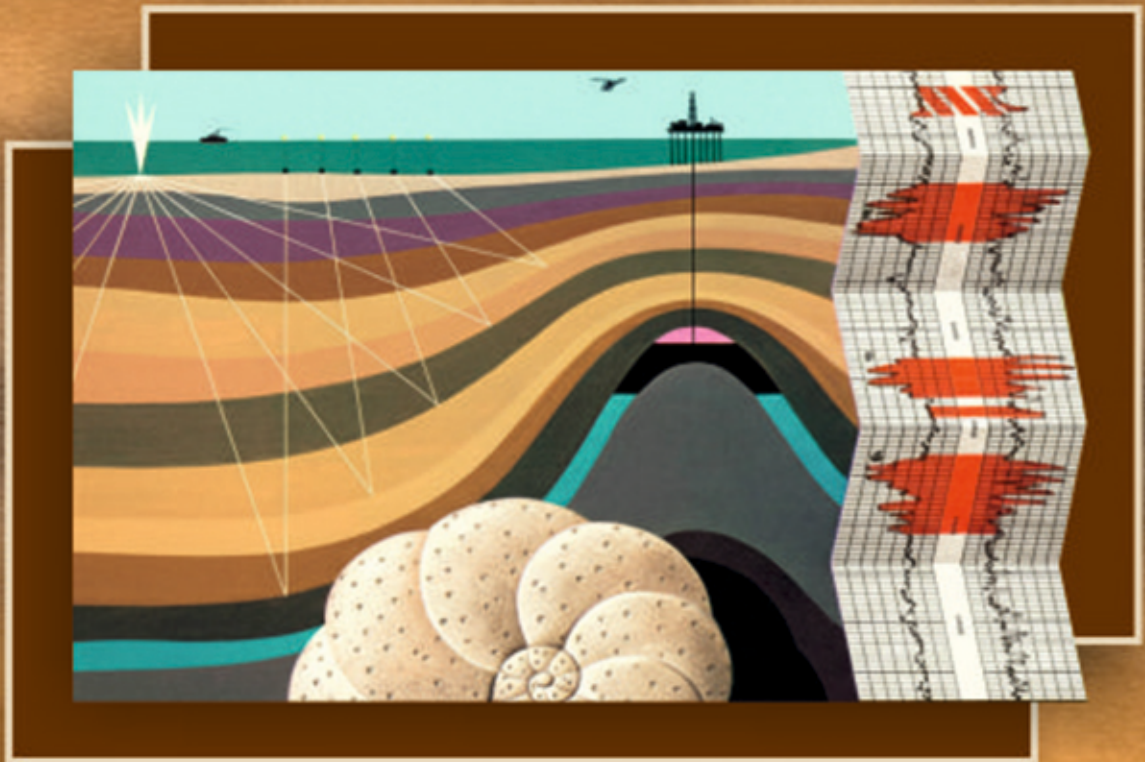


V. N. Karazin Kharkiv
National University



GENERAL OIL AND GAS GEOLOGY



Textbook

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
V. N. KARAZIN KHARKIV NATIONAL UNIVERSITY

GENERAL, OIL AND GAS GEOLOGY

Textbook

Recommended by
the Ministry of Education and Science of Ukraine

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S 89

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The textbook covers basic information about the structure of the universe, the solar system, the Earth and the Earth's crust. Minerals, rocks, groundwater and major stages of the planet's geological development are characterized in the textbook. Much attention is paid to the issues of dynamic geology – vibrational motions and tectonic deformations. The authors highlight geological features and minerals of Ukraine. Separate sections are dedicated to geology and hydrogeology of oil and gas fields. The textbook describes types and methods of geological research, human activity as a powerful geological factor, as well as the basic principles of environmental protection.

The textbook is designed for students of higher education in the field of training "Bachelor of Geology".

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PREAMBLE

Geological structure of the lithosphere and phenomena occurring in it define the formation features of various minerals, including oil and gas. Endogenous tectonic processes caused by internal (nuclear, chemical, etc.) earth energy lead to the formation of most minerals and rocks, various explosive and folded structures.

At the same time, exogenous processes, the main energy source of which is solar energy, not only form, but also actively destroy geological formations (minerals, rocks, mineral deposits, tectonic structure) on the Earth's surface and its surroundings.

Water plays an important role in all these processes, dissolving and transporting different substances from the Earth's crust, including fluid (liquid-gas) mixtures.

The textbook examines the geological structure of the territory of Ukraine and its components. It describes minerals of Ukraine, acquainting students with our wealth of mineral resources.

Some sections of the book touch upon the basics of oil and gas geology, the origin, chemical composition, conditions of occurrence, the concept of resources and reserves of oil and gas, as well as hydrogeological aspects of oil and gas fields.

The textbook lists the types and methods of geological research and characterizes the main areas of subsoils protection and the geological environment.

The textbook "General, Oil and Gas Geology " contains a lot of technical terms and concepts. It was compiled for students of higher educational institutions studying for the degree of "Bachelor of Geology", specializing in areas of "Oil Geology" and "Oil and Gas Hydrogeology."

INTRODUCTION

The textbook "General, Oil and Gas Geology" is designed for students specializing in oil geology and hydrogeology and those who began to study the basics of geology.

The purpose of the book is to familiarize students with the subject and value of geology, formation and structure of the Earth and the planets of the solar system, tectonic hypotheses and theories, factors of formation and destruction of minerals and rocks, groundwater and tectonic processes. It examines geological history of the Earth, the geological structure of the territory of Ukraine, geology and hydrogeology of oil and gas, minerals of Ukraine. Separate sections highlight the types and methods of geological research, basic principles of environmental protection and geological structure of the Geological Survey of Ukraine.

The study of general, oil and gas geology is based on the knowledge of geography, physics, chemistry acquired by students at school. It is associated with various sciences taught in the course of the university curriculum, such as mineralogy, crystallography, lithology, petrography, hydrogeology, structural and historical geology and many others.

Oil and gas geology investigates the origin and chemical composition of oil and gas, reservoir rocks of oil and gas fluids, conditions of hydrocarbon deposits occurrence. The calculation principles of oil and gas resources and reserves are described separately. Oil and gas hydrogeology examines the role of water in the formation of oil and gas, chemical composition and dynamics of groundwater deposits of oil and gas, justifies hydrogeological (hydrogeochemical, hydrogeothermal, hydrogeodynamic, etc.) oil and gas prospecting criteria.

Preparing the textbook, the authors relied on well-known publications in the world and Ukraine, in particular, mining and geological dictionaries, textbooks and manuals listed in the section "References".

*Doctor of Geological Sciences,
Professor O. V. Bartashchuk*

CHAPTER 1

THE OBJECT AND IMPORTANCE OF GEOLOGY

Geology (greek. *geo* – earth, *logos* – science) is the science about the Earth. By the end of the nineteenth century it was the only science that studied the composition of the Earth's crust, geological history, formation of minerals and rocks, groundwater, mineral deposits and many other issues associated with planet resources.

Geology reveals not only the laws of nature but creates a general model of the material world. It also has a great practical importance, being the basis of forecast, prospecting, exploration and mining.

