents at times expressed sound thoughts. Concerning for humus preservation they proposed to alternate "burdensome" crops for the earth with "non-burdensome", for instance, row crops, spring wheat, clover, winter wheat, and oats, i.e. use crop rotation. Wheat left few roots in the soil and legumes left many. Thus, the assets quarrelled with the liabilities.

Liebig only laughed at the "alchemical ravings" of his predecessors. He assumed that since the plants got only mineral substances from the soil each of them "eating" only certain salts and compounds, no plant could enrich the soil for other crops. Liebig explained that pea preferred lime, grains - silicic acid and others took potassium and phosphorus from the soil. It follows that by alternation we could only slow down the process and make a more even use of the nutritive substances to be found in the ploughlands. But, sooner or later, the fields will become depleted all the same if what is taken from them is not restored.

But what is to be done about the manures and composts? Don't they make up for what was extracted with the crops? Liebig assumed that they did not. After all, livestock fodder and litter required straw and the grain was taken to town. Hence, the soil receives only what has been accumulated by the leaves and stalks and what goes to the grains, for instance, phosphoric acid becomes irretrievably lost.

That was the source of Liebig's "painful enthusiasm" for phosphates. He was convinced that the earth, above all, was impoverished in these substances. And that the restoration of field fertility should begin with them. "This rule," wrote Academician Pryanishnikov, "came to be known as the law of minimum. It should be observed, however, that in his main work Liebig did not use this phrase, the law of minimum... the very proposition concerning the overriding importance of the elements to be found in minimal quantities was understood as relative which can be seen from the following phrase: 'An element which is completely missing or is found in insufficient amounts prevents the other nutritive compounds from producing their effect or at least reduces their nutritive action' .... Liebig's law of minimum is the result of the irreplaceability of the elements of plant food with each other ... of potassium with phosphoric acid or lime."

Now, when they speak about Liebig, scientists recall, in the main, his theory of extraction and restoration. In the meantime, his *Chemistry as Applied to Agriculture*, just as his acutely polemical work *Fifty Theses*, contains many other interesting thoughts. "The soil," he pointed out, "can be regarded as quite fertile for a concrete plant species ... if each of its particles in contact with the roots contains all necessary nutrients and in a form which enables the roots to assimilate these substances at any stage of the plant evolution". Here this German chemist writes about specific states of substances in the soil. Some of them, he said, are good "food" for grasses and trees, others are not. Few of his contemporaries analyzed such details.

Later, when much of what Liebig promised to agriculturists never materialized, this former winner was rained with reproaches. Critics said that he took a narrow-minded approach to the evaluation of soil fertility. In fact, they were wrong. Liebig always emphasized: "When farms exchanged good advice or proposed ... improvements they neglected such vital factors as the geographic latitude, the location ... of the place or country, its altitude above sea level, the annual precipitation, its seasonal distribution, the mean temperatures of spring, summer and autumn... and, finally, the physical, chemical and geological properties of the soil."

However, carried away with polemic, Liebig not infrequently made gross miscalculations. One of them was the question of nitrogen. Aware that the air contains very few of its salts - ammonia and nitrates - he nevertheless decided that the earth received enough of them with precipitation. In consequence, the key problem facing agricultural chemistry and soil science failed to find solution in his works. Another error flowed from the first. This German chemist assumed that manure was made valuable exclusively by its ash. Therefore he always publicized his "patent fertilizer" based on phosphates. "If Liebig were right," wrote his opponent Jean Baptiste Boussingault, "what impractical people we, agriculturists, would be putting such great efforts into the delivery of hundreds of cartfuls of manure when, according to Liebig, it would be enough to deliver just one cartful of ashes."

But who was Boussingault? In the early half of the 19th century few people knew this modest professor of Lyons University. Still less was known about the reasons for which he had gone into the "book-keeping" of nitrogen in soils and plants. It all began when this graduate of the St. Etienne mining school, encouraged by Alexander Humboldt, decided to use his knowledge in South America. In those days this scantily studied continent was ablaze with liberation wars. When Boussingault presented his letter of recommendation to Bolivar bullets were whistling around and shrapnel was blowing up. This popular hero, looking through Humboldt's message, said that at that particular moment he found it easier to offer this young man the rank of an officer than that of a mining engineer. And Boussingault unhesitatingly joined the ranks of Bolivar's army of independence. The years spent in campaigns and battles did not prevent him from collecting astrounding material pertaining to the nature of the tropics. But the greatest "miracle" which amazed Boussingault and determined his further career was deposits of Chile saltpetre. This mining engineer for the first time in his life saw a priceless deposit which had not arisen from the depths of Earth, but had been created by a many-century bedding of bird droppings, guano. This "mineral" had one amazing property. Even a small addition of it to lifeless sands turned them into fertile fields which yielded extremely rich maize crops. How Boussingault contrived to build a laboratory in his tent still remains a mystery. But in his laboratory he made his first steps in agricultural chemistry, determining that guano consisted almost exclusively of ammonium salts.

It was precisely then that Boussingault pondered over soil fertility and the role played in it by nitrogen. Much later, in 1836, he launched extensive experiments. Every year he weighed with the accuracy of a pharmacist hundreds of samples of leaves, roots, tubers, stalks, grains, and fertilizers. Then they were burned and again put on scales. Further, came the turn of flasks and retorts. As a result, Boussingault drew up a "book-keeping" balance for a year, two years, five years. Already in a year Boussingault announced his first law: the most effective fertilizers were those which had the greater nitrogen compound content.

But whereas the experiments confirmed his view as to the value of composts and manures, some results of analyses made him ponder. Boussingault thought that plants would show a much greater carbon content than fertilizers introduced in the soil. After all, plants could absorb it from the air. But the nitrogen behaviour discouraged him. It followed that farm crops extracted from the earth several times more of this element than they brought there. Hence, the soil had some other nitrogen accumulator. Here his attention was attracted by clover. Already in Ancient Rome legumes helped to maintain good harvests. It remained to find out how.

Boussingault reasoned as follows: "If crops, generally speaking, deplete the soil, some of them, for instance, clover, make it more fertile .... It should be assumed that the soil-improving crops enrich it not only with carbon, hydrogen and oxygen, but also with nitrogen." But another question arose, where did clover take nitrogen? And Jean Baptiste turned to the aforementioned Thaer circulation. "I will observe," he wrote, "that this method is based on the principle ... that soil depletion is in proportion to the amount of nutrients in the crops; ... to accept the principle adopted by this famous author is tantamount to the tacit admission that all organic matter comes from the soil. The soil undoubtedly stimulates ... plant development but the air ... shares in this process on a par with the soil."

Here is another way of nitrogen accumulation in the fertile layer. Boussingault saw in the circulation of matter many more "characters" than his contemporaries, in particular, Liebig himself. However, indirect data and logical constructions suited him less and less. Boussingault made an experiment which was to confirm his correctness. He planted four crops in calcinated sand-clover, peas, wheat and oats. In three months 42 milligrams accumulated in the sand under the clover and 55 milligrams of nitrogen above the control quota in the sand under the peas. The wheat yielded nothing and the oats even used what little nitrogen remained in the sand. However, the latter stage in the nitrogen absorption from the air eluded this French scientist. But then, it was not his fault. Little was known in those days about the soil bacteria. Only half a century later was the mechanism of nitrogen absorption discovered.

In Ostwald's book *Grosse Manner* scientists are divided into two types - classics and romantics. "The classics," he wrote, "are slow, shy, timid, and ponderous. The romantics are quick, bold, dazzling and light-minded. Hence, the classics' tendency to loneliness and the romantics' inclination towards sociability. The classics go into introspection while the romantics give brilliant lectures and shine in society. They strike sharp blows in debates and tend to occupy the central position. Therefore excellent teachers occur among romantics whereas classics leave behind indelible traces in research."

Precisely such "indelible traces" have been left behind by Boussingault. And Liebig was a hot debater and excellent teacher. And both became the founders of a soil science known as soil chemistry.

“Geo” Versus “Bio”

Paradoxically, the successes of chemists and especially their prestige, won in solving the problem of ploughland fertility, did a disservice to nascent soil science. Agronomists and physiologists silently endured the insults of Liebig, who claimed that they did not understand the elementary notions of "salts" and "alkalis". They blindly obeyed the "wizards of the laboratory table" and blindly performed the latter's instructions. But, making the first steps in studying the natural atmosphere – plants - soil chain, the chemists found themselves below the mark, equating the soil and the arable layer, to which they attributed exclusive importance.

Geologists took a different view of the soil. They were interested in all the "earth's strata" and the rocks and minerals which formed them. True, at first they gave little thought to the origin of the upper level, but were preoccupied only with those which lay deep under the loose alluvia. But what was the way to study the lower layers without the upper? What was the way to unlock the secrets of conversion of rocks and minerals without the study of the soil layer, the closest to us?

The first to give thought to this was Academician Vasili Severgin. Among his colleagues he enjoyed a reputation for being a man of many talents, and expert in chemistry and geography and ... an enemy of Latin. Why? Above all, Severgin assumed that the language of the Ancient Romans was "used both in season and out of season". The only argument in its favour was *noblesse oblige*. However, data obtained from peasants and officials poorly lent themselves to translation, and forced far-fetched phrasing hardly helped the search for the truth. Then the scientist created a new Russian soil terminology. It was he who introduced equivalents of "silica", "oxidation", etc.

According to his contemporaries, Severgin liked strictness in everything. His descriptions of the fertile layer were distinguished for clarity, so uncharacteristic of the scientists of the 18^{th} and early 19^{th} centuries. With regard to the lands which divided Lake Peipus and Derpt (Tartu) he wrote: "Arable land ... is darkish-grey, slightly coarse to the touch, clay which does not boil with acids and mixed here and there with fairly small grains of white-grey quartz." To an uninitiated reader this fact may seem to be of little relevance to the history of soil science. Alas, this is not so. The descriptions of the "Earth's strata," their accuracy and breadth are a yardstick of the qualification both of an individual expert and of science as a whole and its success.

But Severgin had more than an amazing gift of observation. From scrupulously described "pictures" of the fertile layer he went over to a systematization of the Russian lands. The chaos which dominated the Cadastral Records and was handed down to 19^{th}-century works irritated the scientist no less than the Latin names of the soils. Two thousand years before him something like it had been done by Columella. But this Graeco-Roman scientist confined himself to the Apennine Peninsula whereas Severgin was "to take a cohesive view" of the territory of the Russian Empire, colossal as an ocean. Five years of titanic efforts, and two volumes of *Essays* saw light. The first volume collected geographical observations and detailed descriptions of Russia's mountains and plains. The second volume contained data of minerals and soils. A composition which was strange in those times but which had already been exhibited by the Byzantine Theophrastus. In the case of Severgin it was not accidental either. After all, a layer born on the surface, or hypergenic, is the last stage in the chain of transformations taking place in the mineral world - the boundary across which operate entirely different laws, where animate and inanimate nature enter into contact. That was how Severgin thought, assuming that "this earth merges ... the mineral kingdom with the kingdom of growths". His book came out six years before the experiments of Davy, who, although he leaned on experimental finding, made more vague statements to this effect.

Regrettably, many of his colleagues held a different view. Particularly tough were German geologists. The living "classic" Friedrich Fallot claimed that the soil "has nothing in common with plants or any other organic substances ... it can be compared only with inorganic bodies, especially minerals". True, Fallot, although he thought the soil to be a dead body and life in it to be autonomous, recognized pedology, or soil science, as a new branch of geognosy. In the meantime, the Australian William Gamm made the "strictly scientific" statement that the latter science could not exist. The upper layer, itself, in his opinion, was "a product of the weathering of minerals and rocks".

These geologists could be understood. In those days this young science searched for the application of its strength. It made "exclusive" claims now on the interior of the Earth, now on the soils. However, the new searchers for "earthly Eldorados" were not particularly lucky. The depths of Earth were claimed by mining engineers as being senior. The upper levels had still more claimants. One was biology. Its exponents took a stand which was "the opposite of geognosy on all points". In their case the soil was "animate", a "living organism", a "botanical question".

Not all scientists exhibited such extreme convictions. Professor Ferdinand Senft of Jena University, observing for 60 years (!) the slope of Mt. Hesselberg, noted: "Part of the slope, which only too recently consisted of desert crushed stone, in my very eyes put on a forest and shrubbery .... This is how each vegetable community digs its own grave but, at the same time, prepares a new place for others." It was a none too original statement. But Senft's experiment was unique and its results irrefutable. From his experiment this German scientist also drew another conclusion: each crustal layer once was a habitat of plants and organisms, and rocks are remnants of "previous biospheres".

Thus, in the mid-19th century science developed a "no man's land". It was studied by chemists, geologists, biologists, agronomists, and geographers. But its real owner simply refused to turn up. Then a sudden event made this question an acute issue.

In 1840 Edward Ewersman, a scholar of the Russian steppes, assumed that their soils - black earths - were a product "of annually dying and reviving vegetation". Many scientists agreed with him. Except the geologist Roderick Murchison. With an ardour uncharacteristic of an Englishman he proceeded to prove the inaccuracy of such a conception. In view of the uniform structure of black earth over such colossal expanses, he said it would be correct to deny all theories which attribute the origin of black earth to the continental factors now at work. What then gave birth to the steppe soils? Discovering in the north dark clays, formed dozens of millions of years ago, he decided that it was the key to unlocking the Russian phenomenon. All that was left to do was to find a factor which could have taken this dark-coloured material to southern Russia in those times. And it was found in the form of the streams sent forth by a thawing glacier.

However, these speculations, logical at first glance, crumbled as soon as black earth got into the hands of an agronomist or botanist. Blinded by his "conjecture", Murchison did not so much as attempt to make out the origin of its black colour. His colleagues quickly spotted a weakness of the "glacier hypothesis". After all, black earth contained a good deal of organic matter, which accounted for the dark colour to the soils. And the northern clays contained no humus. It follows that the colour comes from the marine mud which had remained after the recession of the Black and Caspian seas and the organisms which had lived in the waters made possible humus formation. Such was the view of Professor Alexander Petzgold of Yuryev University, Liebig's pupil.

One can only wonder why many scientists of those years searched for the source of humus - black earths - somewhere in distant epochs. Whereas it was literally before their very eyes, stirring like a green carpet and at times hiding the horse together with the horseman. But for some obscure reasons the lush steppe vegetation long remained unnoticed.

Fantasy took geologists everywhere! Edward Eichwald thought that black earths were a product of "swamps and tundras". Theodor Wangengeim drew pictures of spectacular streams of water mixed with peat which had allegedly caused the "flood" in southern Russia and the Ukraine. Their debates grew into fierce battles. Murchison accused his opponents of illiteracy, rudely interrupting them with sarcastic gibes, made noise when they spoke and in general behaved disgustingly. But the supporters of the general conception, or the vegetable origin of black earths, if they showed greater restraint, did not surrender either.

Ruprecht assumed that the formation of black earths was a long process. Steppes came into being long ago and had accumulated much humus, and slightly to the north the forest had grown up very recently, following the glacier retreat, and here the humus layer was much thinner. But Ruprecht also made errors. For instance, he denied the role of the roots in humus formation. Why? After all, in the steppe they created two or three times more organic mass than the stalks and leaves of the grasses. As regards the climate and rocks, he held them to be insubstantial factors, too. "Only the grasses and time are of relevance," he wrote.

Occasionally, the debaters grew so carried away with their search for all "fors" and "againsts" that they overlooked the third participant in the discussion, who at times expressed very sound ideas. In this "black earth battle" this was exactly the case. Little-known military geographer Alexander Schmidt studied the soil cover of the Kherson Gubernia. According to his findings, the black earths are divided with regard to their mineral composition and humus quality. It followed that "the homogeneous black mass of sea ooze" was not homogeneous at all. Consequently, the seas and swamps here had nothing to do with it. The four Schmidt-identified stages of black earths - fertile, ordinary, black earth and chernozem-like - formed strips alternating from north to south. "Here a factor at work was the influence of the climate," wrote Schmidt. "I have seen the same in the map of Grossul-Tolstoy. From the Prut to the Ingul stretched a similar alternation of soils with regard to their black earth content."

Thus, the question is: who should study the soil remained open. Perhaps geographers? But the fertile layer is part of the lithosphere. Then geologists? But the soil is also a possession of the biosphere. Hence, botanists or zoologists?

These Ubiquitous Worms

The author will not insist that this question was being solved in the 19th century precisely like this. One thing is clear: this new kingdom of nature had many claimants - agronomy and chemistry, geology and botany. Their demands were supported by important afore cited arguments.

But in the heat of fierce polemic few debaters noticed an event which took place in the Geological Society of London in 1837. The "father" of the theory of evolution, Charles Darwin, read a paper, *The Formation of Vegetable Mould Through the Action of Worms*. Darwin bluntly said that the very name of the soil, "vegetable mould", was inappropriate, that it would be more correct to call it an "animal layer".

Incidentally, many of the geologists who listened to Darwin did not approve of the term "vegetable mould" either. They definitely held it to be a "mineral layer". And, following a half-hearted discussion, they went over to another subject. Even decades later this was recalled as a curious episode. In 1847 D'Archiac in his *Histoire de la geologie*, deciding to sympathize with Darwin's originality, observed: "This theory has to do only with low lying damp valleys." And in 1869 Darwin's compatriot G. Fish objected by saying that worms were incapable of performing such colossal work.

Just a few lines of response in thirty years. His contemporaries obviously failed to appreciate

Darwin's gift of observation and his ability to fathom the essence of phenomena. Back from his voyage aboard the HMS Beagle, this great naturalist was puzzled by a "discovery". He had seen that worms were ubiquitous. "Earth-worms are found in all parts of the world," he wrote. "They inhabit the most isolated islands; they abound in Iceland, the West-Indies, New Caledonia, Tahiti, Kerguelen Land." The very presence of these delicate creatures on any fragment of land prompted Darwin the idea of the "globality" of their influence on the fertile layer.

While addressing the Geological Society of London he had few relevant proofs. The paper about the mysterious disappearance of marl and slags from the surface of British meadows and about "their discovery in a few years under the turf at a depth of several inches" had no success. And a reference to the "spongy layer, composed of dead leaves and innumerable worm-castings", which a French forestry specialist wrote about, did not sound convincing either.

Mistrust and indifference are the worst insults to a naturalist. Experiment was required. And Darwin decided to undertake an extraordinary journey around the "storages of the biosphere". Two flower pots replaced a ship to him. It was precisely these little refuges for earth-worms that enabled the scientist to make the experiments and show how these delicate creatures improved their flats and worked to create a fertile layer and to test their intellect.

Now soil zoologists are preoccupied, in the main with collecting "reference" data - the specific composition, numbers, density, anatomical structure and geographic distribution of the soil fauna. But the great scientist needed living pictures of nature. He was interested in the worms' endurance. And he placed them in a dry room with curtained windows and closed doors and left them under cold and warm water for several hours, days and weeks. These poor creatures died of a shortage of moisture and asphyxia and got drowned. But Darwin was not contented with their tortures. He devised an exquisite "torture" by music. Of course, worms are deaf creatures. But then, they did have to react to vibration. And he placed on his drawing-room piano a pot in which unsuspecting testees lived. Darwin struck a B note in the bass clef. The worms, which were about to look up on the surface hid in their holes. "After a time they emerged and when the note B in the treble clef was struck, they instantly retreated into their burrow."

The execution continued. Studying the worms' endurance, patience and caution, this English naturalist attempted to clear up their mental abilities. "In the pots ... leaves were pinned down to the soil and at night the manner in which they seized could be observed" he wrote. Here it should be observed that for some time before the experiment Darwin kept the worms unfed in extremely pure quartz sand, assuming that hunger would sharpen their "intellect". But to get back to the pots. They generally seized the thin edge of a leaf with their mouths .... In the case of broad flat objects they acted in a wholly different manner." The exquisiteness of hungry worms delighted the English scientist. He discovered that these creatures excellently distinguished the shape of objects and had a whole arsenal of devices whereby they took the food to their holes. "They act in nearly the same manner as would a man who had to close a cylindrical tube... and seize objects by their pointed ends," he concluded with satisfaction. Darwin was happy to realize that his hypothesis received increasing confirmation. The worms were not only ubiquitous and numerous, they were clever and ingenious. Who could expect such talents in these commonly despised lowest creatures?

But what does this have to do with the soil? The point is that the great naturalist assigned the earth-worm the role of the "architect" of the fertile layer. And doesn't the quality of a building depend on the abilities of its creator? Darwin emphasized that a comparison with man was not an exaggeration at all. Worms exhibited "individuality" and "resourcefulness". They regulate the temperature of the soil by dragging into it "an infinite number of leaves and other parts of plants in order to stop up their passages". Agriculturists call such a device mulching. "The leaves which they consume," wrote Darwin, "are moistened, torn into small shreds, partially digested and intimately commingled with earth; and it is this process which gives to vegetable mould its uniform dark tint." Such transformations are a challenge even to man, who can only clumsily imitate worms by creating composts and ploughing them into the earth. But then, composts and other organic fertilizers are mere semi-finished products. And their processing and the creation of humus are a job of the same inhabitants of the storages of the biosphere. Darwin observed this process as well. He released earth-worms into pots with leave-covered white quartz sand. "After about 6 weeks an almost uniform layer of sand, a centimetre in thickness, was converted into humus by having passed through the alimentary canals of these two worms." In many places of England, observed Darwin, over ten tons of dry earth annually pass through the bodies of worms and are taken by them to the surface, so that the soil's entire surface layer passes through the worm bodies in several years.

However, it is not enough to develop humus. It is also vital to create sand and clay, i.e. to grind the rock. Can earth-worms meet such a challenge? Darwin attached major importance to "minor factors". Soil animals, especially worms, are a great force. Every year they not only "eat" earth, but also create innumerable galleries in it. The latter are not eternal. They crumble, the specks of sand which make them up have been rubbing against each other from the beginning of the world, i.e. for billions of years. The earth which is carried by the worms to the surface is exposed to the action of carbon dioxide, sunrays and water. Thus, observed Darwin, particles of earth are placed in conditions which are extremely good to their corrosion and decomposition. Rock particles are rubbed away in the muscular part of the stomach, in which the small stones function like millstones. But do big stones, slabs, and, finally, cliffs defy the strength of these small sensitive animals? On the contrary, Darwin was confident that worms had truly colossal strength. Along with the wind and streams of water, they bury ancient structures and destroy fortress walls built of "wild" stone. In 1877 Darwin observed the excavation of a Roman villa. Its walls and floor were covered with a layer of black earth half a metre thick. The scientist assumed that the soil had been brought from above. Then the floor was cleaned and carefully swept out by special brushes. Not a speck of sand was left on it. The excavation area was covered with tarpaulin for the night. But already "by the next morning little cakes of trodden-down earth had been lifted up by worms over the mouths of seven burrows". They suddenly opened in the stone floor, which had appeared to be so impregnable for these sensitive creatures. "On the third morning twenty-five burrows were counted". In a month over two hundred holes were found in the villa floor. What agencies can stop worms? It turns out that wind and water can. If not for the elements, concluded Darwin, much more earth would have become accumulated over the ruins. Who then riddled the concrete floor into a sieve? Of course, rain, plants and worms did. "Knowing what great muscular power worms possess ... I was not surprised at its having been penetrated by their burrows ... The mortar between the rough stones of the thick walls... was penetrated by worms. Many monoliths and some old walls have fallen down from having been undermined by worm," concluded the scientist.

Enough would appear to have been said about the worms. But Sir Charles discovered what was perhaps the most important aspect of their activity. Worms are skilled agriculturists. They constantly ventilate and sift the soil. They mix the earth like a gardener who prepares the best abode for his extremely rare plants. In such a state the soil retains the moisture and absorbs all solutions best. The bones of dead animals, and insects, the shells of land living molluscs, leaves and branches after a while disappear under the worm excrements and reach there the state of greater or smaller decomposition, in which they benefit plants.... Many sowings owe their germination to having been covered by worm castings.

Darwin did not divide his research into main and secondary. And if his attention was absorbed by the Earth's most "despicable" creatures it most certainly was the first step towards the creation of a new picture of nature. Darwin conducted a series of brilliant experiments with only one element of the extremely complex mechanism such as biogeocenosis, in other words, a partnership of the soil, vegetation, animals, microorganisms, the atmosphere, rocks and water. Undoubtedly, if Darwin had seen the activity of the bacteria or processes of mineral or rock weathering or any other stage of this natural conveyor science would already have become enriched with one of the greatest works on soil microbiology or geochemistry.

The Conservative of Geognosy

The year 1873 brought the Ministry of State Property a great deal of disturbance. The highest order instructed to renew the maps of the Russian lands. Such tasks had not been frequent in the previous years. Back in 1869 Ivan Wilson had compiled a whole atlas of the holdings of various gubernias on the exclusive basis of the records of cadastral commissions, the maps of the General Headquarters and a geographic dictionary. But times were changing. Now these source materials would not be enough even for an ordinary account. And from the Department of Agriculture and Rural Industry raced instructions to "the Arkhangelsk, Vitebsk, Vologda, Vyatka, Olonets and other state property superintendents to deliver new soil maps to the Ministry".

Prelude

Two years had passed since that "formidable year". And on the desk of Junior Statistician Vasili Chaslavskii landed a colossal heap of government papers. Among his fellow-workers Vasili had a reputation for being a capable man but a misfit. This time he was unlucky again. Correspondence with the gubernias took almost all of his time. In addition, he had to look through the materials of military departments, to study the accounts of grain expeditions and the soil maps of credit banks and to tour central and south-eastern Russia. Now he needed an assistant. But where could he get one? Too little money was allotted, and after the debates over black earth the numbers of enthusiasts of studying the fertile layer had dwindled. Suddenly, luck smiled at him. He came across a collector of St. Petersburg University, V. Dokuchaev.

And work went off to a stormy start. The chief swamped his subordinate with maps, references, uyezd descriptions, and reports of land commissions. The analysis of these papers alone could have depressed a whole department, but not Dokuchaev. He easily handled his assignments. He found time to go through archives, and extract a whole heap of census returns concerned with landed estates, and expose the slovenliness of the Tambov and St. Petersburg managers (they had failed to send in the soil maps) in the process.

