MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
National Aviation University

T. V. Dudar

GEOLOGY AND FUNDAMENTALS OF MINERALOGY

Lecture Course

Kyiv 2022

UDC 55:549(042.3)
D 84

Reviewers: V. G. Verkhovtsev — Doctor of Geology Sciences, Head of the Department of Mineral Raw Materials for Nuclear Energy, Institute of Environmental Geochemistry, NAS of Ukraine;
M. R. Maksymiuk — Candidate of Chemistry Sciences, Associated Professor of Chemistry and Chemical Technologies Department
National Aviation University

Approved by Scientific-Methodical and Editorial Board of the National Aviation University (Minute N 8/21 as of 17.12.2021)

Курс «Геологія з основами мінералогії» знайомить студентів з основами геології за допомогою лекцій, лабораторних робіт та самостійного вивчення. Досліджуються теми від загальної інформації про Землю та геохронології до ідентифікації мінералів та гірських порід, від ендогенних процесів до тектоніки плит та від екзогенних процесів до визначення соціальної важливості геології.

Для здобувачів вищої освіти ОС «Бакалавр» спеціальності «Екологія».

Dudar T. V.

D 84 Geology and fundamentals of mineralogy: Lecture Course / Compiler T. V. Dudar. — К. : НАУ, 2022. — 80 с.

The course “Geology and Fundamentals of Mineralogy” introduces students to the basics of geology through lectures, laboratory exercises, and self-study. Topics ranging from general information about the Earth and geochronology to mineral and rock identification, from endogenous processes to plate tectonics, and from exogenous processes to the conveying the social relevance of geology are explored.

It is intended for students specializing in Ecology and Environmental Protection doing their courses in English.

UDC 55:549(042.3)

PREFACE

Geologists have a saying – rocks remember

Neil Armstrong

This Lecture Course complies with the new syllabus of "Geology and Fundamentals of Mineralogy" for students specializing in "Ecology and Environmental Protection", and also contains a lot of useful materials for students doing the courses in "Soil Science", "Landscape Ecology", "Environmental Monitoring" and others.

This is the author's approach to expound the Geology and Fundamentals of Mineralogy for the students of the above academic field in the framework of Education in English Program. The author followed the traditional syllabi and basic methodological concepts used in the Ukrainian universities which are still different from the corresponding syllabi widely used in other countries.

The first part of the Lecture Course provides theoretical basics of geology as a science and endogenous processes led to formation of the majority of rock forming minerals and rocks. The second part emphasizes on the exogenous processes, their ecological characteristics, and impact on the surrounded landscapes, conveying the social relevance of geology. In the frame of courses mentioned above it is highlighted how humans impact and are impacted by geological processes that we discuss in the course. For example, when discussing landslides, we note how land use influences soil cohesion. Even contemporary anthropogenic climate change becomes relevant in the course of geology because we discuss the effects of changes in the precipitation regime on landslide pattern.

The author hopes that the Lecture Course will be useful for all students studying Geology and Mineralogy as a part of Environmental Sciences, as well as for PhD students and young professionals for presenting their research in English.

Part1

ENDOGENOUS PROCESSES OF THE INTERNAL GEODYNAMICS OF THE EARTH. IGNEOUS AND METAMORPHIC ROCKS. ROCK-FORMING MINERALS

1.1. Geology as a Science

Concept of the Subject of Geology.
Connection with the other Subjects.
Brief History of geology as a science.

1.1.2. Concept of the Subject of Geology

Geology (from the Ancient Greek — the earth and — λογία, the study of) as a science is a subdivision of the Earth Science associated with the upper solid part of the Earth, the earth's crust, which is considered as a focal point of research in this Science. It studies the composition, structure, history of development and processes that occur in the Earth's bowels and on its surface. Geology as one of the Natural Sciences of the Earth determines the patterns of its development over time, the evolution of the ancient organic world etc. It is also important for a worldview understanding of Nature. With specific techniques geology investigates the subterranean world. Geological knowledge is not only important because of the science in itself, but has a multitude of practical approaches: the exploration of natural resources (ores, oil and gas, water etc.), the prediction of natural disasters (*природних катастроф*) — earthquakes, volcano eruptions, flooding, droughts etc. The understanding of the Earth's planet climate over times falls under the scope of Geology. During the development of this Science, geology has become significantly differentiated and is now represented by a large complex of interrelated disciplines.

The processes that take place in the depths of the Earth bowels and on its surface are studied in such an important branch as *Dynamic Geology*. Depending on energy sources, they are divided into processes of internal dynamics, or *endogenous*, and processes of external dynamics, or *exogenous*. That is the way how our course is structured: it is divided into two educational modules. The first module focuses on the *endogenous geological processes*, their importance in the formation of relief, rock forming minerals and igneous and metamorphic rocks, while the second part of the course emphasizes on the *exogenous geological processes*: weathering, geological action of wind, water, precipitations including related sedimentary rocks (their origin, content and structure).

Both Modules pay special attention to the relationship between the Earth Science and the society in terms of that everything in any economy depends on the use and extraction of natural resources: fossil fuel extraction, mineral resource mining, water, soil nutrience etc. The future of our society is intertwined with the future of the Earth's resources and surface environment.

The following topics are considered in terms of general concept of Geology as a science: methodology and history of geological science; the concept of geology, subject and tasks of its research; the structure of geological science, characteristics of sections and methods of geology; the practical significance of geology. The following topics are of specific importance because of fundamentality of Geology as a science: fundamentals of periodization of the history of geology; pre-scientific stage of development of geological knowledge; ancient stage of development of geological knowledge; medieval stage development of geological knowledge; development of geology in the Renaissance. The following hypotheses of scientific geology are discussed in many educational sources: the first cosmogenetic hypotheses and the beginning scientific geology; cosmogenetic hypotheses of J. Buffon; cosmogenetic hypotheses of I. Kant, P. Laplace; works by M. V. Lomonosov; geotectonic hypotheses of development and evolution of the earth's crust; geotectonic hypotheses: "Neptuneism" by A. Werner, "Plutonism" by J. Hetton.

The emergence of paleontology and biostratigraphy are thought to be a crucial point in development of the science: works by William Smith; geotectonic hypothesis of "craters of uplift" by Leopold von Buch; works by Alexander Humboldt. "Catastrophe" J. Cuvier, Lyell's Uniformism.

Among the numerous tasks solved in geology, the following are worth emphasizing:

– comprehend the processes that lead to the formation of many types of minerals, soils, and rocks;

– increase the accuracy of forecasts of natural phenomena — dust storms, hurricanes, avalanches, etc.;

– develop scientifically sound methods for prevention of negative phenomena such as flooding, desertification and salinization of lands, pollution of landscapes, erosion, etc.;

– contribute in the development of the environmental safety program at national level.

1.1.2. Connection with the other Subjects

In general, the following major sections (chapters) in Geology can be considered.

GEOLOGICAL SCIENCES that unite the sciences studied chemical, mineral, rock composition of the Earth (*mineralogical crystallography, mineralogy, petrography, lithology and geochemistry*).

Mineralogical crystallography is a science of the crystalline state of a mineral substance, external shape, internal structure and properties of minerals.

Mineralogy is a science of minerals — natural chemically and structurally homogeneous bodies that have certain physical properties and were formed as a result of geological processes.

Petrography is a science of rocks, their mineralogical and chemical composition, structure, origin, position in the geological environment, and regularities of their distribution or change.

Geochemistry is a science of certain chemical elements distribution and migration in the lithosphere.

Geomorphology studies the modern structure and origin of relief, land forms and their development on the earth's surface.

DYNAMIC GEOLOGY is a cycle of sciences about processes on the Earth's surface and in its bowels (*geophysics*, *hydrogeology, geotectonics and some other disciplines*).

Geophysics is a set of sciences that study the physical methods of the Earth and the earth's crust. Geophysics includes *gravimetry* (studies the nature and magnitude of gravity); *magnetic survey* is the study about the earth's; *electrometry* studies the electrical properties of rocks, *geothermy* studies the thermal regime of the earth, etc.)

Hydrogeology focuses on groundwater, their origin, chemical composition, regime, development in the earth's crust, and their activities.

Tectonics, or *geotectonics*, studies the features of the structure and development of the earth's crust, determined by the movements of its individual parts — tectonic movements, which are caused mainly by internal processes. Under the influence of these movements there are appeared deformations, or disturbances in layers of hard rocks: they bend, wrinkle or undergo various destructions, resulting in faults of different sizes. In this case, various forms of massive rocks occurrence are formed. They are the object study of *structural geology*.

HISTORICAL GEOLOGY is dealt with the history of the Earth, the manifestation of geotectonic processes in time. One of its sections is *stratigraphy*, which studies the sequence of formation and occurrence of rock layers and determines their age. *Paleontology*, the study of the remains of plant and animal organisms is important in this case. The relative age of rocks is determined based on their study. The elucidation of absolute *geochronology* is aided by radiological methods based on knowledge of the rate of decay of various radioactive elements.

APPLIED GEOLOGY is aimed at practical use of mineral resources.

Engineering geology studies physical and engineering properties of rocks, processes in them and the dynamics of the geological environment, which are taken into account in all types of large-scale construction and operation of buildings.

Study of mineral resources considers the conditions of formation and distribution of ore and non-ore minerals in the earth's crust.

1.1.3. Brief History of Geology as a Science

A famous geologist Volodymyr Obruchev once wrote: “A man, who does not know the basics of geology, is like a blind man. Wandering around the city or village, he does not understand everything that appears before his eyes. It will perceive only external forms, not the essence of phenomena. He will see but not understand. It is important that every educated person should be acquainted with the basics of geology and should understand its role and importance in the cultural development of the country”.

Since the heyday of ancient Greece (VII-V centuries BC), very serious attention was paid to the study of the Earth and the processes that took place on it. Two opposite directions were formed in the understanding of geological processes, which in later times were called

Neptuneism and *Plutonism*. Proponents of Neptuneism, represented by the ancient Greek philosopher Thales (*Фалес*), claimed that the Earth with all living organisms arose from the aquatic environment. In contrast, the Plutonists claimed that everything came from fire. A representative of this trend was Aristotle, who tried to explain the causes of earthquakes and volcanic eruptions by the existence in the Earth's bowels incandescent gaseous substance. He also recognized that the Earth's surface and surface area are constantly changing due to changes in sea level and its destructive effects.

An important stage in the development of geology as a science began in the fifteenth century, and it was associated with the Renaissance. Famous scientists such as Leonardo da Vinci, I. Fracastro, G. Bager (Agricola), N. Steno paid great attention to studying the Earth. Nicolaus Copernicus (1473–1543) was the first European scientist to propose that Earth and other planets revolve around the sun or the Heliocentric Theory of the universe and thus, explained the structure of the solar system. On this basis repeatedly in the XVII and XVIII centuries there appeared some attempts to create hypotheses for the formation of the Earth (Descartes, Leibniz, Buffon, Hooke, Richman). At the same time, the schools of *Neptuneists* and *Plutonists* were revived. For a long time, the advantage was on the side of the Neptuneists, the leading role among which was played by Professor of the Freiberian Mining Academy Werner (1750–1817). Neptuneists completely rejected the importance of internal forces for the development of the Earth, which to some extent negatively affected the development of geological knowledge.

Much more progressive was the doctrine of the Scottish geologist Getton (1755–1779), who considered "internal heat" to be the leading factor in the formation of the Earth, and at the same time believed that surface forces lead to the destruction of rocks. In the end, the views of the Plutonists at that time prevailed.

The next important step in the development of geology was the conclusions of the English researcher W. Smith (1769–1839), who drew attention to the diversity of organic residues that occurred in the layers of rocks. This scientist laid the foundations of the historical direction in geology, and later on it was developed by the works of Cuvier (1769–1832) to a new science, paleontology. Georges Cuvier was a French naturalist. He is sometimes referred to as the "founding father of paleontology".

In the first half of the XIX century basics of geological chronology were founded and a stratigraphic scheme of the earth's crust layers was made. It summarized all the geological knowledge about the sequence of rock formation and the history of our planet for that time.

Development of geological disciplines in the late of the XIX century was associated with significant industrial progress. Since then a lot of geological research were made, and a number of state institutions emerged. In 1882 the Geological Committee was established. It carried out geological mapping of some territories of Russian empire. At the same time, work on detailed one-layer geological mapping within the Donetsk Basin under the supervision of a mining engineer L. Lutugin was conducted.

In the western part of Ukraine, significant work was carried out by Austro-Hungarian scientists on the geological study of the Carpathians, beginning in the second half of the XIX century. Geological maps of 1:75 000 scale were made. The turning point for the study of mountain geosynclinal structures, and in particular, the Carpathians, was in 1903, when a geologist Viktor Karl Uhlig made a report on their sliding structure at the Vienna Geological Congress.

Today, the territory of Ukraine is fully mapped at a scale of 1: 200 000 and most of the territory — at a scale of 1:50 000.

Geologists of commercial organizations, project and research institutions, and numerous educational establishments are appealed to solve a huge complex of research and practical tasks. The most authoritative scientific organization is known to be the International Geological Congress, which meets every 5 years and whose decisions are binding on all geologists in the world (for example, on the International Geochronological Scale, the Stratigraphic Code, compilation of geological maps). Special issues are also addressed at international conferences, symposia, colloquia of specialists in various fields of *Geology*.

Terminology to chapter 1.1:
applied geology — прикладна геологія
crystallography — кристалографія
dynamic geology — динамічна геологія
earth’s crust — земна кора
engineering geology — інженерна геологія
geochemistry — геохімія

geomorphology — геоморфологія
geophysics — геофізика
geotectonics — геотектоніка
historical geology — історична геологія
hydrogeology — гідрогеологія
mineral resources — корисні копалини
mineralogy — мінералогія
petrography — петрографія

Answer the questions

1. *What is geology the study of?*
2. *What are the major sections in Geology?*
3. *What does Mineralogy study?*
4. *What does Petrography study?*
5. *What is Historical geology about?*
6. *What are the tasks of Geology?*

1.2. General Information about the Earth. Geological Chronology

Position of the Earth in space.
Origin of the Earth (nebula hypothesis).
Absolute and relative Geochronology.

1.2.1. Position of the Earth in Space

It is known that the Earth is the third planet from the Sun. It remains the only place in the universe where ever living organisms are identified. The Earth is the fifth-largest planet in the solar system. It's smaller than the four gas giants — Jupiter, Saturn, Uranus and Neptune — but larger than the three other rocky planets, Mercury, Mars and Venus. The last ones, including the Earth planet, are known as the planets of the earth’s type. They are of relatively small sizes, slow rotation and high density. To the contrary, the planets removed from the Sun to a larger distance are of much bigger sizes. They quickly rotate around their own axis and have low density.

The temperature on Earth is just about right for life and this is because the Earth is the third planet from the Sun: not too far, not too close. The temperature is too cold on the other planets which are far from the Sun and too hot on the planets which are close to the Sun.

The Earth's atmosphere contains about 21 % of oxygen needed life forms to survive. The Earth's atmosphere is of high importance in keeping the conditions on Earth suitable for life. It traps the Sun's heat while blocking the harmful radiation.

The Earth is called the blue planet because 71 % of the Earth is water and to survive — water is one thing that everyone needs. Being the fifth largest planet in the Solar system, the Earth has in mass which gives in gravitational pull strong enough to keep us stuck to the planet.

The Earth has a diameter of roughly 8.000 miles (13.000 kilometers) and is mostly round because gravity generally pulls matter into a ball. But the spin of the planet causes it to be squashed at its poles and swollen at the equator, making the true shape of the Earth an "oblate spheroid" (*сплющений у полюсів еліпсоїд*) (Charles Q. Choi, 2021).

The Earth happens to orbit the sun within the "Goldilocks zone", where temperatures are just about right to maintain water on the planet's surface. The Earth's orbit is not a circle, but rather a slightly oval-shaped ellipse. Our planet is a bit closer to the sun in early January and farther away in July, although this proximity has a much smaller effect on the temperatures we experience on the planet's surface than does the tilt of Earth's axis.