Huge interest in geology, caused by the need to search for raw materials for the industry, has led to rapid accumulation of geological knowledge. Some specific research areas separated from it, turned later into independent sciences. Now, each of these sciences solves their own problems.

Mineralogy – (lat. *minera* – red) studies conditions of formation, chemical composition, structure, physical properties and use of minerals.

Crystallography (greek. *krystales* – ice, rock crystal) – considers the internal structure of minerals and their crystal form.

Petrography (greek. *petra* – rock) – studies different types of rocks, their mineral composition, origin, forms of occurrence.

Lithology (greek. *litos* – stone) – studies the composition, structure, texture and genesis of sedimentary rocks.

Historical geology is the science of history and patterns of crust.

Paleontology (greek. *paleos* – ancient, *ontos* – body) – examines the history of past geological epochs for fossil remains of plants and organisms.

Stratigraphy (lat. *stratum* – layer) is a part of historical geology, studying historical sequence of rock layers' formation.

Geotectonics (greek. *geo* – earth, *tektonikos* – structure) is a science of structural forms of the crust (discontinuous and folded), processes of their formation and development in time and space.

Geophysics – studies physical properties of rocks and physical fields of the Earth, generated and existing in it (gravity, magnetic, electrical, radiation, etc.).

Geochemistry – examines patterns of distribution and behavior of chemical elements in different environments of the Earth, as well as the processes of their migration and concentration, leading to the formation of mineral deposits.

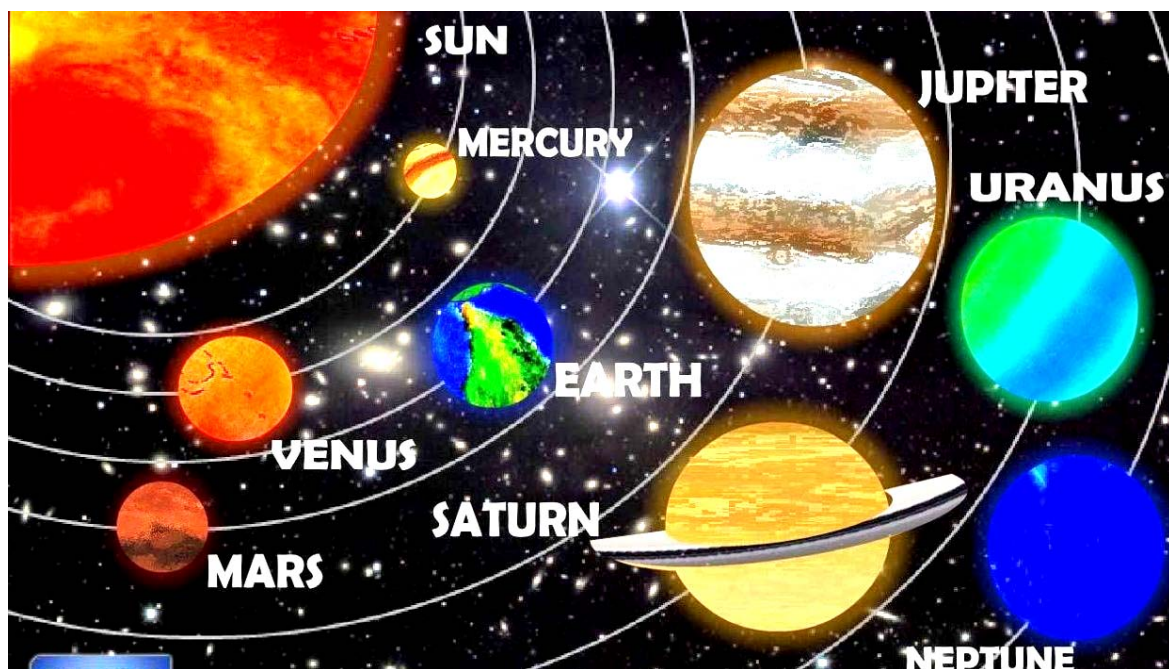
Hydrogeology – (greek. *hydra* – water, *geo* – earth, *logos* – science) is the science of groundwater, its origin, conditions of occurrence and the laws of motion regime, physical and chemical properties, connection with rocks, economic value.

Geomorphology (greek. *geo* – earth, *morfos* – look, *logos* – science) – examines dependence of the Earth's surface on geological processes.

Oil and gas (industrial) geology is a geology section connected with finding, exploration and development of oil and gas. There are also other areas of geology, and their number is increasing.

1.1. Earth – the planet of the Solar System

The Earth is part of the solar system, which has nine planets (?), their moons, asteroids and comets. Earthlike planets (relatively small) are Mercury, Venus, Earth and Mars. The outer planets – Jupiter, Saturn, Uranus, Neptune and Pluto – are bigger (except the last) in size and have relatively small mass and density. There are forty planetary satellites – the Earth and Neptune have one, and Saturn – seventeen (Fig. 1.1).



satellites <https://www.pinterest.com/pin/808607308070377548/>

Fig. 1.1 – Planets and their galaxies

Asteroids or "minor planets" in section have an area about 1000 km.

Comets are cosmic bodies moving around the sun in elongated orbits, throwing fiery "tail".

Meteorites are small bodies, often falling into the Earth's atmosphere from interplanetary space. The largest, which fell to the Earth, was 60 tons.

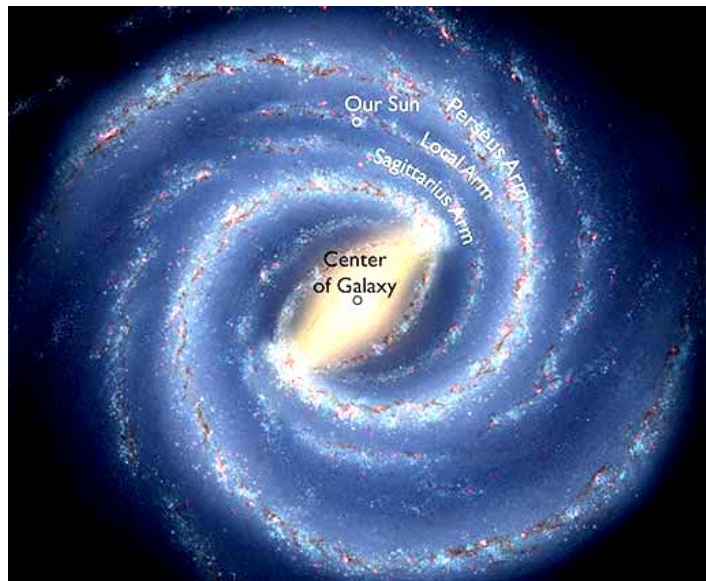
Sun is a star-"dwarf" with a diameter of 1 million 390 thousand 600 km, that is 109 times larger than the Earth, consisting of 90 % hydrogen and 10 % of helium.

Our planet Earth – is a tiny part of a single material world – the Universe (or space), filled with stars and planets, asteroids and comets, meteorites and cosmic dust. Starry sky that we see from the Earth, has been studied for thousand years. Science, exploring the Universe, is *astronomy*. The depth of research reaches 2 billion light years¹. Part of the universe, which is available for research, is called Metagalaxy.

