CHAPTER 2

Geological Factors

ENVIRONMENT OF LIFE, NATURAL ENVIRONMENT, AND GEOLOGICAL ENVIRONMENT

The level of public health is formed under the influence of an enormous number of factors, internal and external. External factors include natural conditions, the type of economic activity, cultural and sanitary - hygienic habits of the population, the level of medical science and nature of medical protection available, the existence of natural settings for disease and harmful substances of technogenic origin, etc. The whole aggregation of external factors in relation to organisms is defined as the **environment of life.**

There are two important components of this environment:

- Parts of the planet Earth on which real conditions exist for maintenance of life in any form;
- Natural conditions that can ert influence on the living world.

For this reason, the term **natural environment (geospace** - the space inhabited by man[4]) is used in the narrower sense.

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[4] Russian naturalists use the term landscape, by which they mean the entire complex of natural conditions on a certain sector of the Earth's surface (the outward appearance of a locality, in addition to characteristics of climate, soil, vegetation, and groundwater) and other superficially unapparent characteristics of nature that play an important role in processes on the Earth (Fig. 1.1). This concept encompasses the great, complex, and unbalanced dynamic system of the Earth's surface, where elements of the lithosphere, hydrosphere, and atmosphere interact and intermingle with each other. Foundations of the science of landscape were laid at the end of the 19th Century by V. V. Dokuchaev in his well-known work "**The Study of Natural Zones**" (1948).

In simplified terms, the natural environment at the level of human life and productive activity is taken to mean the structurally complex system made up of the following five components: *atmosphere, hydrosphere, lithosphere, animal life*, and *plant life*. These components of the natural environment are closely interrelated and in constant interaction with each other to form a single whole material system. Any interference with this natural system created by human engineering activity always disturbs its dynamic equilibrium and gives rise to *technogenic processes* that negatively or positively affect changes in characteristics of the natural environment.

Three planetary functions of the natural environment (biosphere) play a special role in the life of man and his environment. They are: 1) *biological productivity*, which provides all forms of life with food products; 2) *maintenance of the optimal regime and balance of the Earth's aqueous envelope and gas composition of the atmosphere;* and 3) *natural biological self - purification.*

More precisely considered, the natural environment is made up of numerous components, including air, natural waters, soil, and rocks in the substrate, characteristics of relief, vegetation, and animal life. Taken altogether and in various combinations or individually, the given components ert positive or negative influence on human life. Except in the case of certain fundamental investigations, study of the influence of elements of the natural environment on public health is possible only inside certain territorial boundaries around areas where that influence is relatively equal. Moreover, classification of components (factors) of the natural environment creates conditions for their evaluation, as well as for their insertion into some comprehensive model of a medico - geographical (medico - geological) territorial system.

Components (factors) of the natural environment can be classified from various aspects. In the book "**Handbook of Medical Geography**" (1993), the following divisions of components are given:

- *On the basis of periodicity of influence on vital human activities*: 1) Constantly active (reduced air pressure in mountains, high solar radiation in the equatorial zone, etc.); 2) cyclic (seasonal circulation of the agents of certain infectious diseases, low winter air temperatures in nontropical latitudes, flooding of rivers, etc.); 3) acyclic (earthquakes, volcanic activity, rock and mud slides, landslips, etc.);
- *On the basis of preventability of negative influence on vital human activities*: 1) Preventable (for example, adverse effects of life in regions with a harsh cold climate); 2) harder to prevent (rock and mud slides, spring flooding); 3) unpreventable (earthquakes, volcanic eruptions, tsunamis);
- *On the basis of activity in relation to other components of the environment with resultant strengthening or weakening of influence on vital human*

activities: 1) Active (for example, strong wind at low air temperatures); 2) little active; 3) inert;

- *On the basis of mutual influence*: 1) Synergistic (for example, calm weather strengthens the influence of toxic substances on man); 2) antagonistic (for example, soil with a high capacity for self - purification disinfects impurities containing pathogenic microorganisms).

The term of special interest to us - the **geological environment** - is of relatively more recent origin. It refers to the upper layer of the lithosphere as an integral component of the environment of life. The part of the given environment accessible to human activity is made up of the following five components: solid rocks, loose soil, groundwater, natural gases, and microorganisms. All of these components interact with each other to create (under natural and disturbed conditions) a dynamic equilibrium. The surface (relief) of the Earth's crust can be taken as *the upper boundary of the geological environment*. Here it interacts with such components of the natural environment (or environment of life) as the atmosphere and the hydrosphere. This interaction is determined by a complex of constantly transpiring natural processes such as the following: penetration of solar heat into the upper layer of the Earth's crust; global circulation of moisture; hydraulic linkage of surface and groundwater; infiltration of atmospheric precipitation; reciprocal influence between rocks and moisture in the zone of aeration (the zone above groundwater) and in the zone of complete saturation; evacuation of groundwater on the surface; penetration of natural gases (oxygen, carbon dioxide, etc.) into the upper layer of the atmosphere; and geochemical processes in the system composed of *rocks, groundwater, natural gases, and microorganisms*. The indicated processes and other global processes of interaction between the outer spheres of the Earth's crust play a decisive role in formation of the structure of the geological environment, the characteristics of this environment, and its ecological quality.

The lower boundary of the geological environment apparently can be drawn to some extent arbitrarily, depending on the level of modern scientific - technological progress. That boundary today is for the most part determined by the depth of mined mineral deposits (to 4,000 m) or the depth of deep oil and gas boreholes (to 9,200 m)[5]. Whereas diverse processes resulting from interaction of the atmosphere, hydrosphere, and biosphere transpire actively at the upper boundary of the geological environment, global influence of endogenous processes caused by interior

[5] The deepest test borehole in the world (more than 11,000 m) was drilled on the Kola Peninsula (Russia).

temperature, pressure, and gases is erted on the geological environment itself at the lower boundary.

The part of the geological environment most interesting to study is naturally that part in which active forms of life occur and where human productive endeavors are enacted. That part of the geological environment plays a fundamental part in the vital activity of man. Concentrated in it is the main biomass of the Earth, the soil layer, all forms of mineral resources (including oil and gas reserves), various types of groundwater, rocks as building materials, etc. As a result of the engineering activity of man, anthropogenic (technogenic) processes are constantly transpiring in the given part of the geological environment, and their negative or positive influence causes changes in its state and properties.

BASIC FEATURES OF THE GEOLOGICAL ENVIRONMENT

In their major work "**Geology: The Science of the Changing Earth**" (1980), I. S. Allison and D. F. Palmer distinguish the following spheres of the Earth: 1) the *magnetosphere* - a geomagnetic field of great expanse; 2) the *atmosphere* - the gaseous envelope of the Earth; 3) the *hydrosphere* - the aqueous envelope of the solid Earth; 4) the *biosphere* - the envelope within which life unfolds; and 5) the *geosphere* - the solid sphere of the Earth, which is the main subject of the work of geologists. The geosphere is made up of three main parts that differ in their properties: a) the *lithosphere* or *Earth's crust* - the thin solid outer shell; b) the *asthenosphere* - the inner shell; and c) the *Earth's core*.

At depths of 35 - 70 km on the continents, the velocity of spreading of seismic waves increases abruptly from 6.5 - 7 to 8 km/s. Changes in both elementary and mineral composition and materials are presumed to occur at such depths. The given lower boundary of the lithosphere (Earth's crust) was discovered by A. Mohorovicic, after whom it was named. The lithosphere has its greatest thickness (up to 70 km) under mountain massifs and is thinnest (5 - 15 km) at the bottom of the oceans. On the territory of Yugoslavia, thickness of the Earth's solid crust varies between 22.5 km (the Pannonian Basin) and 50 km (the Dinarides of Montenegro).

Until relatively recently, it was considered that the lithosphere does not represent a homogeneous sphere, but is multi - layered instead. Thus, the following three main parts within the continental crust (the part of the lithosphere in the region of continents) are most often singled out:

1. The outer part or *stratosphere*, predominantly constructed of sedimentary rocks of Mesozoic, Tertiary, and Quaternary age, which occur on the surface of terrains and extend to a depth of the order of 12 km;

2. The middle part or *granitic layer* predominantly composed of acidic magmatic rocks (granites, granodiorites, etc.);
3. The lower part or *basaltic layer* composed predominantly of basalts.

The oceanic crust, on the other hand, is mainly constructed of rocks having a basaltic composition.

According to the theory of *new global tectonics*, the lithosphere is composed of six large and several small separated great tectonic plates[6]. These plates are subject to movement, approaching the others or moving away from them (Fig. 2.1). As we shall see later, processes transpiring in the lithosphere (including the greatest part of the asthenosphere) affect the disposal and relief of continents and ocean basins.

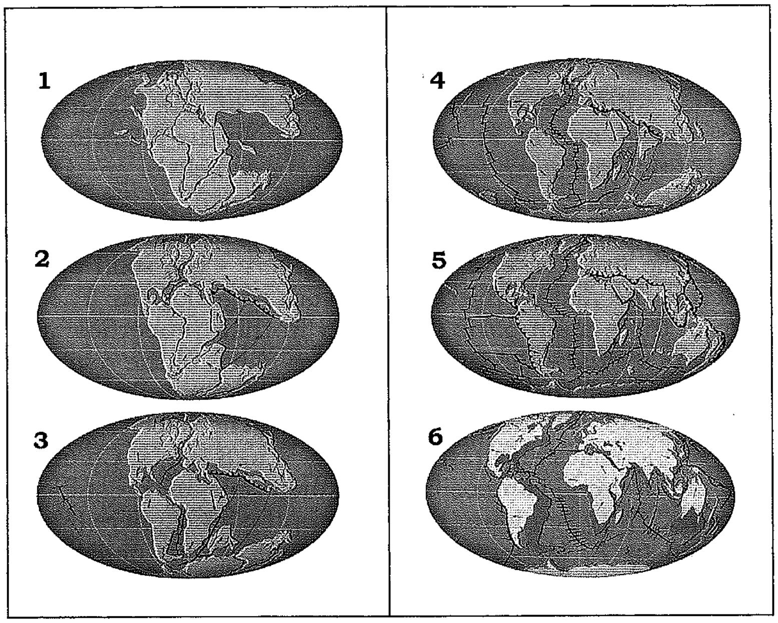

Fig. 2.1. Movement of continents from Pangaea period to nowadays.

In the course of the Earth's geological history, enormous expanses of the lithosphere were subjected to high pressures and temperatures arising as a result of reiterated processes of mountain massif formation. Under such harsh conditions, often accompanied by chemical reactions, magmatic and sedimentary rocks passed over into a new class - the class of

[6] Hence the expression "theory of plate tectonics".

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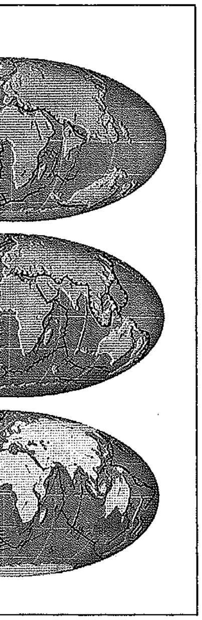

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metamorphic rocks. Thus, the lithosphere today is built of these three main classes of rocks, together with the loose cover formed by their decomposition.

The lithosphere, and especially the part of it called the geological environment, is under the influence of endlessly diverse processes. It is therefore characterized by properties variable in both space and time. Not only are we witness to the changes taking place before our eyes today, but we also have at our disposal the results of changes that occurred hundreds of millions of years ago. The more important among them are:

- *Crystallization of minerals;*
- *Formation, alteration, and decomposition of rocks; soil formation;*
- *Volcanic activity and other forms of magmatism;*
- *Processes of metamorphism;*
- *Deformation of rocks in the process of wrinkling and fault formation; recent tectonic movements;*
- *Movement of tectonic plates;*
- *Consequences of earthquakes;*
- *Formation of deposits of various mineral resources;*
- *Radioactive decay of elements;*
- *Geochemical and hydrogeochemical processes;*
- *Heat currents; magnetic field changes;*
- *Exogenous geological processes;*
- *Biogenic nonanthropogenic changes; and*
- *Anthropogenic geological processes.*

They are all the subject of geology, the science of the eternally changing Earth. These processes and their effects on the geological environment or environment of life will be treated in the corresponding chapters of the book.

Useful properties of the geological environment are of two main categories, namely ones inherent in the geological environment in the narrow sense or *geological ambient* and properties associated with *geological wealth*. The *geological ambient* is utilized by the whole living world, and its useful properties, according to M. Babovic (1992), are manifested in the following: a) the esthetic and sensual ambient; b) shelters and obstacles; and c) the fertile (pedological) ambient. *Geological wealth* refers to that part of the geological environment with its useful properties that can be separated, transported, and then utilized, whether in unmodified form or after certain transformations. The concept of geological wealth includes not only mineral raw materials, but also other mineral substances that are utilized without additional processing. Like the geological environment, geological wealth is characterized by variability of properties in space and time. According to M. Babovic (1992), geological wealth (solid mineral raw materials, energy raw materials, geological building materials) can be classified from the standpoint of application in the following way[7]:

1. ***geological wealth used for food, medicaments, agrotechnic purposes, and hygiene:***
   - *Substances that are consumed (in nutrition and treatment of man and animals);*
   - *Substances that are applied to the body in balneology (medicinal mud, etc.);*
   - *Substances used in agrotechnology;*
   - *Substances used for maintenance of hygiene.*
2. ***geological energy potentials:***
   - *Fossil fuels;*
   - *Nuclear mineral raw materials;*
   - *Pyrotechnical mineral raw materials;*
   - *Geothermal and geoelectric potentials.*
3. ***geological wealth in the guise of useful objects or raw material for their manufacture:***
   - *Rocks as primitive tools or weapons;*
   - *Rocks and minerals as cult objects and decorative elements;*
   - *Materials used in the construction industry;*
   - *Materials used in the manufacture and operation of machines, apparatuses, devices, and installations;*
   - *Mineral substances used in production of chemicals;*
   - *Mineral substances used as technological additives or processors;*
   - *Mineral raw materials used to obtain metals.*

This is a noticeably abridged form of the table given in the book "**Geology and Environment Protection**" (M. Babovic, 1992). Nevertheless, it is sufficient for us to conclude that the economy and indeed human existence itself is almost completely dependent on geological resources. Moreover, the exhaustibility of geological wealth is becoming more and more evident and already now represents one of the leading global problems facing man today.

The list of **harmful substances in the geological environment** for the most part consists of medium - heavy and heavy elements of Mendeleyev periodic system, some of which are strongly toxic or radioactive. The cycles of movement of heavy and harmful elements through the geological environment and through the hydrosphere are associated with inorganic substances, stabilization of such substances,

[7] The author did not include mineral and thermal waters and gases that are bottled (table mineral waters) or ones used for balneological purposes. Moreover, slightly mineralized groundwaters are utilized for drinking as a primary factor in maintenance of life on the Planet.

and their ability to become incorporated into crystal lattices or be liberated in the course of degradation of the inorganic matrix.

Pollutants originating from the geological environment (inorganic agents) are mainly indestructible, and special attention must therefore be paid to them. This is indicated by experience gained in human exploitation of certain inorganic mined forms of geological wealth (coal, oil, and gas, for example). As stressed by D. S. Veselinovic et al. (1995), it is unusually important to bear in mind the fact that all processes transpiring in the course of contamination by materials from the lithosphere are for the most part physico - chemical. The essence of pollution - whether it is from direct geological sources or from deposits of inorganic waste - is predominantly identical for both kinds of pollution. If the physico - chemical regularities governing processes of pollution with inorganic materials in the Earth are known, then those operative on the Earth are known as well. *In all of this, it is essential to have as complete as possible knowledge about the geological environment and its behavior, both in the process of pollution and in carrying out measures for its protection.*

For a long time, the relations of deeper parts of the lithosphere with the biosphere were interpreted as being one - way. It was held that magmatism and metamorphism - through the composition of their products (rocks), volcanic exhalations, rock folding, mountain formation, and other endogenous processes - ert considerable influence on weathering, rock formation, groundwater activity, and other exogenous processes and phenomena. The reverse influence - influence of external processes on endogenous ones - was not taken into account. However, the available data, especially material accumulated in the last quarter century, indicate unambiguously that the relations in question are two - way rather than one - way. For example, processes transpiring in the biosphere affect the composition of hydrothermal solutions, magmatism, etc. We note also the role played by vadose waters in feeding hydrothermal ones, gas breathing of the lithosphere, and sedimentary formation of sulfur. For all of these reasons, it is possible to speak of *unity of the lithosphere as a complex dynamic system with feedback relations that also include the biosphere* (A. I. Perelman, 1979). As Perelman wrote in the conclusion to his work "**Geochemistry**" (1979): "*Continuous arrival of solar energy and deep - seated energy of the Earth determines development of the tectonosphere and biosphere in a certain direction, increasing their complexity, diversity, and imbalance, while causing accumulation of free energy and reducing entropy.*" Vernadskii's remarks on unity of the lithosphere have already been cited.

The geological environment, like the environment as a whole, possesses *ecological properties.* Ecological properties are determined by a series of factors that can favorably or unfavorably affect development of the contemporaneous biosphere. Plant and animal life, microorganisms, and human life and activity develop differently in the upper layers of the geological environment in different climatic zones of the Earth. In connection with this, three types of regionally occurring natural geological environments can be singled out: arid, humid, and cryolithogenic (N. I. Plotnikov, 1989).

The geological environment possesses definite *physical, hydrogeological, engineering - related, geological, and biological properties*. The following can be considered fundamental general properties of the geological environment:

1. Variability of the environment in space and time;
2. Heterogeneity of the environment, which in the hydrogeological sense is manifested in the form of unequal filtration properties of different rocks;
3. Adaptive capacity, i.e., ability of the environment to change under new or disturbed natural conditions;
4. Discreteness of the geological environment, which is manifested in the guise of rock properties such as crack formation, karstification, etc.

The given properties of the geological environment can be altered in either a negative or a positive direction under the influence of anthropogenic processes.

By transforming nature, primarily through projects of waterpower engineering, man strives to improve ecological properties of the geological environment. Desert and steppe regions of arid zones are transformed into fertile oases under the influence of irrigation and drainage, plants are sprinkled in farming, new cities and settlements are built under favorable ecological conditions, etc.

CHARACTERISTICS OF GEOLOGICAL FACTORS AND THEIR INFLUENCE ON HUMAN HEALTH

In the multi - volume manual "**The Ecology of Human Disease**" published in 1958 by the American Geographic Society, J. May in the second chapter entitled "Stimuli" ("Etiological Factors") distinguishes *inorganic factors* (stimuli), *organic factors* (stimuli), and *social and cultural stimuli*. According to May, a disease can arise only where factors of two kinds coincide at a certain point in time and space: *first of all*, factors that take the form of an environmental stimulus (for example, poison in food); and *secondly*, factors that provoke a reaction of tissue in response.

In the category of *inorganic stimuli*, May includes heat, humidity, the regimes of wind and light, and trace elements in soil, food, and water. Other factors such as radiation, magnetic fields, cosmic rays, and static electricity must be considered important, but their action, according to May, has been inadequately studied.

Climatic and inorganic factors affect human health in two ways: directly and indirectly. Little is known about direct action because indirect action is incomparably more prevalent, a fact that befogs the picture of direct action.

Following Vernadskii (1965), Allison and Palmer (1980), and Perelman (1979) - whose outlooks on the Earth's spheres and their unity are presented above - we can relegate practically all natural factors to the category of geological in the broader sense. Similar thoughts were expressed by A. D. Howard and I. Remson (1978), who wrote as follows (among other things) in the Preface to their book "**Geology in Environmental Planning**": "*The geological environment refers to relief, soil and other loose materials, and basic rocks and soil substrates. That concept also includes natural processes that visibly alter the natural environment (landscape) and auxiliary factors which affect the development of these processes, for instance vegetation or the presence for many years of an ice cover.*"

However, we hold *factors of the geological environment* in the narrower sense to include only things that are predominantly the subject of geological research. Among them are: *minerals, rocks, geological formations, soil, geomorphologic factors, tectonic activity and structural forms, geophysical fields, thermal fields, geochemical fields, endogenous geological processes (earthquakes, volcanic activity), exogenous geological processes and phenomena, groundwater (unmineralized, mineral, and thermal), mineral raw materials and ranges of their distribution, radioactive elements and radioactivity, and macro - and microelements in rocks, soil, and water.* The influence of these factors on human health (geochemical risks, hydrogeochemical risks, and geomedical risks) is also considered. Owing to its geological predisposition and interconnection with geological factors, material that has traditionally been the subject matter of other sciences and scientific disciplines - meteorology, hydrology, and biology - will be treated in the next chapter. This refers to climatic, hydrological, and biological factors.

In broader terms, it can be stated that geological composition of the Earth has been studied on different levels: from the level of very small units (chemical elements and their components) to that of very large units (continental massifs and tectonic plates, all the way up to the planet as a whole). Between these extremes, geologists distinguish two important groups of formations - *minerals and rocks* - also counting here *geological formations* such as paragenetic associations of rocks. We shall devote longer attention to these components as basic structural elements of the geological environment.

Minerals

Minerals represent separate solid natural inorganic particles of crystalline structure. Almost all rocks are composed of them (Fig. 2.2). Several different minerals can be present in many types of rocks, but rocks can also be formed entirely of a single mineral, for example limestone or marble from the mineral calcite. The significance of minerals is twofold: first, they enable rocks to be classified; and *second*, they indicate the conditions of rock formation.

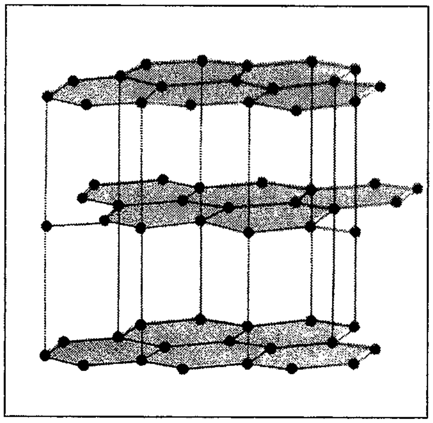

Fig. 2.2. Crystal grid of graphite.

Either a single element or a regular combination of elements can enter the composition of minerals. It has characteristic physical properties. Minerals of artificial or organic origin are excluded here, with the reservation that opal, a series of clay minerals, and some hydroxides that have a crystalline structure are exceptions.

Since more than 98% of mass of the Earth's crust is composed of only eight elements, the number of main rock - forming minerals is not great, regardless of the large number of possible combinations of chemical elements available for mineral formation. Some elements such as gold, silver, copper, sulfur, platinum, and carbon as graphite and diamonds can occur in pure form, but the majority are found in the guise of chemical compounds. Because the content of oxygen in the Earth's crust is about 47% by weight, chemical compounds of this element with other elements are common. Silicon and aluminum, which occupy second and third place, account for the formation of silicate minerals. Silicates are compounds of silicon and oxygen with other elements such as aluminum, sodium, potassium, iron, and manganese. They form the largest group of minerals, as can be seen from Table 2.1. Other mineral compounds include carbonates (salts of carbonic acid), sulfides (sulfur compounds), sulfates (salts of hydrochloric acid), chlorides, phosphates, hydroxides, nitrates, and borates.

The atomic structure of hundreds of minerals is known today. With rare exceptions, atoms or groups of atoms arrange themselves in orderly fashion to assume a regular disposition in conformity with the many mathematically possible modes of spatial grouping (Fig. 2.2.). The property known as the crystalline structure of a mineral is its most characteristic feature. The crystalline structure affects form of the crystal itself, how the mineral breaks up during destruction (weathering), hardness, specific conductivity, and many other physical properties. In general, the crystalline structure dictates the physical properties of a mineral.

Isomorphic mixtures represent an exception to the rule of structural stability established for the majority of minerals. Such mixtures are formed when some common components of minerals are partially replaced by certain chemical elements capable of taking their place. For example, iron can replace part of the zinc in the mineral sphalerite (zinc sulfide - a basic zinc ore).

Isomorphic compounds of silicate minerals - plagioclase, olivine, amphibole, and pyrone - are of the greatest significance. Plagioclases form a continuous series of minerals, from sodium albite ($NaAlSi_3O_8$) to anorthites with high calcium content ($CaAl_2Si_2O_8$), including albite, oligoclase, andesine, labradorite, bytownite, and anorthite.

The majority of minerals arise from several kinds of solutions. They are formed as a result of many processes: 1) cooling of magma (in the interior of the Earth) or lava (on the Earth's surface); 2) separation from deep - lying solutions containing hot water or hot gases (including water vapor), as is the case with many mineral veins and metal ores; 3) condensation of hot vapors during formation of minerals of the sublimation sulfur type near the openings of volcanoes; 4) chemical reactions with already existing minerals, for example during hydrothermal transformations of feldspar into mica or during oxidation of iron - containing minerals in the zone of chemical decomposition at the Earth's surface; 5) replacement of one primary mineral by another; 6) recrystallization of primary minerals with formation of new compounds under the influence of variable conditions of temperature and pressure; 7) evaporation of aqueous solutions.

A fact of special interest to us is that the number of minerals readily soluble in water (halite for instance) is small; most of the rest are either poorly soluble or completely insoluble. The mineral calcite dissolves with separation of carbon dioxide bubbles in dilute hydrochloric acid.

On the basis of stability in relation to chemical decomposition, it is possible to single out the following four groups of minerals:

1. *Very stable*: quartz, topaz, tourmaline, rutile; platinum, gold, zircon, corundum, etc.;

2. *Stable*: muscovite, orthoclase, microcline, acidic plagioclases; hematite, magnetite; disthene, barite, monazite, etc. (Fig 2.3.);
3. *Poorly stable*: amphibolites, pyrone; wolframite, celite, apatite, actinolite; epidote, etc.;
4. *Unstable*: basic plagioclases, feldspathoids, alkaline amphiboles, biotite, augite, olivine, glauconite, calcite, dolomite, gypsum; pyrrhotine, sphalerite, chalcopyrite, arsenopyrite, pyrite.

Chemical decomposition of rocks occurs in connection with many chemical reactions: hydrolysis, hydration, cation exchange, formation of comples, and simple chemical dissolution. Feldspars disintegrate mainly as a result of hydrolysis. Silicates with iron and most sulfide minerals oxidize fairly readily.

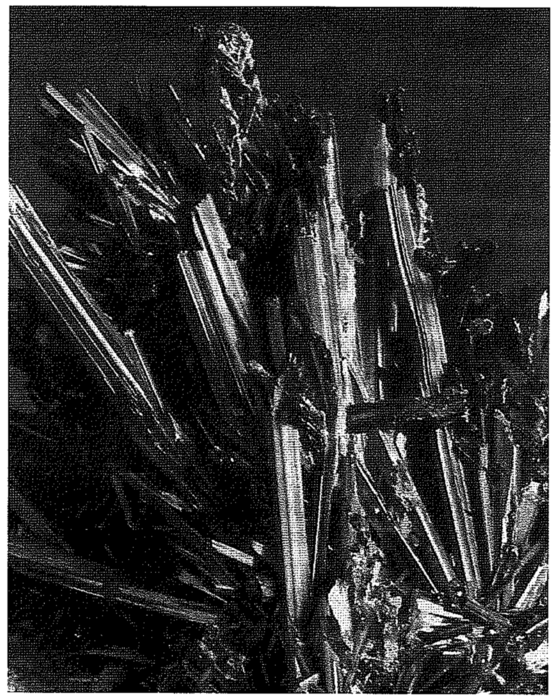

Fig 2.3. Antimonite from the Zajaca mine, Western Serbia.

The picture of mineral stability in relation to chemical decomposition is deceiving at first glance. To be specific, *poorly stable and unstable rocks are constituents of very widespread kinds of rocks and in large measure dictate the macro - and microcomponent composition of the soil. The effects of macro - and microcomponents on human health will be discussed at a later time.*

TABLE 2.1.
The most widespread silicate mineral of rocks.

Non - ferromagnesium (sialic) bright	Content
Quartz	SiO_2
Plagioclase	$NaAlSi_3O_8$ - $CaAl_2Si_2O_8$
Orthoclase	$KAlSi_3O_8$
Microcline	$KAlSi_3O_8$
Muscovite	$KAl_3Si_3O_{10}(OH)_2$
Ferromagnesium (maphite) dark or green	
Orthopyrone (hypersthene)	$(Mg, Fe) SiO_3$
Clinopyrone (augite)	$Ca(Mg, Fe)Si_2O_6$
Amphibole	$Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2$
Biotite	$K(Mg, Fe)_3AlSi_3O_{10}(OH)$
Olivine	$(Mg, Fe)_2SiO_4$

Rocks

Rocks are mineral aggregates that have definite composition, both mineral and chemical, and definite structural features. They are geological bodies, constituents of the Earth's crust. The term **rock** is used in petrography for all natural formations of a certain composition and structure, without reference to hardness and cohesiveness of materials. In the category of rocks, we include compact, hard formations (natural stone); plastic, sometimes semi - fluid aggregates; and unbound loose materials (sand, gravel, volcanic ash). In contrast to rocks, mineral deposits are restricted in extent and characterized by accumulation of certain elements of subordinate significance in structure of the Earth's crust.

The few minerals that determine their characteristics and represent crucial components of rocks are called *petrogenic minerals*. The most important petrogenic minerals belong to the silicate, carbonate, and oxide groups.

The oldest known rocks of the continental crust of the Earth are 3.9 billion years old (Antarctic), which is less than the age of some meteorites and certain moon rocks (4.7 billion years)[8]. It is important to stress that most rocks older than approximately 20 million years belong to the class of hard (rock) formations, whereas younger rocks are predominantly semi - bound and unbound (loose).

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[8] The presence of detritic zircon in some archaic rocks indicates that there existed on the Earth an older continental crust, which probably has not been preserved.

All chemical elements known in nature are present in hard rocks, but the chemical compounds and minerals in which they occur are different, depending on the basic groups of rocks. Most of the minerals of magmatic rocks, for example, are noticeably altered during processes of chemical decomposition, so that sedimentary rocks formed from their fragments differ in composition from the primary magmatic rocks. The minerals of sedimentary rocks can in turn be transformed into new minerals if they reach depths where they are exposed to the influence of high temperatures, pressures, and mineralized solutions. In the process of these changes, certain chemical elements can be lost, while others increase their content. Table 2.2 gives the average chemical composition of several of the most widely disseminated sorts of magmatic and sedimentary rocks. Metam2orphic rocks are not included in this table, since they were formed by alteration of magmatic and sedimentary rocks.

TABLE 2.2.
Average chemical content of magmatic and sedimentary rocks (%).

Components	Magmatic rocks				Sedimentary rocks			
	Acid	Basic	Ultra basic	Average content	Sand-stones	Lime-stones	Clays	Average Content
SiO_2	68.9	48.2	43.8	59.14	81.23	5.19	53.10	57.95
TiO_2	0.5	1.9	1.7	1.05	0.25	0.06	0.65	0.57
Al_2O_3	14.5	17.6	6.1	15.34	2.77	0.81	20.40	13.39
Fe_2O_3	1.7	3.0	4.5	3.08	1.07	0.54	3.02	3.47
FeO	2.2	5.8	8.7	3.80	0.30	-	2.45	2.08
MgO	1.1	8.2	22.5	3.49	1.16	7.89	2.44	2.65
CaO	2.6	10.5	10.1	5.08	4.5	42.57	3.11	5.89
Na_2O	3.9	2.6	0.8	3.84	0.45	0.05	1.30	1.13
K_2O	3.8	0.9	0.7	3.13	1.31	0.33	3.24	2.86
H_2O	0.6	0.8	0.6	1.15	1.63	0.77	6.00	3.23
P_2O_5	0.16	0.3	0.3	0.3	0.08	0.04	0.17	0.13
CO_2				0.10	5.03	41.54	2.63	5.38
SO_3				-	0.07	0.05	0.64	0.54
BaO				0.06	0.05	-	0.05	-
O				-	-	-	0.80	-
MnO	0.07	0.17	0.18	0.14	-	-	-	-
Total				99.70	100.00	99.84	100.00	100.00

The chemical transmission of a health risk in fact begins from rocks - with enhanced or reduced content of elements - of greater significance for life. Further natural pathways are through water, soil, plants, and animals. The importance of knowing the chemical composition of rocks can be illustrated by the example of enhanced content of molybdenum, which is toxic in impermissible doses, in rocks of certain regions of the world. The increased concentration of that element in plants and wider incidence of toxicosis among domestic animals in those regions suggest that rocks with a high concentration of molybdenum are probably found under the loose soil. We have such a case in the vast expanse of the American West, where natural concentrations of molybdenum exceed average values for the Earth's crust. The majority of registered cases of toxicosis were encountered either in areas with high content of natural molybdenum or in regions downstream from them. Cases of toxicosis were also recorded on terrains with moist soil having high content of organic substances, where metals are retained (concentrated) by means of their compounding with organic particles.

Magmatic Rocks

The first stage of magmatic activity involves formation of magma, a fluid silicate solution of rock in the bowels of the Earth. Magmatic rocks are formed during cooling and crystallization (differentiation) of magma. Field investigations indicate that the bulk (9/10 and more) of magma does not flow out on the surface in the form of volcanic material, but is rather hardened under ground. Bodies formed in this way are called *intrusives*, and the largest of them are *batholiths* (Fig. 2.4.). Partially denuded by processes of erosion, systems of batholiths can extend without interruption over distances of the order of 8000 km, as is the case with the Andes mountain range in South America, where the length of individual batholiths exceeds 1300 km. The batholith of the Coast mountain range in British Columbia (North America) is about 2000 km long and from 130 to 200 m wide, with a surface of more than 300,000 km^2. *It can be imagined how greatly different are conditions for human life and health in such a geological environment from those in expansive Neogene basins, for example.*

On the basis of the manner of formation and position in the lithosphere, magmatic rocks are divided into the following three groups:

- *Deep - seated* (intrusive or plutonic);
- *Veined* - differentiated or lateral spurs of deep - seated magmatic rocks; and
- *Extrusive* (effusive or volcanic).

The chemical method of classification of magmatic rocks depends primarily on the content of SiO_2 (quartz) in rocks. On the basis of the content of this oxide, rocks are divided into the following classes:

- *Acidic,* with SiO_2 content above 66%;
- *Intermediate,* with SiO_2 content from 66 to 52%; and

- *Basic,* with SiO_2 content of less than 52% (some authors also single out a group of *ultrabasic rocks*, with less than 45% SiO_2).

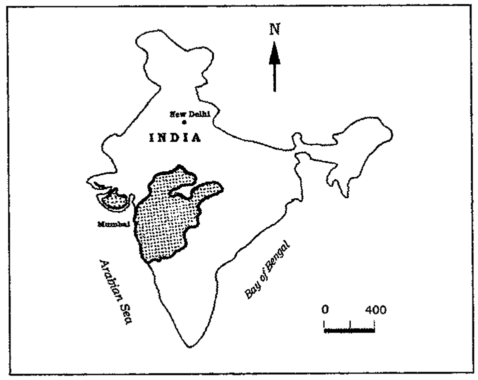

Fig. 2.4. Position of Deccan volcanic province, India.

On the basis of chemical nature and manner of association, magmatic rocks are divided into the following eight groups:

- *Granites and rhyolites* - acidic rocks characterized by the presence of quartz and alkali feldspars;
- *Granodiorites, quartz diorites, quartz latites, and dacites* - rocks of acidic to intermediate nature, with greater or lesser amounts of alkali feldspar and intermediate plagioclase;
- *Syenites and trahytes* - intermediate rocks with alkali feldspar and without quartz;
- *Alkali syenites and phonolites* - rocks rich in alkalis and poor in silica;
- *Monchonites and diorites, latites and andesites* - intermediate rocks with transitional plagioclase and without free quartz;
- *Gabbros and basalts* - basic rocks with basic plagioclase;
- *Alkaline gabbroides* - basic rocks rich in alkaline;
- *Peridotites* - ultrabasic magmatic rocks without feldspar.

We give below the main characteristics of the most widely disseminated representatives of *deep - seated rocks.*

Granites are among the most widely disseminated of deep - seated (plutonic) rocks (Fig. 2.5.). According to known statistics, granites make up as much as about 95% of upper levels of the continental crust. They are built of quartz and alkali feldspars, with the presence of mica or some other colored mineral that more closely determines the variety of rock (Fig. 2.6.). Weathering of granites begins with alteration of the colored minerals and oxidation of iron in them, after which feldspars are transformed into mineral clays. Beginning around the margin of the grain, these processes destroy the rock mass to such an extent that it passes over into a loose state, so - called granitic grus. In the sand - like loose mass, the only minerals not disintegrating are quartz (and muscovite if it was present in the rock).

Granodiorites are also very widely disseminated rocks. They are characterized by being silica - rich. In comparison with granites, however, they are poorer in alkalis and richer in calcium, magnesium, and iron. Together with quartz, intermediate plagioclase occurs as a characteristic mineral. During prolonged weathering in the surface zone, granodiorites also pass over into grus. They are very widespread in the world and in Yugoslavia (Boranja, Zeljin, Kopaonik, Besna Kobila near Surdulica, Jastrebac).

Gabbro consists of basic plagioclase and pyrone as essential components. If olivine is also present as an essential component, the rock is called olivine gabbro.

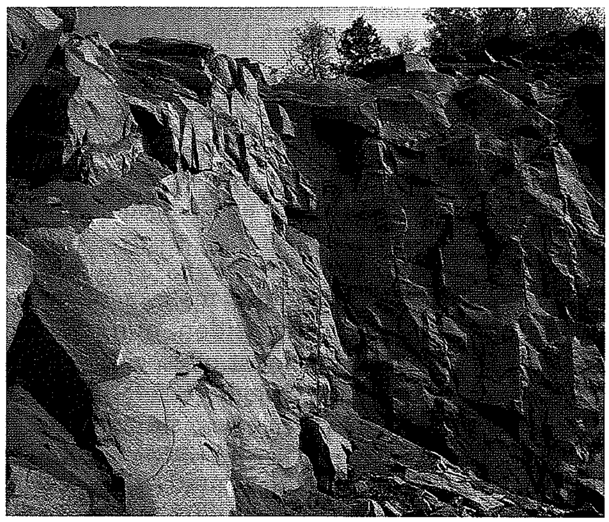

Fig. 2.5. Brajkovac granites, West. Serbia (Photo: D. Milovanovic).

Peridotites are very widespread in the world and in Yugoslavia (Zlatibor, Maljen, Kopaonik, Goles, Orahovac - Djakovica). They are poor in silica and alumina, but rich in magnesium and iron. Alkali and calcium levels are for the most part minimal. Olivine and pyrone are essential minerals, and mined minerals (chromite, magnetite, platinum, and diamonds) play a significant role in these rocks. As rocks, they are rarely fresh, and a more or less advanced process of serpentinization is regularly observed in them. Chrysotile asbestos, talc, magnesite, some chlorite, and opal are encountered as products of alteration, together with serpentine.

Among **extrusive (volcanic) rocks**, particularly widespread are basalts and basaltic rocks, which occupy as much as 98% of the surface of all extrusive rocks on the Earth (Fig. 2.4.). Andesites, quartz keratophyres, and quartz latites are significantly present in Yugoslavia. Of *veined rocks, granitic pegmatites are of interest, primarily because of elevated concentrations of radioactive elements (U, Th, K, and Rb).* Pegmatites occur very often in Yugoslavia, especially in the form of veins accompanying granodiorites.

It was mentioned earlier that each of the indicated types of magmatic rocks is defined by the kind and quantity of essential mineral components, the content of oxides present in them varying within definite limits (V. Knezevic - Djordjevic and P. Djordjevic, 1975), namely as follows:

- Silica (SiO_2) - between 35% (in ultrabasic rocks) and about 78% (in ultra acidic rocks);
- Alumina (Al_2O_3) - from 0.5% in peridotites to about 20% in basic and intermediate rocks (more than 20% in some alkali rocks);
- Oxides of iron (Fe_2O_3 and FeO) - present in amounts ranging from fractions of a percent (in granite) to maximally about 15% of total content (in gabbro and peridotite);
- Magnesium oxide (MgO) and magnesium - present in amounts ranging between fractions of a percent (in granite) and about 40% (in peridotite);
- Alkalis (Na_2O, K_2O) - variable both individually and in total content, their content declining from granite to peridotite;
- Other components - present in small quantities and not subject to any great variation.

For us it is very important that the magmatic masses of certain broader areas exhibit similarity of mineral composition and ratios of individual chemical components. Such areas are most often called **petrographic provinces**. For example, according to Niggli (1954), there are three basic provinces among younger magmatic masses, namely the *Pacific* (rocks of the calcium - alkali series), *Atlantic* (rocks of the sodium series), and *Mediterranean* (rocks of the potassium series) provinces. On the other hand, Russian scientists distinguish the *Atlantic, Pacific, Mediterranean, and Arctic provinces*, and newer research indicates the existence of several more petrographic provinces. For the broader territory of the Balkan Peninsula, L. Maric (1974) concludes that in addition to Pacific and Transitional petrographic provinces, a tendency is discernible toward development of rocks of the Atlantic and Mediterranean provinces (Eastern Serbia), i.e., a potassium tendency of development is evident.

Two separate **geochemical provinces** are clearly distinguishable in the Balkans: the Cu geochemical province of the Carpatho - Balkanides and the Pb geochemical province of the Serbian - Macedonian mass and Dinarides. In the region of Mt. Kopaonik - which is one of the largest and most interesting areas of magmatism and metallogeny in the Pb geochemical province - a regularity is discernible in the behavior of trace elements during intrusive magmatism (and the phase of volcanic effusion): 1) rocks are rich in lead and barium and poor in copper in relation to average rocks of the Earth's crust; 2) average content of Sr, Ba, Mn, and Ti is very high - more than 1,000 ppm; 3) trends of change in the content of trace elements in the direction of the most acidic rocks (quartz monzonites) indicate the following characteristics in the development of intrusive magmatism in this region: a) uniform decrease in content of Ni, Co, and Cu, together with less regular decrease in content of Ti, Cr, V, Mn, Sc, B, and Li; and b) uniform increase in content of Pb, Ba, Rb, Be, and La, together with less regular increase in content of Zr, Y, and Sr (A. Dangic, Z. Maksimovic, and I. Micic, 1995). However, geochemical study of the southeastern part of the Surdulica pluton indicated that granites are with lower average content of a number of trace elements (Ti, Ga, V, Cu, Y, Zr, Ni, Co, Cr, La, Ba, Sr, Yb, Li, and Rb), but higher manganese content in relation to acidic magmatic rocks (N. Vaskovic and V. Jovic, 1993).

It will be seen in the corresponding chapter how significant the study of trace elements in rocks and soil is for *medico - geological evaluation of the environment.* Here we give two examples of the negative and positive influence erted by magmatic rocks and their accompanying products.