1.2.2. Origin of the Earth (Nebula Hypothesis)

Scientists believe that the Earth was formed at almost the same time as the Sun and other planets around 4.6 billion years ago. It was when the solar system coalesced from a giant, rotating cloud of gas and dust known as the solar nebula. As the nebula collapsed under the force of its own gravity, it spun faster and flattened into a disk.

Most of the material in that disk was then pulled toward the center to form the sun. The bodies in the Solar System formed and evolved with the Sun. In theory, a solar nebula partitions a volume out of a cloud by gravitational collapse, which begins to spin and flatten into a circumstellar disk (*диск газу або пилу біля зірки*), and then the planets grow out of that disk with the Sun.

A nebula contains gas, ice grains, and dust (including primordial nuclides).

Radioactive materials in the rock and increasing pressure deep within the Earth generated enough heat to melt the planet's interior, causing some chemicals to rise to the surface and form water, while others became the gases of the atmosphere. Recent evidence suggests that Earth's crust and oceans may have formed within about 200 million years after the planet took shape.

The globe is composed of several outer shells available for study: the *atmosphere* (a mixture of gases that surrounds the planet), *hydrosphere* (total amount of water on the planet) *and the crust* (the outermost shell of a terrestrial planet).

In the early of the XXth century V. I. Vernadsky added the *cryosphere* to them — a discontinuous ice shell, and the *biosphere* — a shell of living matter, and also developed the concept of the *noosphere* as a sphere of reason (*планета розуму*).

All these outer shells continuously interact with each other. This fact is considered as their development.

As a result of such a long and complex interaction, the surface layers of the earth's crust are destroyed, and their upper part is transformed into the soil under the action of chemically active substances and many generations of organisms.

An independent shell, *pedosphere,* the foundation of terrestrial life on earth, is then created (Fig. 1).

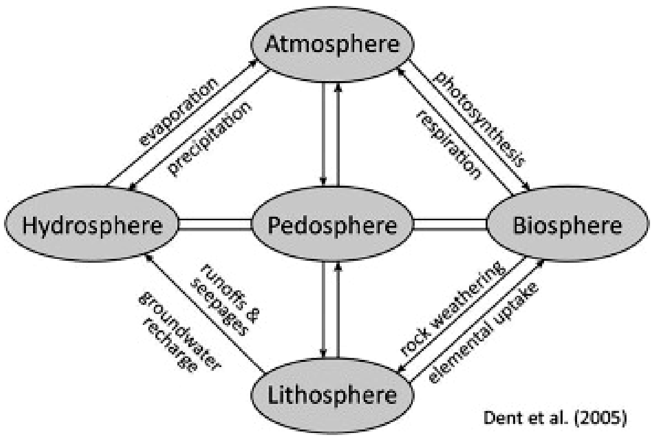

Fig. 1.1. Interaction of outer shells of the Earth

1.2.3. Absolute and Relative Geochronology

GEOCHRONOLOGY is the science about the age, duration and sequence of formation of rocks that make up the earth's crust (D. Makarenko, 2006). There are *Relative Geochronology* and *Absolute Geochronology*. *Relative geochronology* is based on determining the sequence of rocks and the development of organic matter. In case of undisturbed rocks bedding, the lower layers will always be older, and the upper — younger. The relative age of rocks is also determined by the fossilized remains of fauna and flora. The older layers are characterized by more primitive, extinct forms. It was possible to construct a stratigraphic scale of division of rocks into eonothems, erathems (groups), systems, etc. Using a paleontological method based on the so-called guiding forms and characteristic complexes of fossil organisms, it was possible to construct a stratigraphic scale of division of rocks into eons, eras (groups), periods, and epochs (Table 1.1).

Table 1.1

Geochronological Scale

Eon Eonothem	Era Erathem	Period System	Beginning (mln. y.)	Duration (mln. y.)
Phanerozoic *Фанеро- зойський* (duration 570 mln. y.)	Cenozoic *Кайнозойська* (duration 67 mln. y.)	Quaternary (Anthropogen) *Четвертинний* (*Антропоген*)	1.5	1.5
		Neogene *Неоген*	25	23.5
		Paleogene *Палеоген*	67	42
	Mesozoic *Мезозойська* (duration 163 mln. y.)	Cretaceous *Крейдовий*	137	70
		Jurassic *Юрський*	195	58
		Triassic *Тріасовий*	230	35
	Paleozoic *Палеозойська* (duration 340 mln. y.)	Permian *Пермський*	285	35
		Carboniferous *Кам’яно- вугільний*	350	76–65

End Table 1.1

Eon Eonothem	Era Erathem	Period System	Beginning (mln. y.)	Duration (mln. y.)
Mesozoic *Мезозойська* (duration 163 mln. y.)	Paleozoic *Палеозойська* (duration 340 mln. y.)	Devonian *Девонський*	410	60
		Silurian *Силурійський*	440	30
		Ordovician *Ордовицький*	500	60
		Cambrian *Кембрійський*	570	70
Proterozoic *Протеро- зойський* (duration around 200 mln. y.)	Riphean *Рифейська* (duration 1080 mln. y.)	Vend *Вендський*	680	110
		Late Riphean *Верхній рифей*	1050	350
		Middle Riphean *Середній рифей*	1350	300
		Early Riphean *Нижній рифей*	1650	300
	Karelian or Aphebian *Карельська або афебійська* (duration 1000 mln. y.)			
Archean *Архейський* (duration more than 1000 mln. y.)				

Absolute Geochronology determines the time rocks and minerals formation in years on the basis of their isotopic analysis using radiological methods — potassium-argon, rubidium-strontium, uranium-thorium-lead, helium, carbon, etc. Isotope analysis is based on the fact that the time during which the half-life of an isotope occurs is known, it is constant, it is not affected by any factors. By combining multiple geochronological (and biostratigraphic) indicators the precision of the recovered age can be improved.

Terminology to chapter 1.2:
absolute geochronology — абсолютна геохронологія
atmosphere — атмосфера
biosphere — біосфера
cryosphere — кріосфера
hydrosphere — гідросфера
noosphere — ноосфера
relative geochronology — відносна геохронологія
solar nebula — сонячна туманність

Answer the questions

1. *Where is the Earth located in the Solar system?*
2. *When was the Earth formed?*
3. *What is the theory of the Earth formation?*
4. *What are the shells of the Earth?*
5. *What does geochronology study?*
6. *What is the difference between the relative and absolute geochronology?*

1.3. Geological Processes. Processes of Internal Geodynamics

Endogenous Geological Processes.
Earthquakes.
Tectonic movements.
Volcanism.

1.3.1. Endogenous Geological Processes

Geodynamic processes were, are and will be the basis of the development of the Earth and its components. Grandiose processes, which have formed the modern face of the planet, take place under the influence of external and internal forces throughout the geological history of the Earth.

Depending on the source that causes the manifestation of certain changes or causes the emergence of certain forces, all processes are divided into *processes of internal dynamics* or *endogenous*, and *processes of external dynamics* or *exogenous*.

Endogenous geological processes are the processes of internal origin. These processes originate within the Earth's bowels and therefore are called endogenous. They take place within the planet and are governed by forces inherent to the Earth and little affected by external influences. These processes cause phenomena like earthquakes, the emergence and development of continents, oceanic valleys and mountain peaks, generation of volcanic activity, metamorphism of preexisting rocks, deformation and displacement of the earth's crust both vertically and laterally, and more.

The geomorphic characteristics produced by these processes provide the setting for exogenous processes to function. All the characteristics that owe their origin to an endogenous process are invariably modified by exogenous processes.

Endogenous processes are mainly caused by the thermal energy of the crust. This thermal energy derives from the disintegration of the radioactive elements and the gravitational differentiation. Some of the most important endogenous processes are earthquakes, tectonic movements, magmatism, metamorphism, and volcanism.

1.3.2. Earthquakes

An earthquake is a form of energy that happens inside the Earth bowels and is transmitted through the surface layers, ranging from a weak push to a severe movement capable to destroy the buildings and cause cracks in the ground.

An *earthquake* is the shaking of the earth's surface resulting from a sudden release of energy that forms seismic waves. Earthquakes can differ in size from weak movements that can be hardly felt to violent pushes enough to destroy objects and harm people, and cause destruction across large areas. The *seismic activity*, of an area is the frequency, type, and size of earthquakes happened over a period of time. Earthquakes manifest themselves by displacing or disrupting the ground at the Earth's surface. In case if the epicenter of an earthquake is located offshore, the seabed may be displaced to cause a tsunami.

In general, the word *earthquake* is used to describe any seismic activity — whether natural or caused by humans — that produces seismic waves. Earthquakes are caused mainly by breakthrough geological faults but also by volcanic activity, landslides, mine blasts, or nuclear tests.

Around 500.000 earthquakes can occur every year. Minor earthquakes occur almost constantly in places like California in the U.S. or in El Salvador, Mexico, Guatemala, Chile, Peru, Indonesia, the Philippines, and some other places. Larger earthquakes do not occur that often. Most earthquakes occur in the earth's crust at a depth of 30–40 km below the Earth's surface. The most active areas for earthquakes are the Pacific Belt, which runs along almost the entire Pacific coast (about 90 % of all earthquakes) and the Alpine Belt, which stretches from Indonesia to the Mediterranean Sea (5–6 % of all earthquakes). It is also worth noting the mid-ocean ridges, although earthquakes here are shallow and have a much lower frequency and strength.

1.3.3. Tectonic movements

The lithosphere (the crust and upper mantle), is broken into *tectonic plates*. Earth's lithosphere is composed of about seven major plates and many minor plates. Where the plates meet, their relative motion determines the type of boundary: convergent (*ті, що сходяться, конвергентні*), divergent (*ті, що розходяться, дінвергентні*), or transform. Earthquakes, volcanic activity, mountain-building, and oceanic formation occur along these plate boundaries (or faults). The relative movement of the plates typically ranges from zero to 100 mm annually.

Tectonic plates are composed of the oceanic lithosphere and the thicker continental lithosphere, each topped by its own kind of crust. Along convergent boundaries, the process of subduction (*субдукції*), or one plate moving under another, carries the edge of the lower one down into the mantle; the area of material lost is roughly balanced by the formation of new (oceanic) crust along divergent margins by seafloor spreading. In this way, the total geoid surface area of the lithosphere remains constant. This prediction of plate tectonics is also referred to as the conveyor belt principle. Earlier theories proposed gradual shrinking (contraction) or gradual expansion of the globe.

Tectonic plates are able to move because Earth's lithosphere has greater mechanical strength than the underlying *asthenosphere*. Lateral density variations in the mantle result in convection; that is, the slow creeping motion of Earth's solid mantle. Plate movement is known to be driven by a combination of the motion of the seafloor away from spreading ridges due to variations in topography (the ridge is a topographic high) and density changes in the crust (density increases as newly-formed crust cools and moves away from the ridge). At subduction zones the relatively cold, dense oceanic crust is “pulled” or sinks down into the mantle over the downward convecting limb of a mantle cell. Another explanation lies in the different forces generated by tidal forces of the Sun and Moon. The relative importance of each of these factors and their relationship to each other is unclear, and still the subject of much debate.

The tectonic movement of the terrestrial crust is characterized by its great complexity. In the course of the geological history of the earth's crust, the rocks have compressed in folds, pushed one on top of another, broken, etc., giving rise to different relief shapes.

A *divergent boundary* occurs when two tectonic plates move away from each other. Earthquakes are common along these divergent boundaries, and magma rises from the Earth’s mantle to the surface. The Mid-Atlantic Ridge is an example of divergent plate boundaries.

When two plates come together, it is known as a *convergent boundary*. The impact of the colliding plates can cause the edges of one or both plates to buckle up into a mountain ranges or one of the plates may bend down into a deep seafloor trench. A chain of volcanoes often forms parallel to convergent plate boundaries and powerful earthquakes are common along these boundaries. The Pacific Ring of Fire is an example of a convergent plate boundary.

At convergent plate boundaries, oceanic crust is often forced down into the mantle where it begins to melt. Magma rises into and through the other plate, solidifying into granite, the rock that makes up the continents. Thus, at convergent boundaries, continental crust is created and oceanic crust is destroyed.

Two plates sliding past each other form a *transform plate boundary*. One of the most famous transform plate boundaries occurs at the San Andreas Fault zone, which extends underwater. Natural or human-made structures that cross a transform boundary are offset — split into pieces and carried in opposite directions. Rocks that line the boundary are pulverized as the plates grind along, creating a linear fault valley or undersea canyon (*підводний каньйон*). Earthquakes are common along these faults. In contrast to convergent and divergent boundaries, crust is cracked and broken at transform margins, but is not created or destroyed.

1.3.4. Volcanism

Volcanism is the phenomenon of eruption of molten rock (magma) into the Earth's surface or a solid-surface planet, where lava, pyroclastics and volcanic gases erupt through a break in the surface. It includes all phenomena resulting from magma to rise through the crust and form volcanic rocks on the surface.

It is the phenomenon by which matter is transferred in the form of an eruption to the earth's surface. It is one of the most important manifestations of the dynamic processes. *Volcanism* is the process, by which the effusion of magma on the surface forms volcanic structures and/or flows on the surface.

Sometimes, the magma does not reach the surface and cools down to diverse depths giving rise to magmatic bodies of irregular form, called *intrusivos or plutones*. The phenomenon is known as *intrusive magmatism*. The existence of intrusions in the upper part of the Earth can affect the topographical features of any area.

Magma rises from the mantle or lower crust towards the surface. Magma (from the Greek — plastic, viscous mass) is a fiery-liquid silicate solution-melt, which is formed in the deep zones of the Earth. Part of it flows through the craters of volcanoes or cracks on the earth's surface and quickly solidifies in the form glassy lava. The rest does not reach the surface and slowly solidifies at depths of 1 km or more, forming fully crystalline rocks. Most of the minerals made up the earth's crust were formed during the crystallization of magma.

If magma reaches the surface, its behavior depends on the viscosity of the molten rock. Viscous magma produces volcanoes characterized by explosive eruptions, while non-viscous magma produces volcanoes characterized *by effusive eruptions* pouring large amounts of *lava* onto the surface.

Lava ia a hot liquid (effusion) or very viscous (extrusion) melt of rocks, mainly silicate, formed during volcanic eruptions. When the lava hardens, effusive (extrusive) rocks are formed. The lava temperature ranges from 500 to 1200 °C. Unlike magma, lava does not contain gases because they evaporate during an eruption. In some cases magma can solidify under the surface.

The cooled and solidified igneous mass crystallizes within the crust to form an igneous intrusion.

Volcanism is not confined only to Earth, but can be found on other planets having a solid crust and fluid mantle. Volcanoes were observed on other planets in the Solar System — on Mars, for example, in the shape of mountains that are old volcanoes (most notably Olympus Mons). It can be summarized that volcanism exists on other planets as well. In 2014, scientists found 70 lava flows which formed on the Moon in the last 100 million years.

Terminology to chapter 1.3:
asthenosphere — астеносфера
boundary — кордон
earthquake — землетрус
endogenous processes — ендогенні процеси
fault — розлом
lithosphere — літосфера
tectonic plates — тектонічні плити
subduction zone — зона субдукції
volcanic eruption — виверження вулкану

Answer the questions

1. What are endogenous processes? Where do they occur?
2. What are tectonic movements? Why is it important to learn them?
3. Where do earthquakes occur?
4. Where do the most frequent earthquakes happen?
5. What do volcanic eruptions occur?
6. What is the difference between magma and lava?

1.4. Structural elements of the Earth

Structural elements of the earth's crust and oceans.
Geosynclines and platforms.
Tectonic zoning.

1.4.1. Structural elements of the earth's crust and oceans

The *internal structure of Earth* is represented by concentric spherical layers subdividing the solid earth. It consists of an *outer silicate solid crust*, a highly viscous *asthenosphere* and *solid mantle*, a liquid *outer core*, and a solid *inner core (Fig. 1.2)*.