Dokuchaev was careful, diligent like the best ministry official and, at the same time, exacting and sarcastic. He was a great debater. His toughest battle with Chaslavskii flared up over the southern boundary of black earths. The statistician decided to trace it along the edge of the Black and Azov seas. Dokuchaev objected. After all, in geological terms the shore of the seas and the Dnieper delta were young formations. Furthermore, the climate there was much drier than in the Black Sea steppes. As a result, the black steppe soils recede northwards and along the shore of these seas and the lower Dnieper the map shows loams and sandy loams.

Finally, all work with the geological and soil maps, which had emerged from under the pen of excise and other officials, was done. Now ahead lay the most responsible work designed to produce a new presentation of the lands of European Russia. Alas, the heaps of materials which had gone through the hands of Chaslavskii and Dokuchaev brought little clarity. Blank spots covered the entire space of the forest-steppes. In the maps of some gubernias black earths abruptly changed into forest soils. In other cases between them there was a "transitional strip, in some places dozens of versts wide, where black earths gradually and frequently imperceptibly passed into, and merged with, the surrounding soils", Dokuchaev wrote. The statistician proposed calling them grey earths. His assistant did not object. But what was to be done with the black earths themselves? On the maps of the explorations of the gubernias they showed different fatness, depths and crop yields. Chaslavskii assumed that the latter sign was the surest. Why shouldn't black earth be good, middling and poor, as in the old days? But the young geologist rejected these "agronomical ravings". If there are no other criteria the "thickness of the humus layer and its underlying rocks can compensate for ... the insufficiency of the data", he insisted. The chief gave in. By joint efforts, arguing and doubting, they identified on the map nine varieties of the steppe soil - real, clay, sandy, etc.

The statistician and the geologist worked side by side for four years. They already discussed the full details, ended their debates and solved the problems. In other words, their work was nearing a successful conclusion. Suddenly, in 1879, Chaslavskii prematurely died. Having become a recognized soil scientist, Dokuchaev was offered to complete the work. Later, he recalled: "The map was my first experience, therefore it contains a host of errors. Its compilation required much more time than we were allotted, and the soil study had to be done in the field, and not at the writing desk."

Indeed, Dokuchaev was short of time. He compiled a soil map of European Russia, attended sessions in the Free Economic Society, gave university lectures on mineralogy and crystallography, and completed and defended a magisterial thesis. This took him all autumn, winter and spring. Summer saw his excursions to the steppe. But they were excursions in name only. In fact, this young scientist's summer holiday resembled tough peregrinations full of privations. What did he search for in southern Russia?

10000 Versts of Discoveries

Debates about the origin of black earth continued unabated for forty years. Relevant interest now waned, now flared up with renewed vigour. And it was easy to see that lull periods followed good years, and storms broke out in the wake of droughts. But then, the splashes of scientific thought never helped to arrest harvest slumps, the growth of gullies and other troubles of the Russian steppes. In 1873 and 1875 dry winds burned out the greater part of the sowings over the expanse between Voronezh and Kherson.

It was vital to adopt effective measures to save the granary. In the mid-1870s a special Black Earth Commission was set up under the Free Economic Society. Dokuchaev became a member and executor of its designs. Later, in his great work, *Russian Black Earth*, he recalled: "Since Russia's black-earth area occupies from 80 to 90 million dessiatines[1], in order to accomplish at least roughly the task set to me - to see at least the main points of the territory under exploration - I had to cover a distance of almost 10000 versts in the eight summer months."

1 Dessiatine is a Russian unit of land area equal to 2.7 acres. - Editor's note.

Why did this work fall to his lot? After all, the commission included famous chemists, geologists, botanists and agronomists, among them Dmitri Mendeleev, Alexander Inostrantsev, and Andrei Beketov. However, even against their background Dokuchaev stood out as a fine observer with a great feeling for nature, an explorer. "By a few details of the landscape," recalled Academician Vernadsky, "he grasped and outlined the whole in an exceedingly brilliant and clear form. Whoever had a chance to begin field observations under his guidance no doubt experienced the same surprise as I did when his explanations suddenly made the dead silent relief come alive, yielding numerous clear indications as to the genesis and character of the geological processes which had taken place and were hidden in its depths."

The choice of the Black Earth Commission was found to be the more fortunate since Dokuchaev was a geologist. This relieved him of a number of agronomical prejudices - the striving to divide the soils into "good" and "bad" rather than by origin and the exaggerated interest in the "arable layer" to the detriment of all that lay under it.

So, he vigorously attacked his task. His first excursion was to Central Russia. The summer of 1877 was not the hottest. Nevertheless, the mercury column seldom dropped below 30°C.

Noon heat and dry winds were nothing new to Dokuchaev, any more than crossings of 50 and more versts a day. But he did more than just cover such a distance under the drenching sun. He dug pits, collected samples and conducted observations. But he was not confused by the work of navvy and porter. Dokuchaev's only complaint was that "there was no physical possibility to enter during the excursions into details of various questions posed by black earth, to think of a virtual solution to many practical questions, perhaps important but undoubtedly local in character and interest". "Temptations met him at each step of the way," wrote Academician V. Williams. "How could he, for instance, leave unnoticed a miraculous earth clot? It no doubt embodied a colossal strength - the fertility of the steppe soil. And a ploughfield did not leave a trace of these clots. Perhaps therein lay the secret of the harvest slump? But time and tide wait for no man. "I pursued exclusively general aims," continued Dokuchaev. "I strove to study black earth in terms of natural history: it appeared to me that it was the only foundation ... on which to base ... really practical measures to raise the agricultural level of Russia's black-earth belt."

In 1881 the scientist clearly realized the scope of the questions which he had to handle first. "I am to solve," he wrote, "what in general should be called soil, what thickness, structure and position of it should be regarded as normal and what the name of black earth stands for. Should one, in formulating the scientific definition and in classifying black earth, take into account all accidental secondary soils with regard to the place of occurrence? What laws governed the distribution of black earth and other soils in European Russia?" Finally, "what are the sources of the really remarkable fertility of black earth?" But his research was not confined to these problems. On the contrary, in solving them he developed an enthusiasm for new ideas. And so on without end. This made Russian Black Earth a fundamental research monograph as well as a guide to action for the soil scientists of the forthcoming 20th century.

Dokuchaev's search ended the doubts as to whether the soil was a specific natural body. It was precisely this discovery that upset the famous triad of Linnaeus by equating the fertile layer in its rights with the kingdoms of plants, animals and minerals. But then, already Lomonosov had developed ideas concerning some specific geobiological body. However, this Russian titan only contrasted all-powerful eternally renewing nature with original pristine matter, i.e. denied divine interference in earthly affairs. Hence, his "independence of all kingdoms of nature". Lomonosov's conclusions were a fruit of reflections, a hypothesis. In contrast, Dokuchaev's conclusions were confirmed by experiments and observations. Thus, there was no repetition. There was a strict scientific substantiation of an idea expressed a century before.

The discovery of this new kingdom of nature made history in science. But simultaneously, the problem arose of who should own the no man's land. That was what happened to the soil. The geologists' claims at first glance appeared to be quite valid. In the fertile layer they saw the top geological tier of the earth's crust. And they inseparably linked its destiny with various cataclysms which our planet had sustained in the past. Hence, the familiar hypotheses of the maritime, swamp and glacial origin of black earths. But, however spectacular these models, it had to be proved that in southern Russia swamps and lakes had lain precisely where now lay black earths rather than swamp and sandy earths. Even when black steppe soil, Dokuchaev observed, "lies on indubitable swamp" it is sharply different from peat. "In our Northern and Central Russia there have always been more swamps and lakes than in the south. "However, they did not form black earth." But then what does it matter what lay here before - a salt seabed or an acid swamp? They can remain what they are forever if there are no favourable conditions of the climate, vegetation, etc.

Other claimants were biologists. And although they could not explain the origin of black earths and the laws which govern the 1ife and development of this soil its supporters found themselves closer to the truth than anyone else. Possibly, they would have overcome all the mistakes of their hypothesis. But it so happened that the biologists' attention was captured by another question: "What created black earth? The forest? The grasses? The animals?" The problem was not a simple one. The first pair of organisms appeared to balance each other. The trees occurred in the steppe. True, they grew in small pockets. But was the relationship between them and the grasses the same, a thousand and ten thousand years ago? Dokuchaev realized that the debate between the exponents of the "forest" an d "steppe" hypotheses took the attention away from solving the basic problems. Nevertheless, he interfered in it in order to prove the strength of the new science, the viability of its methods and principles. "The answer lies in the soil itself," assumed the scientist. After all it is the result of the many-century impact of water, climate, animals and vegetable organisms on the parent material. And if one were to assume that the first three factors were identical the question of the trees and grasses became much simpler." The scientist turned to the diaries of his travels and recollections. But nothing favoured the forest. "In all parts of black-earth Russia," he said, "in dozens of places amidst typical solid black earth centuries-old forest tracts may be found - on soils which show no difference from the northern lands." But exceptions occurred as well. And Dokuchaev admitted them. True, he made a reservation. "It seems to me that this formulation of the question is hardly correct: if such a conclusion (about the birth of black earth under forest - M.B.) is to be made it first has to be proved that there had never been steppes here, that the forest had not settled on ready-made black earth."

Among biologists there were lonely seekers, the most famous of whom, naturally, was Darwin. His original experiments with worms became zoologists' entry for possession of the fertile layer. Dokuchaev, although he did not deny the role of worms in the creation of soils, assigned to them a more modest place than Darwin. "Everybody knows," he wrote, "that many animals - susliks, hamsters, lizards, a myriad of insects and worms - swarm both on the surface of our steppes and in their soil. It all, swarming and rummaging in the earth, undoubtedly had to further make for the grinding of the soil and a better penetration into it of air and organic substances .... It is also doubtless that most of these organisms, living on dead and living vegetation, had to stimulate its rapid combustion, and that "dying they had to provide the soils with nitrogenous substances". But famous Darwin did not confine himself to this fairly vital role of the animals but proposed renaming the vegetable layer an animal layer, "However, there is no agreeing with such a sweeping conclusion," continued Dokuchaev. "Animals eat only what is to be found in and above the soil. Therefore, as they die, they virtually do not introduce anything new into it. If all soils are formed by worms why do we encounter black earths in some places and light ones in others, thin earths in some places and thick ones in others?"

Now, who had the right to own the soil? Dokuchaev answered: "No doubt in the 19th century the study of nature has taken giant strides .... But as one takes a close look at these colossal gains of human knowledge, which have changed our view of the world of nature upside down ... one will inevitably notice one very substantial and vital defect .... The study was made mostly of individual bodies - minerals, rocks, plants and animals - and individual phenomena, elements such as fire (volcanicity), water, earth, air ... but not their relationships, not that genetic, age-old... relationship ... between inanimate and animate nature, between the vegetable, animal and mineral kingdoms, on the one hand, and man, his everyday life and even his spiritual world, on the other. Whereas it is precisely these relationships ... which add up to the essence of the study of nature, the nucleus of real natural philosophy - the greatest and supreme delight of natural science. It appears to me that at the centre of this new school of nature study - as the nucleus of the theory of relationships between animate and inanimate nature between man and the rest of the world - should be placed and recognized modern soil science, understood in our Russian sense of the word!"

"Miracles" of Nature

The magnificent physiogeographic changes were on our planet and continue to be enacted with amazing gradualness and slowness," wrote Dokuchaev. "Regrettably, the nature of man and the duration of his life are such that in the overwhelming majority of cases we fail to notice the processes themselves and are only surprised at the results, not infrequently attributing them to accidents ... or catastrophes .... Undoubtedly ... it is precisely such accidents and catastrophes that hold the key to the popular disaster which befell Russia, he wrote in 1891.

The drought which then swept through its black-earth belt showed the complete bankruptcy of the agriculture and its helplessness in the face of this calamity.

Dokuchaev had an excellent knowledge of the steppes and realized that the battle for success depended primarily on the disclosure of the key reasons for the "great drought". It took him only one year to make this analysis. And in April 1892 he published another book, *Our Steppes Then and Now*, which in an acutely polemical form presented his views on the protection and sanitation of the steppes. *Russian Black Earth* was a special research publication. The new book represents an entirely different genre, that of topical scientific writing. A timely publication, it was a great success not only among experts, but also among people who stood far removed from the problems in hand. There is no saying that *Our Steppes* was a book within the grasp of the general reader. On the contrary, much of it is written in Latin, it abounds in technical terms and descriptions but the interest in the problem was found to be so great that the entire circulation was sold out. The proceeds from the sales went to the victims of the crop failure.

From the very outset Dokuchaev disclosed an exciting, colourful and, at the same time, tragic picture of the development of the steppes. He proved that the black earth belt, if slowly, stubbornly and inexorably, was drying. Dokuchaev saw the reason for this process in the extermination of forests on watersheds and in river valleys, in the birth of gulleys, in the loss of the green structure by the soil. "Along bared soil-less slopes the water runs down into the rivers," wrote the scientist, "and what is left rapidly evaporates. Furthermore, now water from a friend frequently changes into an enemy of the agriculturists, for nobody can stem its rushing streams during snow melts and torrential rains. With it the most fertile upper layer is removed from the fields. It gets into the rivers, flooding them and making them unfit for navigation. In the meantime, instead of sparing the water, it is thoughtlessly wasted." In his book he outlined measures to normalize the agriculture. The measures were spectacular, considering the times. Dokuchaev proposed a plan for river regulation. In his opinion, the navigable rivers were to be narrowed as much as possible, their cross-section to be straightened, the shallows and crossovers to be destroyed, the crumbling banks and sands to be strengthened by forest plantings, and the gully mouths to be blocked by wattle-fences. On small rivers he proposed building dams in order to store water for the future.

His next proposal was concerned with the "regulation of ravines and gullies". The growth of these "steppe wrinkles" had to be arrested immediately. Dams had to be built, and the gully banks had to be surrounded by trees, and the ploughing of their gentle slopes had to be banned.

Dokuchaev deemed it necessary to "regulate the water management of the open steppes". That was an ably developed strategic plan of collecting and distributing melt and rain water. Dokuchaev thought it necessary to accumulate in it the soil, to raise the level of the ground wasters and, finally, to improve the steppe climate.

But how could this be achieved? "Above all", said Dokuchaev, "on flat interfluves and watersheds it is necessary to make systems of ponds, locating them in natural hollows .... The shores of the ponds should be planted with trees. In other places of the open steppes hedgerows should be planted on small but long dams ... which will no doubt further the accumulation of snow. Sands, knolls, areas unsuited for ploughing should be planted with solid forest. Different types of artesian and other wells should be tried."

Many of Dokuchaev's proposals now appear to be elementary, the ABC of hydraulic construction schemes. But in those days such a programme for the reconstruction of the black-earth belt's water regime amazed the contemporaries with its completeness and depth. That was a step forward in science.

Dokuchaev knew how to answer not only to his opponents. He also fearlessly argued with high-ranking tzarist officials. Reproached by Alexei Yermolov, the Minister of Agriculture, that scientists allegedly stood too far removed from the requirements of life, he said in his book:

"Men of science for already dozens of years have been warning about the impending danger .... Men of science have presented to appropriate quarters dozens of drafts and petitions, and ... if not always, at least in the overwhelming majority of the cases, have received approximately the following reply: 'There are no resources for this. There are more vital requirements'."

Many books about the battle against dryness were published in those years. Their authors, Kliment Timiryazev, Alexander Izmailsky and many other scientists as well as practical experts did not confine themselves to the scientific analysis of the reasons for the drought and criticism of the steppe agriculture system. They demanded immediate action. The pressure was found to be very strong, and the wall of official indifference was breached. On May 22, 1892, within the Forest Department a Special Expedition for the Testing and Registration of Various Means and Methods of Forest and Water Management in the Russian Steppes started to be organized under Dokuchaev's guidance.

Already several days after the decision was signed the head of the expedition, invested with new authorities, set out for the south. He was in a great hurry. The roads had already dried, and it was time to begin the research. The first stop was made in the Kamennaya Steppe near Voronezh. The pace seemed to be fated for the Special Expedition, virginal steppes combining with two colossal forest tracts.

A cursory inspection, several pits, a mark on the map, and the expedition got under way again. The next stop was at the Don-Donets watershed. Here the steppe was entirely different. It was bare, with chalk outcrops on the hillsides. The entire area was open to winds, storms and droughts.

Finally, a third, and last stop was made in Velikii Anadol, very close to the Azov Sea. Dokuchaev found it particularly interesting: Velikii Anadol was the location of the only large artificial forest tract in the black-earth zone.

Alas, the work was hard, with disturbances and overstrain. Then illness prevented the scientist from generalizing the obtained materials and from bringing the expedition's work to its conclusion. But then, he could calmly hand over the guidance of the research to any of his pupils - Nikolai Sibirtsev, Konstantin Glinka, Pyotr Zemyatchensky, Pavel Ototsky, Georgii Vysotsky, Gavriil Tanfilyev, etc. - names which became a pride of Russian and subsequently Soviet soil science.

Five Basic Zones

In our days few people are unaware of the existence of natural zones. Few people do not know that our planet's dry land is divided into a number of wide strips with different climates, animal kingdoms, vegetation and soils. The same holds for the mountains. The theory of vegetation and climatic zones was put forward back in the 18^{th} century by Alexander Humboldt. But among the natural phenomena he discovered one element which was completely independent of the heat and moisture fluctuations. In Humboldt's opinion, that was the mountain surfaces of the earth's crust hence the soil. It may appear strange that Humboldt, who had traveled around the world and observed laterites and red earths, black earths and podzols, should have overlooked but also denied their presence. The reason was that Humboldt did not see in the soils a special natural body. Such short-sightedness of this great geographer and traveller intensely braked the penetration of this idea into young soil science. Many 19^{th}-century Russian scientists also believed that the formation and spread of soils were in no way connected with climate.

Dokuchaev exhibited far greater foresight. He surely had read the notes of the first explorers of Siberia and knew Lomonosov's work *On the Earth's Strata*. And his own travels through Russia suggested to him that "soils and grounds are a mirror, and a quite truthful mirror, the result of age-old interaction between the water, air, and earth, on the one hand, and the vegetable and animal organisms and the country's age, on the other". His "isohumus strips", which evoked particularly furious attacks from Kostychev, became precisely an expression of this idea.

Already in 1879, long before the completion of *Russian Black Earth*, the scientist published his first classification. It included only four soils - grey northern, black earth, chestnut and red solonchaks. In those days he had little material for solving such a global problem. But in another fifteen years he already presented the following picture of the zonality of nature: five main soil zones, or belts, have been exactly established: boreal, taiga, black-earth, aeral and laterite. However, many points remained obscure. In particular, altitudinal zonality in the mountains. In 1898 Dokuchaev set out for the Caucasus for the final solution of the question. Shortly, he published an article in a local newspaper. Here are some excerpts from this article. "My search in these extremely beautiful mountains have confirmed all assumptions as to the zonality of their nature and the similarity of the belts observed here to those pointed out on the plains of Europe, America, and Asia. The first of these, the tundra zone, is a creation of Boreas and lies in the land of eternal subpolar countries, where the earth thaws only for one to three months and only to a depth of one to one and a half feet .... The soils here are not weathered and rich in acid humus and iron monoxide ... they necessitate intensified aeration and heating." Further, Dokuchaev made an equally brief and popular description of the taiga zone with its podzol soils. His outline of the steppes and black earths breathes love and warmth: "South of the taiga lies ... the black-earth zone - the most fortunate creation of Zeus and Jupiter. Our black earth is the king of the soils .... It is five or more times deeper than the northern soddy soils ... ".

Dokuchaev was not inclined to make nature fit the law he had discovered. On the contrary, the scientist realized that "the picture of the zones I have drawn is a scheme ... but, fortunately for mankind in general and for the great Russia in particular and fortunately for culture, there is no deadening dry ... monotony in nature". Later research confirmed his words. Indeed, horizontal zonality was found to be not strictly "horizontal". In North America the natural zones run not so much north to south as east to west. In Siberia and the Russian Far East the alternation of the soils is also different from the "classical" pattern.

A small pamphlet *Toward the Teaching About the Zones of Nature*, published in 1899, completed Dokuchaev's theory of zonality, making the soil an equal member of the other "kingdoms of nature". This book is only 28 pages long. Illness and premature death prevented the scientist from completing his work.

Thus, the boundary of the 19th and 20th centuries marks the completion of the first stage of one of the longest experiments in history - mankind's "experiment" with the Earth's fertile layer. 10000 years of trial and error had led to the creation of a soil science. But, however significant the discoveries of the past centuries may appear, much more has been achieved in the past ten years. The soil has been found to have completely unexpected properties - "appetite", an ability to change some minerals into others, to accumulate energy and nutritive substances, and to change plant and animal remains. Scientists have established the presence of a connection between the fertile layer, on the one hand, and the plants and animals, on the other, to trace the functioning of the natural conveyor, the creation of the extremely complex natural polymer, humus, etc.

Dokuchaev's ideas concerning the soil zonality have been given a colossal impetus. In recent years alone dozens of soil maps of the continents and the entire world have been compiled. Soil scientists have penetrated into the highlands, subpolar and volcanic areas. Having studded these parts of land, bare and almost free of vegetation, they have reconstructed the picture of origination of life on our planet, hence, of the appearance of the soil as well.

But then, problems of pure science did not screen vital questions from soil scientists. They bear in mind Dokuchaev's words saying that soil science is called upon to help agriculture to keep the earth from the riot of nature's elements, to preserve its fertility. The destiny of the "storages of the biosphere" now preoccupies not just individual scientists. It attracts the attention of all governments and peoples. In the Soviet Union alone in the 1982-1984 period two major long-term programmes were adopted designed to provide the country with all types of food product by raising the efficiency of use of nature's greatest wealth - the earth.

Who will Help the Volcano?

Each event at present arises from the past and fathers the future, observed Voltaire. The eternal chain can neither be broken off nor muddled, he wrote.

The evolution of the views on the soil has to be supplemented by an outline of the history of emergence and development of the fertile layer. The entire story was concerned with only the latest stage in the "eternal chain" referred to by this great Frenchman. But what was its beginning? What did the truthful mirror of nature reflect billions of years ago, when living organisms still remained in the ocean and when the sea abysses were only coming into existence along with the hydrosphere and the atmosphere? What were these presoils like and what properties did they possess?

Time travel is perhaps among the most risky in modern science. Even the results of experiments and observations which form the basis for models of natural formations and processes in the course of reconstruction of the Earth's distant past do not always look convincing. Hypotheses born of them are exposed to particularly bitter criticism, contested and declared untenable. Nevertheless, they are found to be extremely viable. Such, for instance, is the idea of Heraclitos of Ephesos saying that nature's prime material is fire. Putting on increasing numbers of facts, it paved its way through millennia until it developed into a modern science known as biovolcanology. But what does it have to do with the soils? The point is that their prototypes were created by volcanoes, which first attempted to create the "fertile layer" unaided.

Born of Ashes

It is incredible that fire-spitting craters and lava torrents, which sweep away all in their way, animals, trees, grasses, soils - should create life. But then, such a parallel did not seem strange to the German physiologist Edward Pfluger. He thought that cyanogens - compounds of carbon and nitrogen - ejected during eruptions - were the substance which made the beginning of life. "Nothing can be clearer than the possibility of formation of cyanide compounds when the Earth ... was in an incandescent state," wrote the scientist. "Consequently, life comes from fire." Such a conclusion, of course, did not find support in the 19th century but in our time many scientists, including Academician A.I. Oparin, agreed with it. "Pfluger's theory has retained its relevance to this day," wrote Academician Oparin. "Its basic proposition, which says that 'life has come from fire', remains immutable. Only in fire, only in red heat could the substance form which later gave rise to life."

True, not all specialists agree with this even now. But whereas the theory of emergence of life from "fire" is problematic, the role of fire in creating "pre-soils" and "original soils" is apparent.

In 1980 Ye.K. Markhinin published the book *Volcanoes and Life*. It features the work which in the distant past was done by the plants of fire and lava and their activity now.

At the very outset, approximately to four and a half billion years ago, these enterprises faced spectacular tasks. They were to build whole continents, create the atmosphere, fill the oceanic troughs with water, eject into the air, on land and into the seas enough organic compounds to keep the incipience of life from being interrupted by any vexing fortuity. So far, it is difficult to reconstruct the scale of the former production factors. One thing is clear: they surpassed the modern ones many times. (Now volcanoes belch an annual three to six billion tons of matter. This would barely suffice to create the present continents - an annual 22 by 10^{18} tons of material.) However, it would only be possible if erosion, which devours 41 by 10^{9} tons of material per year, is to be excluded in its entirety. But then, the ups and downs of volcanic activity are not the subject of the story in hand. It is far more important that 90 per cent of the material ejected from the craters consisted of particles less than one millimetre in diameter. In other words, the substratum for the manufacture of soil prototypes was ready long before the emergence of the early organisms. After all, living beings required an atmosphere which would protect them from the deadly cosmic rays and abrupt temperature fluctuations, water and, finally, organic matter, necessary for the "construction" of cells and protein substances.

Their manufacture was also attended to by volcanoes. Together with fire and white-hot lava from their craters they belched magmatic gases, which, in the main, consisted of water vapour with nitrogen, carbon dioxide, sulphur, phosphorus and other substances "dissolved" in it. The latest calculations show that the moisture ejected by the volcanoes comprised from 50 to 75 per cent of the present hydrosphere.

"For this reason alone," writes Markhinin, "volcanoes took and take to the Earth's surface simple gaseous compounds of carbon, hydrogen, nitrogen and oxygen, from which animate matter has formed. It can be assumed that life on the Earth takes its beginning from volcanoes." In effect, their participation in the creation of pre-life, hence, "pre-soils", has been found much greater.

The study of the bombs and ashes of the Kamchatka volcano Tolbachik showed that in 1975-1976 it had belched almost one million tons of organic carbon from inside the Earth. Now these compounds have not made any noticeable environmental changes, but four billion years ago the grounds fertilized by them undoubtedly offered more comfortable homes to early living beings. As further search has shown, pre-humus consisted not only of carbon, but also of amino acids, nucleotides, hydrocarbons and heteroatomic compounds.

But at this point experts developed quite substantiated suspicions: haven't these organic substances been created by microbes? After all, the volcanoes are modern. Inoculations in flasks and a careful study of the newly fallen ashes with a microscope removed the last doubts. The elected material was found to be sterile. The volcanoes' ability to produce organic substances remained to be proved. This was done by the American biochemist S. Fox.