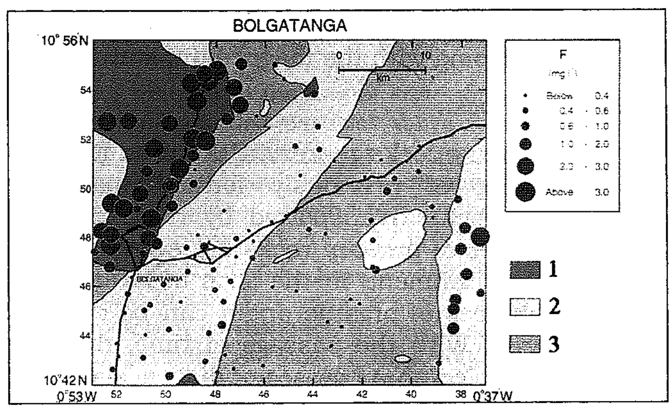

Fig 2.6. Distribution of fluoride in groundwater in the Bolgatanga area of northern Ghana. 1 - Bongo granite; 2 - Birmian magmatic and metamorphic rocks; 3 - Birmian green schists (BGS, ODA-funded program).

Negative consequences on the natural environment (environment of life) can be very pronounced in *regions of current volcanism and young volcanic rocks.* It is known that liberation of H_2O, HCl, H_2S, CO_2, SO_2, and other gases goes on for a long time after eruption of volcanoes in these regions. A portion of these gases enters the atmosphere directly, while another part dissolves in groundwater and causes formation of acid thermal springs. There are many such springs in Japan, the Kurile Islands, and other regions. For example, the water of some thermal springs in the Kurile Islands has pH values of from 0.2 to 1.0 and hydrochloric acid composition of as much as Cl 45 g/l. This water is very aggressive and profoundly alters the surrounding rocks: it extracts Fe, Al, Ti, Ca, Mg, Na, K, and Al from the rocks, which acquire the composition of almost pure SiO_2. Thermal waters contain up to 3 g/l Al and 1 - 0.5 g/l Fe. They are also enriched with titanium. Brooks, rivers, and lakes in such regions have very acidic water rich in aluminum and iron. Volcanic geological (natural) environments have not been studied enough geochemically. This applies particularly to biological circulation and migration of water in these regions.

Living conditions are completely different in regions of *peridotite massifs*. Let us take, for example, the Zlatibor peridotitic (ultramafic) massif, which - with an area of about 800 km^2 - is one of the largest in Europe[9]. Peridotites, the soil on them, and underground and surface waters in this region are rich in magnesium. Apart from widespread waters rich in magnesium bicarbonate, of interest are calcium hydroxide waters, as well as very rare alkaline waters (pH 11.4 - 11.9), which issue only from several peridotitic terrains. According to Z. Maksimovic et al. (1996), in the human population of the Zlatibor region, the content of magnesium in blood serum is in the highest part of the reference range (15.8 - 25.5 mg/l). Medical data indicate lower mortality from cardiovascular diseases in the area of Zlatibor than in other regions of Serbia (M. Djordjevic et al., 1992), which is in keeping with the magnesium status in the human population.

Sedimentary Rocks

Most sedimentary rocks represent the product of chemical and mechanical weathering of previously formed magmatic, sedimentary, and metamorphic rocks. Transported by river currents, glaciers, wind, and gravity, particles of primary rocks are eventually deposited (most often in an aquatic environment) in the form of layers on top of the rocks below them. Substances of organic origin can be deposited together with inorganic material. With the passage of time, the deposited unconsolidated sediment is subject to processes of diagenesis, consolidation (lithification), and transformation into a compact sedimentary rock. Three fourths of the land on our Planet is covered by sediments and sedimentary rocks, and only one fourth by magmatic and metamorphic products.

Sedimentary material can be divided into three large groups: 1) *clastic material*, which is transported in the form of hard particles; 2) *chemogenic*

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[9] A comprehensive survey of ultrabasic rocks on territory of the former Yugoslavia was given by Z. Maksimovic (1975). Among other things, the author stressed the assumption that the interior (Vardar) and central (Bosno-Zlatibor) ultrabasic zones are with different chemism of peridotites, the central zone being particularly distinguished by elevated content of Na, Ti, and Li.

sediments, which are deposited directly from solution; and 3) *organogenic sediments*, which are created by organisms deposited together with inorganic (chemical and clastic) material.

1. *Clastic sediments.* Sorting by size of particles (grains) with the texture of gravel, sand, silt, and clay occurs in the course of their transport. If a river empties into a basin with calm water, gravel is deposited near the shore, sand settles somewhat farther away, and fine material can be carried a significant distance from the coastline. The natural binding matter or cement in semi bound or bound rocks of this group - which incidentally are the most widespread of sedimentary rocks - can be of a carbonate, siliceous, clay, marl, or iron nature.

Certain bound or semi bound rocks are formed, depending on texture of the unbound rock mass. The given regularity is illustrated by the following series of rocks, starting with those having the coarsest texture:

- *Breccia* is formed by binding or cementing of *detritus*, i.e., unbound material consisting of angular broken rock fragments measuring more than 2 mm in size. The detritus matter is deposited near the source of clastic material, so that breccia generally has a composition similar to that of the parent rock (limestone breccia, dolomitic breccia, marble breccia, serpentine breccia, etc.);
- *Conglomerates* are rocks composed of *gravel*, i.e., rounded rock particles with diameter greater than 2 mm, cemented by some natural binding matter;
- *Sandstone* is rock formed by natural binding of *sand*, fine - grained unbound material composed of rounded particles varying in diameter between 2 and 0.05 mm (from 2 to 0.5 mm in coarse - grained sand, 0.5 to 0.25 mm in medium - grained sand, and 0.25 to 0.05 mm in fine - grained sand). The most common component of sand (sandstone) is quartz, but muscovite is also fairly well represented. As in gravels, scattered veins of useful minerals (gold, monazite, ilmenite, garnets, diamonds, sapphires, etc.) can be formed in places in sands;
- *Aleurolite* is the bound rock that corresponds to *aleurite*; a term applied to unbound sediment with particles the size of dust (0.05 - 0.005 mm). Composition of the given rock formations includes particles of quartz, feldspar, mica, carbonate, and clay minerals, while the binding material is most often of carbonate (sometimes clay) nature;
- *Shale* is formed from mud, which represents the unbound pelitic sediment accumulating in water. Because of the high dissolving action of water, this finest of clastic material contains only remaining stable components, primarily clay minerals. Diagenesis of mud results in the formation of *clay*, or *shale* in the case of transformation into a hard stratified rock. Among clay minerals, the most important are kaolinite, hydro micas, montmorillonite, and other alumosilicates. Admixtures include hydroxides of iron, which give the rock a reddish, yellow, or brownish - red color; organic substances (especially bitumen), which give it a dark - gray or

even black color; and small amounts of manganese, which give it a greenish color.

Clay minerals make up the bulk of products formed in *rock - water* interaction under conditions of the Earth's surface. Owing to characteristics of their structure, they represent material that acts effectively during ion exchange. It turns out that the composition of many natural waters approximately corresponds to that resulting from equilibrium with secondary clay minerals, and with primary minerals of volcanic rocks in the exceptional case of potassium feldspar (J. I. Driver, 1982.).

2. Chemogenic and organogenic sediments. Rocks of a large group are created in various aquatic basins as a result of diverse chemical processes or accumulation of organic remains after the death of animals and plants (the shells of macro - and microorganisms or plant remains). *Chemogenic formations* include carbonate rocks (limestones, dolomites, and marls), silicate rocks, ferrous rocks, onyx marble, travertine, and sediments of salt deposits. The most important *organogenic sediments* are limestones and dolomites, including writing chalk, silicate sediments (cherts), diatomaceous earth, coal, petroleum (to some extent), etc. It is evident that the same rock, limestone for instance, can belong genetically to both the group of chemogenic formations and the group of organogenic formations.

Limestone consists mainly of calcium carbonate, manifested in the form of the mineral calcite. It usually contains chemical admixtures of iron, manganese, magnesium, and clay; organic matter; etc. It can be created inorganically by chemical accumulation of calcite, by accumulation of lime - rich shells, or by a combination of the two processes. If the rock is composed of 40 to 60% $CaCO_3$ and clay particles account for the remaining 60 to 40%, it is called *marl*. Clay minerals - kaolinite and montmorillonite - make up the noncarbonated part of marls. Chemically purer limestones are almost regularly affected by an intensive karst process.

Dolomite represents a carbonate rock composed of the mineral of the same name, the double salt of calcium and magnesium carbonic acid: $CaMg(CO_3)_2$. Pure dolomite is very rare. It usually contains many admixtures, and clay dolomites are distinguished, together with marl, iron, bituminous, and other dolomites.

Certain ***sediments with significant iron content*** accumulate chemically. Thus, for example, large amounts of iron are given up to the sea in the form of exhalations during intensive submarine effusion of basic volcanic rocks, and hematite deposits can be created in this way. Like all typical sedimentary rocks, iron deposits can be formed in the usual sedimentary manner.

Phosphate rocks represent sedimentary formations containing 12 - 40% P_2O_5. Very high content of phosphate minerals is characteristic of deposits of the *Phosphoria formation* in the states of Wyoming, Utah, and Idaho, while the phosphate admixtures present in limestones in the vicinity of Nashville (Tennessee) are wholly sufficient for industrial production of fertilizer. Phosphate minerals, by the way, can be present in the form of cement and other sediments.

Evaporites or saline deposits are formed by accumulation from solutions, usually in closed basins and lagoons. This group includes such single - mineral rocks as anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$). Of special economic significance are rock salt (NaCl), salts of potassium, borates, and nitrates.

Caustobiolithes are combustible organogenic rocks. They include caustobiolithes of the coal - peat series, brown coal, hard coal or anthracite, and members of the bitumen - petroleum series.

An interesting fact is that only three types of rock account for nearly 100% of the total amount of sedimentary formations on the continents. Thus, according to Pettijohn (1957), claystones and related rocks constitute about 58% of all sedimentary rocks formed on land, sandstones about 22%, and limestones about 20%. On the other hand, such formations as coal, iron ore, gypsum, raw materials for fertilizer, etc., are relatively rare, but of great value.

According to Howard and Remson (1978), sedimentary rocks can be relegated to three *geochemical classes*. The *first class* consists of rocks such as sandstone, with grains of minerals first eroded from other rocks, then transported to regions of sedimentation without significant chemical changes. The *second class* includes rocks such as shale, which basically consists of clays and (or) aqueous compounds of quartz, aluminum, iron, or magnesium formed during chemical decomposition or interaction with water. Represented by rocks such as limestone, the *third class* encompasses rocks whose components fall into sediment from water as a result of a chemical reaction or biological activity. Table 2.2. shows average composition of the indicated three types of sedimentary rocks.

As for the chemical composition of sedimentary rocks, chemogenic and organogenic formations - being single - mineral aggregates - are characterized by very simple chemical composition. Limestones, dolomites, silicate rocks, and many other kinds of rocks are of this type, as are some sands and sandstones among clastic sediments. By way of contrast, most clastic deposits have a complex and varied chemical composition, depending on the kind of fragments and their heterogeneity, the kind of binding mass, and the quantitative ratio of fragments and binding mass. This type includes conglomerates, some sandstones, marls, shales, clays, and other similar sedimentary rocks. *Shales are especially rich in heavy metals and other environmentally important elements.*

Linkage between magmatic and sedimentary rocks is confirmed by data on their chemical composition indicating similar content of various components (Table 2.2.). At the same time, the following visible and basic differences are also present:

1. The ratio of Fe_2O_3 to FeO is opposite in sedimentary and magmatic rocks. Oxide iron is prevalent in sedimentary rocks. The reason for this lies in the fact that sedimentary rocks are formed in the biosphere in the presence of free oxygen, which oxidizes significant amounts of iron (and other polyvalent elements);
2. Levels of sodium expressed as Na_2O are noticeably (almost three times) lower in sedimentary rocks than in magmatic rocks, whereas the quantity of K_2O is approximately equal. This is attributable to the fact that sodium under conditions of the biosphere is readily soluble and is transported to the ocean, where it accumulates in great amounts and is also fid in pelagic colloidal sediments of the sea floor;
3. Sedimentary rocks are richer in H_2O and CO_2, components that in magmatic rocks occur in extremely small quantities; and
4. Sedimentary rocks contain organic carbon in varying amounts, whereas this component is completely lacking in magmatic rocks. Organic compounds in sedimentary rocks are products of photosynthesis, which has transpired in the Earth's biosphere since time immemorial.

A geological environment built of sedimentary rocks can ert positive and negative influence on forms of life. The following examples of this can be cited:

1. The concentration of selenium in black shales, hard coal, and petroleum is 10 to 20 times greater than the average content of this interesting element in the lithosphere. For example, selenium - bearing black shales (schists) represent the parent material of the widespread selenium - bearing soil on the Western Plains of the United States. Here certain fodder plants fed to cattle, horses, and sheep concentrate selenium in their tissues. The concentration can attain 15,000 mil^{-1}. Absorbed in such concentrations, selenium affects the motor system and senses of animals and can even cause their death. Luckily, cultivated plants and wild grasses do not accumulate amounts of selenium great enough to threaten the life of animals;
2. The Izhor Plateau near Saint Petersburg (Russia) is built of carbonate sediments rich in calcium carbonate. The richness of the rocks dictates richness of the soil itself in this calcium compound, as a result of which the soil is very fertile. Surface and groundwater are also calcium - enriched and have a neutral or weakly basic rather than acidic reaction. Humic materials and iron compounds do not dissolve in these waters, and

springs and rivers in such natural environments are especially clean and transparent. The vegetation has all the attributes of completely calcium - sufficient food. Farm animals rarely suffer from rickets, and the milk productiveness of cows is greater;

3. As an interesting example, J. Zujovic (1922) cites the famous cognac of France: "*The refined palates of alcohol lovers distinguish three kinds of French cognac, depending on the wine from which it is made. The first quality (Grande or Fine Champagne) is made from white wine from vineyards planted on layers of chalk, light and flaky. The second kind (Petite Champagne) is from vineyards on less chalky soil. The third and poorest cognac is made of wine from vineyards on hard limestone (like the one in the Topcider section of Belgrade) where forests once stood (this third class of cognac is called Pays des Bois). By looking at the geological map of the region in question, it is possible to determine the quality of cognac when the origin of the wine used to make it is known.*"

Metamorphic Rocks

Metamorphic rocks are formed from magmatic and sedimentary rocks by means of their profound alteration and transformation under the influence of high temperature, pressure, hot solutions, and gaseous components. This involves a complex process of recrystallization of minerals and rocks, changes of chemical composition, breakdown of old structures and formation of new ones, etc. Metamorphic rocks themselves can also be recrystallized anew if they meet with the corresponding thermodynamic conditions. One of the characteristic features of such rocks is their schistose structure, with pronounced parallel arrangement of components.

The following seven basic groups of rocks are singled out: 1) phyllites; 2) schists; 3) gneisses; 4) amphibolites and amphibolitic rocks; 5) marbles; 6) quartzes; and 7) other massive metamorphic rocks.

Phyllites are rocks of low crystallinity and well expressed schistose texture formed by metamorphosis of claystones. The leading mineral of these rocks is sericite, followed by quartz. The rocks are very subject to mechanical disintegration and pass over easily into a friable mass.

The **schist** group includes rocks of medium to high crystallinity with well expressed schistosity that is predominantly formed by metamorphosis of claystones. They are named for the mineral or minerals dominant in them: *mica schists* (if mica is dominant), *muscovite schists, and chlorite schists, talc schists,* etc. They readily undergo mechanical disintegration.

Gneisses are highly metamorphosed medium - to coarse - grained rocks composed mainly of quartz, alkali feldspar, and mica. *Mica, amphibolic, pyrone,* and other gneisses are distinguished, depending on the colored mineral present in them. Weathering of gneisses occurs in the same way as in granites, but due to facilitated circulation along the surface of their schistosity, the process is accelerated in relation to granitic rocks.

Amphibolites are rocks of high crystallinity built mainly of amphibole and plagioclase with or without quartz. Although they are massive in texture, there also exist partially schistose rocks of this group.

Marbles are rocks of massive structure formed by metamorphosis of limestones and dolomites. They are composed of calcite, more rarely of dolomite or calcite and dolomite together. Of accessory minerals, muscovite has somewhat higher content than others. Like limestone, marble is very subject to the karst process.

Quarzites are metamorphic rocks in which more than 80% of the rock mass consists of quartz. They are formed by metamorphosis of quartz sand and sandstones.

Serpentinites are singled out in addition to many kinds of regional metamorphic rocks. They represent an expanded mass formed by metamorphic transformation (serpentinization) of peridotites. The rocks are built of the mineral serpentine and as accessory ingredients can contain chlorite, talc, chromite, and magnetite. They are green to dark green in color.

A certain association of minerals or *metamorphic facies* is characteristic for every condition of pressure and temperature prevailing during the metamorphic process. For example, we note the zeolite facies, the blueschist facies, the greenschist facies, the amphibolite facies, and the granulite facies, which consistently reflect the degree of regional metamorphism under conditions of pressure and temperature increase.

Any rock, metamorphic rock as well, with concentration of an element or compound perceptibly greater than the average content acts as a potential source of pollution of soil, water, flora, or fauna. Whether it will act as a source of pollution depends on whether that element or mineral is present in exceptionally great quantities and in a *form that can be assimilated* (by plants for instance).

Mercury can be cited as an example of variability in the distribution of elements in the lithosphere. An interesting case is that of ultramafic rocks in California whose original composition included mercury - rich sedimentary rocks. The content of mercury in soil at a certain distance from these rocks is ten times greater than mercury content in other soil. If the soil is still closer, it can contain mercury in amounts obtainable on the premises of mines in the basic rocks.

Geological Formations

A geological formation represents an equal taxonomic unit in the series: *mineral - rock - formation - lithosphere - planet.* Every preceding unit in that series is elementary in relation to the next. Thus, a geological formation is a unified whole composed of a paragenesis of rocks. In the simplest case, a formation can be homogeneous and composed of a single kind of rock. Thus, it is possible to distinguish limestone, sandstone, evaporite, granite, or basalt formations. The Deccan basalt formation in southwest India, for example, which occupies an area about 700 km long and up to 500 km wide, is estimated to reach a depth of 1.6 km (Fig. 2.4.). It is very often the case that a formation consists of a number of regularly alternating rocks or is defined by extreme lithological heterogeneity that in itself is characteristic. It then gets its name from the main and/or characteristic petrographic members (for example, a flysch formation, a diabase - chert formation, etc.). To be specific, flysch represents a formation widely disseminated in many geosynclinal regions of the globe. It is a thick series of sedimentary structures with rhythmic alternation of interlayers of sandstones, shales, marls, and other rocks. Naturally, the geological environment in the given case cannot be formed solely in the sandstone or shale, but rather within the rock complex as a whole. It thus acquires the features of the complex itself.

The discipline devoted to study of geological formations is called **formation geology**. One of its final goals is to obtain a comprehensive knowledge (picture) of a formation. This requires information about lithological composition of the formation and the geological conditions under which it arose, its geochemical characteristics, the presence of mineral raw materials in it, and its hydrogeological and geological engineering features. Also significant is information about the type of soil arising on land built by a certain geological formation.

Every formation is distinguished by quite definite geochemical characteristics. For this and other reasons, *analysis of geological formations in areas of interest can be of significance for medico - geological evaluation of the environment* and eventual discovery of the causes of certain diseases. The following examples can be cited:

- Apambire et al. (1977) examined groundwater rich in fluorine and iron in the upper part of Ghana. They found that the content of fluoride (the most widespread inorganic compound of fluorine) ranges from 0.11 to 4.6 mg/l (even comprising up to 95 mg/l in one spring). The highest fluoride concentrations occurred in regions built of hornblende - granite and syenite, where dental fluorosis is outlined (Fig. 2.6.). It was concluded that the occurrence of F in granitoid groundwater is caused by dissolution of fluoride minerals and exchange of anions with minerals of micas and their clay products;
- The concentration of fluoride in Northern Tanzania is probably the highest in the world (with maximal levels of 12 - 26 mg/l in river waters and 63 mg/l in thermal waters). The elevated level of fluoride originates from marine sediments episodically enriched with ash and fluoride - rich subli-

mates deposited during volcanic activity from the Miocene to the present day;

- Very widespread on continental shields and platforms (as well as in Paleozoic orogenic belts), crystalline schist formations are generally poor in selenium and other important elements. This indirectly affects human health and growth in these regions. Due to inadequate intake of selenium, an increased risk of cancer, above all, is discernible in the human population;
- A formation of quartz sands created by weathering of moraine material during the Quaternary has a broad extent in Poland, the European part of Russia, and Western Siberia. As it is often composed almost exclusively of quartz, the content of biologically important elements (P, K, Ca, etc.) is negligible, which determines the geochemical and geomedical characteristics of the given terrains;
- Peridotite (serpentinite) formations occur in the guise of expansive massifs. The content of MgO in such rocks varies around 43% (in contrast to silicate rocks, with only 0.1%). Such terrains have soil, groundwater, and surface water rich in magnesium. As a result, in the human population the content of this element (which is biologically essential for plants, animals, and humans) in blood serum is in the highest part of the reference range. Under such natural conditions, cardiovascular diseases occur more rarely, as do hypertension and renal calculoses.

Rock Weathering

By *weathering,* we mean processes of mechanical disintegration and chemical decomposition of minerals and rocks caused by the action of temperature fluctuations, ice, water, oxygen, carbonic acid, and organisms. In the upper part of the Earth's crust, where rocks are found under conditions of close interaction with the atmosphere, hydrosphere, and biosphere, they undergo significant and diverse changes of their composition and state. To be specific, the overwhelming majority of rocks were created under specific thermodynamic conditions in the depths of the Earth, in zones of magma activity and metamorphic processes, or on the sea floor. On reaching the Earth's surface, these rocks are surrounded by new physicochemical conditions, become impermanent, and start to disintegrate under the influence of various factors. Their alteration itself occurs in different ways. In some cases, it amounts to breakdown of hard rock into fragments of different size or even into individual minerals. In others, radical changes of primary minerals and rocks occur, such changes resulting in the appearance of completely new minerals different from the primary ones. *The process of destruction of rocks by means of disintegration and formation of soil (the pedological cover) as a result of the process is of exceptionally great significance for mankind.*

Depending on the factors affecting rocks and the results of this influence, weathering processes can - with a certain degree of arbitrariness - be divided into the following two types:

- *Physical disintegration*; and
- *Chemical decomposition.*

The two types of weathering are closely linked with each other, acting together and at the same time. Only the intensity of manifestation of each is unequal. It depends on climate, relief, duration of the process, rock composition, and other factors.

Physical disintegration is caused by various factors. Still, the decisive role is played by factors that induce mechanical movement of rock particles, which leads to destruction of the mutual adhesion holding the components of rocks together. Physical disintegration occurs under the influence of: 1) *insolation*; 2) *frost* (ice); 3) *mechanical action of salt* crystallizing in depressions and cracks in rocks; 4) *capillary action of water*; and 5) *mechanical action of plant roots.* The most *widespread is disintegration under the influence of insolation* (temperature weathering), more precisely the weathering that takes place under the influence of daily temperature changes.

Chemical decomposition results from interaction between rocks of the outer part of the lithosphere and chemically active elements of the atmosphere, hydrosphere, and biosphere. The following materials are characterized by having the greatest chemical activity: oxygen, water, carbonic acid, and organic acids. Changes of volume occur during transformation of one mineral into another. This is of decisive significance for processes of rock destruction, since it frees space into which new amounts of water can enter. Processes transpiring during chemical decomposition are of several types.

- *Oxidation* of minerals and rocks. Oxidation occurs where free active oxygen exists, usually in the presence of water. Air and water in ionizing form destroy iron silicates such as olivine, pyrones, and amphiboles, and carry bivalent iron over into the trivalent form. Limonite - a compound most unstable under conditions of the Earth's surface - is formed from pyrite in this way;
- *Hydrolysis.* Chemical processes of the greatest complexity occur in the course of hydrolysis or decomposition primarily of silicates, which occupy about half of the volume of the outer part of the Earth's continental crust. Hydrolytic decomposition of feldspar results in the formation of clay, kaolin, micas, and other minerals, as well as in separation of free SiO_2;
- *Carbonization.* Crystals containing calcium, magnesium, sodium, and potassium ions enter into reaction with natural water saturated with carbonic acid, forming carbonates and bicarbonates of those elements. Such a process of ordinary chemical dissolution is also called carbonization. Dissolution of minerals in water is characteristic of limestone, marble,

dolomite, and (to a lesser extent) marl. The process results in formation of karst hollows and other forms of karstification. A process even simpler and faster than carbonate dissolution transpires in readily soluble mineral materials such as NaCl, KCl, anhydrite, and gypsum;

- *Hydration.* Hydration represents chemical annexation of water by minerals of rocks, with formation of new minerals, primarily hydrosilicates and hydroxides. Kaolinite is formed from feldspar during hydration, and various hydro silicates (chlorite, serpentine, talc, and zeolites) also arise in this way.

Organisms play a large part in the complex processes involved in chemical decomposition of minerals and rocks, and many weathering products are of biogenic origin. Weathering of rocks begins with action of microorganisms on their surface. These microorganisms create the necessary substrate for plant development, leading to further destruction of the rocks. Thus, *chemo - biological decomposition* is basically initiated by the work of bacteria, algae, and lichens, to be completed by the action of higher plants. Drawing inorganic substances from the ground, plants in this way accelerate and amplify hydrolytic decomposition. Certain organic acids (humic and others) and carbon dioxide are separated during decomposition of organic matter, and acids and gas increase the dissolving capability of water.

The nature and degree of weathering processes are for the most part determined by *climatic conditions*. The hot damp climate of the equatorial belt is especially favorable for complete and profound chemical decomposition. In temperate zones with a damp climate, chemical and chemo - biological decomposition usually occurs at a slower rate. In the former instance, thickness of the weathering crust is enormous and is measured in tens of meters (up to 100 - 120 m). The crust in this case exhibits readily discernible zonal structure. In regions of moderately damp climate in North America, Europe, and Asia, on the other hand, the crust in question is today not very thick (1.0 - 1.2 m at the most) and is practically identical with the pedological cover. According to N. M. Strahov (1963), slight thickness of the weathering crust is a consequence of short duration of the weathering process itself, since this zone in the north was only recently (12 - 15 thousands of years ago) freed of an ice cover.

There is a rich literature on weathering processes (physical disintegration and chemical decomposition) (Allison and Palmer, 1980; Gorshkova and Yakusheva, 1957; Knezevic and Djordjevic, 1975; Milovanovic, 1949; Perelman, 1975, 1979; Veselinovic et al., 1995).

We note that disappearance of a number of elements in the process of weathering and soil formation is usually incomplete. Thus, for example, soil formed from rock rich in copper - containing minerals will contain more copper than in other types of soils. Such soil is poisonous for plants[10]. By contrast, it happens not rarely that an original magmatic rock is almost completely transformed into clay minerals.

We cite in conclusion some interesting remarks of Perelman (1956) as to certain characteristics of life in damp tropical zones that depend on products of the weathering of various kinds of rocks.

It is known that loose clay material marked by a red color is the most widespread product of chemical decomposition in the tropics. This material contains much iron and aluminum because almost all other elements have been removed from rocks in the process of weathering. Since it is poor in calcium and other metals capable of neutralizing organic acids, the soil (and water) of the damp tropics has an acidic reaction. The given geochemical characteristic of landscapes in the damp tropics determines certain characteristic features of their plant and animal life. Perelman gives the following examples:

- One of the most familiar and obvious characteristics of such landscapes is their coloring. This is especially manifested in parrots, hummingbirds, and other tropical birds, which get appreciably more aluminum in their food than do their relatives in temperate geographic latitudes. The higher the content of aluminum in bird feathers, the more striking their color;
- Hollows in the stems of bamboo trees growing in tropical mud are sometimes found to contain fairly large excrescences of opal, an amorphous mineral composed of quartz and water. The opal was formed here in the course of weathering of granites and other rocks, and it has enriched soil water, as well as underground and river waters. Hence also the high silica content in many tropical plants, whose individual parts appear to be "petrified" as a result.

It may well be asked how such specific geological, geochemical, and climatic conditions affect man. How much influence do they ert on his anatomical structure and appearance, how great a trace do they leave on his organism, on its pathology, resistance, and adaptiveness? The complex and very numerous processes that transpire in rocks, the weathering crust, soil, and water can only be sketched in the present book. Greater attention must be devoted to these questions by investigators, including geologists, geochemists, geographers, biologists, and doctors. Without a good understanding of them, it will be difficult to attain the final goal: optimization of the

[10] Since many soils reflect the composition of rocks in the substrate, chemical analysis of soil (including useful elements in it) can be of great assistance in geological investigations of terrains. On the other hand, such analysis can be useful in resolving practical problems of agronomy, for example where we need to explain the causes of different natural soil fertility on the same space.

environment so as to achieve the highest level of public health in many territories of our planet.

Soil

Surface weathering of rocks and minerals is of exceptionally great significance for life, not only because it is the first (initial) stage in the process of soil formation, but also due to the fact that rocks represent the primary source of biologically essential macro - and microelements needed for life of plants and indirectly for that of animals and man.

Processes of soil formation (formation of the pedological cover) are closely associated with the process of rock weathering in the highest part of the Earth's crust. *By "soil" we mean the loose superficial horizon of the weathering crust capable of supporting plant life.* In this connection, soil formation is unquestionably the most important result of rock weathering from the human point of view. That active environment guarantees the entire biomass needed by humans, animals, and plants, predetermining (to a certain extent) the existence of all life on land, including human life[11]. The well - known Russian geologist and pedagogue V. V. Dokuchaev stressed that the soil constitutes a *fourth natural kingdom*: in addition to plants, animals, and nonliving nature, the soil generates (brings forth), alters, and under certain conditions disappears. Rarely more than several meters deep, this thin membrane envelopes a large part of the land of our planet, making it the fifth and youngest geosphere - the *pedosphere.*

Soil represents a natural mixture of inorganic mineral material, living and dead organic substances, air, and water. It has characteristic structure, texture, color, and other physical properties. From place to place, soil differs in thickness, composition, and ability to support plant life. It can be formed by surface weathering of rocks where they are found or from loose material transported from another region (alluvial soils for instance).

Basic Features of Soil

Factors that affect soil formation. The main factors affecting soil formation are the *bedrock* on which soil develops *climate, plant life, soil organisms, relief,* and *time.* A leading role in this complex process is played by the *biological factor* (mainly plants). Thus, soil formation (and rock weathering, as we have seen) occurs most intensively in the zone with

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[11] In considering the *engineering properties of soil* as an environment for construction work, all loose materials above bedrock are interesting, regardless of whether or not they are capable of supporting plants. The same can be said of *secondary deposits of mineral raw materials or geological building materials.* The soil also plays a large part in formation of the hydrogeological conditions of a given region, especially in the feeding of groundwater.

activity of root systems and circulation of substances produced by organisms during their lifetime. An especially important role here is played by microorganisms, millions and billions of which are present in every gram of soil. The geochemical essence of soil formation consists of decomposition of organic substances by microorganisms.

The influence of different types of *rock as a source of material for the pedological cover* is evident in the early stages of soil formation, but bedrock has little effect on the end result of this process. Thus, almost identical soil can be formed from rocks of the greatest diversity under influence of the same set of conditions. Nevertheless, viewed overall, a link between soil types and different geological substrates is always present in greater or lesser measure. Somewhat greater genetic linkage is especially discernible in cases where some geological formation encompasses a large territory. The given regularity can be illustrated by several examples:

1. Analyzing the role of factors in creation of soil types, V. Nejgebauer (1952) stressed that the most widespread geological substrate of chernozem is *loess* (an Aeolian sediment of Quaternary age rich in fine quartz sand, clay, and calcium carbonate), since two thirds of Eurasian chernozem was formed on loess. In Vojvodina, a large part of Srem and almost half of Banat are built of loess covered by fertile chernozem, as is also the case with Macva, the vicinity of Belgrade, and lands along the Sava and Danube. Apart from it favorable physical characteristics as a parent rock, loess in our country has the additional advantage of being rich in calcium carbonate, which promotes better maintenance of this soil, its stability, and resistance to degradation;
2. *Neogene lacustrine sediments* of Serbia, Macedonia, and Bulgaria are covered by a dense sticky clayey soil having an almost completely black color and a resinous sheen, for which it is known as smonitza. Smonitza was formed after the withdrawal of Neogene lakes from residual lake and swamp clay greatly enriched with humus at the surface owing to rotted bog plants. This relict soil is widely disseminated in the regions indicated;
3. Soils of the *terra rossa* type are known to be characteristic of limestone terrains, where they were formed by dissolution of the limestones themselves and represent their insoluble residue composed chiefly of iron and aluminum. The Dinaric karst represents the typical region of their distribution. Similar soil in Eastern Serbia was formed by weathering of *red sandstones*;
4. In addition to chernozem and smonitza - whose black color arises from organic material (humus) - there is another kind of black soil whose color is dictated by color of the parent rock from which the soil was formed. Such black soil formed by weathering of *basic eruptive rocks* consists of undisintegrated or partially disintegrated ferromagnesian silicates - pyrone, amphibole, and chlorite. According to the pedological literature, it is found on several continents.

Climate determines not only the type of weathering, but also the kind of vegetation that takes part in soil formation. Infiltration of precipitation through the soil, dissolution of mineral salts, and their accumulation are linked with the climate. High temperature accelerates chemical reactions in the soil.

A terrain with broken *relief* usually erodes, and material is transported into morphological depressions. On plains, however, weathering products remain in place. Land relief also influences infiltration and the level of groundwater.

Time is also one of the key factors in the process of soil development, primarily because thousands and tens of thousands of years are needed for formation of a mature soil profile. In the case of long enough time and a favorable tropical or subtropical climate, ground is transformed into overly mature infertile laterite soil. Laterites are developed on large areas of India, Southeast Asia, countries of the Caribbean basin, Brazil, and Central Africa.

Soil components. *Mineral substances* of soil consist of secondary minerals formed by degradation of primary minerals of rocks and amorphous inorganic material. They are represented by sand, silt, clay, or a mixture of particles of these dimensions. Texture is determined on the basis of the content of these fractions, and clayey soils, sandy soils, dusty soils, and combinations of these basic soil types exist in nature.

Organic components of soil include living microbes (bacteria, fungi, etc.), soil nematodes, earthworms, insect larvae, tree roots, plant and animal remains, and various organic compounds formed in the course chemical decomposition of rocks. In spite of the fact that they represent from 2 to 5% of the soil at most, organic components are very significant for its quality. The colloidal matter of incompletely decomposed organic components is called *humus*. The role of humus is especially significant because it supplies microorganisms with nutrients, facilitates infiltration and retention of water and salts, increases the ion - exchange capacity of soil, affects soil structure, and improves plowed fields.

Water and *air* fill the space between soil particles. The amount of water retained in the soil for plant needs is determined by the relative content of sand, dust, and clay. Moreover, air and water in the soil are especially significant for lower plants, algae, and bacteria, since they affect whether oxidative or reductive degradation occurs in the soil.

The pedological profile. Plants are capable of concentrating various chemical elements. Acting like a pump, plant roots lift the elements P, S, Ca, and K - as well as many trace elements - from lower horizons of the soil to upper ones. Such so - called *biogenic accumulation* can bring about an improvement in the environment of plants. Together with biogenic accumulation from lower to upper horizons, descending migration of elements in aqueous solutions is also discernible in soil. Depending on the rates of these two processes, soil is divided into horizons with special physicochemical conditions. The *pedological profile* is formed in this way. From top to bottom, the following three horizons are more often than not present in the soil profile:

- *Horizon A* is rich in organic matter and organisms; it is characterized by accumulation of humus and many elements in its upper part (subhorizon A_1) and leaching of a portion of soluble salts in its lower part (subhorizon A_2);
- *Horizon B* is the middle horizon; by means of infiltration of water, clay and iron minerals accumulate in it, building a distinct crust in places; elevated content of Cu, Ni, Zn, Pb, and other minerals is discernible;
- *Horizon C* represents a loose and partially weathered rock mass, which in its lower layers gradually passes over into compact bedrock.

In the past decades, pedologists and geochemists have increasingly faced the problem of the role played by rare and dispersed chemical elements - trace elements - in the soil, as an invaluable and complex natural system that is open to degradation and pollution[12].

Here we shall analyze the natural soil content of trace elements as a function of bedrock and processes transpiring in soil (binding of elements as ion exchangers for clays, binding of Fe and Mn for oxides and hydroxides). Biogenic accumulation of Be, Co, Ni, Zn, Ge, AS, Cd, Sn, and other rare elements in the humus horizon of forest soils was discovered already at the outset of the 1930's by V. M. Goldsmith. Such phenomena were later confirmed in chernozem and other soils.

Table 2.3 presents the natural concentration of rare and dispersed elements in soil as compared with their content in magmatic (ultrabasic, basic, and acidic) and sedimentary rocks. It can be seen that the concentration of those elements in soil can be greater or lesser, depending on the bedrock in question. Ultrabasic and basic rocks are usually richer

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[12] Of the total land surface of the Earth, arable land occupies only 10% (10% of the Earth's dry land is suitable for agriculture, but economically unprofitable for commercial production); 17% is occupied by pastures; 28% is under forests; and the remaining 45% is occupied by deserts, glaciers, inhabited settlements, and other types of covering in areas with little soil. This means that human beings feed themselves from a surface of about 1,450 million hectares. The given arable land provides 85% of the energy consumed by people in the form of food; 10% of this energy is from natural sources such as forests and pastures; and 2% is from the seas and oceans. It follows that arable land must be conscientiously conserved. The extent to which improper farming can contribute to erosion of arable land whose formation took hundreds or thousands of years is evident from an example in the United States that was analyzed by Howard and Remson (1978). The negative effects of unregulated surface courses and other causes are noticeable.

in Co, Cr, Cu, Ni, V, and Zn, but poorer in alkaline and earth - alkaline metals, whereas precisely the reverse situation is observed in granites and other acidic magmatic rocks. The difference in content of heavy metals can to a certain extent be attributed to greater content of oxides and hydroxides of Fe and Mn in ultrabasic and basic rocks and soil formed from them, as well as to their ability to bind these metals. According to R. L. Mitchell (1945), soils formed from basic rocks can contain cobalt in amounts of 20 to 100 ppm, whereas ones arising from acidic magmatic rocks contain less than 20 ppm. Some elements like B, Pb, and Mo are concentrated in soil, so that it is in most cases richer than the parent rock in these metals.

Let us examine the geochemistry of Co, Cr, Ni, and V in surface weathering of Cretaceous - Tertiary volcanites in Serbia according to V. Jovic (1990). The examined volcanites include basalts (basic rocks), andesites (neutral rocks), and dacites (acidic rocks). The given elements behaved differently in the course of surface weathering of these kinds of volcanites.

TABLE 2.3.
Content of trace elements in the Earth's crust, rocks and soil (ppm).

Element	Earth's crust	Basic rocks	Acid rocks	Sedimentary rocks	Soil
As	2	1.5	1.5	6	2
B	10	1 - 2	9	100	20 - 40
Co	22	40	20	20	3 - 15
Cr	150	200 - 2000	20	100 - 500	60 - 200
Cu	55	80 - 180	10	8 - 80	15 - 40
Mn	950	1500	700	600	300 - 500
Mo	1.5	1.2	2.5	1.2	1 - 2
Ni	80	50 - 800	5 - 25	52	20 - 90
Pb	65	3	24	17	18
Se	0.05	0.1	0.1	0.5	0.01
Ti	5600	9000	2300	3800	4000 - 5000
V	110	200 - 250	40 - 80	100	100
Zn	70	80	50	65	30 - 70

1. *Cobalt* is an element poorly represented in the Earth's crust (average content: 22 ppm; Krauskopf, 1979). Basalts contain 40 ppm of cobalt on average, while andesites show variations in the range of 10 - 30 ppm (Wedepohl, 1972). The content of this element is in large measure correlated with that of magnesium in rocks. Normal cobalt content in soils is 1

- 40 ppm, most often 3 - 15 ppm (Kabata - Pendias and Pendias, 1985)[13]. The content of cobalt varies from 2 to 24 ppm in volcanites of Serbia and is somewhat lower in soil. Although it is mobile under conditions of surface rock weathering, this element never migrates in the dissolved form, since it is adsorbed in significant amounts on Fe - Mn minerals and clay minerals (V. Jovic, 1989);

2. *Chromium.* The average content in continental basalts comprises approximately 200 ppm (Wedepohl, 1978). Andesites have lower chromium content (55 ppm on average), while dacites are poorer still (20 ppm). The average content of Cr in volcanic soils of the United States varies around a value of 85 ppm (Kabata - Pendias and Pendias, 1985). In Serbia, the basalt of Mt. Rudnik has the highest Cr content (250 ppm), while the andesite of Mt. Radan has the lowest (35 ppm). As for soils, Cr content remains practically unchanged in the case of soils formed from basalt and andesite, but is somewhat lower in ones formed from dacite (110 ppm in the rock, 50 - 55 ppm in soils formed from it);
3. *Nickel.* Average nickel content is 80 ppm in the Earth's crust (NAS, 1975) and 40 ppm in soil (Swaine, 1955), although there are very many localities with average content of as much as 90 ppm. Nickel is a typical element of basic and ultrabasic rocks: in basalts it occurs in the range of 25 - 530 ppm, in contrast to a range of only 3 - 28 ppm in andesites. In volcanites of Serbia, the content of nickel varies from 20 ppm (dacite) to 150 ppm (basalt). In soils formed from them, it ranges from 15 ppm (soils formed from dacite and andesite) to 240 ppm (soils formed from basalt). During weathering of basalt and formation of a soil cover, the content of Ni increases, whereas decrease in the content of this element is discernible in soils formed from andesite and dacite;
4. *Vanadium.* Average content of vanadium in the Earth's crust is 110 ppm (Krauskopf, 1979). It ranges from 200 to 250 ppm in basic rocks (basalt, gabbro), but is perceptibly lower (about 70 ppm) in acidic magmatic rocks (Kabata - Pendias and Pendias, 1985). Average content of vanadium in soil is 90 ppm, the range of its somewhat more frequent occurrence in soil being 3 - 500 ppm (Bowen, 1979). In Serbia, basalts and andesite - basalts have the highest content of V (220 - 225 ppm), while dacites have the lowest (44 ppm). The content of this element declines during weathering of basalts and is approximately the same in weathered andesites and dacites.

The author concludes from the given data that the parent rock erts the greatest influence on behavior of the analyzed elements.

Due to the possibility of increased concentration and great damage resulting from it, trace element content permissible for agricultural use of soil is limited by law (standards). As we have seen, cases of overstepping can be found in nature, and such a possibility has already been indicated

[13] The content of heavy metals tolerated by plants is given in Table 2.4.

by Table 2.3.[14]. However, testing of the content of Zn, Cu, Cd, Pb, and As in soils of Vojvodina (Ubavic et al., 1993) and analyses of heavy metals in land along the Morava River (M. Jakovljevic et al., 1997) and in the Sabac - Loznica region (P. Sekulic et al., 1997) have shown that (with rare exceptions in the cases of Cr and Ni) the content of heavy metals in our main agricultural regions is below the maximum permissible concentration (MPC), i.e., these soils satisfy criteria for production of safe food. It is interesting to note that all of the mentioned soils of Serbia arose over young sedimentary formations (loess, alluvial sediments, and comples of lacustrine sediments)[15].