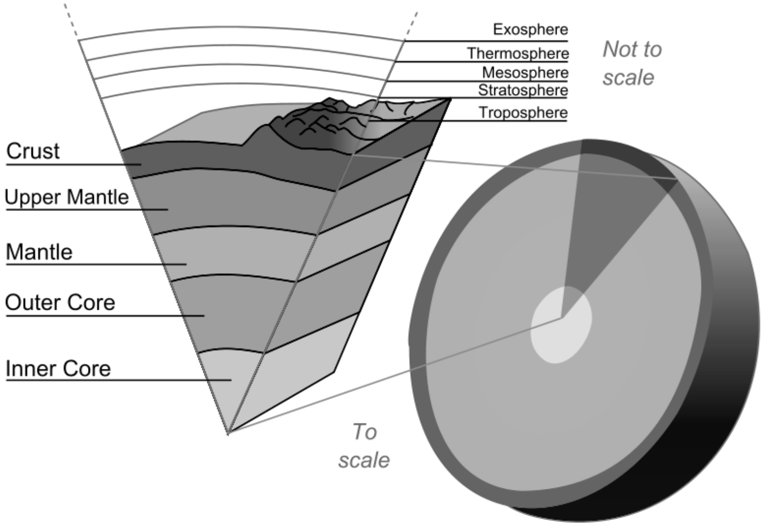

Fig. 1.2. Structure of the Earth' crust

Present-time understanding of the internal structure of the Earth is based on observations of rock in outcrops, samples brought to the surface from greater depths by volcanoes, analysis of the seismic waves that pass through Earth, measurements of the magnetic and gravitational fields of Earth, and experiments with crystalline solids at pressures and temperatures characteristic of Earth's deep interior.

The earth's crust varies from 5 to 70 kilometres in depth and is the outermost layer. The thin parts are the oceanic crust, which underlie the ocean basins (5–10 km) and composed of mafic iron magnesium silicate igneous rocks. The thicker crust is continental crust, which is less dense and composed of felsic sodium potassium aluminium silicate rocks, like granite. The upper mantle together with the crust constitutes the lithosphere. The crust-mantle boundary occurs as two physically different events. First, there is a discontinuity in the seismic velocity, which is most commonly known as the Mohorovičić discontinuity or Moho.

Many rocks of the Earth's crust were formed less than 100 million (1×10^8) years ago. However, the oldest known mineral grains are about 4.4 billion (4.4×10^9) years old, indicating that Earth has had a solid crust for at least 4.4 billion years.

Earth's mantle extends to a depth of 2,890 km, making it the planet's thickest layer. The mantle is divided into upper and lower mantle separated by a transition zone. The mantle is composed of silicate rocks rich in iron and magnesium. The mantle's hot silicate material can flow over very long timescales. Convection of the mantle causes the motion of the tectonic plates in the crust. The source of heat is the primordial heat left over from the planet's formation renewed by the radioactive decay of uranium, thorium, and potassium in earth's crust and mantle.

Earth's outer core is a fluid layer about 2.400 km thick and composed of mostly iron and nickel that lies above Earth's solid inner core and below its mantle. Its outer boundary lies 2.890 km beneath the Earth's surface. The transition between the inner core and outer core is located approximately 5.150 km beneath the earth's surface. Earth's inner core is the innermost geologic layer of the planet Earth.

In early stages of Earth's formation about 4.6 billion years ago, melting would have caused denser substances to sink toward the center in a process called planetary differentiation, while less-dense materials would have migrated to the crust. The core is believed to compose of iron (80 %), along with nickel and one or more light elements.

Continental shelf (*континентальний шельф*). The continental shelf is an area of relatively shallow water; usually less than a few hundred feet deep, that surrounds land. Starting from land, a trip across an ocean basin along the seafloor would begin with crossing the continental shelf.

Abyssal plains (*підводна рівнина на дні океану*). Abyssal plains are the largest habitat on earth located at depths of over 10.000 feet and covering 70 % of the ocean floor. Sunlight does not penetrate to the sea floor, making these deep, dark ecosystems less productive than those along the continental shelf. These plains are interrupted by hills, valleys, and underwater mountains that are hotspots for biodiversity.

Mid-ocean ridge (*серединно-океанічний хребет*). This is a seabed mountain system formed by plate tectonics. It usually has a depth of about 2.600 meters and rises about two kilometers above the deepest part of the underwater basin. This is where the ocean floor spreads (spreading) along the diverging plate boundaries. The world's mid-ocean ridges are linked to form the Ocean Ridge, a single global mid-ocean ridge system that is part of every ocean, making it the longest mountain range in the world.

The continuous mountain range is about 65.000 km long (several times longer than the Andes, the longest continental mountain range), and the total length of the oceanic ridge system is about 80.000 km.

Ocean trenches (океанічні западини). A deep-sea trench, or oceanic trench, is a deep and long depression at the bottom of the ocean (5000–7000 m or more). Formed as a result of subduction, that is, pushing the oceanic crust under another oceanic or continental crust (plate convergence). For this reason, the trough areas are often the epicenters of earthquakes, and the bottom is the base of many volcanoes. The Mariana Trench, for example, is the deepest place in the ocean. In the area of the Mariana Trench many living organisms, previously unknown to science, are inhabited.

1.4.2. Geosynclines and platforms

A *Geosyncline* concept was developed in the late 19th century before the theory of plate tectonics arrived. A *geosyncline* was described as a giant downward fold in the earth's crust associated upward folds called *geanticlines* (or *geanticlinals*).

In structural geology, a *syncline* is a fold with younger layers closer to the center of the structure, whereas an anticline is the opposite to a syncline (Fig. 1.3).

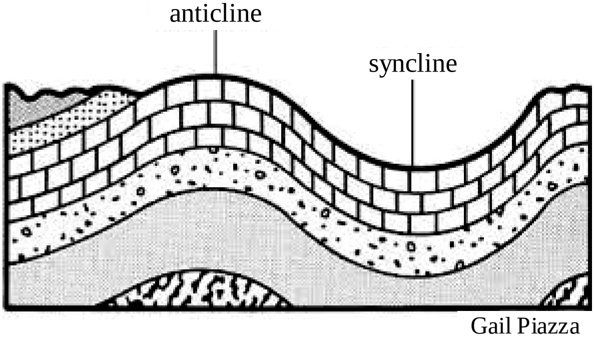

Fig. 1.3. Anticline and syncline

An anticline is a large, arcuate (*дугоподібна складка*) upward fold, and a syncline is a downward fold. Gas and oil traps can form in anticlines (but not synclines). Folds of the anticlinal type expose rocks for erosional processes. If anticlines are relatively young and have not yet been destroyed by erosion, they come to the surface in the form of ridges. A series of young growing oil-bearing anticlines is a chain of hills that traverse the Los Angeles Basin.

A *platform* is a continental area covered by relatively flat or gently tilted, mainly sedimentary strata, which overlie a basement of consolidated igneous or metamorphic rocks of an earlier deformation. Platforms, shields and the basement rocks together constitute *cratons*.

The Eastern European platform is one of the largest relatively stable areas of the earth's crust, belonging to the ancient (pre-Riphean) platforms. It occupies the territory of Eastern Europe between the Caledonian fold structures of Norway in the northwest, the Hercynian folds of the Urals in the east and the alpine fold ridges of the Carpathians, Crimea and the Caucasus in the south. Morphologically, the East European Platform is a plain dissected by valleys of large rivers. The East European platform includes the Baltic, Ukrainian shields and the Russian plate. The total area of the platform is 5.5 million km^2. In most of the area, the East European Platform has a Precambrian folded basement, almost everywhere covered by horizontally lying sedimentary rocks.

1.4.3. Tectonic zoning

Tectonic map demonstrates various types of tectonic structures of Ukraine, which have a long history (over 3,8 billion years) (Fig. 1.4). The two types of folded basement are distinguished in the platform areas: bedrock and platform cover. The first type, crystal bedrock, is represented by the Ukrainian crystalline shield which includes intensively located metamorphic and intrusive complexes of archean-proterozoic age. The second type consists of dislocated metamorphosed and non-metamorphosed sediment volcanic formations of refeys-Jurassic (fragments of Western European platform in PreCarpatian, Skiff plate, internal zone of Stry Jurrasic deflection, Riphean-Triassic (internal zone of Peredbrudzovskiy deflection).

Tectonic zoning of the territory of Ukraine means the allocation of large elements of the earth's crust within its boundaries on geological and structural grounds. Most of Ukraine's territory belongs to the Eastern European platform; extreme western and southern regions — to the Mediterranean mobile belt (Fig. 1.4).

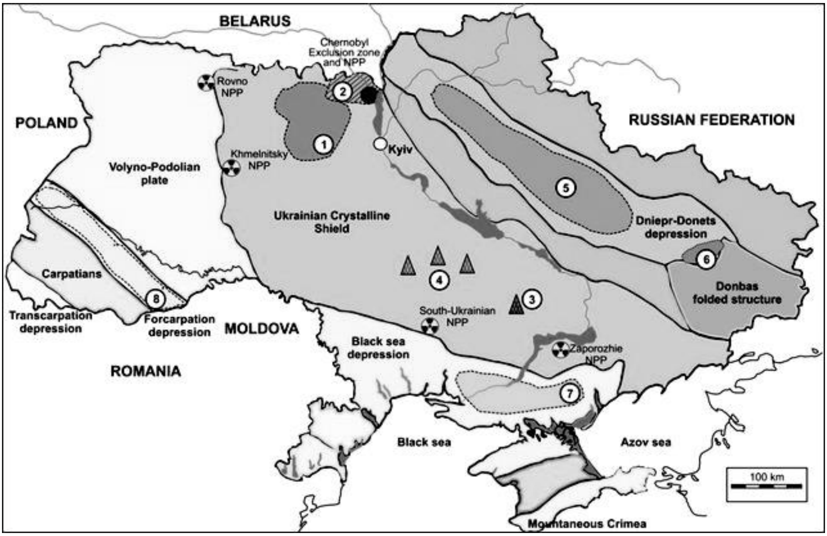

Fig. 1.4. Structural and tectonic scheme

The central structure of the ancient platform is the Ukrainian Shield, composed mainly of metamorphosed rocks of the Archean — Lower Proterozoic age. During the early Archaea (4–3.5 billion years ago) the sialic protocrust began to form, a complex of tonalite gneisses ("gray gneisses") was formed.

The slopes of the shield are the sides of the adjacent depressions. The northern slope is the southen board of the Dnieper–Donetsk depression — a sloping structure of the platform type, which was formed since the Viseu age of the Early Carboniferous over the west. Part of the Late Devonian rift of the same name.

Volcanism in frames of Crimea Mountain corresponds to the active area geo-dynamical regime, which appeared at the same period as did the Carpathian folding under the conditions of island band geodynamical activity.

Terminology to chapter 1.4:
abyssal plane — абісальна рівнина
ancient platform — древня платформа
anticline — антикліналь
basalt crust — базальтова кора
continental shelf — континентальний шельф

depression — западина
earth crust — земна кора
fold — складка
granitic crust — гранітна кора
inner core — внутрішнє ядро
mantle — мантія
Mariana Trench — Маріанська западина
outer core — зовнішнє ядро
slope — схил
syncline — синкліналь
tectonic zoning — тектонічне районування
Ukrainian crystalline shield — український кристалічний щит

Answer the questions

1. How is the Earth planet structured?
2. What parts does the Erath consist of?
3. What is the Mohorovicic discontinuity?
4. What is the difference between anticline and syncline?
5. What is the main tectonic structure of Ukraine?
6. What are the sloping structures of the Ukrainian Shield?

1.5. Minerals, their type, chemical composition and properties

> The concept of minerals.
> Primary and secondary minerals.
> Physical properties of minerals.
> Hardness (Mohs scale) of minerals.
> Silicates and oxides.

1.5.1. The concept of minerals

A mineral is a solid phase in which a substance exists in specific natural conditions of the earth's crust or its surface (temperature, pressure, component composition). That is, a mineral is a natural solid physically and chemically individualized substance that formed inside or on the Earth's surface due to chemical (biochemical) processes. Mineral individuals are divided from others by natural surface of separation.

Minerals are natural chemical compounds or simple native elements that have arisen as a result of certain physic and chemical processes in the earth's crust and on its surface. Artificial minerals, which include synthesized formations that are similar in structure to known natural compounds, are sometimes mentioned. However, this is not entirely correct, because minerals are natural formations.

Most minerals are crystalline bodies, and only a few are amorphous. The crystal structure of minerals is expressed by their geometrically correct shape — crystals. According to the conditions of formation, minerals are divided into two groups: *endogenous* — associated with the origin of the processes of internal energy of the Earth; *exogenous* — minerals formed in the upper part of the earth's crust and on its surface due to the processes of weathering and redeposition (precipitation) of water, air masses, glaciers, etc.

Each mineral is characterized by a certain chemical composition and has a characteristic internal structure. These two important features determine the fairly constant and individual physical properties of minerals. Each mineral has its own unique characteristics. For some minerals a constant feature is color, for others — hardness or density or form of crystals, etc.

When determining minerals by external features, it is necessary to pay first attention to the features common to all minerals, and then proceed to consider the individual characteristics of individual minerals. First of all, attention is paid to the luster of minerals, then to the hardness, color, streak (*риска мінералу**), etc.

**In mineralogy the mineral streak means the color of a fine mineral powder, which is left as a trace on an unglazed porcelain plate*

1.5.2. Primary and secondary minerals

Minerals are also divided into *primary* and *secondary*. Primary *minerals* are formed during the original crystallization of the host igneous *primary rock*. The essential minerals are used to classify the rock along with any accessory minerals. In ore deposit geology, *hypogene processes* (*гіпогенні, глибинні*) occur deep below the earth's surface, and tend to form deposits of primary minerals, as opposed to *supergene processes* (*гіпергенні*, *приповерхневі*) that occur at or near the surface, and tend to form secondary minerals.

In the case of the first acquaintance with minerals we will try identify them “*by eye*”. To do this, you need to know their most important, well-“manifested properties. This is the so-called *macroscopic method*, which is the most often used by geologists in the field or in case of lack of time. The main tools to do that are a magnifying glass (*лупа*) than, other handy means, and as the main reagent — hydrochloric acid.

PRIMARY VS SECONDARY MINERALS		
	Primary Minerals	Secondary Minerals
DEFINITION	Primary minerals are substances that form from primary igneous rocks via original crystallization	Secondary minerals are substances that form from the alteration of primary minerals
FORMARION	Directly from the crystallization of magma	Larger than the average size
OCCURENCE	Occurs in the soil but not formed in the soil	Found and formed in the soil
EXAMPLES	Quartz, feldspar, muscovite etc.	Clay, gypsum, alunite etc.

Solid minerals occur in nature in the form of crystals that have a more or less well-defined *crystalline* form, or in the form of irregular grains or solid masses, which are also composed of crystalline and less *amorphous* (non-crystalline) substance. Amorphous substances (among them very few minerals, literally units) are similar in structure to liquids or melts.

Therefore, in amorphous minerals, the physical properties (thermal conductivity, electrical conductivity, hardness, graft strength, refraction) are the same in all directions. Such minerals with the same properties in all directions are called *isotropic*. Crystalline substances are always *anisotropic*. They are homogeneous bodies that have different properties with common properties in non-parallel directions. And only with respect to certain properties a crystalline substance can be isotropic. In particular, cubic syngony crystals are optically isotropic.

1.5.3. Physical properties of minerals

To determine the minerals for external signs and clarification of their approximate chemical composition it is necessary to know physical properties of each mineral.

Since certain physical properties may be the same in different minerals, or vice versa, some specific property may vary in one mineral, it is necessary to identify a few main features. It depends on the number of different impurities. Therefore, for a more accurate identification, it is necessary to determine as many of its properties as possible. The most important physical properties of minerals are *color, color of a mineral streak, luster, fracture, cleavage, hardness, specific gravity*, approximate *chemical composition* (for example, reaction to hydrochloric acid — identification of a carbonate mineral) and some others. This also includes such features as *magnetism, electromagnetism, optical properties*, etc.

The *color of minerals* is very diverse. It depends on their chemical composition, on the presence of impurities, on the state of atoms and ions inside the crystal, on the scattering of light rays inside the mineral, on the interference and diffraction of light waves. They can be colorless, glass-transparent. Very often the color of the same mineral can be very variable, depending on impurities. For example, quartz is usually colorless — rock crystal. However, the same quartz can be colored in purple — amethyst (an admixture of manganese), black – morion (an admixture of organic). The group of alumina includes: corundum — grayish-gray, sapphire — pure blue, ruby — red (chromium impurity) and others. Some minerals change color due to light: for example, labrador. This property mineral is called iridescence (*иризація*). For certain minerals, the color is so constant and characteristic that it was included in its name: olivine — olive green, red iron ore, chlorite.