He reproduced the entire process of conversion of ammonia, methane, carbon dioxide and water into amino acids and other polymers. The device he had constructed was amazingly simple (a glass tube filled with sand heated to a temperature of 1000°C, a flask of water and a structure for obtaining a spark discharge) and simultaneously exactly reproduced the conditions which obtained in the volcanic crater. The conclusion was all too clear: "The formation of biologically vital compounds in the conditions of the primitive Earth could proceed from simple gases which contained carbon, nitrogen, hydrogen and oxygen under the impact of high temperatures."

True, in those distant times volcanoes were no longer the only productive force. The air and water they had created also took an active part in the formation of the biosphere and, of course, of the future soils. Rains washed away from the particles of ashes the substances which enveloped them. The atmospheric oxygen destroyed the least resistant minerals. They decomposed into elementary chemical compounds, salts. It was discovered that the most stable was quartz, while volcanic glass oxidized first. The place of the destroyed metals was taken by hydroxides of aluminium, iron, and silicon. Micas and "shapeless" allophanes came into being. Weathering gained in intensity - a process which to this day causes specialists debate. But then, billions of years ago its mechanism was noticeably simpler than now. After all, no part was played by organisms in the spectacular efforts of volcanoes and air and water streams. Without the organisms the production in fact ran idle. Apparently, as it belched products of the Earth's interior to the surface, as it washed and sifted it, nature checked the operation of future systems but lingered to connect to them the central link - living beings such as microbes, algae, bacilli, and fungi.

They joined in the process imperceptibly. Already in the oxygen-free atmosphere these organisms, invisible with the naked eye, set down to work, contenting themselves only with carbon dioxide or simply minerals. The scant nutrition, however, did not prevent their multiplication and evolution. Endless mutations and natural selection generated more and more representatives of the micro-world. Some of them learned to catch solar heat, others to absorb nitrogen and its compounds from the air and magmatic gases, still others specialized in rock ground. Ten Khak Mun, a well-known "bacterium hunter", discovered in diatoms and blue-green algae, which have changed so little in the last billions of years, an ability to rework aluminium and silicon compounds by wetting them with slime. As a result, strong minerals changed into sand, dust particles and products accessible to higher plants, which could participate in the element and energy exchange between animate and inanimate nature. That was how a new era in biospheric evolution set in. The dwarfing of material below the limits achieved by volcanoes created clays. As is known, the properties of this plastic substance and sand are noticeably different. While sand is incapable of retaining either moisture or nutritive elements clay, on the contrary, can do both. Grounds developed mobile compounds of potassium, phosphorus, nitrogen, sulphur, etc. - the "currency" which is used by the soil and plants.

But is it correct to refer to the formations of those distant eras as soils? No doubt it would be more correct to refer to them as original soils. The well-known Soviet soil scientist S.V. Zonn, who for a long time studied these natural bodies in the Soviet Far East and other parts of the world, assumes that such formations may have been among the first stages of soil formation on the globe in distant geological epochs. Another Soviet soil scientist, I.A. Sokolov, assumes that volcanic soils once claimed larger territories on our planet than now.

Even a cursory glance at tables and diagrams which cite data related to the composition and content of different minerals and the organic substance of original soils reveals the chaos which rules these volcanic products. They contain all possible things - pieces of volcanic glass, pumice, undecayed remains of peat and vegetation.

But then, the chaos here is only seeming. A close look shows that the material belched from inside Earth obeys strict sorting. It takes place at eruptions.

An eruption of Volcano Bezymyanny on Kamchatka covered the surrounding territory with 100 million cubic metres of ashes - enough to fill a small reservoir to the brim. At the foot of the bald peak its layer reached 20 to 30 metres and 10 kilometres away the thickness of the precipitation decreased to half a metre. Near the vent funnel their composition was far more motley than at a distance. Such differences make it possible to divide the entire coverlet into several zones which ring the volcano. The first and smallest is made up of rough fragments but the farther we go from it the smaller the material.

In volcanic soils everything is located upside down. The upper level is not only the youngest, but also the freshest. It is formed of lithospheric fragments just appeared from inside Earth. They are barely affected by weathering. In other natural conditions one would have to dig deep pits to reach down to minerals and rocks. Try to find a basalt or granite fragment in the upper levels of black or red earth. To this end, sometimes one has to reach four or five metres and more into the soil mass.

The incipience of soils and the renewal of the substratum in the volcanic activity zone run parallel to each other. Furthermore, they rival with each other. After all the plants and animals which settled on the ashes are exposed to constant hazards. They die of incandescent particles, are corroded by the acids and alkalis of slags and burn down in lava torrents. True, this is the way a volcano looks like from close quarters. From a distance rain of minute specks of dust causes the opposite reaction. When it irrigates forests, meadows or vegetable gardens a biological explosion takes place. Life on this area, becomes activated, the grasses and trees set records of biomass manufacture and the fields yield considerable additions to the harvests. Following an eruption of Volcano Bezymyanny in 1956 in the settlement of Klyuchi and other places of ash fallout the vegetable harvests jumped. Why? The study of volcanic precipitations showed that compounds of phosphorus, potassium and other elements accessible to plants become accumulated on their surface. A small dose of such a "rain" is the best fertilizer patented by nature. Incidentally, in one day of work the Bezymyanny Volcano ejected 450000 tons of easily soluble salts of nitrogen, 80000 tons of potassium, 36000 tons of magnesium, and 35000 tons of calcium.

The original soil created by volcanoes jointly with living organisms in the tropical countries has always had extraordinary fertility. In the 17th and 18th centuries the Pacific islands exposed to volcanic activity were frequently referred to as paradisal. Such a reputation was largely due to the fertile layer of ashes which covered them. It was enough to plough up and sow these lands to harvest fabulous crops. But the original soil also had another – unenviable - property. More than any other representative of the fourth "kingdom of nature" volcanic soil rapidly lost its precious gift. In damp climate areas the fields which cover the remnants of ashes and lava become fully depleted after two or three years of use. Therefore on the islands of Japan and the Philippines ricers draw up special rations for their charges - the tiny flooded fields. The dishes designed for the earth contain much fish meal, fresh volcanic ashes, etc. Aided by the gifts of the sea and the interiors of the Earth, the fertility of the local soils is preserved for centuries.

Now let us try to take a closer look at the ancestors of the modern soils. A simple magnifying glass helps to reconstruct their genealogy up to ten generations back - all stages of evolution from the birth to one of the burials of the original soil under fresh ashes during a volcanic eruption. Unlike black earths, podzol, alkali soils and other representatives of the fourth "kingdom of nature" volcanic soil develops brokenly. It has a clearly expressed beginning and end, when it is covered with rocks belched from inside Earth. This is confirmed by the stratification of the original soils - the colour gamut of their profile: black, ocherous, dove-blue and whitish-ashen colours alternate here with enviable regularity. The first glance at them creates the impression that nature has endowed the original soil with all properties so that it would have something to choose from in the course of evolution. In effect, things are much simpler. Stratification is merely a consequence of periodic volcanic eruptions. Another belching of the ashes, and the old soil begins to put on a new one. The fresh layer shows a humus horizon with an ash band with ocherous veins and volcanic sand under it. It also contains many charred remains of plants, poorly decomposed moss and grasses, rusty pendants, etc.

The microscope reveals smaller particles as well - fragments of volcanic glass and grains of minerals. They look fresh, having been scarcely touched by weathering and washed clean of admixtures, including nutrients, in which they abounded before.

The several-hundred-fold increase points to the reason for the great but short-lived abundance created by these soils. The savages, in distinct from their civilized counterparts, lay nothing aside for a rainy day. They spend whatever is given to them by nature. When the last thing they have is "eaten" all the plants can eat is stones. But for most of them such food is out of reach.

But then, volcanic soils are not so simple. Their inability to retain fertility is just another way of prolonging plant life. Nature does not do anything aimlessly. A case in point is the conditions in which the "life film" develops in Kamchatka and other seismic zones. Here each minute the lava, mudflows and ashes can smother it, wash it away and bury it under a many-metre mass of dead rock. This is why it has to hurry and yield all it can, exhibiting "explosive fertility".

A Zone of Chemical Surprises

Time went by, and many areas of our planet began to get rid of the despotic rule of volcanoes. Islets of land out of reach for lava torrents and the sounds of crater explosions made their appearance. The kingdom of animals, plants and, naturally, soils began to live according to other laws. There was nowhere to hurry. Everything was to be created sturdily, for millions upon millions of years to come.

And the role of the main creators of the biosphere was assumed by water, air and living organisms. Rivers and streams for whole geological epochs carried and washed remnants of volcanic bombs, ashes and lavas. The wind spread and sifted them. Innumerable colonies of microbes and algae, fungi and lichens also shared in the creation of a basically new mineral substratum - clays.

The key element in this new material was its amazing properties. It could absorb various elements and compounds from aqueous solutions and exchange moisture and plants with them. The clays were found to be plastic and stable, defying sunrays and water torrents. True, other laws operated here. In the case of clays the combination of chemical elements and the character of their bond with each other were determined by specific climatic features and the heat-moisture relationship. Red clays rich in iron and aluminium came into being in the globe's hot and humid areas. They contained a good deal of carbonates of calcium, magnesium and sodium where there was a shortage of moisture and aluminium and silicon in the cold areas.

But then, clays had shortcomings as well. In hot weather they baked, becoming hard as stone. Neither plant roots nor animals could break through such a hard ground. They poorly moisture. But nature made appropriate provisions as well. Among its creations were also sand, loess and other materials. By mixing or simply by providing them simultaneously, it created loams, which imbibed the best properties of their components.

But how did the post-volcanic plants operate? For a long time it was believed that there was nothing simpler than to explain what was known as weathering. Some old-time textbooks attribute the grinding of rocks into sand to dally temperature fluctuations and the activity of vegetation and water. But then, no one has ever denied that water can dissolve, organisms corrode and temperature differentials split rocks. It is only a list of the *dramatis personae* and the distribution of their roles in one of the longest and most mysterious industries conceived by nature .. And what are its operating mechanisms? What does this have to do with the wind (the Russian equivalent of "weathering" comes from that of "wind")? The point is that the term "weathering" is not simply unfortunate. It is also erroneous. There are two versions as to how it penetrated into geology and soil science. According to one it comes from the German notion of *Virwetterung*, which stands for the sum total of climatic factors including weather, which operate on rocks. It comes from the word *Wetter*, and not *Wind*. But it was precisely this error in the choice of the "root" that gave rise to the Russian equivalent of "weathering".

According to the other version, this notion is of a purely Russian origin, entering geology in the 19th century. One way or the other, it has nothing to do with the wind. Experts realized that such a definition only deluded, and did not explain what takes place on the Earth's surface. Nevertheless, it was never expelled. Back in 1922 Academician Alexander Fersman proposed replacing the erroneous term by a new one, hypergenesis, i.e. born on the surface. But this ill-fated notion continued to rule geological literature unchallenged for another forty years.

Only in 1966, when V.V. Dobrovolsky published his book Hypergenesis of the Quaternary Period, which discussed details of the origin and spread of familiar clays, loesses and sands, was the term "weathering" crowded. Nevertheless, it has struck such deep roots that Dobrovolsky himself now and then used it in explaining the mechanism of processing the virginal material of the Earth's interior.

In his book Dobrovolsky described hypergenesis in various natural zones. The Kola Peninsula in the Arctic is the place where the "variolitic" type of weathering occurs. The study of pieces of rock which cover the tundra with the naked eye shows that not all minerals, but only the most yielding become destroyed here. As a result, the surface of the boulders and rock fragments is extremely rugged, deepenings in them resembling smallpox traces on the human body. The most unstable in these conditions are nepheline and plagioclase.

The microscope study of these smallpoxes shows that weathering is not destruction into components but transformation into new forms, or compounds. Nepheline changes into opal and iron hydroxides. Here is how this proceeds. First, it puts on a white spider's web. It is easy to identify veins of opal in it. Along the veins' edges one can see rusty spots - iron hydroxides. Gradually, the network of veins grows thicker, and so do the veins themselves. White-rusty metastases turn up against the green background of nepheline. This creates the impression that it becomes dissolved in new formations.

In the Arctic the weathering processes are suppressed by its rigorous climate. Here a small amount of protogenic rock is processed. This is why the tundra surface is covered with a thin clay casing - a product of hypergene transformation.

The study of alluvia of the penultimate geological period – Pleistocene - and of the bedrocks shows that clays do not owe their origin to the glacier. It was not the glacier which ground the northern granites and gneisses. It was not its water torrents which spread over the plains soft plastic material on which modern soils formed. Clays existed in the tundra long before the first glaciation. They were the result of the processes which took place in the river valleys and on the mountain plateaux under the skimpy rays of the Arctic sun.

And now let us travel south, to the steppes of Kazakhstan. While in the north the rocks and boulders were barely covered with a thin film of clays, here the depth of loesses and loams in some places reaches dozens of metres. And they have an entirely different aspect. Not a single fragment of the primary material is left in them but they contain much dust whose particles are at times much smaller than a micron in size.

Now it is the time to take up the microscope again. How little do the loesses of Kazakhstan have in common with the clays of the Kola tundra! The latter were dominated by compounds of silicon, aluminium and iron and the steppe samples are filled with calcium carbonates. They permeate the entire mass of the sediments. The local soils show a mass of white little pipes, specks, and nodules, which look like sea urchins and concretions. At a slightly greater depth turn up spots of gypsum and other salts. They are very mobile and cannot remain at the surface, where they are washed by melt and rain waters.

A brief excursion to two areas of our country shows how widely different results come from what is actually the same process. So far, the author has been discussing only the original and final products of weathering, but not its mechanism. For a fairly long time it was believed that this was no secret at all, that everything could easily be described by chemical equations. But even what has been outlined shows the exact opposite.

The destruction or dissolution of a piece of rock is only a simple part of weathering. The rest of it is far more complex and mysterious. It was not for nothing that V.V. Dobrovolsky turns to an example of a hypergene transformation to a fairy-tale by Ernst Hoffmann. "Among the figments of his lurid imagination," he wrote, "there is the following: mirages of mountain treasures carry away the young miner inside the earth, where the dark forces which guard the treasures change him into a statue made of a precious metal." Here he explains: "The myth about the 'ore man' arose from real events of the 13^{th} century. A man who worked in the Falun mines, located in Sweden, lost his life by falling into a deep underground fissure. When he was found in several dozen years his clothes, body and hair were turned to be all replaced by small gold crystals of pyrite (ferrous sulphide). It was a real statue of a metallic mineral which glittered like gold."

Now, this exceptional incident in general is not so exceptional. Similar conversions occur in the world of minerals every day. The chemical reaction to which it was frequently likened was a simple exchange of ions, atoms and molecules. Its result being always known beforehand, surprises are ruled out. From a certain selection of elements there can emerge only planned substances. And what is to be done about the poor miner? After all, the sulphur and iron which were contained in him would not be enough even for a much smaller copy. And here a full-length statue formed.

Such metamorphoses are frequent in the inorganic world. A case in point is feldspar. Consisting of aluminium, potassium, silicon and oxygen, due to weathering it becomes replaced by limestone. Quartz or silicon oxide change into iron compounds.

As said earlier, the result of the exceptional metamorphoses scarcely depends on the starting material. The same quartz in different natural conditions can be replaced with hydroxides of metals or alkaline minerals like calcium carbonate or kaolinite.

Try as you might, the voids which would inevitably have to form between the primary and weathered substance will never be detected. On the contrary, the incipient and the starting materials will fuse together. Suffice it to recall the nephelines of the Kola Peninsula. These nephelines and the opal metastases which have struck them are tightly fitted to each other. But whatever the change in the relationship between nepheline and opal, the shape of the boulder or rock fragment remains what it is.

This unorthodox phenomenon has come to be known as metasomatosis. Amazingly, for the first time it was noticed inside the earth. It was discovered in the course of exploration of the magma and the abyssal processes of rock compression attended by high temperatures and pressures. Who could expect to come across it on the surface?

In metasomatosis everything is the other way around. How the crystal lattice of mineral changes into a new one became clear immediately. The explorer did not doubt for a minute that weathering did not destroy the old framework to its foundations. He knew that it would gradually reshape it. This is easy to imagine in the case of a block of flats at the stage of overhaul. First, one after another, intermediate floors are removed and replaced. Then water and gas supply and sewerage are provided. Finally, the block is tiled and its windows are glazed. As a result, it changes into an entirely unfamiliar building which resembles the old one only in shape and size.

But where did the building material come and how did it make its way between the fused minerals remained a puzzle. Dobrovolsky found himself in the position of a spectator watching a juggler's performance. Everything proceeded in front of him and, at the same time, he could not grasp a thing.

But the difference between a scientist and an ordinary onlooker is that the former is not contented with nebulous conjectures. Before he believes something he has to see or even to touch it. His last stake was on a scanning electron microscope. The magnification of dozens of thousands of times confirmed his guess: the minerals were found to be divided by an extremely thin gap of 10^{-4} to 10^{-5} centimetre. Such cracks were also found in rocks and clay mass. They were the bed along which moves water, this universal natural solvent. True, not only water, but also alkalis and organic acids released by plants.

Dobrovolsky succeeded to determine the chemical composition and element concentration where the minerals were in contact. In penetrating into nature's laboratory he was helped by an electron-probing apparatus capable of making analyses within a negligible volume nearly in a point. It was discovered that such cracks were a scene of intensive transformations. Here with water and other liquids come new elements and the destroyed old material is carried away by the same flow. However, the most amazing thing about the newly discovered phenomenon is that it proceeds on a plane in a two-dimensional space. After all, the thickness of contact between minerals is thousands of times less than the length and width of the surfaces in contact.

The dissolution of the starting substance and the deposition of a new one on such a limited space as the crack between them make it possible to preserve the former volume and shape. Metasomatosis distantly resembles galvanoplastics. It is used for growing parts of certain size and shape. The only difference is that in nature the matrix should disappear. The finale of such a transformation may appear to be the most surprising .. A rock will change into a clay hill and a dead mollusk into a hard ammonite or a devil's finger. In Brazil, for instance, a topaz has been discovered which weighed 117 kilograms and an aquamarine which was 50 centimetres long. They had grown in mountain masses. In the Ilmen Mountains, in the Southern Urals, in a solid rock of feldspar a whole mica mine was dug out. These are also products of metasomatosis.

Now the starting material disappears and a new one turns up in its place. What next? Where the processing is intensive for instance, in the steppes, savannas and tropical forests, powerful loose masses are being formed, also known as the crust of weathering. Does this cause changes in the local relief? "One of the remarkable specific features of the hypergenesis zone," writes Dobrovolsky, "is the spontaneous dispersion of a solid substance. Crystalline rock masses on the surface of dry land change into sand and crushed stone, monolithic rocks into rottenstone. In this process of progressive dispersion of the Earth's crust substance the crucial role is played by water. The well-known physical chemist Academician Pyotr Rebinder showed that water, as it interacts with the surface of mineral particles, reduces their free surface energy and decreases the work necessary for the formation of new cracks and the further grinding of minerals."

It is safe to say that modern plateaux and plains largely owe their appearance to hypergenesis. They are far from being always the result of the recession of the sea or of the drying of an enormous freshwater lake. But before the discovery of the mechanism of metasomatosis the explanations for the emergence of low-lying parts of dry land spreading in place of highlands sounded none too convincing. For a particularly long time the active role of water in hypergene transformations was ignored. The reader has already seen that water interacts with minerals the more successfully, the greater their surface. "When the latter reaches order of 10^4 to 10^5 cm the force of interaction of the molecules of water changes the force of ion bonds, and the minerals' crystal lattice becomes destroyed. This explains the absence of fragments of abyssal silicates among particles less than

0.0001 centimetre, a phenomenon well known to experts," says Dobrovolsky.

What does the Earth Stand on?

All the aforementioned metasomatoses of minerals surprise rather than convince that they touch off the incipience of the crust of weathering. Indeed, metasomatosis is merely one of the first elements of the exceedingly complex natural machine which grinds rock into clay, sand and loess, changes highlands into plains and creates the soil for future soils.

Slightly earlier the author compared the change of a mineral's crystal lattice with the overhaul of a housing block. But not a word was said about where the units of the old framework go. Now the time has come to recall them. The new crust of weathering is born when the first chemical elements break free from the minerals' lattices. They immediately join in the circulation between animate and inanimate nature, between land and sea. The flow of atoms, molecules and ions is absorbed by plants and spread by wind and water streams. On their way they form new compounds, minerals, rocks and landscapes. At times some chemical elements largely determine the make-up of the environment. Their surplus or shortage determines the character of the soils, vegetation and local relief. True, the elements of the D.1. Mendeleyev's Table do not behave as they see fit. They obey the rigid laws set by nature, including the law of zonality. Furthermore each chemical element which has got rid of the crystal lattice gains its own inherent degree of mobility. Among them occur "fidgedy" and extremely conservative elements and compounds. At times circumstances, more exactly, climatic conditions, keep even the most "devoted travellers" at home or, on the contrary, force even lazybones to leave their customary places.

The outstanding Soviet soil scientist Academician Boris Polynov was the first to point to the chemical elements which dictate the composition and properties of the grounds and soils, hence, the make-up of the environment. His book *The Crust of Weathering* is a vivid, fascinating story of how atoms, molecules and ions have divided the entire surface of the Earth into spheres of influence. But before he set out in pursuit of the traces left by elements in the landscapes the scientist had devoted many long years to the study of their mobility. Not that it was a complex matter, but he had to study the content of thousands of samples obtained in the vaporization of river waters from different areas of the world. The atoms and molecules that dominated in them were identified as the most enthusiastic travellers - migrants. Polynov divided the notions of "predominance" and "quantitative prevalence". It was vital to know not the total amount of the substance, but the proportion which was dissolved and washed away by water from the rocks, he assumed. After all, the content of the elements in them at times differs thousands and even tens of thousands of times.

"We can see," he wrote, "that the composition of the mineral part dissolved in river water is substantially different from the composition of those rocks which give their mineral parts to water. We can see that chlorine, which comprises a negligible proportion of the mass of fresh primary rocks untouched by weathering exceeds six per cent in the water's mineral residue. Naturally, this is not because from somewhere new chlorine portions got into the river water, but because its compounds in the rocks became dissolved in the water much sooner than the compounds of other elements.

Let us imagine that within a certain period some rock mass of a certain size gives all chlorine it had to the river water solution. If the sulphur compounds of amount of $SO^{2-}{}_4$ dissolved in the river water would have to be three times that of chlorine .... In reality, only 57 per cent of the sulphur to be found in the rock passed into the solution within the same period."

And the scientist concluded that the intensity of migration of chemical elements could be inferred from the proportion of their content in the mineral sediments of natural waters to their concentration in the rocks. Elementary calculations show that chlorine and sulphur become leached a thousand times faster than silicon, aluminium and iron. But these are only the beginning and end of the chain of the elements' migratory abilities. What is the middle? Laboratory experiments and more or less elementary arithmetical operations help to align the remaining elements of the Mendeleyev Table, whose content in the Earth's crust lends itself to calculation. Equal "liveliness" with sulphur and chlorine is shown by boron, bromium and iodine. Calcium, magnesium, sodium, fluorine, strontium, zinc, uranium, molybdenum, and selenium were found to be less "nimble". These were scarcely kept up with by silicon, potassium, manganese, phosphorus, barium, radium, nickel, copper, lithium, and cobalt. Together with aluminium and iron, "tailed off" titanium, metals of the platinum group and tin. Finally, the chain was ready. But it the least resembled the sequence which was searched for by Polynov. The chemical elements' inclination to travel dwindled by leaps from chlorine to aluminium. This suggested a multistage process. "The first phase," the scientist explained its essence, "is marked by the fact that products of weathering lose chlorine and sulphur compounds. It stands to reason that some amount of cations also escapes with these anions but a considerable proportion of the former still remains bound to other anions, mostly in the form of silicates.

In the second phase the products of weathering already without the chlorine and sulphur compounds lose the alkaline and alkaline-earth bases. This phase falls into two stages, in keeping with the higher mobility of calcium-sodium compounds compared to magnesium-potassium ones.

In the third phase the products of weathering which were devoid of considerable part of alkaline and alkaline-earth bases lose the silica. Finally, in the fourth stage, when the weathering products consist almost exclusively of sesquioxides (oxides of iron and aluminium - M.B), the latter are also exposed to greater or smaller migration."

The identified phases of weathering opened up before Polynov a new picture of the evolution of volcanic fragments into clay. The scientist realized that processing could have different results. The more tangible the result is, the more heat, moisture and time nature gives. He identified four main types of the crust of weathering. The first barely touched by weathering, is fragmentary - in fact: protogenic rocks belched from inside the earth or relics of past geological epochs. They remain in extremely dry and cold areas of our planet, where rains do not water the land for several years. A case in point is the high-mountain deserts of the Pamirs and Tibet. Here even the mobile ions of chlorine and sulphur have changed into "stubborn homebodies".

But suffice it to climb down from under the clouds to the submontane areas, where rains are far more frequent (although evaporation here exceeds watering), and the first traces of rock processing - calcination of the crust - are there. The ion of chlorine and, following it, that of sulphur, snatched out of the crystal lattice of the minerals, cause the restructuring of the entire fragmentary mass. Clay minerals such as montmorillonite, beidellite, muscovite, etc. come into being. "The migration of these elements," noted Polynov, "leaves a clear stamp on the soils, and on the local waters, and on the vegetation, tying all these 'landscape features' between themselves with a strong causal connection."

In the moderately warm and humid climate, where precipitation exceeds evaporation, the materials of the past geological epochs lose, together with sulphur and chlorine, carbonates of calcium, sodium and other alkaline and alkaline-earth compounds. The silicates begin to crumble. Clays come into being, dominated by silicon and aluminium. It is the siallite crust of weathering. Its name comes from the first letters of the words silicon and aluminium.

In the tropics the surplus of heat and moisture make even silicon set out on journeys. True, it is extracted only from the most yielding combinations of silicon and oxygen - silicates. In contrast, quartz remains almost untouched. Concerning the crusts of weathering, which form here Polynov wrote: "Research shows that this crust of weathering has accumulated a vast amount of aluminium and iron. But it is a residual accumulation. Their vastness of amount is not due to the fact that they have been brought from elsewhere and have thus become accumulated but because the colossal amounts of other elements have become removed .... The waters which wash this red crust of weathering have the highest silica content ... up to 50 per cent of the entire mass of the substances dissolved in water. Thus, it is a case of landscape characterized by the fourth group of the migratory series. The first series have already largely been washed away, the third series is being vigorously washed away ... and some mobility is already beginning to be shown by iron and aluminium."