The yield of any agricultural crop can be limited by the amount of nitrogen, phosphorus, or some other element present in the soil, potassium for instance. The given regularity was noted already in the middle of the 19th century by the well - known German chemist Ju. Libih, founder of agrochemistry and creator of the *theory of plant mineral nutrition.* Libih stated that the absence or deficiency of one of the essential elements in the presence of all others in the soil makes the soil infertile for all plants which require that element. Formulated later on this basis was *Libih's law of the minimum,* according to which the quantitative development of organisms (or "yield" in the broad sense of the word) is determined by those elements (or factors) present in relatively minimal amounts in the natural environment. Libih's law is most often referred to in the case of irreplaceable (incompensable) resources. Thus, for example, it is clear that if a plant lacks phosphorus, no increase in the content of nitrogen, potassium, or some other element can raise the yield of that plant beyond certain limits determined by the deficient amount of phosphorus.

Constant soil productivity depends on agricultural measures, including fertilizer use, calcification, melioration, and measures to prevent erosion. Nitrogen, phosphorus, and potassium - substances extremely necessary for plant growth - are introduced into the soil in the form of fertilizers. Moreover, acid soils react well to introduction of calcium in the form of slaked lime, high - quality limestone, or gypsum and the effects of calcification can be exceptional. Calcification sharply alters physicochemical and biological processes in the soil: not only does acidity decline, but so does the concentration of aluminum and manganese compounds harmful to plants, good conditions are created for life of

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[14] In many regions of the world, anthropogenic pollution of soil with toxic elements today far exceeds the level of its natural pollution.

[15] The diversity of possible geological effects is illustrated by the following example. In the first hours of eruption of the volcano Hecla on 5 May 1970, ash covered 1/5 of the island's surface. Ash particles with fluorine content of up to 2,000 min^{-1} were scattered over a distance of more than 200 km and covered damp pasture regions. More than 100,000 sheep and cattle were poisoned by the ash-covered grass.

beneficial microorganisms, and there is an increase in content of mobile forms of N, P, K, Ca, Mg, Mo, and other elements important for plants. Repair of soils is increasingly being accomplished with the aid of zeolites, owing to their particular ability to retain soil moisture. Significant agricultural effects can also be obtained through drainage of lowland peat mud accompanied by application of potassium and copper fertilizers (plus boron and manganese in a number of cases) to replenish deficient trace elements[16]. The pronounced deficit of selenium in soil and cereals in Yugoslavia can be compensated by using selenium - enriched NPK fertilizer (Z. Maksimovic, 1990).

Soil and Risks

Many regions with agricultural soil are exposed to natural hazards such as erosion or deposition due to the action of wind or water, flooding, liquefaction, suffosion, land slippage, gas emission, sinking, cracking, seismic activity, and volcanism. They limit the exploitation of soil improved or threatened by human activities. Among human activities aimed at improving land quality, we note soil recultivation, other farming measures, and reforestation. Degradative human activities include exploitation of mineral resources, industry, transport, water management, urbanization, recreation, etc. We shall dwell in greater detail on problems of *soil in relation to life.*

One of the basic characteristics of life is the constant exchange of matter between organisms and the natural environment. In other words, plant and animal organisms constitute an indivisible whole with nature. The link between them is realized by various organic and inorganic substances that continuously enter all of the cells of organisms. Those substances needed for life, so - called nutrients, are introduced into the organism of animals and man by eating. An exception to this is oxygen, which is introduced by breathing. The introduced food serves as a source of energy for the organism on the one hand and as material for building of body tissues on the other. Energy is liberated and new living material is synthesized in the course of the very complex biochemical processes to which ingested food is subjected. Those processes are referred to as metabolism or turnover of substances (M. Jovanovic, 1989).

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[16] Around the world and in Yugoslavia, intensive high-yield crop growing is causing removal of water-soluble forms of elements (including magnesium) from soil. Tests have shown that the amount of magnesium removed from soil varies from 1.05 to 6.3 kg/h or from 43 to 259 gmol/h. If the given values are compared with values of removed potassium (80-430 gmol/h) and phosphorus (73-547 gmol/h) - whose quantities are regularly and calculatedly replenished with each new planting - it is clear that the same measures must be undertaken in regard to magnesium.

Metabolism of mineral substances represents a significant segment in overall turnover of substances in the organism. Mineral salts are above all an important ingredient of all cells and bodily fluids. Every organ has its own characteristic mineral composition, which can in certain measure be influenced by diet. The physiological role of mineral substances is multifold. According to M. Jovanovic (1989), they are regulators of the following things: osmotic pressure in bodily fluids and cells; electrochemical reactions of the blood, lymph, tissue fluids, and tissues; cell membrane permeability and exchange of substances between cells and tissue fluids; and secretory and excretory processes and resorption. They are structural components of bones, teeth, cartilage, and other supportive elements of the body. In addition to this, they participate in the synthesis of substances of special significance for the organism (hemoglobin, coenzymes, hormones, and vitamins). The presence of certain ions is necessary for the functioning of muscles and nerves.

Let us now consider the question of trace elements in the soil and possible risks to human health. We have seen that trace elements can be found in different concentrations in the soil. Among them are the series of elements or *nutritive ingredients* needed for maintenance of life. However, every nutritive element can become toxic or even fatal in certain concentrations (Table 2.4.). A substance is considered poisonous if it prevents growth and metabolism of any organism when its concentration exceeds the norm. All elements are toxic in high concentrations, and some are toxic at low ones. For example, copper is very toxic at relatively low concentrations, and it is widely used in the form soluble compounds to eradicate algae. Especially toxic are so - called *cumulative poisons*, which are retained in organisms more easily than they are eliminated. Selenium and cadmium can serve as examples. This also applies to *combined action of two metals* when one metal enhances toxicity of the other. Especially important is the *form in which the poisonous substance is found.* For example, compounds of mercury and lead with hydrocarbons are far more toxic than inorganic compounds of mercury and lead. Conversely, organic compounds of copper are less toxic than inorganic ones[17].

Not all plants have the same threshold of sensitivity to certain elements or, more precisely, to accessible forms of elements. Increase in content of an accessible form of an element above the level of tolerance for a given plant acts toxically, blocking the metabolism of enzymes and vitamins.

In response to toxicity of metals, a certain degree of tolerance to them has developed in plants as a result of physiological processes. However,

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[17] Soil is known to possess a certain capacity for self-purification in regard to biological and mineral pollution. This capacity can be estimated by recording the rate of increase of the biological component, the quantity of microorganisms, and the value of solar radiation.

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the *mechanism of plant tolerance* has still not been adequately illuminated. There is a voluminous literature on biochemical changes, both as indicators of metal toxicity and as aids in estimating the tolerance of plants. Several mechanisms have been described whereby plants achieve tolerance. They include reduction of metal intake in the first place, processes of exclusion (a metal is either rejected or absorbed in limited amounts, its transport is limited, etc.), and processes of accumulation of a metal in certain parts of the plant (A.J.M. Baker and P. L. Walker, 1989, 1990). For example, tests on territory from Pancevo to Pozarevac - where soil was highly contaminated during the NATO aggression on Yugoslavia in 1999 - indicated that grain plants protected their fruit by accumulating heavy metals in their green parts.

The adaptive capacity of plants, animals, and man can be expressed to a greater or lesser extent, but it is generally limited in every case. Plants have adapted to soil conditions in the course of their evolution, and many varieties characteristic of definite biocenoses have been formed. In animals, adaptation or disappearance of extremities occurred (moles, etc.), together with enlargement or shrinkage of digits. Man became shorter or taller in stature, as well as more resistant to diseases. Meanwhile, the struggle for life on certain unfavorable soils often had visible negative consequences. This is examined below on several examples given by Perelman (1956) in his book "**The History of Atoms and Geography**".

TABLE 2.4.
Bearable content of heavy metals for plants
(Jakovljevic et al., 1990).

Metal	Total in mg/kg of soil		
	Often	Range	Bearable
Be	1 - 5		10
B	5 - 30		25
F	50 - 200		200
Cr	10 - 50	1 - 100	100
Ni	10 - 50	1 - 100	100
Co	1 - 10	1 - 50	50
Cu	5 - 20	2 - 100	100
Zn	10 - 50	10 - 300	300
Mo	1 - 5	0.2 - 10	5
Cd	0.1 - 1	0.01 - 1	3
Hg	0.1 - 1	0.01 - 1	2
Pb	0.1 - 5	0.1 - 10	100
As	2 - 20	1 - 50	20
V	10 - 100		50
Sn	1 - 20		50
Se	1 - 5	0.1 - 10	10

1. Plants on tundra soil contain small amounts of such elements as calcium, sodium, magnesium, and phosphorus. Lichens are especially poor in them. This solved the puzzle of the peculiar behavior of deer in such a landscape. Since precisely lichens constitute the basic food of deer in winter, they then suffer strongly expressed "mineral starvation": the organism of the animals is short of calcium, magnesium, phosphorus, and sodium. With the approach of spring, the deer for this reason start to exhibit "greedy" tendencies, eating bird's eggs, unfledged birds, etc. Such food at least partially compensates the deficiency of mineral elements, and it is not surprising that the animals eat bones, bird excrement, marine algae, and fish, and even drink seawater;
2. The acid swamp soil of very extensive forest belts in the European part of the former Soviet Union and Western Siberia is often composed of 98% quartz minerals. It is poor in mobile mineral compounds and so unfavorable for plant life that few species have adapted to such an environment (their number including pine, lichens, heather, and blueberry). Animals are especially acutely affected by the deficiency of calcium - an element that enters the composition of bones - and they for the most part suffer from rickits and are runty. The cause of an unknown disease that afflicted a considerable portion of livestock herds in these regions was for a long time impossible to ascertain. All attempts to isolate a microbic agent ended in failure, and various methods of treatment were of no help. It was finally established that the enigmatic disease is caused by reduced cobalt content in the food of livestock. The content of this rare metal was very low - below 0.0005% - both in the soil and in the food consumed by livestock. Since cobalt enters the composition of vitamin B12, a special vitamin vitally needed by animals, the deficiency of cobalt reduced the amount of it present in the organism, which led to sickness of domestic animals. Adding quite small amounts of a cobalt salt to food or using a special cobalt fertilizer completely eliminated acobaltosis (the name given to this disease, which was at one time also present in Australia, New Zealand, and Scotland) and raised the productivity of sheep and cows;
3. Podoconiosis (or non - filarial elephantiasis) - described by E. W. Price in 1988 - is frequent in Ethiopia, Kenya, Tanzania, Ruanda, Burundi, Cameroon, and the Cape Verde Islands. It was noticed that this disease occurs above all in regions with soil rich in red clay. Analysis of the lymph nodes of patients indicated the presence of micro - particles containing Al, Si, and Ti. It was concluded that the pathological agent is a mineral from the substrate of volcanic rocks (basalts), probably the amphibole eckermannite (Harvey et al., 1996);
4. In many developing countries (especially ones in tropical zones), negative influence of mineral deficits or imbalance in fodder is evident in addition to undernourishment of cattle. Areas with problematical deficits of trace elements or toxicity of trace elements in cattle are traditionally investigated by mapping of regional changes in the composition of elements in soil, fodder, and serum;

5. In tropical zones built of rocks containing clay minerals, the geochemistry of aluminum - because of the effects of this element on human and animal health - is particularly interesting for medical geochemists. In zones where weathering of such rocks occurs, the ability of mobile aluminum to be concentrated sometimes erts great influence on health, and its toxic effects have been the subject of many discussions (B. Smith et al., 1996; S. G. Epstein, 1988; C. N. Martyn et al., 1989; C. R. Harrington et al., 1994; etc.).

As can be seen, both high and low content of biologically essential elements in soil can have negative effects on living organisms, and a deficit or imbalance of trace elements - whatever its origin - represents a clear problem for the health of humans and animals. This problem is magnified by intensive agricultural activity, which leads to depletion of some important soil elements by plants grown on large areas. The influence of geochemical composition of the soil on human health can be best illustrated by the following examples.

1. Modern medicine has demonstrated the multiple action of selenium on various degenerative diseases of man. Among other things, it is known that cardiomyopathy occurs in extensive regions of China as a consequence of extreme deficit of selenium in the soil; that mortality from cardiovascular diseases in general increases with reduction of selenium intake by the organism; that a relationship exists between selenium content in agricultural products and human blood on the one hand and mortality from cancer on the other in different regions of the United States; etc.;
2. In the notable work "**Cancer and Soil**," R. M. Armstrong (1962) stressed the pronounced dependence of gastric cancer on the content of certain trace elements in soil. Writing of the indisputable link between gastric cancer and soil characteristics, S. W. Tromp assigned a certain role to copper, iodine, cobalt, boron, magnesium, and molybdenum. Soil - linked mortality of populations living on chernozem is significantly lower than in ones living on other types of soil;
3. Dental caries and endemic goiter are widespread in 70% of the inhabitants of West Africa living on the Bauta - Djalon Plateau, a situation linked with deficits of calcium and iodine in the soil. Insufficient iodine content in soil, drinking water, and food products is the cause of widespread endemic goiter in inhabitants of the tropics and subtropics. Goiter resulting from iodine deficiency is frequent among inhabitants of the Alps and Andes (J. R. Paul, 1972), as well as many other mountain regions. According to the results of investigations in Vietnam (L. N. Krepkogorskii, 1953) and Egypt, increased fluorine content in soil and water led to formation of fluorosis foci...

In forming medico - geological evaluations, it is also important to note the existence or nonexistence of microorganisms pathogenic and beneficial to man in the soil and establish whether the soil is habitat to parasites (fungi) and other possible agents of infectious diseases. An acidic reaction of the soil is favorable for development of the lowest fungi, and this can cause the various fungal diseases of the skin widely disseminated in the tropics and subtropics. Mountain soils ert various kinds of influence on human health, among other things creating conditions for anaerobic infection of wounds and incidence of tetanus or anthrax if microbic pollution of the soil is pronounced. According to Addington (1967), highly endemic zones in relation to histoplasmosis are situated in many river valleys of the world, and reddish - yellow podzolic soils with certain temperature, humidity, and wind conditions represent the environment needed for preservation and growth of this parasite.

Pedological Characteristics of the Territory of Yugoslavia

The diversity and wealth of soil types on the territory of Yugoslavia represents the main characteristic of its pedological cover. This applies above all to the territory of Serbia, where the diversity and physical differentiation of geological and other pedogenetic factors has contributed especially greatly to the complexity and diversity of that cover[18]. Thus, formation of a large number of classes and types of soil was possible on a relatively small area. A brief sketch of the classes and types represented is given according to J. Dinic (1997).

With respect to area, **automorphic soils** are dominant in Yugoslavia. Such soils are characterized by the fact that they obtain moisture exclusively from precipitation and precipitation is retained for a longer time in them. The *first class* of automorphic soils consists of undeveloped or poorly developed soils such as *lithosols, Aeolian sand,* and *colluvial soils,* which occupy an insignificant area of the country's territory.

The *second class* of automorphic soils is represented by the following types:

1. *Limestone - dolomitic dark soils* and *rendzinas,* which are developed in the carbonate terrains of Eastern and Western Serbia and Montenegro;
2. *Rankers,* soils on a silicate substrate, suitable for development of a forest cover;

[18] Most of the soil resources are found on the territory of Serbia, where the area of plowed land is 3,670,091 ha and there are 257,031 ha of orchards, 84,883 ha of vineyards, 668,633 ha of meadows, 1,011,884 ha of pasture land, 35,760 ha of land with fish farms and bogs, and 2,420,000 ha of forest land.

3. *Chernozem,* one of the most widespread and productive soils in Serbia (13.7% of its territory), formed predominantly on loess in Vojvodina, Macva, the vicinity of Belgrade, and Stig; and
4. *Smonitza,* developed on the Neogene lacustrine sediments of Central Serbia, as well as in basins of Eastern Serbia and in Kosovo and Metohija (8.6% of the territory of Serbia). Due to its richness in humus and other nutritive material and considerable distribution, smonitza is one of the most valuable of Serbia's soils.

The *third class* of automorphic soils is made up of so - called cambic soils:

1. *Brown forest soil,* formed on various rocks in Macva, Sumadija, land along the Sava River, land along the Morava River, the Timocka Krajina region, and Kosovo and Metohija (8.3% of the territory of Serbia). It is an excellent forest soil and very good agricultural soil;
2. *Acid soil* (distric cambisol), formed on acidic silicate rocks (granite, gneiss, phyllites) and sedimentary rocks (sandstone, shale), the most widely disseminated type of soil in Serbia (30.6% of its area) and the northeastern half of Montenegro. It is very suitable for development of a forest cover;
3. *Brown soil on limestones and dolomites* (calcocambisol), characteristic of karst (carbonate) terrains; and
4. *Terra rossa* spatially confined to karst of the Montenegrin Dinarides.

The *fourth class* of automorphic soils includes the following three types of eluvial - illuvial soils: *podzol,* formed on acidic rocks under conditions of a cold and damp climate; *leached soil* and *brown soil,* typical forest soils; and *rigosol* and *garden soil* (anthropogenic soils).

Apart from automorphic soils, **hydromorphic soils** also have a considerable distribution. They are soils whose evolution is influenced not only by atmospheric water, but by underground and flood water as well. The following are such soils:

1. *Pseudogleyic soils* are found in the valleys of the Kolubara, Jadar, and Western Morava Rivers. They are of low fertility;
2. *Alluvial soils* are characteristic of the alluvial plains of the larger river courses of Serbia (5.6% of its territory). They are often exceptionally fertile soils;
3. *Semigleyic soils* are found on alluvial plains and in marshes of Vojvodina;
4. *Marsh dark soils* and *swamp gleyic soils* (class of gleyic soils) are characterized by the constant presence of groundwater in the profile (Vojvodina, parts of Macva, the valley of the Sitnica River, the Pozega basin);
5. *Peat soils* (histosols) are of local distribution.

Halomorphic soils or **saline soils** are divided into two classes: *solonchaks* (acutely salinized soils) and *solonetzes*. Solonchaks contain more than 1% soluble salts, which is harmful for the development of higher plants. They are most widespread in Backa, somewhat less so in Banat and Srem. This type of soil is formed under the influence of groundwater, whose strong evaporation results in accumulation of salt in the surface layer. In contrast to solonchaks, solonetzes are characterized by low concentration of salt in the surface layer because it is leached and transferred to deeper parts of the profile. Solonetzes are present more in Banat than in Backa.

In considering the geographical distribution of soils, M. Ciric and Dj. Filipovski (1972, 1974) singled out four pedogeographic regions on the territory of Serbia. It can be seen that these regions to a considerable extent coincide with the main geotectonic units. Also characteristic is the great concentration of fertile soil (as much as 83.1%) in Vojvodina.

Geomorphologic Factors

Relief is a very important element of the natural environment. In the words of Jovan Cvijic (1922), "*Different factors are involved in determining the nature of a large natural region. Of primary importance are morphological characteristics, which constitute the basic features of such a region.*" The strong influence of relief on other elements of the natural environment and on human life results in noticeable coincidence between features of relief and geographic (economic) divisions, especially in morphologically more developed regions of the Planet. Thus, for example, the cartographic part of the "**Atlas of Prospective Development of Rural Health Protection in the Armenian SSR**" (1970) begins with an orographic map, since relief in Armenia very strongly affects many aspects of life of the population, including the organization of medical health protection.

By relief as an object of geomorphologic study, we mean the totality of all superficial lithosphere forms of different geological composition and origin. These forms can be at different stages of development, but they are connected in a complex way with each other and are in complex interaction with the natural environment. The type of relief represents a certain linkage of relief forms that have similar origin, geological composition, and history and which are repeated on large areas of the lithosphere's surface. Two groups of relief forms are distinguished: *positive forms* (mountains, mountain ranges, hills), which are convex in relation to the level horizon and surrounded by lower elements of relief; and *negative forms* (valleys, basins), which are concave and surrounded by elevated parts of relief.

One of the most significant factors in development of the morphology of terrains is *geological structure of the area on which the forms themselves are sculpted.* Regional geomorphologic characteristics are also determined by geological structure. To be specific, the tectonic pattern dictates the form of larger morphostructures, the position of such morphostructures, and their interrelations, while lithological composition determines the kinds and intensity of processes that is the features of relief forms. The karst process is dominant on terrains built of carbonate rocks, whereas fluvial, fluviodenudational, and slope forming processes are dominant on ones built of noncarbonated rocks. Thus, the relief of some area directly or indirectly tells us about the area's geological history in the last periods of its existence. We see in relief reflections of old denudational surfaces, forms of glacial accumulation, and traces of former rivers, rock slides, land slips, etc. By studying relief and its genesis, we get a rough idea of the geological composition of the upper parts or surface cover of the Earth's crust (usually the parts most important for building purposes and agriculture).

Apart from the influence of geological structure, development of exogenous processes and formation of individual types of relief are significantly affected by *climatic characteristics*, which determine the emergence of glacial, periglacial, and Aeolian relief. On the other hand, relief has an indirect effect on climate. Influence of elevation and exposure is evident in specific local climatic phenomena (air temperature, precipitation, cloudiness, winds, etc.), accompanied by corresponding characteristics of the water regime and particular aspects of the genesis of soil and animal life. To be specific, *elevation* is the most influential property of relief forms. It is usually expressed especially strongly in mountainous regions, where other characteristics - *slope inclination* and *exposure* - are also of great significance.

Sculpted in moraine and glaciofluvial material, *glacial relief* is characteristic of enormous areas in northern parts of Asia, North America, and Europe. Series of moraine bulwarks and hillocks stand out, together with gently rolling moraine plains and types of uniform relief. Forms of Pleistocene glaciation have been significantly altered under the influence of younger fluvio - denudational processes.

Several characteristics of relief need to be further considered as a direct factor in the disposition of *geochemical landscapes*. The given role of relief is essentially determined by the degree of its horizontal and vertical breakup. Relief above all dictates to a considerable extent the form of contours of autonomous and dependent landscapes, as well as the area between them. Thus, for example, regular alternation of hillocks, plateaus, lakes, and bogs is discernible in regions of hillocky moraine relief. Completely different is the picture of autonomous and dependent landscapes under conditions of typical erosional relief or under conditions of dunes, even if all these types of relief are situated in the same climatic zone. No less significant is the influence of *relief on the ratio between migration of* *matter in solid form and its migration in the dissolved state*: erosion of upper horizons of the soil and weathering crust, i.e., mechanical denudation, occurs under conditions of drained forms of relief, whereas chemical denudation is far more prevalent on undrained plains. Influence of relief is also manifested in other ways:

- *The rates of water circulation and redox processes in a landscape* depend on relief. If the relief is greatly broken up, then water circulates more intensively in the landscape, the oxidation ambient is better developed, and the reduction environment is less developed under otherwise equal conditions. Under conditions of less broken relief, the reverse is the case;
- On sectors with very broken relief, the Quaternary cover is usually thinner, and river valleys are completely or largely entrenched in different bedrocks. This results in *involvement of chemical elements of these bedrocks in recent migration*, and such elements can ert crucial influence on the landscape itself;
- Mountainous relief, with its sharply expressed vertical and horizontal breakup, can dictate landscape *heterogeneity*, whereas predominantly Quaternary formations are involved in recent migration under conditions of old continental shields and platforms, with relatively horizontal deposition of layers and level surfaces;
- *Diversity* of the soil - plant cover is characteristic of young, unbroken plains. Only future erosive breakup can bring about a more uniform landscape and its greater conformity with climatic conditions.

Relief and Living Conditions

Through modification of other elements of the natural environment, relief indirectly (and sometimes directly in several of its properties) influences the conditions of human life, exploitation of various resources, and other anthropogenic activities. The consequences of influence erted by relief can be negative for human life (worsening of agroclimatic conditions with increase of elevation, destruction of soil and vegetation by erosive processes, shortage of water in karst regions, impeded building and exploitation of roads and other construction projects, etc.), but also positive (the possibility of development of special forms of tourism in regions of high mountains, etc.).

High mountains (arbitrarily taken to mean elevations above 2,500 m) are characterized by a familiar affliction, namely *mountain sickness*. Already in 1590 the Spaniard Acosta, traveling in the Peruvian Andes, noted in himself and his companions strange symptoms of asthma, weakness, heart palpitations, headache, nausea, etc., which he lumped under the concept of *mountain sickness*. In his opinion, the given symptoms arose due to inhalation of rarified air. Only in 1887 did the well - known French physiologist Bert prove the link between *mountain sickness* and oxygen deficiency. Despite the long period of investigation of this question, serious elaboration of pathological processes transpiring during residence in high mountains is today still far from complete, although many physiologists have worked on the problem. Evidently, the whole gamete of pathological reactions encountered under conditions of high mountains cannot be covered by the single term *mountain sickness* or reduced to hypoxia (oxygen starvation of the organism) alone, even though the latter is of important pathogenic significance.

For most people, the climate of **high mountains** is deleterious, since it provokes overertion of the organism's system of accommodation. This does not apply to the extended zone of the Andean Plateau from Columbia to Chile, where more than 10 million people live at elevations above 2,500 m. That zone (up to the snowline above 5,300 m) is not merely favorable for life; it was even the center of the Inca state, one of the great civilizations of pre - Columbian America. In the present day, inhabitants capable of performing normal work live there, and their numbers are not declining. This applies especially to the Indians and "*gauchos*," who systematically endure *hypoxia* and the action of moderately low temperatures. As a result, development of the younger generation of "*gauchos*" has a hypoevolutionary character, with slowed growth and delayed appearance of teeth. The thoracic cavity in children of the local population has greater measurements in all dimensions than among children living at lower altitudes[19,20].

For climatic and other advantages, **low mountains** (with elevations of from 750 to 1,000 m) and **medium - high mountains** (with elevations of from 1,000 to 2,500 m above sea level) are of great value for rest, recreation, and therapy. Mountain spas are every year gaining in significance throughout the whole world. For example, it has long been considered that treatment of tuberculosis can be especially successful in mountains, and it is not without reason that such spa as Davos in Switzerland and many others on the shores of Swiss lakes, as well as ones in the mountains of Scotland and in the Caucasus, has enjoyed worldwide popularity. Moreover, it has turned out that not only lung ailments, but also cardiovascular diseases and atherosclerosis, are much more successfully treated in mountains than on plains. Mountains can also be used for recovery from more serious treatable diseases such as bronchial asthma in adults and children.

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[19] Investigating Indians living in the high mountains of Peru, where oxygen pressure is reduced by 44%, scientists established that total ventilation of the lungs is only 22% greater than in the inhabitants of plains, and that the quantity of blood in aborigines there is 1.74 liters greater than in the sea-level population of Lima.

[20] Classification of mountain regions according to altitude above sea level can be arbitrary, since the same elevation in different mountain massifs of the world can act on man in different ways.

In study of natural biocenoses, special attention has been paid to the significance of mountain and inter - mountain territory, river valleys, and lowlands for diseases of man in areas with different morphological manifestations. They are the main points of orientation for workers engaged in drawing up an epidemiological regionalization or trying to classify the foci of diseases. For their part, those forms of relief dictate the nature of the soil and plant cover and characteristics of animal life. For certain regions in such areas, it is sometimes possible to strictly establish natural biocenoses with which natural foci of diseases are linked, i.e., to discover the pathways of circulation of disease agents. On the basis of her field studies of diseases with natural foci conducted over a number of years, P. A. Petrishcheva (1965) concluded *that river valleys in the medical sense represent the greatest danger, being distinguished by diversity of natural foci of diseases*, and gave 10 examples of such diseases.

Karst Areas and Living Conditions

Many extensive areas of the world (in countries bordering the Mediterranean, France, Great Britain, the former Soviet Union, the Southeastern United States, Canada, Mexico, Western India, the Malay Archipelago, Australia, and North Africa) are marked by karst phenomena sculpted in limestones, dolomites, gypsum, and other soluble rocks[21]. It is difficult to find in nature a similar geomorphologic formation or a type of relief so unusual. The main condition for development of the geologically predisposed erosion process is the presence of a specific lithological base, most often one composed of limestone. Dissolution of limestone, i.e., the process of karstification, gives rise to a rocky surface relief furrowed by sinkholes and crevices and marked by ponors, sinking streams, dry dolines, uvalas, enclosed karst poljes, and karst plateaus, with scarce tillable soil and degraded vegetation (Fig. 2.7.).

In addition to its specific surface morphology, a special underground morphology develops as the most conspicuous consequence of the karst process in the given geological environment, and this feature clearly distinguishes karst regions from non - karst terrains. The indicated underground morphology is expressed through an irregular network of karst galleries and caverns formed by means of dissolution and by the

[21] For example, in Asia karst terrains occupy an area of around 1.6 million km^2 or 3.6% of the continent's surface (the largest karst region in Southern China has an area of 500,000 km^2, of which 200,000 km^2 falls on the famous conical karst, with limestone elevations of conical and columnar form surrounded by valleys and rice paddies, while the karst of Asia Minor occupies an area of about 150,000 km^2). In the case of North America, karst regions occupy 15% of the territory of the United States, 60% of Jamaican territory, and 50% of the territory of Cuba. In Australia, the Narlabor Desert occupies an area of about 200,000 km^2.

mechanical work of water to great depths[22]. For this reason, karst is characterized by scarcity of water at the surface and abundance of groundwater. In contrast to non - karst terrains, most precipitation is filtered into a pervious environment in which circulation of water to the lowest drainage basins proceeds along privileged collectors and deformed cracks (Fig. 2.8). Runoff of water accumulated in karst poljes during rainy periods occurs through ponors and estavelles. For example, the Niksic polje in Montenegro is drained by more than 880 ponors and estavelles, and the swallowing capacity of the Slivlje ponor alone is as much as 120 m^3/s. Groundwater is evacuated through strong karst springs, mainly formed at points of contact between limestone and some impervious rock. The springs themselves are characterized by great variations between minimal and maximal output in the course of every hydrological year, depending on the level of precipitation. Thus, one of the strongest karst springs in the world, the Durmanli spring in Turkey, has a maximal output of more than 100 m^3/s, average output of 50 m^3/s, and minimal output of 20 m^3/s. The fountainhead of the Trebisnjica in Herzegovina has a maximal output of more than 300 m^3/s, average output of 80 m^3, and minimal output of only 2 m^2/s.

The described inorganic factors dictate the forms of life and human activity on karst. The thin layer of soil, hard rocky substrate, and special morphology of terrains has limited economic activity in the past, and indeed do so today. The specific natural conditions gave rise to a specific organization of settlements, road networks, and the like, which even today, with all the possibilities of modern technology, has remained virtually the same.

For a long time, it was believed that conditions for survival of living organisms are lacking in the dark karst underground. When the guide Luka Cec in 1831 discovered a cave beetle deep underground in the cave Postojnska Jama in Slovenia, it was the first discovery of such a species in Europe. Gradually other caves were found to be home to an increasing number of endemic and other species of animals and plants adapted to

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[22] The deepest pit in the world to be investigated so far is the Reseau Jean Bernard in France with a depth of 1,535 m. In Yugoslavia, the pit Jama na Vjetrenim Brdima on Mt. Durmitor has the greatest depth (897 m) among known pits. The longest known cave systems are as follows: the flint Mammoth Cave system in the United States (530 km); the Optimisticheskaya system in Russia (153 km); and the Holloch system in Switzerland (133 km). One of the largest known cave systems on Earth is the system of Carlsbad Caverns in the national park named after it in the state of New Mexico, which is sculpted in limestones and gypsum of the Guadaloupe Mountains, with caves of giant dimensions (the Big Chamber has a length of 1,200 m, width of 190 m, and height of about 90 m). It is calculated that from 13 to 16 thousand pits and caves exist on the territory of former Yugoslavia, the longest of the caves being the cave Pecina nad Vrazjim Firovima, with the entrance in Montenegro and extending to the Pester plateau - 10.5 km.

life below the Earth's surface. The well - known tailed amphibian *Proteus anguineus* is certainly one of the most interesting inhabitants of groundwater of the Dinaric karst.

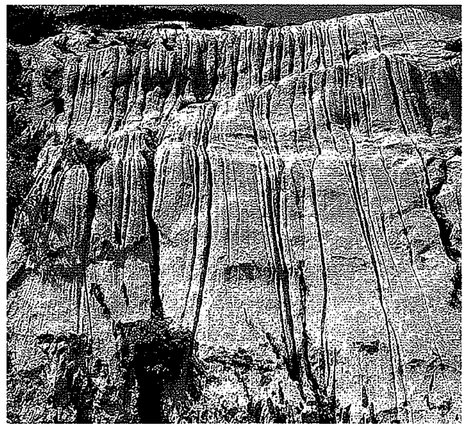

Fig. 2.7. Karstified limestone (Photo: D. Milovanovic).

Thirty thousand years have elapsed since the *Krapina prehistoric man* lived in the cave of Husnjakovo near Krapina (in the Zagorje region of Croatia). Tools of the Krapina man were fashioned of several kinds of silicate rocks or coarsely grained aggregates of quartz, opal, and chert. Prehistoric man of that era found shelter and sometimes took up permanent residence in the antechambers and darkness of many caves.

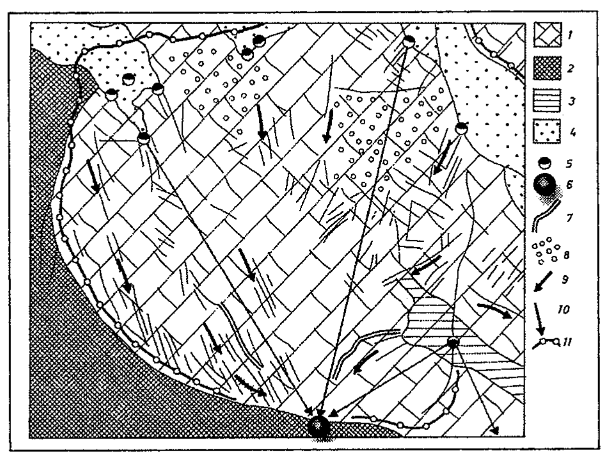

Fig. 2.8. Sketch map of a watershed in open karst. 1. limestone; 2,3,4. impermeable rocks; 5. ponor; 6. spring; 7. wet dolina; 8. pockmarked karst; 9, 10. flow directions; 11. water divide.

In the karst of Serbia proper, a number of Paleolithic cave finds have been made[23]. These finds are characterized by a small number of cultural artifacts and a large quantity of faunal remains (D. Mihailovic, 1998). In the late period of prehistory, caves were used as temporary residences by bands of humans. Discoveries in the cave Lazareva (Zlotska) Pecina near Bor in Eastern Serbia indicate that as early as 5,000 years ago, there existed true *metalworks* in this cave and that men of that time were already familiar with copper ore and the basic metallurgical processes needed to obtain *final products*. The drawings of a horse and rider discovered in a cave near the village of Gabrovnica (in the vicinity of Kalna) probably also date from that period.

Much later, during the Middle Ages, many caves served as shelters from various enemies. Due to exceptionally attractive calcite ornamentation, they have today become increasingly transformed into tourist attractions. We also note familiar cave drawings and engravings as important monuments of cultural heritage. Today millions of people annually visit the famous caves of the United States, Belgium, France, and countries of the Balkan Peninsula and other parts of the world.

Speleotherapy, i.e., curing in caves, is not a modern invention. Already in states of the ancient world and the Middle Ages, it was known that sojourns in caves - especially ones where the air is heated to 30 - 40°C - help to reduce pain in the bones and improve the feeling of general well - being. It was speculated by N. A. Danilova (1971) that the inaccessibility of caves to electromagnetic fluctuations and storms, together with increased temperature, air sterility, and microclimatic stability, can act as therapeutic factors for patients suffering from bronchial asthma, chronic bronchitis, whooping cough, rheumatism, and certain skin diseases. In the former Soviet Union, increasing use was made of *cave sanatoria* such as Kungurska in the Urals, Proval in the Northern Caucasus, Cufat, Kale, and Tepe Kamen in the Crimea.

One of the specific characteristics of karst lies in the wide range of *risks it holds for any form of human activity aimed at altering nature, particularly construction of hydrotechnological projects and structures for water capture and formation of artificial reservoirs.* We cite certain aspects of the given problem as discussed in the book "**Geological Engineering in Karst**" by P. Milanovic (1999).

1. *Breaches (collapses)* are spatially independent, unforeseen, and random events that represent grave danger for all structures built in karst. One of their most dangerous characteristics is the fact that they occur practically

[23] The Middle Paleolithic lasted from 130 to 40 thousand years before the period of recorded history, the Upper Paleolithic from 40 to 10 thousand years, and the younger period of prehistory from 10 to 0 thousand years.

instantaneously. They occur on terrains where karstified rocks are covered by loose sediments, most often after a long phase during which material from a ponor is carried away by underground streams (Fig 2.9). Since 1950 in the United States, for example, there have been thousands of such collapses, accompanied by the formation of pits measuring up to 100 m in diameter and 65 - 70 m in depth. In one such collapse in the vicinity of the Blyvooruitzig Mine in 1964, three residential buildings with five residents formally disappeared, and the Pennsylvania Bus Garage sank 60 meters in the course of several hours when the land under it collapsed into a cavern or karst sinkhole;

2. Despite very complex and often long - term studies employing the latest research methods, the *risks of building in karst* must be accepted as unavoidable. In dam construction, for example, the dominant risk is that of water loss, and cases are known where certain reservoirs (Lar in Iran, Montejaque in Spain, Vrutac in Yugoslavia, etc.) remained empty or were only partly filled with water. The majority of such reservoirs were sanated successfully or with partial success, but often with extensive sealing work. Especially great water losses were recorded in the cases of the Keban Reservoir in Turkey (26 m^3/s after the first filling, less than 10 m^3/s following sanation) and the Vrutac Reservoir in Yugoslavia (25 m^3/s after the first filling, sanation unsuccessful). Negative ecological consequences include changes in the regimes of downstream karst springs, sometimes with alteration of water quality;

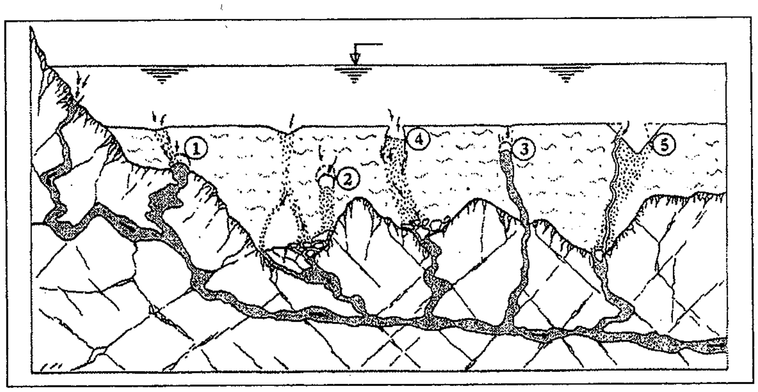

Fig 2.9. Scheme of important stages of collapses in alluvial cover (P. Milanovic, 1999).

3. *Gypsum* and *anhydrite* are especially sensitive geological environments for construction of dams and formation of reservoirs. After filling of the reservoir, the rate of dissolution abruptly increases and suffosional processes are manifested in such an environment. Several dams in the United States (the McMillan, Avalon, and Hondo Dams in Texas and New Mexico) were abandoned because of such problems. The enormous mass of dis-

solved gypsum on the shores of the Kamsk Reservoir near the city of Perm in Russia caused many collapses in the vicinity of the reservoir itself. Six months after filling of a reservoir on the Euphrates River slowed by the Mosul Dam in Irak, great amounts of gypsum and anhydrite (13,000 t) were dissolved and leached, which resulted in the formation of large cavernous spaces under the dam's foundation;

4. Undesirable consequences can also arise in the case of *underground accumulation.* The possible risks arising here can be illustrated by the two following examples: a) the underground stream Jijao in the province of Guangxi in China was blocked for irrigation purposes. Completely unexpectedly, fields upstream were flooded during the first rainy season as a consequence of this measure, and 240 persons were evacuated from the threatened region; b) on the outlet part of the channel of the Obod estavelle on the rim of Fatnicko Polje in Herzegovina, a concrete plug measuring 10 m in height and 3.5 m in average width of 3.5 m was constructed to prevent flooding of the polje. The first heavy rains after construction of the plug caused a sudden rise in the level of groundwater with appearance of several tens of springs on the slope 80 - 100 m above the level of the plug, these springs having a total output of around 11 m^3/s. This state in the discontinuous karst groundwater provoked strong local earthquakes in the vicinity, ground tremors, and slippage of rock masses. The experiment had to be stopped: the plate of reinforced concrete was mined, and water pressure dropped suddenly as a result[24].

Geomorphologic Characteristics of the Territory of Yugoslavia

Endogenous relief. Global geomorphologic features of the territory of Yugoslavia were determined by development and characteristics of the basic geotectonic units of the region. This is especially evident on the Geomorphologic (Morphostructural) Map of Serbia (M. Zeremski, 1990). Thus, the Inner Dinarides (Montenegro and Southwest Serbia) are characterized by karstic relief with dominant plicated morphostructures oriented in the direction of the given range. The same can be said about karst of the Carpatho - Balkanides, which is marked by two series of mountains running from north to south with a turn to the southeast. The Serbo - Macedonian mass in the central part of Serbia represents a zone of insular and peninsular mountains with a characteristic parquet structure. Negative relief forms are manifested in various depressed morphostructures - trenches, valleys, basins, and depressions. The Pannonian Basin in the north of Serbia stands out with respect to its dimensions.

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[24] Under conditions of hard to foresee negative consequences of regulating the regime of groundwater, a possible solution to the problem in both cases could be to work in several stages, with partial closure of the channel initially, observation of effects during the first rainy season, and subsequent determination of the required scope of the next intervention.

Created over the course of their long geological history, positive and negative morphostructures resulted from the action of plicative and radial tectonics. The latter type was dominant during the Neogene and Quaternary, when the contemporaneous morphotectonic structure of Serbia was formed.

Exogenous relief. A number of morphological agents took part in the creation of exogenous relief. Some of them were active during earlier geological periods (abrasional, glacial, and Aeolian agents); creating various erosive and accumulative forms that today have a fossil character. Other natural agents (fluvial and karstic agents, forms of surface and linear aquatic erosion, landslips, and the Aeolian process) are active today, and the results of their work are recent. Creating various erosive and accumulative forms, all of the indicated agents have helped to make the relief of Yugoslavia become in every respect much more complex, varied, and discontinuous.

Fluvial relief is by all means the most strongly expressed and spatially widespread among all of the exogenous relief forms of Yugoslavia. A developed hydrographic network participated and is participating in its formation and development, effects of the erosive and accumulative work of this network having been determined by a series of geomorphologic factors (J. B. Dinic, 1997). As the largest forms of river erosion in Yugoslavia, river watersheds belong to three marine basins (Black Sea, Adriatic, and Aegean), among which the Black Sea basin embraces by far the greatest territory. Representing a second conspicuous form of fluvial erosion, river valleys here are characterized by considerable morphological diversity.