The color of a mineral streak. Many powdered minerals have different color than in crystal or grain form. To determine a mineral streak, one should draw a line on a porcelain surface, where the mineral leaves a streak of a certain color. For example, pyrite is light brassy yellow; the pyrite powder is black with a faint greenish tinge. Calcite is colorless, white, yellow, green, blue, purple, and black. Calcite powder is white, regardless of the mineral color.

The luster is the ability of minerals to reflect light. There are metallic and non-metallic luster. *Metallic* is a strong luster characteristic for metals, in particular native metals. Most sulfides and iron oxides have metallic luster. Minerals with *non-metallic* luster are divided into several differences: with metallic-like (*металовидний*, *semi-metallic*) luster (graphite, molybdenite); with diamond luster (diamond, sphalerite, cinnabar); with a glassy luster that is very common among transparent minerals (quartz, calcite); with a greasy luster (nepheline, halite); with a pearly luster, which is due to the reflection of light from the inner planes of the mineral; with a silky, reminiscent luster of silk threads inherent in mineral aggregates having a fibrous structure (gypsum-selenite, asbestos).

Transparency is the ability of minerals to transmit light through them. There are transparent, semi-translucent (*напівпрозорі*), translucent (*просвітлюючи*) and opaque (*непрозорі*) minerals.

1.5.4. Hardness (Mohs scale) of minerals

The *Mohs scale of mineral hardness* is a qualitative ordinal scale, from 1 to 10, characterizing scratch resistance of various minerals through the ability of harder material to scratch softer material. The scale was created in 1822 by German geologist and mineralogist Friedrich Mohs. It is one of several definitions of hardness in materials science, some of which are more quantitative.

The method of comparing hardness by observing which minerals can scratch others is of great antiquity, having been mentioned by Theophrastus in his treatise *On Stones*, c. — 300 BC, followed by Pliny the Elder in his *Naturalis Historia*, c. — AD 77. The Mohs scale is extremely useful for identification of minerals in the field, but is not an accurate predictor of how well materials endure in an industrial setting — *toughness*.

The Mohs scale of mineral hardness is based on the ability of one natural sample of mineral to scratch another mineral visibly. The samples of matter used by Mohs are all different minerals. Minerals are chemically pure solids found in nature. Rocks are made up of one or more minerals. As the hardest known naturally occurring substance when the scale was designed, diamonds are at the top of the scale. The hardness of a material is measured against the scale by finding the hardest material that the given material can scratch, or the softest material that can scratch the given material. For example, if some material is scratched by apatite but not by fluorite, its hardness on the Mohs scale would fall between 4 and 5.

"Scratching" a material for the purposes of the Mohs scale means creating non-elastic dislocations visible to the naked eye. Frequently, materials that are lower on the Mohs scale can create microscopic, non-elastic dislocations on materials that have a higher Mohs number. While these microscopic dislocations are permanent and sometimes detrimental to the harder material's structural integrity, they are not considered "scratches" for the determination of a Mohs scale number.[11]

The Mohs scale is a purely ordinal scale. For example, corundum (9) is twice as hard as topaz (8), but diamond (10) is four times as hard as corundum. The table below shows the comparison with the absolute hardness measured by a sclerometer, with pictorial examples.

Table 1.2

yyyyyyyyyyyyyyyyyyyyyyyyyyyyyyy

Mohs hardness	Mineral	Chemical formula	Absolute hardness	Image
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	1	
2	Gypsum	$CaSO_4 \cdot 2H_2O$	2	
3	Calcite	$CaCO_3$	14	
4	Fluorite	CaF_2	21	

End Table 1.2

Mohs hardness	Mineral	Chemical formula	Absolute hardness	Image
5	Apatite	$Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$	48	
6	Orthoclase feldspar	$KAlSi_3O_8$	72	
7	Quartz	SiO_2	100	
8	Topaz	$Al_2SiO_4(OH^-,F^-)_2$	200	
9	Corundum	Al_2O_3	400	
10	Diamond	C	1500	

1.5.5. Silicates and oxides

Silicate minerals are rock-forming minerals made up of silicate groups. They are the largest and most important class of minerals and make up approximately 90 percent of the Earth's crust.

In mineralogy, silica SiO_2 is usually considered a silicate mineral. Silica is found in nature as the mineral quartz, and its polymorphs. A wide variety of silicate minerals occur on the Earth, in an even wider range of combinations as a result of the processes that have been forming and re-working the crust for billions of years.

These processes include partial melting, crystallization, fractionation, metamorphism, weathering, and diagenesis. Living organisms also contribute to this geologic cycle. For example, a type of plankton known as diatoms construct their exoskeletons (“frustules”) from silica extracted from seawater. The frustules of dead diatoms are a major constituent of deep ocean sediment, and of diatomaceous earth.

A silicate mineral is generally an ionic compound consisted predominantly of silicon and oxygen atoms. In most minerals in the Earth's crust, each silicon atom is the center of an ideal tetrahedron, whose corners are four oxygen atoms covalently bound to it. Two adjacent tetrahedra may share a vertex, meaning that the oxygen atom is a bridge connecting the two silicon atoms. An unpaired vertex represents an ionized oxygen atom, covalently bound to a single silicon atom, that contributes one unit of negative charge to the anion.

Oxides minerals, any naturally occurring inorganic compounds with a structure based on close-packed oxygen atoms in which smaller, positively charged metal or other ions occur in interstices. Oxides are distinguished from other oxygen-bearing compounds such as the silicates, borates, and carbonates, which have a readily definable group containing oxygen atoms covalently bonded to an atom of another element

The oxide minerals can be grouped as simple oxides and multiple oxides. Simple oxides are a combination of one metal or semimetal and oxygen, whereas multiple oxides have two nonequivalent metal sites. The oxide structures are usually based on cubic or hexagonal close-packing of oxygen atoms with the octahedral or tetrahedral sites (or both) occupied by metal ions; symmetry is typically isometric, hexagonal, tetragonal, or orthorhombic.

So, a mineral is a naturally occurring, inorganic solid substance that has a well-ordered chemical structure. There are two main types of minerals as primary minerals and secondary minerals. The key difference between primary and secondary minerals is that primary minerals form from igneous primary rocks whereas secondary minerals form as a result of weathering of primary rocks.

Terminology to chapter 1.5:
Cleavage — тріщинуватість, кліваж
Hardness — твердість
Luster — блиск
Mohs scale — шкала твердості (шкала Мохо)
Primary and secondary minerals — первинні і вторинні мінерали
Transparency — прозорість

Answer the questions

1. What is the difference between primary and secondary minerals?
2. List the main physical properties of minerals?
3. How do minerals differ according to their hardness?
4. What is the least hard mineral? What is it hardness?
5. What is the hardest mineral? What is it hardness?
6. Why are the silicates and oxides important? How are they called?

1.6. Igneous rocks

Origin and texture of igneous rocks.
Structure and classification of igneous rocks.

1.6.1. Origin and texture of igneous rocks

Igneous rocks (from the Greek word for "fire") form when hot, molten rock (magma) crystallizes and solidifies. Magma originates deep within the Earth, near active plate boundaries or hot spots. Magma that rises to the surface is called lava. Igneous rocks are classified into two groups depending upon where the molten rock solidifies

Three main steps in formation of igneous rocks: 1) *partial melting* of *original rock* — increase in temperature; decrease in pressure; 2) *transport of magma* — magma is less dense than surrounding rocks;

it rises through fractures; it may destruct host rocks and may cause collapse of the wall rock; 3) *crystallization of magma* — decrease in temperature (cooling); sometimes decrease in pressure (decompression).

There are two main types of igneous rocks:

• intrusive (*plutonic*) — the rocks turn solid underground;

• extrusive (*volcanic*) — the rocks turn solid on the surface.

The texture of igneous rocks is a result of melting, transport, and crystallization history (Table 1.3).

Table 1.3

Texture of igneous rocks

Texture	History	Igneous rock type environment
Fine-grained	Generally fast crystallization	Extrusive (volcanic)
Glassy	Turn solid almost instantaneously	Extrusive (volcanic)
Porphyritic	Mixture of crystals that form slowly and those that form quickly	Intrusive (plutonic) or extrusive (volcanic)

1.6.2. Structure and classification of igneous rocks

The structure of an igneous rock is comprised the mutual relationships of mineral or mineral-glass aggregates that have contrasting textures, along with layering, fractures, and other larger-scale features. The structure often can be described in relation to masses of rock, and can be closely correlated with physical conditions that existed when the rock was formed.

The structure of igneous rocks depends on the conditions of magma crystallization, its composition and the presence of volatile compounds. According to grain sizes, there are uniform-grained and uneven-grained structures. The first are characteristic of deep (abyssal) rocks, which are formed for a long time in stable, physico-chemical conditions.

Intrusive igneous rocks. When magma solidifies in the bowels of the Earth, where the cooling process occurs slowly, its atoms and molecules have time to settle down in a certain order, i.e. form crystals. Therefore, these rocks have a fully crystalline (granular) structure. It can be: uniform and non-uniform (porphyritic).

In fully crystalline rocks, all minerals are in the form of crystalline grains. Pegmatite structure is a kind of full-crystal structure. It is formed when large crystals of one mineral germinate in equally oriented small crystals of another mineral.

The size of the crystals distinguish the following types of structures: coarse-grained — grain size over 5 mm in diameter (characteristic of deep rocks, which crystallize slowly and the crystals have time to grow to large sizes); medium-grained — grains 5–2 mm in size; fine-grained — less than 2 mm (characteristic of semi-deep rocks formed with rapid cooling of the magma).

Forms of occurrence. Intrusive rocks form massive bodies: lacolites — mushroom м shaped bodies with a convex surface (diameter from 100 m to several kilometers; lopolites — have the appearance of a flat dish or bowl; batholiths — dome — shaped bodies of large size (over 200 km^2); they have steep sides and widening down, the foundation of the batholiths is on a large depth; rods — similar in shape to batholiths, but smaller (less than 200 km^2 in area).

In the case of filling cracks with intrusive rocks the followings are formed: veins — do not have the correct shape; dykes — veins that cross the layers vertically (hundreds of kilometers long, 3–12 km wide); nek — frozen lava in the crater of the volcano.

Effusive igneous rocks. In the case of the outpouring of magma on the Earth's surface in the form of lava, it cools quickly and crystals do not have time to form. Therefore, these rocks form solid amorphous or latent crystalline masses. They have the following types of structure: - glassy (aphonite) - grains are invisible even in a magnifying glass, it is an amorphous mass with a cancerous fracture (for example, obsidian); - porphyry - against the background of fine-grained, dense or amorphous mass, some large crystals are latent crystalline rocks (trachyte, andesite).

Igneous rocks are classified based on their: composition; relative abundance of various minerals; relative amounts of oxides; texture (coarse, fine, glassy, porphyritic); field relationships. Four main groups based on mineralogy/chemistry (SiO_2, Fe, Mg) of igneous rocks are considered (Table 1.4).

Comparison of many rock analyses show that *rhyolite and granite* are felsic, with an average silica content of about 72 percent; *syenite, diorite, and monzonite* are intermediate, with an average silica content of 59 percent; *gabbro and basalt* are mafic, with an average silica content of 48 percent.

Table 1.4

Classifying Igneous Rocks

Group	SiO^2 content	Fe, Mg content	Color
Felsic	High	Low	Light-colored
Intermediate	Intermediate	Intermediate	Medium or speckled
Mafic	Low	High	Dark grey to black
Ultramafic	Very Low	Very High	Dark Green to Black

Evolution of igneous rocks. Magma changes over time: chemistry of the magma changes as crystals form; mineralogy changes as crystals react with magma; crystals settle out or separate from the magma (fractionation); magma mixes with other magmas; magma incorporates wall rock (assimilation); volatile content changes; temperature changes.

Summarizing. Magma forms from the melting of existing rocks. Magma rises as a result of its low density compared to wall rocks. Igneous rocks are classified based on composition, from ultramafic (silica poor and iron rich) to felsic (silica rich and iron poor). Igneous rocks are also classified based on texture, from glassy (no crystals) to fine-grained (small crystals) to coarse-grained (large crystals) and porphyritic (large crystals within a fine-grained matrix). The texture of an igneous rock reflects its cooling history. Magma evolves from mafic to silicic as minerals crystallize within it. The composition of an igneous rock reflects its tectonic environment. Geologists study igneous rocks to better understand the composition of Earth's interior, igneous processes, and plate tectonics.

Terminology to chapter 1.6:
extrusive — екструзивний
felsic rocks — кислі породи
igneous — магматичний
intrusive — інтрузивний
mafic rocks — основні породи

Answer the questions

1. In what way were the igneous rocks formed?
2. What is the difference between intrusive and extrusive igneous rocks?
2. What is the difference between felsic and mafic igneous rocks??
4. Give examples of felsic, intermediate and mafic igneous rocks?
5. How are the igneous rocks classified?
6. Describe the evolution of igneous rocks.

1.7. Metamorphic rocks

The concept of metamorphism.
Common metamorphic rocks.

1.7.1. The concept of metamorphism

Metamorphic rocks arise from the transformation of existing rock to new types of rock, in a process called *metamorphism*. They may be formed simply by being deeply buried beneath the Earth's surface, where they are subject to high temperatures and the great pressure of the rock layers above.

Metamorphic rocks started out as some other type of rock, but have been substantially changed from their original igneous, sedimentary, or earlier metamorphic form. Metamorphic rocks form when rocks are subjected to high heat, high pressure, hot mineral-rich fluids or, more commonly, some combination of these factors. Conditions like these are found deep within the Earth or where tectonic plates meet.

The word "*metamorphism*" comes from the Greek: meta = after, morph = form, so metamorphism means the after form. In geology this refers to the changes in mineral assemblage and texture that result from subjecting a rock to pressures and temperatures different from those under which the rock originally formed. The original rock that has undergone metamorphism is called the *protolith* (*вихідна неметаморфізована порода*). Protolith can be any type of rock and sometimes the changes in texture and mineralogy are so dramatic that is difficult to distinguish what the protolith was.

Metamorphism therefore occurs at temperatures and pressures higher than 200 °C and 300 MPa. Metamorphic rocks are rocks formed as a result of metamorphism of sedimentary and igneous rocks and are characterized by a granular structure, mostly shale texture. These include shales, phyllites, gneisses, quartzites and more. Rocks can be subjected to these higher temperatures and pressures as they get buried deeper in the Earth. Such burial usually takes place as a result of tectonic processes such as continental collisions or subduction.

There are two types of metamorphic formation — regional and contact. The first type of formation of metamorphic rocks is associated with the pressure of loads on the thickness of rocks that lie above or are surrounded by heat fluxes escaping from the depths of the planet. The second type is characterized by the introduction of igneous masses in relatively narrow areas. As a result, there is contact with the earth's crust, and hard rocks are formed — marble, spotted and nodular shales, and others. Both processes of metamorphic rocks formation provoke structural transformations and recrystallization. Due to such ways of rock formation they contain the following minerals: chlorite, distene, andalusite, cordierite, fan, graphite, sillimanite, staurolite, talc, prenite, corundum. They are absent in sedimentary and igneous rocks.

Temperature increases with depth in the Earth along the Geothermal Gradient. Thus higher temperature can occur by burial of rock. Temperature can also increase due to igneous intrusion. *Pressure* increases with depth of burial, thus, both pressure and temperature will vary with depth in the Earth.

Metamorphic rocks occur in a number of geological environments, including orogenic areas, aureoles of igneous intrusive bodies, sea floor, and most parts of the lower and intermediate crust and the upper mantle. Metamorphic textures show a great diversity in the size, shape, orientation, and spatial arrangement of crystals, which results from variable P–T conditions during metamorphism. Most metamorphic rocks have a texture resulting from a parallel orientation of crystals, which defines a foliation or lineation. Others have a more isotropic arrangement of mineral grains.