The main object of the study is metagalaxy star systems or *galaxies* (greek. *halaktikos* – milk). In each galaxy, there are hundreds of millions to hundreds of billions stars. Planets of the solar system belong to one of these galaxies ("our Galaxy") (Fig. 1.2).

All the planets in our solar system revolve around the Sun in elliptical orbits that are almost the same plane that passes through the solar equator. Planets move in one direction, as well as most satellites.

Since ancient times, old Greek scientists believed that the Earth was the center of the world (Pythagoras – VI centuries. BC, Aristotle – VI centuries. BC). Later, Ptolemy (II century BC) mathematically substantiated this geocentric system. The hypothesis of Ptolemy was so successful that it existed for 1500 years. Only in the XVI century Polish astronomer Copernicus in his book "On the rotation of celestial spheres" proposed the heliocentric system of the world. The center of rotation of celestial bodies in it was the Sun. At the beginning of the XVII century, German astronomer Kepler discovered the laws of planetary movement, whereby each planet moves in an ellipse, one of the focuses of which is the Sun. In the middle of the XVII century, Newton discovered the law of gravity, theoretically grounded movement of celestial bodies in space.



<https://public.nrao.edu/radio-astronomy/our-milky-way-galaxy/>

Fig. 1.2 – Our galaxy – "Milky Way"

¹ Light year-distance that passes light ray for 1 year with the speed 300 000 km/s. 1 lg.year = $9,460 \cdot 10^{12}$ km.

There are different hypotheses about the origin of the Earth and the solar system. The idea of the divine creation of the Sun, planets and comets was dominant in the middle of the XVIII century. I. Newton also supported this idea. All later hypotheses of the solar system's formation of scientific value can be divided into three groups:

- the origin of the Sun and planets from homogeneous mass ("nebula") – Kant-Laplace Fesenkov's hypotheses;
- origin of planets from the Sun's substances – hypotheses of Buffon, Milton, Chamberlain, Jeans and Jeffreys, Krat and others;
- formation of the Sun and planets from different cosmic matter – the hypothesis of Schmidt's and others.

Hypotheses of the first group are based on the notion of the existence of cold or hot nebula, whose particles in motion, scorched, boiled up and formed (gravitational capture of the substance) huge hot clot – the Sun as a result of accretion. At the periphery of the nebula, planets and their satellites began to form, revolving around it.

The second group of hypotheses explains the formation of the solar system by explosion of a huge great grand-Sun.

Hypotheses of the third group are associated with the formation of the Solar system with the passage of the star-Sun – with huge mass and a short momentum through the gas and dust cloud.

At present, a generally considered hypothesis is formation of the Sun and planets from gas and dust clouds. Small bodies – asteroids, comets, meteors are the remnants of the once existing swarm of intermediate bodies participating in planet-building process. Asteroids and meteorites are considered primary material of the Earth-like planets, while comets and meteor showers – material of giant planets. Based on the age of the meteorites, terrestrial rocks and lunar soil (4.7 billion years), we can conclude that the asteroid bodies were formed simultaneously with other planets of the Solar system. Difference in their density indicates that the planets were built from heterogeneous material.

Thus, modern cosmogony, which relies on the achievements of astronomy, geology, geophysics, geochemistry believes that the solar system originated from a single cloud of gas and dust. Moreover, each planet and moon were formed by the accumulation of material particles around certain centers that were embryos of the future planets.

1.2. The shape and size of the Earth

Rotating around its axis, the Earth revolves around the Sun, and simultaneously around the center of the Galaxy. Rotation around the Sun is in an elliptical orbit with a period of 365,2564 stellar days. The farthest orbital

point is at a distance of 152 million km from the Sun, while the closest is at the distance of 147 million km. The average speed of the planet rotation on its orbit is 29,76 km/s. The rotation of the Earth on its axis takes 23 hours 56 min. 4,0905 sec.

The speed of rotation and position of the axis of rotation are not constant. These parameters may vary in geological time. This is evidenced by movement of geographic poles and drift of lithospheric plates. The reason for this phenomenon is a cosmic gravitational field, including the gravity of the Sun and Moon. The effect of these forces can be seen in the ocean's high and low tides.

From ancient times people have been interested in the form of the Earth. For the first time, the idea of its spherical shape appeared in Pythagoras (IV BC), later it was confirmed by Aristotle (IV century BC). Back in the XVII century measurements showed that the Earth was not a perfect sphere but flattened at the poles. Its radius on the poles is 6356,8 km, near the equator is 6378,2 km. The flatness was explained by a centrifugal force, and the form itself was called ellipsoid of revolution. Later, it was found that the Earth was slightly flattened on the equator. Thus, an idea of a three-axis ellipsoid or ellipsoid of Kravosky's revolution was born. The study of the Earth's forms, based on measurements of gravity force, has led to crossing out a tiered surface perpendicular to the direction of the vector of this force. It was called the geoid. This surface is not perfect but it is used in mapping, measuring it against the mark of the land surface and depths of the oceans bottom.

The Earth's most important parameters were calculated on the basis of geodetic measurements: the meridian length – 40 025 km, surface area – 510 million km², and its volume – 1 083 204 million km³.

Most of the Earth's surface – 70,8 % is covered with water, the rest – 29,2% are land. Water surface, or the World ocean, is divided by continents into four oceans, connected with each other: the Pacific, Atlantic, Indian and Arctic. There are six continents – Eurasian, North American, South American, African, Australian and Antarctic. The average height of the continents relative to the sea level is 850 meters, while the average depth of the ocean is 3800 m. The highest point on the globe is mount Qomolangma (Everest) in the Himalayas. Its height is 8,884 m, and the lowest is in the Pacific Ocean – Mariana Trench, 11,022 meters deep.

Continents are located unevenly. They occupy most of the area in Northern and Eastern hemispheres. Relief surface is asymmetric because the mountain ranges are mostly in their marginal parts. Globe encircles three mountain belts. Two of them are curved in the meridional direction and one – in latitude. West ocean zone includes Mount Chukotka, the Kuril Islands, Sakhalin, Japan and others up to the Australian Cordillera. East ocean zone is