Created by the action of snow and frost, forms of *periglacial relief* are dominant above the tree line in higher mountain regions, while forms of *glacial relief* created by the powerful action of Pleistocene glaciers have been preserved in the highest parts of the Prokletije, Durmitor, and Sar Mountains. Enormous amounts of fluvioglacial material were accumulated in the Skadar Depression (Cemovsko Polje in Montenegro). Also preserved in the relief of Yugoslavia are forms of *abrasional relief*, which arose during the Neogene in the course of rhythmic sinking and withdrawal of the Pannonian Lake. Such regression resulted in the formation of stepped abrasional plateaus and terraces.

Genetically linked with the action of wind, *Aeolian relief* is spatially limited to the plain of Vojvodina and land along the Danube. Forms of this relief arose as a result of accumulation of loess and sand in the guise of expansive loess plateaus and two sandy regions.

Karst relief is linked with the occurrence of carbonate rocks and is most widespread in the Dinarides (Montenegro and Western Serbia). This is for the most part mountainous terrain marked by the presence of various karst forms. We have already discussed characteristics of karst geomorphology.

The main morphometric index - *hypsometric structure* - of the territory of Serbia is given according to J. B. Dinic (1997). The following hypsometric categories are represented here:

- Plains and lowlands up to 200 m above sea level, which occupy 32,540 km^2 or 36.83% of the territory of Serbia;
- Hilly land - 21,829 km^2 or 24.79%;
- Low mountains - 24,105 km^2 or 27.28%;
- Medium - high mountains - 9,681 km^2 or 10.96%; and
- High mountains - 206 km^2 or 0.23%.

The highest peak of Serbia, Mt. Djaravica in the Prokletije Mountains, is 2,656 m high, while the lowest point of Serbian territory, with an elevation of 30 m above sea level, is the place where the Timok River empties into the Danube. The difference in altitude between these two points comprises 2,623 m. The significant participation of low and hilly land in the hypsometric structure of relief (61.53%) can be considered a favorable circumstance for agricultural and other production.

Tectonic Movements and Structural Forms

Tectonic Movements

Throughout the entire geological history of the planet, and even in the historical period as well, the Earth's crust has been constantly subject to bending, leaning, rising, and falling. The relative position of rocks has been altered as a result of such movements. All such shifts are united under the term *tectonic movements*. Tectonic movements can have any direction: they can be upward, downward, at an oblique angle, or horizontal. They can be extremely slow and gradual or sudden and powerful. The effects of such activity are present everywhere. In the Himalayas, marine sediments are raised to more than 8,500 m above sea level. Deposits of similar origin with faunal remains are widespread in the interior of the United States, where the rim of the Grand Canyon of the Colorado River is more than 2000 m high. Over the last 10 million years on the territory of Yugoslavia, vertical movements have attained a maximum value of almost 8,000 m, with more than 2,000 m of uplifting (in the region of the Sar Mountains) and more than 5,000 m of downwelling (Segedin).

While on the subject of vertical movements, we note the fate of the Temple of Serapis, built around 2,000 years ago on the shores of the Bay of Naples in Italy. Due to long - term gradual sinking of the ground, this temple from the 13th to 16th Centuries was under water. The marble columns of the temple bear unmistakable marks of time spent in water, namely channels excavated by the marine mollusk *Lithdomi*, from which it can be seen that water reached a maximum level of 5.71 m above sea level. After that period, the temple "resurfaced" due to uplifting of the ground, only to suffer its old fate at the beginning of the 19th Century due to renewal of the sinking process. By 1954, water was already 2.5 m above the bases of the columns.

Another well - known example is sinking of the Adriatic shoreline. Sinking has resulted in shrinkage of the coastal zone, transformation of peninsulas into islands, and inundation of sand beaches and cultural - historical monuments, all of this taking place during the historical period, with obvious influence on the environment.

Two forms of tectonic movements are distinguished here: *epeirogenic* movements and *orogenic* movements. Epeirogenic movements (upliftings and downwellings) can affect rock masses on areas of continental size and are accompanied by only slight internal deformations. Some sectors of the Earth's surface rise above sea level, and processes of denudation are prevalent there. Others sectors sink, and sediment accumulation is prevalent in them. Generally regarded, the youngest period in the Earth's geological history has been marked by uplifting of continents and sinking of the ocean floor. Mountain formation on once geosynclinal areas is a result of orogenic movements. These movements create enormous mountain ranges, during whose formation both uplifting and compression of rock masses occur.

An *active tectonic regime* is peculiar to regions of Alpine and Mesozoic folding. Such regions extend in a belt along the Cordillera and Andes in America; along the Alpine - Mediterranean zone in Eurasia; and along a belt in East Asia embracing regions of Far Eastern seas and island chains (Fig. 2.10.). The relief of tectonically active regions is very broken. Activity of the tectonic regime is manifested as well in powerful seismicity and development of volcanism.

A *passive tectonic regime* is characteristic of a large part of Precambrian platforms. This applies to the entire territory of the North American and Russian platforms; the Siberian and Brazilian platforms; a large central zone of the African platform; the Indian platform; and others. The relief of such regions is level, low - lying in some and slightly elevated in others. Only on separate small sectors of the platform can the tectonic regime be somewhat activated and the sectors themselves marked by mountain ranges of limited dimensions (the region of the African rifts, for example). Shallow seas have developed on inundated sectors of some platforms. It goes without saying that all of the indicated territories are aseismic and without volcanism, except for a few active sectors (Fig. 2.10.).

During the 60's and 70's of the 20th Century, it came to be recognized that the outer shell of the Earth or lithosphere consists of seven large and several small plates. The large plates support both the American continents and the continents of Eurasia, Africa, Australia, and Antarctica, as well as a large part of the Pacific Ocean. The largest of them is the Pacific Plate, composed entirely of oceanic lithosphere. With a thickness ranging from 75 to 125 km, these plates migrate gradually in relation to each other.

Depending on the nature and relative movement of the plates, the boundaries between them can be: 1) *divergent* (boundaries between objects moving apart), when plates separate from each other, building a rift in the process; 2) *convergent* (boundaries of compression), when plates collide with each other or one descends beneath another in a zone of subduction; or 3) *transformational*, when plates slide against each other along a transform fault. The objects subject to the movements indicated are united under the term *tectonic plates*. Based on ideas of A. Wegener about continental displacement, this relatively new geological theory at the end of the 20's of the last century supplanted the *geosynclinal theory* of development of fold mountains, which up to that time had been the most generally accepted model of development of the Earth's crust.

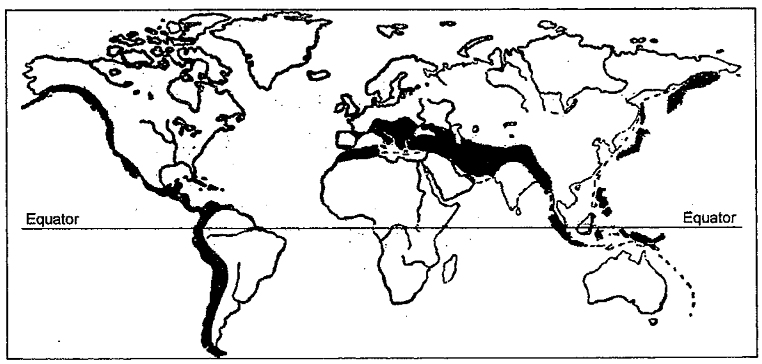

Fig. 2.10. Areas of geosynclines and continental masses during the end of Alpine orogeny (after Shatsky).

Recent Tectonic Movements

The history of the temple of Serapis serves as an excellent illustration of the nature and intensity of fluctuating recent vertical movements. A large number of other examples can be cited from different seacoast localities throughout the world. Precise geodetic measurements and other observations indicate that the rates of positive and negative vertical movements in different regions of the world are different. On the vast territory of the former Soviet Union, for example, the rate of lifting varies from 14.4 to 66 mm/year, whereas the maximum rate of sinking (52 - 65 mm/year) is recorded on the coast of the Black Sea, which for this reason is marked by active processes of abrasion and slipping. In the former East Germany, on the other hand, recent vertical movements of the Earth's crust are almost exclusively confined to sinking, which in certain regions exceptionally attains a rate of 4.0 - 4.5 mm/year, but throughout most of the country occurs no faster than 2.0 mm/year. Generally speaking, the average rate of recent tectonic movements on platforms is usually from 1 to 2 mm/year. The maximum intensities of both vertical and horizontal movements are controlled by faults, a fundamental type of environmental heterogeneity.

Influence of recent vertical tectonic movements is reflected above all in inundation of low - lying zones beside seas and oceans, where coasts have to be defended against encroachment of the sea by construction of dikes, as is done by the inhabitants of Holland. Land must also be defended against landslides and to some extent against flash floods. The indicated influence is realized indirectly, through such more important factors as relief, the level of groundwater, and the level of seas and oceans, which dictate changes of relief. In the case of landslides and material transported by flash floods, the influence in question is realized through the action of seismic factors (since it has been established that seismically active regions are characterized both by increased rates of recent movements and by significant differentiation).

Recent horizontal movements are characterized by faster rates in comparison with vertical movements. Thus, for example, throughout the system of the San Andreas Fault in California and that of the North Anatolian Fault in Turkey, the rate of such movements attains several centimeters a year. Precise geodetic observations have shown that these movements occur unevenly (precipitously) in time and space, and that recent activity in different parts of faults varies significantly.

A number of geodynamic testing grounds have been set up in regions of active rift structures. Repeated geodetic observations on Iceland established that an active rift process with intense horizontal movement (extension) of the order of 7.5 m and vertical movement of 3 m took place along the Krofla deformation zone during the period of 1975 - 1981. It has been established with a precision of up to 1 cm that the inner zone of the Asal Rift in East Africa is subject to the action of current forces of extension (movement) at a rate of 5 cm/year along the rift's axis. This is apparently caused by intrusion of deep - lying solutions into the axial zone of the rift.

Structural Forms

When rocks are subjected to pressure above their limits of elasticity, they start to bend plastically, forming series of folds in the process. Many fold belts tens and hundreds of kilometers wide have been formed in this way.

The main types of structures formed are: *anticlinal* and *synclinal flexures*; and *structural domes*, roughly symmetrical folds that are especially well expressed in regions with salt deposits (Fig. 2.11.).

Cracks and *faults* represent disturbances of the compactness of moveable parts of the Earth's crust. Sliding (movement) parallel to the fault surface occurs in faults, in contrast to cracks. Faults are encountered in all types of rocks, but share a common feature, namely that one wing of the fault has shifted in relation to the other. In some cases, faults are grouped into zones, when movement is distributed over several fault surfaces, and the total jump can comprise not more than 1 mm or attain several kilometers.

The rate at which the wings of faults move can vary greatly from place to place. Movement of the order of up to 12 m and more in only a few minutes has been observed along some faults. Earthquakes almost always occur during such sharp movements of the Earth's crust. On the other hand, movement along the fault surface is slow in many cases. Sometimes the occurrence of a very large total jump indicates that there were hundreds of smaller movements separated by long intervals of dormancy.

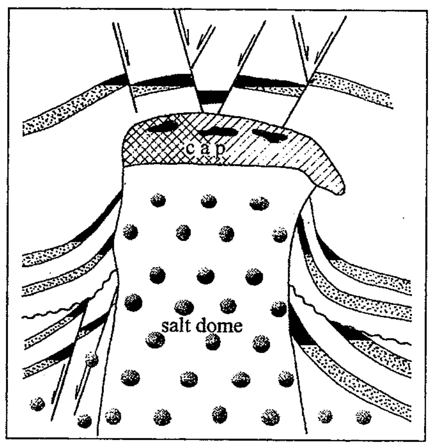

Fig. 2.11. Scheme of salt dome.

Some tectonic deformations are vertically oriented, but faults with an inclined fault surface are prevalent. Characterized by a steep drop, so - called *normal faults* are created in zones of shifting of the Earth's crust. On the other hand, zones of folding are characterized by reverse movement of one wing across the other at a slight angle, in which case *reverse faults* or *tectonic nappes* are formed. For example, the Alpine massif consists of a series of plates that have moved one over the other.

There are also horizontal faults, i.e., faults with horizontal movement of blocks parallel to their extension. One of the most famous examples of such a structural form is the San Andreas transform fault, which is characterized by generation of enormous seismic energy, i.e., it is known for causing the earthquakes of California. Total length of the fault is estimated at 800 km, while the total value of relative movement of one wing against the other from the Miocene to the present day comprises about 240 km, about 1 km in the Quaternary alone.

Sinking of a block between two bordering faults results in the formation of *tectonic trenches* (*grabens*), while uplifting produces *horsts*. Thus, due to sinking of the narrow trench in which they were formed, the Dead Sea and valley of the Jordan River are today below the level of the World Ocean: the surface of the shallow Dead Sea is as much as 430 m below the level of the ocean. Certain lakes were formed in the same way, for example Lake Tanganyika, which is 1,418 m deep and whose bottom is 620 m below sea level. The deepest graben in the world is Lake Baikal in Eastern Siberia, which has a depth of 1,713 m.

It was postulated in the 30's of the last century that there exists a network of faults deep in the Earth's crust, such faults being somewhat later called *deep faults* (A. V. Peive, 1945). Hundreds of kilometers long, these global tectonic breaks erted significant influence on the nature and localization of both tectonic and other deep - seated processes. They are usually manifested in a kilometers - wide zone of rock break - up. Among larger deep structures of this type, apart from the San Andreas Fault, is the Talaso - Fergana Fault in Central Asia, which is about 400 km long.

So - called *transform faults* represent a peculiar type of deep faults. They are structural forms for which an intensively crumbled oceanic crust is not unusual (Fig. 2.12.). Transform faults as a new type of tectonic plate boundary was proposed by J. T. Wilson in 1965. They are most numerous in mid - ocean ridges, 50 large structures existing in the region of the Mid - Atlantic Ridge. They generally extend parallel with each other and perpendicular to the ridge. Major transform faults attain a length of several thousands of kilometers. Regional transform faults are encountered much more often, the distances between them attaining hundreds of kilometers.

Deep faults between two moving plates are called *rift structures* or *rifts*. Basaltic magma pouring out along normal faults forms volcanic domes or volcanic plates (plateaus). Rifts are young complex tectonic structures characterized by great length measured in hundreds and thousands of kilometers and considerable vertical amplitude of movement (of the order of 2 to 5 km). The Afro - Arabian and Rhein Rifts are well - known, as is the Big Basin Rift in the Cordillera of North America. The width of rifts varies: from several tens of kilometers (the Rhein Rift, 40 km) to several hundreds of kilometers (the Big Basin Rift, 600 km). Among the rift belts of continents, the largest is the Afro - Arabian one, about 6,500 km long. Its composition includes deep faults, trenches, and rifts: the Syrio - Lebanon Fault, the Dead Sea, the Ethiopian - Kenyan (East African) Rift, and the Nyasa - Tanganyika Rift.

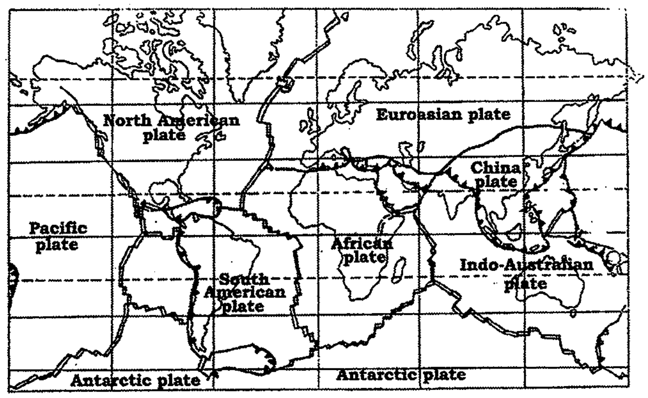

Fig. 2.12. Position of main tectonic plates.

Risks within Fault and Rift Zones

Many rifts, regardless of the depth at which they were formed, extend to the surface (Fig. 2.13.). Two main groups of risks can be present in regions with such structures: 1) *risks arising from the destructive power of faults*; and 2) *risks arising from so - called "gas breathing" of the Earth's crust through such structures*[25].

[25] Apart from risks, positive **indirect influence on human health** also exists without question. Above all, faults serve as conduits for circulation of mineral and slightly mineralized waters, as well as for gases of interest from the balneological standpoint (Fig. 2.13.), in spite of the fact that some faults perform a barrier function. Water-bearing faults are marked on the surface by lines of springs and concentrations of water-loving plants. High-quality waters of faults (privileged collectors) in karst regions are evacuated through numerous powerful fountainheads, and many faults in other types of water-bearing environments bring mineral and thermal waters and brines to the surface. For example, the mineral waters and brines of one of the meridional faults of the Lapland Tectonic Seam (within the framework of the Baltic Shield) have (among other interesting components) 288 mg/l of bromine and 73 mg/l of iodine. Fumaroles and hydrothermal phenomena in the Western United States follow well-known faults, and drilling along such structures resulted in the discovery of water vapor and hot water (the temperature of steam and thermal water in Yellowstone National Park at a depth of up to 350 m is more than 240°C, while highly thermal brines with a temperature of 360°C were discovered at a depth of 2,000 m on the southern extension of the San Andreas Fault).

Destructive effects are manifested in the case of active faults, i.e., faults with movement of blocks during the period of human history. Such faults can destroy structures in their path (buildings, roads, or dams), and the underground earthquakes caused by them are registrable at great distances away. As a rule, movement along faults is temporary, occurring after long pauses. For different faults, the periods of dormancy last from several years to several centuries and more rarely can exceed even a thousand years.

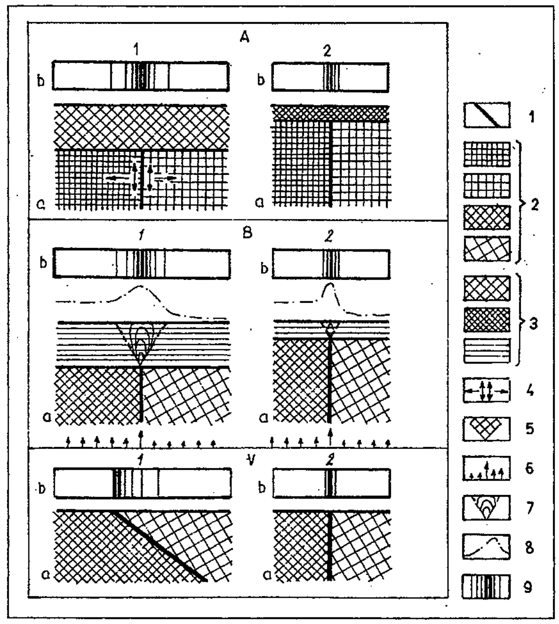

Fig. 2.13. General schematic map of development in the cross section of the Earth crust and their reflections at the surface. A,B - hidden faults (at deeper [1] or shallower levels [2]); V - open faults.

Small movements are incapable of causing earthquakes, but can be accompanied by great damage. Such movements have in recent time occurred along several large faults in California, including the Calaveras, Heyward, and San Andreas Faults (Howard and Remson, 1978).

Unfortunately, major construction is going on even today in zones of movement. For example, tectonic movements along the San Andreas Fault destroyed the concrete walls of a wine cellar, and measurements established an average movement rate of 1.25 cm/year. Discovery of movement along the Heyward Fault becomes especially alarming in the light of the destructive earthquakes that occurred in the zone of the indicated fault in 1836 and 1868 and in view of the fact that it passes through several highly urbanized regions. Although block movement itself can with difficulty cause physical damage to people, they can be hurt during loosening and destruction of buildings.

Accompanied by heavy human casualties and material damage, noticeably greater movements of rock masses along faults occur during earthquakes. The extent of such movements will be discussed in the appropriate chapter.

Zones of deep - seated and superficial faults, rift structures, and volcanoes are marked by *gas breathing* of the Earth's crust due to migration of gases along these structures from the depths of the Earth to the surface (Fig. 2.14.). Filtration of helium, argon, mercury vapor, CO_2, and other gases occurs in zones of deep faults[26] (Fig. 2.15.). After the Tashkent earthquake of 1966, increased content of radon, fluorine, uranium, nitrogen, and carbon dioxide (in addition to helium) was recorded in thermal waters of boreholes located in the zone of deep faults.

Content of mercury vapor can also be elevated on sectors with tectonic activity of faults, even in cases where structures are covered by young formations to depths of up to 1.5 km. Thus, for example, anomalous concentrations of mercury vapor were measured in the snow along a fault structure over the Srednje - Vetoubanski gas field in the former Yakut SSR. Regional investigations in Central Asia, Kazakhstan, and the European part of Russia have shown that mercury anomalies 20 to 100 km wide are formed in air of the soil cover over zones of deep faults (A. I. Perelman, 1979).

Broadly speaking, the underground atmosphere is rich in CO_2, H_2, CH_4 and heavy hydrocarbons, and N_2. The high capacity of gases for migration dictates their filtration and diffusion far beyond the boundaries of some gas field. The gas aureoles that are formed imitate the disposition of fault structures. For example, this is the case with aureoles of radon, a gas that is inert but very dangerous to man. Formed as a product of the radioactive decay of U_{238} in regions with uranium deposits, radon is especially present along fault zones and in adjacent air of the soil cover. It is also the case with aureoles of mercury in regions with mercury deposits or deposits and surrounding soil containing that very harmful element. Similar phenomena are encountered above sulfide deposits, as well as over coal and oil fields.

Radon content can be high in zones of faults and cracks. In certain waters above deep tectonic deformations in the Caucasus, Ural, and Tien - Shan Mountains, it attains 36,000 emans. Anomalous zones of nitrogen - containing waters in Trans - Caucasia, on the Kamchatka Peninsula, in

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[26] We note the Jasenica Fault in the region of Smederevska Palanka, along which carbon dioxide gas migrates from a depth of the order 1,000 m and enriches shallower water-bearing horizons. The well-known "Karadjordje" mineral water here is drawn from the alluvial horizon.

the Altai Mountains, and in other regions of the world are likewise characteristic of tectonically deformed regions, where rare gases (Ar, Kr, , and He and Ne in somewhat smaller amounts) are also present.

In any event, tectonically disturbed zones can ert significant influence on mortality, especially on the incidence of cancer (of the bronchi and lungs). The SE index (Table 1.1.) directly affects mortality from disturbed circulation of blood and (especially) cardiac ischemia.

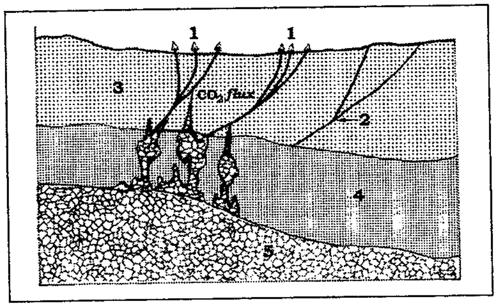

Fig. 2.14. Cross - section of a terrain rich in deep faults within the Earth's crust. 1. occurrence of CO_2 at the surface; 2. deep fault; 3. Betic detached crust; 4. Lower crust; 5. Upper mantle.

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The negative and in some cases positive (from the balneological and industrial standpoints) effects of the given processes, gases, and waters on health of inhabitants of the regions where they occur unfortunately have not to date attracted the attention they deserve among scientists.

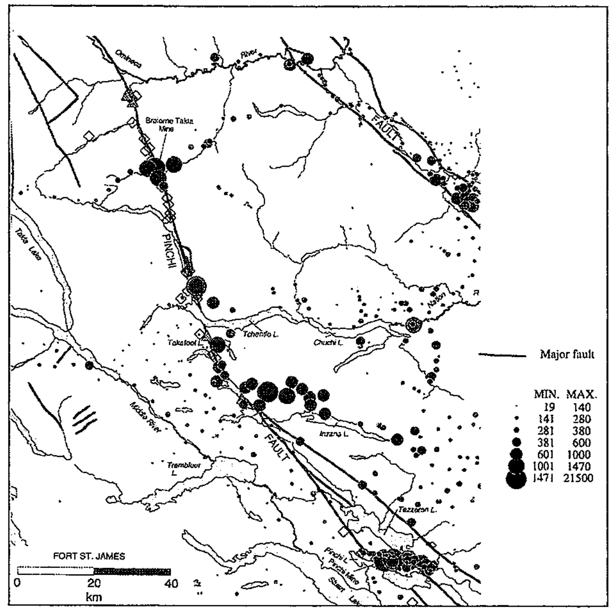

Fig. 2.15. Mercury concentrations in the clay - sided fraction of till of central British Columbia; modified from Plouffe (1995b). Sites with high mercury concentrations in trees from Warren and others (1983a).

Geophysical Factors

Recent years have witnessed a sudden growth of interest in research on geodynamics, i.e., study of deep - seated processes as causes of recent structural differentiation and contemporaneous heterogeneity of the lithosphere. The results of such research can be useful in resolving important practical problems, namely prediction of seismic and volcanic activity, investigation and utilization of mineral resources of the Earth's crust, and study of the effects of human activity on the environment.

Accelerated development of modern geodynamics has contributed especially in the following ways: *in the first place*, important scientific results have been obtained in measuring vertical movements of the Earth's crust on large territories; and *secondly*, recent movements of the Earth's crust have been found to be closely linked with structural differentiation of the lithosphere and the distribution of geophysical fields (magnetic, geomagnetic, thermal, etc.). Among other things, it has been the Altai Mountains, and in other regions of the world are likewise characteristic of tectonically deformed regions, where rare gases (Ar, Kr, , and He and Ne in somewhat smaller amounts) are also present.

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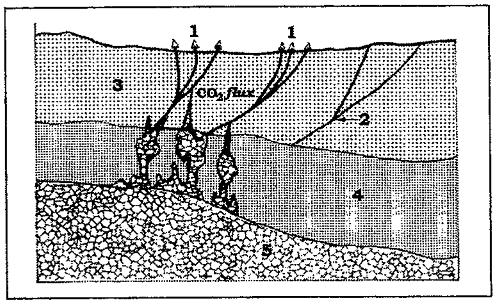

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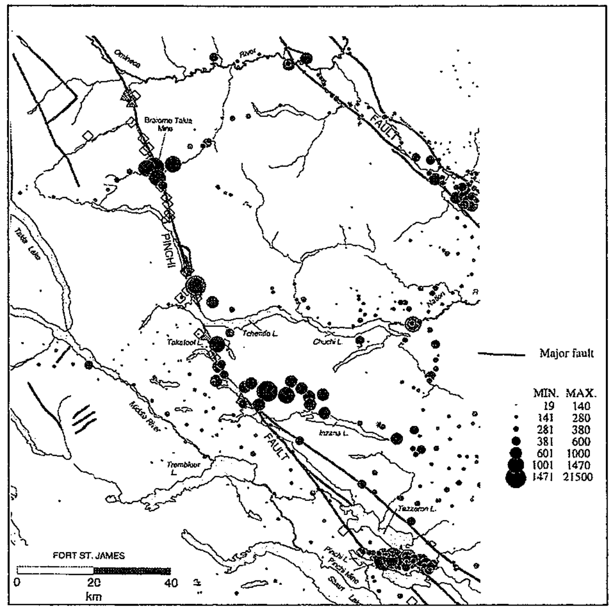

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Long - term investigation of changes in geophysical fields has been carried out in seismically active regions to discover processes involved in preparation for a phase of earthquakes. Thus, in one region in California, a decrease of gravitational force by 50 mGal was established before the earthquake of 1978 (with a magnitude of 5.6 M). In Romania during the period 1977 - 1979, anomalous changes of gravitational force before several earthquakes ranging in magnitude from 2 to 4 M comprised 20 - 200 mGal at a distance of the order of 100 km from the epicenter. Similar results were obtained in measuring changes of the geomagnetic field.

Let us now direct our attention to electromagnetic, gravitational, and thermal fields (radioactive fields will be treated in a special chapter).

Magnetic, Electromagnetic, and Electric Fields

Earth, Jupiter, the Sun, i.e., the entire Solar System and Galaxy as a whole, all have magnetic fields. These fields play a significant role in many processes in that part of the Cosmos accessible to us for research, erting powerful influence on the movement of compacted particles. Earth is characterized by a powerful magnetic field that is believed to be generated by movement of material in the outer part of the core. In this way it acts a gigantic magnet. In rough approximation, the planet's magnetic field can be represented as a magnetic dipole with a momentum of 8.1×10^{25} $gs{\cdot}cm^3$ at a distance of about 340 km from the center of the Earth, the axis of the dipole cutting its surface in points known as geomagnetic dipoles.

Under the influence of terrestrial magnetism, the needle of a compass takes a position parallel with the geomagnetic field and points to magnetic poles of the Earth. The geomagnetic poles miss coinciding with the geographic poles by about 11.5° (Fig. 2.16.), so it is understandable that the needle of a compass does not indicate true north or south and that there exists a *line of zero deviation* or *magnetic declination.* Another characteristic of the geomagnetic field is that there exists an *angle of inclination*, which is assumed by a freely hung magnetic needle level with the horizon.

The old magnetization of rocks (i.e., the natural lag in expression of the magnetization of rocks) indicates position of the magnetic field at the time of formation of a given rock. It is therefore possible to establish the path of shifting of poles in the course of geological time by using many samples of rocks of different ages. The average rate of movement is 3 cm/year.

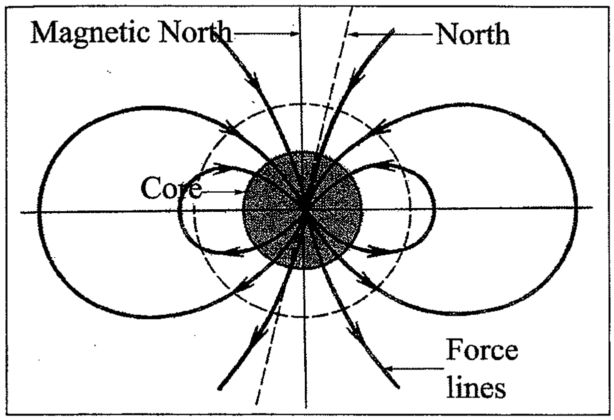

Fig. 2.16. Position of magnetic and geographic poles of the Earth.

During cooling in the Earth's magnetic field, magmatic rocks containing magnetite were magnetized in the direction of the general magnetic field prevailing at the time. In the course of erosion of such rocks, minute magnetized particles pass through the cycle of transport and sedimentation. During sedimentation, magnetic grains are oriented along the geomagnetic field. In this way, the formed sedimentary rock acquires natural old magnetization, from which it is possible to determine the time of that rock's formation. On the other hand, some magnetized rocks, tectonically brought out of their original position under influence of the geomagnetic field, take on new magnetization (*remnant magnetization*).

Since different rocks have different abilities to accept induced magnetism, stronger or weaker isolated magnetic fields are created in upper parts of the lithosphere. *Geomagnetic anomalies*, i.e., local deviations from regional average magnetic field values, are formed in this way. Such deviations can be considerable. For example, the well - known *Kursk Anomaly* in Russia has intensity of the order of 10,000 nT (Nikitin and Novikov, 1986). Of magnitude unique in the world is the *Zlot Magnetic Anomaly* near Bor (15,000 to 40,000 nT), whose main cause is still not known with certainty. Generally speaking, extensive masses of basalt and diabase, as well as granite massifs, can act as powerful magnets (*positive anomalies*), whereas fold regions with thick masses of sediments usually behave as weakly magnetized bodies (*negative anomalies*).

Differences in the magnetization of individual minerals or rocks are used to discover deposits of mineral raw materials, and geomagnetic (geophysical) methods are based on them. It goes without saying that geomagnetic methods give the best results in investigating magnetite deposits. On the other hand, investigation of the migrations of poles of the main magnetic field throughout the geological past (study of the magnetic field of past geological epochs or paleomagnetism) enables us to reconstruct the geometry of tectonic plate movement. Thus, for example, it is known today that during the Pleistocene, more precisely in a period of a million years, the North Atlantic between Europe and America widened by 23 - 25 km, Africa and South America moved 30 - 40 km away from each other, etc.

Natural electric fields are a consequence of geological action (telluric currents and self - polarization) or atmospheric electricity linked directly with ionization of the air.

Gravitational Field of the Earth

Gravitation represents the ability of bodies to attract each other. The force of gravity or gravitation of the Earth depends on its mass and decreases with removal from the Earth's surface to become nonexistent in the remote atmosphere. On the surface of the Planet, gravitation is stronger at the poles than in the region of the equator, due to the action of rotation. Moreover, due to the greater density of rock, it is stronger in oceanic zones than in continental regions.

Experimental study of gravitational force was initiated by Galileo, who already in 1590 conducted experiments with freefall of bodies. In 1673 Huygens established that gravitational force can be determined by measuring the period of a pendulum. The first indicators of change in gravitational force with latitude were discerned by J. Richer. The correct interpretation of this fact was given in 1687 by Isaak Newton, who formulated the law of universal gravitational attraction and determined volume of the Earth.

A deficit or surplus of mass in the point of measuring noticeably affects the value of gravitational force. A *negative gravity anomaly* is formed if rock masses have below normal density, whereas a *positive gravity anomaly* is formed if their density is above normal. Great *positive gravity anomalies* are recorded in South America, Europe, in the southeastern part of the Indian Ocean, and in the Western Pacific. On the other hand, great *negative gravity anomalies* occur in the northwestern and central parts of the Atlantic, in the eastern part of the Indian Ocean, and in the South and North Pacific. On the territory of Yugoslavia, the lowest values (110 mGal) are registered in the region of Podgorica in the framework of the Adriatic Coastal Anomaly, which runs in a SE - NW direction, whereas values generally increase moving toward the northeast of the country, the highest values (about 18 mGal) occurring in the region of Fruska Gora.

With the passage of time, changes can occur in the value of gravitational force in some examined point. The cause of this lies in geological and geophysical processes in the Earth's interior that lead to redistribution of mass. Also, changes in position of the Sun, Moon, and other celestial bodies affect the values of gravitational force. The given fluctuations can be divided into periodic fluctuations, which are linked with rotation of the Earth in relation to the Sun, Moon, and other celestial bodies; and non - periodic (time - linked) fluctuations, which are caused by geological and geophysical processes in the Earth's interior. As will be seen later, the dynamics of gravitational field changes can have significant effects on the environment.

Thermal Fields

People have observed for a long time that there exist on the surface of the Earth various phenomena possessing heat that originates from its interior. Around 355 B.C., the Greek philosopher Plato, in lecturing on the legendary Atlantis, mentioned that there were hot springs in the center of the city. It follows that more than 3,500 years ago, man already knew about the internal heat of the Planet.

Today it is estimated that the Earth gives off about 10^{21} J of heat annually. Relatively speaking, that is not a great amount, in view of the fact that our planet receives 6,000 times more energy from the Sun. On the other hand, it is still quite a lot, considering that annual production of electrical energy in the world is measured by a value of the order of 2×10^{19} J. Heat from the Earth's interior is today attracting increasing attention as a very promising energy resource that to date has been but little harnessed. Geothermal heat unquestionably represents the greatest source of energy at man's disposal at the present time.

A large part of the Earth's heat arises under the influence of *internal (planetary) sources*, above all at the expense of heat liberated during radioactive decay of uranium, thorium, and one of the isotopes of potassium. Another part originates from deep - seated zones where the temperature of rocks is in many places close to the melting point. Solar radiation is the most important *external (cosmic) heat source.*

In the Earth's crust, heat is for the most part transmitted in two ways: 1) by means of *conductive transmission,* i.e., heat transmission directly from particle to particle; and 2) by means of *convective transmission,* i.e., heat transmission by groundwater. The thermal conductivity of rocks represents the main mechanism of heat redistribution. This mechanism is expressed by the general rule that temperature increases with depth under a neutral layer. But owing to its practical significance, the phenomenon of heat conveyance from the Earth's interior by groundwater has attracted greater attention of investigators around the world. The given material is treated in more detail in the book "**Hydrogeological Explorations. Applied Hydrogeology, III**" (M. Komatina, 1995).

A natural thermal field is largely determined by the thermal properties of rock masses. For example, it is known that the thermal conductivity of sedimentary rocks is on average less than that of magmatic and metamorphic rocks, being greatest in peridotites and granites among magmatic rocks; and in compact carbonates, quartzes, rock salt, etc., among sedimentary rocks. Thermal fields can be disturbed by various local natural factors such as the exposure of slopes, form of relief and coloration of land surfaces, nature and thickness of the snow cover and vegetation, etc., or under the influence of human activity (building of reservoirs and irrigation systems, cutting down and planting of forests, etc.).

The average depth of a temperature increase of 1°C comprises 33 m. That relationship of temperature and depth is known as the *geothermal degree.* It can be greater or less than 33 m for 1°C, depending on the composition and structure of a region. For example, faster temperature increase is characteristic of volcanic regions, but appreciably slower increase is recorded in regions of continental platforms.

Of all characteristics of a thermal field, the *thermal flux* gives the most complete information about the energy regime of the Earth and separate sectors of the Earth's crust. This parameter is of decisive significance in estimating the geothermal energy potential of a studied region, and zones with a thermal flux greater than 100 mWm^{-2} are considered interesting for exploitation of ground heat.

It has been estimated that the amount of heat that rises from the interior to the surface of the Earth on average comprises 59 mWm^{-2} (about 77 mWm^{-2} according to A. M. Jessop et al., 1976). Regional fields with a low thermal flux (30 - 40 mWm^{-2}) are predominantly typical of old shields and platforms. On the other hand, zones surrounding younger fold mountains are characterized by high values of this parameter - from 100 to 600 mWm^{-2}. Anomalous values are associated with regions of current volcanism and to some extent with younger tectonic faults.

Geophysical Fields - Risks and Positive Effects

The past decade in the world of geophysics will be remembered for strengthening of a new branch of this applied science, namely

ecogeophysics (S. Komatina, 1996). Thus, instead of a depth range of several kilometers, geophysical methods of investigation are concerned with depths of only a few meters (or twoscore at most) below the surface of terrains. The questions resolved in this way can be represented in the form of two spheres of interest:

1. Investigation of natural and artificial physical fields arising in the Earth, as well as their action on the biosphere and living organisms (man, animals, microorganisms, and plants); and
2. Possibilities of quantitative determination and qualitative estimation of phenomena erting primary or secondary influence on the environment and its protection (D. Vogelsang, 1995).

In the region of the biosphere, interaction between physical (geophysical) fields and living organisms occurs due to:

- *Penetration of the organism by fields and their spreading throughout it;*
- *Primary interaction between fields and the organism; and*
- *Secondary response of the organism as a consequence of primary interaction.*

According to behavior of the organism, interaction can be of the following kinds:

1. **active** (when fields ert biological influence on the organism):
   - *Positive (stimulatory) influence,* where activity of the organism increases; and
   - *Negative (inhibitory) influence,* where activity of the organism decreases.

Inhibitory interaction can be reversible, in which case a return to the normal state is possible; and irreversible, when permanent damage is done to vital functions of the organism; and

2. **Passive** (when changes in the nature of a physical field are registered, but the organism itself is not affected by their influence).

I. **Influence of Natural Electromagnetic Fields.** Natural electromagnetic fields can be divided into the following categories:

1. *Fields of extraterrestrial origin.* In comparison with natural terrestrial or artificial fields, insignificant influence is erted on living organisms by radiation in the ionizing part of the electromagnetic spectrum (gamma-, X-, or certain parts of corpuscular radiation) and its no ionizing part (ultraviolet, visible, and infrared radiation, as well as radio waves);
2. *Fields of terrestrial origin.* A clear link is discernible between high - frequency electromagnetic radiation and weather fronts, mortality, births, traffic accidents, and industrial accidents.

Natural electric fields arise from geologically induced fields (telluric currents and self - polarization) or from atmospheric electricity directly linked with ionization of the air. A natural electric field arises due to the potential difference between positively charged ground and electricity produced by meteorological phenomena (130 V/m to maximum values of 10 kV/m due to lightning discharge). In the course of breathing, man daily inhales about 20,000 l of air and thereby introduces ions with electricity of the order of 10^{-14} A into the lungs. It has been established that dominance of negative ions affects organisms favorably, whereas positive ions cause fatigue, headaches, and indisposition.

Natural magnetic fields are formed wherever movement of charged particles occurs. The area of pathological reactions (and possibly diseases?) linked with fluctuations of terrestrial magnetism has been insufficiently studied. It is certain that geomagnetic storms can ert definite influence on living organisms. We note that the first symposium on *magnetobiology* (chaired by I. V. Toropcev) examined phenomena arising at the molecular level under the influence of magnetic fields. Magnetic fields can ert positive (favorable) and negative (unfavorable) influence on organisms, depending on their intensity, frequency, orientation, exposure time, and origin. Unfavorable influence is primarily manifested as disturbances in the central nervous system, glands, and sensory perception, but also in the respiratory, immune, and bone systems. Positive influence is manifested as magnetotherapeutic effects in treatment of certain diseases of the skin and nervous system. They are divided into the following classes:

1. *Heliogeophysical effects* (effects of magnetic storms and solar activity, the distribution of whose fields is variable in space and time within the range of 0.01 - 0.05 mT) have been insufficiently studied. However, it is known that the highest mortality occurs two days after maximum intensity of magnetic storms and solar activity. These fields also affect the number of traffic accidents, incidence of diphtheria, and worker absenteeism due to sickness (all of which increase under their influence); and
2. *Geomagnetic effects* are manifested in the following examples: it is known that the geomagnetic field is of assistance in the orientation of sharks and migratory birds (pigeons maintain their direction of flight with a deviation of up to 0.3 deg). Birds sense changes in magnetic field intensity of the order of 1 nT, while bees sense changes of the order of about 5 nT. In man, negative influence of geomagnetic storms is manifested in weakness of the heart and cerebral system (Miroshnichenko, 1987) (Fig. 2.17.). Also, geobiologists have established that man is sensitive to the Earth's magnetic field, and even to insignificant changes of it (like messenger pigeons). According to Rocquart, man became more insensitive and even adapted to greater field changes since he began to use iron. Nevertheless, it is known

that the body's ideal position is with the head pointing north and the feet pointing south.

The indicated factors together make up the constant magnetic component of the environment.

The Kursk Anomaly is the only geomagnetic phenomenon of geological origin proven to ert influence on human health. Nikitin and Novikov (1986) reported the registration of considerable influence of this anomaly on mortality of inhabitants of the Kursk Province. However, of much greater significance from the biological aspect are sudden changes of the geomagnetic field - pulsations and micropulsations with frequencies of 0.1 - 10 Hz. Negative influence of pulsations has been established in laboratory experiments, so their significance cannot be ignored. The situation is similar with periodic changes in the polarity of a natural magnetic field. The frequency of inversions in the last 10 - 20 million years is about every 700,000 years, which from the geological aspect is a relatively short period. Still, it is impossible to reject assertions that influence is erted on the genetic system in the sense of mutations and hereditary changes (Mares, 1997).