The process of metamorphism does not melt the rocks, but instead transforms them into denser, more compact rocks. New minerals are created either by rearrangement of mineral components or by reactions with fluids that enter the rocks. Pressure or temperature can even change previously metamorphosed rocks into new types. Metamorphic rocks are often squished, smeared out, and folded. Despite these uncomfortable conditions, metamorphic rocks do not get hot enough to melt, or they would become igneous rocks.

1.7.2. Common metamorphic rocks

The chemical composition of metamorphic rocks is diverse and depends primarily on the composition of the source rocks. However, the composition may differ from the composition of the source rocks, as in the process of metamorphism there are changes under the influence of substances introduced by aqueous solutions and metasomatic processes.

The mineral composition of metamorphic rocks is also diverse. They can consist of a single mineral, such as quartz (quartzite) or calcite (marble), or many complex silicates. The main rock-forming minerals are represented by quartz, feldspars, mica, pyroxenes and amphiboles.

Common metamorphic rocks include clay shales, phyllite, schist, quartzite and gneiss.

Clay shales — represent the initial stage of metamorphism of clay rocks. They consist mainly of hydromica, chlorite, sometimes kaolinite, relics of other clay minerals (montmorillonite, mixed-layer minerals), quartz, feldspar and other non-clay minerals. They easily split into tiles. Slate color: green, gray, brown to black.

Phillites — dense dark with silky luster shale rock, consisting of quartz, sericite, sometimes with an admixture of chlorite. According to the degree of metamorphism, the transition rock from clay to mica shales.

Crystalline schist are the general name for a large group of metamorphic rocks that are characterized by a medium (partially strong) degree of metamorphism. In contrast to gneisses in crystalline schists, the quantitative relationships between quartz, feldspar and dark minerals may be different.

Quartzite is a granular rock consisting of quartz grains cemented with finer quartz material. It is formed by metamorphism of quartz sandstones, porphyries and occurs in weathering crusts, formed by metasomatosis (hypergenic quartzite) with oxidation of copper deposits. Microquartzites are formed from underwater hydrothermal vents, which are carried into seawater by silica, in the absence of other components (iron, magnesium, etc.). Gneiss — metamorphic rock, characterized by more or less defined parallel-shale, often thin-striped texture with predominant granoblastic and porphyroblastic structures and consisting of quartz, potassium feldspar, plagioclase and non-ferrous minerals. There are: biotite, muscovite, amphibole, pyroxene, some others.

Marble is a metamorphic rock formed by recrystallization of limestone or dolomite. It consists mainly of calcite. Small-crystalline grains with a toothed grain connection are characterized by the greatest strength. Homogeneous white species are especially valued for their ability to transmit light to a certain depth and create shades. 80 % of the world's marble is in Turkey. In Ukraine, marble is found in Carpathian mountains, Donbass, and Crimea.

Terminology to chapter 1.7:
foliated texture — шарувата текстура
gneiss — гнейс
marble — мармур
metamorphism — метаморфізм
phyllite — філіт
schist — сланець
quartzite — кварцит

Answer the questions

1. What is the process of metamorphism?
2. In what way were the metamorphic rocks formed?
3. Give examples of common metamorphic rocks?
4. What is the essence of orogenic metamorphism?
5. What is the essence of contact metamorphism?
6. What are the main key factors of metamorphism?

Part 2

EXOGENOUS PROCESSES OF EXTERNAL GEODYNAMICS. SEDIMENTARY ROCKS

2.1. Geological processes. Processes of external dynamics

Exogenous processes. Weathering
Geological work of wind

2.1.1. Exogenous processes. Weathering

Exogenous processes are caused by sources of energy exterior to the earth's *surface*, mainly solar radiation in combination with the force of gravity. Exogenous processes include weathering and the geological action of wind (eolian processes, deflation), flowing surface and ground waters (erosion, denudation), lakes and swamps, the waters of the seas and oceans (abrasion).

The most important manifestations of exogenous processes on the earth's surface are chemical transformation of disintegrated rocks' minerals (physical, chemical, and organic weathering), the removal and transport of the resulting products by water and wind, and the deposition (accumulation) of these products in the forms of sediments on land or at the bottom of water basins and their gradual transformation into sedimentary rocks (*sedimentogenesis, diagenesis, catagenesis*).

Weathering is the alteration and breakdown of rock minerals and rock masses when they are exposed to the atmosphere. Weathering processes occur in situ, that is, in the same place, with no major movement of rock materials involved. Weathering is a fundamental Earth process. Weathering changes rocks from a hard state, to become much softer and weaker, making them more easily eroded. The following main groups of weathering processes are usually identified.

Physical weathering: the group of processes, such as frost wedging and volume changes of minerals that result in the mechanical disruption of rocks (e.g. granular disintegration, exfoliation, joint block separation, shattering by changes in temperature or pressure).

Chemical weathering: the decay of rock forming minerals caused by water, temperature, oxygen, hydrogen and mild acids (e.g. solution, hydration, oxidation, carbonation).

Biological weathering: the group of processes that are caused by the presence of vegetation, or to lesser extent animals, including root wedging and the production of organic acids.

The types of weathering processes that occur at any particular place location depend predominantly upon the climate. Physical weathering (mechanical processes) dominates in cold and dry climates. Chemical weathering (processes of mineral decay) dominates in warm and humid climates. Biological weathering (vegetation and animals) tends to be more active in warm and humid climates.

The type, rate and extent of weathering depend upon several controlling factors: climate, rock type, rock structure, topography, erosion, time.

Climate dictates the type of weathering processes that operate, largely by determining the amount of water available and the temperature at which the processes occur.

Chemical reactions are faster at higher temperatures, while frost wedging occurs in colder climates.

Rock type and structure determine the resistance of the rock to the weathering processes that operate in that particular environment. Each rock type is composed of a particular set of minerals, which are joined together by crystallization, chemical bonding or cementing. When the forces of plate tectonics move these rocks from the environment in which they formed and expose them to the atmosphere they begin to weather.

Topography is very important when talking about weathering type. The slope angle determines the energy of the weathering system by controlling the rate at which water passes through the rock mass. Generally, higher, or tectonically active areas with steeper slopes have more dynamic weathering systems, whereas flat plains have slower weathering systems.

The dynamism and efficiency of *erosion* determines how rapidly any weathered material is removed, how frequently fresh rock is exposed to weathering, and if deeply weathered profiles are preserved.

Time: the duration of the period that the same type of weathering has been operating, uninterrupted by climatic change, earth movements, and other factors, determines the degree and depth to which the rocks have been weathered.

2.1.2. Geological work of wind

Wind is a natural phenomenon that occurs due to the movement of air masses relative to the earth's surface from the area with higher atmospheric pressure to the area with lower pressure. The work done by the wind is called aeolian. It involves the destruction of rocks, grinding, polishing of their surface, transportation of debris and accumulation (deposition) of debris in certain areas of land. At a speed of 4–7 m/s the wind can carry dust, 19 m/s — gravel, 22–58 m/s (storms and hurricanes) — pebbles, small fragments of rocks.

The destructive work of wind is determined by the processes of *deflation* and *corrasion* (*коразія*). Deflation is a removal of loose rocks on the earth's surface by air currents. Mineral particles captured by air currents constantly collide with the surface of rocks, boulders, polishing, destroying soft areas of rock. Due to this process the strokes and scratches are formed on the surface of the rocks, oriented in the predominant direction of the winds. This phenomenon is called corrasion. Deflation and corrasion are interrelated processes. As a result of deflation, ditches up to 20 m deep can be formed in loess rocks.

The products of weathering, deflation and corrasion can be transported by air currents over long distances. The range of transportation depends on the wind speed, the size of the fragments, the shape of the terrain, the strength of the rising air currents, which raises the particles of rocks to a certain height. Sandy material is also transported mainly by jumping under the influence of wind. During sandstorms, sand and fine gravel can rise to a height of 2 m and slightly higher. Dust particles are transported to the greatest distance — the range of their transportation is almost unlimited.

The largest areas on Earth are covered by sandy sediments, which form sandy deserts. *Dunes* are typical forms of relief created by wind in sandy deserts. These are asymmetrical crescent-shaped (*серподібний*) sand hills, the elongated parts of which are turned in the direction of the wind. Dunes have a long gentle wind slope (slope up to 10–15°) and a steep leeward slope (32–35°). The growth of dune begins with the accumulation of a mound of sand near a wind barrier. The dunes connect with each other to form ridges that extend perpendicular to the wind. Their height in the deserts of Central Asia is 60–70 m, in Central Asia — up to 100–150 m and more, length — up to 20 km. Sand deposits in deserts under the influence of wind are constantly moving in the direction of air flows. Small dunes can move several hundred meters a year, large ones — 30–40 m, dune ridges move even slower. This phenomenon is called aeolian transgression.

Terminology to chapter 2.1:
deflation — дефляція
dune — дюна
exogenous processes — екзогенні процеси
loess — лес, лесовий ґрунт
wind erosion — вітрова ерозія

Answer the questions

1. What do we call exogenous processes?
2. What is the process of weathering?
3. Give examples of weathering.
4. What is in common in two processes of deflation and corrasion?
5. What are sand dunes and loesses?
6. What do we call dunes?

2.2. Geological activity of surface and sea (ocean) waters

Geological work of the seas and oceans.
Geological work of rivers.
Geological work of groundwaters.

2.2.1. Geological work of the seas and oceans

It is well known that about 71 % of the surface of the earth is covered by the oceans and seas. The oceans and seas cover an area of about 361 million square kilometer out of 510 million square kilometer of the surface of the entire globe.

About 1.4 billion cubic kilometers of water is concentrated in oceans and seas. The greatest known depth in the ocean is 11 022 meters at the Mariana Trench in the Pacific Ocean. Nearly 61 per cent of the area in the former and 81 per cent in the latter are covered by water.

The four recognized oceans in the world are — the Pacific, the Atlantic, the Indian and the Arctic ocean. The Pacific Ocean covers about 49 % of the earth surface, the Atlantic Ocean-26 %, Indian ocean-21 % and Arctic ocean — 4 % of the world ocean.

The geological activity of seas and oceans, like other geological agents, comprises the processes of erosion, transportation and deposition, which depend on a large number of factors such as: relief of the floor; chemical composition of the sea water; temperature, pressure and density of sea water; gas regime of seas and oceans; movement of sea water; work of sea organisms etc.

At great depths, the waves have almost no effect on the seabed. Even at a depth of 200–300 m, the biggest waves are not felt, but near the shores the destructive work of the sea is very large. The surf pressure in some areas is up to 35.000 kg/m^2. When it reaches the rocky shore, a sea wave crashes against it, destroying the rocks. Since the latter are far from homogeneous, the less hard rocks are destroyed first, and then the harder ones. As a result, sea-washed grottoes and caves are formed at the surf level. The same phenomenon is observed in coastal rocks in the presence of cracks.

The destructive effect of sea waves is called sea abrasion. Due to the abrasion, the coastal ledge eventually moves towards the land, leaving a slightly inclined underwater abrasive terrace. Between the underwater terrace and the shore ledge, a narrow strip first appears, which is covered with pebbles, gravel and larger fragments called the beach. Over time, the beach develops, expands, and the debris on it becomes smaller, turning into sand. The beach becomes a protective strip that prevents further destruction of the shore. The oceanic water contains a large number of dissolved salts and has almost a uniform composition. These salts result in the property of salinity. The average salinity of sea water is 35 parts per thousand i.e. one liter of sea water contains 35 grams of various dissolved salt.

Sea water of normal salinity contains mostly chlorides which aggregate above 88 % followed by sulphates more than 10 % and small amounts of carbonates and other compounds.

Sodium chloride constitutes the bulk of the dissolved salts in sea water, followed by magnesium-chloride, magnesium sulphate, calcium sulphate, potassium-sulphate. Apart from these salts, there are also elements like iodine, fluorine, zinc, lead, phosphorous etc. in sea water.

Salinity determines features like compressibility, thermal expansion, temperature, density, absorption of insolation, evaporation, humidity etc. It also affects the movements of the ocean waters.

2.2.2. Geological work of rivers

Rivers are powerful and dynamic geological agents. The water flowing through a stream performs three kinds of geologic works as erosion, transportation and deposition. Hence, a river is considered as one of the geological agents on earth. The flowing water has the force, velocity and power to generate electricity. The flowing water also has the ability to dissolve the soluble mineral substances available on its way. A lot of landforms are developed due to the geomorphic processes of rivers. They are called as fluvial landforms. Fluvial processes and fluvial landforms are the dominant land surfaces all over the world, when compared to the limited effects of glacial, coastal, and wind processes. Understanding of the fluvial geomorphic processes is an essential aspect in earth science studies.

How does the river "work"? The living force of a river, or its energy, depends on the speed of the flow of water in it and the amount of material carried. The higher the flow rate, the stronger the erosion produced by the river, and vice versa, the slower the river flows, the more it deposits material suspended in the water. The living force of the river produces both *bottom and lateral erosion*.

Bottom erosion consists in deepening the river bed by cutting into the underlying rocks. The depth of this incision is associated, as in the incision of ravines, with the position of the base of erosion, that is, with the level of that reservoir (a larger river, lake, sea, ocean) into which the river flows. In addition, the rate of tectonic uplift of the territory along which the river flows, affects the strength of bottom erosion. The higher the rise, the faster the river cuts in. Bottom erosion is carried out by debris carried by the river. Pebbles and sand, large stones act on the bedrock in its bed as an abrasive mixture that abrades the rocks, destroying them, and the water carries away the rock particles.

Lateral erosion manifests itself more vigorously in the later stages of river development, when its channel is no longer straightened, but more meandering. At this time, the river tends to wash away one bank, and on the other, on the contrary, to deposit sandy material. Everything that it carries and lays down is called alluvium (from the Latin alluvio — sediment). *Lateral erosion* widens the river valley and takes the form of a trough. If a river flows in a meridional direction in the Northern Hemisphere from north to south, then its right bank will always be higher than the left and more steep, if in the Southern Hemisphere it is vice versa. This is due to the action of the Coriolis force, which deflects the moving water due to the rotation of the Earth from west to east.

Rivers carry a large amount of debris. In lowland rivers, it is predominantly sandy. Part of it is dragged along the bottom, the other — the thinnest in size — is transferred in suspension, and the third is in water in a dissolved form. Various debris, falling into the river and carried along the bottom, will gradually roll and turn into rounded pebbles. The size of the fragments decreases with time, and their diameter is determined by the flow velocity. In mountain rivers with their steep slopes, water carries large boulders (see Fig. 1.3 in the color insert), and in lowland rivers — small pebbles and sand. Interestingly, the river's ability to carry material is enhanced by the fact that most debris in the water loses up to 40 % of its mass (weight).

Geological work of the river consists of erosion of the bottom and shores, transfer and deposition of rock fragments. All these aspects of activity can be manifested simultaneously. In the upper parts, where the river valley has the largest slopes, erosion predominates, in the lower parts - sediments, and in the middle parts of the river, erosion, transfer and sediments are combined.

Rivers perform significant geological work: they wash and destroy banks (river erosion), dissolve chemical compounds that are part of rocks, transport the products of destruction in dissolved form, in a suspended state and by rolling along the bottom. These products in the lowlands, where the flow rate decreases, settle and accumulate. During transportation, the sharp corners of the fragments are erased, a flattened pebble is formed. Three main types of processes occur in a river. They are erosion, transportation and deposition. All three depend on the amount of energy there is in a river.

The energy in a river is a cause of erosion. The banks can be eroded making the river wider, deeper and longer. Headward erosion makes a river longer. This erosion happens near its source. Surface run-off and through flow bring erosion at the point, where the water current enters the valley head. Vertical erosion causes deepening of a river channel. This happens more in the upper stages of a river (the V of vertical erosion should help us remember the V-shaped valleys that are created in the upper stages). Lateral erosion makes a river wider. This happens usually in the middle and lower stages of a river.

There are four main processes of erosion that occur in rivers. These are hydraulic action; abrasion; attrition; and corrosion.