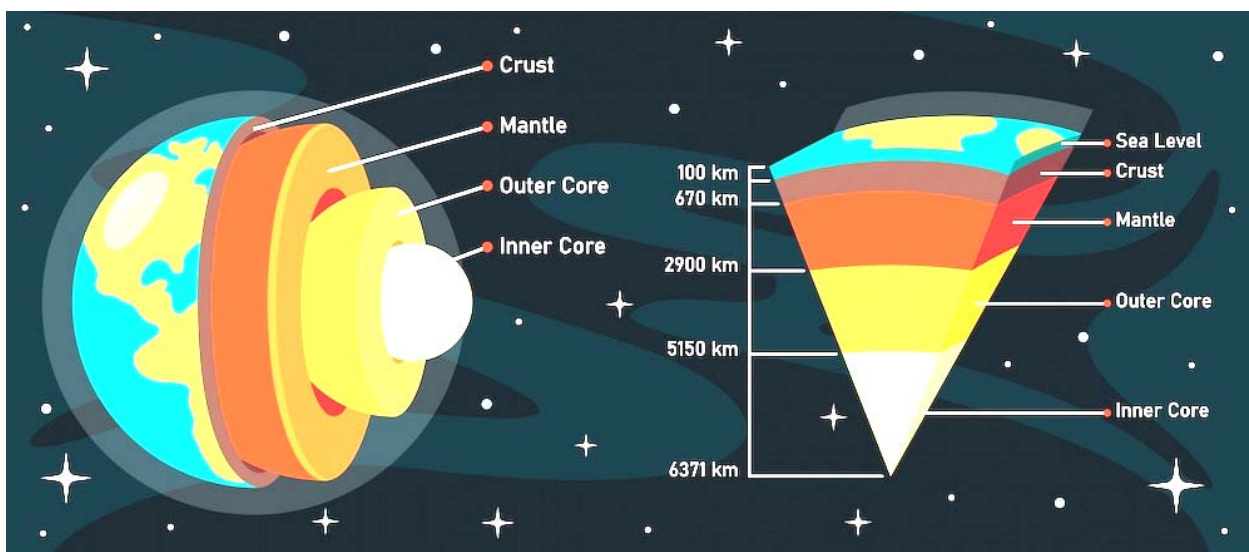
covered with the Cordillera mountains in the North America and the Andes in South America. Mediterranean latitudinal belt starts the Atlas mountains in North America and continues to the east, covering the mountain ridges of the Pyrenees, the Alps, the Apennines, the Balkans, the Carpathians, Crimea, Caucasus, Pamir, Himalayas down to the Malaya Archipelago.

1.3. The structure of the Earth

There are three inner shells in the solid body of the Earth: central –the core, intermediate – the mantle and outer – the crust (the lithosphere). The stone body of the planet is surrounded by air, water and biological shells. These are called external shells. The internal and external shells have a common name of the Earth's geospheres. The phase state of the geosphere is different: the atmosphere – gas, hydrosphere – liquid, lithosphere – solid (Fig. 1. 3).

External geospheres – the atmosphere, hydrosphere and biosphere form a single shell of life on the planet.

The atmosphere extends to a height of 130 km from the Earth. Above 100 km, it is almost absent. The main components of the atmosphere are nitrogen, oxygen, argon, carbon dioxide, water vapor. Others – hydrogen, helium, neon, radon, ozone, methane, etc. (making about about 0.01 %). The atmosphere consists of the troposphere (up to a height of 8 km over the poles and 17 km above the equator), the stratosphere (up to 55 km altitude), ionosphere where the very thin air is ionized by ultraviolet solar radiation. Physical processes in the atmosphere (mainly in the troposphere) determine the weather, and, in turn – the climate of our planet.



https://www.freepik.com/premium-vector/structure-planet-earth_9404055.htm#page=6&query=earth%20structure%20infographic&position=1&from_view=keyword

Fig. 1.3 – Structure of the Earth

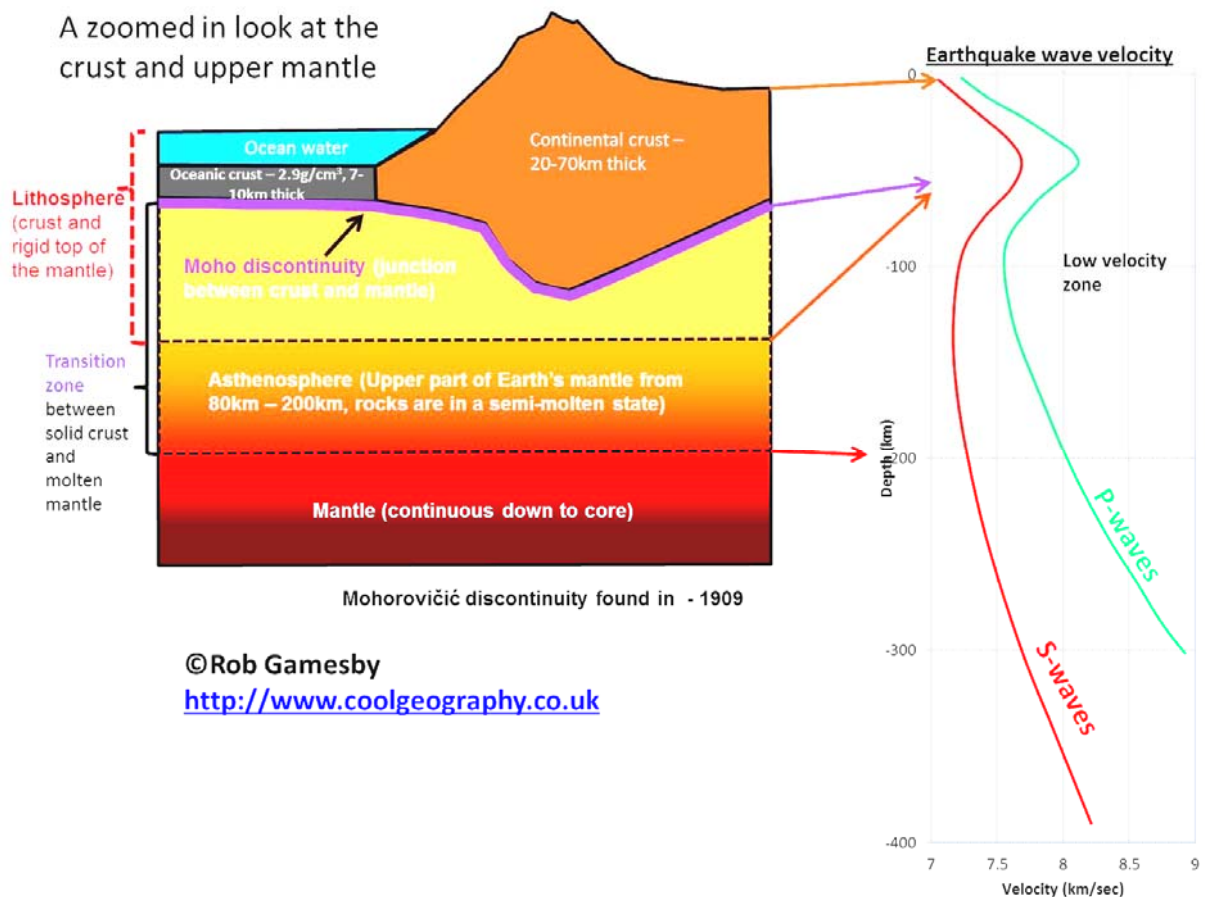


Fig. 1.4 – Structure of the Earth's crust

Hydrosphere is a water shell of the Earth, including water of seas and oceans, rivers, lakes and swamps, glaciers and ice (surface hydrosphere). Hydrosphere also includes groundwater (underground hydrosphere). According to the prominent Ukrainian geologist, hydrogeologist and geochemist V. I. Vernadsky the total amount of water in the hydrosphere is 18 billion km³.