But then, this is only a scheme. In nature everything is much more complex. After all, the crust of weathering, just as the soil, is a reflection, and quite a truthful reflection, of the age-old interaction between the climate, rocks, organisms, and, naturally, the geological history of the land where it formed. But the scheme is not abstract. It furnishes an insight into many questions which face soil and landscape scientists and other naturalists. An example of such a problem and its solution is cited by Polynov himself. "A railway traveller from Leningrad to Pskov," he writes, "at a place called Krasnaya Gorka, not far from the city of Porkhov, can observe an interesting picture. On one side of the road one can see a large sloping elevation, partly covered with an oak grove, partly occupied with cultivated fields. In the appropriate season these fields are marked with thick sprouts of cereals, showing all signs of what is usually referred to as 'fertile fields'. Below, at the foot of this elevation, spreads a meadow crossed by a small stream of crystal-clear water and covered with a motley carpet of flowers dotted with clover balls.

An entirely different picture can be observed across the road. An elevation located there is covered with a dark spruce forest with an admixture of birches and aspens. There, around the forest, there are cultivated fields but even the naked eye can see that the crop yield of these more sparse sprouts and the very quality of the grains are clearly lower. There, too, there is a meadow depression at the foot of the elevation, but there are no bright flowers on these meadows. They are covered with a solid thicket of sedges with spots of tussocky swamp."

What is the explanation for these striking contrasts of poverty and affluence? The answer is to be found in Polynov's own descriptions. It should be noted that on one side of the road there are oak groves, fertile fields and a meadow covered with clover. The other side has a spruce forest, lean fields and a damp meadow with spots of swamps. Clearly, the soils are responsible. But why should so different representatives of the "fourth kingdom" arise in similar conditions? Apparently, the underlying materials, i.e. the crust of weathering, on which they have formed, were different. In particular, the abundance of clover is a direct indication that one of them abounds in calcium. Indeed, in the first case, the elevation is formed by what is known as carbonate moraine - a rock rich in carbonate of lime. The study of the elevation's soils showed that there is no carbonate of lime already on the surface, that it is washed away and removed to a depth of almost a metre. But in another form, however, enough calcium is left for high grain crops as well as for oaks, which, generally speaking, are not so widespread in these latitudes. But there is still more carbonate of lime below, where it is carried by water which washes this elevation. Ground waters and the hard water of the stream contain it there in threshold amounts, i.e. in amounts which can dissolve in water. This water feeds the meadow grasses. This is why clover occurs there, for clover, like other grasses of the same family, exhibits a particularly high selective ability with regard to lime.

"On the other side the picture is entirely different. There moraine glacier deposits are represented by leached clays and loams which contain negligible amounts of calcium. In complete accord with this are the field soils, which already show signs of podzol formation, the result of which is a low yield of crops and dull wet meadows with mosses and sedge and soft salt-poor water," wrote Polynov.

Thus the building matches the foundation. But this is not the only consequence which follows from Polynov's problem. It turns out that the rock fragments and the ready-made crust of weathering are objects of "export" and "import". In our case the glacier literally dug out and carried over a long distance carbonate fragments, of which there is a shortage in the southern taiga. It was they which have created a "corner of plenty" amidst the monotonous poor landscapes of the forest zone. However, after a while nature will win the day by destroying and leaching the carbonates. Then the oaks will yield place to spruces and birches and the fields and meadows will lose their former fertility.

And where will the chemical elements which have left the rocks go? After all, some day their peregrinations will no doubt come to an end. At times this happens much sooner than it can be assumed. The point is that far from all atoms, molecules or ions, freed from their crystal lattices, form salts like sodium and calcium carbonate. For instance, aluminium, silicon, iron, titanium, and manganese barely create any mobile salts. They can move about only in the form of colloids. And not only move about, but also create new crusts of weathering. Because a colloidal particle - a micella - is a fairly unstable being. It is oriented to the external world with the negative and positive electric charges of its compensating layer, which conducts all negotiations and makes all commercial transactions with the surrounding world. The micella is always ready to capture a weaker rival or join a stronger partner. Thus, a new crust of weathering, which contains practically no salts, imperceptibly comes into being.

"The colloidal state of matter is extremely typical of the crust of weathering," notes the Soviet geochemist A.I. Perelman. "In the case of intensive weathering practically all solid components of the crust are to be found in the colloidal state or pass through the colloidal state in the course of their formation. Cases in point are the numerous clay minerals and the hydromicas of silicon, iron and aluminium." This amounts to one answer to the questions. Metasomatosis and other mechanisms of hypergene "production" work to create material for colloids.

But there are other consumers of these products - living organisms. Over 80 years ago the American scientist Howard Holland assumed that thick red crusts of weathering, laterites, were a specific tropical disease of basalts and other rocks belched from inside the earth. Was this an exaggeration? Of course, it was. But his hypothesis also contained a rational element. Much later Vernadsky wrote: "The processes of weathering, in particular, sharply expressed in the biosphere, are always biogenic and biologically inert. Microscopic life in them plays the leading role." Microorganisms were also referred to by Polynov, who noted that one gram of weathered granite at a depth of 12 to 17 metres contained several million such microorganisms. In the 1970s microbes were discovered in water contained in the pores of clay shales which were over 200 million years old. And research into the leaching of sulphide ores by thiogenic and other species of bacteria finally confirmed Vernadsky's thought. Now the participation of microorganisms in the creation of the crust of weathering gives no doubt to anyone, any more than the role of worms in the soil formation. But this is the exact reason why scientists should not do too much search for "the only" or "the main" builder of the foundation for present and future soils. Because the crust of weathering is a product of joint creation of all forces of nature, to which the division into "superiors" and "subordinates" is alien.

Assets and Liabilities

Simultaneously with the foundation the soil itself also continues to grow. Nature does not create its products in several stages, but works at once on all stages of the conceived building. A particularly active role in this process is played by higher and lower plants. From time immemorial they have been establishing "business relations" with the fertile layer and their underlying grounds. The trees and the grasses, the mosses and the lichens, the algae and the fungi are so experienced dealers that they can wheedle out a "loan" even from the most stingy representatives of the "fourth kingdom" and even from fragments of rocks and sands.

This was pointed out by Liebig. He was so carried away with the analogy of the element exchange between plants and soils, on the one hand, and banking operations, on the other, that he reduced it to the widely-known debt-should-be-repaid formula. In the meantime, this German scientist was close to unlocking the secret of the mechanism of biological circulation.

The Liebig "theory" was revised only in the late 1920s, when a research centre for the industrial cultivation of subtropical crops had opened on the Black Sea coast of Adzharia. Polynov, who took the lead of an Adzharian expedition, was firmly convinced that the problem of cultivating tea, citrus and other exotic crops could be solved only if the secret of the springs which actuate the mechanism of the southern landscape were unlocked.

The lands of Adzharia were regarded as relics of the Tertiary period, when the climate was milder and a considerable part of what is now the Soviet Union was covered with tropical forests. A major authority, Academician Konstantin Glinka, called the local soils "failure laterites", or red earths. In Latin later stands for "brick". This alone gives an idea about their colour, density and other characteristics. Polynov, however, assumed that such claims were not convincing. "First," he reasoned, "nobody has seen anywhere soils that would be ten or more metres deep. Rather it is the crust of weathering survived from the past epochs. The preservation in it of the texture of the crystalline rock furnishes evidence that crystalline material was changing into clay for a long (in geological terms) time. First, it was forming in the conditions of flat relief. Then tectonic forces took it out of the horizontal position. Mountain streams caused violent erosion, and the soils of the past epochs together with part of the crust of weathering were washed away. Consequently, the top layer is represented by young soils, which made their appearance in the course of the advent of the forest."

Hence, according to S. Zakharov, red soils are our heritage. To this day they constitute a well-adjusted mechanism actuated by vegetation. Polynov got down to study the motion of chemical elements in the subtropical landscape. But he departed from Liebig's "classical scheme." The extraction and restoration were studied not only between the soil and vegetation, but also analysed were the crust of weathering, bedrocks, and water. But major attention was focussed on the classical element - the vegetation and soil.

That was how extraordinary work got under way in the Botanical Gardens near Batumi. On the very top of the ridge the researchers laid out a small plot on which they cut off all plants - beeches, hornbeams, rhododendrons, lianas, and grasses. Their root systems were carefully prepared, the branches and leaves were separated from the trunks and stalks, and a complete calculation of the biological mass was carried out. Next, together with the samples of soils, and rocks and the dry residue of the ground waters all this was exposed to chemical analysis.

But was the problem worth damaging what was the only plant collection of its kind? After all, the experiment was carried out in the interests of subtropical nature itself. A spectacular development of this zone was forthcoming. But without the knowledge of the laws which governed the life and development of the Adzharian landscapes of the Black Sea coast man could have touched off a catastrophe of the kind that had already on many occasions taken place on our planet.

What did the experiments show? They showed what is absorbed from the soil by the plant roots, and in what amounts, the speed with which the chemical elements are returned with the falling of, what remains in the soils and what escapes with the water. The result was whole series of biological absorption and leaching. For instance, aluminium oxide in the ashes of the leaves of a hornbeam, chestnut and tea bush reached from 10 to 20 per cent. Its compounds were found to appeal to plants most. In contrast, silica, although its mobile forms were represented in far greater amounts in the soil and the crust of weathering (about as much as those of calcium) was consumed in more moderate quantities. Iron did not exhibit the slightest desire to move about in the earth mass. That was why it was so red.

The observations also led to other conclusions. Before Polynov's research the Adzharian red earths were classed with the subtropical variant of our taiga lands, i.e. the podzol soils. The podzol family has always been distinguished by the poorness of nutrients and humus. But was the fertile layer of the Black Sea shore identical? Some pointers to similar kinship occur in many red soils. Take sesquioxides (iron and aluminium). Their distribution in the red soil mass could be regarded as proof of the red earths' kinship with the northern podzols. But other elements of the subtropical soils show an entirely different pattern of behaviour. Why? The answer was obtained by studying the location of roots in the soil mass. Polynov noticed that the tree roots stretched horizontally, the thinnest of them stretching upwards, towards the litter, where fallen leaves accumulated. Hence, the share of aluminium in this level was decreased by vegetation, which captures its compounds. And the water here had nothing to do with it. Furthermore, the depth of the greatest root accumulation coincided with that which, judging by the enrichment with silica and the impoverishment with aluminium oxides, had to be located at the "podzol" level. This furnishes added evidence that alumina was not removed from this layer by solutions, but was absorbed by the roots. Following the return with the fallen leaves, it long remained in the forest litter. The uncompensated outflow of aluminium created the relative accumulation of alumina. But, as was discovered in the course of the experiment, the latter's compounds not only accumulated, but, on the contrary, became dissolved and washed away by the soil waters. In other words, in the red earths a process took place which was directly opposite to the podzol one. That was why although in the subtropics the soils had far more time to create their profile than in the taiga, they never formed any pronounced whitish layer - the sign and measure of development of podzolization.

Later, in describing the landscape of the Adzharian seashore, Polynov went back to this problem. "If we recall that any eluvial process is accompanied by a struggle between the capture of elements by organisms and the removal from the sphere of soil formation, if we consider the work of the powerful subtropical vegetation, which lasts annually for the long - and almost continuous - vegetation period, and if we recall that, vigorously absorbing the sesquioxides, this vegetation for a long time keeps them in the soil levels we will receive ... an explanation and answer to our question."

Indeed, as he observed the vegetation, the scientist learned many facts pertaining to the soils themselves. He realized that their connection was indivisible and unravelled the mechanism hidden behind the dry "booking" calculations of the assets and liabilities of chemical elements and substances. But he had no complete confidence of the validity of his conclusions. The research appeared to be incomplete. After all, Polynov had established the relationships between mature soils and luxurious vegetation. And how did it all begin? How did the first plants develop rocks? The volcanic soils of Kamchatka have already been discussed. How the clays and loesses formed has been pointed out. But the fact that living organisms can challenge rocks themselves and win the battle has not been considered.

This problem was attacked by Polynov. In 1939 in Ilmen Mountains study of metabolism began between rocks and vegetation. At that time the scientist took an interest in the activity of the most primitive plants - mosses and lichens, whose entire mass grew into the granites. Making several sections and studying them with a microscope, he discovered that the hyphae of primitive plants could break rock into tiny bits. They do this without hurry. A hypha hooks a small glume and draws it into the lichen body. However small the hole is, fine earth can already accumulate in it. Loose original soil settles mosses followed by dwarf vegetation such as pines and birches. Polynov established that fine earth is formed by lichen's own decomposed remains rather than destroyed rock. And how about metasomatosis? Well, it functions simultaneously with the vegetation. There is enough work for everything.

His exploration of the Urals enables Polynov to complete the history of the emergence and development of the Earth's soils. His attention was attracted by very "ordinary" phenomena. For instance, he saw a"small grove in a low place between rocks. At first glance, there was nothing remarkable about it. But the scientist stopped, dug a pit and made an amazing discovery. Under the fine earth he saw completely fresh boulders and crushed stone untouched by weathering. How did the soil turn up on these rock fragments? Polynov was convinced that the loose loads were washed away on top. That had been done by lichens. "Their action can ... hardly be regarded as a local particular phenomenon," he wrote. "One can hardly question their indispensable participation, together with the glaciers and the action of heat and cold, in that age-old denudation which rubs away all protrusions of land and accompanies the phase of the glyptogenesis of each geological cycle. At any rate, it can be postulated that the transformation of a rock into rottenstone is not a sterile process and rottenstone itself forms with the active participation of organisms."

Laboratory research showed that lichens are fed not by all elements indiscriminately. On the contrary, they are ready to "tear apart" the strongest of the minerals if only to obtain food to their taste. This is how apatites lose phosphorus and nephelines lose aluminium. These elements are snatched out straight from their crystal lattice. The farther the scientist penetrated into the secret of exchange of matter between the vegetation, soils and rocks the more deeply he realized that clays were a product of animate nature.

Now it is on record that not only mosses and lichens worked to create them. But who would say that the actions of vegetation and metasomatosis are not elements of a cohesive production process!

Thus, the "pseudo theory of complete Liebig restoration" opened the way to the study of one of the crucial mechanisms of biogeocenoses, which had come to be known as biological circulation. But then, not only the terms had changed. The essence and the notions had changed as well.

Modern science bears a dialectical character. Looking at the life of nature from new positions, scientists realized that the present is not an exact repetition of the past. The present is at least a tiny bit different from the past. The element exchange between the vegetation and soil is not a closed cycle either. It is an untrodden path travelled by atoms and molecules. Rather, this process resembles a spiral or a screw-shaped pyramid. However, such a model is not ideal either.

Nothing in the world can constantly consume and lose substances and simultaneously retain the old form, essence and property. A case in point is Polynov's discovery made in the Ilmen Mountains. The accumulation of fine earth in the valley touched off the emergence of a new landscape. It had no suggestion of rocks and lean mosses. On the contrary, sturdy young trees whose roots drew food from thick fertile soils.

It turns out that at a certain stage gradual evolutionary changes break off and a "revolutionary" leap takes place. This is why the smooth motion along a spiral or a screw-shaped pyramid is not endless. At times it ends in a splash, a storm, a catastrophe, and a new substance comes into being, for instance, the soil. Then the "run" resumes but the composition of its participants noticeably changes.

However, if one is to sort out the colossal multiformity of the biogeocenoses which cover the Earth the knowledge of their evolutionary principle is obviously insufficient. After all, it is identical everywhere. And can one compare the tundra with the tropics or the steppe with the taiga? Of course, not. It follows that the solution is not furnished by this principle alone, but also by the action of the exchange mechanism, of its provision with "fuel", depth and other characteristics.

Any transformation requires energy. Biogeocenoses receive it from outer space in the form of solar radiation. The more heat, the more intensive the weathering of minerals, the more fertile the soils, the more luxurious the vegetation. In other words, the potential of a biogeocenosis depends on the amount of the radiant fuel given to it by nature.

Many references having been made to the tundra, the reader knows that the vegetation-soil exchange there is scarcely noticeable. No wonder not more than two kilograms of lichens, grasses and shrubs are "produced" on one square metre of the surface area. There is extremely little time for the processing of their falling off remains. Barely have the leaves and small branches covered the earth when snowfalls and blizzards resume. The falling off remains undecomposed until next spring. The formation of the humus layer has clearly inconductive conditions. This is heightened by a shortage of calcium - an exceedingly vital element for the creation of soft and fat humus. In the tundra plants its content is negligible. But even there the modicum of calcium which returns with the falling off is grabbed by mosses and lichens. Many Arctic inhabitants try to find a "substitute" for it. They pounce on magnesium, aluminium, or silicon - on whatever is to be found in the free state, accessible to living organisms. But in vain. They fail to rectify the situation caused by the shortage of the radiant fuel. The exchange mechanism in these rigorous conditions not just has a low modicum of product, but nature can create magnificent structures in millennia. The trouble is due to imbalance. The plants, receiving a credit from the soils, are in no hurry to repay it. They, as it were, close the exchange in the plant-litter fall-plant system, and the soils, having neither the power nor the ability to regain the share due to them, lose even these crumbs.

The next stop is in the taiga. The plant cover here cannot boast diversity either. Pine, spruce, a small admixture of birch, alder, mountain-ash, and moss, shrubs of blackberry, stone-berry and bilberry, and sedge on the ground - such is its composition. Tall trees and a fairly thick layer of dead falling off of needles, moss and little twigs create the impression of an intensive exchange. In reality, this is not so. Only 30 to 40 centners of organic remains per hectare of the taiga are restored. But it was discovered that the spruces and especially the pines repay their debts in priceless "currency". Its "gold" content is one or two per cent, i.e. not more than 20 grams of the elements consumed from the soils per kilogram of needles. Among them there is little calcium and magnesium - a factor which also reduces the value of the falling off.

The forest zone receives more solar heat than the tundra. However, even here it is found to be in short supply. The litter, thick and barely touched with rotting, furnishes relevant evidence. In the Arctic sunrays did take an active part, if not for long, in the decomposition of the moss and lichen remains. In the taiga the destruction proceeds in the shade, hence, more slowly. Many chemical elements which have become accumulated in the falling off never reach the soil. Straight from the semi-rot they are captured by the roots of the same unreliable "debtors".

As a result, the humus of the forest lands is poor, primitive and not much better than in the tundra. The exchange mechanism is also far from being balanced, and taiga soils – podzols - have always been among the poor representatives of the "fourth kingdom".

However slightly further south, in the deciduous and especially broad-leaved forests, the vegetation-soil relations grow better. Every year the birches, limes, oaks and hornbeams up to 90 per cent of the leaves with the "gold" content of two to five per cent return to each hectare of the forest. The falling off is rich in calcium. These relations help adjust fruitful plant-soil cooperation. The oaks, hornbeams and other trees increase the mass and the soils raise their fertility. Here there is no place for the utterly poor soils of the north. Their place is occupied by the soddy-podzolic, grey and brown forest earths.

This could well conclude the excursion. The principle of the exchange mechanism has been cleared up and its connection with solar heat has become apparent. But, following oak and hornbeam groves, steppes open up. How can one neglect this cradle of fertility? True, now the steppe is no longer what it was, for instance, in the times of Taras Bulba. It has been ploughed up and become crisscrossed with gullies and ravines. And in those days "all the South, all that region which now constitutes New Russia, even as far as the Black Sea, was a green virgin wilderness. No plough had ever passed over the immeasurable waves of wild growth; horses alone, hidden in it as in a forest, trod it down. Nothing in nature could be finer. The whole surface resembled a golden-green ocean, upon which were sprinkled millions of different flowers. Through the tall, slender stems of the grass peeped light-blue, dark-blue, and lilac star-thistles; the yellow broom thrust up its pyramidical head; the parasoll shaped white flower of the false flax shimmered on high. A wheat-ear, brought God knows whence, was filling out to ripening ... ".

Nobody could have depicted the steppe and its vegetation better than Nikolai Vasilyevich Gogol. But the beauty he portrayed is not a thing of the past. It has survived on virgin land plots and in preserves. The unique mechanism of element exchange between the grasses and the black earth - functions to this day. Many representatives of the "fourth kingdom" dim in the rays of its fame. But let us not run ahead. Later, in the gallery of soils this earth and its "relatives" will be described in greater detail. Now let us try to penetrate into the secrets of the steppe circulation.

The steppe grasses are the biggest "investors" of the moderate latitudes. Their contributions are not just great, although they reach 140 to 200 centners per hectare. What arboreal strain will risk putting a half of its "flesh" into the soil bank even at the highest interest rate? The bulk of the earnest is the roots. Approximately 40 per cent of the thick, rough and quite thin and delicate "threads of life" annually settle in the underground "safes". Together with them calcium, phosphorus, potassium, and sulphur, without which the birth of "tasty" and "calorie-rich" humus is inconceivable, are exceeded in roots only by silicon. And if one adds all elements together their share in the underground falling off will exceed ten per cent, i.e. will be found five or six times higher than in the taiga.

The tops and stalks of the grasses, of course, are not so rich in chemical elements. But they also leave far behind the leaves of hornbeams, oak and other giants of the southern forests.

The fate of the remains of steppe plants varies. If their roots are doomed to gradual rotting for several years the grasses themselves, living through the winter, change into steppe litter (kaldan). It is very unstable and usually disappears by the end of summer, burned by sunrays and eaten by soil animals and microorganisms.

Number and Measure

Nature's conveyor draws to the storages of the biosphere not simply cellulose, proteins, carbohydrates and other organic compounds. Each blade of grass, leaf, piece of wood, remains of animals all include a particle of a sun ray, more exactly, of the energy brought from outer space. Apart from the vegetable litter-fall, it saturates the soil humus, and the clays, and the minerals borne of metasomatosis.

It turns out that a biogeocenosis is a major energy complex. If not for the film of life on the Earth's surface the Sun would be unable to do even a half of the work it has done in the past billions of years. After all, its radiant energy first has to be converted. Man has learned to convert it into electricity, and the earth into plant nutrition. In essence, the soil plays in the biogeocenosis the role of a complex unit which combines the functions of an accumulator and a generator of heat transformation. Hence, all processes in it can be measured and described by equations? No doubt they can. The first to realize this was Academician Alexander Fersman, who wrote: "An energy approach to the analysis ... of nature is the ultimate aim of our research .... We should go over to a cohesive yardstick ... of the process. Such a yardstick can be either calorie or kilowatt".

Such a "yardstick" was discovered. In 1956 Vladimir Volobuev, Corresponding Member of the USSR Academy of Sciences, as he studied the soil-climate relationships, introduced, among other indicators, solar radiation data. Already in those days he established a connection between the amount of "solar fuel" and soil fertility. In several years the scientist offered an entirely new interpretation of Dokuchaev's law of zonality. Previously, scientists scarcely "touched" the Sun. It was assumed that the direct connection between the Sun and the Earth was negligible. This bias for a long time prevented scientists from connecting the cause and the effect - solar energy and the soil. In the meantime, a simple calculation of the heat calories at the surface of our planet would have been enough to describe a whole natural zone in terms of "number and measure".

But let us stop here. Too little has been said about the soils and their maps. This is why before we resume the story let us try to make out a simplified variant of the global distribution of the representatives of the "fourth kingdom". We need it in order to get a better insight into Volobuev's works.

The reader must have already noticed that the names of most of the soils are connected with their colours - podzol (pod zolu, "like ash"), grey, brown, chestnut, red earths, black earths, etc. In the map they are presented in appropriate colours. True, the cartographer frequently falls short of shades to convey this on paper. Then he introduces conventional colours. That was how podzol became pink and desert grey earths yellow. The picture comes motley. On the plains the colours change north to south. The soil zones here stretch west to east. But if we are to discuss a highland the colours begin to alternate in reverse order. The higher man climbs the less heat he encounters, and the soils grow less fertile. While subtropical vegetation ran riot at the mountain foot on the red earths, at the eternal snows miserable lichens cover the thin and lean soils of the mountain tundra.

Volobuev had to deal with a more complex map. When an expert has to make an accurate experiment simplified schemes do not work. He put data about the heat and moisture on the latest product of the soil cartography of his time. The information about the precipitation was derived from reports of meteorological stations, whose thick network covers the entire globe. A colossal aid to the scientist came from the *Map of the Heat Balance of the Earth's Surface*, compiled by Mikhail Budyko et al. in 1956.

It is inconvenient to identify such boundaries on the map itself. Aid came from diagrams. If one were to believe funny stories about the well-known German mathematician Karl Gauss, it was he who made popular the method of graphical analysis in many branches of knowledge. Gauss usually advised his friends: "When you have doubts as to the benefit of a forthcoming scheme draw on paper or sand a cross. Let the vertical line be the yardstick of good and the horizontal of evil. Then find some space for your schemes in the right upper sector depending on how much good and evil they contain and link this point with the crossing of the axes. If the line comes steep go ahead, if it is sloping chuck the occupation as unworthy."

Let us take Gauss' advice. We will put the indices of heat in calories on the vertical "line", the axis of ordinates, and those of moisture in millimetres on the horizontal. The Gaussian "cross" is ready. Now we can calmly enclose in it the data about solar radiation and moisture allotted to each soil for subsistence. Thus, diverse figures will appear on the diagram. One overlapping another they will at first glance create a chaos. But a closer look makes everything fall into place. Here are desert soils. They hug the ordinate axis. Their formation requires not more than 100 to 200 millimetres of moisture a year while the amount of solar energy can be anywhere between 30 and 80 kilo calories. The red earths and laterites are an entirely different matter. These can do with varying moisture - from 1000 to 3000 millimetres, but they require no less than 70 kilo calories of heat a year.

Volobuev not only specified the well-known law by determining the quotas for each inhabitant of the "fourth kingdom". He gave concrete meaning to such notions as desert, steppe, forest, and tundra. While previously geographers and soil scientists frequently argued about the boundaries of the soils and climatic zones, now they can be established with enviable accuracy. Help came from the same Gaussian "cross". It was enough to project any of the soil "figures" on one of the diagram axes. The lower showed the moisture fluctuations, i.e. the limits within which deserts could exist, hence, grey earths, steppe, and, of course, black earths, forest and podzols, etc. Volobuev counted seven such elements - or stages. And, most interestingly, their total can neither decrease nor increase. It is a constant. Now only the desert, grey earth, chestnut, black earth, podzol, gley podzol and gley types are on record. Various combinations can form between them but nothing new can be found, so far. And now let us perform the same operation with the vertical axis. It also falls into seven stages, or seven thermal belts - Arctic, Subarctic, moderately cold, moderate, moderately warm, subtropical, and tropical.