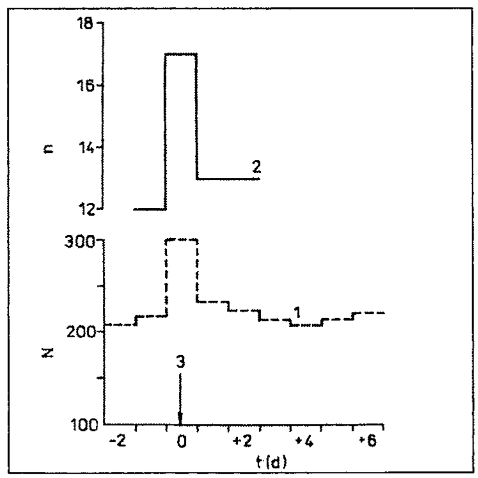

Fig. 2.17. Geomagnetic storms and heart - cerebral diseases. 1. mortality *N* on heart attack during 1960 to 1966 in Sverdlovsk (former Soviet Union); 2. daily averages *n* of morbidity on heart attack and on cerebral failures in Vilnius (former Soviet Union) during 1963 - 1966; 3. beginning of geomagnetic storms. *t* (d) - days before (-) and after (+) the storm started (after Miroshnichenko, 1987).

Above tectonically disturbed subvertical zones characterized by conductivity greater than that of the surrounding environment, a vertical air zone can appear with conductivity twice as great as the value for air in the immediate surroundings. It is therefore believed that both conductivity of the disturbed zone in the crust and that of air in the atmosphere simultaneously affect the people who live above such zones. Gruntorad and Mazac (1995) demonstrated that anomalous processes above such zones are a result of processes transpiring in the interior of the Earth. They also established that microclimatic conditions above these zones are different, not only in the geophysical respect, but in the chemical and physicochemical sense as well. Statistical processing of geologic - geophysical and socio - ecological factors and comparison with data on mortality in 56 municipalities in the Czech Republic (Table 1.1.) showed that:

- Tectonic and disturbed zones (TZ) ert significant influence on mortality, especially mortality due to increased frequency of cancer (primarily of the bronchi and lungs). The SE index also directly affects mortality from circulatory disturbances (cardiac ischemia in particular);
- No special correlation has been established between regional concentration of radon (RN) or radioactive field intensity (RA) and mortality. The same is true of the relationship between gravitational and magnetic field intensity and mortality; and
- Influence of TZ on mortality (in %) varies between 8.0 and 23.4%;

while that of SE is in the range of 14.1 - 23.8%, which corroborates the assertion of Gruntorad and Mazac (1995) that physiochemical elements from tectonic zones can be one of the reasons for increased mortality in some regions.

In the past ten years, a link has been detected between traffic accidents and the action of electromagnetic fields on man. For natural electromagnetic fields of extraterrestrial origin, a correlation has been established between magnetic field changes (the K index) and the frequency of traffic accidents. In regard to natural fields of terrestrial origin, it is postulated that the variable magnetic field with frequency of up to 10 Hz that is formed during driving at normal speed over a highway whose foundation contains a variety of rocks with different magnetic characteristics affects Alfa rhythms of the brain. A traffic accident is the consequence of this negative influence on the psycho - physiological state of the driver (Dohnal and Vacek, 1983). According to these authors, the occurrence of traffic accidents is affected not only by meteorological factors, but by electromagnetic ones as well. Thus, the number of accidents increases by 4 - 5% on days when an increase of the K index is noticed. Also, accidents are 4% more frequent during periods when pulsations of the geomagnetic field's horizontal component last more than eight hours for three days on end. In the event that pulsations lasted more than 16 hours over the next nine days, the frequency of accidents increased by 5%.

Natural ionizing radiation arises due to ionization of the environment during electromagnetic or corpuscular radiation (Dj. Sofrenovic, 1993). Ionizing rays have exceptionally great penetrability and chemical action, causing luminescence and ionization of gases and erting biological action on living organisms. Specific irritation of tissues occurs at insignificant intensities of radiation, while high intensities result in damage of the most severe kind to tissues. It has been established as a regularity that species of organisms at the lowest stage of development are most unresisting to radiation (a dose of 300 rads is enough to cause death of more than half of irradiated animals after a month's time, whereas for man that dose is 500 rads), and that local irradiation is easier to withstand than when the whole body is exposed. Moreover, not all tissues are equally sensitive: most sensitive are tissues where cells multiply rapidly, i.e., tissues with high metabolism. Inside the cell itself, the nucleus, cytoplasm, and cell membrane are more sensitive to radiation. In mammals the gonads, bone marrow, lymphoreticular tissue, and intestinal epithelium are most liable to damage, while the skin, kidneys, liver, and nervous and muscular tissue are exceptionally resistant. Lymphopenia (disturbed antibody formation) occurs due to radiation in lympathic tissue; agranulocytosis, anemia, and thrombocytopenia with a tendency to bleed, are recorded in bone marrow; desquamation of the epithelium with subsequent inflammation occurs in the stomach and intestines; etc.

Natural no ionizing radiation encompasses the segment of the spectrum of electromagnetic radiation that does not have photon energy sufficient to cause ionization in living tissue (12.4 eV) (B. Vulevic, 2000). According to the range of frequencies, i.e., wavelengths, no ionizing radiation in the integral electromagnetic spectrum is divided into the following categories: ultraviolet radiation (UV); visible light; infrared radiation (IR); radiofrequent radiation (RF); and electromagnetic fields of extremely low frequencies (ELF) (Table 2.5.). Laser radiation represents part of the spectrum of no ionizing radiation (UV, visible light, IR) that is manifested in the form of coherent bundles of radiation. This type of radiation also includes mechanical ultrasonic vibrations, i.e., ultrasound, since its biological effects and ways organisms protect themselves from it are similar to those observed in the case of electromagnetic radiation.

The *natural source of UV radiation* is the Sun, whose exceptionally broad continuous spectrum is in large measure absorbed in the atmosphere (especially in the ozone layer of the stratosphere), so that only wavelengths greater than 290 nm reach the Earth. People who spend a large part of their working day in the open - farmers, construction workers, sailors, fishermen, etc. - are especially exposed to UV radiation. Since the penetrating power of this radiation is limited, the most pronounced consequences of intense exposure to UV radiation are evident on the skin (mnemelanomic skin cancer, malignant melanoma of the skin, accelerated aging, enhanced pigmentation, freckles, etc.) and eyes (acute photokeretitis or snow blindness).

TABLE 2.5
Basic classification of electromagnetic spectrum (1 THz = 10^{12}Hz, 1peV = 10^{-12}eV) (B.Vulevic, 2000).

Type of radiation	Frequency (f)	Wavelength (λ)	Photon energy (E)
Ionizing radiation	> 3000 THz	< 100 nm	>12.40 eV
UV radiation	3000 - 750 THz	100 - 400 nm	12.40 - 3.10 eV
Light	750 - 385 THz	400 - 780 nm	3.10 - 1.59 eV
IR radiation	385 - 0.3 THz	0.78 - 1000 mm	1590 - 1.24 meV
RF radiation	300 GHz - 3 kHz	1 mm - 100 km	1.24 meV - 12.4 peV
ELF fields	< 0.3 kHz	> 1000 km	< 1.24 peV

The Sun is also the strongest *natural source of IR radiation.* Thanks to the presence of water vapor in the atmosphere, radiation with wavelengths above 1 μm does not reach the Earth. Workers who spend the greater part of their time outdoors are most exposed to this kind of radiation also. Due to its limited penetrating power, the consequences of exposure to IR radiation are similar to those of the previous kind. Like UV, IR radiation causes heat damage and can lead to sunstroke. Erythematose changes occur on the skin, together with appearance of unpigmented parts in the form of a network, atrophic changes, etc. Inflammation of the eyelids occurs in the eyes, in addition to conjunctivitis, cataracts, damage to the cornea, etc.

The *sources of RF radiation* are the Sun and other bodies in space.

Natural sources of ELF fields are natural electric (stationary and variable) fields and natural magnetic fields (internal and external).

II. Influence of Natural Radioactive Fields. Apart from electromagnetic fields, the fields that have been studied most thoroughly in regard to harmful action on man and other living organisms are radioactive fields.

Natural radioactive fields can be of extraterrestrial and terrestrial origin. Inasmuch as the intensity of cosmic radiation is insignificant and more or less constant, living organisms are used to its presence (even at an altitude of 10 km, at which passenger planes fly) (Table 2.6.). Under conditions of sunspot appearance, these values increase as much as 100 - fold. However, the most dangerous source of radiation for man and all other organisms is radon, specificically the products of its decay. Already in 1901, Elster and Geitel noticed that the elctroconductivity of air in caves and cellars is significantly higher than in the free atmosphere. They attributed this to the presence of natural radioactive gases - radon (Rn_{222}) and thoron (Rn_{220}) - which is products of the uranium or thorium series (I. Petrovic, 1998). The greatest concentrations of radon are registered in the part of the atmosphere next to the ground, and radon is liberated in high concentrations from uranium - containing soils and rocks: granites, clays, and phosphates.

TABLE 2.6.
Radon ratio received by humans (after Barnet et al., 1992).

Source of radiation	Quantity
Radon	55%
Natural radiation - cosmic and gamma radiation	26%
Medical sources	18%
Others	1%
Total radiation	100%

The main sources of radon are air originating from the ground, above all from U_{238} in rocks, where its content is highest in volcanic rocks, lower in metamorphic rocks, and lowest of all in sedimentary rocks (Fig. 2.18., Table 2.7.); groundwater, where it is present in insignificant amounts; and building materials, where its content is highest in concrete, lower in bricks, and almost nil in wood (Mares, 1997.).

Migration of radon, and consequently its influence on man, is dictated by permeability of soils and rocks, as well as by tectonic disturbances in rocks. Permeable rocks like sand and sandstone are much more suitable for migration than are less permeable ones (clays, shales, etc.). Also, tectonically disturbed rocks, as places suitable for occurrence of secondary minerals of uranium, are defined as zones favorable for migration of radon.

According to Matousek (1987), natural sources of radiation can from the biological aspect be considered passive in relation to active natural sources arising in every living organism (K_{44}, C_{14}, Ra and products of its decay, and Th). The muscles, skeleton, and skin of a man weighing 70 kg contain about 0.0166 g of K_{44}. The presence of the element Ca_{14} in the organism is a product of cosmic radiation, whereas Ra and Th enter the organism through breathing.

III. Influence of Natural Seismic Fields. Seismic fields are divided into natural (of terrestrial origin) and artificial categories. Natural fields are represented by the phenomenon of earthquakes. The probability and frequency of earthquakes can be estimated on the basis of magnitude M (Table 2.8.).

The number of earthquake casualties throughout the world during the period of 1970 - 1981 is known to have comprised 442,000, while material damage is estimated as having been at least 18.6 billion dollars. It is therefore not surprising that great efforts are being made to develop methods for predicting earthquakes, particularly in seismically active regions. Although certain animals (fish, snakes, cats) are capable of sensing an earthquake in advance, it still cannot be proved that some connection exists between changes in geophysical and physical fields and the occurrence of earthquakes. However, it must also be kept in mind that extraterrestrial natural fields affect the phenomenon of seismic activity (Fig. 2.19.).

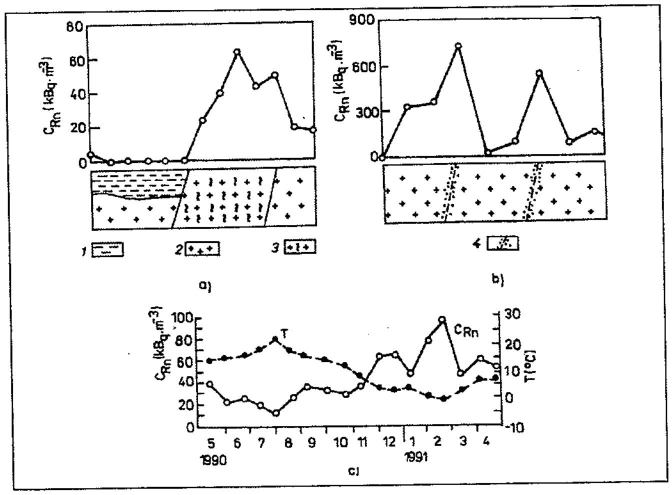

Fig. 2.18. Radon migration vs geology. a) Impermeable clayey cover decreasing the volume radon activity. b) increase of volume radon activity above uranium mineralization along tectonic disturbance; 1 - clay cover, 2 - granite, 3 - disturbed granite, 4 - tectonic disturbance with radon content. c) Seasonal variations of radon activity as a function of atmosphere temperature (after Barnet et al., 1992).

Endogenous Geological Processes

The regions in which we grew up and solid ground we live on give an almost permanent impression of exceptional stability and invariability. This stability creates the deceptive impression of constancy. In contrast to it, however, a number of occurrences in many regions of the world - often sudden and explosive, sometimes catastrophic for the population - indicate evident instability of the ground below us. Moreover, there are many areas where severe earthquakes devastate whole regions, where eruptions of huge volcanoes threaten many settlements, or where coastal regions sink so rapidly that the land must be defended by embankments from incursions of the sea.

All of these endogenous processes are linked with events in deeper parts of the endogeosphere. Very significant for life on our planet are sudden manifestations (earthquakes, volcanic eruptions), since defense against their unwanted action is a matter of great urgency. This does not lessen the importance of slow tectonic processes (neotectonic movements), which represent generators of the indicated sudden manifestations and are an important factor in the genesis of relief.

TABLE 2.7.
Radon sources in the geological environment (after Barnet et al., 1992).

Rocks	Radon content (kBq x m^{-3})		Ratio of fine-grained fraction F (0.063mm)
	Maximum	Average	
Durbachite	435	100	26
Granite	352	52	29
Diorite	126	40	32
Orthogneiss	155	30	35
Phonolite	59	25	38
Phonolite	126	24	41
Shale	61	23	44
Granulite	50	22	47
Terrace	183	21	50
Loess	75	18	53
Metasediments	106	17	56
Sandstone	73	16	59
Neovolcanite	162	15	62
Claystone	55	14	65

Earthquakes

In 1948 near Hollister in California, a vine grower built himself a new wine storehouse reinforced with concrete. After a few years, the walls on opposite sides of the storehouse started to shake. The cracks grew wider with the passage of time, and the concrete slabs on which the floor was constructed began to move. In fact, the building was so situated that one part of it lay on one side of the famous San Andreas Fault, the other part on the other side of it. Because no earthquake strong enough to destroy the building occurred in those years, the opposite sides of the fault slowly moved away from each other at an average rate of 1.2 cm per year. The vine grower's wonder was great because he didn't know that the Earth is never absolutely at rest. Far greater catastrophes than this have certainly been caused by powerful earthquakes, spreading indescribable terror among people with their appearance.

TABLE 2.8.
Frequency of earthquakes (after Mazac, ed., 1988).

Magnitude M	Number of earthquakes yearly	
3	> 100 000	Weak earthquakes
4	15 000	
5	3 000	
6	100	Intense earthquakes
7	20	
8	2	

In his book "**Earthquakes**," G. A. Eiby (1980) describes the atmosphere in London during an earthquake that occurred in February of 1750. "*Unlike the inhabitants of New Zealand or Japan, most Englishmen had up to then never experienced earthquakes, and the unrest was therefore considerable. This unrest increased following a second shock, which occurred four weeks later. After John Wesley declared that no divine punishment acts so strongly on sinners as an earthquake, it was no wonder the churches were overflowing the next Sunday and most preachers referred to the recent divine warning in their sermons.*"

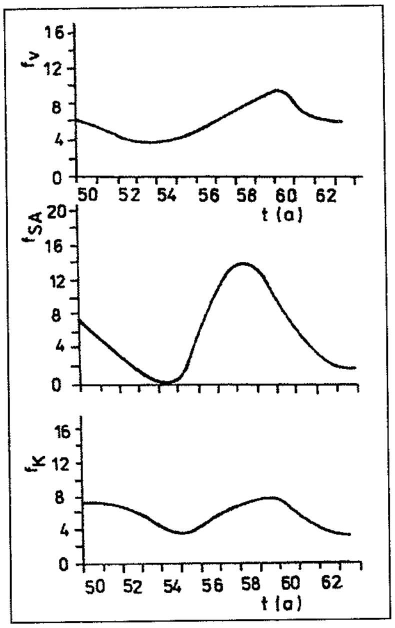

Fig. 2.19. Comparison of the frequency of earthquakes f_V, frequency of Sun activity f_{SA} and geomagnetic index f_K from January 1, 1950 to June 30, 1963 for mean monthly values (modified from Miroshnichenko, 1987).

People have known about earthquakes since ancient times and have feared them with reason. To be specific, earthquakes are among the limited number of natural phenomena that ert powerful destructive action which threatens the lives and property of human beings. Earthquakes are sometimes even more terrible than volcanic eruptions, possibly because they shake the Earth's surface, which most people are accustomed to consider stable. The feeling that the ground under foot is moving, that everything around is shaking and being destroyed, causes shock that can hardly be compared with any other. A map can best show how unquiet the Earth is and how its surface is only apparently stable (Fig. 2.20.). The series of black dots on the map would be transformed into completely black stains if it showed the epicenters of all shocks that have occurred from 1900 to 2000, since their number is truly enormous. Thus, during the period of earthquakes on the Hawaiian Islands in 1868, more than 2,000 clearly separate shocks were recorded only in the month of March; 300 to 320 strong shocks occurred from August of 1870 to August of 1871 in Fokidi (Greece); and more than 700 shocks were recorded on certain days in 1930 in northern Ido (Japan).

The initial cause of earthquakes is associated with liberation of heat from the Earth's core. However, the following are regarded as the most direct causes: 1) *formation of tectonic faults*; 2) *volcanism*; 3) *artificial arousal*; and 4) *summary action of different factors*.

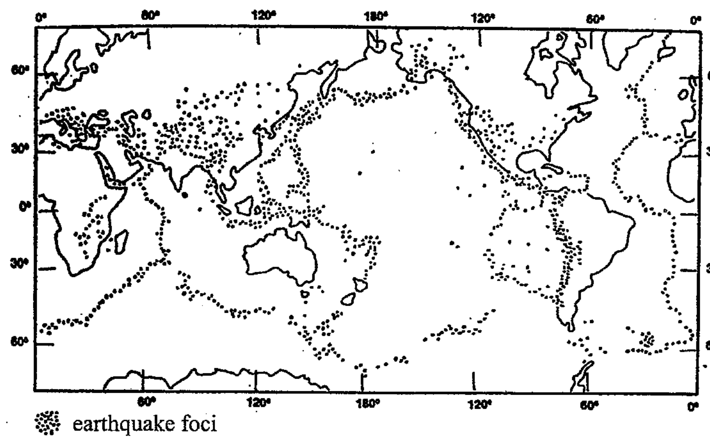

Fig. 2.20. Earthquakes distribution in period 1961 - 1967.

With the formation of *tectonic faults*, rock masses lying along such structures undergo crumbling and movement. The given processes cause earthquakes[27]. Rock crumbling can be linked with three main types of movement in the Earth's crust: *compaction*, *divergence*, and *horizontal movement*. The most numerous and powerful earthquakes occur in *compaction zones* along the shores of the Pacific Ocean, where the Pacific tectonic plate in subduction zones is gradually drawn beneath the continental boundary region and island arcs (Fig. 2.20.). In cold brittle submerging plates, faults are repeatedly formed from grooves in the process of downward movement, and this causes many shallow earthquakes (not deeper than 60 m).

[27] The potential energy of deformation increases to such a degree that the force of friction is overcome, causing movement along the fault's surface. The sudden break and release of energy cause seismic waves, which spread in all directions.

Only about 5% of earthquakes, usually shallow ones, are accompanied by a *regime of divergence*. The San Andreas structure in California (Fig. 2.21.) is most often cited as an excellent example of a seismogenerative transform fault. In just one earthquake (the California Earthquake of 1906), movement along the fault attained up to 7 m. We note that geologists know of the existence of thousands of faults, but only a smaller number of them are today active sources of earthquakes.

Volcanism is the cause of many local, predominantly weak oscillations of the ground. Both the famous eruption in 1883 of the volcano Krakatoa in Indonesia and the eruptions of many other volcanoes were accompanied by weak, but numerous earthquakes.

Artificial earthquakes occur due to human action on the existing state of equilibrium in upper parts of the lithosphere. For example, many weak earthquakes have in a number of cases been caused by overburdening of the ground with water during filling of reservoirs. We note also effects caused by the pressure of water polluted with radioactive waste that was pumped into deep boreholes drilled to receive it between 1962 and 1970 in the vicinity of Denver, Colorado: it caused more than 700 weak earthquakes around the boreholes.

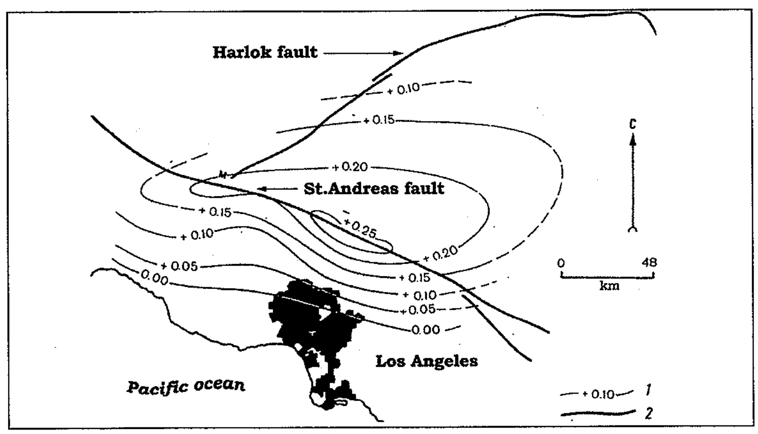

Fig 2.21. Regional deformation of the Earth's crust in the territory intersected by the St. Andreas fault, northern from Los Angeles. 1 - Shift during sinking or uplifting; 2 - fault (after USGS).

Most sources of seismotectonic waves are linked with two main belts:

1. The *Circum - Pacific belt*, which extends from Chile to Central America; passes through Mexico, California, and the Aleutian, Kurile, and Japanese

island arcs; and then runs through the Philippines and Indonesia to New Zealand; and

2. The *Alpine - Mediterranean - Trans - Asian belt,* which encompasses the regions of the Mediterranean countries, Iran, India, Burma, and China (Fig. 2.20.). Both belts are linked with the same basic cause: movement of plates of the Earth's crust. In contrast to regions located along the boundaries of plates, internal regions of geologically old continental platforms and shields (the eastern part of Canada, Brazil, Scandinavia, part of the territory of Siberia, a large part of Africa, Southern India, and West Australia) are relatively aseismic, with the sole exception of fault zones.

About 15 to 20 powerful and destructive earthquakes occur in an average year, but there are millions of relatively weak shocks annually. According to Howard and Remson (1978), a million people were killed by earthquakes in a hundred - year period (1875 - 1975), the victims being predominantly inhabitants of densely populated regions of the globe[28].

In certain localities, earthquakes repeat themselves with the passage of time, but obviously with no regularity[29].

Notes on Famous Earthquakes and Their Consequences.

1. The catastrophic earthquake that struck the *Shensi* Province of China in 1556 left behind it about 830,000 human casualties. The greatest number of deaths and enormous material damage were caused by strong quaking of the loose rock (filled with groundwater) of which the valley of the Yellow River is built, and by flooding that followed breaching of the river's embankments;
2. Although the earthquake in the Shensi Province was the most terrible seismic disaster recorded in the annals of history, primacy is usually granted to the *Lisbon Earthquake* of 1755. The magnitude of this earthquake possibly attained a value of 9, and the amount of energy released may have been equivalent to 17 million tons of TNT[30,31]. It is

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[28] Seismic sea waves or *tsunamis* frequently accompany major earthquakes in marine or maritime regions. They often leave great devastation behind them. For example, a tsunami that arose in the Aleutian Islands on 1 April 1946 destroyed a lighthouse on Dutch Cape (Alaska), which was situated 15 m above the level of the sea. The wave reached the Hawaiian Islands, traveling a distance of 3,800 km at an average speed of 780 km/h and attaining a length of 150 km on the open sea. One hundred and fifty-nine people were killed in the narrow coastal zone, while the total material damage in Hawaii was estimated at 25 million dollars.

[29] The possibility of predicting earthquakes is being investigated today in California, Russia, Japan, and China, but so far with little success.

[30] The real energy of an earthquake released in its focus (hypocenter) is estimated according to the *standard scale of magnitude* proposed by C. F. Richter, with a range of from not much more than zero to 9. According to this scale, among the most powerful earthquakes (apart from the Lisbon Earthquake) were the Assam Earthquakes (India, 1950), with a

calculated that the epicenter of the Lisbon Earthquake was in the sea, 100 km off the coast of Portugal. The radius of territory on which the earthquake was registered perceptibly exceeded 1,500 km from the epicenter. The destruction of Lisbon was terrible. The city at that time had about 230,000 inhabitants, and according to the most modest counts about 30,000 were killed. The earthquake was followed by sea waves (tsunamis) around 7 m high, as well as by many fires. The catastrophe shook Europe, and moralists and sages of all stripes did not miss the opportunity to profit from that capital.

3. The history of *Chile* is marked by a large number of powerful earthquakes. The epicenter of the earthquakes that began on 22 May 1960 and had a maximum magnitude of 8.5 was characterized by a number of destructive aftershocks following the main shock. For this reason, it was difficult to establish which aftershocks were responsible for this or that damage done. The long series of several hundred earthquakes lasted several months and was accompanied by release of enormous energy. In addition to human casualties and enormous material damage, we note many geological consequences, namely the spreading of tsunamis over the entire Pacific Coast, destruction of river banks, landslides, torrential rock - and mud-slides, eruption of the volcano Puehu, local uplifting of terrains, general sinking of arable land and flooding of it with seawater, etc.
4. The 1964 earthquake in the vicinity of *Prince William Sound in Alaska* had a magnitude of 8.5 and 10 destructive aftershocks. Much of the city of Anchorage was destroyed, and the wider neighborhood (an area of 130,000 km^2) was severely damaged. Tsunamis 10 - 15 m high caused enormous damage, even in distant California, and spread to the Hawaiian Islands, Japan, and Antarctica. The elevation of terrains was visibly altered: one zone of land measuring 65 - 90 thousand km^2 in area was uplifted, while a neighboring region with an area of about 100,000 km^2 sank by an average of 1 m. Maximum uplifting of the sea floor comprised more than 16 m, which represents the greatest vertical movement in historical time.
5. A powerful earthquake in 1976 caused horizontal movement of up to 3.25 m along the fault that cuts across *Guatemala* between the North American and Caribbean Plates. The earthquake struck central regions of Southern Guatemala. According to official statistics, 22,778 people died and 76,504 suffered serious consequences. Material damage was estimated at 1.1 billion dollars. Movement of terrains along the fault caused thousands of landslides.

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magnitude of 8.7; the Columbian Earthquake (1906), with a magnitude of 8.5; and the Great Alaska Earthquake (1964), with a magnitude of 8.5.

[31] According to Howard and Remson (1978), the energy released in the Great Alaska Earthquake (1964) was equivalent to 32 million tons of TNT; that released in the earthquakes in the Indian state of Assam (1950) was equivalent to 65 million tons; and the energy released in the earthquake in San Rikyu and the coastal region of Japan (1933) was equivalent to 125 million tons of TNT. The atomic bomb dropped on Hiroshima was equivalent to 20 thousand tons of TNT.

6. One of the greatest of modern earthquakes took place in March of 1933 not far from *San Rikyu* on the eastern coast of Japan 120 km north of Sendai on the island. Thanks to the fact that it occurred far from the shore, the earthquake did not possess great destructive power, but it caused sea waves with a height of 29 m above the water level in which about 3,000 people were drowned.

Seismic Characteristics of the Territory of Yugoslavia. The seismotectonic picture is marked by the region's very complex geological structure. It exhibits characteristics dictated by the meeting of a number of geotectonic units and existence of a network of many longitudinal and transverse neotectonic faults. Tectonic tensions caused by subduction of the African Plate beneath the European Plate are the main source of energy. The accumulated tensions are transmitted through a system of faults to the deeper interior in the northeastern part of the country. Depending on the distance from geotectonic contacts on the Adriatic Coast, the intensity of tectonic tensions, i.e., the value of magnitude, declines.

According to B. Sikosek and M. Petrovic (1992), the seismotectonic framework of Serbia is composed of four seismogenic (geotectonic) units: the Dinarides, the Pannonian Mass, the Serbo - Macedonian Mass, and the Carpatho - Balkanides, with 45 seismogenic blocks and 13 seismogenic faults. The territory of Montenegro belongs to the Dinarides, while the narrower region of the Negotin Depression is a component of the Misiska Plate.

The Dinarides Seismogenic Belt manifests the greatest seismic activity, with as many as 70% of all earthquakes. The central tectonic blocks are the site of 20% of them, while the Carpatho - Balkanides have the lowest earthquake frequency, with only 10%. As for depth of occurrence, 18% of all earthquakes on the territory of Yugoslavia had a hypocenter at up to 5 km of depth, 66% were in the depth interval of 6 to 10 km, 15.3% were in the range of 11 to 15 km, and only 0.7% was in the depth interval of 16 to 20 km.

A significant part of the territory of Yugoslavia is a region with a high degree of seismicity (VII to IX° MCS)[32]. According to historical data and research conducted to date, the following seismogenic regions can be singled out: 1) Montenegrin Coast and hinterland; 2) Kosmet; 3) Western Serbia; 4) Sandzak; 5) Central Serbia; 6) Pomoravlje; 7) Kopaonik; and 8) Fruska Gora. The strongest earthquakes attained an intensity of IX° MCS: Prizren (1456), Svilajnac (1893), Vranje - Ristovac (1904, epicenter around Berovo in Bulgaria), Pristina - Urosevac (1921), Lazarevac (1922), Rudnik

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[32] The Mercalli-Cancan-Sieberg scale (MCS, with a range of I to XII°, is a measure of the damage caused by an earthquake on the surface.

(1927), Montenegrin Coast (1979), and Kopaonik (1980). The Berovo Earthquake is considered to have been the strongest of all earthquakes that occurred on the Balkan Peninsula in the past century[33].

In recent time, Yugoslav territory has witnessed the generation of several powerful earthquakes. The last two decades were marked by those on the Montenegrin Coast and in vicinity of Mt. Kopaonik. The former (15 April 1979, magnitude of 7.1) was registered at 227 seismological stations throughout the world and represents the strongest recent earthquake in this part of the Mediterranean. The earthquake on Mt. Kopaonik (15 May 1980, magnitude of 5.8) was reliably registered at 164 stations. The strongest earthquake on the Montenegrin Coast was accompanied by a series of powerful aftershocks, while a very strong earthquake (magnitude of 5.1) occurred in 1984 in the Kopaonik focal zone after the main earthquake in 1980.

The damage caused by earthquakes has been very great. Just during the period of 1963 - 1974, this damage on the territory of former Yugoslavia was estimated at about 2 billion dollars. Here it must be kept in mind that the famous catastrophic earthquakes on the Montenegrin Coast and in the Kopaonik seismic area occurred after the indicated period.

Volcanic Activity

Volcanic eruptions are one of the most impressive, destructive, and terrifying of natural phenomena. The very term *volcanism* arose from the word Volcano, the name of a small volcanic island (crater) of the Lipari Island group off the coast of Italy. It was believed that the smithy of Vulcan - the legendary ancient Roman god of fire and metal working - was located here. Better known than the island of Volcano is the neighboring active volcano Stromboli: this unique lighthouse of the Mediterranean Sea is a mountain 900 m high that ejects clouds of steam by day and whose surroundings are illuminated by the reflected light of hot lava from its crater at night (Allison and Palmer, 1980). The volcano Etna - a mountain nearly 3,300 m high on the nearby island of Sicily - began to manifest activity in the 12th Century. Lava from its crater (about 450 m deep) during a grandiose eruption of the volcano devastated the city of Catania. Other eruptions followed and have continued down to the present day.

Volcanoes can be divided into *effusive* volcanoes (with a quiet nature of emission), *explosive* or violent ones, and ones of the *transitional type.* Quiet emission, as in the Hawaiian Islands for example, results in the formation of gently sloping volcanic cones composed of basaltic lava. On

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[33] The earthquake in the vicinity of Dubrovnik in 1667 was especially catastrophic; the city was for practical purposes completely destroyed, and Budva suffered the same fate on that occasion.

the other hand, fountaining lava produces cones of slag with a relatively great angle of slope inclination (from 30 to 35°), as in the case of Wizard Lake (Crater Lake in the state of Oregon, USA). Vesuvius and Etna represent volcanism of the transitional type, with medium angles of slope inclination (usually from 20 to 30°).

The majority of present - day volcanoes are conical hills with a funnel - shaped expanded *crater* on top, which continues downward in a *volcanic conduit*. The cones of some volcanoes have in the course of geological history been from time to time partially destroyed by powerful eruptions and violent explosions, and then built up again by newly ejected material. *Calderas* were formed in this way on many volcanoes. They are extremely expanded craters named after the enormous La Caldera Depression on the Canary Islands, with a diameter of more than 5 km and surrounded by rock walls nearly 1,000 m high. The term caldera is today used for larger depressions in volcanic regions that are sometimes of gigantic size (the caldera of Aniakchak Crater in Alaska has a diameter of 10 km, while that of Crater Lake in Oregon measures 8 km in diameter). However, the usual crater rarely exceeds 300 m in diameter.

Apart from flowing in the indicated way across the crater's central vent, lava can in certain cases also be emitted along some larger fissures from a series of smaller vents and cones that function simultaneously. For example, about 12 km^3 of lava and 2 km^3 of tuff flowed out in the course of only two months in 1783 from such openings along the famous 24 - km - long Laki Fissure on Iceland, and the given mass covered an entire region with an area of about 565 km^2. Basaltic ash carpeted a valley with its surroundings, destroyed thousands of head of livestock, and caused starvation and death of more than 10,000 people. The volcano Taravera on the North Island of New Zealand can be cited as an example of an explosive eruption along fissures. Here in 1886, volcanic products ejected along a fissure 30 km long covered an area of about 10 thousand km^2 with a layer up to 75 m thick (near the fissure).

Similar plates of consolidated lava formed by *fissure eruptions* exist in East Africa, Northern Syria, India, New Zealand, the Rocky Mountain region of the USA, etc.[34]. It is calculated that about $2.6 \cdot 10^6$ km^2 of dry land is covered by old, prehistoric products that arose due to emission of lava from fissures similar to the lava flows that can be seen today on Iceland.

Volcanoes eject material in three aggregate states: fluid, gaseous, and solid. To be more precise, there are three main kinds of products of volcanic eruptions: 1) lava; 2) gases and vapors; and 3) pyroclastic products. Volcanites - surface (effusive) magmatic rocks - are formed from lava, tuffs

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[34] The lava plateau in the states of Washington, Oregon, and Idaho (USA) embraces an area of 520,000 km^2 and has a thickness of 1,200 to 3,000 m and more. The basaltic plateau in India is even larger.

and tuffites from pyroclastic material. Gases and vapors perform several more important geological functions, emerging in many places on the Earth's surface long after volcanic eruptions.

Lava is the main product of many volcanic eruptions and is sometimes emitted in truly enormous quantities. It is a superheated fluid mass with a temperature of 1,000 to 1,100°C. On the surface, lava cools relatively rapidly and at 700 - 600°C starts to solidify and pass over into rock. With respect to its chemical composition, lava forms a series of rocks, from basic to acidic. The very widely disseminated alkaline (basaltic) lavas, with low silica content, have relatively low density, are readily mobile, and can flow at a high speed (more than 30 km/h in the case of the lava of Hawaiian volcanoes). Length of the emitted mass can be more than 100 km, its width up to 4.8 km. Silica - rich acidic lavas are characterized by much greater plasticity, as a result of which they tend to accumulate on hard slopes, forming obstacles in the form of plugs. Blocking vents, they cause explosions. Masses of lava emissions can attain significant dimensions: 980 million m^3 in the case of Etna (1669) for instance. The total mass of consolidated volcanic lava of which the Hawaiian Islands are composed has a volume of more than 300,000 km^3. Put descriptively, the mass of Hawaiian basalt alone could blanket the whole of Europe with a cover about 32 - 33 m thick.

Great amounts of various gases and vapors enter the atmosphere as a result of volcanic eruptions. *Volcanic gases and vapors* consist mainly (75 - 90%) of water vapor. The remaining gases include nitrogen, oxygen, hydrogen, carbon dioxide, hydrogen sulfide, sulfur dioxide, chlorine, fluorine, sulfur, boric acid, ammonia, methane, argon, or products of their reactions. Some of the gaseous components are poisonous for animals and man. As for carbon dioxide, just its emission during volcanic eruptions has already for a long time maintained atmospheric equilibrium, and the whole diversity of plant life could not exist without it. If reserves of this gas were not replenished, it would in time be completely absorbed by plants, as well as by captive buried deposits of caustobioliths. We note that truly enormous amounts of gases and vapors can be released in a short time during volcanic eruptions (more than 1.5 km^3 by Vesuvius in 1929; 1.6 km^3 by Katmai in Alaska in 1912).

Loose *pyroclastic material* arises during explosive action of volcanic vapors and gases. It consists both of solidified lumps of lava and solid particles of different size arising from break - up of older rocks forming underground galleries and the volcano itself. *Volcanic ash* constitutes the finest fraction. This ash is spread by wind over great distances and falls still hot on the surface of the ground. For example, during eruption of the Katmai Volcano in Alaska in 1912, an area of 7.8 km^2 was covered by a layer of ash 30 to 90 cm thick, and thickness of the layer shrank by a few millimeters only at a distance of 6.6 km from the center of the eruption.

Activity of volcanoes in the late stages of cooling is for the most part reduced to exhalation of volcanic gases and vapors. On the basis of temperature, way of manifestation, and composition, all post - volcanic phenomena can be divided into four main groups: 1) solfataras; 2) fumaroles; 3) mofettes; and 4) geysers and hot springs.

Fumaroles are associated with vents from which water vapor and other superheated gases are released. Their name derives from the fact that they emit smoke ("fumare" in Italian means "to smoke"). They are encountered in the vicinity of both active volcanoes and volcanoes in the dormant state. Temperature of the vapor fluctuates between 100 and 650°C. Apart from water vapor, exhalations of fumaroles contain SO_2, HCl, and other compounds. They emit NaCl, Fe_2O_3, and other salts, and in this way form fumarolic deposits (Fig. 2.22.). Recent formation of mineral resource deposits in the vicinity of fumaroles is treated by E.A. Baskov and S.N. Surikov (1989) in the book "**Thermal Springs of the Earth**."

The term *solfatara*[35] is applied to phenomena characterized by exhalations of superheated water vapor, gaseous sulfur compounds, and the volcanic gases H_2S and CO_2 with temperatures ranging between 100 and 200°C. They get their name from the volcano Solfatara in the Phlegraean Fields (Italy), where water vapor with gases is emitted from fissures on the bottom of the crater. The category of solfataras also includes springs of water vapor and volcanic gases in Tuscany. Situated in groups on an area of about 30 km^2 or forming chains along faults (island of Ischia), these springs are well - known for yielding great amounts of boric acid, which has been obtained from them for more than 150 years. The indicated region in Tuscany is also famous for successful exploitation of volcanic (geothermal) energy, inasmuch as steam from the Larderello deposit has since 1904 been used to drive the first geothermal electric power plant on Earth. Also, the content of native sulfur in the vicinity of solfataras can attain industrial significance, and it is extracted in Italy, Mexico, and Japan.

Mofettes are gaseous exhalations of carbon dioxide in areas with almost completely cooled volcanoes. One of the best - known mofettes in Europe is the previously mentioned Dog Cave west of Naples.

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[35] One solfatara exists on the territory of former Yugoslavia. This is Duvalo in the village of Koselje north of Ohrid. The local inhabitants call it that (Duvalo = Blower) because a jet of H_2S and CO_2 is constantly emitted from a miniature crater of elliptical shape. Inasmuch as the depression of the crater itself is filled with these gases, any animal that descends into it soon dies. The exhalations of H_2S are so intense that it can be smelled far around the village.

Geysers and *hot springs* are mainly characterized by an intermittent nature of emission of hot water. They are most numerous in New Zealand, Iceland, and North America. There are about 3,500 of them in Yellowstone National Park (USA) alone, including hundreds with periodic strong eruptions in the form of fountains several tens of meters high. The geyser Waimango in New Zealand in just one eruption ejects about 80 thousand liters of water in the form of a column as much as 400 m high.

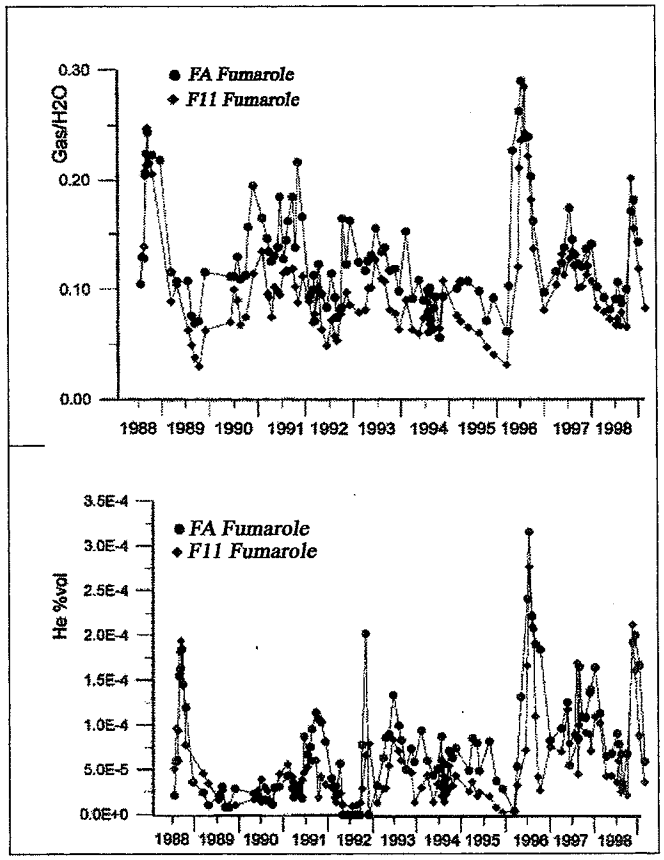

Fig. 2.22. Volcano island. Ratio gas/steam and time changes of helium content for fumarolas FA and F11 (Volpe et al., 1999).

Notes on Better - Known Volcanoes and Their Activity. The main active volcanoes of the Earth are situated on the boundaries of great tectonic plates. Like earthquakes, two thirds of the 600 known volcanoes active in historical time are situated in island chains around the Pacific

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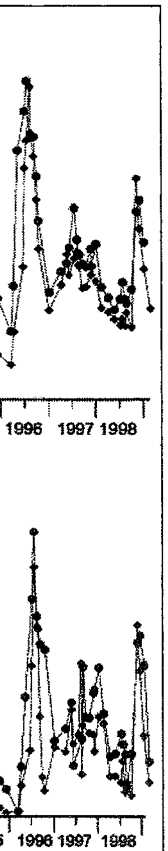

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Ocean (Fig. 2.20.) or on the continental side of boundaries between plates. In other words, this largest mass of water on our planet is girdled by a ring of fire that has many times and in many places killed enormous numbers of people. A second belt with concentration of volcanoes (approximately a fourth of their total number) extends from Italy, Greece, and Turkey across South Asia to Indonesia. Apart from these dry - land geological phenomena, there are about 10,000 underwater volcanoes not less than 1,000 m high in the aquatorium of the Pacific Ocean.