Biosphere – forms a zone on the edge of the atmosphere and the lithosphere, which includes the hydrosphere. It is characterized by organic life. A great role in the study of biosphere belongs to V. I. Vernadsky, who separately identified a contemporary sphere of the Earth, formed under the influence of anthropogenic processes called the *noosphere*.

Internal geospheres – the crust or lithosphere, mantle (which is divided into upper and lower) with the core – form a cosmic body – the planet Earth.

The earth's crust. It has been established that the continental crust has a thickness of up to 75 km and consists of three layers of rocks: sedimentary, granite-metamorphic and basalt. Oceanic crust has a thickness of 5 km. It consists of two layers – a low-power sedimentary and basaltic (Fig. 1.4).

Mantle is the intermediate shell of the Earth separated from the surface of the Mohorovich surface (section M). Its lower border or the Gutenberg's boundary, is at a depth of 2900 km. The density of mantle material increases with depth from 3,64 to 9,4 g / m³. The upper mantle reaches the depths

of 60–250 km, and the bottom – 2900 km. The weight of the mantle is twice the size of the mass of the core and the crust together. The temperature of the mantle on the edge of the core is 3 000°C, pressure – 127...137 GPa.

The core – the most dense shell of the Earth. Its density is 10 to 12 g/cm³. Various changes in the velocity of seismic waves suggest the existence of external liquid and a solid inner core. Theoretical calculations suggest that the temperature in the center of the core is about 6 000°C and pressure of 343 GPa. The core origin is explained by gravitational differentiation of primary matter of the Earth. During this process, the heaviest chemical elements such as Fe, Ni, separated from the central part of the planet and lighter elements, group in the upper shells. There is another opinion, according to which the composition of the core and the mantle is the same.

1.4. Tectonic hypotheses and theories

Geotectonic ideas on the development of the Earth and the Earth's crust have played and still play an important role in the development of geology.

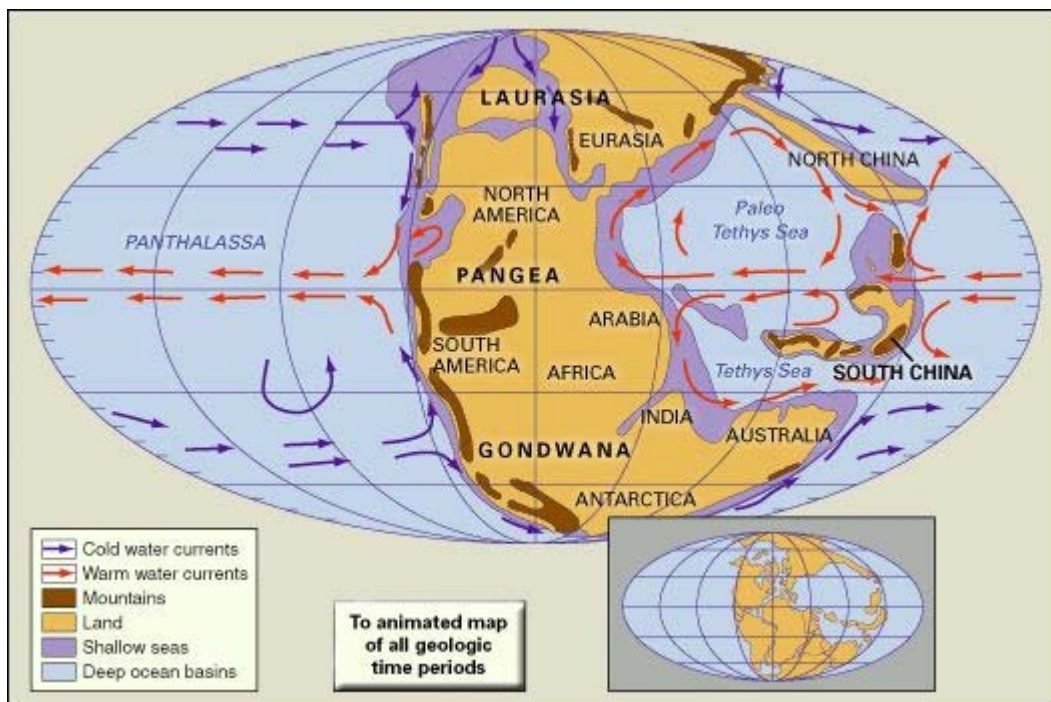
One of the first hypotheses in the late XIX century was a hypothesis of geosynclinal development, based on the work of American geologist John Dan on geosynclines, and professor of the University of Paris O. Og on platforms.

According to this hypothesis, which was the only theory for almost hundred years, vertical movements are the main factors in the development of solid outer shell of the Earth: the crust moves mainly up and down, barely moving horizontally. In this way, the Earth "breathes". Supporters of this theory are called "fixists", the doctrine itself is called "fixism". Now, based on new geological researches, it has been found that together with vertical movements, there are horizontal movements of individual blocks in the crust. This is a theory of lithospheric plates which originated from the hypothesis of "mobilism" and is dominant in modern geological science.

How did it happen? In 1913, a German geophysicist A. Wegener suggested that the key to the development of the crust were horizontal tectonic movements, which had spread the continents that were once a single entity (the supercontinent Pangaea) in different directions (Fig. 1.5). This new idea was called "hypothesis of continental drift." For a long time, it was not perceived and was under constant criticism. However, new geological evidence convincingly demonstrated that continental and oceanic crustal blocks were continually moving. Having acquired the actual confirmation, this hypothesis was called "the theory of tectonics of lithospheric plates." Thus, by the end of the 1960s the basic principles of this theory have been formulated: spherical lithospheric plates – stone shell of Earth – move horizontally on the surface of our planet. The lower boundary of the lithosphere is determined by the

temperature of basalts crystallization (or melting), their starting point is phase transition, which is the intermediate layer between the solid stone shell and plastic-liquid mantle.

There are different sizes and speeds of lithospheric plates. What speed do they move? Oceanic lithospheric plates move very fast. Their speed is 3–7 times faster than the speed of continental plates. Thus, "the fastest" Pacific plate moves to the north-west (near Hawaii) 10 cm per 1 year. At the same time, the Antarctic and Eurasian ones are the slowest among major lithospheric plates.



<https://www.britannica.com/science/Mesozoic-Era>

Fig. 1.5 – Earth reconstruction in the early Mesozoic

If a lithospheric plate is a single plate, then it should crumble at the edges, and each such break is a source of earthquakes, volcanic and magmatic activity and orogeny. That is why most of lithospheric plates are covered with mountain ridges.

In the course of their migration lithospheric plates collide with and diverge from each other. Sometimes these processes take place between platform (continental) plates, sometimes – between the platform and ocean, and sometimes – between ocean plates. Accordingly, there are two main tectonic processes – sea floor spreading and subduction.

Sea floor spreading is a sliding – process of rigid lithospheric plates in the rift place and mid-ocean ridges with constant reproduction of the crust by mantle material heated with convectional flows.

Subduction is slipping of lithospheric plates of oceanic crust and mantle rocks under the edges of other plates, accompanied by the deep focus earthquakes zones, the formation of active volcanic island arcs and mountain ranges.