Well what is so new here? First, the stages themselves. By superimposing them on each other, we will obtain a grid, more exactly, a system of the Earth's basic soils. It is precisely a system, in which each cell is a soil thermohydrotype. Another term! But it is easy to decipher. Let us run up the diagram's axis. On it there are the quotas of the calories allotted by the Sun to the Earth. Here are the lowest of them, below six kilo calories a year per square centimetre of the surface. It is the Arctic. The minimum radiant energy does not permit many soil processes to exercise their potential. The Arctic variant is simple. It consists of one hydrotype. Loose shallow loads with a thin coarse humus bear some resemblance to the desert. But then, the similarity is not accidental. The heat-moisture relationships here are the same as in the most arid areas of the world. This is why the coast and islands of the Arctic Ocean are referred to as the Arctic desert.

Now the narrow coastal strip has ended. We proceed into the continent's interior. The tundra begins.

It grows slightly warmer. And there is more precipitation here. But the radiant energy is clearly insufficient for their evaporation. And there is a sprinkling of little bogs. It is a kingdom of waterlogged gley soils. True, they frequently show other processes - the podzol and soddy formations. In other words, podzols and soddy soils are to be found already in the tundra.

A few more notches up the axis, and we are in the moderate belt. Heat here is much greater, from 12 to 50 kilo calories. The precipitation, too, has increased - some threefold. In the mid-latitudes one can already encounter all the seven hydrotypes - desert, grey earth, chestnut, black earth, podzol, gley-podzol, and gley soils.

Now the sun blazes more strongly. Already 60, 70 and even 90 kilo calories of radiant energy fall annually per square centimetre of the Earth's surface. The humidity changes within still wider limits. At times the annual precipitation fluctuates from 500 to 3000 millimetres. Therefore in the deserts, savannas and tropical forests the range of the soils which enter the hydrotypes is particularly varied. Light earths, alternating with stony deserts, comprise the very beginning of the tropical hydro-series. Red and brown soils are its second most and element. Red cinnamonic, cinnamonic and red brown soils are the "steppes" of the tropical belt. Red earths, laterites and their podzolized variants occupy the extreme right end of the chain, frequently suffering from surplus humidity.

The development of the system was only the beginning of the research into soil energy. This new branch of Science faced many problems, which had to be interpreted in a new light. Take, for instance, the vegetation-soil substance exchange. After all, the falling off is also charged with energy. As it decomposes, it releases it. And the chemical elements themselves are far from the inert. Only too recently were scientists interested, above all, in nitrogen, phosphorus and potassium and slightly less in iron, manganese and micro elements. A particular place was assigned to carbon. It was even referred to as a life element. But at times there arose a question: why are some "tenants" of the Mendeleyev Table more readily absorbed by plants and others less? As regards nitrogen, it was clear. This element went into the protein formation. Potassium and phosphorus did not cause doubts either. They were among the active creators of organic matter. But then, the family of chemical elements has over a hundred members. Perhaps it is a question of the plant tastes? Partly. This question was discussed in one of the previous chapters. Some plants prefer calcium and magnesium, others iron and aluminium. Legumes, for instance, are typical nitrogen-gatherers while grain crops are silicon-gatherers. Another explanation was the influence of the landscape. The surplus of some element could change the plants' taste and make them increase its share in its ration.

That is all. But whoever wants to understand all the barrenness of the approach dominated by "tastes" and "circumstances" should look through the plant menus in different natural zones. In the tundra it includes nitrogen, calcium, potassium, magnesium, silicon, phosphorous, manganese, sulphur, iron, and aluminium. In the steppes, deserts, subtropics and tropics changes occur only in their relationship. The remaining part of the Mendeleyev Table is used at best as a "seasoning". The microelements "salt" and "sweeten" the food of grasses and trees. Their doses are one-hundredth of what they are in the staple "foodstuffs". What is the secret?

Academician Fersman saw the reason for such selectivity in the chemical elements' ability to accumulate and release energy. He noticed that the "field of life" is comprised of the lightest elements of the Table. They group around the axis of the noble (inert) gases. Nitrogen, phosphorus and potassium, for instance, change in the soil into anions with a loose structure and weak atomic bonds. Such dishes are easy to digest. Energy is easy to extract from them. True, it is not so abundant in similar compounds. Otherwise it would be far more complex to split them into atoms. The key benefit of such food is the elements themselves. For due to nitrogen, phosphorus and potassium plants can rapidly create new cells and gain in weight.

But the grasses and leaves have to take care of... the skeleton. They also need a framework that would support their rapidly growing flesh. Take a dried-up leaf. It is precisely such a framework. Practically no nitrogen and negligible amounts of phosphorus and potassium are left in it but very much silicon and calcium. With a microscope one can discern the "bones" themselves - the phytoliths, or stones of vegetable origin, which wholly consist of silicon oxide and sometimes of calcium. Furthermore, the calcium and silicon compounds are very strong. It is a problem to decompose them. They have much energy. In the course of their gradual destruction these "tough nuts" release their calories, thus feeding the plants as long as they grow.

Fersman found a place for the third group as well. It included, in the main, heavy elements. In the scientist's opinion, part of them occurred in the Earth's crust so seldom that they could be captured only by chance. Others were simply inert. The remaining ones became accumulated in negligible concentrations – ten thousandth and even millionth fractions. The American soil scientist Henry Cooper, writing in the Soil Science Magazine, said that Fersman had put forward a number of brilliant ideas concerning the energy ability of ions and elements and had charted a path which should be followed by the researchers of this little-studied field of soil science. And Cooper proceeded along this path. From his very first experiments he understood that the plant tastes did not depend much on the abundance or shortage of chemical elements in the soils. Of far greater importance was the force of the ions, their potential. His assumptions were confirmed experimentally. Comparing the composition of the leaves and grasses, Cooper saw that the plants' next most preferred elements after nitrogen were potassium and phosphorus. The scientist immediately took an interest in these elements. First, he established their electrical potential, i.e. the charge of their ions. The highest, he discovered, belonged to potassium and calcium. They were followed by sodium, magnesium, aluminium, manganese and iron. In the same order diminished their concentrations in plants. No such connection was discovered in the anions which formed non-phosphorus, sulphur, chlorine and nitrogen.

Nevertheless, Cooper explained that the presence or absence of appetite among plants for charged particles were due to other factors. In his opinion, the grasses and trees consciously refused from calcium. If they had not done this calcium would have captured the carbon dioxide which they had accumulated and which is so necessary for chlorophyll formation.

Fersman's hypothesis and Cooper's unfinished experiments were all that was left to Volobuev to go by. Above all, this scientist was interested in the strange "apostasy" of the anions which comprised the non-metals. Why did they obey the general regularity? He decided to check Cooper's conclusions. Volobuev immediately noticed that the American researcher's experiments had been made far from ideally. First, the ions of metals were homogeneous, containing no outside elements. This does not apply to nitrogen, phosphorus and sulphur. These elements form various oxides in the soils. For instance, sulphur, as it dissolves in water, creates a hydrosulphate-ion, i.e. a compound of hydrogen, sulphur and oxygen. Cooper's mistake was to have compared the force of pure ions and of mixture ions. Naturally, the regularity obtained in the first case was not confirmed in the second.

A different procedure should have been employed here. He should have calculated the "contribution" made by each nonmetallic element to the oxides formed. That was how it was discovered that nitrogen was the energy richest element and that sulphur and phosphorus were way behind it. Their quotas in the plants were accordingly distributed.

And do the grasses and trees accumulate much energy? The results obtained by Volobuev show that its quantity in vegetation increases from the pole to the equator, i.e. obeys the same zonality law. On each square centimetre of the tundra less than one kilo calorie falls to the share of plants. In the tropics the same square centimetre of greenery receives 70 times more heat. It turns out that the most nutritive falling off goes to red earths? But the conditions make it impossible to preserve the caloric value for long in these soils. Because they are indifferent accumulator. Processing here runs fast without delay. And if, for instance, the forests are cut the soils, losing the energy supply source, will soon become impoverished.

The exchange in black earths proceeds differently. Here the change of vegetation into humus exhibits minimum losses. The thick and fat layer of humus can be used long unaided by fertilizers. After all, up to ten calories of humus fall to the share of each calorie of the green mass in the steppes. In the tropics the relationship is reverse - ten to one. But whatever the energy distribution between them the soil remains its accumulator. In recent years it can more and more frequently be heard that the soil is like coal, oil and gas. Attempts are made to include it in the general list of energy resources of a specific country. There are really all grounds for this. But at times this provokes alarming thoughts: "And what if it is treated as only too recently man treated forests, coal and oil deposits?" After all, the calorie reserve in the soil is not great. It is not difficult to exhaust it.

Apparently, soils should be considered in a different light. They are not treasures and not deposits, but a fragile mechanism which is easy to make unserviceable by mishandling. Even black earths at times become helpless, let alone other earths. Now, with a view to preserving the soils agricultural practices are improved, millions of tons of fertilizers are produced, enormous territories are reclaimed, and new varieties of cultivated plants are evolved. But, however great the successes of agronomists and plant breeders, it should be borne in mind that the finest industry of nature has been at work for millions of years. Its departments run on the purest fuel - solar energy. Their main task is to synthesize the biological substance. Perhaps man should try his luck here? After all, so far, the coefficient of the use of solar heat in the biogeocenoses is low - just one per cent. Only at the very equator can the luxurious tropical vegetation exceed it. And what great effect is thus yielded! Just a few per cent of radiant energy create an annual two or three tons of the green mass on one hectare of the surface.

And what if man learns to handle the synthesis of the soil's organic substance? This will slash the fertilizer losses in the soils, and the environment will become cleaner. True, raising the efficiency of biogeocenoses should be left to the future. Now soil scientists face more modest tasks - to learn the laws governing soil life.

Linnaeus “Paradox”

For a long time science knew nothing about the insects, worms and protozoans which populate the "storages of the biosphere". Not because their existence was not suspected. On the contrary, the comparisons of pestering people with flies and of worthless people with worms go a long time back. The underground fauna has long been on record. Some 200 years ago the British naturalist Keerby even devoted to it several lines in his report to the Royal Society of London. He said that the underground animals sped the decomposition of the giants of forests - the trees. Since then for a whole century it never occurred to anyone that the animal world of the storages of the biosphere was an important and irreplaceable link in the mechanism of elements exchange between the vegetation and the soils.

Only the work of great Darwin, *The Formation of Vegetable Mould through the Action of Worms*, made the first breach in the wall of silence which surrounded the beetles, polypodies, ring-worms and other invertebrates. But then 19th-century biologists can be understood. The discoveries of Pasteur, Koch and Mechnikov stirred the minds. The extraordinary power of microbes staggered and relegated to the background the activity of their "elder brothers" - ticks, wingless insects, etc. And Linnaeus dictum saying that three flies eat a horse's body faster than a lion appeared to be a funny paradox.

But nature has no superfluous stages. The circulation of matter in the forests, steppes and savannas is "thoughtout" in minute detail. Each living being in it performs its functions which cannot be shifted either to the stronger or to the weaker.

The soil which appears to be motionless knows no rest. For hundreds, thousands, and millions of years the devious conveyor of fussy little spiders, carabides and springtails move. It moves along numberless passages carrying raw materials, semi-manufactured goods and ready-made products.

But then, such a division is merely a scheme. And nature is alien to schemes. In a real soil, as in any other kingdom of life, the circulation of matter, or the "food chains", is extremely complex. Take at least the fact that one animal cannot eat the remains of trees and grasses indiscriminately. It is not a question of volume, but a question of "taste". Some small insects prefer leaves, others bark, still others wood. Each animal species uses a negligible part of the energy included in the falling off, which enables the next animals in line to live on its remains. And so on until the tribute received from the plant changes into mineral salts and water.

It is easy to imagine what would have happened to the forests, fields and meadows if the "millstones" which grind vegetable remains suddenly disappeared. The Earth's surface would find itself under a thick layer of needles, leaves, branches, bark and trunks. All this heap, all this wind-fallen mass would defy the burning action of sun rays. The winds would be unable to scatter it and the water torrents would be unable to wash it away. The "all-powerful" microorganisms would even find themselves in straitened circumstances. After all, they frequently need semi-manufactured goods digested in the stomachs of worms and insects. But even this is not the greatest trouble either. Nature's conveyor would stop. Nobody would be there to carry humus into the depth of the soil mass. The fertile layer would find it more difficult to "breathe". For the passages of the fussy underground denizens help air penetrate into the fertile layer. Air as well as water. But the water which has not soaked into the soil runs down over it, hence, washes it away. In such conditions the Earth's fertile film would grow all too dense, becoming unsuited to the life of many plants, both higher and lower. Simultaneously, it would be unable to offset the intensified erosion, and dead rock would expose over enormous expanses. The number of lifeless deserts would sharply increase.

But then, there are no reasons for anxiety. A myriad of protozoans envelop each branch and trunk fallen to the ground. One square metre of a field accumulates up to 20 million nematodes, or tiny worms, hundreds of thousands of ticks, wingless insects and springtails, hundreds of earthworms, slugs, snails, polypodies, etc.

Even in the arid tundra their number remains considerable. They also occur in shifting sands, and on rocks around the eternal snows, and even in the Antarctic. Their total weight sometimes reaches 3.5 tons a hectare. Sometimes one can only wonder to learn that billions of them have exceeded the permissible rate. Where can they live? But it turns out that there is place for them. In this case the biological millstones begin to turn faster and, coping with their day-to-day preoccupations, the invertebrates begin to attack field crops.

The underground denizens link their life not only with the food, but also with their home, the earth. The latter is very specific. It is made up of three types of substance - solid, liquid and gaseous. Depending on what relationships these three principles connect, the flats are filled on different underground floors.

At times the air humidity in the soils reaches 90 per cent and over. This creates conditions like those on the bottom of a water body. Then a great migration of invertebrates begins from the nearest pond or lake. Of course, this affects only the protozoans. But the lightness with which these creatures change the habitat suggests that billions of years ago the conquest of the land proceeded exactly along these lines. The soil is a "trans-shipping point" of life, where it accumulated strength in preparation for spilling over to the surface. But then, many indigenous denizens of the underground are typified by features both of denizens of water bodies and of earthmen. Their teguments are penetrable by water, ions and gases, and simultaneously they can breathe by means of air.

All this information became known comparatively recently: soil zoology is one of the youngest sciences. It may appear strange but the founder of soil science, V. Dokuchaev, in general took a fairly cool attitude to the invertebrates. Of course, he noted their activity alongside that of the vegetation, but he never went beyond that. In contrast, his life-long opponent Kostychev experimentally proved the enormous role of insects in the decomposition of the vegetable leaf fall. At about the same time Darwin's aforementioned book about worms saw light. That was the beginning of soil zoology. This great English naturalist summed up his observations in words which were cited in all books about the underground denizens. "The plough is one of the most ancient and most valuable of man's inventions; but long before it existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earth-worms. It may be doubted whether there are many other animals which have played so important a part in the history of the world."

Over a hundred years have passed since. A good deal has been achieved in the intervening period. Already in the 1920s, right after the Russian Civil War, a large expedition led by Alexander Brodsky set out from newly opened Tashkent University to the Hunger Steppe, in Kazakhstan. Its aim was to study irrigation systems. Its basic method was to take a census of the soil denizens. They will hardly put up with poor housing conditions, the experts correctly decided.

Indeed the semi-desert lands literally came back to life with 'the advent of water to the fields. Their fertility grew in the people's very eyes and was in proportion to the density of the invertebrates. According to Brodsky's figure of speech "on the underground soil-dressing factory work seethed around the clock. 'Raw ore' was fed along the conveyor here - litter fall, which momentarily became changed by millions of insatiable mouths. Passing through the most perfect units - animal stomachs - the ore changed into a high-quality 'concentrate'."

Several years later the experiments of Nikolai Dimo showed that worms alone annually pass through their stomachs up to 120 million tons of soil per hectare. From there it emerges enriched with organic and mineral substances.

The first censuses created a real boom in biology. Laboratories, institutes and research centres sprang up one after another. All were interested only in worms, insects, larvae, ticks and other invertebrates. Moscow, Leningrad, Voronezh, Perm, cities of Soviet Central Asia and Kazakhstan opened chairs of soil zoology. Relevant new data came from all parts of the world. In the 1930s and 1940s the research spread to the United States, Britain and Denmark. In the Soviet Union fundamental works were published by such best-known scientists of the time as Georgi Vysotsky, K.K. Saint-Hilaire, V.N. Beklemishev, etc.

Zoologists more and more frequently began to notice the numbers of invertebrates, Which not infrequently exceeded a million on one hectare of a field. There was no calculating the insects without reliable methods. How then did Brodsky, Dimo and others work? They undoubtedly calculated the soil fauna but each in his own way. And the results of such research are difficult to compare.

In 1941 the young zoologist Merkuri Gilyarov collected and analyzed all existing methods of taking underground population censuses. A scientific review was found exceedingly appropriate. From now each study and each assessment could be "reduced to a common denominator". The old data gained a new meaning. These data could be linked with their characteristics now and it was a success to denote a symbol by figure. Soil science took yet another step in the direction of the disciplines where all phenomena could be expressed in a formula, foreseen and calculated. Many scientists rushed to introduce statistical calculations into their works and to subordinate everything to mathematical logic. It appeared that the time had come to grasp all laws of the surrounding world by solving equations with many unknowns.

However, the animal world and the soils themselves did not yield much even to this universal science owing to the nonstandard character of the natural phenomena. We know that they defy all schemes. A mathematician if he is to solve a problem, has to have an exact characteristics of the object. Elementary algebraic equations are the simplest case. But even in these equations the *x*'s and *y*'s are limited by a multitude of conditions.

And now try to set similar limitations to an ant or a worm. It doesn't work? Naturally. The limits into which you will try to thrust them first have to be found in the environment. How can this be done? Primarily, by grasping the laws which govern the life of the underground denizens, their relations with the vegetation, moisture, soils, etc. By collecting all this information one can begin to compile a computer programme. But in the early half of the 20th century the science of the connections which prevail in nature - ecology was still very young. It could not furnish answers to many questions which arose interest among scientists.

Cybernetics, which now can model a natural phenomenon, a body, a community, was also in its infancy. The languages employed by soil scientists and mathematicians and their conceptions of the environment were incomparable.

Now, in 1949, Gilyarov published his book *Specific Features of the Soil as a Habitat*. In it the denizens of the "kingdom of darkness" and their home - the soil - were presented in an entirely new light. For instance, the abundance of food was no longer regarded as the only condition of the well-being of insects. Temperature and humidity were found to be of equal importance to them. The rise in the content of water drops, it turned out, furthered the multiplication of the worst enemies of the underground denizens - pathogenic fungi, reduced the influx of air and caused insects to contract an illness which resembled human dropsy. Heat and cold were the cause of the vertical motion of all soil animals without exception. The mechanism behind biogeocenoses was found to be much more complex than it had been thought before.

Gilyarov's monograph became the first major work on the ecology of the soil fauna. But soon new books about the denizens of the "fourth kingdom" were brought out in the German Democratic Republic, Austria, France, Britain, etc. Then in 1958 came the first international conference on problems of soil zoology. This new science found the state borders to be too narrow. Some problems gave rise to others. Ecology had just been regarded as the most up-to-date branch of biology when a still younger branch of biology - the taxonomy of the invertebrates - sprang up. Previously, only big animals were registered in the thick volumes. Now it was necessary to scrupulously "classify" data about the larvae, to divide into species and classes the innumerable hordes of small insects, etc. Decades of stubborn work brought long-awaited censuses. But most of the reports had an essential disadvantage - a host of blank spots. They were avoided by the thick *Identification Book of Soil Larvae*, published in the USSR in 1964. It can rightly be called an encyclopaedia of larvae - so ample is the relevant information it contains. In another two years Soviet scientists prepared for publication another edition, concerned with polypodies. Now a considerable proportion of the soil denizens are described and classified. To discover a new species of tick or slug is as great a challenge as to find an unfooted island in an ocean. Colossal efforts in this direction have been made. But have they brought great results?

They undoubtedly have. Whoever uses identification book can code and put into a computer programme data about practically each inhabitant of the "storages of the biosphere". Thus, brick after brick, the long-awaited building - a model of biogeocenosis - arises before our eyes. So far, it is hidden behind symbols, clear only to an expert. But within minutes the computer turns out formulae of which scientists could only dream two or three decades ago. By now mathematicians and soil scientists have developed better mutual understanding.

But to get back to our animals. They keep researchers wondering. When extremely detailed "dossiers" had been compiled for them it suddenly emerged that beetles worms, wingless insects and larvae could tell a detailed story about the soils themselves. With their aid it was found possible to set diagnoses to various earths. Again, the first to do this was Gilyarov. Each of his works opened a new page in biology and soil science simultaneously. His method of zoological soil diagnosing was not only of colossal scientific, but also of practical relevance, helping to establish the mechanical composition of the soil without taking samples to the laboratory and without digging innumerable soil pits. It is enough to analyse the composition of the world of underground denizens. Of course, in this case the accuracy is not great but it makes possible rapid orientation in the situation and forming an idea about the territory under study.

For instance, in loose grounds the entire mass is pierced with a host of "holes". Such fragile structures will hardly be good for big awkward invertebrates. The walls of their holes are not strong and soon crumble. This is why the sandy terraces of the Don form an impregnable barrier to cockchafers and in the light soils of the deserts where moisture remains poor, there are no pill bugs. And, on the contrary, a sure sign of loose grounds is larvae with special adjustments for life and motion in these grounds.

Many underground denizens are indicators of how humus accumulation proceeds. It is on record that the larvae of one of the types of a nutcracker are widely disseminated in the mixed forests of the European part of the USSR, where crude fibrous humus which shows an acid reaction forms, and that they are absent in the southern beech, hornbeam and oak groves with grainy "sweet" humus.

Invertebrates are very sensitive to different properties of soils which elude direct research. Above all, this applies to their temperature regime. Usually, all expeditionary work ends in autumn. Winter is a dead season for a soil scientist - dead season. Research in Eastern Siberia has shown that the larvae of a May beetle avoid the ground where the upper frozen layer and the permafrost layer join in winter. People also bypass such territories. Because cultivated plants will not take on here.

The character of underground denizens is not always permanent, frequently changing from place to place. In Soviet Central Asia, for instance, a June cockchafer in the soil is a good sign for an agriculturist, since colonies of this insect gravitate towards soils which have accumulated enough moisture. And in Central Russia the same cockchafer behaves differently, preferring dry places.

Using the soil-zoology methods, scientists now determine the degree of pollution of lands by various wastes of production. Many denizens of the "storages of the biosphere" prefer to diversify their menus by technogenic additions. Thus, ground beetles have a soft spot for lead, worms for lead and cadmium and pill bugs for copper. These metals form deposits in their bodies. Awareness of these animals "vicious proclivities" makes it easy to establish a leakage or a rise in the concentrations of toxic substances in the environment. To this end, it is enough to expose them to a chemical analysis.

Frequently films about nature show how roes, elk and wild boars are delivered to some specific area of the Soviet Union. They gain their second homeland there. But apparently few people have heard about similar migrations of invertebrates. The most ardent travellers among them are worms. They crossed whole continents. Once some species got from the northern hemisphere to the southern. True, those were unplanned, casual migrations. Recently, the Soviet Union has carried out special schemes designed to acclimatize worms from the Zeravshan banks and in the Kyzylkum semi-desert. The experiment was a success. The biological activity of the arid lands has noticeably increased together with the soil fertility. Such a curing method has been called "biological soil improvement". It is successfully practised in many arid areas of the globe.

It would appear that many agricultural problems have found solutions. Suffice it to choose a specific "culture" of worms - or insects, and the soil is cured of barrenness. Alas, this is not the case. Things are much more complex. Take, for instance, the fact that animals need food and water. And where can they be obtained in the sands or on salt takyrs? Water has to be supplied, trees and grasses to be planted and the make up of a whole landscape changed. Otherwise our "modernizations" will not be long-lived.

Scientists and agriculturists saw that nature remaking was a complex matter. The replacement of one element will not be enough. Alongside this, it is vital to renew the rest. But before taking up the creation of highly productive biogeocenoses a study should be made of the components of the former systems.

So far, man lingers in the department of preliminary processing of "raw materials". The leaf fall was destroyed by sun rays and temperature differentials in our very eyes. It was wetted by torrents of spring and "enriched" by animals. Now is the time to go over to the departments of fine chemistry or, more exactly, biochemistry. Here the tiniest organisms are at work. Amoebas and infusoria make them appear to be Lilliputians.

About the Tiniest

The world of microbes has been known for a long time, since the 17th century. But their ability to decompose vegetable remains and minerals, to create exceedingly complex natural "polymers" and humus substances and to cause human illness and death became known as late as the 19th century. Science owes this not only to Pasteur and Koch, but also to Kostychev and Dokuchaev. It was precisely Dokuchaev who created the world's first programme of research into soil microorganisms. This could be done only due to the discoveries of Kostychev. It should be admitted that here the "founder of genetic soil science" yielded the palm to his "eternal opponent".

While great Pasteur saw in the majority of microbes murderers Kostychev took a much broader view of their activity. Furthermore, this Russian scientist saw them as creators rather than destroyers. Their chief handiwork, he thought, was humus. "Humus is not a dead mass. Each cell of it breathes life in its various manifestations; it is a seat riot only of processes of decomposition of complex organic compounds, but, at the same time, the processes of formation of complex compounds from elementary," noted Kostychev. "Of decisive importance are not dead chemical agents, but living beings, ranging from shrews to microscopic protozoans, fungi and bacteria."