Like earthquakes, volcanoes are a geological phenomenon that can cause many human casualties and great material damage. Twelve thousand people were suffocated during an eruption of the volcano Timbora on the island of Zumbawa in 1815. An enormous area was covered with a layer of ash 60 cm deep. All crops were destroyed and 44 thousand inhabitants died of starvation. An eruption of the volcano Mt. Pelee (Martinique) in 1902 destroyed the town of Ste. Pierre, and all 28 thousand of its inhabitants were killed.

Ejecting solid particles and gases into the atmosphere, volcanoes can alter the Earth's climate. Ash ejected by the eruption of the volcano Krakatoa (an island between Sumatra and Java in Indonesia) in 1883 circled the entire globe, causing evenings to be red - colored for several years, and mean - annual temperature on the planet declined by several degrees.

Not all manifestations of volcanic activity are harmful. Volcanoes act as safety valves (A. D. Howard and I. Remson, 1978). If pressure were not reduced by small eruptions from time to time in various places, the consequences would be far worse. Moreover, volcanic eruptions contribute necessary gases to the atmosphere and make the soil fertile; deposits of mineral raw materials are formed as a result of volcanic activity; and volcanoes serve as a source of geothermal energy, while lava acts as a collector of groundwater. Volcanoes are very picturesque: they beautify monotonous landscapes and offer considerable recreational possibilities.

Several of the world's better - known volcanoes are described below, together with the consequences of their activity for the environment and life.

Vesuvius (Italy). The most famous of the world's volcanoes, Mt. Vesuvius near Naples has been continuously active for more than 19 centuries (Fig. 2.23.). The first eruption in modern history (in 79 A.D.) was at the same time the strongest eruption of this volcano and was described in great detail by Pliny the Younger in his letters to the historian Tacitus. It is known that during this terrible eruption, volcanic lava and ash completely buried the up to then advanced cities of Pompeii, Herculaneum, and Stobia, with more than 20 thousand inhabitants. Something less than a tenth of the population met their deaths under a blanket of hot ash 6 m thick. From that time to the present day, about 12 additional powerful eruptions of Vesuvius have been recorded, and ash from one of them (in 1631) even fell in Istanbul, at a distance of about 1,300 km away.

Etna (Italy). This is the largest active volcano in Europe and one of the largest in the world. Rising 3,280 m above the sea, Mt. Etna is characterized by having on its sides more than 1,000 lateral or parasitic craters in addition to the main crater. The fissures along which the parasitic craters are situated can be more than 15 km long. One of them, with a length of 18 km, opened in 1869 on the southern side of the main crater. Its lava in the form of an enormous tongue covered an area of about 50 km^2, destroying the greater part of the city of Catania and 12 surrounding villages. Etna destroyed the city in several stages and completely buried it is 1669. This time, 49 other towns were destroyed in addition to Catania, and about 94 thousand people died. The last more powerful eruption of Etna devastated Messina in 1908, when about 100 thousand people lost their lives.

Volcanoes of Iceland. The island of Iceland is among the most volcanic areas on Earth. Two volcanic regions, eastern and southern, can be clearly singled out on it. Of nine dry - land and three underwater volcanoes in the eastern part of the island, two are especially significant: Sveinagja and Askja. The former volcano is famous for a powerful eruption in 1875, when 0.3 km^3 of lava was ejected along a single fissure 25 km long. With about 14 volcanoes, the southern region is considerably more active than the eastern and much better known for strong eruptions. Among volcanoes in the southern region is the famous Mt. Hecla, well - known for many powerful eruptions. Still, the greatest disaster Iceland suffered throughout its entire history was caused in 1783 by the volcano Laki. On that occasion, 12.3 km^3 of lava and 3 km^3 of loose material were ejected along one fissure with a length of 25 km, and the emitted lava covered an area of 565 km^2. Volcanic ash and sand blanketed meadows, pastures, and the small amount of arable land on Iceland, and a dense fog never seen before hung over the whole island for months. That was a great national disaster for Iceland: nearly a fifth of the island's population died of contagion and starvation, and the majority of domestic animals perished. The volcanoes of Iceland (like those of Kamchatka, the Aleutian Islands, and Alaska) are also interesting for a special phenomenon that accompanies eruptions in ice - covered regions. Thus, an enormous mass of ice melted during an eruption of the volcano Mt. Katmai in 1918, creating terrible steam - enshrouded torrents up to 70 m deep flowing toward the surrounding lowland. These torrents flooded extensive areas and covered them with mud, boulders, and large pieces of ice.

Tambora (Indonesia). One of the most terrible volcanic eruptions in the memory of man occurred at the beginning of the 19th Century on the island of Sumbawa east of Java. At that time, the volcano Mt. Tambora was lowered by approximately 1,500 m in an explosion that was clearly heard 3,300 km away, and a gigantic mass of pyroclastic material with a volume of 150 km^3 was ejected. More than 66 thousand people lost their lives, both during the eruption and as a result of the starvation and contagion that followed it. Wind carried ash over a considerable distance equal to that from Vesuvius to the Baltic Sea. On the island of Lomboko 120 km away, the ash destroyed all crops and caused terrible starvation of which 44 thousand people died, and severe epidemics appeared in places even farther away. The population of nearly the entire Sunda Archipelago long talked of that event as a kind of end of the world.

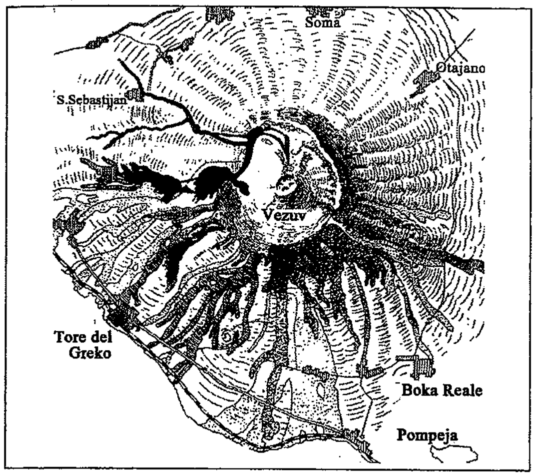

Fig. 2.23. Horizontal projection of Vesuvius with lava flows (dark).

Krakatoa (Indonesia). Among several active volcanoes between the islands of Sumatra and Java, a volcano on the deserted island of Krakatoa has for more than a century represented a symbol of the destructive power of volcanoes as a unique geological phenomenon. Following a 200 - year period of dormancy, Krakatoa showed signs of activity in May of 1883 and exploded powerfully on 27 August of that year, when the greater part of the volcanic island was blown to pieces and a depression in the sea about 360 m deep was created on an area of 72 km^2. Ash rose in the atmosphere to a height of about 30 km, and its depth on the remainder of the island attained 60 m. The total amount of ejected material is estimated at 20 km^3; due to evacuation of the underground reservoir, the surface sank suddenly to form a basin about 6 km wide and 230 m deep. The 40 m - high wave created in the sea pounded with enormous power against the shores of Sumatra and Java, washed over several parts of the islands, and drowned about 36 thousand people, then spread to all coasts of the Pacific and part of the Atlantic Ocean. Sea - going ships carried by the advance of this wave were later found in forests as much as 4 km away from the shore.

Extinct Volcanoes of Yugoslavia. In the not distant geological past, a large number of volcanoes were active in many parts of Yugoslavia. The products of those volcanoes are today found in several extensive volcanic regions such as the Timok Volcanic Region in Eastern Serbia, the Southern Morava and Rhodopo - Toplica Volcanic Regions in Southern Serbia, or the Kosovo - Kopaonik - Rudnik Volcanic Region in Kosmet and Western Serbia. The formation of many of the great ore deposits of Yugoslavia - the Majdanpek and Bor deposits in the domain of the Timok andesite massif, the Trepca deposit in the neighborhood of Kopaonik, and the Rudnik deposit in Sumadia - is linked with old volcanism, which was especially active in the Tertiary.

The country's old volcanoes have for the most part been considerably destroyed and modified by denudation and erosion. In the Timok andesite region, with length of about 50 km and greatest width of the order of 20 km, three main series of cones in the vicinity of the spa Brestovacka Banja and partly on the land between Mt. Rtanj and Tupuznica have been best preserved. Around Kosovo are found the more or less destroyed old craters Mrkonski Vis, Veletin, and Zvecan. Especially characteristic is the old crater Djurdjevi Stupovi near Novi Pazar. Modified by the work of exogenous forces, this crater is very deformed.

As the last gasps of volcanic activity, warm and hot springs occur in certain parts of the country, being in large part linked with great fault lines and fissures. Such phenomena include the spas of Vranjska banja (92°C), Sijarinska banja (71°C), Josanicka Banja (78°C), and many other springs in regions with younger volcanic formations. The numerous paleohydrogeothermal phenomena in Serbia have been treated by M. Milivojevic (1982).

Exogenous Geological Processes and Occurrences

On 28 June 1974 in Villavisensio on a sector of a road 150 km east of Bogotá (Columbia), an enormous mass of earth separated from a rocky slope and with a terrible crash started downhill. More than 750 m of roadbed was buried by pieces of rock, under which 200 workers died. The river below was clogged by the rock, forming a lake that today threatens to overflow in a catastrophic flood. In Northern Italy, a gigantic landslide in October of 1963 came rushing down into the deep but narrow reservoir formed by the Vajont Dam. Enormous waves breached the dam and caused great damage along the part of the valley downstream, on which occasion five towns were devastated and 2,100 people were killed. This was the greatest catastrophe in the world associated with economic activity. There have been many similar examples. Thus, people have died throughout the planet, great material damage has been done, and the fruits of human work have been destroyed as a result of shifting (movement) of rock masses caused by the action of gravitational force. According to predictions for the period of 1970 - 2000 in California (USA), damage from landslides and terrain subsidence could cost 10 billion dollars, which constitutes a significant part of losses from all forms of geological risks (55 billion dollars) in the state for that period.

Geological processes and occurrences (abrasion, river erosion and ravine formation, soil erosion, landslides, rockfalls, torrential rock - and mudslides, karstification) accomplish the basic work of relief modeling.

These exogenous (external) processes are caused by the action of gravitational force, atmospheric agents, or water. As we have seen, they often occur fast and energetically, and changes in the relief of slopes and shifting of enormous masses of rock and rock products from slopes act destructively on constructed objects, thereby altering the conditions of human economic activity.

Classification and Brief Survey of Exogenous Processes and Occurrences

According to the main factors causing them, exogenous geological (geodynamic) processes and occurrences can be relegated to the following six categories:

- *Processes under the influence of atmospheric agents and organisms* (rock weathering);
- *Processes caused by the action of surface water* (denudation, river erosion, abrasion, glacial erosion);
- *Processes caused by the dissolving action of surface and groundwater* (karstification);
- *Processes caused by wind* (eolian erosion);
- *Processes caused by groundwater* (suffosion, filtrational deformation of bedrock, etc.); and
- *Processes caused by the action of gravitational force and underground and surface water* (deformation of slopes and inclines).

In addition to processes of *sedimentation* (accumulation) of eroded material, processes occurring in water - saturated incoherent rocks in the presence of vibrations (*liquefaction processes*) are also worthy of attention. Moreover, effects of processes associated with *human activity* are becoming increasingly more pronounced with the passage of time, and their harmful consequences are being felt to a constantly growing extent.

Processes caused by the action of atmospheric agents and organisms (rock weathering) have already been discussed.

The geological action of surface water starts with atmospheric precipitation, which dissolves and erodes solid components from surface layers, performing *denudation* or *erosion* in the process. Atmospheric precipitation collects in the channels of surface streams, which then accomplish further downcutting of the stream bed and erosion of banks through the action of their own kinetic energy. This form of exogenous processes is called *river* or *fluvial erosion*. Also active in the world are processes associated with the denudational action of ice or *glacial erosion*.

Zones with a moderately damp climate outside annual isotherms of +10°C are characterized by weak and moderate mechanical erosion. The belt of damp tropical climate between isotherms of +10°C is characterized by great and very great *mechanical erosion* (especially in regions with temperatures above +20°C). Inside an area with a moderate tropical climate, the energy of mechanical erosion increases with increase in tectonic activity of the region and is noticeably greater in mountains than on plains. According to N. M. Strakhov (1963), minimal mechanical denudation (less than 10 tons per km^2) in the temperate zone is characteristic of the northern part of North America, the Baltic Shield, the Western Siberian Depression, and the Central Siberian Plateau between the Yenisei and Lena Rivers; mechanical erosion varies from 50 to 100 t/km^2 in lowland regions of South America, Africa, Hindustan, and humid sections of Australia; it is in the range of 100 - 240 t/km^2 in mountainous regions of the Caucasus, Iran, and Andes; and it comprises about 390 t/km^2 in Southeast Asia, attaining as much as 600 - 1,000 and 1,200 t/km^2 in certain regions of the basins of the Indus, Ganges, and Brahmaputra Rivers. With increase of mechanical erosion, there is also an increase of *chemical denudation*, whose action is on average half as great as that of mechanical erosion.

That mechanical erosion and the geological work of rivers can be of gigantic proportions is best seen from the amount of mud that certain great river courses introduce annually into seas and oceans:

- Danube - 82,000,000 t;
- Mississippi - 350,000,000 t;
- Indus - 446,000,000 t;
- Yangtse - 700,000,000 t; and
- Amazon - 1,000,000 t.

Coastal erosion (abrasion) is characterized by great intensity and continuous action. For example, sea waves during a storm shifted a quay wall weighing 8,000 KN in one Scottish harbor and a breakwater weighing more than 17,000 KN in the port of Bilbao in Spain. The rate of shoreline destruction due to the action of waves, marine currents, and other factors can be very different and depends on the conditions under which those factors act. For instance, on the coast of the Black Sea near Odessa, 0.93 m of shoreline is on average destroyed every year, while a coastal strip about 2 m wide disappears annually on the shores of the English Channel.

In limestones and other readily soluble rocks, geological processes are predominantly reduced to dissolution or *karst erosion*, which results in the formation of a specific geomorphologic and hydrogeological environment. Characteristics of karst regions, including risks to buildings, have already been discussed. We note also the great damage done by collapse of terrains, i.e., formation of recent sinkholes and ponors, in certain urban environments. Thus, more than 4,000 new collapses were recorded in the state of Alabama (USA) during the period of 1900 - 1976, and the given occurrences were reported on city streets, in the dooryards of buildings, under workshops, along highways, and in other places.

The velocity of wind and its influence on activity of the inhabitants of arid regions can be very great. During the drought of the mid - 1930's, the fertile upper layer of soil was carried away by wind, i.e., destroyed by *eolian erosion*, due to feebleness of the crops on a large area of the Western Plains of the United States. Something similar happened in certain regions of the Ukraine during a strong storm in 1928, when the top 12 cm of soil was carried away by wind. The potential destructive power of wind erosion can be illustrated by the example of large basins in Kazakhstan (up to 145 km long, from 2 to 10 km wide, and from 100 to 142 m deep) that were formed by the process of deflation[36]. There are hundreds of depressions formed in this way throughout the world. We mention ones in the Gobi desert of Central Asia (up to 50 km long and about 30 m deep) formed in weathered granites by winds dislodging tiny disintegrated particles of quartz and feldspar; and seven such depressions (from 200 to 300 m deep) in the Libyan Desert and Northwest Egypt. Rocky deserts from which all finer material has been blown away, so - called *hammadas*, represent the wildest and most desolate parts of deserts, "*regions of thirst and death*" in the words of a famous French geographer, vast areas on which caravan trails are lost as far as the eye can see[37].

Only 10 thousand years ago, in the Pleistocene Epoch, glaciers covered an enormous area of the planet. Although they withdrew soon thereafter, they had a significant effect on relief. In certain mountainous regions and in high latitudes of the Northern and Southern Hemispheres, glaciers continue to alter the appearance of nature. The process of *glacial erosion* is caused by expansion of water during freezing and by expansion and contraction during temperature changes. Glaciers act on land because they move under the influence of gravitational force, detaching fragments of rock and carrying enormous masses of morainal material. Pieces of morainal material can be very large: measuring 27 x 12 x 9 m, one of largest known was found in the United States near the city of Madison in the state of New Hampshire.

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[36] Detachment and carrying away of particles from rocks by wind.

[37] Deposition of sand under conditions of a dry climate results in the formation of widely disseminated *loess* deposits. The enormously thick loess in northwestern regions of China was formed at the expense of materials from the deserts of Central Asia. Subsequent downcutting of riverbeds created an arena of catastrophic landslides caused by the earthquake of 1920, when about 100 thousand people met their deaths under the masses of material set in motion. Extensive regions of loess are found in Argentina, the Sudan, the northern part of Central and Eastern Europe, the basin of the Mississippi River, etc.

Shifting of rock masses on slopes under the influence of gravitational force represents a very widespread exogenous process, one that more or less deforms the slope and causes damage to man. *Landslides* are the best - known type of movement on slopes, but torrential *rock* - and *mudslides* are also frequently observed, as are *rockfalls* and *talus accumulations*.

The process of sliding represents movement of a portion of rock mass under the influence of gravitational force to a hypsometrically lower level with retention of contact between it and the immobile base (Fig. 2.24.). The process can occur at very different rates, from fractions of a millimeter per day to several tens and even hundreds of meters per hour. Formation and development of landslides can be affected by many factors, among which it is possible to distinguish geological factors (lithological composition, properties of rock masses, conditions under which subsidence of rocks occurs, and seismotectonic conditions) and hydrogeological conditions (properties of rocks as carriers of groundwater, manner and depth of subsidence of groundwater, characteristics of groundwater regimes, etc.). The mechanism of sliding processes can be different, and the following types are most often distinguished according to its nature: *sliding, out - pressing, flowing, subsidence,* and *softening* (M. Komatina, 1995).

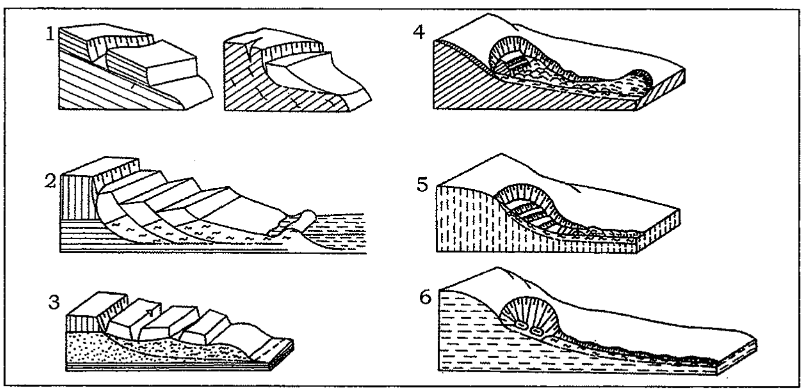

Fig. 2.24. Scheme of landslides types according to their mechanism.

In *rockfalls*, predominantly solid rock masses become detached and move down steep slopes, the process being accompanied by crumbling, rolling, and break - up into smaller pieces (Fig. 2.25.). Sometimes considerable amounts of snow and ice are set in motion together with rock fragments, and in this case the rockfall can be gradually transformed into an avalanche. In contrast to rockfalls, accumulation of *talus* is characterized by gravitational movement of rubble that has formed a slope in accordance with its own internal friction.

Torrential *rock* - and *mudslides* represent sudden currents copiously saturated with rocky material that arise during strong rains in highland regions or after intense melting of snow. They sometimes occur due to bursting of dams in valleys creating torrents with large amounts of coarse - grained material (M. Komatina, 1995). As in the case of landslides, years with extreme manifestation of the given geodynamic phenomena approximately coincide with solar activity and other cosmic factors.

Suffosion can be singled out among processes caused by the action of groundwater. It represents shifting and carrying - out of fine fractions of incoherent loose rock due to hydrodynamic pressure of filtered water, without destruction of the rock structure. The negative effects of suffosion and other kinds of filtrational deformations on rocks and building foundations can be obvious.

Water - saturated incoherent sediments (fine - grained sand, etc.) can pass over into a close to liquid state if they are subjected to dynamic forces caused by vibrations. This process is called *liquefaction*. The consequences of liquefaction can be manifested in different forms and with different intensities. For example, certain buildings sank as much as 1 m into the ground and some were destroyed as a result of liquefaction of sand in Nagata (Japan) in 1964. That same year, liquefaction caused the occurrence of landslides on a front 2,500 m wide on the shores of Cook Inlet in Anchorage (Alaska). Liquefaction caused by the Montenegro Earthquake of 1979 greatly damaged buildings (the Hotel Fjord in Kotor was destroyed), piers, and roads along the shoreline.

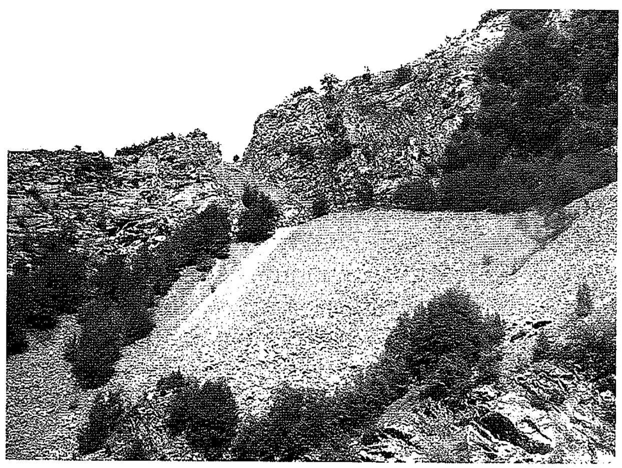

Fig. 2.25. Slope debris in limestone terrain (Photo: D. Milovanovic).

Caused by compaction of land under the influence of overburdening, *terrain subsidence* is pronounced in many large cities such as Tokyo, London, Venice, Houston, and Mexico City, and in numerous agricultural regions. It is most widespread in regions built of loose sediments - deltas, floodable valleys, etc. The Leaning Tower of Pisa (Italy) can serve as a typical example of the action of overburdening on a weak foundation. The tower started to lean in the early stages of construction; as a result of compaction, differential subsidence of the layer of clay under the foundation (8.5 m thick) continued long after completion of the tower, for all of 1,350 years. Attempts were later made to stabilize the tower, which was achieved only after very expensive work. It is generally the rule that subsidence occurs on a greater scale where deep water - bearing horizons are exploited, and many cases of such subsidence with catastrophic consequences are known in the world literature. Several examples of subsidence are as follows: 1) In 50 years of exploiting the groundwater reserves of Tokyo, the rate of ground subsidence attained 10 cm/year in some sectors of the city, and total subsidence amounted to as much as 3.34 m; 2) the rate of ground subsidence in Mexico City was perceptibly greater - 30 cm/year; and 3) in Long Beach it even attained 75 cm/year. Significant subsidence accompanied by great damage (total subsidence attaining 8.5 cm in places) is in many cases associated with pumping of gas and oil (at localities in Japan, in the region of Lake Maracaibo in Venezuela, and in California and Texas), as well as with evacuation of water from surface coal mines and underground exploitation of salt (salt deposits in England and in the vicinity of Tuzla in Bosnia - Herzegovina) or metal mineral resources. We note that during exploitation of gold from a deposit southwest of Johannesburg (Republic of South Africa), eight sinkholes measuring more than 46 m in diameter and 27 m in depth appeared on the surface in five years of drainage, causing much damage and loss of human life.

Risks from Exogenous Processes and Occurrences

Some of the possible risks from exogenous processes and occurrences have been indicated in the foregoing text. By his destructive action, man has every day raised those risks, i.e., constantly increased the danger of floods, landslides, mudslides, and avalanches. In general, movement of rock masses or various processes of erosion, together with possible disastrous consequences, can disturb the normal course of life and work, cause economic damage, hinder transport and communications, etc. If we were to compare the destructive action of landslides with that of other contemporaneous geological processes, we could conclude that they occupy a leading position, together with earthquakes and floods[38]. Catastrophic landslides, rock - and mudslides, and rockfalls take on especially grandiose dimensions at times of powerful earthquakes and volcanic eruptions. The greatest landslides on Earth occurred at such times. Among others, they include the following:

- Sliding of rock masses on the northern shores of the Peloponnesus, which occurred immediately after an earthquake in the 4th Century B.C.;
- Mass activation of landslide processes in the Konsu Province of China in 1920, which led to the destruction of tens of villages and the deaths of 200 thousand inhabitants;

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[38] Floods are among the most serious of natural disasters and are well-known for causing enormous damage. Flooding of the Yangtze River in 1991 devastated more than 4 million dwellings, while the damage done by flooding of the Mississippi River two years later was estimated at more than 10 billion dollars.

- A landslide with a volume of 2.2 km^3 at the time of a strong earthquake in the Pamirs (Russia) in 1911, which completely dammed up the Murgab River; and
- Detachment of part of the mountain's slope with a volume of 2.8 km^3 due to eruption of the volcano Mt. St. Helena (USA) in May of 1980, which resulted in an avalanche that transported material 22 km to the west and covered an area of 60 km^2 in a river valley.

We mention three more characteristic examples of destructive movement of rock masses in the last century:

- Near the town of Frank in the Canadian province of Alberta in 1903, the whole frontal part of a mountain with a volume of about 30 million m^3 tumbled downhill to its foot, and was then raised up on the opposite slope to a height of 120 m. That landslide attained a length of 4 km. The whole sliding process lasted less than two minutes;
- An enormous landslide occurred in the valley of the Gros Ventre River south of Yellowstone Park in Wyoming in 1925. With a volume of around 38 million m^3, the landslide mass descended about 600 m, sliding along a sloping layer of water - saturated clays. The natural dam formed was about 75 m high and more than 750 m long; and
- The mudslide that covered the town of Hait in Tadzhikistan in 1949 moved at a speed greater than 360 km/h. A monument today marks the place where a town once stood at a depth of 30 m in relation to the present level of the terrain[39].

Disastrous landslides and rock - and mudslides have caused the deaths of hundreds and thousands of people throughout the world. According to F. O. Jones (1973), the direct material damage caused by landslides in the United States during the period of 1925 - 1971 was in the neighborhood of 75 billion dollars, which is three times higher than the damage caused by floods, hurricanes, tornadoes, and earthquakes in the same period of time. The annual damage from landslides and flash floods is about 1.5 billion dollars in Japan, while in India it is about a billion dollars in the case of the road network alone.

[39] Movement of material is also possible on the seafloor. The occurrence that took place in the region of the Grand Banks of Newfoundland is an excellent example of a so-called underwater landslide that was transformed into a mudslide. An earthquake with a magnitude of 7.2 and epicenter in the upper part of the continental slope served as the impulse for formation of several underwater landslides on an area of 150 x 300 km. One such great landslide instantly cut six trans-Atlantic cables and activated a mudslide that moved above the landslide and carried pieces of rock over distances greater than 350 km to cut the last cable as far as 730 km from the earthquake's epicenter.

Engineering - Geological Characteristics of the Territory of Yugoslavia

Engineering - geological characteristics of the territory of Yugoslavia were formed as a consequence of the geological structure of terrains as the main precondition, then as a result of the action of various physical (exogenous) factors and human activity affecting the geological environment. According to Lazic and Bozovic (1995), the following four main *engineering - geological categories of rocks* arose on this territory as a result of the given influences:

- *Unbound and weakly bound soft rocks* are widespread in the flat regions north of the Sava and Danube and along river courses. They are represented by fluvial and eolian formations that are highly to moderately deformable in regard to compactability. For such media, water represents the main unfavorable factor in evaluation of terrains from the engineering - geological standpoint;
- *Unbound and weakly bound soft rocks and poorly hardened rocks* of Neogene lacustrine basins represent a highly to moderately deformable medium, especially in the case of unstable slopes. They fill the Velika Morava Depression, the Kolubara Basin, the region of the Tamnava, the Valjevo Basin, the Cacak - Kraljevo Basin, the Zajecar - Knjazevac Basin, basins along the valley of the Southern Morava River, the Kosovo - Metohija Basin, etc. These are provisionally stable to markedly unstable terrains, with many landslides around the rims of the indicated Neogene basins;
- *Poorly hardened to hard rocks* are represented by clastic and sedimento - volcanogenic rocks, manifestations of a diabase - chert formation, and schistose metamorphic rocks of the Vardar Geotectonic Zone and southern part of the Serbo - Macedonian Mass. They constitute highly anisotropic media, ones that are very fractured and profoundly disintegrated, moderately to little deformable, and poorly permeable. Erosion processes and flood activity are very pronounced in the region of the Vranje Basin, the Grdelicka Gorge, and the watershed of the Vlasina River; and
- *Hard to very hard rocks* are predominantly disseminated in boundary - forming geotectonic units marked by limestone massifs such as the Inner Dinarides and Carpatho - Balkanides. They are characterized by great hardness and permanence. The limestone masses are karstified, with rockfalls on steep slopes.

The regionalization of terrains according to engineering - geological advantages for development of human activity, i.e., for human life, is based on a number of more important elements characterizing individual terrain categories. Such elements include:

- *Compactability*, in regard to which swampy and muddy terrains along larger river courses and in the vicinity of their deltas stand out for being highly to moderately compactable;
- *Instability of terrains*, marked by landslides and rockfalls, is characteristic of Neogene sediments, as well as of poorly hardened older rock masses that are greatly fractured and altered;
- *Fluvial erosion* and flooding along unregulated river courses;
- *Abrasion processes* along steep seacoasts;
- *Eolian processes* in unprotected parts of sandy regions; and
- *Karst processes* in the limestone terrains of Southwest and Eastern Serbia.

Terrains with relatively favorable engineering - geological characteristics are found outside regions with the indicated unfavorable elements, zones of increased seismic risk, and areas with more significant unfavorable technogenic influences. Such terrains include the extensive area of the Pannonian Basin and regions between the valley of the Southern Morava River and the Kopaonik Massif.

Groundwater

Water represents the most widely disseminated material in nature. It covers the surface of the Planet, permeates the Earth's crust, and takes part in natural processes. All forms of life require water, and it is found in the atmosphere, hydrosphere, cryosphere[40], biosphere, and lithosphere. Let us dwell on groundwater, i.e., water accumulated in permeable rocks of the lithosphere, as a very important reservoir of infiltrated atmospheric precipitation.

It is calculated that around 23.4 million km^3 of groundwater is found at a depth of up to 2 km, about half of it consisting of slightly mineralized (fresh) water[41]. Of the quantity of slightly mineralized water, something around 4 million km^3 lies in the zone of active exchange with surface water and precipitation. In any event, the amount of groundwater is enormous, 3,000 times greater than the quantity of water in all rivers of the Planet at any given point in time (B. J. Skinner, 1986). In terms of potential, groundwater is therefore unquestionably a primary resource for supplying the population, agriculture, and some industrial concerns with water of good quality.

The distribution of groundwater on our planet is very uneven, with the result that the amount of this essential raw material available to the population is very unequal. The geological structure of a territory is of great significance in the distribution of fresh (potable) groundwater. The

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[40] That part of the Earth's shell with freezing temperature and ice.

[41] Not counting the groundwater of Antarctica, which is for orientational purposes estimated at 2 million km^3.

largest reserves of such water are characteristic of mountain and inter - mountain depressions built of coarse - grained loose materials, especially alluvial, alluvial - lacustrine, and fluvioglacial sediment, as well as coastal plains and fans built predominantly of sand and gravel. Very significant amounts of water are accumulated in regions with open karst and in artesian basins of the platform type.

It is also evident that the distribution of groundwater is subject to latitudinal zonality. Climate represents an especially significant factor here. The general rule is that regions with a humid climate have enough fresh water suitable for water supply or a surplus of it. On the other hand, there is a shortage of fresh groundwater in arid and semiarid regions, for example in dry regions of India, Afghanistan, China, and Mongolia, many African countries, America, and Europe.

Porosity and *permeability* are hydrogeological properties of rocks essential for accumulation of groundwater and its movement.

Total porosity of rocks refers to all spaces not occupied by solid mineral material, whereas the concept of *effective porosity* applies to those spaces in rock filled only by free (gravitational) water. Young loose material (gravel, sand, etc.) is characterized by intergranular porosity, hard carbonate sediments by cavernous (karstic - fracture) porosity, and most other kinds of hard rocks by fracture porosity (Fig. 2.26.).

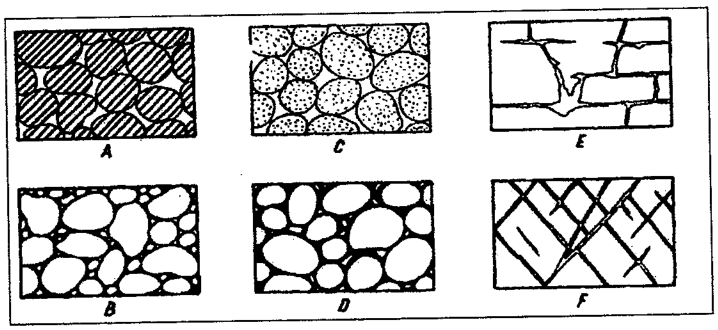

Fig. 2.26. Types of porosity after Meinzer. A, B, C, D - intergranural porosity (different grain - size); E - karst porosity; F - fracture porosity.

Permeability is the capability of rock to admit free (gravitational) water. According to the value of permeability, three *categories of rocks* are often singled out:

- *Highly permeable rocks* (gravel, sand, karstified limestones, dolomites, marbles);
- *Poorly permeable rocks* (deluvial and terrace sediments, marly limestones, serpentinites, peridotites, sandstones); and

- *Practically impermeable rocks* (most magmatic and metamorphic rocks, clays, flysch deposits, and diabase - chert formations).

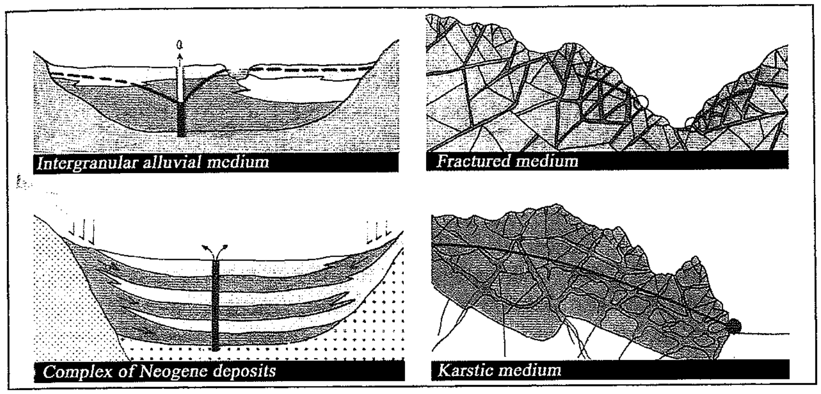

Fig. 2.27. Schemes of typical aquifers.

From the standpoint of water supply, the following four *types of water - bearing (permeable) media* are significant: 1) *alluvial media*; 2) *water - bearing horizons of artesian basins*; 3) *fractured media*; and 4) *karst media* (Fig. 2.27.). Most of the planet's sources of groundwater are linked with alluvial plains, and water of the very permeable gravel - sand layer is utilized (Fig. 2.27.). Karst water - bearing media are also very significant. Their water reserves are regularly evacuated through strong springs (Fig. 2.28.). Among other types of water - bearing media, sedimentary fans, fluvioglacial sediment, and permeable horizons of coastal plains stand out, in addition to artesian basins.

Fig. 2.28. Siphon karst spring Klokun (W. Herzegovina, Croatia).

The *composition of groundwater* is very diverse, since it depends on many factors: physico - geographic, geological, physico - chemical, physical, biological, and artificial. As a highly complex natural solution, groundwater contains practically all known chemical elements in the form of simple and complex ions and complex chemical compounds dissolved in the Earth's crust. More than 70 elements are found in groundwater. Exceptionally, the number of basic dissolved components in slightly mineralized (fresh) groundwater is relatively limited (Fig. 2.29.).

The complexity of composition of groundwater is dictated not only by the presence of a large number of chemical elements, but also by varying quantitative content of each of them - variable in different types of water - as well as by the diversity of soluble forms of each element. It is sufficient to say that groundwater regularly contains different ions of the bulk of chemical elements, dissolved molecules, gas - forming molecules, natural and artificial isotopes of many elements, involved organic compounds that form a completely unique class of dissolved substances, many living and dead microorganisms (bacteria), mechanical and colloidal materials of varying composition, complicated organominerals and other comples, etc. Different ratios of all these compounds, together with quantitative changes in the content of each element, determine the great diversity of groundwater, expressed in the existence of several thousand hydrogeochemical types.

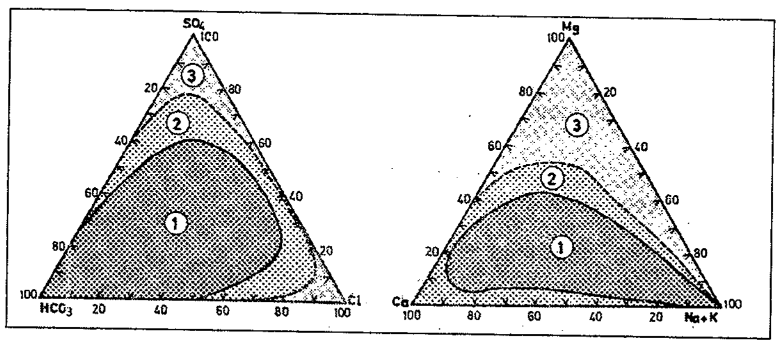

Fig. 2.29. Relative content of main dissolved components in drinking water (Davis, de Wiest, 1966).

Every genetic type of groundwater has its own characteristic properties. Thus, sedimentogenic waters differ from others in having relatively low content of SiO_2, high content of NH_4, and low K/Na, Li/Na, SO_4/Cl, F/Cl, and B/Cl ratios; on the other hand, volcanogenic and metamorphogenic waters are characterized by high content of SiO_2, low content of NH_4, and high Mg/Ca, K/Na, Li/Na, SO_4/Cl, F/Cl, and B/Cl ratios (D. E. White, 1960).

Because groundwater contains chemical elements in very different concentrations - from hundreds of grams per liter to billionths of grams and less - it is expedient to divide these elements into the following four groups depending on their content in water:

- *Macrocomponents*: Na, Ca, Mg, Cl, SO_4, and HCO_3; these components make up more than 90 - 95% of all dissolved salts and determine the chemical type of water;
- *Microcomponents*: Fe, Al, Br, I, F, B, Li, Rb, Ba, As, Sr, Mo, Cu, Co, Ni, etc; these components characterize the specific composition of water;
- *Ultramicrocomponents*: Au, Bi, Te, Cd, Se, etc.; these components are present in water in very small quantities; and
- *Radioactive elements*: U, Th, Ra, and Rn.

The mineralization of water and its pH value, redox potential (Eh), hardness, and aggressiveness represent the main indices of the chemical composition of water.

An especially significant index of the chemical composition of water is its *mineralization*, which represents the sum of all mineral substances in the water. This index has very different values, ranging from 0.1 to 650 g/l. Water with mineralization of less than 1 g/l is used for drinking purposes. Generally speaking, extremely low mineralization is characteristic of groundwater near larger glaciers and in tropical and subtropical regions (160 and 180 mg/l, respectively); groundwater in mountainous regions has low mineralization (about 200 mg/l); and groundwater in the region of old platforms is the most mineralized (having mineralization most often perceptibly above 500 mg/l). As a rule, mineralization increases more or less rapidly or slowly with depth. Thus, for example, in the central counties of Great Britain, it varies from 0.1 to 3.8 g/l in limestones nearer the surface; increases to 10.8 g/l at a depth of 3,200 m; and attains 100 g/l at depths of 5,000 - 5,100 m. The following types of water are distinguished according to mineralization:

- Slightly mineralized (fresh) water, up to 1 g/l;
- Brackish water, 1 - 10 g/l;
- Saline water, 10 - 100 g/l; and
- Brine, above 100 g/l.

Among *macrocomponents*, compounds of iron, manganese, nitrogen (ammonia, nitrates, and nitrites), phosphorus, and silicon (silicic acid) occur in addition to the three leading anions (chlorides, bicarbonates, and sulfates) and cations (calcium, magnesium, and sodium + potassium). As a rule, bicarbonate and calcium ions predominate in slightly mineralized water, whereas chlorine and sodium ions predominate in mineralized and highly mineralized water, with sulfate and magnesium ions occupying an intermediate position.

Although they do not determine the chemical type of groundwater, *microcomponents* can ert significant influence on formation of its specific characteristics and on biological processes in nature. The more important microcomponents belong to several groups:

- Microcomponents that form anions (I, Mo, As, and Se);
- Alkaline metals (Li, Rb, and Cs);
- Dispersed metals (Be);
- Chalcophilic elements (Zn, Cu, Pb, and Ag).

Table 2.9. gives hydrogeochemical characteristics of the more important microcomponents in groundwater.

The *pH value* represents a value that characterizes the activity or concentration of hydrogen ions in solutions. The concentration of hydrogen ions reflects the chemical (acidic or basic) reaction of water. The reaction of water is neutral at pH = 7, acidic at pH < 7, and basic at pH > 7. In groundwater, this value most often ranges from 5 to 8.

In addition to the pH value, the *redox potential (Eh)* erts significant influence on the form of elements in groundwater and conditions of their migration. Closely linked with the pH value, the redox potential fluctuates between 400 and 700 mV, Eh values of 100 to 300 mV indicating transitional redox conditions. Geochemical conditions of the environment can be estimated on the basis of this parameter.

The *hardness of water* is dictated by the content of certain salts such as Ca^{2+}, Mg^{2+}, Fe^{3+}, Mn^{2+}, Al^{3+}, Ba^{2+}, and Sr^{2+}, above all Ca^{2+} and Mg^{2+} ions. There are a number of classifications of groundwater on the basis of its hardness. Shown in Table 2.10., the classification of Klut (in °dH) is most often used in Yugoslavia. Water with hardness of up to 15°dH is best for drinking purposes.

The attention of investigators throughout the world is being increasingly drawn to the content of *natural organic components* in drinking water, as well as to the composition, distribution, and transformation of organic pollutants in different components of the hydrosphere. The influence of organic compounds in water on human health represents a special area of research.

The *microflora of groundwater* is a very important and active part of the hydrosphere. It is made up of tiny plant organisms, among which bacteria have been the main object of study. In the process of their vital activity, bacteria have performed and are performing enormous geological work on alteration of the chemical composition of groundwater.

TABLE 2.9.
Content of important trace elements in lithosphere and water ((μg/l).