Test questions to the theme

1. *What does geology study and what is its practical value in human life?*
2. *Name the individual chapters of geology*
3. *What are the planets of the Solar system?*
4. *What is a galaxy?*
5. *What hypotheses explain the origin of the Earth and the Solar system?*
6. *What is the division of continents and oceans on the Earth?*
7. *What parameters of the Earth are based on the geodetic measurements?*
8. *Describe the outer shell of the Earth.*
9. *What are the main layers of the atmosphere?*
10. *How many major rock layers are there in the crust?*
11. *Describe the main types of crust.*
12. *What shells does Mohorovich (Moho) surface and Gutenberg's border separate?*
13. *What is the theory of tectonic plates?*
14. *How fast do lithospheric plates move?*
15. *Which of the geological theories of the crust is dominant?*
16. *What role does spreading and subduction play in the formation of the crust?*

CHAPTER 2

MINERALS AND ROCKS

The substance of the earth's crust is composed of chemical elements that rarely occur in the native state, mostly forming chemical substances of two or more elements. They are the basis of *minerals* which form the rocks in the cause of various *geological processes*.

2.1. Minerals and their properties

Minerals are natural chemical compounds, predominantly with crystalline structure, with certain physical and chemical properties. In nature, minerals are found largely in solid and only occasionally – in liquid condition. Some researchers consider substances in gaseous state minerals. Minerals have names. A name is given to each mineral: according to the place of first discovery, chemical composition, physical and chemical properties, the name of the scientist or researcher who discovered it. Thus, mineral *olivine* was named for its olive-green color, *calcite* – for its chemical composition and *vernadskit* – in honor of the famous geochemist V. I. Vernadsky.

There are more than 2 000 known minerals, and together with variations – about 4 000. Minerals are formed both in depth and in surface conditions. According to these conditions, they are divided into *endogenous* and *exogenous*.

Endogenous mineral processes are associated mainly with magma – fiery liquid-silicate solution formed in the deep areas of the Earth's crust and upper mantle. Moving into the upper layers of the lithosphere, magma cools and crystallizes, turning into igneous and postmagmatic (pneumatolytic, hydrothermal, etc.) minerals.

Exogenous minerals are formed in the process of physical and chemical sedimentary transformation, accumulating in oceans, seas, rivers, lakes and swamps. That is why they are called *sedimentary*.

Both magmatic (postmagmatic), and sedimentary minerals change under high temperatures and pressures. Changes are related to crystal structure, physical properties, chemical composition. New minerals, formed as a result of such changes, are called *metamorphic* (metamorphogenesis).

Solid minerals have amorphous or crystalline (prevailing) structure. *Amorphous* minerals are often formed as a result of rapid and intensive cooling and intensive crystallization of magma. They consist of particles (atoms, ions or

molecules) randomly located in their structures. *Crystalline* minerals are characterized by natural location of particles (the laws of crystal lattices). Conditions of mineral formation and chemical composition of mineral- building solutions are reflected in their appearance (their morphology). Minerals exist as single crystals, crystal twins, inflows, inclusions, grains, needles and other forms.

Crystals are solid mineral bodies that look like polyhedron (prisms, pyramids, cubes, etc.). Their form is called *syngony* (Fig. 2.1).

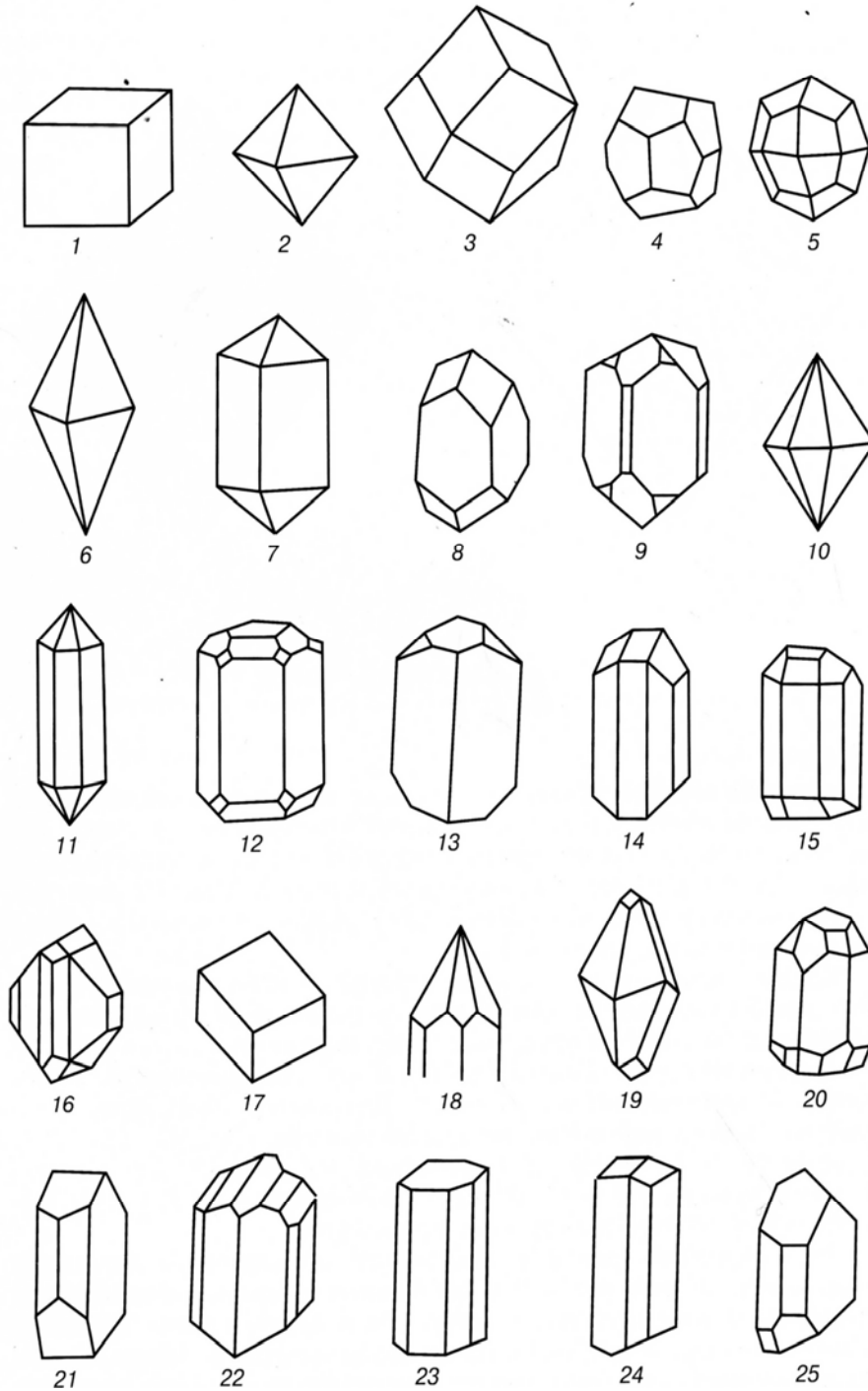


Fig. 2.1 – Forms of crystals in different syngony:
 1–5 – cubic; 6–9 – tetragonal; 10–12 – hexagonal; 13–16 – rhombic; 17–20 – trigonal;
 21–22 – monoclinic; 23–25 – triclinic

The planes, limiting crystals, are called *facets*, lines that section faces – *ribs*, rib section points are called the – *top* (Fig. 2.2).