This outstanding scientist described in just a few lines the scheme of production of the most complex natural substance and pointed out its main creators. But then, he could not even imagine how wide was the sphere of influence of these smallest creatures. The reader has been introduced to their functioning in volcanic ashes and the crusts of weathering. Metasomatosis takes place not without the participation of microbes. Indeed, it is nothing for them to penetrate into a crack between minerals one hundred-thousandth of a centimetre wide. It turns out that clays owe their birth to bacteria as well? Undoubtedly, they are a powerful factor in soil formation. Furthermore, microorganisms are among the first to settle uncomfortable rock fragments. Perhaps only lichens can vie with them as regards the ability to accommodate. It is difficult to establish who prepares the home for whom. Where a blue-green crust turns up one can also find microflora colonies. Together they are a powerful force capable of destroying the mineral's crystal lattice. Thus, diatoms corrode feldspar. Bacteria can even remake clays to suit their taste. In some cases on record they changed kaolin into a liquid slime. Nevertheless, the most subtle work of microorganisms is the synthesis of humus.

The well-known Soviet soil scientist Maria Kononova thus described this process: "Vegetable remains are very complex compounds as regards their chemical composition. They cannot pass into another state immediately. Therefore bacteria prepare them for future reactions. They split natural polymers into simple constituents - peptides, amino acids, etc. Other microbes release enzymes which catalyze the reaction of decomposition. Further comes the integration of the fragments of former molecules into new formations. Depending on the natural conditions primitive compounds of the taiga and tundra humus type or more complex steppe types of humus are formed."

A simple comparison of the results of the work by these "tiny things" in the north and south shows that they live and function obeying the laws of zonality. True, this fact was recognized as many as a hundred years ago. Further, a similar census of the soil's microbe population was required. While beetles and worms could be seen with the naked eye, then with bacteria things were much more complex.

Back in the early 20th century scientists used what is known as the method of microbiological reactions, which took into account only the final product of the bacterial work. Such "depersonalization", although made it possible to identify soils with an active and with a passive microflora, left the toilers themselves hidden from the experts' view. In his last works Kostychev proposed exploring instead of abstract microorganisms concrete groups and species in order to assess the contribution of each to the soil creation.

One of the first baits in microbe hunting was agar - a substance obtained from marine algae containing many polysaccharides, and "sweet tooths" which inhabit the "storages of the biosphere" yield to the temptation. But time went on, and their menu was enriched with more and more dishes. The "broths" were already cooked with meat and gelatine with frequent additions of ammonia and starch. And when a more lean bait was required use was made of an extract of "soil juices". But then, the baits varied not only with the soil. Sometimes, in order to lure out of them as many representatives of the micro-world as possible, use was made of all known media. But, occasionally, the diversity and food value of expert-proposed dishes cause the opposite reaction. Some scant colonies of microorganisms with an obscure structure grow on them. This happened in the case of the discovery of the *Proactinomyces* of the *Nocardia* genus. Fat baits were characteristic of colonies which looked like agglomerations of bacteria (the closest relatives of the *Actinomyces*). But it was enough to place a piece of the soil under testing into the medium where the microorganisms could content themselves with only a small amount of organic compounds, and the *Nocardia* groups ceased to camouflage. A wide assortment of dishes was not always beneficial. Of course, the search for exotic microorganisms required more and more agars. But the more hunting methods were known to scientists the more they strove to develop one universal technique suited in each individual case. Some twenty years ago the Soviet microbiologist Alexander Imshenetsky discovered a "dish" favoured by practically all denizens of the underground micro-world. It was a liver extract. Its popularity with the Lilliputian denizens of the storages of the biosphere was so great that it was decided to use the liver broth for investigation of the lunar ground. Alas, this time the experiment yielded no results. The soil of the Earth's natural satellite was found to be dead.

Agars and other nutritive media helped man to introduce himself to many species of microorganisms and to bring out their inclinations, including "vocational". Scientists discovered organisms responsible for the decomposition and reduction of various nitrogen and carbon compounds, lovers of cellulose, etc.

Hunting with bait had its disadvantages as well. The numbers of bacteria and other "midges" were established with its help only approximately, up to a certain order. The census of the soil microorganisms required different methods.

And what if use was made of a microscope? Back in 1924 such an idea was proposed by the well-known Soviet scientist Sergei Vinogradsky. His first observations upset the conceptions about the numbers of microbes. Previously, the analyses of nutritive media showed that they were several million in a gram of the soil. But the optical microscope yielded different results - over a billion.

The advent of electron microscopes brought new discoveries in the soil micro-world. The magnification hundreds of thousands of times made it possible to discover unknown forms, and the total microflora numbers grew by a few more orders. However, agars were not forgotten. On the contrary, they very well supplemented microscope observations. After all, by simple watching man cannot get an exhaustive information of a microorganism. And there is practically no possibility to distinguish living cells on the object glass from dead ones.

Now microscopes and agars are among the most widespread methods of assessing the soil micro-world. But they are not the only methods thus employed. There are indirect assessments, whose principle resembles the described method of "microbiological reactions". By the amount of ammonia, nitrogen oxides, carbon dioxide, etc. in other words, by the final product one can compare the population and activity of the microflora in various grounds.

But while so much information can be obtained from a clot of earth, then one method used in different natural zones makes it easy to bring out the geography of the soil's microbial population. The reader already knows that the total of microorganisms increases north to south. But does their composition change as well? This question was confronted by Dmitri Nikitin. The point is that in the study of the tundra earths he discovered a host of bacteria which do not react to agar seasoned with a soil extract. Such things happened even south of the tundra, in the forest, steppe and even tropical soils. But in the north the "bait" attracted one-hundred-thousandth of the total of microbes of any other zone. Perhaps this was due to the difference between the population of the cold and warm areas? The electron microscope disproved this assumption. The proportion of the microorganisms not covered by the nutritive medium in the dwarf tundra soils was found to be the highest.

Academician Yevgeni Mishustin in his book *Associations of Soil Microorganisms* (1975) proposed two explanations for this phenomenon. One was that the circulation of elements in the Arctic is slow. The reader remembers that the humus in the northern soils has no time to "ripen" when it is snatched out by plants and animals. Naturally, many of them get nothing. This is why they have learned to receive food from other sources. And they have changed their tastes so much that they fail to react to sweet agars. What are these sources? Possibly, minerals. The other explanation is simpler. In the north the litter fall destroys slowly, accumulating on the surface. And, as the reader remembers, there is no distinguishing dead cells from living with a microscope. This is why everything has to be counted.

Mishustin's book contains many interesting observations. It depicts a living dynamic picture of the phenomena at work in the "storages of the biosphere" in different zones. The northern soils suddenly present themselves to the reader in a new light. For a long time the question as to why the tundra lands had so little food for plants and contained practically no high-quality sweet humus elicited a hackneyed answer saying that this was due to the unfavourable climatic conditions. But the same conditions explained the absence of dense vegetation, the small depth of the loose loads, etc. The climate is really a vital factor here but a reference to it introduces little clarity. It is another matter if it is connected with the mechanism of the circulation of elements.

This is a new stage of nature's conveyor. The remains of poor northern vegetation, processed by its scant invertebrates have already come here. It is time for the most skillful creators of fertility to join in. But, alas, there are few real masters of their jobs among the microbial population of the Arctic. "Unskilled", nonspore-bearing bacteria live here in the main. *Bacilli* and *Actinomycetes* capable of enriching the earth with substances available to plants and of preparing organic remains for the birth of high-molecular compounds of humus yield to them in numbers by two, if not three, orders.

An entirely different picture is observed in black earths and chestnut soils. Their micro-world consists by half of *Bacilli* and *Actinomycetes*. As a result, the steppe earths for a long time have no shortage of nutrients and soft humus.

Incidentally, the soil's different requirements in fertilizers are also largely explained by the composition of their microflora. The more "skilled workers" are to be found in it, the fuller use is made by plants of composts and mineral additives. This is why their dose on podzols is much higher than on black earths. Manure and the nitrogen-containing substances in their turn stimulate the multiplication of bacteria. Actually, by feeding the soil, we replace or repair one of the stages of biogeocenosis the stage of microorganisms known as saprophytes.

But the microflora is not a simple part of the natural system, but a complex mechanism. The reader has just been introduced to how it produces plant food from plants themselves. But then, destruction is not its only preoccupation. It can create stocks of nutrients in the soil. Groups of microbes specialize in the seizure of concrete chemical elements. For example, nitrogen-obtaining is the job of a whole clan of bacteria. Crude vegetable remains are decomposed by butyric microbes. When a processed substance is enriched with proteins, vitamins and amino acids it is also attacked by its closest relatives butyl microorganisms. The most privileged caste in the clan is the *Azotobacter* genus. Its position is indicated already by the soils in which it lives. And these bacteria live in well-wetted black earths. They seldom penetrate north and south, and not for long. An azotobacter needs a whole complex of comforts and conveniences. First, the earths which claim their good will require a sufficiency of phosphorus, potassium and microelements. Second, they have to be provided with warm and moisture. And, third, they must have a neutral reaction, i.e. equal amounts of acids and alkalis. Therefore in the deserts on grey earths azotobacters occur only in spring, and on grey forest earths, when the sun warms them to the required temperature. It generously leaves podzols and especially the tundra soils to the "junior" brothers in clan - butyric and acetone-butyl microbes.

Only man can resettle the azotobacter north. Using fertilizers and other agricultural practices, he rectifies nature's "flaws" and creates comfortable flats for these pampered organisms.

The reader has been introduced to a department processing vegetable material into high-quality foodstuffs and preparing substances from which humus emerges slightly later. However, even the most perfect production does not do without wastes. Not all leaves and grasses passed through worm and insect stomachs are processed by bacilli, *Actinomycetes*, Azotobacter and other microorganisms disappear without a trace. Frequently it occurred that their remains accumulate at the very end of the food conveyor. But nothing is wasted in nature. Use is found for them as well. They were called oligotrophs, from *Gr*. Oligotrophic, meaning deficient in plant nutrients.

The accommodating character of these microbes should not be taken to mean that they prefer northern earths. Of course, the "poor eaters" find it easy to live in podzols and even in the rigorous Arctic but many of them nevertheless prefer rich and moist black earths. After all, they contain more "wastes" left by their fellow-microbes.

And now let us imagine that oligotrophs complete the processes of circulation of matter in biogeocenoses. What can come further? All elements are placed each where it belongs. Some of them are designed for plants, others for humus formation. But humus cannot only come into being and accumulate. It has to become destroyed, mineralized and give away the nutrients it has accumulated. And what forces will make it part with the wealth it has hoarded? The sun, wind and water? But they are strong on the surface, barely touching the lower layers. Perhaps the trees and grasses? Yes, their roots can decompose part of the humus, but only a very insignificant part. The main role in this process is played by microorganisms which have come to be known as autochthonous or indigenous. They can long do without fresh food by obtaining energy from the humus.

There was a time when scientists assumed that the indigenes were a numerous tribe which operated separately from the rest of the microflora. But recent experiments have shown that there is no clear boundary between these indigenes and the remaining microbes. For instance, some fungi can simultaneously feed on fresh "salads" from leaves, roots and humus. Such omnivorousness of the microflora explains its viability.

The smallest inhabitants of our planet have a host of advantages which help them to populate land and sea, hot springs and volcanic craters. But these "positive properties" in many of them, alas, are overcompensated for by many "disadvantages" of their next-of-kin, microbes, which bring plants, animals and man illness and death.

Form and Content

All that has been discussed, so far, has been concerned with the world of soils, the world in which they came into being and live. Relations between the fertile layer and the vegetation as well as the animals and microorganisms have been surveyed. But this layer itself has remained a puzzle. The author will introduce this subject beginning with the simplest thing - the signs and properties which catch the eye whenever man looks at the soil. As he studied the "anatomy" of black earths as many as a hundred years ago Dokuchaev set apart in them specific layers - genetic horizons A, B and C, thus discovering the ABC of modern soil science.

A Wall of Puzzles

It does not take an expert to distinguish layers of different colouring on the vertical wall of an earth pit. Ordinarily, the top layer is the darkest and those which lie under it are lighter. These are horizons into which the soil mass is divided. Their description opens practically all works concerned with the "storages of the biosphere". The first thing that interests scientists is the boundary between the mother rock (a product of metasomatosis and other hypergene forces) and the layer which accumulates the substances removed from the top by melt and rain waters - silts, salts, colloids, etc. It is a vital boundary, dividing the horizons designated by the Latin letters B and C. The B layer is a seat of all possible processes the accumulation of mobile compounds of humus, iron, aluminium, calcium, sodium, etc. The C horizon is less active, taking little part in the "life" of the soil mass. True, from its "building material" its upper storeys are made. Of course, the C horizon is not isolated. It is reached by "echoes" of many events which take place on top. For instance, winter brings abundant precipitation and in spring part of it, catching chemical substances "on its way", can find itself in the lowest soil horizons. A climatic change will immediately mark them with the dove-coloured spots of reduced iron and signs of water-logging or salt efflorescence - an indicator of a shortage or moisture.

The B horizon in the fertile layer functions as a safe of its emergency stocks. Melt and rain waters constantly penetrate here, bringing along all possible substances.

If violent rains or winds remove the fertile top layer a new humus level will begin to form on a rich mineral substratum. In the disturbed volcanic areas it keeps substances lost by the top horizon. It abounds in unstable volcanic glass as well as humus compounds and amorphous allophanes which have leaked here. In the forest soils the B horizon is filled with clay substances and products of their decomposition. Both film grains of minerals, clog up pores and cracks and form flakes and clots of iron and manganese oxides. Dark-brown humus seepages also occur here.

In contrast, in the steppes the B horizon accumulates calcium, magnesium and sodium salts. They are also brought from the top but occasionally get here from below together with the ground waters. The greater part of these salts are distinguishable with a microscope but some are visible with the naked eye. They thread the entire horizon with veins, show white spots and form stable concretions.

It would be an error to assume that the B horizon only receives and keeps various substances of the fertile layer's upper part. Occasionally it produces clays itself and shares the reserves it finds superfluous with the mother rock. Imagine that the climate has changed. Then the soil which arose from the carbonate crust of weathering begins to adapt itself to the new conditions. The B horizon, like an experienced banker, momentarily evaluates the situation and begins to get rid of the previously accumulated substances. Their place is occupied by heavy clays free of carbonates and saturated with iron and aluminium oxides. They were not brought from the top or from any other part of the soil profile, but, as said earlier, were born right here.

Still higher there lies the A horizon, the head of the soil. Here the plants find their food and here the bulk of the worms, insects and microorganisms lives, too. This horizon is ploughed and fertilized. And while the B horizon is comparable to a bank, the A horizon is comparable to a savings bank. Trees and grasses, animals and microflora created it in order to keep here their "savings", make constant use of them and redeposit them. And only part of the "profits" obtained by the soils in such "financial" operations goes to "safes" of the lower horizon and is deposited "for a rainy day".

But then, the Dokuchaev triad is only the beginning of the modern soil alphabet. Far more levels are now identified even in the steppe black earths, where the Earth's strata first received their name. Soil scientists already take an interest not only in the mother (soil-forming) rock, but also in what underlies it. They find it vital to know the nature of the crust of weathering on which the black steppe soils have "grown". If the transition is gradual the processing of rocks proceeded more slowly without being upset by the wind and water torrents. The sharp boundary points to powerful erosion which once picked up a colossal mass of the ground and carried it to a new place, where it smoothly enveloped the mother rocks. Therefore the fourth horizon of black earths, D, at times has the most surprising origin - granite fragments, carbonate-free clays, marine deposits, etc.

Nor did Dokuchaev take a special interest in the top horizon of black earths, the steppe felt. This cover of the steppes consists predominantly of fallen grasses, thickly interwoven with the stalks of living plants and is only slightly mixed with mineral particles - dust and the soil animal castings. But the felt is a source of organic and mineral substances for the accumulation horizon - the A horizon. The steppe felt is very unstable. In some places it does not survive even until the end of the summer, burning down under the sun rays and being eaten by insects.

R.I. Zlotin, an associate of the Institute of Geography of the USSR Academy of Sciences, made interesting observations of this phantom horizon. He devised a simple technique for establishing the real destroyer of the steppe belt. The idea was to trace the destinies of the fallen grasses in the shade and in the sun. On artificially shaded parts the felt lay until the end of the summer while on open ones it disappeared already in several weeks. However, the experiment did not exhibit sufficient "purity". After all, the insects were never isolated. Then Zlotin carried out an additional series of experiments. Using toluene, this powerful poison, he cleared several areas of living creatures and then made his observations all over again. But this time the sun rays again proved that they did not need helpers, working only several days longer than the first time.

Of course, the steppe felt is an unstable formation. The forest soil horizon, the A_0 horizon, is an entirely different matter. Even in artificial forest plantings of steppes and semi-deserts the litter of fallen leaves and branches lasts the whole summer. From it the upper mineral A horizon receives the bulk of the organic matter processed by insects, worms and microorganisms. The forest litter, alongside the tree crowns, protects the soil from sun rays and the hot dry winds. It is also divided into several layers. The upper layer consists of a fresh litter-fall and the lower abounds in humus substances and half-decayed rot.

Litters play a special role where the soils are none too fertile, and the plants have to draw their food straight from half-rotten and even fresh leaves and branches. Such a picture has already occurred in northern biogeocenoses and in subtropical red earths, where tree roots literally drained the forest litter-fall of their nutritive substances, blocking their way to the soil. And it is simply impossible to neglect organic horizons on swamps. Because they, and they alone, determine the "anatomy" of the peat soils. Here there is nothing like the customary division into the A, B and C horizons. All horizons are designated by one letter T, the first letter of the word *torf*, the Russian equivalent of "peat". They are divided only by the degree of decomposition of the vegetable remains. On the Ob-Irtysh interfluve, where one of the largest swamps in the world, Vasyugan, is located, the following picture can be observed. Right under the green "tarnish" of living bog moss appears a brown mass (T_1) barely touched by rotting. It may be from two to three metres deep. It is underlain by a thinner layer, already noticeably decomposed. Its colouring changes from brown into grey (T_2). More deeply there lies a dark-grey, almost black smearing mass, which does not a bit resemble former vegetable remains (T_3). And so on until the mineral horizon G (dove-coloured sand or loam) shows up.

A host of such organic horizons occur in the fourth "kingdom of nature". It is the barely distinguishable crust of algae on the surface of steppe and desert soils, only several millimetres thick. And the sod of meadow-lands mixed with the ground and interwoven with plant roots. And the arable layer changed by prolonged processing and the introduction of organic fertilizers.

Incidentally, the Dokuchaev "alphabet" did not remain unchanged for long. The additions made to it were found to be the more important, the more broad was the research of the fourth "kingdom of nature". Already in the course of a detailed study of black earths and other steppe soils Alexei Sokolovsky proposed using nine entirely new symbolic designations of their horizons - H for humus, E for eluvium (poor in colloids), I for illuvium (enriched with colloids), C for carbonates, G for gypsum, S for salts, Gl for gley (waterlogged), T for peat and P for the mother, or underlying, rock. This new "alphabet" was an eloquent proposal. Above all, it shows that the steppe earths were far more different with regard to their "characters" than had been believed before. They could accumulate humus and carbonates, at the same time, hide in their lower tiers salts lethal to plants like some salines. The Sokolovsky symbols formed the next step in the decipherment of the cryptograms made by nature on the walls of underground pits.

Apart from the accumulation of humus and mineral substances in some black earths and grey forest soils, the scientist pointed out a diametrically opposite phenomenon - impoverishment in colloids. The layer which lost them was located precisely between the horizons which Dokuchaev called A and B and which he dubbed H and I. Sokolovsky designated it with the symbol E (from the initial letter of the Latin word *eluvio*).

Although this eluvial horizon occurs in the soils of all natural zones in each individual case its appearance had its own reasons. In the subtropics red earths were impoverished by the vegetation, in the steppes the formation of whitish horizons in solods is connected with the activity of diatoms and the decomposition of minerals by alkaline solutions. In the forest zone podzols will be discussed separately.

Back in the early 20th century the study of podzol soils showed that the A horizon was underlain by a horizon which not only did not look like the Dokuchaev B horizon, but also had different functions and composition. Nor could it be described as a transition between the zones of accumulation of humus and mineral substances. After all, it was dominated by quartz sand and it contained practically no oxides of iron, aluminium and other chemical elements. First, the names of the horizons were left unchanged. Thus, the whitish horizon was named B, the dark horizon with rusty spots and powerful black manganese concretions C, the mother rock D. But, alas, the supporters of the Dokuchaev triad miscalculated. The blind following of the tradition led to a situation in which soil survey in borderland areas of the steppe and forest zones was found impossible. Because the same symbol designated opposite soil processes-loss and accumulation. Eventually, however, a way out was found. The whitish horizon came to be known as A_2 - the designation it retains to this day.

The discussions of the soil "alphabet" would fill a separate book. At present the soil scientists of different countries have no common language. Furthermore, even in the Soviet Union more than eight grammars are in official use, many including ten and more symbols. But, most importantly, the designations of the horizons have a host of transcriptions, readings, interpretations, indices, specifications, variations and compromise combinations. The more closely experts study the fertile layer and the more intensively it is processed, the more complex becomes its "alphabet". This shows that the pit wall still keeps many secrets from Scientists.

But then, soil scientists are less and less satisfied with search on a plane. For many years they have already been trying to identify the soil individual, a three-dimensional natural body. The complexity of the problem facing the researchers can be shown by an attempt to find the lower and still better, the lateral boundary of some soil individual. The clearcut division of the fertile layer into independent individuals exists only on the map, so far. In nature such boundaries are invisible,. being blurred, gradual and diffuse. The search is also impeded. by the fact that there is no telling to what extent the soil cover can be divided. Where is the boundary that the representative of the "fourth kingdom" ceased to be an operating unit of natural communities rather than simply a face-less piece of ground?

For a long time soils were looked upon as an object whose size and limit of division were determined by the map's scale. But any contour put on it, according to the laws of cartography, presupposes the unity of the properties of the territory enclosed by it. By virtue of its nature soil cannot be such a unit. In consequence, this single and indivisible cell of the fertile layer had to be searched for by its specific homogeneity inherent in it alone.

Theoretically, it all looked simple. It was enough to clear up the amplitude of fluctuations of the main properties of the soil, to find out their certain regularities and to establish the permissible boundaries of their deviations. Thus thought the American scientist M. Klein, who assumed that the soil individual is the smallest natural body with all the specific features of the bodies of the given class. However, the standard does not come into being of its own accord. It has to be calculated. But how?

An attempt to obtain an answer to this question was made by another American soil scientist, Hans Jenny. It represents a combination of different elements in which, as in a luxurious richly ornamented Oriental carpet, there is constant recurrence of one of several motifs, complexes of properties. Recurrence, this is not too bad a thing! The first step in this direction was made. It was followed by a number of specifications. The elementary soil unit was called pedon. Its presumptive size was from one to ten square metres. In the broken or wavy outlines of the horizons scientists saw rhythms, or cycles of periodic fluctuations of the properties of the fertile layer. With their help it was divided into cells.

Alas, no sensation came of it. The Americans themselves, as they launched the practical search, saw that it was too early to triumph, that serious specifications were needed. For instance, what was to be regarded as the full cycle of "fluctuations" of the soil horizons? Which of them were more important? Furthermore, the very first verification of the method showed that the pedon had unsubstantiated boundaries. "A multitude of cases can be named," wrote Boris Rozanov, "when the soil individual has an area of less than one square metre and vice versa, a very large area.

Furthermore, in the case of the sinusoidal character of the horizons the study of the forms of, and relationships between the horizons will be exceedingly inaccurate if they are held to extend over a distance of only half a cycle. It is necessary to have at least two cycles if the pedon is to be fully representative."

A different search was conducted by Lev Karpachevsky. "Since the soil is a true mirror of the landscape," he decided, "it must reflect in detail all its structural units, all its cells." It turned out that each tree or shrub and each clump of trees or shrubs left a trace in earth. And not just a trace, but perhaps its entire photographic picture. Thus, the idea of the adequacy of the state of soils and vegetation came into being. According to this idea, the most rigid connection with the natural communities existed between the vegetation and the fertile layer. In other words, the tree generated a soil individual, a pedon; a grove, a polypedon; a biogeocenosis, a soil combination.

Indeed, a single plant at times leaves a noticeable trace in the "body" of the soil. At times such a phenomenon is observed in black earths, where shrubbery gets among the grasses, or a forest strip is planted, or in the mountains, where a tree with a thick crown can abruptly change the pattern of soil moistening. However this is not a rule, but an exception. There is no direct adequacy of soils and vegetation in nature. Already Vladimir Sukachev noted that a biogeocenosis is a far more complex mechanism than the soil-vegetation system. An equally important role in it is played by rocks, ground waters, climate and even cosmic rays.

It should be admitted that until very recently hunting elementary soil areas, pedons and other representatives of the fourth "kingdom of nature" resembled a search for the legendary yeti, the abominable snowman. A good deal was known about them. There were debates about the procedures for the identification of individuals from the soil cover, proposed conceptions were criticized but none of the experts could boast having "caught" precisely this wondrous "beast".

It was discovered that at this stage it can be seen only in the light of mathematical formulae. It all began when Felix Kozlovsky, an associate of the Soil Institute named after V.V. Dokuchaev, declared the pedon to be a statistical category. Using during the search the theory of accidental functions, he deciphered many "writings" on the pit walls and discovered some laws which govern their seeming heterogeneity. What the practised eye of a soil scientist did not catch and before which was powerless his entire experience manifested itself in the pictures created from numbers, formulae and equations. Kozlovsky created his first portraits of soil individuals in the forests near Moscow, the steppes around Kursk and in the Sarpinsk Lowland, where sodd-podzol soils, black earths and chestnut soils "posed" for him. Work on their images began with the laying of very ordinary trenches over ten metres long. When they were ready the scientist made a meticulous study of the alternation of the soil horizons and their slightest bends on the freshly cleaned wall of this unorthodox pit. Like a veritable painter, he tried to make out the character of his models behind the exterior. His sketches, including those made in pencil, his reflections about nature-coded writings which showed up in the soil sections, wavy and tongued levels resembled to him familiar relationships of the $Y = F(x)$ type. It appeared that it was enough to project them to the coordinate axes and the result would be that "function of the climate, mother rocks and organisms multiplied by time" of which already Dokuchaev had written.

The scientist remembered and well understood that the failure which had befallen the Americans was the result of an enthusiasm for simple cycles and rhythms, of a desire to see in them perhaps signals sent to man by soils.