Hydraulic action. The pressure of water breaks away rock particles from the river bed and banks. The force of the water hits river banks and then pushes water into cracks. Air becomes compressed, pressure increases and the riverbank may, in time collapse. Where velocity is high e.g. the outer bend of meaner, *hydraulic action* can remove material from the banks which may lead to undercutting and river bank collapse. Near waterfalls and rapids, the force may be strong enough to work on lines of weakness in joints and bedding planes until they are eroded.

Abrasion. The sediment carried by a river scours the bed and banks. Where depressions exist in the channel floor the river can cause pebbles to spin around and turn hollows into potholes.

Attrition. Eroded rocks collide with each other and break into smaller pieces. The edges of these rocks become smoother and more rounded. Attrition makes the particles of rock smaller. It does not erode the bed and bank. Pieces of river sediment become smaller and more rounded as they move downstream.

Solution. Carbon dioxide dissolves in the river to form a weak acid. This dissolves rock by chemical processes. This process is common where carbonate rocks (limestone and chalk) are available in a channel.

Transportation of material in a river begins when friction is overcome. Material that has been loosened by erosion may be then transported along the river.

Running water has to be considered as a geologic agent of great importance. A great part of the present day earth's landscape appeared because of the action of water. Most of the material now present in sedimentary rocks was somehow in the past moved by running water.

Particles of rocks washed away by the river are transported over long distances and deposited in places where the flow velocity decreases. The process of falling out of the water particles carried by it is called sedimentation, and their accumulation — accumulation. T

he resulting deposits are called alluvial (or alluvium). Precipitation can occur in floodplains of rivers during floods, in the lower reaches and, finally — in estuaries. Accordingly, the alluvium can be floodplain, channel and delta.

Floodplain alluvium is characterized by thin horizontal stratification, heterogeneity of particle size distribution and low thickness of formations with a characteristic lenticular wedge. *Channel alluvium* is deposited in the riverbeds a year after the recession of flood waters. It is also characterized by horizontal or inclined stratification, small layer thickness and good sorting of the material. *Delta alluvium* accumulates in the mouths of rivers as they flow into the sea and lakes, where river water loses speed and all the debris brought by it settles to the bottom. It is deposited on the coastal slope of the bottom in sloping layers, gradually thinning towards the pool. River sediments at a distance from the mouth of the river spread on both sides, forming a cone-shaped area, bordered by channels. In shape, such a site resembles the Greek letter delta, hence the name “river delta”.

The quantity of the dissolved material depends on climate and geologic setting. The dissolved load is usually expressed as parts of dissolved material per million parts of water (parts per million or ppm). As much as around 4 billion metric tons of dissolved mineral matter is supplied to the oceans by the streams each year.

Terminology to chapter 2.2:
alluvium — алювій
bottom erosion — донна ерозія
dissolved load — вміст розчиненої речовини
floodplain — заплавна тераса
geological work/activity — геологічна робота
hydraulic action — гідравлічна дія
lateral erosion — бокова ерозія
pebble — валун
running water — проточна вода

Answer the questions

1. How do the seas and oceans work?
2. How does a river work?
3. What are the bottom and lateral erosion?
4. What is alluvium?
5. How is going transportation of material in a river?
6. What processes occur in a river?

2.2.3. Geological work of groundwaters

Groundwater plays an important role in many geologic processes. For example, the fluid pressures that build up on faults are now recognized to have a controlling influence on fault movement and the generation of earthquakes. On another front, subsurface flow systems are responsible for the transfer of heat and chemical constituents through geologic systems, and as a result, groundwater is important in such processes as the development of geothermal systems, the thermodynamics of pluton emplacement, and the genesis of economic mineral deposits. At depth, groundwater flow systems control the migration and accumulation of petroleum. Nearer the surface, they play a role in such geomorphologic processes as karst formation, natural slope development, and stream bed erosion.

One of the most exciting recent developments in geologic thought concerns the influence of groundwater pressures on fault movement and the possible implications this has for the prediction and control of earthquakes. The concepts were first put forward by Hubbert and Rubey (1959) in their classic paper on the role of fluid pressure in the mechanics of overthrust faulting (*шар'яж*).

Groundwater is the largest reservoir of liquid fresh water on Earth and is found in *aquifers*, porous rock and sediment with water in between. Water is attracted to the soil particles and *capillary action*, which describes how water moves through a porous media, moves water from wet soil to dry areas.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far from where the aquifer is located; for example, it may be in a mountain area.

The amount of water that is available to enter groundwater in a region is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water goes into the ground where there is a lot of rain, flat land, porous rock, exposed soil, and where water is not already filling the soil and rock.

The residence time of water in a groundwater aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages.

To be a good aquifer, the rock in the aquifer must have good:

porosity (small spaces between grains) and *permeability*: (connections between pores).

To reach an aquifer, surface water infiltrates downward into the ground through tiny spaces or pores in the rock. The water travels down through the permeable rock until it reaches a layer that does not have pores; this rock is *impermeable* (Fig. 2.1). This impermeable rock layer forms the base of the aquifer. The upper surface where the groundwater reaches is the *water table*.

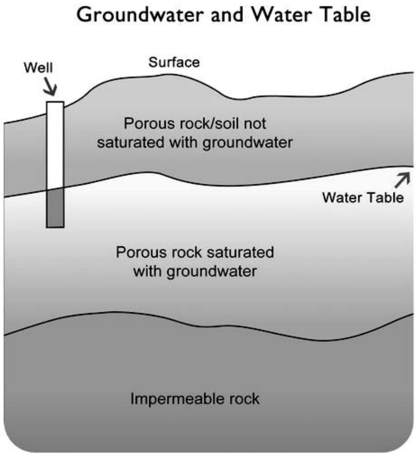

Fig. 2.1. Groundwater is found beneath the solid surface
Notice that the water table roughly mirrors the slope of the land's surface.
A well penetrates the water table

For a groundwater aquifer to contain the same amount of water, the amount of recharge must equal the amount of discharge. What are the likely sources of recharge? What are the likely sources of discharge? (Fig. 2.2).

In wet regions, streams are fed by groundwater; the surface of the stream is the top of the water table. In dry regions, water seeps down from the stream into the aquifer. These streams are often dry much of the year. Water leaves a groundwater reservoir in streams or springs. People take water from aquifers, too.

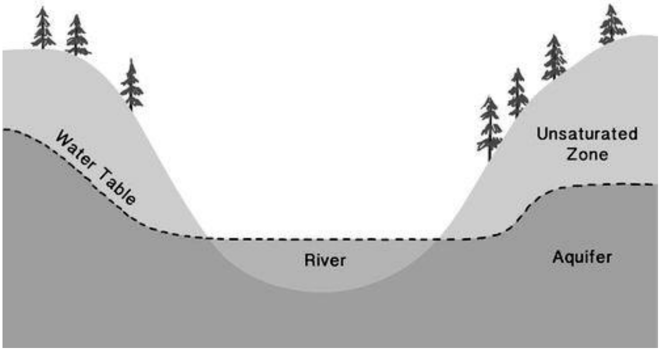

Fig. 2.2. The top of the stream is the top of the water table.
The stream feeds the aquifer

What happens to the water table when there is a lot of rainfall? What happens when there is a drought? Although groundwater levels do not rise and fall as rapidly as at the surface, over time the water table will rise during wet periods and fall during droughts.

Terminology to chapter 2.3:
underground — підземний
water table — дзеркало ґрунтових вод
aquifer — водоносний горизонт
permeability — проникність
porosity — пористість
unsaturated zone — ненасичена зона
penetrate — проникати

Answer the questions

1. *Where are the underground water horizons located?*
2. *What is a water table?*
3. *What is the role of underground waters in geological processes?*
4. *What is the role of underground waters in karst formations?*

2.4. Development of landslides and karst formation on the territory of Ukraine

Concept of a landslide.
Development of landslides on the territory of Ukraine.
Karst formation and development.

2.4.1. Concept of a landslide

Landslide is a sliding displacement of rock masses down a slope under the influence of gravity. Formed in various rocks as a result of imbalance or weakening of strength. Landslides are caused by both natural and man-made reasons. Natural ones include: an increase in the steepness of slopes, undermining their foundations by sea and river waters, seismic shocks. The destruction of slopes by road excavations, excessive soil removal, deforestation, and unreasonable farming on the slopes are artificial causes of landslides. According to international statistics, up to 80 % of present day landslides are associated with human activities.

The volume of soil during a landslide can reach tens and hundreds of thousands of cubic meters, and in some cases even more. The displacement rate of the landslide ranges from several meters per year to several meters per second. The highest rate of landslide displacement is observed during an earthquake. Slip of soil masses can cause destruction and blockages of residential and industrial buildings, engineering and road structures, trunk pipelines and power lines, as well as injury and death of people.

The greatest hazard of natural landslides is near settlements and areas with steep slopes, usually in the presence of significant precipitation, static and dynamic loads or short-term seismic effects. Statistics shows that the number of landslides in different regions in the world and in Ukraine is growing in proportion to the intensity of anthropogenic impact on the environment.

Types of landslides. The main factor of a landslide is considered the fact of availability of heavy masses of soil that fall asleep or destroy everything in its path. Therefore, the main indicator of the landslide estimation is its volume measured in cubic meters. And measuring the length, width and height of the landslide, calculating its volume, is an easy way to determine its mass in tons, most likely in thousands and hundreds of thousands of tons. So, landslides can be classified by volume of rocks (Table 2.1).

Large landslides are usually caused by natural causes and are formed along the slopes for hundreds of meters. Their thickness reaches 10–20 m, and sometimes more. Average and small landslides are more likely to be brought by anthropogenic processes.

Table 2.1

Classification of landslides by volume of rocks

Type of a landslide	Volume of rocks
Small landslide	Up to 10 thousand m^3
Average landslide	From 10 to 100 thousand m^3
Large landslide	From 100 to 1000 thousand m^3
Very large landslide	More than a million m^3

2.4.2. Development of landslides on the territory of Ukraine

The study on landslides and other exogenous geological processes in the *Ukrainian Carpathians* has revealed their close relation with the geological and geomorphological structures. The close interrelationship of lithological, geomorphologic, structural, neotectonic seismic, and other similar factors with the emergence and development of gravitational landslides and erosion phenomena is described for different reasons within the area of Carpathians Mountains and foothills. The areas of these processes development are associated with definite formation complexes, characterizing by complicated spatial structure in accordance with geological and physical characteristics of the corresponding rocks. Such distinct formations bring different influence on natural exogenous and endogenous processes. There are predominantly structural landslides and those formed in heterogeneous environment within the Carpathian region. Most landslides formed in the Oligocene flysch deposits affected by weak zones relating to slopes. The special role of weak zones is characterized by intense fracturing, brecciation and bedding of flysch deposits. These zones are characterized by contrast permeability and strength properties of host rocks. The availability of weak zones affects the tectonic factor at assessment of predicted scale and intensity of landslides and mud flows. The region of the Ukrainian Carpathians, characterized by complicated and heterogeneous geological background, has to be considered as an important site for the development of analytical techniques for the analysis of hazardous exogenous and endogenous geological processes and has to be permanently monitored to prevent them.

Landsclides in *the Odessa region* are widespread, causing the destruction of buildings and the loss of valuable agricultural land. A special place in belongs to the sea coast and the slopes of estuaries.

The landslide-prone areas occupy almost 20 % of the region's territory. The greatest landslides were developed in the north-western and western parts of the region on the territory with strongly heterogenous relief.

The largest number of landslides (more than 500) is concentrated in the Kotovsky district, where the relief is maximum broken. Almost all rivers of the Odessa region originate in the territory of this district.

The largest and most hazardous landslides are developing on the Black Sea coast. Visual inspection of the sea coast revealed their significant intensification. The greatest intensification of landslides is manifested in the area of the sea coast between the village of Kryzhanivka and the Great Adzhalytsky estuary.

The main natural factors that cause the development of landslides in the region are geological structure, hydrogeological conditions, relief, climate, intensity and contrast of neotectonic movements. At the same time, such processes as erosion and abrasion, disturb the balance of the slopes and are also one of the main factors in landslides development.

One of the regions of the active formation of landslide processes within the Middle Dnieper area is the *Kyiv city*, where more than 120 landslides have been recorded. Gravitational processes in Kyiv, and first of all, landslides, are connected with specific conditions, the geological environment of the right bank of the city, where layers of sedimentary rocks of different permeability are interspersed. Feature of the relief of this territory is a significant difference in height, sharp fluctuations basis of erosion and slope angles. Under certain conditions, the hydrometeorological factor is the trigger mechanism of landslides, and man-made loads on the slopes — destabilizing, which causes the danger of the existence of urban infrastructure and human life.

Within the city of Kyiv, landslides are developed in two zones: Prydniprovska — the right slope of the Dnieper and the estuary of ravines and gullies; Miska — is the valley of the Lybid River and its ravine-beam network. Landslides of the Prydniprovska landslide zone are territorially grouped into Podilska, Tsentralna, Lavrska, Zalavrska, Vydubytska and Miska sites according to the nature of the manifestation and geological and hydrogeological conditions. Each site has its own specific characteristics and features.

The total number of slides from year to year changes due to occurrence of new landslides under the influence of the geologic and hydrometeorological factors. The most dangerous districts in terms of landslide hazard are currently Podilskyi, Pecherskyi and Holosiivskyi. Lithological, stratigraphie, geomorphological and hydrogeological conditions in conjunction with the hydrometeorological factor determine the intensive formation of landslide processes. A specific category of factors includes dynamic processes that change the state of slopes, including erosion processes, weathering, tectonic regime of the territory, seismicity and man-made loads on slopes. The combination and priority of these factors determine the mechanism and conditions of gravitational processes formation.

Landslide mitigation and prevention. Landslides cause a recurrent hazard to human life and livelihood in most parts of the world, especially in some regions that have experienced rapid population and intensive anthropogenic growth. To forecast and control the development of landslides, detailed geological surveys are conducted and maps are drawn up, indicating landslide-prone regions. First, the aerial photography method detects areas of accumulation of soil material prone to be disturbed. Then the features of the rock, the angles of inclination, the nature of groundwater and surface water are studied. Registration of landslide processes is carried out on the slopes with the help of reference benchmarks.

Landslide prevention and protection involves a number of *passive and active measures*. The passive ones include protective and restrictive measures: prohibition of construction and blasting works, pruning of landslide-prone slopes. Active measures include strengthening the landslide-prone slopes of seas, rivers and lakes with retaining (*підпорними*) and water-repellent (*водовідбійними*) walls, embankments (*набережними*). Shifting soils are strengthened with concrete piles arranged in a checkerboard pattern (*шахматному порядку*). Artificial soil freezing is carried out; plants with a strong root system are planted on the slopes. To stabilize the landslides in wet clays, they are pre-dried. Ditches, galleries (*штольні*), horizontal wells are made to drain surface and groundwater.

The cost for landslide prevention is very high, but the tangible costs, caused by the landslide, far exceed the set of precautionary measures. The last ones include a system of monitoring, public awareness, plans towards the possible consequences management.

2.4.3. Karst's formation and development

The term "karst" (from the name of the Karst plateau in Slovenia) means a set of specific landforms and features of terrestrial and underground hydrography, characteristic for some areas composed of soluble rocks, such as rock salt, gypsum, limestone, dolomite, and others. However, rock salt and gypsum are more soluble than limestone or dolomite, gypsum and salt karsts are relatively underdeveloped due to the low prevalence of these rocks, especially their outcrops on the day surface. Limestone and dolomite are characterized by poor solubility under normal conditions. But they are incomparably more widespread in nature than gypsum or rock salt. In addition, the chemical aggressiveness of water under certain physical and geographical conditions can get significantly increased in the areas of carbonate rocks development. They can occupy large karst landscapes and/or relief composed of mainly lime stones and dolomites.

The essence of karst processes is in dissolution of rocks by atmospheric, thawed, underground, and, in some cases, sea waters.

The main condition for the solubility of limestone is a sufficient amount of dissolved CO_2 in water. Then the water becomes chemically aggressive and energetically affects the carbonate rocks. Sources of CO_2 contained in natural waters are: the atmosphere, biochemical processes occurring in the soil and weathering crust, decomposition of organic residues in free access of air, carbon dioxide from the Earth's interior in areas of neotectonic activity. This is explained by the fact that Ca and Mg carbonates, which are not easily soluble in water, form quite soluble bicarbonates of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ with carbon dioxide.