The angles between the crystals faces in every mineral are the same, which is its diagnostic feature.

If several crystalline embryos form simultaneously on one basis, groups of crystals are formed– *druse*. With the rapid growth of crystals in different directions, *dendrites* are formed – crystals in the form of tree branches, ice patterns on the windows and others.

Cavities in the mineral (rock), which is partially or completely filled with other minerals are called *secretions*. Small bullet-like forms of particles up to 10 mm are called *oolitics* (iron ores of the Kerch peninsula).

When a substance settles from solution, it forms a flow form. Icicles form nodules that grow from the top down are called *stalactites*. And those that grow from the bottom up – *stalagmites*. Halite, malachite, gypsum and others are flow forms.

One common form of the mineral is *inclusion* – individual interspersions (in size from millimeters to several centimeters) minerals in rocks. There are also powder like minerals, earthy, dense and crystalline structures. Mineral aggregates are different, depending on the shape of the grains they are: grainy, needle, scale like and others.

An important diagnostic feature of many of them is color. Green color signifies malachites, the red are cinnabar, etc.

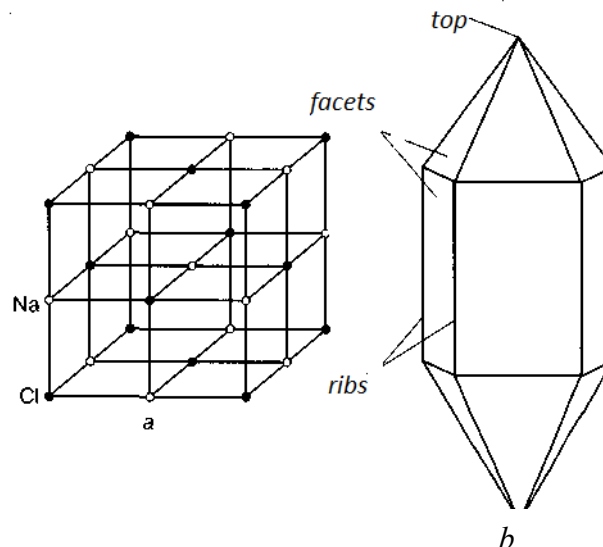


Fig. 2.2 – Crystal lattice:
a – halite, b – quartz crystal

The ability of minerals to reflect light is called *brilliance*. There are diamond, glass, metal, silky, matte, oily and other kinds of shine. Streaks *color*

or color of *mineral powder* that remains on the surface of the rough porcelain plate and is unchanged is often used in determining a mineral.

Hardness is mineral ability to resist mechanical stress (scratching, cutting). It is determined on the Moho scale (Tab. 2.1).

Table 2.1

Mohs hardness scale

Mineral	Hardness*on the Mohs scale	Mineral	Hardness*on the Mohs scale
Talc	1	Orthoclase	6
Gypsum	2	Quartz	7
Calcite	3	Topaz	8
Fluorite	4	Corundum	9
Apatite	5	Diamond	10

*Each of the next minerals scratches previous

The ability of minerals to split in the directions of potential facets, forming flat smooth planes, is called *cleavage*. There are several types of cleavage. The most common are perfect, too perfect and imperfect cleavage. Ability of minerals to turn magnetic compass arrow characterizes its *magnetic properties*.

In determining minerals, we use their most characteristic qualities called **diagnostic**. It should be noted that minerals are diagnosed by a set of features.

2.2. Classification of minerals

There are different classifications of minerals. Depending on what features are preferred, classifications of minerals are divided into chemical, geochemical, geological, crystal, crystallographic and external features. Crystal-chemical classifications are the most modern ones. They laid the basis for the relationship between the chemical composition and minerals structure, as well as their properties and morphological features.

By chemical classification we distinguish:

- native elements;
- sulfur compounds or sulfides;
- oxides
- halide compounds;
- silicates;
- borates;
- carbonates;
- nitrates;

- phosphates, arsenates, vanadates;
- sulfates;
- tungstates, molybdenum.

Below are examples of some of the main representatives of widely spread classes of minerals.

Native elements. About 30 chemical elements (gold, silver, platinum, graphite, diamond, copper, iron, mercury, arsenic, antimony, palladium, osmium, iridium and others) are in the native state in nature. The most common of these are sulfur, diamond, graphite, gold, platinum.

Gold Au. High-temperature hydrothermal mineral that in nature occurs as small grains, dendrites and nuggets weighing up to several tens of kilograms. Color – golden yellow, glitter – metal. Hardness is 2,5–3. Density – 19,3...19,3. Well forged. Gold is currency and jewelry metal.

Diamond C. Mined from kimberlite pipes, formed both by volcanic eruptions, and because of the fall of meteorites on the Earth's surface. It occurs in nature in the form of small crystals (octahedra) of isometric form. The weight of large crystals is from hundreds to several thousand carats (ct – 0,2 grams). The largest diamonds have their own names: "Kollinan" (3025 car.), "Excelsior" (971,5 car.), "Mughal" (793 car.), etc. Diamonds are usually colorless and transparent. Sometimes due to impurities they are blue, yellow, green, brown, black and other colors. Diamond has a strong glitter. Its hardness is 10, density – 3,5. It is used in the manufacture of jewelry (transparent crystals) as well as abrasive material for metal and drilling (opaque varieties). Artificially cut diamonds (diamonds) are precious stones.

Graphite C. Differs from the structure of the diamond by crystal lattice. It has both magmatic and metamorphic origin. It occurs as disseminations and scaly aggregates. Its color is black to steel gray. Glitter is metal. Hardness is 1. Density – 2,2. Widely used in electrical and as additive in lubricants.

Sulfides are compounds of the chemical elements sulfur. Most of them are formed from hydrothermal solutions in the temperature range 400–600°C. They are brightly colored (yellow, red, blue, green, black, etc.), easily oxidized in the presence of free oxygen, forming oxides, carbonates or sulfates. They are widely used in ferrous metallurgy as the main raw material.

Pyrite Fe₂S (pyrite). Formed by hydrothermal and exogenous way, it occurs as crystals of cubic form, granular masses. Straw-yellow color. Shine is metal. Hardness is 6–6,5. Density – 5. The oxidation goes into limonite (HFeO₂nH₂O). It is used in the manufacture of sulfuric acid.

Cinnabar (HgS). Hydrothermal low – or average temperature mineral (60–250°C). It forms rhomb-like crystals, granules, powder aggregates. Color is bright and brown-red. Glitter is diamond, mat. Hardness is 2–2,5. Density – 8. Red mercury is used in electrical engineering, medicine, etc.

Chalcopyrite $CuFeS_2$ (*copper pyrite*). As pyrite, it is formed in different conditions. It has a crystalline form and grainy mass. Color is brass-yellow. Shine is metal. Hardness is 3–4. Density – 4,2. Color risk – black with a greenish tinge. It is copper on ore.