As he studied literally each centimetre of the trenches Kozlovsky arrived at the conclusion that the "bend" or "jump" of the horizon could not be taken as part of some unknown relationship, where each x value corresponded to Its own y. On the contrary, soil individuals were the sum total of many similar deviations each playing a minor role in their formation. Search for representatives of the fourth "kingdom of nature" and the identification of them from the cover required a multitude of measurements and complex calculations. Finally, from the sea of figures, formulae and equations began to emerge the outlines of long-awaited pedons.

Soddy-podzolic soils, black earths and chestnut soils showed most surprising shapes. Some of them had oval streamlined sides, others were elongated, resembling trees with branching crowns, some figures were angular and amorphous. But they claimed different areas. The soddy-podzolic individuals contented themselves with two square metres each. Some giants, however, claimed twenty square metres each. The Kursk steppes exhibited no such variety. The black giants were found to be gorgeous one and all. The ornaments they created spread over an area of 25 to 30 square metres each. The mosaic on chestnut earths occupied one-fourth of the territory.

But is all this necessary? After all, the Kozlovsky method was awkward. It was difficult to practise it in ordinary scientific and practical research. And what could it yield to such research? Here it is pertinent to recall that computers only too recently were big bulky structures and their speed of response raised great doubts. But an agriculturist and a land improver do not care whether the components of the soil cover which require a special approach are identified by mathematical statistics or in any other way. After all, ploughing and sowing, desalinization and drainage will be applied not to abstract notions, but to concrete soils. And what was for such a long time called black earths, podzols, red earths, etc.? What territories were covered with black, red and other soils? Their nutrient content, their stock of humus and other major characteristics were indicated very inaccurately. Paradoxically enough, the agriculturist dealt not with the soil, but with fields, ploughland and meadows. And how much more effective would be the efforts of agronomists if they were not only offered a map indicating the geographical distribution of all representatives of the fourth "kingdom of nature" under their jurisdiction, but were also told the difference between their "characters" and properties?

A few observations are merited by the evaluation. There is a special science known as soil rating, i.e. the division of soils by the degree of suitability to, and value for, agriculture, forest management and the economy in general. It is of great importance for long-term economic planners. And what forecast can be issued when all the forecaster goes by is a map showing simply grey earths or soddy-podzolic soils? It is an open secret that both can be used agriculturally. But what next? Next, a question arose, how much could they be used? After all, the Earth's surface was not an even layer. It has watersheds, slopes and low-lying areas. But the soils on a watershed and a slope have different possibilities. Let them look as like as two peas and contain equal amounts of humus. But the former can be ploughed without any limitations and the latter depending on the steepness of the slope. If it exceeds ten degrees the ploughing is simply impossible. Hence, the angles of incidence should be indicated. As well as each solonchak or waterlogged spot. But a map, depicting soil individuals with so many specifications, will be simply read and analyzed.

Of course, the map does not have to reproduce each individual separately. If they are homogeneous or at least resemble each other they can be grouped together. When the individuals are small and different they are usually referred to in an explanation appended to the map - the legend. For instance, the background soil is black earth, the inclusions are solontsi of small swallow holes up to 50 per cent, with alkaline black earths in the periphery. Looking through such an explanation, an expert will quickly say: "The territory has a contrasting soil cover, is filled with small soil individuals, the use of the lands is impeded and reclamative intervention is required."

However, a land improver for a successful soil treatment needs maps, X-ray pictures of the territory. Here again it is vital to know what the "patent" is like, what his size and shape are. In the 1930s a decision was adopted to irrigate the Volga lands. The soils began to be irrigated. In some places noticeable results were achieved, in others everything remained unchanged. The map showed a "kingdom" of chestnut soils. Some twenty years later it was discovered that chestnut soils here neighboured on meadow soils, scattered on innumerable low-lying places. True, even this discovery introduced little clarity.

In another twenty years soil scientists began to give thought to the structure of the soil cover. That was when it was decided to take a new survey of the Volga Area. The survey bore an unorthodox character. Not just individual pits were dug, but deep trenches like Kozlovsky's. The measurements were taken at a distance of several centimetres. Soil samples were chosen in their thousands. The new maps showed that the soil layer is made up of large massifs of chestnut soils with a sprinkling of their meadow varieties. In some places they looked like spots, where the gradient was slightly bigger than a spot, they stretched and fused into large contours which resembled branchy trees. Now it became clear why the watering had yielded results in some cases and had yielded none in others. On the territories occupied by closed patchy meadow soils the moisture stagnated. Under its impact chestnut soils lost the salt surplus and displayed better accumulation of humus and nutrients. They were gradually conquered by more fertile meadow soils, which emerged from their refuges extending their influence to their former rulers. But where the slope was slightly steeper the meadow-lands had an elongated shape. Along them the water flowed unobstructed to ravines and gullies. It was enough only for their irrigation. But then, the moisture which fell to the share of the chestnut soils also flowed to the low-lying places. The effect of irrigation was scarcely felt at all.

It is still more important to know the location and "external appearance" of the boggy soils and their individuals. Here a diversity of variants is possible. The simplest of them is little bogs forming small patches amidst large tracts of podzol. Then it is enough to reduce the level of the ground waters, and the waterlogged areas will disappear. Podzol and boggy individuals on a river terrace are another matter. Here no reduction of the level of the natural collector will bring substantial changes in the soil cover. At best, it can be expected that the boggy soils will cede a small territory to podzols.

As the reader can see, these are not thought-up problems. They arise quite frequently and not only during the drainage or irrigation of territories for meadows and ploughland, but also while digging canals and reservoirs. Therefore soil maps of a new generation, which will reflect soil individuals and their relations between themselves and the surrounding world, are awaited not only by land improvers, but also by builders, hydraulic engineers and other experts.

In Search of the Simplest

Soil, just as any other product of nature, is now studied at a variety of levels. One is search for the elusive individuals which make up the fabric of the fertile layer, another - the study of metamorphoses exhibited in it by minerals and organic substances and, finally, penetration into the world of the elementary particles which form its mass. As was said earlier, over 90 per cent of the soil are sand, clay, crushed stone and other lifeless components whose size ranges from several centimetres to a micron. The giants are inert. But the dwarfs, which occupy an intermediate position between rock fragments and colloids, show amazing activity. The well-known German soil scientist Walter Kubiena has called the former the skeleton and the latter the soil plasma (1938). The scientist took an interest in more than the composition of the "bone" tissue. He also tried to clear up its internal structure. Kubiena established that soils give birth to three basic types of association - elementary, micro aggregate and cemented. He was helped by a microscope. As he studied floodplain soils he observed that micro particles were united in it without any visible connection with big fragments. The latter were simply scattered against the background of a homogeneous mass like raisins in a cake. Pulled out, such a raisin leaves an empty cavity in its place. Something like it occurs when a large concretion or fragment is extracted from the lower horizons of podzols. Such a variant is an example of an elementary association. Big and small particles are loosely interconnected in it.

Kubiena's next type was discovered already with the aid of Darwin's work *The Formation of Vegetable Mould through the Action of Worms*. Kubiena saw in this work what many other experts had overlooked. In terms of micropedology, worms are really among the main creators of soil particles - micro aggregates. It is these clots which form a second group of associations - mineral particles cemented by humus substances. But then, the role of a binding substance can also be performed by inorganic colloids. Such brown and dark-grey clots at times form whole horizons of forest soils.

Finally, a third type-crusts of carbonates, gypsum, iron and silica, which not infrequently occur in steppe and desert soils. They come into being when soil solutions evaporate. Kubiena vividly described their emergence in his work *Micropedology*. "The calcium-saturated solution moved from the lower horizons to the upper. It rises higher and higher up the capillaries. Here it encounters pores filled with air. Touching it, part of the liquid momentarily evaporates, and a crust of calcium carbonate or calcium sulphate forms on the pore walls, depending on the compound which filled the soil solution." Such a pore is well disclosed even by a microscope with a magnifying power of only 100 to 200 times.

True, there is no putting a soil sample on an object glass. If it is to be studied its thin section is to be manufactured. It is a meticulous job. A small monolith is cut out from a pit already in the field. It is sealed in paraffin. Then, already in the laboratory, it is extracted by boiling in Canada balsam (larch resin) or plexiglass. Safely cementing the soil particles, the sample is carefully ground. The operation is frequently repeated up to five times until a sturdy smooth plate is formed. Only then it is glued on to glass.

When the section is ready it can be studied. Ordinarily, a man who first sees a soil sample with a microscope is amazed at its devious patterns. The pores are found to be not just little holes, but whole "supply lines" faced with crystals of calcium as if with paving blocks. This invisible horizon in black earths, which boils from a drop of hydrochloric acid, magnified a hundredfold, is found to be an agglomeration of calcium crystals.

In the sections it is easy to tell the initial stages of specific soil processes. For instance, on the pore walls thin clay films turn up - a sure sign of lessivage, or the movement of various compounds from the upper horizons to the lower undestroyed. Something like it can be seen in the case of podzols but their pores will already accumulate decomposition products such as oxides of iron aluminium, manganese, etc.

If all these thinnesses are to be seen under a microscope it is necessary first to learn to perform the simplest operation-to distinguish with great magnification sand and clay. This is easy to do by touch even without a preliminary training. But what particles of sand and clay look like is known to few people. Magnified several hundred times, they are much more attractive than when viewed with the naked eye. Sand is found to contain not only colourless quartz fragments, but also other minerals of background can already be traced, being formed by thin clay particles. Here the pattern shows itself with greater clarity. In loamy sand the particles form individual islets. Their sections look like a starry sky. And clays rather resemble landscapes painted in water-colours. Their sections do not show sharp transitions, their tinges are soft.

Such contemplation yields only the most superficial information about the bone tissue of the soils. And, of course, it cannot satisfy an expert searching for elementary, absolutely simple particles which make up the fertile layer. Therefore soil micromorphologists handle entirely different categories, associations or aggregates. The Kubiena triad has just been discussed. This German scientist has proposed just the most general classification of the "simple" soil formations. But even this classification at times makes it possible to find a way out of a difficult situation.

In the early 1950s two groups - geologists and soil scientists - worked in the steppes of the Kalmyk Autonomous Republic. In one of the pits the experts saw a strange picture. At the very surface of the earth, some place at a depth of ten to twenty centimetres under the clay loads sand turned up nobody knew from where and clays lay under it again. It was found impossible to explain the origin of this "layer cake" in the field. Only in a university laboratory, when sections were obtained from samples of this enigmatic sand, did it become clear that the "shifting "material", as recorded in the field report, was clay, more exactly, aggregates of clay particles which were kept from gluing together by crystals of calcium and sodium salts.

But then, more surprising formations occur among the aggregates. For instance, pores, cavities, cracks and pores in grounds can tell us detailed stories as those of the clot. Frequently occurring oblong cavities are traces of the roots and "supply lines" laid by small insects. Oval "rooms" are larva dwellings. The interstices between aggregates are also an aggregate. Among the latter are cracks resulting from temperature and moisture fluctuations.

Salt crystals have already been referred to. They also create their shapes - needles of calcium, tubes within pores and fibres. They give clear pointers with regard to the history of the soil. If it arose on the deposits of a lake or sea among the chaotic weaving of fibres, fragments of mollusc shells will be seen. If the lowest horizon D consists of fragments of granite and in the upper horizons, in spite of this, still occur fragments of limestone – carbonates - there can be only one conclusion: the climate here has been invariably dry throughout the soil's lifetime.

The reader must have heard about amazing concretions lifted from the ocean bed. They contain much cobalt, nickel, manganese and other useful minerals. Much earlier their distant relatives were discovered in the soil. These denizens of the sea had an impressive size, up to a metre and a half across. The denizens of the storages of the biosphere were only several centimetres and frequently fractions of a millimetre across. Both resemble an onion. A microscope does not help to see in them either rays or fibres. Their sections perhaps resemble hard shells with most surprising filling inside. Sometimes they are fragments, sometimes white limestone, sometimes a cavity. The concretions keep long memories. This is easy to see by looking at their sections. It happens that under the armour of iron oxides a soft half-destroyed piece of chalk occurs - a distinct steppe mineral in a rim of forest origin. Ordinarily, such nuts mark soils with complex destinies. The latter could, for instance, have been born some place in the taiga on fragments of limestone which accidentally had found its way to the surface. Here calcium carbonates were given a hostile reception by the climate and vegetation. The moisture, infused on "acid" needles of pines and spruces, uniting with the aggressive acids of the soils, not only destroyed the limestones, but also enveloped their particles with a "cloak" of iron oxides borrowed from other dissolved minerals.

Of course, it is not always enough just to look into a microscope to disclose the past "inside story" of soils. Therefore experts have developed a whole system of "interrogation" - an aptly chosen name for a questionnaire which has to be filled by the researcher during the observations. It embraces tens of "simple" questions about the colour, origin of shades, composition, width and shape of the pores. All these "formalities" should be passed through by each particle "under investigation" soldered in the resin. Particular attention is merited by prints left by roots and decomposed vegetable remains on rocks and minerals. Thus, what at first glance is scattered information creates pictures of various natural processes which form the fertile layer.

At times the mineral under investigation does not give answers to questions put to it. Then the soil scientist uses a tried and tested method: he examines it in a polarized light. A ray of light resembles a wire brush for bottle cleaning, so chaotic are its oscillations. And a polarized ray is disciplined. Its oscillations take place on strictly definite planes. Such a light changes the colouring of minerals and show up features which they strove to conceal at simple lighting. For instance, the presence of clay particles in concretions.

The microscope makes it possible to find out facts not only about the soil itself, but also about the vegetation which covered it in the past geological epochs. The point is that the grasses and trees, as they die out, give back to the earth not only the organic mass, but also the minerals formed in their trunks, stalks and leaves. These are bio-, or, more precisely, phytoliths. They have different composition. But more often than others the phytoliths include grains of silicon oxide, more seldom carbonates, sulphates, chlorides and phosphates of calcium. At times the soil may be found to contain undisturbed remains of diatoms, algae, sponges and other plants. How does this happen?

It is an open secret that many grasses and trees avidly absorb mineral compounds from the soils. For instance, cereals have a predilection for silica. In the vegetation period, when plants gain in strength, their tissues gradually become filled with mineral compounds. The cells of cereals become incrusted with silicon oxides and calcium salts become detained in the leaves of lime-trees, ashes and oaks. As a result, some of them accumulate compounds of the SiO_2 by nH_2O or $CaCO_3$ type. By the end of summer the grasses wither away, the trees shed their leaves and the soils become saturated with a myriad of small grains of silica and calcium carbonate.

So far, a better study has been made of opal phytoliths. They lend a whitish colour to humus clots and little prisms which make up Horizon A. Such a powdering occurs even in the black earths of dry steppes. Light, almost white veins of opal thread their profile from the sod to Horizon C. It happened that they deceived experts throwing them into confusion. Back in 1908, studying black earths under forest strips, Mikhail Tkachenko was amazed at an abundance of whitish spots and other external signs of podzolization in their profile. The conclusion suggested itself: steppe soils degrade under forest stands. This rash conclusion was not contested for twenty years until Academician Leonid Prasolov disproved it in the late 1920s. Studying aggregates of black earths with a binocular, he realized that the grains of opal which cover them were of vegetable origin (1927).

The taiga lands are seasoned with this whitish powder still more. In 1951 Alexandra Novorosova calculated that up to 60 kilograms of silica annually return to each hectare of forest with coniferous litter-fall. The greater part of these receipts is under 0.005 millimetre and does not stay long in the soil. It becomes dissolved and again takes an exceedingly active part in the circulation, being absorbed by plants and taken by soil solutions, etc. to the surface. Bigger bioliths remain in the "storages of the biosphere" much longer.

The grains of opal help to find out facts about the vegetable cover and climate of long-gone days. After all, phytoliths have the shape of the cells of the plants which gave rise to them. Back in the late 19th century it was known that the cells of a buttercup are unlike those of wormwood and that the cells of oak leaves can never be confused with those which make up birch leaves. It turns out that phytoliths make it very easy to reconstruct the vegetable cover, hence, the climate of the past epochs. From this it is very easy to form an idea about soil life in this period.

Nature has also taken care to impart the sense of time to phytoliths. It has put into them something like a dock-a piece of carbon. Even pure opal of vegetable origin contains up to one per cent of natural soot. Exposing it to radiocarbon analysis, the American scientist Joseph Hill established that the age of grains of opal, hence, of the soils sometimes exceeds 13000 years.

At first glance, many phytoliths look alike. They have identical oval shapes and smoothed-over edges. But a closer scrutiny shows that each of them is unique, having exclusive individuality. So far, the stone chronicle keeps many puzzles from researchers. However, the study of it has already begun. Four classes of signs have been identified. The class of fescues bears remote resemblance to grains. It numbers up to eight varieties ranging from round to oblong and winding particles. They are scarcely rugged and slightly rounded. In contrast, the chloris class is less expressive. It has only two types of grain. But millet-shaped phytoliths have set a record diversity. Eleven specific forms have been singled out among them. They bear scant resemblance to millet. These grains rather look like nibbled bones or dumbbells. Finally, the class of elongated phytoliths is to be found in all plants.

The American scientist Paul Twiss, who has developed this classification, used it in analyzing atmospheric dust accumulated in modern and buried ancient soils of Kansas. His data showed that tens of millennia ago they had deposited in them grains of the fescue and chloris types, i.e. the present territory of Kansas was covered with less drought-resistant plants than now. In modern soils the scientist discovered dumbbell-shaped millet-like grains. The picture was clear: the past few millennia have made the Kansas climate much drier.

And does humus have shape? Can it be divided by external signs, like mineral substances? The first to obtain answers to these questions was Hans Muller. He identified three main forms in the organic substance of the soil as well – Mor, Moder and Mull. Mor is the first stage of decomposition of vegetable remains. It is a purely organic formation already processed by insects. Microbes have only begun to process it but nevertheless Mor can hardly be described as a semi-finished product of real humus. It is the most primitive, rough treatment of vegetable litter-fall. Moder is another matter. It is less homogeneous than Mor. This class contains already substances mixed with the soil's mineral part. Moder is a product processed in the stomachs of the soil animals. It still contains many mobile organic substances - signs of "unripe" humus. Mull is an entirely different matter. It is the concentration of all the positive properties which were only in an embryonic state in the previous forms. Its connection with minerals is particularly close.

In the study of organic substances Kubiena used the same "questionnaire" as was employed for mineral substances. Already in the study of sections which included particles of Mor he identified four stages of decomposition of vegetable remains. At the very outset of the processing leaves, needles and grass stalks were little changed by animals and sun rays. But they already showed early upsets. Here and there the leaf tissue passed into the dark blurred spot of humus. Signs of rotting showed the more clearly, the greater was the resolving power of the microscope.

In some sections with Mor Kubiena saw utterly untypical spots of this form of humus. They were dark-brown. And only by the smallest "fragments" of the leaf or needle did the scientist guess that he faced a rotten piece of vegetation at the next stage of decomposition. The preparations obtained from Moder and Mull helped Kubiena to introduce himself to a still deeper lysis of the falling off of grasses and trees. The sections of Moder were dominated by brown and grey remains. Among these spots one could distinguish the outlines of vegetable remains. Mull looked more monotonous. It was dominated by grey and dark-grey colours, here and there the walls of tissues and cells of disappeared grasses could be seen.

Experts did not content themselves with the Kubiena triad for long. By analogy with the mineral, bone tissue of the soil they identified "organic plasma". It was recognized as the fourth form of humus, alongside Mull, Moder and Mor. But, in contrast to these forms, very little was known about its composition. It was believed that the plasma was a mixture of colloidal particles with solutions of organic substances. In 1970 the well-known French soil scientist Filippe Duchauffour assumed that the "plasma" had different forms, calling it a "purely organic" formation. The American Leon Ball held it to be a homogeneous organic mass which fills the space between the clay particles. Then it was discovered that scientists knew only part of the truth about this fourth form of humus. Back in the 1930s the Soviet soil scientist Dmitri Sideri, studying thin sections of black earths with a microscope, saw in them clay particles covered with dots and flakes of organic matter. Of course, there was nothing extraordinary about this. But Sideri was amazed at one specific feature of these formations: they resembled balls. Previously, and much later they were regarded as the result of simple envelopment of mineral particles with a humus substance. But already in those days the scientist was not satisfied with such a formal explanation. A meticulous study of these enigmatic balls showed them to be humus-clay associations. The mineral particle formed a nucleus, and the humus films enveloped it with several layers. Sideri realized that these were elementary, the simplest particles of Mull humus. True, then his discovery was denied recognition. Only in the late 1970s did the French researcher Patrice Chassin arrived at the same conclusion.

The Kubiena triad for organic matter and the discovery of Sideri formed the foundation for the classification of the Soviet Union's soils based on the form and mixing ability of humus. In 1982 its authors, Anna Romashkevich and Maria Gerasimova, divided all Soviet territory into zones of prevalence of Mor, Moder and Mull.

The possessions of coarse humus covered, in the main, mountainous areas. At the very boundary of the eternal snows where the soils of alpine meadows lie, the organic substance is perhaps processed least and there is practically no connection between this substance and the mineral part. It is Extramor. Its antagonism to clay minerals is so strongly expressed that the horizons of alpine Soils are divided into purely organic and purely mineral. But suffice it to step slightly lower, where under the coniferous vegetation mountainous podzolic brown forest soils are located their structure easily showing that the enmity between "animate" and "inanimate" nature has weakened. Organic substances and clays "compromise". The result is the transitional layer between the coarse humus and mineral horizons.

The kingdom of Moder covers almost the entire zone of the northern taiga. The developed humus substance of the podzolic soils here had already been exposed to the action of animals. Nevertheless, it still bears a stamp of severe climatic conditions and of an admixture of Mor.

Further to the south, the milder the humus substance and the more readily it forms an alliance with clay particles. Mixed forests on soddy-podzolic and grey earths no longer show an imprint of severe climatic conditions. The character of Moder becomes more easy. It shows more and clearly features of Mull until it finally changes into this form, known as forest or forest-steppe Mull. It is a very important reservation. Although externally the humus of grey forest soils is very close to classical Mull it is still far more mobile than this form, i.e. is not mature enough.

The Mull homeland is black earths. The top-quality humus - the standard of processing of vegetable literally - is kept by these steppe soils. By way of distinguishing it from similar forms of the same category it has been named calcium Mull.

True, such a division of the spheres of influence is merely schematic. And the scheme is very approximate. After all, it does not consider either the history of the development of the soil cover or the human influence. And they cannot be discounted. This was proved already by Kubiena. Simultaneously with the discovery of his triad he described a form of humus which came to be known as Tangel. He came across it in one forest soil which had literally grown into its predecessor - rendzina. As a result its humus horizon acquired a two-tiered structure. The lower part preserved Mull and the upper part retained Moder with signs of Mor.

The picture is changed still more rapidly and radically by man. When he ploughs up the soils with coarse humus and begins to introduce in them organic fertilizers in several years a new form turns up in the place of Moder with clear signs of Mull, or even Mull itself.

The Most Complex Polymer

Thus, what is humus? Introduction to its particles in sections, horizons and pits was merely the first step in the study of the soil's organic substance. If there is to be a deeper study of its essence, it is necessary to go over from the anatomy of Mulls, Moders and Mors to studying the substances which make up their tissues and to understanding from what raw material this amazing natural polymer is manufactured. A few observations about the raw materials. So far, by humus the author understood a specific product of biochemical transformations in which animals and plants take part. But with regard to such a production process it is necessary to have a clear definition of the role of each participant, for instance, animals. They were frequently and without any valid reason included among the raw material sources of humus. But the point is that the remains of fauna, especially the mammals, reptiles, amphibians and many invertebrates, become processed in the soil following an entirely different pattern than the grasses and leaves. None of the denizens of the storages of the biosphere, dying, passes the humus stage in the course of decomposition. They directly become carbon dioxide, water and mineral salts. The author has on many occasions attended excavations of burial mounds and necropolises. These burial sites, whose age ranged from 1000 to 2500 years, were found to contain a host of bones. Sometimes whole herds of sheep, goats, cows and horses had been slaughtered during burials. But the earth, intensely fertilized with organic products, did not react in any way to these generous offerings. Not a single dark spot which would remotely resemble humus occurred around the skeletons of sacrificial animals. But in the places of rotten wooden rafts, sods and even where millennia ago individual grapes, pieces of grapevines or leaves were dropped one could distinctly see dark, almost black veins, spots and specks of real Mull or Moder.

What is the matter? It turns out that animal tissues consist, in the main, of proteins and fats. They do not contain the slightest bit of necessary raw material for humus formation such as wax, lignin, cellulose, resins and other substances. Of course, the absence of a necessary material is an important factor. But it has been seen on many occasions already that nature is capable of performing even more amazing transformations. Therefore it is vital to bear in mind that animals do not only contain "raw material" for the manufacture of humus, but do not directly need it, i.e. have an entirely different ecological destination.

The grasses and trees are autotrophic. They are tightly attached to the earth. To them it is the only source of mineral nutrition. And, however poor it is, break with it would spell death to them. Neither atmospheric carbon dioxide nor moisture will be able to replace to the plants the soil, from which they derive elements, biophyles. Photosynthesis, which now turns out up to 450 billion tons of organic matter on our planet, owes its "capacities" precisely to these elements. It turns out that the soil is the foundation of life and the grasses and trees are not only among its main builders, but also its organic part. Nature has given their roots a whole arsenal of devices, fitting them with special adjustments for extracting food. Penetrating into the storages of the biosphere, they surround themselves with products of decomposition of withering vegetable remains and release acids and other compounds, which literally wrest necessary chemical elements from minerals.

The soils themselves largely depend on plants and still more, the composition of their humus as well as the speed of its manufacture. After all, mosses and lichens do not contain the least bit of resins and fats, wood has a negligible amount of protein, and the conifer of pines and spruces includes many resins. Naturally, in identical conditions such "raw materials" yield different products and periods of their manufacture are also unequal.

The well-known Soviet soil scientist Maria Kononova has traced how alfalfa roots change into humus. The first to disappear from them is starch. This happened on the fifteenth day of the experiments. In the same period cellulose shrank in them in proportion to the total mass and lignin showed stubborn resistance. The pine needles displayed an entirely different pattern of behaviour. After all, they consist of one-quarter of resins, whose ability to resist rotting was well known already in ancient times. Parallel with this experiment, Kononova made observations of the roots and leaves of other plants. After each term she enclosed a piece of the decomposed material in a section and carefully studied it with a microscope. This enabled her to see a whole chain of transformations. The first block seemed to be completely unaffected by rotting. But deeper analysis showed the disappearance of living tissues, the core of plants. They, as it were, fell out of the "envelope" and became dissolved without a residue. In the next block the picture changed. The vessels along which water circulated in the plants were found to be clogged with a mass of bacteria.