Element	Content in lithosphere (without sedimentary cover) %	Content in water (μg/l)		
		Ocean	Low-mineralized drinking water (fon)	Maximal content in water
J	$5.0 \cdot 10^{-5}$	64	6	$120 \cdot 10^{3}$
Li	$2.0 \cdot 10^{-3}$	170	5	$320 \cdot 10^{3}$
Rb	$9.0 \cdot 10^{-3}$	120	3	$100 \cdot 10^{3}$
Cs	$2.0 \cdot 10^{-4}$	0.3	2	$20 \cdot 10^{3}$
Be	$1.5 \cdot 10^{-4}$	0.0006	0.2	$n \cdot 10^{3}$
Zn	$8.7 \cdot 10^{-3}$	5.0	74	$1 \cdot 10^{6}$
Cu	$6.5 \cdot 10^{-3}$	0.9	11	$1 \cdot 10^{6}$
Pb	$0.9 \cdot 10^{-3}$	0.03	6	$6 \cdot 10^{4}$
Ag	$9.0 \cdot 10^{-6}$	0.28	0.3	50
Mo	$1.3 \cdot 10^{-4}$	10	1.3	700
As	$1.9 \cdot 10^{-4}$	2.6	1	$n \cdot 10^{5}$
Se	$1.0 \cdot 10^{-5}$	0.009	1	300
U	$1.5 \cdot 10^{-4}$	3.3	3	$n \cdot 10^{4}$
Ra	$2.0 \cdot 10^{-10}$	$0.1 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	$n \cdot 10^{-2}$

Slightly Mineralized (Fresh) Groundwater

Without doubt, slightly mineralized (fresh) groundwater represents the most important part of our water resources. In many regions of the world, this is the only source of water supply for the population and industry or for irrigation of agricultural land.

TABLE 2.10.
Classification of water according to hardness, after Klut.

Hardness ^{0}dH	Type of water
0 - 4	Very soft water
4 - 8	Soft
8 - 12	Moderate hard
12 - 18	Almost hard
18 - 30	Hard
> 30	Extremely hard

Slightly mineralized water can have different *chemical composition.* The overwhelming bulk of such water belongs to the HCO_3-Ca and HCO_3-

SO_4-Ca water types. It is characterized by pH values from 6.0 to 8.0 and redox potentials ranging from +500 to - 200 mV.

All slightly mineralized groundwater contains diverse *organic components*. The total content of organic substances expressed by the value of organic carbon on average comprises 25 mg/l. Among organic components that have been discovered, the greatest interest has been shown in various organic acids, phenols, and humic and bituminous components.

Slightly mineralized water contains a large number of *microorganisms* (bacteria, algae, fungi, protozoa, and viruses), but considerably less than in the soil. Water represents the normal place of residence for some of these tiny and generally very numerous organisms, while others (so - called contaminating microorganisms) enter water from the air or soil, from plants, and from excrement of human or animal origin. From the standpoint of human health, the most significant contaminants of drinking water are microorganisms entering it from human and animal excrement due to unhygienic disposal of sewage. Drinking water can contain pathogenic microorganisms that cause disease in plants and animals, and consumption of such water can be risky for humans.

With rare exceptions, all groundwater is to a certain extent radioactive. However, the *content of radionuclides* in it is considerably lower than in rocks. The greatest concentration of radionuclides is found in the groundwater of uranium deposits.

Hydrogeochemical zonality is expressed in hydrogeological structures with slightly mineralized water. It consists of regular changes in general chemical and gas composition, concentrations of microcomponents and organic substances, and pH and Eh of the water. *Horizontal (latitudinal, climatic)* zonality is characteristic of shallower water - bearing horizons. It is manifested through increase in the total mineralization of groundwater, as well as in the concentration of basic anions and cations, with transition from a humid zone to an arid one. The concentration of organic substances of the humic series decreases in this case, Eh and pH parameters rise, and increases are recorded in the concentrations of many anionic elements such as fluorine, molybdenum, arsenic, selenium, etc. Manifestation of *vertical hydrogeochemical zonality* depends upon the composition of hydrogeological structures. In artesian basins, such zonality is expressed in regular alternation of geochemical types of groundwater in the vertical profile of a given structure. In regions of hydrogeological massifs, regular transformations of geochemical types of groundwater are recorded with increase in the depth of their occurrence.

Under natural conditions, slightly mineralized groundwater is characterized by good *physicochemical properties*. Thus, the quality of water from fractured and karst media, for example, is usually excellent. An exception to this is observed in the case of salinization of water in coastal zones and arid regions, due to intrusion of seawater in the former instance and concentration of salt by means of evaporation in the latter. In water - bearing media with intergranular porosity such as alluvial media and media of artesian basins, the chemical composition of water is for the most part favorable; negative quality indices for such water are observed more rarely and involve content of iron, manganese, and sometimes humic substances in it and arsenic.

The content of *radionuclides and toxic chemical components* in slightly mineralized groundwater is predominantly low, below limits permitted by "Guidelines for Drinking Water." Risks to human health caused by higher (or lower) concentrations of these elements will be discussed in the corresponding chapter of the book.

The degree of *natural protection of groundwater* from pollutants depends mainly on geological (hydrogeological) factors. For example, water - bearing artesian horizons as a rule are protected from sources of pollution on the surface because they are covered by a thick overlying layer of clay (Fig. 2.27.). In the case of alluvial gravel - sand horizons, apart from possible lateral influence of a polluted surface stream, the danger of pollution from the surface also exists. The degree of protection then depends on thickness and permeability of the overlying layer of clay: if it is thinner than 3 - 4 m, there exists a greater or lesser possibility of influence from agricultural and other pollutants. Sporadic shallow groundwater in fractured rocks is very sensitive, a circumstance manifested in bacteriological contamination of the majority of springs through which such water is evacuated. Karst media are without doubt the most sensitive, since carbonate rocks in fold (geosynclinal) regions are for the most part exposed and very permeable, and the risk of pollutant infiltration is especially heightened by the direction of *permanent ponors* and *karst springs* (Fig. 2.8). The fact that karst water has so far predominantly retained its high quality is primarily due to the limited presence of industrial and other polluters in more inaccessible mountainous terrains.

In any event, to be used for drinking purposes, water must satisfy norms prescribed for physicochemical parameters, content of toxic chemical components, parameters of radioactivity, and microbiological and organoleptic properties. Special (preventive) *sanitary measures* are taken to protect sources, and appropriate purification systems remove undesirable ingredients from raw water. Laws require formation of the following *zones of sanitary protection* of water sources: *zone I*, where a strict regime of direct protection is established around the source from which water is obtained; *zone II*, where measures of "bacteriological" protection are implemented to prevent bacteria from entering the water;

and *zone III*, where chemical pollution is controlled over the entire area feeding the water source. In karst regions, the first or second zone must be expanded by the addition of a narrower zone encompassing privileged canals (faults) connected with the ponor zone.

Because of its quality, man has always been interested in groundwater for drinking purposes. It can therefore be freely stated that investigation of groundwater and its use as drinking water already began in the distant past. The first information about artificial structures for removal of water from wells date from the 3rd Millennium B.C. Large centralized systems of water supply already existed during the period of flowering of Ancient Greece and Rome. The first gravitational aqueducts of Paris and London appeared at the end of the 12th Century and in the 13th Century, respectively. In the year 1980, apart from 2,306 km^3 (or 73.1×10^3 m^3/s) of water used in agriculture, 1,194 km^3 (or 34.6×10^3 m^3/s) was used throughout the world to supply industrial concerns and the population, and groundwater accounted for a significant share of it. A high level of groundwater use is evident in most countries of Europe, Africa, North America, and Australia, and water supply in arid and semiarid zones of the globe is almost completely based on capture of groundwater. Thanks to the existence of deep water - bearing horizons, new oases have sprung up around boreholes that struck those horizons in many desert territories, the Sahara above all. The first borehole drilled in Gwardaja in Algeria struck a water - bearing horizon at a depth of 1,200 m, and water gushed in a jet 180 m high. Until the discovery of that rich horizon, oases in the Algerian Sahara were under threat of extinction due to lack of water and sandstorms. Limitation of resources of sprinkling water led to the appearance of salt on the surface of the ground, which resulted in the death of date palms. With the beginning of exploitation of the indicated horizon, salt was washed from the ground and dunes were consolidated by planting vegetation and in other ways. We note that the area of this horizon in North Africa is exceptionally great, extending to Libya in the east and for a distance of hundreds of kilometers from the Atlas Massif in the south.

Irrigation of desert regions has played a visible role in the history of mankind. Many states of the East, Egypt and Babylonia among others, arose and achieved a high degree of culture precisely on irrigated land. In most desert regions, however, reserves of groundwater are shrinking every day due to shortage of precipitation without renewal.

Until recently, man regarded water as a God - given "free" resource that can be utilized without limitation wherever it is found. But with the advent of the Industrial Revolution, living conditions changed suddenly: enormous urban populations arose, industrial and agricultural installations appeared, the population and standard of living grew at an accelerated rate, and the need for pure water increased accordingly. On the other hand, pollution of streams and reservoirs (and some groundwater too) has reached alarming levels, while exploitation of water resources has been irrational, sometimes literally greedy. We are thus confronted with one of the basic negative features of the modern world, namely the **global water problem** or the **problem of pure water**.

Due to the indicated problem and the anyway unequal distribution of water resources, the problem of supplying the population with water has become acute in large areas of our planet. Thus, in 1975 already, only 38% of the populations of developing countries had access to hygienically acceptable drinking water, with the result that nearly 800 million people suffered from gastroenteritis, malaria, schistosomiasis, and oncocercosis. The consequences of the shortage of pure water are even more serious today and are increasingly affecting countries of the developed world as well.

The global water problem must be resolved by a wide range of activities that cannot be postponed. Such activities should take two main directions: a) implementation of urgent measures for *protection of water resources from pollution*; and b) *protection of water from overexploitation*. In the distant future, man will be forced to employ more costly approaches to ensure an adequate amount of drinking water, namely desalinization of mineralized (sea and underground) water and transport of icebergs to regions of the Earth with a water deficit, and thereby shift the water balance in his favor. Until then, solutions to the problem of supplying the population with water of good quality will be found in more organized and intensive exploration, and in rational use and better protection of groundwater sources. Man is not even close to having exhausted the unlimited possibilities of regulating the regime of groundwater in especially widespread permeable rocks, and almost nothing has been done to reduce the loss of much good water into the sea (M. Komatina, 1990).

Mineral Waters

By mineral waters, the majority of investigators mean all waters with a dissolved ingredient content of more than 1,000 mg/l, as well as natural waters with low mineralization if they contain one or several specific components that ert therapeutic action on the human organism. In order for groundwater to be classified as mineral waters, they must contain specific components such as Li, Sr, Ba, Fe, Mn, Br, I, F, B, H_2S, $HSiO_3$, CO_2, and Ra. For therapeutically active components, the following values of content (mg/l) are prescribed: iron, 10; arsenic, 0.7; iodine, 1.0; titrated sulfur, 1.0; carbon dioxide, 250; and radon, above 185 Bq/l[42].

The very concept of mineral water differs to some extent in different countries. By mineral waters, French scientists most often mean waters with therapeutic properties and acknowledged as such by the Medical Academy of France. In Belgium, Spain, Italy, and Switzerland, it is also held that the term *mineral water* must be linked with its therapeutic properties. Water can be called mineral water if it erts pharmacological action on the human organism, which can be caused by the presence or absence of any specific elements (or element) regardless of their (its) quantitative content.

Mineral waters have been used to treat diseases since ancient times. Folk wisdom very early called attention to the medicinal properties of many mineral springs and elaborated practical means of using them. Moreover, mineral waters in the infancy of man, like other natural phenomena, were the object of blind admiration and the most fantastic speculations as to their origin. This can be in some measure ascribed to the fact that many sources of mineral waters were hot, gas - bearing, or fountaining springs. Especially grandiose occurrences of hot vapor and water are typical of regions with *"fire - bearing mountains"* or volcanoes, whose nature were unclear and gave rise to many legends. The views that arose as to the nature and origin of mineral waters were in Ancient Greece and Rome mechanically transferred to mineral springs situated far from the foci of volcanic activity.

In Hellenic science, a fairly clear idea prevailed as to the origin and properties of natural waters. Already in the First Century A.D., the well - known physician Archigenes divided mineral waters into alkaline, iron, saline, and sulfuric categories. The remains of marble basins and old caps of mineral water sources dating from the Roman epoch can be seen in many spas of Italy, Austria, Germany, France, Hungary, Romania, Yugoslavia, Croatia, Bulgaria, Libya, Algeria, and other countries.

In contrast to the period of the Roman Empire, massive utilization of mineral waters stopped in the Middle Ages, to be revived only in the 19th Century. The scientific study of mineral waters and their utilization was formed prior to the end of that century.

Distribution of mineral waters. The formation, renewal, and evacuation of mineral waters are processes closely linked with definite geological environments and certain structures in constitution of the Earth's crust, a knowledge of which is of great importance. A territory within whose boundaries certain mineral water groups are found is called

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[42] In the former Czechoslovakia, appreciably greater minimal levels of specific components (mg/l) are prescribed: CO_2, up to 2,000; Li, 5; Br, 25; Iz, 10; H_2S, 5-10; and radioactivity, 36.2 Ki/l.

a *mineral water province.* To be more precise, a province represents space on which certain mineral water groups occurring there are linked by the entirety of structural, hydrogeological, hydrogeochemical, hydrothermal, and other characteristics. For example, three mineral water provinces are isolated on the vast territory of what was once the USSR (E. V. Posokhov and N. I. Tolstikhin, 1977). The *first province* is characterized by prevalence of the carbonated mineral waters and encompasses regions with current and recently extinct volcanic activity (the Caucasus, Pamirs, Kamchatka, etc.). The *second province* is marked by the presence of nitric thermal waters, includes regions with recent seismic occurrences in the East and South of the former USSR, and borders on the first province. The *third province* is linked with platform regions and boundary zones with geosynclines, where cold and thermal brines, saline waters, and N_2 - methane waters are formed.

Classification of mineral waters. A great number of mineral (medicinal) waters are present in nature. They can be classified on the basis of a number of criteria such as total mineralization, ion and gas composition, content of active therapeutic components, radioactivity, acidity or alkalinity, and temperature.

Among the many classifications of medicinal waters and mineral waters in general, the *genetic classification of V. V. Ivanov and G. A. Nevraeva* (1964, supplemented 1977) stands out by virtue of its completeness. The indicated classification makes it possible on the basis of the ionic composition of different mineral waters to gain an idea of their hydrogeological and balneological properties and ascertain from mineralization values their suitability for treatment by drinking or bathing. Medicinal waters are divided into four basic groups on the basis of mineralization:

1. *Waters with elevated mineralization* (1 to 5 g/l), which when consumed by drinking act on the human organism in a manner similar to the action of "ordinary" slightly mineralized water;
2. *Waters with medium mineralization* (5 to 15 g/l), whose osmotic concentration approaches that of blood plasma; these water are most suitable in balneology and are also imbibed as medicine;
3. *Waters with high mineralization* (15 to 35 g/l), mainly used for therapeutic bathing, but certain types of chloride - hydrocarbonate water of the sodium group are also imbibed;
4. *Brines* (water with mineralization of 35 to 150 g/l) in natural form are used exclusively for bathing purposes. In exceptional cases, brines with mineralization greater than indicated can also be used in balneology, but in this case they are preliminarily diluted with slightly mineralized water or water with elevated mineralization.

Certain gases, organic substances, trace elements, and radioactive elements can be balneologically active. Among gases, for example, CO_2, H_2S, and Rn have such properties. From the balneological standpoint, trace elements can be divided into the following four groups:

Group I - elements with expressed pharmacological action (Fe, Co, As, I, Br, and possibly B);
Group II - elements with precisely established influence on hormonal and enzymatic processes in the organism (I, Fe, Cu, Mo, Zn, Co, Mn, and possibly Ni and Ba);
Group III - elements toxic for the human organism (As, Pb, Se, He, V, and F); and
Group IV - elements that have been discovered in human tissues and fluids, but whose biological role has not yet been established (Ti, Zr, Ir, Cs, Ge, and many others).

In regard to content of specific components, Ivanov and Nevraev single out eight balneological groups of mineral waters, the more important characteristics of which are noted below.

1. *Medicinal mineral waters without specific components and properties.* Such mineral waters ert balneological action on the human organism as a result of ionic composition and mineralization. Chloride and sulfate ions are prevalent in their chemical composition. In regard to gas composition, these waters belong to the nitrogen and methane types. Their mineralization can attain 150 g/l;
2. *Carbonated mineral waters.* Such mineral waters are very widely disseminated in nature. Their medicinal effect is determined by high concentration of carbon dioxide, as well as by its ionic composition and mineralization value. They have varying chemical composition, HCO_3^- being dominant among anions. Mineralization of these waters fluctuates from fractions of a gram per liter to 90 g/l. Of all types of mineral water, they are characterized by the greatest saturation with gas. Apart from refreshment, carbonated waters are used to treat diseases of the stomach, intestines, bile and urinary ducts, etc. Today it is customary to isolate five types of carbon dioxide waters;
3. *Hydrogen sulfide (sulfide) mineral waters.* Their medicinal properties are determined by free hydrogen sulfide and hydrosulfide ions. Mineral waters of this group are characterized by great diversity of chemical composition, mineralization, and H_2S and HS^- concentration. They include hydrocarbonate, sulfate, and chloride waters with high mineralization, often above 500 g/l. In balneology, bathing in such waters is used to treat certain diseases (diseases of the skin, rheumatic diseases, nervous disorders, etc.). On the basis of concentration of hydrogen sulfide and hydrosulfide ions, these waters are divided into four subgroups. With

respect to the conditions of their formation, nitric, methane, and H_2S - CO_2 waters are distinguished;

4. *Radioactive mineral waters.* These waters have elevated content of radioactive elements. The following lower limits are prescribed: Ra, above $1 \cdot 10^{-11}$ g/l; U, above $3 \cdot 10^{-5}$ g/l; and Rn, above $1.85 \cdot 10^{2}$ Bq/l. Radium, radium - radon, radon, or uranium waters are distinguished, depending on which radioactive element is prevalent. Radon waters are the ones predominantly used in balneology. They are employed to treat diseases of the nervous system, cardiovascular diseases, skin ailments, and gynecological diseases;
5. *Iron waters, arsenic waters, and waters with elevated content of Mn, Al, Cu, and Zn.* The medicinal properties of this group of waters are determined by the presence of iron (lower limit of 20 mg/l), arsenic (lower limit of 0.7 mg/l), and other metals;
6. *Bromine and iodine waters.* Patients drink these waters and bathe in them. Such waters need to contain more than 25 mg/l of bromine or more than 5 mg/l of iodine, and their mineralization must be such that their drinking is permissible;
7. *Waters with high content of organic substances.* The basic balneological properties of such waters are linked with action of the complex of dissolved organic substances on the human organism. The total content of organic substances in these mineral waters varies within wide limits, from several mg/l to more than 400 mg/l and higher in exceptional cases. Mineral waters of peat bogs, mud flats, and petroleum deposits are especially rich in organic substances; and
8. *Silicic thermal springs.* They are represented by thermal and highly thermal waters with temperatures above 35°C containing not less than 50 mg/l of silicium in the form of silicic acid (H_2SiO_3). These waters often contain other medicinal components (Rn, CO_2, and trace elements) as well.

The frequently used *classification of mineral waters according to their gas composition* divides them into the following six groups: *carbonated waters; H_2S - CO_2 waters; hydrogen sulfide (sulfide) waters; nitric waters; N_2 - methane waters; and methane waters.*

There are a number of *classifications of mineral waters on the basis of temperature.* According to one of them, all mineral waters are from the balneological standpoint relegated to one of the following five groups: *cold*[43], with temperatures below 20°C; *warm*, 20 - 37°C; *thermal*, 37 - 42°C; *highly thermal*, 42 - 100°C; and *superheated*, above 100°C.

On the basis of *pH value*, one of the factors that in significant measure determines the physiological action of water on the human organism, the following groups of mineral waters are distinguished: *strongly acidic* (pH < 3.5); *acidic* (pH 3.5 - 5.5); *weakly acidic* (pH 5.5 - 6.8);

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[43] More recently, cold water has been taken to mean groundwater with temperature below the average-annual temperature in a given locality.

Certain gases, organic substances, trace elements, and radioactive elements can be balneologically active. Among gases, for example, CO_2, H_2S, and Rn have such properties. From the balneological standpoint, trace elements can be divided into the following four groups:

Group I - elements with expressed pharmacological action (Fe, Co, As, I, Br, and possibly B);
Group II - elements with precisely established influence on hormonal and enzymatic processes in the organism (I, Fe, Cu, Mo, Zn, Co, Mn, and possibly Ni and Ba);
Group III - elements toxic for the human organism (As, Pb, Se, He, V, and F); and
Group IV - elements that have been discovered in human tissues and fluids, but whose biological role has not yet been established (Ti, Zr, Ir, Cs, Ge, and many others).

In regard to content of specific components, Ivanov and Nevraev single out eight balneological groups of mineral waters, the more important characteristics of which are noted below.

1. *Medicinal mineral waters without specific components and properties.* Such mineral waters ert balneological action on the human organism as a result of ionic composition and mineralization. Chloride and sulfate ions are prevalent in their chemical composition. In regard to gas composition, these waters belong to the nitrogen and methane types. Their mineralization can attain 150 g/l;
2. *Carbonated mineral waters.* Such mineral waters are very widely disseminated in nature. Their medicinal effect is determined by high concentration of carbon dioxide, as well as by its ionic composition and mineralization value. They have varying chemical composition, HCO_3^- being dominant among anions. Mineralization of these waters fluctuates from fractions of a gram per liter to 90 g/l. Of all types of mineral water, they are characterized by the greatest saturation with gas. Apart from refreshment, carbonated waters are used to treat diseases of the stomach, intestines, bile and urinary ducts, etc. Today it is customary to isolate five types of carbon dioxide waters;
3. *Hydrogen sulfide (sulfide) mineral waters.* Their medicinal properties are determined by free hydrogen sulfide and hydrosulfide ions. Mineral waters of this group are characterized by great diversity of chemical composition, mineralization, and H_2S and HS^- concentration. They include hydrocarbonate, sulfate, and chloride waters with high mineralization, often above 500 g/l. In balneology, bathing in such waters is used to treat certain diseases (diseases of the skin, rheumatic diseases, nervous disorders, etc.). On the basis of concentration of hydrogen sulfide and hydrosulfide ions, these waters are divided into four subgroups. With

respect to the conditions of their formation, nitric, methane, and H_2S - CO_2 waters are distinguished;

4. *Radioactive mineral waters.* These waters have elevated content of radioactive elements. The following lower limits are prescribed: Ra, above $1 \cdot 10^{-11}$ g/l; U, above $3 \cdot 10^{-5}$ g/l; and Rn, above $1.85 \cdot 10^{2}$ Bq/l. Radium, radium - radon, radon, or uranium waters are distinguished, depending on which radioactive element is prevalent. Radon waters are the ones predominantly used in balneology. They are employed to treat diseases of the nervous system, cardiovascular diseases, skin ailments, and gynecological diseases;
5. *Iron waters, arsenic waters, and waters with elevated content of Mn, Al, Cu, and Zn.* The medicinal properties of this group of waters are determined by the presence of iron (lower limit of 20 mg/l), arsenic (lower limit of 0.7 mg/l), and other metals;
6. *Bromine and iodine waters.* Patients drink these waters and bathe in them. Such waters need to contain more than 25 mg/l of bromine or more than 5 mg/l of iodine, and their mineralization must be such that their drinking is permissible;
7. *Waters with high content of organic substances.* The basic balneological properties of such waters are linked with action of the complex of dissolved organic substances on the human organism. The total content of organic substances in these mineral waters varies within wide limits, from several mg/l to more than 400 mg/l and higher in exceptional cases. Mineral waters of peat bogs, mud flats, and petroleum deposits are especially rich in organic substances; and
8. *Silicic thermal springs.* They are represented by thermal and highly thermal waters with temperatures above 35°C containing not less than 50 mg/l of silicium in the form of silicic acid (H_2SiO_3). These waters often contain other medicinal components (Rn, CO_2, and trace elements) as well.

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[43] More recently, cold water has been taken to mean groundwater with temperature below the average-annual temperature in a given locality.

neutral (pH 6.8 - 7.2); *weakly alkaline* (7.2 - 8.5); and *alkaline* (pH > 8.5). A strongly acidic reaction is characteristic of the sulfate waters of mineral deposits, highly thermal waters of active volcanic regions, and ultra - strong calcium chloride brines. All carbonated waters are characterized by a weakly acidic reaction. Neutral and weakly alkaline reactions are typical of sulfide waters and waters with elevated mineralization. Slightly mineralized waters of nitric thermal springs have an alkaline reaction.

Thermal Waters

Occurring primarily in volcanic regions, the numerous and diverse forms of thermal waters and vapors (hot springs, geysers, and fumaroles) have unquestionably attracted man's attention since prehistoric times for their medicinal properties. That thermal springs were used in the Stone and Bronze Ages for various purposes is indicated by an abundance of archaeological finds in the cultural layer of many sites on the territory of Iran, New Zealand, Kamchatka, and other regions of the world. In the Antic Period (Fifth to Fourth Century B.C.), the works of Democritus, Aristotle, and Pliny the Elder contain views on the genesis of mineral and thermal waters that in general features are largely consistent with modern views.

During the Middle Ages, the general shutdown of cultural and scientific development was reflected in the study and utilization of thermal waters, although a certain advance was perceived in the period of the Crusades (1096 - 1270) and during the Hundred Years' War (1337 - 1453). Interest in mineral and thermal waters grew during the 16th and 17th Centuries in Western Europe. In the 19th Century and first half of the 20th Century, numerous and diversified investigations of thermal waters were carried out, primarily for *healing purposes.* The thermal waters of popular spas were studied with particular care, and increase in the number of chemical analyses of water was especially rapid.

Starting from 1920 in the United States and predominantly in the 50's and 60's of the 20th Century in many other countries (the Soviet Union, New Zealand, Japan, Mexico, Kenya, Italy, France, Yugoslavia, etc.), exploratory drilling was initiated for the purpose of discovering geothermal resources in many localities marked by the occurrence of thermal springs. At the beginning of 1970, such drilling in the USA had been conducted in more than 35 regions and resulted in the discovery of six productive geothermal fields. Ten years later, 16 geothermal power plants were already in operation on this territory.

According to current ideas, the bulk of thermal waters and mixtures of steam and thermal water are formed at relatively great depths mainly from meteoric (infiltration) water, which is then (as a result of rising filtration along fault zones) evacuated on the Earth's surface or accumulated in permeable horizons of sedimentary basins. *Geosynclinal and platform regions* differ markedly with respect to conditions of distribution, formation, and evacuation of thermal waters.

In *geosynclinal regions*, thermal waters and steaming thermal springs are formed predominantly in areas of Cenozoic volcanism and more recent tectonic movements, where we find numerous sites of their evacuation linked with zones of large fault structures (M. Komatina, 1995). The waters usually have mineralization of the order of 1 g/l, more rarely 20 g/l, and in exceptional cases up to 100 g/l (New Zealand, Indonesia). The greatest possible hydrothermal activity occurs in regions with intensive manifestation of Cenozoic volcanism. Thermal waters and steaming thermal springs with temperatures of up to 100°C in the places where they are naturally evacuated and from 270 to 390°C in boreholes 2 - 3 km deep (California, Mexico, New Zealand) are found near active volcanoes, where they form deposits. The waters have diverse chemical composition and elevated concentrations of various microcomponents.

Platform regions are characterized by enormous reserves of thermal waters accumulated in deep permeable layers. The waters are very diverse in regard to temperature, composition, and mineralization. Young platforms are distinguished by high output of boreholes and high temperature of the water. On the other hand, brines with mineralization of up to 620 g/l (the Siberian Platform) and temperatures of 40 - 70°C are widespread in old platforms.

Depending on geological, geochemical, and geothermic conditions, thermal waters and steaming thermal springs can possess highly varied ion and gas composition and be characterized by a wide range of mineralization and very different temperatures. There are today a number of classifications of such waters. Thus, for example, V. V. Ivanov (1961) distinguishes the following five groups of thermal springs, primarily depending on gas composition:

- H_2S - CO_2 (fumarolic) thermal springs;
- Carbonated thermal springs;
- N_2 - CO_2 thermal springs (steaming thermal springs);
- Nitric alkaline thermal springs; and
- Methane thermal springs.

The Russian authors E. A. Baskov and S. N. Surikov (1975, 1989) systematized thermal waters according to acid - base properties (pH values), anion composition, and gas composition. With respect to acid - base properties, they distinguished two main groups, viz., *acidic* (pH < 4.5) and *alkaline* (and *weakly acidic*) (pH > 4.5).

On the basis of prevailing anion composition, **acidic thermal waters** are divided into chloride, sulfate, and silicic categories.

1. According to Baskov and Surikov, *acidic chloride thermal waters* are very widespread in areas with current volcanism (Eastern Kamchatka, the Kurile Islands, volcanic zones of Japan, the Philippines, Indonesia, the Cordillera de los Andes, etc.). The vents of thermal springs here appear on

fumarole fields of active volcanoes and emit natural condensates of fumarole gases. Temperatures of these thermal springs usually fluctuate from 70 to 100°C. Low pH values are characteristic: predominantly less than 2 - 2.5, often as low as 0.1 - 0.5. Mineralization is fairly variable, often from 3 - 5 to 10 - 50 g/l. Acidic chloride brines with mineralization of up to 300 - 400 g/l are formed on fumarole fields only in regions with developed halogenic formations (in the Danakil Depression in Africa, for instance). Acidic chloride fumarolic thermal springs are often characterized by high concentrations of the following components (mg/l): F, up to 400 - 800; H_2SiO_3, 200 - 400 (up to 800); H_3BO_3, 100 - 500 (up to 500 - 600); Fe, 100 - 600 (up to 5,000 - 10,000); Al, 100 - 500 (up to 2,000 - 8,000); and many other metals. With respect to gas composition, these waters are mainly of the H_2S - CO_2 and carbonated types.

2. Acidic chloride thermal waters represented by highly concentrated chloride, calcium - sodium, and calcium brines (with mineralization usually greater than 25 - 270 g/l, up to 400 - 420 g/l) are widespread in artesian basins rich in halogenic formations;
3. *Acidic sulfate thermal waters* usually have their vents on fumarole fields, in craters and calderas, and on the slopes of active volcanoes. The vents of these thermal springs for the most part occur in the form of "boiling" mud kettles and scattered ascending springs with water temperatures of 30 - 40, more often 70 - 90°C. Value pH usually varies from 1 - 2 to 3, mineralization from 1 to 3,5 g/l (92 - 106 g/l in exceptional cases on Java). The main anions are SO_4^{2-} and HSO_4^-. The cation composition is more complex, often with Fe^{3+}, Al^{3+}, NH_4^+, and H^+ as the main cation. These thermal waters are characterized by high concentrations of H_2SiO_3, usually 200 - 300 mg/l and higher. The following metals are found in them (mg/l): Cu, up to 0.1; Zn, up to 1 - 5; Mo, up to 0.3; and others. Gas composition is usually characterized by prevalence of CO_2 with a significant admixture of H_2S and (or) nitrogen; and
4. *Acidic silicic thermal waters* are known in regions of current volcanism on Iceland. The temperature of vapor condensates varies around 100°C, pH around a value of 4.4. The content of H_2SiO_3 comprises 234 mg/l at a mineralization of 307 mg/l. With respect to gas composition, these thermal waters are of the carbonated type.

The group of **alkaline (and weakly acidic) thermal springs** embraces thermal waters with pH values above 4.5. These waters are very diverse with respect to ion - salt and gas composition. They differ from the group of acidic thermal waters primarily in the presence of carbonate and hydrocarbonate compounds.

1. *Alkaline (and weakly acidic) chloride thermal waters* are very widespread, but have been most thoroughly studied in areas of current volcanism and artesian basins. In regions of current and early - Quaternary volcanism, CO_2 is prevalent in the gas composition of chloride thermal springs. Water temperature in springs situated at the foot of volcanoes generally

fluctuates from 40 - 50 to 80 - 90°C. Incidentally, chloride thermal springs have been discovered by many boreholes at depths of as much as 1,000 - 2,500 m, where temperatures attain 200 - 300°C. Mineralization of the water for the most part varies from 1 - 3 to 15 g/l. These waters are characterized by elevated content of the following components (mg/l): arsenic, up to 8 - 10, more rarely 40 - 60; boron (H_3BO_3), up to 50 - 100, more rarely 500 - 1,200; lithium, up to 2 - 10, more rarely 20 - 50; rubidium, up to 1 - 3, more rarely as much as 5 - 10; cesium, up to 2 - 5, more rarely as much as 10 - 20; H_2SiO_3, up to 100 - 200, more rarely as much as 300 - 500. Sodium is prevalent in their cation composition.

Nitric thermal saline waters and brines are widespread in many artesian basins. They are characterized by prevalence of chlorine and high content of calcium. Also represented here are chloride methane and N_2 - methane thermal springs, with mineralization usually from 15 - 20 to 200 - 300 g/l and relatively high content of iodine (up to 120 mg/l in artesian basins of Japan);

2. *Alkaline (and weakly acidic) sulfate thermal waters* occur relatively rarely. Springs of sulfate thermal waters are known in regions with active volcanoes on the Kamchatka Peninsula, in the Kurile Islands and islands of Japan, and in California. Water temperature attains 60 - 100°C, and mineralization varies predominantly within limits of from 0.8 to 1.5 g/l;
3. *Alkaline (and weakly acidic) hydrocarbonate (carbonate) thermal waters* are found on a large area in all regions with current and Quaternary volcanism. The conditions of their distribution in hydrogeological structures are characterized by great complexity and diversity, especially in regions with current volcanism. In New Zealand, the temperature of spring water attains 80 - 85°C, mineralization 1 - 2 g/l. Hydrocarbonate nitric thermal waters are widely disseminated in regions of fold mountains with more recent uplifts. As a rule, they are sodium waters with low mineralization (not more than 0.6 g/l) and elevated content of fluorine (up to 10 - 15 mg/l) and silicic acid (of the order of 50 - 100 mg/l). Among gases, nitrogen is by far the most prevalent; and
4. *Alkaline (and weakly acidic) silicic thermal waters* have greater distribution on Iceland and in regions with current volcanism. Water temperature at the Earth's surface is about 100°C. Silicic acid is markedly dominant in composition of the water, as is sodium among cations. The primary gases are hydrogen and carbon dioxide.

Bacteriological composition of thermal waters is diverse. Many investigators have shown that different groups of aerobic and anaerobic microorganisms adapted to extreme conditions exist in thermal waters even at fairly high temperatures (up to 100°C and higher). Moreover, activity is manifested by anaerobic bacteria (as shown by investigations of the microflora in thermal waters of deep horizons of artesian basins). The presence of microbes was established in acidic thermal springs with temperatures of 70 - 100°C in Iceland, Yellowstone Park, New Zealand,

and the Uzon Caldera in Kamchatka. Such microbes were called *caldera microbes* from the place of their finding (T. D. Brok, 1978). Certain data indicating even better the ability of microorganisms to adapt to high temperatures were obtained in investigating the bacteriological composition of high - temperature jets (with temperatures up to 380°C) in areas of mid - ocean ridges at depths of 2,000 - 2,500 m and more (J. A. Barros et al., 1982). A complex community of bacteria was established on that occasion.

Hydrogeothermal Energy

Heat accumulated in the Earth's crust unquestionably represents the greatest source of energy available to man today. The role of groundwater in redistribution and transfer of heat from the Earth's interior has taken on great significance in the past 30 years, and *hydrogeothermal energy* (the energy of thermal waters) is every day becoming a more important source of energy for mankind[44].

It is known that the heat regime of the Earth was formed and is being formed under the influence of many sources of heat energy, external and internal. Solar radiation is the most important external (cosmic) source of heat energy, while the heat released during radioactive decay is especially important among the diverse heat sources located in the Earth's crust. Particularly interesting to man at the present time are effects of current and young - Cenozoic volcanic activity, which erted crucial influence on the conditions of distribution and formation of thermal waters and vapors, as has already been discussed.

Fig. 2.30. shows zones with intensive hydrogeothermal manifestations in the Earth. This does not mean that other areas of the Planet (apart from the territory of old crystalline shields) are uninteresting from the standpoint of utilization of geothermal energy. For example, the expansive Pannonian Depression is characterized by anomalously high values of heat flow, from 100 to 120 mWm^{-2} (according to D. S. Chapman, H. V. Pollack, and V. Cermak, 1979, the world average of heat rising to the surface of the Earth from its interior comprises 59 mWm^{-2}).

In the majority of cases, thermal waters represent a complex mineral raw material: they often possess balneological properties; they act as a natural carrier of heat energy in the interior of the Earth; they serve as a source of valuable microcomponents (or their compounds), salts, and auxiliary gases; and they are used in technological processes. Because of the energy crisis in many countries, man in the last decades has

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[44] We are today only in the phase of intensified work on development of technology for utilization of heat accumulated in rocks or *petrogeothermal energy*.

increasingly relied on so - called alternative energy sources, including hydrogeothermal energy.

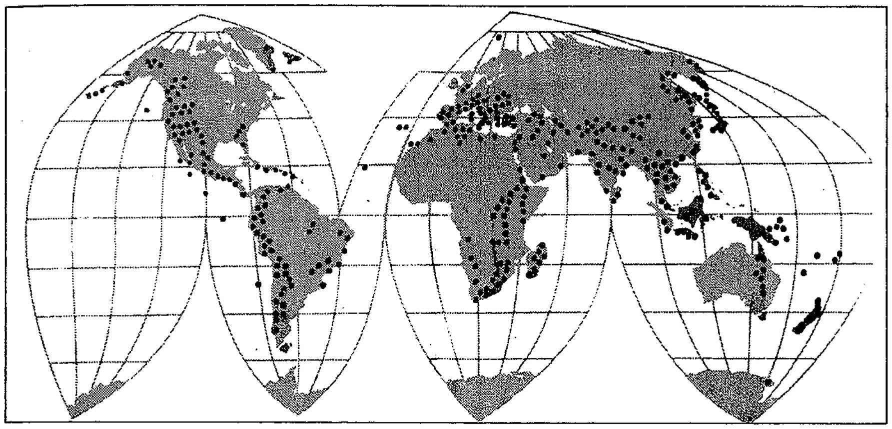

Fig. 2.30. World distribution of hydrogeothermal location.

In keeping with their potential for use as a source of energy, thermal waters can be relegated to one of the following classes: 1) *high - potential* waters (with temperatures above 150°C), which can be efficiently used for direct production of electrical energy; 2) *medium - potential* waters (with temperatures of 100 - 150°C), suitable for effective heating of industrial, agricultural, and communal - residential buildings, as well as for production of electrical energy in conjunction with isobutane, freon, and other liquids having a low boiling point; and 3) *low - potential* waters (with temperatures of 20 - 100°C), suitable for thermotechnological uses (warming of the aforementioned kinds of buildings), mainly with the aid of heat pumps.

Work on discovery and exploitation of high - potential reserves (steam - water mis or dry steam) has been carried out since the 50's of the last century in a number of countries, and 188 hydrogeothermal electrical power plants with total capacity of 4,764 MW were already operating throughout the world in 1986. With a capacity estimated at 1,000 MW, the largest plant of this type (The Geysers) was erected on a deposit of geothermal energy with an area of 52 km^2 in California.

Together with use of high - temperature geothermal resources to obtain electrical energy, hot waters with lower temperatures are being widely investigated and exploited. The captured thermal waters are used (sometimes with the aid of heat pumps) for balneology and recreation, to warm buildings, and (to a lesser extent) for heating of settlements.

Highly Mineralized Waters and Brines

As we have seen, highly mineralized waters and brines (with mineralization of 15 - 35 g/l and 35 - 650 g/l, respectively) serve as surface markers of many terrains throughout the world, especially areas of current and younger Cenozoic volcanism. They are present in enormous quantities in the deep horizons of great artesian basins.

Basins with halogenic (sulfate, halite, and potassium) formations contain groundwater with a wide range of mineralization: brines of sodium, calcium, and (more rarely) magnesium composition. In such cases, brines usually have sodium - chloride composition at mineralization below 280 - 350 g/l, and calcium - chloride or magnesium - chloride composition at higher mineralization. Both contain little sulfate, but are rich in various chemical elements.

Brines of rock salt deposits are characterized by low concentrations of calcium, magnesium, strontium, potassium, lithium, bromine, etc. The content of calcium and sometimes magnesium and strontium increases appreciably in carbonate and gypsum - bearing rocks. When potassium salts dissolve, the content of potassium and bromine increases sharply.

Calcium - chloride and magnesium - chloride brines differ in composition from the water - bearing rock itself. Due to the high degree of mineralization (from 290 - 350 to 600 g/l and higher), which exceeds the solubility of NaCl in water, these brines are called *concentrated brines* (E. V. Pinneker, 1968). They contain the following components in elevated concentrations: potassium, up to 40 g/l; bromine, up to 10 g/l; strontium, up to 8 g/l; hydrogen sulfide, up to 2 g/l; and lithium, barium, boron, and other elements.

Characteristics of highly mineralized thermal waters and brines formed in zones of current and younger - Cenozoic volcanism and in artesian basins have already been discussed. The *metal content of thermal waters* in different regions of the Earth is examined more closely below. To be more precise, high and extreme levels of certain metals are considered, using the book of Baskov and Surikov "**Thermal Springs of the Earth**" (1989). This question is interesting because it is important to establish the possibility of using such waters for balneological and industrial purposes, as well as their possible toxicity.

Copper represents a very widely disseminated metal in thermal springs of different regions. The content of this metal in different types of thermal waters usually fluctuates within limits of from 0.05 to 0.25 mg/l. The highest concentration (18.5 mg/l) has been established in acidic chloride thermal waters of the Dallol Dome (Ethiopia), and available information indicates anomalously high (up to 51 mg/l) content of copper in acidic fumarolic thermal springs of the volcano Ebeko (Kurile Islands).

Mercury is present in the greatest amounts in thermal waters and gases of regions with current volcanism. Its content in most localities does not exceed 0.002 mg/l. Elevated concentrations (up to 0.13 mg/l) are characteristic of the Geyser Springs in California. Conspicuously high content of mercury ().1 - 0.5 mg/l) is present in saline chloride methane waters of the Cimrik oil field in Southwest California. It is known that in regions with volcanic (magmatic) activity, ore occurrences and deposits of mercury are used as an excellent indicator of concealed accumulations of hydrogeothermal fluids and young paleohydrogeothermal systems.

The distribution of *cadmium* in thermal waters has been very little studied. According to existing knowledge, the maximal concentration of this metal in chloride - methane brines is up to 2.3 - 4.5 mg/l.

Zinc is present in different types of thermal waters in both fold and platform regions, but its distribution is very uneven. Anomalously high levels of zinc (even up to 300 - 500 mg/l) were established in brines discovered by boreholes in the vicinity of the Salton Sea in California, very high levels (up to 100 - 160 mg/l) were recorded in brines of the Siberian Platform, and high levels (up to 33 - 367 mg/l) occur in brines of the Central Mississippi Basin.

Potassium attains its highest concentrations in waters of springs in regions with current and Cenozoic volcanism, where concentrations from 0.02 to 0.36 mg/l have been established. The maximum content of this metal (0.65 mg/l) was established is carbonated chloride thermal brines in the vicinity of the Salton Sea.

In contrast to potassium, *lead* has significant distribution in thermal waters of different types. Very high concentrations of this metal have been established in chloride (1.6 mg/l) and sulfate (2.0 mg/l) springs in regions of volcanic thermal springs in the Kurile Islands, as well as in acidic chloride thermal springs of Japan (1.6 - 2.6 mg/l). Lead attains far greater content in highly concentrated chloride thermal brines of artesian basins rich with halogenic formations. For example, lead content comprises up to 115 mg/l in podsolic brines of Eastern Siberia and 125 mg/l in the Amu - Darya Basin.