Other important conditions that determine the development of karst include: 1) *relief* — on horizontal and sloping surfaces karst formations occur faster and are more diverse than on steep slopes; 2) *thickness of limestone* — the cleaner and more powerful the thickness of lime stones, the more intense they are prone to karst formation; 3) *rock structure* — coarse-grained or shell karst lime stones are much smaller than homogeneous fine-grained lime stones; 4) *climate* — temperature, amount and nature of precipitation, nature of vegetation, which increases the chemical aggressiveness of water (due to the decomposition of plant residues, water is enriched with CO_2, humic acids, nitric acid, etc.); 5) *rocks fracturing* — in the presence of fractures there is a possibility of aggressive waters penetration into the rock and the formation of various forms of underground karst.

Types of kast relief. Karst relief can occur on the surface or underground, due to the erosion of rocks. This can generate a multitude of forms discussed below.

External karst relief. These types of formations are found on the surface; and they are usually characterized by irregular shapes. In the area of open karst under the action of rain or melt water on the surface of limestone microrelief of shallow holes is formed. This is a system of ridges and furrows separating them, up to 2 m deep.

Transitional forms connect surface and underground karst zones. In places of increased fracturing of limestone, with the vertical circulation of water, ponors/shallow holes are formed, i.e. channels that absorb surface water. When they expand, karst sinkholes are formed. With a large expansion, the fractures turn into wells and mines, which can reach great depths. Example: the depth of the Snezhnaya mine in the Caucasus is of 1 370 m depth.

Failure, or surface sinkholes, when merging form blind ravines, gorges, and the largest karst forms — *poljes*. The *poljes* are extensive, usually flat-bottomed, with steep walls, karst depressions of several kilometers, and sometimes several tens of kilometers in diameter. Thus, the area of Popov Field (180 km^2) is a polje in Bosnia and Herzegovina. *Canyons and gorges* are narrow and deep valleys created by the action of rivers where carbonate rocks are available.

Underground karst relief. The karst relief found in underground areas creates caves, grottos and other very unique karst landscapes.

Caves are the most common underground karst forms appeared thanks to the filtration of water by fractured rocks.

Stalactite is a mineral formation that hangs from the ceiling of caves, hot springs, or man-made structures such as bridges and mines.

Stalagmite is a type of rock formation that rises from the floor of a cave due to the accumulation of material deposited on the floor from ceiling drippings.

Terminology to chapter 2.4:
canyon — каньйон
cave — печера
fracture — тріщина

gorge — ущелина
polje — внутрішня долина, польйо (*в карстових областях*)
sinkhole — воронка, провал
stalactite — сталактит
stalagmite — сталагміт

Answer the questions

1. What do we call landslides?
2. In what way the landslides are formed?
3. What are the types of landslides?
4. Where are the landslides developed?
5. What do we call karsts?
6. What are the forms of karsts?

2.5. Sedimentary rocks

Factors of rock formation.
Sedimentary Rocks' Classification.
Weathering resistance.

2.5.1. Factors of rock formation

Sedimentary rocks are types of rocks formed by the accumulation or deposition of mineral or organic particles at Earth's surface. They are formed in the process of destruction and weathering of various rocks, redeposition of products, mechanical and chemical precipitation of water sediment, the activity of organisms or all processes simultaneously. The particles that form a sedimentary rock are called sediment, and may be composed of minerals or biological detritus (organic matter).

More than 3/4 of the land area is covered with sedimentary rocks. They form the upper layer of the earth's crust sometimes up to 25 km. They are also involved in the development of mineral deposits such as gas and oil.

The remains of extinct organisms are perfectly preserved in sedimentary rocks, and thanks to them scientists can trace the history of our planet's development.

Sedimentary rocks are formed close to the earth's surface, opposite to metamorphic and igneous rocks formed deep within the Earth planet.

The most important processes that lead to the formation of sedimentary rocks are *erosion, weathering, precipitation, and lithification.*

Erosion and weathering are the processes that lead to the effects of wind and rain that break down rock debris into smaller parts. Erosion and weathering transform pieces of rocks into sediments (*sand or mud*). Chemical weathering involves slightly acidic water which slowly wears away rock debris. These processes create the raw materials for sedimentary rocks.

Precipitation and lithification are the processes that lead to creation of new minerals. Precipitation leads to the formation of minerals from chemicals precipitated from water. For example, the California's Death Valley was created from minerals deposits left as a result of the lake drying up over many thousands of years. *Lithification* (*перетворення осадового матеріалу на монолітну породу*) is the process by which different sediments are slowly compacted into rocks from the weight of overlying sediments on the bottom of the ocean or other water bodies.

2.5.2. Sedimentary Rocks' Classification

Sedimentary rocks are formed within the surface layers of the earth's crust in the process of subsidence under the influence of precipitation and gravity on land and at the bottom of water bodies. Sedimentary rocks are divided into the following groups according to the way they were originated.

Sedimentary rocks can be organized into three categories: *detrital, chemical and organogenous* rocks. *Detrital rock,* which comes from the erosion and accumulation of rock fragments, sediment, or other materials categorized in total as detritus, or debris. From the name it is clear that detrital rocks consist of fragments of other rocks. Their formation is associated with the processes of weathering, movement of debris by glacier, water or wind, as well as the process of debris accumulation. This is how fragmentary sedimentary rocks of different sizes are formed. Examples of rocks: cobbles, pebbles, gravel, sand, silt stone, clay.

The *geological detritus* was originated from rocks weathering and erosion, or from the solidification of molten lava erupted on the land surface. The geological detritus is transported to the place of deposition by nature agents – water, wind, ice or mass movement, which are called agents of denudation. *Biological detritus* was formed by parts of dead aquatic organisms, as well as their fecal mass, suspended in water and slowly piling up on the floor of water bodies (marine snow). Sedimentation may also occur as dissolved minerals precipitate from water solution.

Organic detrital material is formed when parts of plants and animals decay in the ground, leaving behind biological material that is compressed and becomes rock.

Coal is a sedimentary rock that was formed over millions of years from compressed plants. Examples of sedimentary rocks: phosphorites — clusters of bones, phosphate shellfish; combustible minerals — oil, oil shale, gas, coal; limestones — chalk, limestone, shell rock. This type of sedimentary rocks is considered the most valuable mineral. In addition to the fact that they are widely used in human farming, so also due to their layered texture, you can study the prints and remains of plants and animals left between the layers.

Inorganic detrital rocks are originated from broken up pieces of other rocks, but not from living organizms. These rocks are usually called clastic sedimentary rocks. One of the best-known clastic sedimentary rocks is a *sandstone*. Sandstone is formed from layers of sandy sediment that is compacted and lithified.

Chemical rocks are produced from the dissolution and precipitation of minerals. Such rocks are formed from minerals that are dissolved in water. At the bottom of reservoirs there is a constant sedimentation of table and potassium salt, and silica comes from the waters of hot springs.

These are the simplest chemical sedimentary rocks by formation. Many of them are used by man in the economy, both in the food industry and to obtain various raw materials.

Chemical sedimentary rocks can be found in many places, from the ocean to deserts and caves. For example, most limestone forms at the bottom of the ocean from the precipitation of calcium carbonate and the remains of marine animals with shells.

If limestone is found on land, it can be assumed that the area used to be under water (Table 2.2).

Table 2.2

Typical chemical weathering products of common minerals

Mineral composition	Residual minerals	Dissolved ions
halite (Na chloride)		Na^+, Cl^-
gypsum (hydrated Ca sulfate)		Ca^{2+}, $(SO_4)^{2-}$
calcite (Ca carbonate)		Ca^{2+}, $(HCO_3)^-$
quartz (SiO_2)		$(SiO_4)^{4-}$
plagioclase (Ca-Na-Al silicate)	clay minerals	Ca^{2+}, Na^+, $(SiO_4)^{4-}$
alkali feldspar (K-Na-Al silicate)	clay minerals	K^+, Na^+, $(SiO_4)^{4-}$
olivine (Fe-Mg silicate)	limonite, hematite, clay	Mg^{2+}, $(SiO_4)^{4-}$
pyroxene (Ca-Fe-Mg silicate)	limonite, hematite, clay	Ca^{2+}, Mg^{2+}, $(SiO_4)^{4-}$
amphibole (Ca-Fe-Mg silicate)	limonite, hematite, clay	K^+, Mg^{2+}, $(SiO_4)^{4-}$
biotite (K-Fe-Mg-Al mica)	limonite, hematite, clay	K^+, Mg^{2+}, $(SiO_4)^{4-}$
muscovite (K-Al mica)	clay	K^+

2.5.3. Weathering resistance

Here is the list of mineral resistance to weathering (Table 2.3). Like primary minerals, secondary minerals can get weathered and disappear. So, this table compares weathering velocity for primary and secondary minerals.

Weathering resistance, however, does not necessarily mean that a particular mineral is content in a big amount in weathered materials. Some of the minerals at the top of the list in the table are uncommon compared with others.

Zircon, rutile, and tourmaline, for example, are very resistant to weathering but rarely are major components of sediments because they are only minor minerals in most parent rocks.

Minerals at the bottom of the list are very unstable when exposed to the elements and, consequently, are absent from all but the youngest sediments.

Table 2.3

Resistance of minerals to weathering

most weathering resistant *least weathering resistant*	zircon – циркон rutile – рутил tourmaline – турмалін ilmenite – ільменіт garnet – гранат quartz – кварц epidote – епідот titanite – тітаніт muscovite – мусковіт K-feldspar – польовий шпат plagioclase – плагіоклаз hornblende – амфібол chlorite – хлорит augite – авгіт biotite – біотит serpentine – серпентин volcanic glass – вулканічне скло apatite – апатит olivine – олівін	anatase – анатаз gibbsite – гібсит hematite – гематит goethite – гетит kaolinite – каолініт clay minerals – глинисті мінерали calcite – кальцит gypsum – гіпс pyrite – пірит halite – галіт other salts

Sedimentary minerals. The previous chapter (1.5.5) discussed silicate minerals common in igneous rocks. In general, they could all be detrital grains in sedimentary rocks. In practice, most break down so quickly that they cannot be weathered or transported very much before completely decomposing. Quartz is a mineral, which is the most resistant to weathering. It is also very common in many igneous and metamorphic rocks met at the earth’s surface. Many minerals weather to produce clays. It is true as quartz and clays are the main silicate minerals in majority of clastic rocks. Feldspars and sometimes muscovite are usually subordinate to quartz. They are absent from rocks formed from sediments transported long distances or weathered for long times. Mafic silicate minerals are exceptionally rare in sediments or sedimentary rocks. Besides quartz and clays, other silicates, including zeolites, may occasionally be present. Important nonsilicate minerals in clastic rocks include carbonates, sulfates, oxides, halide minerals and sometimes pyrite.

The clay minerals include many different sheet silicates. They usually contain less potassium than micas. The major differences between the different clay species are the compositions and stacking order of atomic layers. The formulas of clay minerals are only approximate because clays often contain many elemental substitutions.

Clay minerals account for nearly half the volume of sedimentary rocks. They are usually very fine grained, often less than 1 μm (10^{-6} m) in size, have complex chemistries, and are structurally variable. This makes identification of individual clay species difficult. X-ray analysis is often necessary to identify them. In contrast with quartz and feldspar, clays are not usually formed in igneous and metamorphic rocks.

Clays are common in sedimentary rocks. The availability of clay species depends on the sediment sources. They also develop as coatings on other minerals subjected to weathering and erosion. At low temperatures mineral structures are usually more complex or disordered, and many different mineral varieties may form.

Terminology to chapter 2.5:
chert — кремінь
clay mineral — глинистий мінерал
dolomite — доломіт
limestone — вапняк
litification — літифікація
precipitation — осадконакопичення
sandstone — пісковик
sedimentary rock — осадова порода
shale — сланець
sheet silicates — листові силікати
weathering resistance — стійкість до вивітрювання

Answer the questions

1. What way sedimentary rocks are formed?
2. How are sedimentary rocks classified?
3. List the most typical minerals of sedimentary origin.
4. What does the process of precipitation mean?
5. What does the process of lithification mean?
6. What is weathering resistance?

2.6. Mineral resources in the sedimentary cover of Ukraine

> The Concept of Sedimentary (platform) Cover.
> Characteristics of sedimentary deposits in Ukraine.
> Anthropogenic impact on the geological environment.

2.6.1. The Concept of Sedimentary (platform) Cover

The sedimentary rock cover of the continents of the earth's crust is extensive (73 % of the Earth's current land surface), but sedimentary rock is estimated to be only 8 % of the volume of the crust. Sedimentary rocks are a thin cover over the earth's crust consisting mainly of igneous and metamorphic rocks. Sedimentary rocks are deposited in layers as strata, forming a structure called bedding. Sedimentary rocks are often deposited in large structures called sedimentary basins. Sedimentary rocks have also been found on Mars.

Minerals (корисні копалини) of sedimentary origin are distributed within platform plates. That is, they are characteristic of structures that in the past were basins of accumulation of sedimentary material deposited from adjacent areas. Some of them were formed due to the destruction of rocks. These are fragmented rocks. The size of the fragments varies from boulders and pebbles to dusty particles, which makes it possible to distinguish between them rocks of different particle size distribution — boulders, pebbles, conglomerates, sands, sandstones and more. Organogenic rocks are formed with the participation of organisms (limestone, chalk, oil). A significant place is occupied by hemogenic rocks formed by chemical sedimentation of water or solutions without the participation of biological processes.

Regularities of minerals distribution. Minerals are extracted, as a rule, from shallow depths (up to 1 thousand m). Therefore they are closely related to the structure of the upper layers of the earth's crust. Therefore, different groups of minerals are characteristic for different tectonic structures.

2.6.2. Characteristics of sedimentary deposits in Ukraine

In the economic analysis of minerals, the classification of minerals by origin is accepted — fuel, ore, non-ore.

Fuel (combustible) minerals (паливні корисні копалини). Coal, like oil and natural gas, is an organic substance that has undergone slow decomposition due to biological and geological processes. The basis of coal formation is plant remains. Depending on the degree of conversion and the specific amount of carbon in coal, there are four types of coal: brown coal (lignite), coal, anthracite and graphite.

Brown coal — solid fossil coal formed from peat, contains 65–70 % of brown carbon, the youngest of fossil coal. Used as a local fuel, as well as chemical raw materials. Contains a lot of water (43 %), and therefore has a low heat of combustion. In addition, it contains more volatile substances (up to 50 %). It is formed from dead organic residues under pressure and elevated temperature at depths of approximately of 1 km.

Coal (*кам'яне вугілля*) is a sedimentary rock that is the product of deep decomposition of plant remains. Most coal deposits were formed in the Paleozoic, mainly in the Carboniferous period, about 300–350 million years ago. In terms of chemical composition, coal is a mixture of high molecular weight polycyclic aromatic compounds with a high mass fraction of carbon, as well as water and volatile substances with a small amount of mineral impurities, which form ash during coal combustion.

The carbon content in coal, depending on its variety, is from 75 % to 95%. Contains up to 12 % moisture (3–4 % internal), so it has a higher heat of combustion compared to brown coal. It contains up to 32 % of volatile substances, so it ignites well. It is formed from brown coal at depths of approximately 3 kilometers.

Anthracite is a fossil coal that warmed the deepest when it originated, coal of the highest degree of carbonization. It is characterized by high density and gloss. It contains 95 % of carbon. It is used as a solid high-calorie fuel (calorific value 6800–8350 kcal/kg). Has the greatest heat of combustion, but does not ignite well. It is formed of coal with increasing pressure and temperature at depths of about 6 kilometers.

There are Donetsk and Lviv-Volyn coal and Dnieper lignite basins on the territory of Ukraine. The Donetsk basin within Ukraine (Great Donbass) covers an area of more than 50 thousand km^2 (coking, gas coal, anthracite is deposited here). Since 1949 Western Donbass, located in the northeast of Dnipropetrovsk region and partly in Kharkiv region, is being developed.

Currently more than a hundred sites with total reserves of about 12 billion tons are located in Donbass.