In the next section one could observe the initial moment of the formation of humus substances. In the leaf channels where the previous block accumulated microorganisms there formed a brown substance. One of the last stages of decomposition was represented by a filbert leaf. Only a petiole remained of it. 300-fold magnification showed that the first, primitive humus had already formed and that lignin in the remaining vegetable tissues hardly lent itself to decomposition.

Kononova also studied these elementary humus substances. Processing them with a solution of alkalis, she obtained aromatic rings. Here some explanation is warranted. The point is that organic substances do not always consist of rings. Quite frequently, these are simple chains of endlessly recurring compounds of carbon and hydrogen or carbon and nitrogen. Before they have closed, or formed rings, it is too early to speak of humus.

Back in 1924 the Soviet scientist Alexander Shmuk for the first time in the world isolated from the organic substance of black earths the compounds akin to benzenes such as indole, skatole, pyrrole, etc. They all down to the last had ring-shaped nuclei connected with each other by bridges formed by one or several atoms of oxygen, nitrogen or a whole group of chemical elements. Such a structure precisely distinguishes humus from "semi-manufactured products".

At present a soil scientist finds humus interesting not so much because of its aromatic structure as because of its composition. Already in the mid-19th century in the organic substance of the fertile layer scientists distinguished two main components - fulvo acids and humic acids. The former derived their name from the Latin word fulvia, yellow. Indeed, they resemble weak tea. Light on the background of other humus substances, the colour of fulvoacids is the result of their poorness in carbon. They contain from ten to twenty five per cent less of this element than humic acids. As a result, the fulvoacid is incapable of retaining any valuable substances and chemical elements. The reason of it was discovered by the Canadian soil scientist Michael Schnitzer. He attempted to isolate aromatic substances from the fulvoacid. But this was found to be a difficult matter. For a long time the scientist could not find traces of ring-shaped nuclei. Only by repeating the experiment twelve times did he obtain a modicum of the sought-after substance. At the same time, humic acids frequently by one-quarter and sometimes by a half consisted of aromatic acids. Schnitzer saw that fulvoacids did not keep all elements which abounded in humus and which made it valuable to man in the ring-shaped nucleus but carried them in side chains accessible to all. They do not strive to keep even nitrogen, which lends importance to any compound in soils, as long as possible, easily parting with its molecules. For this reason Schnitzer for a long time held them to be nitrogen-free substances. But, as was discovered later, with regard to the content of this element fulvoacids had little difference from humic acids.

In contrast to humic acids fulvoacids may refer their aggressiveness. It is to them that the whitish horison of podzolic soils owes its birth. It is they which destroy minerals. And considering that these acids easily dissolve in water, their role in the soils of the humid areas of the globe becomes abundantly clear. They are the main chemical agent which transforms the mass of glacier moraines, loams, and red-earth crusts of weathering. Apocrenic acid, J. Berzelius wrote back in the 19th century, stands but for its specific chemical affinity t_Q aluminas. Indeed, the fulvoacid captures iron and aluminium oxides, changes them into mobile compounds, takes them deep into the soil mass and deposits them in Horizon B - the bank of the fertile layer.

Another humus component is the humic acid - the most valuable component of the soil's organic substance, the custodian of its fertility. The more of it is contained in the earth, the richer it is in nutritional elements. In black earth humus, by more than one-third consists of its compounds and in podzols humic acids are only one-tenth of all their organic substance. But it is not only the quantitative aspect that matters. Nitrogen in the fertile layer imitates carbon in all respects. And while the former makes up ring-shaped nucleus the latter follows its example.

Is it a good fact? On the face of it, the more accessible the key elements are to plants, the better. But here in order to reach nitrogen one has to destroy the ring. This is no doubt a difficult process. But due to such a strong packing this element does not fall prey to water, does not change into gas and does not escape into the atmosphere. When necessary, microorganisms will open the nucleus, and the plants will receive the share due to them.

Kononova's book *The Organic Substance of the Soil* includes a picture of a molecule of humic acid taken by an electron microscope. In this photograph the molecule resembles a grape cluster. But it is not this that is of importance. The photograph has a caption saying: "The picture is taken at the Institute of Combustible Minerals". Why? What do coals, shales, oil and gas have to do with the soil? It turns out that they are directly related. Humus and especially humic acid are akin to coal. The soil also includes a particle of a sunray. But coals are different. There is anthracite and there is brown coal. A similar analogy is traceable to the soil. Many experts divide humic acids into black and brown. Back in 1954 the German chemist F. Scheffer investigated them. The darkest humic acids were found to surpass their brown counterparts in nearly all indices. They contained more carbon, more intensively absorbed light and more intensively enveloped clay particles. Even their tastes for the cations of soil solutions were found to be different. Black ones preferred calcium while brown ones aluminium, iron and hydrogen. Only in one respect did the former fraction of humic acids lag behind the latter - solubility in water. Many soil scientists thought so. Furthermore, it was believed that humic acid in general was incapable of dissolving in water. For many long years it symbolized all that is immutable in the fertile layer. Now, in 1975 an article was published by the Soviet soil scientists Valentina Ponomareva and Tatyana Plotnikova *Concerning the Solubility of Preparations of Humic Acid in Water*, which categorically denied the main property of this component of humus - immobility. "Having made a long study of the composition and properties of humus in deep profiles of many types of soil," they wrote, "we have noticed a fairly wide dissemination of profile migration of humus substances not only in soils of humid climates, but also in black earths"!

Incidentally, ten years ago such a statement would hardly have found specialists' support if it had not been backed by the results of prolonged deep research. For twenty years Ponomareva and then Plotnikova searched for an answer to the question as to how humic acid moves about in the soil mass. "Naturally," they reasoned, "in the soil mass the humus substances, in particular, humic acid, are in a fixed state with various mineral components, and it would be naive to try to dissolve humic acid with water taken directly from soil samples. Atmospheric water to a larger or smaller extent operates on all soils, and if its dissolving action on the humus fixed in the soils were considerable it would be impossible even to expect the accumulation of soil humus" (1980).

Indeed, the scientists who proclaimed the insolubility of humic acid used dry powders in their experiments. These powders really resist the action of water. In nature, however, everything operates differently. The soils accumulate not powders, but colloids! That was why the authors of the aforementioned article chose their own path. They did not dry soil samples, but extracted solutions from them and, aided by chemical reagents, settled from them the gel of humic acid. Then they already dissolved it in distilled water. Of course, they did not obtain real solutions. After all, water contained colloids, and not ions. But it was not this that mattered, but the fact that humic acids gained mobility.

Three different soils were tested - black earth and grey and brown forest soils. The humus of the steppe earths, in the main, consisted of black humic acids, i.e. the most difficultly soluble ones. But their clots – gels - easily dissolved in water in the experimenters' very eyes. True, the very process was slow, not as in the case of fulvoacids. And the resulting solution was none too concentrated. Nevertheless, they moved!

The experiments with grey forest soil no longer seemed to be so important. After all, the main thing had already been proved. But here the researchers were awaited by another surprise. Black humic acid passed from gel into the aqueous solution only by half. And this is in the top A horizon. And what is below it? But already at a depth of 30 to 40 centimetres, and then of 50 to 60 centimetres and further down to one metre, the picture becomes restored. The jelly of humic acids literally thawed in the distilled water. The experiment showed that the extraction of the most organic compounds in the soil proceeded from Horizon A.

With the brown forest soil the experiments began as with the grey one. The humic acids were in no hurry to pass into the solution in Horizon A. Only a quarter of their total volume found itself in water. True, these were not black humic acids, but their brown counterparts. Those which, according to Scheffer, had greater mobility. "Apparently, their greater part was already carried out into the depths of the soil," the researchers decided. But the brown organic acids did not show activity in Horizon B either. Why? Apparently, here, too, the soil had become adapted to nature's conditions - an abundance of moisture and acid solutions infused on leaves of beech and hornbeam.

The soils of broad-leaved forests had a different job to do - to preserve the small but sufficiently fertile humus horizon.

Brown and black humic acids suddenly swopped places. The former were found to be slow, the latter quick. But another question arose here, how did humic acid pass through the mass of black earths without bleaching its calcium carbonates? It is a really difficult question. After all, the fulvoacids, for instance, sow only destruction in their path, washing away and splitting practically all minerals in the upper soil horizons. And can these components of humus be compared? After all, it has just been pointed out that the closest kins in it - brown and black humic acids - were so unlike. The structure dictates the properties. And while the fulvoacid came into being in order to create podzols black humic acids created black earths.

The latter humus component is not known in all details. And the fact that it was found to be different from what it appeared to be is a guarantee of fresh surprises which this acid will present to researchers. Only too recently these acids were called "ripe", "barely mobile" and brown acids, "young" and "mobile" fractions. The reality has been found to be different. But then, are the epithets themselves correct? In the brown forest soil the young fraction will never be able to "grow old", i.e. to change into a black humic acid. And the latter never happens to be brown even in a really young, just formed organic particle of black earths. In general, the deliberateness with which the black fraction dissolves in water, its "moderate" mobility rather "weakens" the rapid decrease of the humus content as we go deep into the profile. This process does not impoverish the humus horizon of the black earth, but, on the contrary, as it were, "fills it to the limit". It follows that the thick black horizon of organic substance cannot form without certain degree of humus mobility.

Now that the behaviour of humus acids is known it is easy to see why the same soils are unlike in different parts of the globe. For instance, black earths in the east of the Soviet Union, where precipitation is scant, abound in humus but have thin layers. And in the west, where precipitation is greater, they form thick Horizon A and have a lower humus content. The same goes for the forest soils. After all, the inability of brown humic acids to move about in the soil mass is one of the reasons why a thin A layer has formed in the earths of the broad-leaved forests and the taiga.

Thus, various humus substances of different colours, compositions and properties come into being in the soils of the steppes and forests. It follows that here, too, the law of zonality remains valid? No doubt in the world of soils it governs the production of everything ranging from complex natural polymers to simple salts, minerals and rocks. But then, this is not blind obedience, but compositions of organic, mineral and organo-mineral substances "thought out" in minute detail and best suited to the environmental conditions. Slightly above the author has discussed the "fourth form" of humus substances - the organic particles with mineral frames discovered by Sideri. Here soil scientists first encountered a stable alliance between "animate" and "inanimate" matter. Now scientists from simple contemplation pass to the chemical analysis of humic acids. Again, amid the endless chains of carbohydrates and ring-shaped nuclei of calcium, iron, aluminium, and silicon are encountered. The inorganic world is always invisibly, and at times very tangibly, present in each creation of nature. It is this "purely earthly basis of photosynthesis" that was meant by Academician Ivan Tyurin when he wrote: "The soils of different types are distinguished from each other not only with regard to their relative (absolute) content of the main groups of humus substances, but also with regard to the forms of their state or the forms of their connection with the soils' mineral part."

Now is the time to recall "calcium Mull" and the predilection of humic acids for this alkaline-earth element. As early as 1965 Academician Tyurin thought it to be a symbol of steppe soil formation and saw in it the reason for the birth of the thick humus horizons in black earths. In the scientist's view, calcium functioned as a regulator of the distribution of black humic acids in the soil profile. Academician Tyurin confirmed this by a simple experiment. Flasks of fresh black humic acid just isolated from the soil were poured over with an alkali solution. In one the jelly-like substance became dissolved without a residue, in the other it remained unchanged. The explanation was that the substance which resisted the alkali action contained calcium and what yielded to it had first been cleaned of this element. Brown humic acids showed an entirely different pattern of behaviour. No matter how much they were saturated with calcium they continued to dissolve in alkaline solutions.

In a quarter of a century Ponomareva and Plotnikova decided to see how such great differences in the properties of "kindred" organic substances influenced the thickness of humus horizons. As said earlier, black humic acids penetrate into the soil mass the more deeply, the greater the local precipitation. But their advance cannot be endless. Otherwise the upper horizons of the black earths would lose the greater part of their organic substances. And, as is known, this does not take place since their way is blocked by calcium ions. If there is little calcium the acids move about unobstructed. But the situation changes when up to 500 milligram-equivalents of calcium fall to the share of each 100 grams of humic acid. Black organic compounds slow down their course. Few of them break through this barrier. When the concentration of calcium ions increases by 50 to 100 per cent the humic acid movement grinds to a complete halt. They precipitate.

Some earths of Western Siberia have two humus horizons. In the upper part they resemble soddy-podzolic soils and in the lower - destroyed remains of black earths eroded by fulvoacids. This leaves the impression that podzol has "saddled" and has been systematically destroying the steppe soil. But experts have every reason to mistrust such an obvious picture. The black earth is destroying too slowly. The humus horizon of the upper, podzolic soil is from 1000 to 2000 years old and that of the lower almost 3000 to 4000 years old. In this period the aggressive fulvoacids not only have failed to cope with the carbonate mass, which lies close to the surface, but have left part of the humus layer of the past epochs. And what if the black humic acids are not a relic, not a leftover of former black earths, but the result of processes currently at work in the soils? Of course, this is difficult to tell, so far. But the scheme proposed by Ponomareva and Plotnikova makes possible a fresh view of this curious experiment of the fourth "kingdom of nature".

The experiment with the brown humic acid proceeded on entirely different lines. The acid stubbornly refused to react with calcium. Only when up to 200 milligram equivalents of this element fell to the share of each 100 grams of the brown polymer did the slimy runny mass begin to emerge from the liquid. It refused to leave part of the solution. The sediment hardly yielded to moisture action filling all the pores of the filter with slime but, amazingly, easily ceded the calcium ions "imposed" on it to the water. The researchers' attempt to operate on brown humic acids with an element alien to them ended in failure. They saw that they had committed an act of violence over nature, because in the natural conditions the sway of brown organic compounds and an abundance of calcium in the soil are incompatible things. That was the exact reason why the use of lime does not rid plough lands of over acidity, but only slightly weakens the acid action. Brown humic acids are far more attached to iron and aluminium oxides. Fusing with them, these organic substances become still less soluble in water than during the experiment.

The study of humus is far from completed. The best studied, so far, are the black humic acids. Much less is known about their brown counterparts and fulvoacids are given inadequate attention. But the worst fate is that of humins, or humic coals. Ordinarily, they are referred to as non-hydrolyzed residue, and there their description ends. Many stories due to which they were allegedly discovered are told about humins. One of these stories - the most authentic - says that it all began with the negligence of a laboratory assistant who worked with Academician Tyurin. Once she misguidedly poured concentrated sulphuric acid into a flask with a waste sample. The solution grew dark. This amazed her. After all, all organic acids had long been removed from the soil. The strange behaviour of this handful of earth interested everyone. But no matter how many times the experiment was repeated the result remained unchanged. Shortly, these phantom acids were known in other laboratories. This touched off something like a competition to find out who would "squeeze out" more from the insoluble residues. They were already called humins. The competition was won by Dmitri Khan, who extracted almost 90 per cent of the content. Humic coals were found to consist of thickly interwoven humic acids and fulvoacids. But their strength also had another reason - connection with minerals!

The Fourth Dimension

At the very beginning of the book soils were described as a function of the climate, organisms and rocks multiplied by time. But, as he recalled time, the fact that representatives of the fourth "kingdom of nature" are natural historical bodies, he has never raised the question as to their age.

This is not a new problem in soil science. Experts have time and again requested archaeologists to help them establish the birth date of some specific horizon or of a soil as a whole. And when it was found possible to discover a crock or some Stone Age tool in a pit the problem found a simple solution. They carried little information about their real age. Accurate metric data could be reported only by a clock wound and set running at the soil's birth. But who can make similar observations for centuries and even millennia? But then, this was needless. In producing each creation, it always provides it with a clock. Trees have annual rings and the soil has humus. The point is that it accumulates not only carbon compounds, but also its isotopes ^{14}C. However, for a long time this fact remained unknown.

It all began with gas-diffusion technique of uranium isotope division where young chemist Willard F. Libby took part in the working out of this technique. Later Libby left research in this field and went in for "abstract research" connected with radioactive carbon. Why did he develop an interest in isotope ^{14}C? In those days the scientist himself hardly had a clear answer to this question. In two years Libby announced to the entire world that he had discovered a method of determining the age of organic tissues.

The essence of his method was as follows. It is on record that the Earth's atmosphere is exposed to a prolonged action of cosmic rays. They are the chief culprits of the formation of the neutrons which enter into a reaction with the atoms of atmospheric nitrogen. As a result, there arises a certain amount of isotope ^{14}C. Mixing with carbon dioxide, it reaches the Earth's surface.

The plants absorb tagged gas in the process of photosynthesis. Subsequently, along the familiar food chain it gets into the earth. As well as into animals and people. It all would have been of narrowly specialist interest if ^{14}C had not been radioactive. Furthermore, this radioactivity can be measured. After all, similar substances decompose with a certain speed. Hence, after a period which is easy to calculate the radioactivity of the material which has accumulated ^{14}C should decrease two-fold. Another equal stretch of time, and the amount of the isotope will diminish by one-quarter of the initial, etc. This is known as half-life. In the case of ^{14}C it is equal to 5730 years.

The level of absorption of ^{14}C by plants remains constant during their lifetime and its amount remains invariable due to fresh intake. At the moment of death disintegration begins, whose degree can be established by using a special instrument. Thus, it is easy to find out the time which passed since the death of any living being. But humus does not die? It doesn't. But it does not have an ability for photosynthesis either and receives hardly any isotope ^{14}C except for with plant remains, and is their product itself. There is no finding a better material. But it will be discussed later. Now about the method itself. Libby's main task was to evolve hypersensitive methods of measurement. After all, all objects he studied had negligible radiation. He did not care much for the choice of test materials, basing his speculations on the simplest facts. According to his theoretical estimates, a tree cut 5730 years ago was to cause half as many clicks in the device as a freshly cut one. Experience confirmed that this assumption was predominantly correct. It took Libby very little time to construct accurate and even super accurate devices.

The first fruits of his efforts were used by students of antiquity - archaeologists. To them the method of direct dating of objects salvaged in earth was simply a godsend. Dr. Libby's room soon became filled with unorthodox objects such as fragments of Egyptian mummies, charcoal from a fire at which man's distant ancestors had warmed themselves, tusks of a mammoth, sandals of American Indians, planks from burial mounds, rafters of ancient temples and other exotica.

Regrettably, the Geiger counter does not react to an object brought up to it. The radiation energy of ^{14}C is too weak. Furthermore, its readings can be influenced by other radioactive substances, of which the present-day world has an abundance.

The first thing that has to be done is to isolate pure carbon from the object under research. Amazingly, it is an absolutely simple procedure: the object is burned. During the combustion carbon first passes into gas, then back again into a solid substance. Libby immediately calculated that the analyses required at least 65 grams of wood and 200 grams of peat and that the amount of soils depended on how much organic substance it contained. For instance, black earth, which has accumulated ten per cent of humus, would require up to three kilograms.

The very first trials brought forth a host of funny episodes. For instance, young trees which grew near highways, when tested, showed that they were several hundred years old. That was a glaring absurdity. Was the method erroneous? Not a bit. This was due to the waste gases of motor vehicles and factories which annually eject colossal amounts of carbon into the air. It increases the already existing level. As a result, the proportion of radioactive isotope ^{14}C drops. And the decrease of this quota in organic matter increases the latter's age. Reverse phenomena occurred as well. But this time Libby's ex-colleagues were to blame. Nuclear weapon tests sharply raised the total radioactivity of the environment and spurred the "rejuvenation" of objects of the hoary past.

In 1960 Libby won the Nobel Prize in chemistry the only scientist to earn such a high award. The first to use it were archaeologists. But they also became the first critics. After all, the error of age determination was from five to ten per cent. For an expert in the history of Ancient Rome or Greece it would equal from 100 to 250 years,which made it entirely unacceptable. But for a soil scientist, a biogeocenologist, a geographer, who studies the Earth's post-glacial period, such accuracy is not necessary. But they lingered before they used the discovery of this American scientist for their needs. Already in the early 1950s it was adopted by archaeologists, several years later by geologists, and only in 1958 did the first publications about the determination of the absolute age of soils made in the laboratory of the Dutch town Groningen make their appearance. Ideal conditions were chosen for these early experiments. After all, this little town could boast the world's biggest soil museum. It has on display thousands of representatives of the fourth "kingdom of nature", and their collection continues to grow. True, research here began from samples of fossil soils. It was believed that modern representatives of the said "kingdom" had a host of all possible admixtures and that the dates would be inexact. But the experts' misgivings were found to be unjustified. Nevertheless, their caution benefited them. The reader already knows that buried earths soon lose fulvoacids. That was why all the scientists could do was to exploit their humic counterparts and humic coals. Furthermore, the properties of humic acids are better studied. According to de Weers's data, those of them which have "fused together" with minerals can lie unchanged for 30, if not for 40 thousand years. All they will lose in this period will be isotope ^{14}C.

In 1972 the Institute of Geography of the USSR Academy of Sciences opened the first Soviet laboratory of radiocarbon dating of soils. But it did not arise on a bare ground: by then determination of the age of soils in the USSR had already been decades old. By now, several thick catalogues which register the birth dates of many earths from various parts of Siberia, the Soviet Far East and the Russian Plain have been compiled. These are not only buried soils, but also normal representatives of the fourth "kingdom of nature". Soviet experts have rejected the discrimination with respect to fulvoacids and established their age. They were found to be twice as young as humic acids.

When one handles modern soils one has to know everything about them. Incidentally, it was discovered that carbon ejected by factories, plants and motor-vehicles barely ever makes the soil grow old. The determination is impeded, in the main, by fresh precipitation. It is a serious impediment. If a sample is not cleaned of the roots or other fresh intake the soil will take advantage of the researcher's negligence and show that it is 500 to 600 years younger. Ordinarily, to avoid such inaccuracies, scientists search for the horizon and the soil in which some evidence would survive - a witness of their birth - a bone, a remainder of wood or a piece of coal. Such dual control makes it easy to avoid mistakes.

Once soil scientists, just as archaeologists, developed a conflict with the US war department. In the early 1960s Canadian scientists were the first to establish the age of modern soils in Saskatchewan. The results frequently amazed the researchers. The soils were found to be extremely "young" in the top layer down to a depth of three centimetres. It turned out that this top horizon was suddenly born 600 to 800 years after the rest of the soil mass. The Canadians quickly detected the culprits. Since 1962 Canada's southern neighbour had been hard at work testing hydrogen bombs. The Saskatchewan black earths appropriately registered these tests. The scientists announced their discovery in Bucharest. But here they were surprised to learn that they had rivals in France and Holland, who had also discovered in their soils traces of ^{14}C imported from across the ocean. The Dutch did not immediately believe in the bomb effect of rejuvenation. They added charged earth to a sample taken from a pit in 1881. And the "venerable old man" lied at the next test by knocking 700 years off its age.

Now the radiocarbon dating has helped in conducting investigation among 4000000 soils from different countries of world. Black earths and chestnut soils were found to be the oldest. Their age at the top horizon was identified as equaling from 600 to 700 to two to three thousand years. Naturally, it grows with the depth. And in Horizon B it reaches 7000 years. Podzols were found to be younger. They are not more than 800 years old. And under the ice of the permafrost zone there are humus horizons long-living soils nine to eleven thousand years old.

In recent years the method itself has been noticeably perfected. No one uses coals any longer, as in the Libby times. Now they are only a raw material, a semi-finished product which is first fused with lithium. Then, on obtaining acetylene from lithium carbide, scientists begin the main operation - the manufacture of benzene, the material to be tested.

However young the radioactive dating of soils by isotope ^{14}C, it is already being replaced by new methods of determining the age of the fertile layer and its underlying rocks. These are the potassium-argon, paleomagnetic, neutron-activation and other methods whereby. By means of these methods the date of earth's layers birth are possible to determine. True, they have not gained dissemination in soil science, so far. But they already evoke an intense interest in archaeologists and geologists. Possibly, the history will repeat itself ....

An Unfinished Conversation

(in lieu of an afterword)

Man has been studying the fertile layer for 10000 years. And in each historical epoch the soil presents itself to him in new garb. First, it was simply black earth, Ta Kemet, an object of envy, an occasion for war. Centuries passed, and it was not only the loot of a fortunate conqueror, but an object of close attention of philosophers and one of the sources of world creation. Further, the "grain-producing layer" became a political and economic notion. The richer it is, the more powerful the state. It is not an accident that Russia's power and wealth "for centuries became augmented by the fruits of Siberian land", as Lomonosov put it. But in the wake of the flight and boom resulting from the discovery of the extremely fertile steppe lands comes their neglect. The fertile layer, when it fails to live up to the expectations, becomes forgotten by economists, and politicians lose interest in it. Only a handful of fogey scientists continue their search. They want to discover the laws governing soil life. It is precisely this "fall" that disclosed soil's real greatness and value for man. Changing a host of "masters", soil trusted its secrets to "experimental science", which saw in it not only a "grain producing layer" or "noble rust", but an amazing complex mechanism - the fourth "kingdom of nature".

Losing old and gaining new masters, the soil, far from losing its multifaceted character, on the contrary, has shown to man its entirely new properties. The reader already knows them. The soil is a link which connects the world of minerals and plants, animate and inanimate nature. It is the home of worms, insects and microbes, a complex aggregate which accumulates and processes solar energy. Finally, it is a complex system which has length, width and thickness. A body which comes into being, develops and at times dies in catastrophes or due to human bungling. A body whose age can be measured.

But however hard the author tries to tell about all the peripeties of the birth of soil science, its designation in the life of society and the multiform properties of the fertile layer, it cannot be done in one book.

The author regretfully has to note that the only guide to the past of this science to him: was the book of Igor Krupennikov, *The History of Soil Science*. Still more amazingly, soil science today is not listed among the fundamental sciences! And for the same reason its formation and development are not studied by the historians of science ....

The study of the fertile layer is an entirely different matter. The abundance of publications created the same difficulties as their shortage. This is why, here, too, the author decided to give preference to the least known aspects of soil science, to look at the fertile layer as a complex enterprise "manufacturing" extremely necessary products for life. But the discussion of the "storages of the biosphere" cannot be regarded as completed and dot one's "i's" and cross one's "t's" is still early.