Arsenic is widely disseminated in different types of thermal waters in many regions of the Earth, especially in ones with current and Quaternary volcanism. Anomalous concentrations of arsenic (up to 59 mg/l) are found in waters of the Latera geothermal system in Italy, while somewhat lower values occur in those of the El - Tataio geothermal system in Chile (up to 47 mg/l) and the Kizildere geothermal system in Turkey (up to 39 mg/l).

The distribution of *chromium* in thermal waters has been little studied. The content of this metal ranged from 0.0043 to 0.01038 mg/l (with a maximum value of 2.5 mg/l) in 38 springs of Japan and from 0.006 to 0.225 mg/l in 20 samples of acidic thermal waters in the Kurile Islands.

Vanadium has been unevenly studied and is unevenly distributed in thermal waters of different types. It achieves its greatest distribution in H_2S - CO_2 and carbonated thermal springs in regions of current volcanism. High concentrations of vanadium were established in natural condensates of chloride composition from fumarole fields of the volcano Ebeko (up to 7.5 mg/l) and in several springs in volcanic regions of Japan (6.1 to 7.0 mg/l).

Manganese is among the most widespread of metals in different types of thermal waters. Its content usually varies from 0.1 to 1 - 2 mg/l and attains 10 - 15 mg/l in chloride emissions of acidic fumarolic springs in regions of current volcanism. Anomalously high concentrations of manganese were established in acidic sulfate thermal springs in the neighborhood of the volcano Issaika in Japan (350 mg/l) and in highly concentrated chloride brines discovered by boreholes near the Salton Sea. Very high levels (up to 500 - 700 mg/l) of this element were also recorded in highly concentrated acidic brines of artesian basins constructed of salt deposits (E. A. Baskov, 1977).

Iron is a component of all thermal waters. It attains its greatest content (up to 1000 - 3000 mg/l) in chloride and sulfate thermal emissions of volcanic regions that for practical purposes represent natural condensates of fumarole gases formed in calderas and craters of many active volcanoes. The maximum content of iron (10,600 mg/l) in thermal springs of the given type was recorded in condensate of the fumarole Big Donald in New Zealand (S. H. Wilson, 1953). Very high concentrations (up to 1,000 - 9,000 mg/l) of this metal are achieved in highly concentrated brines of platform regions.

Cobalt is most often found in acidic thermal waters. In acidic thermal springs of the Kamchatka - Kurile region, for example, maximal cobalt content attains 0.48 mg/l in chloride waters and 0.12 mg/l in sulfate waters. Anomalously high content of cobalt (2.19 mg/l) was recorded in acidic sulfate waters of the Tentoku Spring on the Japanese island of Kyushu (Uzumasa, 1965). However, in the majority of tested samples from different localities throughout the world, this metal was not recorded.

Like cobalt, *nickel* has no great distribution in thermal waters. As in the case of cobalt, the highest concentration of nickel (9.38 mg/l) was discovered in acidic sulfate waters of the Tentoku Spring.

Molybdenum is widely, but unevenly, disseminated in different types of thermal waters. High levels of it most often occur in hydrocarbonate and sulfate nitric thermal springs in different fold regions of the world, where it can attain a concentration of 0.5 mg/l. Otherwise, the content of this metal in thermal waters from different localities throughout the world predominantly varies from 0.001 to 0.03 mg/l .

Tungsten is one of the least studied elements of thermal waters, primarily due to the very low sensitivity of existing analytical methods of detecting it. The most reliable results of testing the content of this element are linked with hydrocabonate and sulfate - nitric thermal waters in several fold regions. In regions of current volcanism, tungsten content in acidic and weakly acidic thermal springs is lower and usually does not exceed 0.001 - 0.01 mg/l. Exceptionally, it often attains a relatively high concentration (up to 0.3 - 0.4 mg/l) in thermal springs of Yellowstone National Park in Wyoming (USA). Anomalously high tungsten content (9.4 mg/l) was established in the Vibur Spring (D. E. White, J. D. Hem, G. A. Waring, 1963). It has also been established that tungsten can sometimes be concentrated in brines of salt strata in the northeastern part of the Mohave Desert in California (USA), where it even attains a content of 60 mg/l.

Lithium is one of the most thoroughly studied and widely disseminated of metals in thermal waters of different hydrogeological structures of the Earth. Its concentration in different types of water fluctuates within a very wide range: from thousandths and hundredths to hundreds of milligrams per liter. Very high concentrations of lithium are linked with weakly acidic and weakly alkaline thermal springs in regions of current volcanism (up to 48.9 mg/l in Chile, up to 25 mg/l in New Guinea, up to 10 - 24 mg/l in New Zealand, and up to 11 mg/l in Italy and Japan). Even greater values were established for thermal springs emitting carbonated waters in regions of current volcanism (the Arima Spring in Japan - 55.8 mg/l; and the Hervidea spring in Peru); and in regions of Cenozoic volcanism rich in carbonated waters (Caucasus, Turkey, Afghanistan, China, Yugoslavia, France, and other countries). Lithium is widely disseminated in methane and nitric thermal waters of artesian basins, but in these conditions its concentration varies greatly. Anomalously high concentrations (up to 100 - 300 mg and higher) have been recorded in brines of artesian basins of the platform type associated with salt formations.

Rubidium is fairly widespread in different types of thermal waters. Its content usually does not exceed 0.2 - 0.5 mg/l and more rarely attains 7.7 mg/l in acidic thermal springs in regions of current volcanism; more rarely, levels of the order of 3.5 - 10.0 mg/l are found in alkaline and weakly alkaline thermal springs. The greatest concentrations have been recorded in highly concentrated methane thermal brines of artesian basins in whose geological profile halogenic deposits are represented (up to 60 - 78 mg/l in the Western European Artesian Basin).

Cesium has been most thoroughly studied in thermal springs of regions with current and extinct volcanism. Its concentrations are somewhat greater in weakly alkaline carbonated thermal waters and in H_2S - CO_2 chloride thermal waters (maximum content of 20 mg/l was recorded in waters of the El - Tatio geothermal system in Chile). In most of the springs tested in Japan, the content of this element varied from 0.01 to 1.0 mg/l. In saline and briny methane thermal waters of artesian basins in platform regions, cesium content varies within wide limits (from hundredths of a milligram to several milligrams per liter) and generally is perceptibly lower than in volcanic regions.

Strontium belongs to the group of most widely disseminated elements in thermal waters, but its concentration varies within wide limits. Waters of hydrocarbonate nitric thermal springs are characterized by the lowest levels of strontium (below 0.1 mg/l). Strontium content often exceeds 4 mg/l (up to 24 mg/l) in carbonated waters of some fold regions, and relatively high concentrations also occur in sulfate nitric thermal springs of Jasper National Park in Canada (up to 13 - 15 mg/l). Strontium is usually found in higher concentrations (10 - 200 mg/l) in saline thermal waters and brines of artesian structures (anomalous content of the order of 5,000 - 7,000 mg/l have been recorded in greatly concentrated calcium chloride brines of artesian basins rich in salt deposits). It is interesting to note that relatively high concentrations are also characteristic of crystalline rocks (up to 1,600 mg/l within the framework of the Canadian Shield).

Barium is a very widespread element in thermal waters, but its concentration is highly variable. In fold regions its content can range from 2 to 6 mg/l. Appreciably greater concentrations of barium (62.4 mg/l) have been established in carbonated brines of the Arima Spring in Japan. Variability of barium concentrations is especially pronounced in thermal waters of artesian basins, where they range from tenths of a milligram to several tens of milligrams per liter and more rarely comprise as much as a couple of hundred milligrams per liter. Anomalously high barium content of 235 mg/l was established in very hot carbonated brines from boreholes in the neighborhood of the Salton Sea in California.

Aluminum is very widespread in thermal waters of regions with current volcanism, especially in acidic media (where its content depends mainly on pH and mineralization), sometimes attaining levels of several grams per milliliter (4.913 and 2.018 g/l in the fumarolic thermal springs Idjen on the island of Java and Big Donald on the Isle of Wight in New Zealand, respectively). Certain acidic springs discharge significant amounts of aluminum, which with neutralization of the water is precipitated in the form of the hydroxide of this metal. It is calculated that the thermal springs of some volcanoes every day discharge up to 200 kg and more of aluminum. Still, this metal is present in insignificant quantities in alkaline and weakly acidic thermal waters of different composition, more rarely attaining a few tens of milligrams per liter.

Groundwaters whose solutions contain elements and their compounds in concentrations making it profitable to extract them are called **industrial waters.** They are for the most part mineral waters of high mineralization (brines), which were discussed in the foregoing text. More precise names are given to these waters according to the element of interest, for example bromine water in the case of water containing bromine in industrial concentrations. Table 2.11. gives the classification of industrial mineral waters after Bondarenko and Kulikov (1984).

Among about 30 exploitable components of high - mineral waters (brines), iodine, bromine, and compounds of boron are most often singled out, as well as a number of others in recent years (lithium, rubidium, germanium, uranium, tungsten, copper, calcium and potassium salts, calcium fluoride, ammonium chloride, etc.).

Gases in Mineral Waters

All mineral waters - like all natural waters (surface and underground) in general - contain gases in various amounts. The main gases of these waters are O_2, N_2, CO_2, H_2S, CH_4, H_2, NH_3, He, Rn, Ar, , and Kr. The gas composition of water best indicates the circumstances of formation of its chemical composition, as well as the origin and medicinal value of the water. It is known that gases in groundwater can be of atmospheric, biochemical, radioactive, volcanic, and magmatic - metamorphogenic origin.

Mixtures of different gases are very often present in water. However, it has been demonstrated that the diversity of natural water composition can be reduced to the following three basic groups:

- *Acidic gases* (CO_2, H_2S, etc.);
- *Nitric gases* (N_2); and
- *Methane* or *hydrocarbonaceous gases* (Ch_4, etc.).

Radon and inert gases (Ar, He, Ne, Kr, etc.) always play the part of accessory gases.

TABLE 2.11.

Classification of mineral industrial waters (Bondarenko, Kulikov, 1984).

Type of water	Components	Minimal concentration (mg/l)
Iodine	J	18
Bromium	Br	200
Iodine - bromium	J+Br	J - 10 Br - 200
Boron	B	250
Iodine - boron	J+B	J - 65 B - 162.5
Strontium	Sr	500
Lithium	Li	10
Rubidium	Rb	5
Cesium	Cs	1
Radium	Ra	10 - 5

Carbon dioxide (CO_2), hydrogen sulfide (H_2S), nitrogen (N_2), methane (CH_4), and radon (Rn) are the gases of greatest interest in balneological evaluation of the gas composition of mineral waters.

Carbon dioxide (CO_2). This is a very widely disseminated gas in groundwater. Its greatest concentrations occur in mineral waters. Large reserves of this gas are formed in the Earth's crust as a result of dynamo - and thermometamorphism of carbonate rocks, as well as due to biochemical reactions in sedimentary rocks. It can also enter groundwater from the atmosphere. Carbon dioxide formed at great depths by the process of metamorphism migrates along fault structures to the surface and mis with groundwater of different origin. Depending on partial pressure and temperature, it attains a concentration of 1 to 3 g/l in such water and as much as 20 g/l in deep water - bearing horizons.

The presence of carbon dioxide in definite amounts gives water specific characteristics. From the balneological standpoint, such waters are judged to be medicinal. According to norms adhered to in our country, the content of CO_2 should be greater than 250 mg/l. If carbonated mineral water is used in baths, the content of CO_2 must be greater than 1,000 mg/l, since its solubility in water at a temperature of 33 - 37°C and normal atmospheric pressure ranges from 1,100 to 1,200 mg/l.

Hydrogen sulfide (H_2S). It is formed in zones of hypergenesis under the influence of combined action of water and organic material with the participation of sulfate - reducing bacteria. In deeper parts of the Earth's crust, the indicated gas is associated with thermocatalytic decomposition of sulfur compounds and reduction of sulfates under conditions of high temperatures and pressures. Very large amounts of H_2S are also emitted during volcanic eruptions. The content of hydrogen sulfide in groundwater rarely exceeds 50 mg/l, and only in exceptional cases can it attain 2,000 mg/l in petroleum deposits.

Like carbon dioxide, hydrogen sulfide is of very great balneological significance. This gas lowers sugar levels in the blood of diabetics, contributes to lowering of blood pressure in humans, etc.

Nitrogen (N_2). Nitrogen is the most widespread gas in groundwater. It is most often of atmospheric origin, especially in shallower water - bearing horizons, where its quantity is proportional to partial pressure of the gas. Nitrogen of biogenic origin is also widespread, but this gas is rarely formed during volcanic processes. Its concentration is of the order of tens to hundreds of milligrams per liter, but can attain 1,200 mg/l.

Slightly mineralized acrothermal - alkaline waters of atmospheric origin usually belong to the category of nitric thermal waters, such waters being very often enriched with silicic acid (the waters of silicic thermal springs).

Methane (CH_4). Dispersed organic substances in sedimentary rocks and coal beds serve as the main source of formation of this gas, which is very widely disseminated in groundwater. In addition to methane, heavy hydrocarbons occur in a high percentage (up to 40%) in gases of petroleum deposits. Hydrocarbonaceous gases in general achieve their greatest content (13,000 mg/l) in waters of petroleum deposits. Also characteristic is the presence of helium (from 0.001 to 0.005, more rarely 2%), as well as elevated nitrogen content.

Methane (hydrocarbonaceous) mineral waters are especially valued for medicinal action if they are formed in deep closed hydrogeological structures under reducing conditions with intensive development of biochemical processes. Waters of petroleum deposits and coal beds are of this kind. By the way, it should be stressed that hydrocarbonaceous gases are of great industrial significance.

Hydrogen (H_2). In groundwater, hydrogen is formed by the process of dissociation of water during decomposition of organic substances or by the process of hydrolysis of the sulfates of heavy metals (Fe, Cu, Al, etc.) in zones of oxidation of sulfide minerals. It is often present in deeper parts of the Earth's crust, in reducing environments, and in regions with current volcanic activity. Hydrogen in mineral waters is considered to be of volcanic origin.

Oxygen (O_2). This gas is primarily of atmospheric origin. In groundwater occurring at shallower depths, content of oxygen can attain 15 - 20 g/l. Its concentration as a rule declines with depth, so that oxygen in deeper water - bearing horizons can be found only in areas of faults or - in karst regions - in zones of privileged collectors connected with ponors. The presence of this gas in groundwater is of enormous biological and geochemical significance.

Inert gases. Of inert gases, helium (He) and argon (Ar) occur most frequently in groundwater. They are both predominantly of radiogenic origin and will be treated (together with radon) in the chapter dealing with radioactive elements.

Geological and Hydrogeological Characteristics of the Territory of Yugoslavia

The territory of Yugoslavia is characterized by varied lithographic composition and a complex structural framework. Several geotectonic units can be singled out within this territory. They are characterized both by specific geological composition and by special geomorphologic and hydrogeological relations. The following geotectonic, that is hydrogeological units are distinguished here (Fig. 2.31.):

- The *Pannonian Basin* (the regions of Backa and Banat);
- The *Sava Trench* (Srem, Macva, and land along the Sava and Tamnava Rivers);
- The *Inner Dinarides* (Montenegro and Southwest Serbia);
- The *Vardar Zone* (the bulk of Western Serbia);
- The *Serbo - Macedonian Mass* (Central Serbia); and
- The *Carpatho - Balkanides* with the *Dacian Basin* (Eastern Serbia).

The given primary hydrogeological units are marked by a certain type (or types) of basic water - bearing media. Thus, masses of karstified limestones are the main water - bearing media in morphologically broken - up regions (*Dinarides and Carpatho - Balkanides*), water - bearing media of the *Vardar Zone* consist almost exclusively of rocks with fracture porosity, and water - bearing media of young depressions *(Pannonian and Dacian Basins*, as well as depressions within the *Serbo - Macedonian Mass*) are represented by alluvial formations and Neogene lacustrine sediments, i.e., water - bearing media with intergranular porosity.

The *Pannonian Basin* is filled with Tertiary and Quaternary deposits up to 4,500 m thick. A clearly expressed geological, geomorphologic, and hydrogeological whole is thereby formed in the north of Serbia, one that is set off from the other units approximately by the valleys of the Sava and Danube Rivers. Two parts can be singled out in the Tertiary parcel: 1. the *lower part*, represented by rocks of Miocene and older Pliocene age, within which Lajtovac and Sarmatian limestones with highly mineralized waters constitute a rich water - bearing medium; and 2. the *upper part*, with significant content of permeable Pliocene and Pleistocene sands and gravels, in which several artesian horizons are formed. The main water - bearing medium of Pleistocene age is the so - called basic water - bearing complex in the upper part of the indicated parcel, whose slightly mineralized waters represent the main drinking water of the Backa and Banat regions. Alluvial formations of the Danube and Sava Rivers are also significant from the standpoint of water supply.

The *Sava Trench* represents a region with significant accumulations of groundwater formed in alluvial sediment of the Drina and Sava Rivers. Thickness of the sand - gravel sediment is greatest in the valley of the Drina, where it attains 85 m, so that the given zone is regarded as a potential source of water for Belgrade and part of Serbia.

On the territory of the *Inner Dinarides*, the most important formations are highly karstified limestones of the Middle and Upper Triassic (Southwest Serbia) and Jurassic and Cretaceous (Montenegrin Dinarides). The given karst environment is characterized by high infiltration of atmospheric sediments. Movement of groundwater is realized through systems of karst channels and fissures, while evacuation is through powerful karst springs. With minimal output of 400 - 1,000 l/s, 12 such phenomena are registered in the Serbian part of the Dinarides (the springs Vrelo Raske, Vrelo Bistrice, Podpec, Sopotnica, Vapa, Seljasnica, Grabovica, Susica, Bucje, Vrelo Belog Drima, Vrela Istok, and Vrelo). The springs Vidrovanska Vrela, Bijeli Nerini, Mareza, Oko Karuc, Dubravska Vrela, Alipasini Izvori, and Bistrica are located in the Montenegrin Dinarides. Most karst springs are characterized by great variation of output every year, from 1:4 to 1:100.

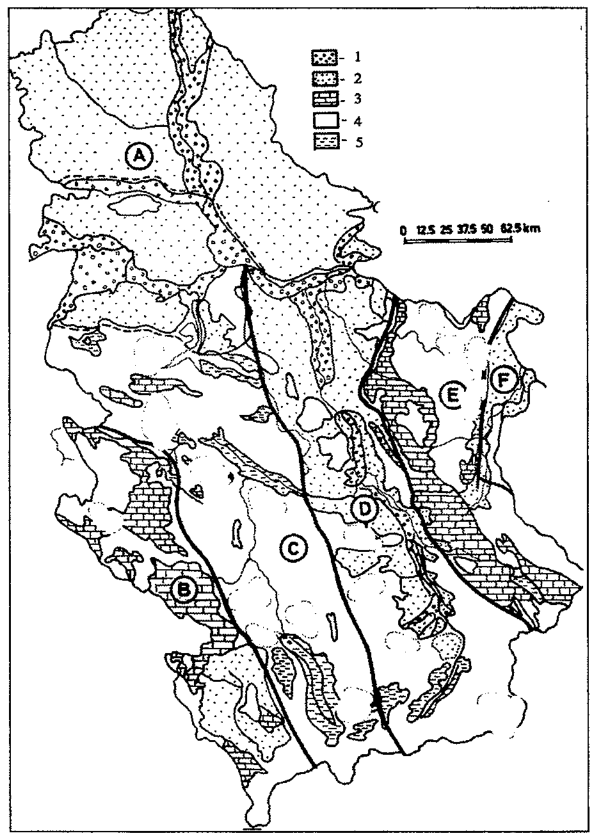

Fig. 2.31. Geotectonic units at the territory of Serbia: A - Pannonian Basin; B - Inner Dinarides; C - Vardar zone; D - Serbo-Macedonian mass; E - Carpatho - Balkanides; F - Dacian basin; 1 - Alluvial sediments; 2 - Neogene lacustrine sediments; 3 - Limestones; 4 - Fractured medium; 5 - Neogene clayey sediments.

The *Vardar Zone* is characterized by scarcity of slightly mineralized waters. Although very diverse, rocks of this exceptionally complex

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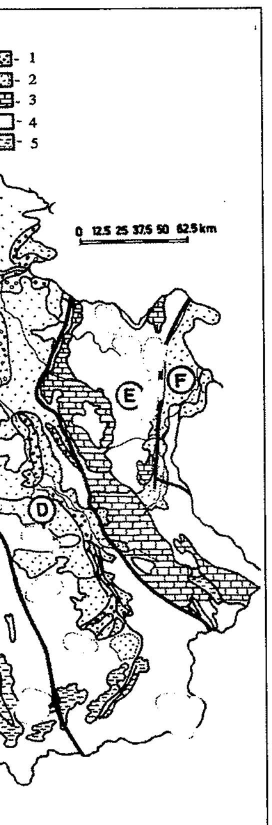

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geotectonic zone represent poorly permeable to practically impermeable media marked by springs with low output.

The region of the *Serbo - Macedonian Mass* hydrogeologically stands distinctly apart from the other units. It has a relatively uniform hydrogeological framework. In the northern half, crystalline schists constitute a floor of permeable horizons, and water - bearing rocks are represented by sandy Mio - Pliocene layers and coarsely grained sediment of the Morava River. The bulk of terrains in the southern half are built of crystalline schists very poor in potable groundwater. Quaternary sand - gravel deposits in the alluvial plain of the Morava River represent the main water - bearing medium, while accumulations of slightly mineralized waters of greater significance from the practical point of view are formed in water - bearing sands of Pliocene age in the Leskovac and Jagodina - Paracin Basins. Fractured media in Southern Serbia are evacuated by numerous weak springs with output below 0.5 l/s, more rarely up to 3 l/s.

Masses of Upper Jurassic and Lower Cretaceous limestones give the *Carpatho - Balkanides* their main hydrogeological characteristics. The limestones are very cracked and karstified, and so represent an exceptionally permeable medium. The discontinuous groundwater formed in them is evacuated through karst springs that arise where the limestones come into contact with impermeable rocks. More than 70 springs with minimal output of more than 10 l/s are registered, 16 of them having an output greater than 100 l/s. The most powerful are the Ljuberadja Springs near Babusnica. Also with a very high output are the springs Vrelo Mlave, Krupajsko Vrelo, Radovansko Vrelo, Beljevinska Vrela, Modro Oko, Belopalanacko Vrelo, Krupac in the vicinity of Pirot, etc. From the standpoint of utilization of groundwater, an unfavorable circumstance is the great variation in output of most of the springs, which depends on the amount of precipitation.

Slightly mineralized waters on the territory of Yugoslavia represent the main resource for supplying the population and industry with water. It is estimated that the many sources of these waters satisfy close to 90% of requirements for high - quality water.

The extent to which slightly mineralized waters are protected depends mainly on geological factors. Artesian horizons as a rule are well protected, while karst water - bearing media are most sensitive in this regard.

Favorable geological and hydrogeological factors have dictated the formation of many springs of ***mineral and thermal waters***, which differ greatly among themselves with respect to mineral - chemical composition, temperature, presence of gases, etc. If we proceed from the density of occurrence of these waters and their diversity, we are able to conclude that Serbia in proportion to its area is the richest country in the Balkans and in Europe. Utilization of this natural wealth dates from the oldest times, and special attention was paid to them during the period of the Roman Empire, as is indicated by the baths that have been preserved in a number of spas.

The following three *hydrogeochemical provinces* can be singled out on the territory of Yugoslavia:

1. *A province with carbonated and carbono - nitric waters* mainly of atmospheric origin, a region with young magmatic and thermometamorphic processes;
2. *A province with nitric and nitro - oxygenated waters of atmospheric origin.* This province is predominantly represented by thermal waters linked with regions of younger tectonic movements; and
3. *A province with artesian nitric, nitro - methane, and methane waters* of atmospheric and marine or mid origin.

The first province encompasses central parts of the country's territory (the Vardar and Serbo - Macedonian geotectonic units); *the second* includes zones in the southwest and eastern parts of it (Dinarides and Carpatho - Balkanides); and *the third province* coincides with the Pannonian Basin and connected lacustrine sediments of Neogene age south of the Sava and Danube Rivers.

The significant explored (available) reserves of mineral and thermal waters have not been even close to fully utilized, either for bottling and balneological uses or for energy purposes. To be more precise, only a small percentage of the total reserves are utilized. We note the existence of 49 active spas, among which only a few are relatively organized (in the modern sense); and more than 230 tested springs, the waters of only 20 of which are bottled. The heat energy of thermal waters is mainly used in the traditional way, mostly for balneological and sport and recreational purposes. The use of this natural wealth unquestionably needs to be far more diversified.

Mineral Resources of the Earth

Since the Pleistocene, i.e., for the past million and a half years, man has used solid rocks and hard minerals for tools. Rocks and minerals for a long time remained the main material used by man in his work. In the second half of the Third and Second Millennia B.C. (at the transition from the Neolithic to the Metal Age), he began to use metals (copper, gold, and silver) as well. These metals are found in nature both in the native state and in minerals from which they have to be extracted and purified, and the development of metallurgy began in that period. Thus, copper and bronze started to be used (together with rocks and minerals) as constructive materials almost five thousand years ago, while gold and silver (in addition to copper and bronze) were used to fashion jewelry.

As we see, man has passed through several periods (the Stone, Copper, Bronze, and Iron Ages) prior to the advent of the atomic era. In each stage of his development, materials obtained from the interior of the Earth took on increasing significance, and it can be freely asserted that mineral resources were the starting base on which human civilization evolved in all phases of man's development.

With respect to their significance in improving the population's living conditions, mineral resources at the present time occupy second place behind agriculture. Thousands of ways of utilizing energy and mineral raw materials have been developed to obtain fuels, metals, building material, abrasives, chemical raw materials, etc. It is therefore not surprising that the demands for these raw materials increase every year, at an exponential rate for many of them (B. J. Skinner, 1986). For example, gold production increases by 4% annually and the period of doubling of production is equal to 10 years. Since this is a limited unrenewable resource very unevenly distributed in the Earth's crust, it is clearly high time for man to proceed far more cautiously with its consumption, in keeping with a strategy of sustainable (adjusted, long - term) development.

Energy Resources

Viewed historically, human utilization of energy sources for thousands of years was a slow and long - term process. Solar energy and wood as a source of energy have been used since the prehistoric period. Coal became the main energy source before about three centuries, as did oil and gas nearly 150 years ago. Atomic energy was discovered after the Second World War.

Energy is unquestionably an essential condition for the existence of modern society, and energy resources are for this reason the most highly prized of mineral products. Today we use only three forms of caustobioliths (fossil fuels): coal, oil, and natural gas. This "big three" supplies more than 95% of the world's energy[45]. If we analyze factual data on the rate of their exploitation, we are able to draw two conclusions: *first of all*, the time of their utilization has been exceptionally short[46]; and *secondly*, the rate of increase in production over the past several decades cannot be sustained too long, especially since caustobioliths make a visible negative contribution to deterioration of the environment. Use of uranium and production of nuclear energy can be counted on for a considerably longer time, but the risks from breakdown of nuclear power

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[45] In terms of world reserves, coal is in the first place, with more than 73% of them, followed by oil (17%) and natural gas (10%). However, with respect to consumption, oil comes first (53%), followed by coal (26%) and natural gas (21%).

[46] One half of the coal exploited to date was burned in the last quarter of a century, while half of total world oil production falls on the 12-year period starting from 1956.

plants and the dangers of radioactive radiation are well - known. For this reason, constantly increasing attention is being devoted to noncombustible forms of energy - hydroenergy, solar and geothermal energy, and new energy sources - and new technologies are being developed for their exploitation.

Oil and natural gas. The wide dissemination and specific appearance and properties of oil and other (solid and gaseous) hydrocarbons have always made it possible for their extrusions to be easily recognized on the Earth's surface. For this reason, oil, asphalt, pitch, bituminous formations, and natural gases are mentioned in the oldest of written documents, and since ancient times they have played an important role in the religious beliefs, medicine, and even economics of many regions. However, only in the second half of the 19th Century - after the discovery of naphthids in significant amounts - did their potential economic significance become apparent.

The initial phase of oil utilization unfolded at a very slow rate. That time, more precisely the period from 1858 to 1900, is known as the "*kerosene age.*" It was only approximately at the start of the 20th Century, with introduction of the internal combustion engine into practice, which we have, intensive development of the oil industry, and the rate of its growth has not abated down to the present day. It can be said that we live in the "gasoline age," since gasoline is the main product of natural petroleum. When it is also taken into account that we obtain thousands of other products from oil and gas, it is clear why it can be asserted that naphthids represent one of the main mineral resources (in the broadest sense) of modern society (Fig. 2.32.), and understandable that from 31 to 50 billion dollars were in the past decade invested annually throughout the world in exploration for oil and gas and their exploitation.

Oil and gas finds are very widespread, but unevenly distributed throughout the globe. For example, over vast areas of Asia, Australia, and Africa, no industrially interesting deposits of these raw materials have been discovered, or else the reserves of discovered deposits are insignificant. At the same time, certain territories are very rich in oil and gas. This is the case with the so - called "*oil axis,*" on which the region of the Middle East (Iran, Iraq, Kuwait, Saudi Arabia, the Apsheron Peninsula in the former USSR) sits on the one hand, and the region of the Gulf of Mexico (the Caribbean Sea, including parts of the USA and Mexico, Columbia, Venezuela, and Trinidad) on the other side of the globe. Two thirds of the world's oil reserves are concentrated in those two regions. Smaller with respect to reserves, but also industrially significant regions are found in North America) parts of the USA, Mexico, and Canada).

Surface occurrences of naphthids are encountered in different forms. *Active naphthids* can migrate along faults from deposits all the way to the Earth's surface, where they are often associated with groundwater reserves. Such occurrences are sometimes large, as for example in California, Venezuela, or Trinidad, where they can cover more than 5 km^2 and be economically interesting. Solid naphthids are encountered on the surface either in the form of scattered impregnations in rocks or in the guise of accumulations of bitumen along fissures and faults.

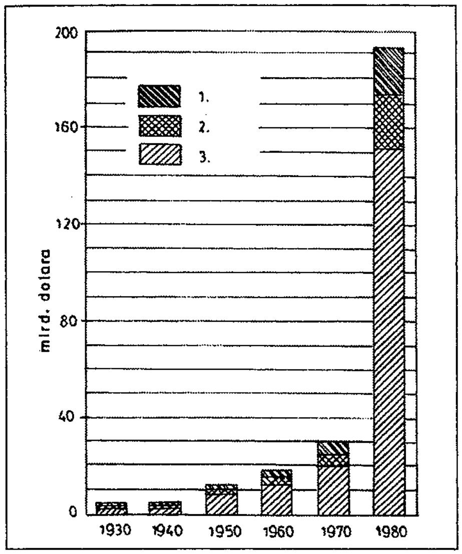

Fig. 2.32. Annual production of mineral raw materials in US. 1 - metals; 2 - nonmetals; 3 - oil and gas.

Oil is usually accumulated within porous sandstones, limestones and dolomites (Fig. 2.33.). Particularly rich oil deposits are formed in sandstones (the largest deposit in US East Texas, deposits of Venezuela, Kuwait, etc.)

A porous medium of permeable rocks in the vicinity of any deposit fills with water of increased salinity, oil, and gas. In natural reservoirs - so - called *stratigraphic traps* - gas, oil, and water are arranged in layers: as the lightest of the three, gas accumulates in the upper part, oil in the middle, and water (the heaviest) at the bottom. A close connection of oil and gas deposits with anticlinal structures is discernible.

There are three spheres of utilization of petroleum: as fuel, as a lubricant, and as a chemical raw material. Oil accounts for about half of all combustible materials used for energy production.

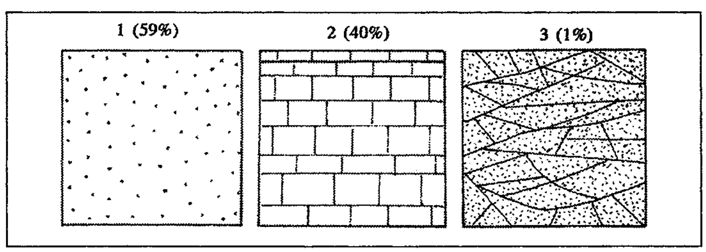

Fig. 2.33. Parts (percentages) of world oil production obtained from the main types of collectors. 1 - sandstones; 2 - carbonate rocks; 3 - fractured formations.

The total reserves of oil in the world amount to about 640 billion barrels, which at the current level of consumption is enough for approximately 30 years (according to Allison and Palmer, 1980). Known gas reserves are estimated at 65.1 trillion m^3 (potential reserves are estimated at not more than 138.8 trillion m^3). Since gas will probably replace oil when the latter is exhausted, it is calculated that all oil and gas resources will be used up by the year 2050.

Coal. Coal is formed from the remains of freshwater vegetation. Especially favorable conditions for coal formation prevailed 250 - 350 years ago. During that period of a hundred million years, particularly large deposits of coal were formed in North America (USA and Canada), Europe (Great Britain and Germany), and Asia (China), since those territories were for longer periods of time at equatorial and temperate latitudes, where a warm climate and copious precipitation favored the development of enormous swamps. Approximately 43% of the world's coal is found on territory of the former USSR, 29% in North America, 14.5% in Asian countries (without the USSR), and 5.5% in Europe.

Most large coal basins have already been discovered. The world's reserves of all forms of coal are estimated at 8,620 billion tons, with potential reserves of 15,270 billion tons, which is equivalent to heat energy of the order of $4.2 \cdot 10^{23}$ J. About 50% of the given amount can be exploited.

Wide use of coal as fuel began in the 12th Century A.D., when the inhabitants of the northwest coast of England found that combustible black rocks uncovered by wave action can nicely replace wood. Since that time, the new form of fuel was used to an increasing extent and on such a scale that dissatisfaction of the citizens of London was expressed already in 1273 because of air pollution caused by coal burning. Coal today represents the leading fuel in many countries of the world, and it is predicted that coal will again become the dominant fuel on the Planet around the year 2020 due to possible difficulties in oil and gas supply.

Coal is primarily used as a fuel to satisfy personal and industrial needs. About three fourths of all coal is consumed in production of electrical energy, a sixth of it is used to produce coke, and a tenth is burned in different branches of industry. Coke is especially valued as a high - quality fuel and is used for smelting of iron ore in blast furnaces.

Oil shales and bituminous sandstones. Oil shales contain solid components from which hydrocarbons can be separated by distillation. Bituminous sandstones, on the other hand, contain viscous asphalt, which is extracted by heating and used to obtain gasoline and other products.

World reserves of oil shales are predominantly concentrated in the USA, Brazil, Zaire, and the former Soviet Union. These resources are very large, but current conditions of production do not permit their more intensive utilization. Just on the territory of Wyoming, Utah, and Colorado in the USA, usable reserves are estimated at more than 1.6 billion barrels.

Resources of bituminous sandstones on the Earth have been inadequately studied, but the usable reserves in Canada (300 billion barrels), the USA (29 billion barrels), and Venezuela (79 billion barrels) indicate that this source of oil can take on considerable significance in the future.

Nuclear fuel. Uranium represents one of the main forms of fuel in the category of combustible raw materials. Used in practice for release of nuclear energy, initially for military ends and later for peaceful purposes as well, uranium (and to some extent thorium) is of first - class significance as a fossil material. During the period of 1950 - 1960, prospecting for uranium was carried out on a previously unseen scale similar to that observed during periods of *gold fever*. A new boom in prospecting for uranium and thorium deposits set in at the outset of the 1970's.

Uranium is a very mobile element and as a result forms its deposits in diverse environments by means of endogenous and exogenous processes. Nevertheless, deposits formed in sandstones account for nearly 30% of current world production. Uranium - bearing conglomerates occupy second place in terms of productive reserves and overall potential. It is also possible to single out uranium - bearing phosphates, schists, granites, and granodiorites.

This element is very widely distributed on all continents. The main areas of its occurrence (outside countries of the former Communist Block, for which only sparse data are available) are in the United States: Wyoming and the Colorado Plateau, including parts of Colorado, Utah, and New Mexico. The main deposits in sandstones were estimated in 1969 at more than 200,000 t of U_3O_8. In Canada, on the other hand, 85% of uranium is produced from deposits in conglomerates, the bulk of uranium being extracted from the Dennison Mine, which is one of the largest mines of this raw material in the world. Significant deposits have been discovered in the northernmost part of Australia, south and southeast of Darwin in the Northern Territory. Already in 1915, radioactive materials were discovered in gold - bearing conglomerates in the vicinity of Johannesburg in the Republic of South Africa, and the mineral uraninite was described in 1923. It is believed that conglomerates in South Africa contain nearly 20% of the world's uranium reserves. In Europe, the largest amounts of exploitable uranium have been found in France.

Uranium reserves in the world (without the former communist countries) exploitable at a cost of 80 dollars per kg at the beginning of 1977 comprised a total of 1,647,300 t, of which 31.7% fell on the USA, 18.6% on South Africa, 17.5% on Australia, 10.1% on Canada, 9.7% on Niger, 2.2% on France, 1.7% on India, 1.7% on Algeria, 1.2% on Gabon, 1.2% on Brazil, 1.1% on Argentina, and 3.1% on other countries. If calculations are based on a cost of more than 80 dollars per kg, then the exploitable reserves of 300,000 t possessed by Sweden would lift this country to first place in the world[47].

In the year 1976, a total of 22,325 t of uranium was produced in the world, 44% of that amount falling on the USA, 21.7% on Canada, 11.8% on the Union of South Africa, 9.2% on France, 6.5% on Niger, 3.6% on Gabon, 1.6% on Australia, and 1.6% on other countries.

If safe reactors were to be developed with the advance of technology, then nuclear energy would probably have a great future. In the meantime, the chief problem remains to be resolved, namely the deposition of wastes of nuclear reactions.

Geothermal energy. A steam - water mixture or dry steam is used to produce electrical energy. Techno - economic analyses indicate that geothermal energy

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[47] Estimates of thorium reserves are unreliable, but it is known that this element is more widespread than uranium in the continental crust.

is the cheapest raw material for power plants, appreciably cheaper than energy of thermoelectric or hydroelectric power plants.

Larderello (in the Italian province of Tuscany) can serve as a classical example of a natural vapor deposit. The first turbine in Larderello was established already in 1904. Exactly a decade later, the first geothermal electric power plant in the world was put into service. Together with the Geysers in California and the Matsukawa geothermal deposit in Japan, Larderello represents a unique phenomenon in the world in that it yields dry steam, which is very suitable for production of electrical energy. The leading producers of this kind of energy today are the United States (2,012 MW), followed by the Philippines (894 MW), Mexico (645 MW), and Italy (519 MW).

In comparison with other sources of electrical energy, use of heat of the Earth's interior has both advantages (cheapness, renewability of reserves, minimal pollution of the environment, etc.) and disadvantages (technical problems, formation of incrustations in pipes, etc.). As the technology involved in hydrogeothermal systems improves and petrogeothermal reserves begin to be exploited, the importance of such systems will grow and their disadvantages shrink and become less of an obstacle.

Metallic Mineral Raw Materials

Deposits of mineral raw materials are exceptionally diverse in regard to ore composition, geological structure, and conditions of formation. If we proceed from their origin, two groups of deposits can be distinguished: 1) *endogenous*, formed under conditions of high temperatures and pressures; and 2) *exogenous*, formed at temperatures and pressures close to conditions of the Earth's surface. The origin of endogenous deposits is linked with geochemical processes in the deep part of the Earth's crust. In the series of endogenous deposits, the following can be singled out: magmatic, pegmatic, pneumatolithic, and hydrothermal. Among exogenous deposits, weathering crust deposits (bauxites, iron and manganese deposits) and disseminated deposits (gold) are distinguished.

Metals in nature occur in the following paragenetic groups:

1. The *iron group* (Fe, Mn, Cr, V, Ni, Co), genetically linked primarily with basic and ultrabasic magmatic rocks;
2. The group of *molybdenum* and *tungsten* (Mo, W, Ma, Re), mainly linked with acidic magmatic rocks;
3. The *platinum group* (Ru, Rh, Pd, Os, Ir, Pt), linked with ultrabasic and (sometimes) basic rocks;
4. The *group of elements of polymetallic deposits* (Fe, Cu, Zn, Pb, Au, Ag, Sn, Hg), formed by hydrothermal processes; and
5. The *group of As, Sb, Bi, Se, and Te,* isolated during hydrothermal processes in the form of sulfides, arsenides, antimonides, and sulfosalts of heavy metals.

According to industrial classification, metals can be relegated to one of the following six groups:

1. *Ferrous metals* (Fe, Mn, Cr);
2. *Rare metals* (V, Ni, Co, W, Mo, Sn, Bi, Sb, As, Hg);
3. *Non - ferrous metals* (Cu, Pb, Zn, Al, Mg);
4. *Precious metals* (Au, Ag, Pt, Ir, Os, etc.);
5. *Radioactive metals* (Ra, Th, U); or
6. *Metals of the rare earth group* (Nb, Hf, Zr, Ta, La, Ce, etc.).

Of all metals, ferrous metals are of the greatest industrial significance.

Local concentrations of metallic mineral raw materials formed under especially favorable geological conditions can be truly imposing. For example, the Chucvicamata deposit in Chile has a surface area of just 2 - 3 km^2, but contains reserves of as much as a billion tons of first - class ore or 21.5 million tons of copper. Butte Mountain (USA) - considered to be the richest mountain in the world - in the course of 82 years of exploitation yielded about 6 million tons of copper, 1.5 million tons of zinc, 0.6 million tons of lead, 25 thousand tons of silver, and 500 tons of gold.

Deposits of metallic raw materials are very unevenly distributed throughout the Planet. Iron ore is most plentiful in Africa and Asia, although Europe and North America are the largest producers of iron. Russia, China, and the countries of Central Africa are outstandingly rich in manganese, chromium, molybdenum, vanadium, nickel, and tungsten, which are important raw materials for production of special steel and for the arms industry in general. Always sought non - ferrous metals (copper, lead, aluminum, zinc, etc.) are primarily found in countries with vast territories - Russia, China, the USA, and India. In production of gold, the undisputed record holder is the Republic of South Africa, with more than 600 tons annually.

Widespread Metals.

1. *Iron* , the second most widespread metal in the Earth's crust, is one of the main pillars of civilization. Its share in consumption of all metals is 95%. On the other hand, significant amounts of such metals as nickel, chromium, molybdenum, tungsten, vanadium, cobalt, and manganese are added to iron to obtain high - quality steel.

Three types of iron deposits can be singled out: 1. deposits linked with magmatic rocks; 2. weathering crust deposits; and 3. sedimentary deposits. *Deposits of the first type* can arise when magma comes into contact with surrounding rocks, whose modification results in the formation of so - called aureoles of contact metamorphism with accumulations of iron ore; or when hydrothermal fluids moving along fissures gradually cool and dissolved materials settle with formation of hydrothermal deposits. *Weathering crust deposits* are formed in zones with intensive weathering of rocks when bivalent iron from the