The Carpathian oil and gas region covers the fields of Precarpathia, the Ukrainian Carpathians and Transcarpathia. Most oil and gas fields are located in Lviv and Ivano-Frankivsk regions and are timed to the Pre-Carpathian Depression. More than 30 gas fields have been discovered here, many of which have been almost completely depleted as a result of long-term operation. The largest oil and gas fields are Dolynske, Boryslavske, Volytske, Bytkivske, Uherske, Zaluzhanske, Dashavske. The recently discovered gas fields of Transcarpathia are also of industrial importance.

The Black Sea oil and gas region (Prychornomorsk occupies the territory of the Black Sea lowland and the steppe plain of Crimea. It has explored more than 60 oil and gas fields. The largest among them are Dzhankoyske, Glibivske, Stormove, Kazantipske. Deep areas of the earth's crust and the submarine subsoil of the Black Sea are considered promising for gas and oil. *Oil shale* reserves (3.7 billion tons) have been discovered at the border of the Kirovohrad and Cherkasy regions.

There are more than 2.500 *peat deposits* (2.2 billion tons). Peat deposits are located mainly in the Volyn, Rivne, Kyiv, Chernihiv, and Lviv regions.

*Graphite***.** Ukraine holds the second place in the world in terms of graphite reserves (about 300 deposits with more than 1 billion tons, 20 % of the world reserves, China — 26 %).

Large reserves of *potash salts* are concentrated in the Ivano-Frankivsk and Lviv regions. The Ukrainian reserves of native sulfur are the largest among the countries of the former USSR.

The reserves of such *building materials as limestones, chalk, marl, gypsum, clays* are large and diverse. They are distributed throughout the country. Kaolin deposits are widely used in the porcelain and faience industry. Ukraine has very large reserves of *building stone*, including the most high-quality facing stone: *granites* of the Zhytomyr, Vinnitsa, and other regions; *marbles* and tuffs of the Crimea and Transcarpathia.

Sandstone is made of sand. Because it is easy to work with, sandstone has been a popular building material around the world for a long time. In areas where it is common almost every building is made from it.

Limestone is made primarily from the mineral *calcite* (calcium carbonate). It is formed from the remains of billions of tiny sea creatures which have been pressed together and compacted below the ocean floor.

Mud, silt and clay are the ingredients of shale. These are compacted to form a soft, easily broken, usually dark coloured rock. Shale can be used as a filler in the production of paint, used in brick making and is sometimes used as a base material under roads.

2.6.3. Anthropogenic impact on the geological environment

Irrational use of the geological environment destroys not only this environment, but also the associated soil and vegetation, surface and groundwater, and so on. As a result of extraction, enrichment and processing of minerals, accumulation of waste rock and production waste there is a concentration of harmful elements — heavy metals, radioactive elements, etc., which leads to serious diseases and even mass death of plants and animals.

Transportation of goods, research equipment or drilling rigs off-road, movement of heavy self-propelled units, tractors always leads to severe environmental consequences, partially, in the steppes and deserts.

During geological exploration works, the natural landscapes of the area change — the soil and vegetation cover is disturbed, depressions are formed due to open ditches, clearings of rocks.

The construction and operation of various buildings and mining and engineering structures have a significant negative impact on the geological environment. This is especially true of quarries and mines. Underground cavities formed as a result of the laying of mines disrupt tectonic processes in the upper layers of the earth's crust, which is often the cause of man-made earthquakes, landslides and landslides. As a result of quarry development and accumulation of waste rock in dumps and heaps, fertile soils are destroyed.

Nowadays, more and more often technical and construction activities on fertile lands are preceded by the removal, movement and storage of soil, which is then used to cover other areas with worse soils or to rehabilitate quarries and heaps. Gardens, parks, and orchards are divided on reclaimed lands.

In connection with the large-scale destruction of the geological environment, the problem of its rational use is becoming increasingly important. To this end, it is necessary to create a state fund of mineral deposits and its reserve, and develop regulations on its use. It is necessary to provide a clear economic relationship between the owner and the user of subsoil, which would take into account the payment for land, subsoil, penalties for violations of legislation on the use and protection of subsoil.

It is necessary to rehabilitate lands on the site of open-cast deposits. This concept covers the whole set of works aimed at restoring the fertility and economic value of disturbed lands. In a narrow sense, reclamation is the restoration of a layer of soil previously removed from areas where it is expected to be mechanically destroyed or contaminated.

There are physical and chemical types of man-made impact on the geological environment. *The physical impact* is determined by mining, civil engineering, agriculture and military activities. Giant mining and processing plants or complexes for fuel extraction are able to change the geological environment in a short time so that it will not be possible to restore it. The deeper horizons of the earth's crust are also man-made due to the huge number of oil and gas wells, underground construction in cities, laying of pipelines, tunnels, etc.

Today, almost 15 % of the land (almost 1/6 of its total area) is covered by engineering structures — roads, canals, reservoirs, industrial complexes, buildings and more. This activity changes the relief, properties of rocks (compaction, destruction), regime and level of groundwater, etc.

The chemical impact on the earth's crust is carried out by solid waste dumps, industrial and municipal wastewater, polluting drinking water supplies. One person produces almost a ton of municipal waste per year. Large areas are allocated for the storage of various wastes from mining and other human economic activities. This includes unused toxic waste. All this destroys the upper part of the earth's crust — the geological environment — and leads to irreversible changes.

Throughout human history, we have only consumed without thinking about the consequences. The task of geologists is to make the Earth's mineral resources available to everyone and humanity in its knowledge of the Earth has reached a level that will allow it to realize that it is on the verge of a state of the planet, for which there is no future.

Terminology to chapter 2.6:
building materials — будівельні матеріали
deposit — родовище (*корисних копалин*)

fuel (combustible) minerals — паливні (*горючі*) корисні копалини
geological environment — геологічне середовище
impact — вплив
man-made impact — антропогенний вплив
minerals — корисні копалини
oil and gas — нафта та газ

Answer the questions

1. What is sedimentary cover?
2. What are mineral deposits of sedimentary origin?
3. List the most important deposits of sedimentary origin.
4. Characterize (briefly) Carpathian oil and gas region.
5. What is the anthropogenic impact into the geological environment?
6. What is physical and chemical impact on the geological environment?

2.7. Influence of geological environment on biota

> Resource function of the geological environment.
> Natural geochemical anomalies and their influence on biota.
> Natural geophysical anomalies and their influence on biota.

2.7.1. Resource function of the geological environment

Resources needed for biota life **(***resource function of the geological environment*). The resource function of the geological environment is in its ability to meet the needs of biota (ecosystems) in abiotic resources, including human needs for minerals. In this case, human needs should not contradict the needs of biota.

The resource function is basic in the system "lithosphere — biota", because it is associated not only with the conditions of life and evolution of biota, but also the possibility of its existence. It reflects the role of mineral, organic, organic-mineral resources of the lithosphere, as well as its geological space for life and activity of the biota as a biocenosis, and the human community as a social structure.

The resource function includes: resources necessary for the life and activity of biota; resources necessary for the life and activity of human society; resources as a geological environment necessary for the settlement and existence of biota, including human society.

Resources of geological space for agricultural and forestry development can be considered both as resources for economic development and as resources for biota settlement. One of the methods of assessing the resource potential of the lithosphere is to create maps of resource distribution.

2.7.2. Natural geochemical anomalies and their influence on biota

Geochemical anomaly is an area in which the content of a chemical element or the value of another geochemical parameter (Eh, pH, etc.) is significant (due to value) differs from the geochemical background. Anomalies can be positive — values above the background, or negative — values below the background: very small and very high levels of element concentrations, according to the law of general dispersion, are highly doubtful.

Anomalous sites are the areas of processes development which are not typical for the background geochemical field, associations of elements and forms of their location. Anomalies can be global, regional, local, point, etc. (ore bodies, deposits and ore fields are also geochemical anomalies).

Secondary (epigenetic) areolas of dispersion — i.e. areas of enhanced concentrations of elements arisen as a result of epigenetic processes in relation to the ore body. In contrast to the primary halos, the concentration of elements in the secondary halos is always higher than the background, although the level of such excess may be very small. The size of the secondary halos is usually much larger than the size of the primary halos — they reach hundreds of meters and even kilometers. The form of finding elements in secondary halos is often mineral-matter-free (adsorption by clays, etc.).

Secondary halos are classified according to the components of the middle in certain fixed areas of enhanced concentration: *lithochemical* — in rocks, weathering crusts, and soils; *hydrogeochemical* — in underground and surface waters; *atmochemical* — in the underground and aboveground atmosphere; *biogeochemical* — in organisms.

Natural *lithochemical* anomalies are explained by the geological and structural features of the area, its metallogeny, the mineral composition and petro-geochemical features of the rocks, as well as the physical and chemical characteristics of the elements and their complexes migration. In addition, anomalous elements content is often met within the areas of tectonic-magmatic activation, which are not consistent with the lithological compositin of the geological fields. Such anomalies are considered as reflectance of power energy flows in order to form asymmetric growth in a set of elements in all rocks. As a matter of fact, the enhanced concentration of Bi, As, Sb, Hg, Sn, Be, Li, F serve as an evidence of openness geological system.

Lithochemical (as well as the other) anomalies can be manifested not only by a meaningful change of the elements content but also by change in their forms of occurance. In some cases the anomalies of this kind are the cause of environmental hazards (oxidation of low-mobile sulfide metals in the zones of oxidation of sulfide deposits etc.).

Waters migration through the ore bodies is a cause of formation of hydrogeochemical anomalies that contain enhanced concentration of elements in solubale condition.

2.7.3. Natural geophysical anomalies and their influence on biota

Organisms, including humans, are affected by natural geophysical fields such as *magnetic, gravitational, temperature, electromagnetic and radioactive*. Properties of geophysical fields of the lithosphere affect the state of the biota (including humans).

It is well known about the direct influence of the Earth's *magnetic field* on the evolution of animals and humans. For example, a comparison of the sizes of their skeletons with variations in the magnetic field with a period of 8000, 600, 60, 22 and 11 years showed that the sizes of the skeleton of animals and humans increase during periods of decreasing magnetic field intensity in the 8000-year cycle. In any case, two periods of acceleration (increase of a skeleton) are precisely established: from VI millennium BC to the middle of the IV millennium BC and from the middle of the first millennium AD to the present time.

The Earth has a strong *gravitational field*, which is able to hold on its surface the atmosphere, hydrosphere, provides a large water cycle and the movement of ice masses and, at the same time, ensures the existence of life on our planet. Gravitational influence becomes potentially significant for tissue cells and microorganisms whose sizes exceed 10 microns. However, for animals such as insects, the gravitational field does not play a significant role as they are able to withstand a hundredfold overload, which cannot be said about large animals and humans.

On the earth's surface, throughout the geological time of the biosphere, the average temperature was maintained in the range from 0 to +40 °C. These figures can be considered limits of tolerance for the Earth's biota (although scientists believe that the temperature limits of some microorganisms range from –200 to +100 °C). However, even a decrease in the current average temperature on the Earth's surface by 3–4 °C or its increase by 3–3.5 °C can lead to phenomena that the civilization is not able to cope with: in the first case — with icing and a sharp reduction in the amount of free water, and in the second case — with the flooding of vast areas and the reduction of the biota’s habitat, which is adapted to terrestrial life.

It is also known about the natural *electromagnetic fields* caused by solar radiation (light), which have a direct ecological impact on organisms. But we are also interested in the ecological role of the electrostatic field, which is largely generated by the lithosphere and manifested in the surface of the atmosphere. This field significantly affects the content of positive and negative air ions, which have a physiological effect on organisms. At optimal doses of negative air ions (air oxygen ions) the usual positive effect, for example, increases the germination of plant seeds, their growth and the amount of biomass. It has been experimentally established, including in animal experiments, that negative air ions enhance the vital activity of the organism in its optimum, but in excess can cause a marked suppression of physicochemical processes occurring in the body. Positive air ions usually have a negative effect on the body, and in excess can cause it some harm.

The Earth's natural *radioactive field*, or field of ionizing radiation, is observed on the surface and in the near-surface part of the lithosphere. The natural radiation background is formed due to the radiation of radionuclides that are part of the rocks. More than 40 % of a person's dose from natural radiation is provided by radioactive gases radon-222 and radon-220 (toron). However, currently the intensity of ionizing radiation has increased significantly as a result of human use of nuclear energy, including for military purposes. The radioactive fallout that fell as a result of nuclear weapons tests was perceived by the lithosphere, and the radionuclides of this fallout thus becomes a source of additional radiation.

The natural background may differ several times, but varies from 2 to 20 mSv in different parts of the Earth's surface. It is in this range of radiation background that all living things on Earth existed and developed. Radiation above the mentioned level can be considered as a mutagenic factor. No animal or plant is able to survive in the area of powerful radiation sources, usually man-made.

Terminology to chapter 2.7:
geochemical anomalies — геохімічні аномалії
geophysical anomalies — геофізичні аномалії
mineral-matter-free — безмінеральний
resource function — ресурсна функція
natural background — природний фон
weapon's tests — випробування зброї
lithochemical anomalies —літохімічні аномалії
hydrogeological anomalies — гідрогеологічні аномалії
biogeochemical anomalies — бігеохімічні аномалії

Answer the questions

1. *What does the resource function of the geological environment mean?*
2. *What kinds of geochemical fields do you know?*
3. *What kinds of geophysical fields do you know?*
4. *What way does the magnetic field influence living organisms?*
5. *What way does the gravitational field influence living organisms?*
6. *What way does the radioactve field influence living organisms*

REFERENCES

1. Charles Q. Choi. Planet Earth: Facts about our home planet. URL: https://www.space.com/54-earth-history-composition-and-atmosphere.html Retrived 08 Aug2021.

2. Ivanik, O., Shabatura, O., Homenko, R., Hadiatska, K. and Kravchenko, D. (2020). Local forecast of landslide hazards: case study from Kyiv region.Conference Proceedings: Geoinformatics: Theoretical and Applied Aspects 2020, May 2020, V. 2020, 1–5. https://doi.org/10.3997/2214-4609.2020geo118 Retrieved 10Aug2021.

3. Introduction to Geology. Free download textbook. URL: https://openpress.usask.ca/physicalgeology/front-matter/physical-geology/ Retrieved 1Oct2021.

4. The Origin of Earth and the Solar System. Free download textbook. URL: https://openpress.usask.ca/physicalgeology/front-matter/physical-geology/ Retrieved 18May2021

5. Minerals. Free download textbook. URL: https://openpress. usask.ca/physicalgeology/front-matter/physical-geology/ Retrieved 10June2021.

6. Geological resources. Free download textbook. URL: https:// openpress.usask.ca/physicalgeology/front-matter/physical-geology/ Retrieved 3July2021

7. Макаренко Д. Є. Геохронологія // Енциклопедія Сучасної України: електронна версія [веб-сайт] / гол. редкол.: І. М. Дзюба, А. І. Жуковський, М. Г. Железняк та ін.; НАН України, НТШ. Київ: Інститут енциклопедичних досліджень НАН України, 2006. URL: https://esu.com.ua/search_articles.php?id=29172 Retrieved 12Sept2021.

8. Зінченко М. О. Геологія. Робочий зошит для лабораторних занять. навч. посібник / М. О. Зінченко, О. В. Давидов. Херсон, П. П. Вишемирський В.С., 2016. 102 с.

CONTENTS

Навчальне видання

ДУДАР Тамара Вікторівна

ГЕОЛОГІЯ З ОСНОВАМИ МІНЕРАЛОГІЇ

(курс лекцій)

(*Англійською мовою*)

В авторській редакції

Технічний редактор *А. І. Лавринович*
Комп'ютерна верстка *Л. Т. Колодіної*

Підп. до друку. 18.02.2022. Формат 60х84/16. Папір офс.
Офс. друк. Ум. друк. арк. 4,65. Обл.-вид. арк. 5,0.
Тираж 50 пр. Замовлення № 29-1.

Видавець і виготівник
Національний авіаційний університет
03058. Київ-58, проспект Любомира Гузара, 1
Свідоцтво про внесення до Державного реєстру ДК № 7604 від 15.02.2022