Galena PbS (*lead shine*). Hydrothermal mineral that exists in the form of crystals and grains mostly in cubic form. Color lead-gray. Shine is metal. Hardness – 2,5. Density – 7,5. The ore is for lead.

Oxides. Oxides are widely distributed in the Earth's crust, taking 17 % of its weight. They are formed in igneous, hydrothermal and other mineral building processes, as well as in hypergene oxidation of sulfide minerals. Some oxides form in water basins. They are mainly used in the steel industry.

Magnetite Fe_3O_4 (*magnetic iron ore*) is formed in the process of magmatism and metamorphism. It occurs in the form of crystals and crystal-grained masses. Color of the iron is black. Glitter is half metal. Hardness is 5,5–6,5. Risks density is black. Magnetite is the richest iron ore.

Hematite Fe_2O_3 (*hematite*) – hydrothermal and metamorphological mineral. Color of iron is black, it has cherry-red line. It has half metal gloss, hardness 5,5–6,5. Its density is used in production of iron and steel.

Limonite $Fe_2O_3 \cdot nH_2O$ (*ironstone*). It is mostly of sedimentary origin. It occurs in the form of powder masses, nodules (oolites), secretions, flowing forms. Color is from yellow to dark brown. Glitter is mat. Hardness is 1–4. Density 2,7–4,3. It is ore for iron.

Aluminium oxide Al_2O_3 . Hardness is 9. It is of dust-gray and red color. Shine is glassy. Density is 4. The density occurs as crystals, inclusions, grain masses. Origin is igneous, metamorphic. Widely used as an abrasive in the watch industry. Transparent varieties are ruby (red) and sapphire (blue) as precious stones jewelry.

Quartz SiO_2 . The genesis is magmatic, hydrothermal, metamorphological. It occurs in the form of single crystals, twins, druses, crystal granular masses. Latent crystal quartz is chalcedony, transparent uncrystallized is rhinestone. Mostly is white. Partly colored in pink, green, black, yellow. Shine is glass. Hardness – 7. Density – 2,6. This rock gives a mineral that forms sand, sandstone, quartzite, granite and other rocks. It is used in many industries. Transparent and colored red is used in jewelry (Fig. 2.3).

Opal $SiO_2 \cdot nH_2O$. Amorphous mineral, found in the form of dense glue-like masses. Formed with hot and cold water solutions. Color is white, transparent blue, red. Shine is glass. Hardness – 5,5. Density is 2,0. Transparent and translucent varieties are used as raw materials for jewelry.

Halide composition. These are salts of fluoride, iodide and bromine acids. Formed in the salt water pool with hydrothermal solutions. The most common are chlorides.



<https://en.wikipedia.org/wiki/Quartz>
<https://www.fossilera.com/minerals/5-8-polished-malachite-chrysocolla-slab-thick-cut-congo--2>

Fig. 2.3 – Quartz crystals



<https://www.fossilera.com/minerals/5-8-polished-malachite-chrysocolla-slab-thick-cut-congo--2>

Fig. 2.4 – Malachite



<http://www.awminerals.com/minerals/preview/minid:PM39>

Fig. 2.5 – Topaz crystal from the Volyn deposit (Ukraine)



<https://www.mindat.org/min-1375.html>

Fig. 2.6 – Emerald (Colombia)

Halite NaCl (rock salt). It occurs as granular or crystalline mass. It can be colored, white, blue, red, brown. Hardness – 2, salty taste. Density – 2,2. Used in food and chemical industries.

Silvinit KCl (potassium salt). It often occurs with halite as crystal-grained masses. Colorless. Can be blue, pink, red. Shine is glass. Hardness – 2. Density – 2,2. Taste is bitter-salty. Used in the chemical industry and agriculture.

Fluorite CaF_2 (spar). Color is purple, sometimes – green, blue, colorless. Shine is glass. Hardness – 4. Density – 3. It occurs as cubic crystals, druses,

crystal-grained masses. Formed from hydrothermal solutions, is used in metallurgy, optics, chemical industry.

Carbonates. Salts of carbonic acid, is common among most sedimentary rocks.

Calcite $Ca[CO_3]$. Hydrothermal – sedimentary mineral that appears in the form of single crystals, druses, flowing forms of crystalgrained masses. Colored and transparent varieties characterized by high double refraction are called "Iceland spar". Color white, pink, from gray to black. Shine is glass. Hardness – 3. Density – 2,7. Easily determined by rapid reaction with hydrochloric acid. An important rock-forming mineral (limestone, chalk, marble). It is used in construction (cement, etc.), as a flux in metallurgy.

Dolomite $CaMg[CO_3]$. Is of hydrothermal and sedimentary origin. Appear in the form of crystals, crystal-earthy and granular masses. Color is white, sometimes yellow or brown. Shine is glass. Hardness – 4. Density – 2,9. Unlike calcite reacts with HCl only in powder. Rock- forming mineral, that forms rocks with the same name. Is used in construction, as a flux in steel and cement.

Malachite $Cu_2[CO_3](OH)_2$. Formed by oxidation of sulphide copper. It occurs in the form of flowing shapes and earthy masses. Color is green. Glitter glass, mat. Easily decomposed in HCl. Is used as copper ore and carpentry material (fig. 2.4).

Sulfates . These are salts of sulfuric acid. They can be water and anhydrous. Formed mainly in sedimentary processes.

Gypsum $Ca[SO_4]2H_2O$. Mostly of sedimentary origin. Forms as monocrystals, druze, needle, plate and fine-grained aggregates. In the form of crystals are transparent and colorless. Color is white, sometimes pink, yellow and black. Shine is glass. Hardness – 2. Density – 2,3. In dehydration transforms into the dense bluish mineral *anhydrite* $Ca[SO_4]$. Gypsum is a rock - forming mineral that forms the rock of the same name. It is used in architecture, sculpture, medicine, chemical industry.

Phosphates . Salts of phosphoric acid.

The most important representative is *apatite* $Ca_5[PO_4]_3(F_2Cl_2OH)$ of a magmatic origin. Calcium phosphate is called phosphorus of sedimentary origin. They are formed in a biochemical way and are found as nodules of light gray, brown or black color. Apatite occurs as crystals and solid granular mass. It has pallid green or bluish color. Shine is glass. Hardness – 5. Density – 3. Apatite and phosphorus are used to produce phosphate fertilizer and phosphorus.

Silicates . Of all the minerals silicate crust share reaches 75%. They have a different chemical composition, and preferably endogenous (igneous, metamorphic) origin. Many of them are *rock-forming*.

Olivine $(Mg,Fe)_2[SiO_4]$. Magmatic mineral. Occurs in the form of grains. Shine is glass. It has olive-green color. Hardness – 6,5–7. Density – 3,3–3,6. Under the influence of hydrothermal solutions transforms into mineral serpentine.

Topaz $Al_2[SO_4](F,OH)_2$. Precious stone. It occurs as crystals and inclusions in pegmatite, hydrothermal quartz veins.

In Ukraine, they are widely represented in the Volyn deposit. Transparent. Color – blue, yellow, pink and sometimes colorless. Shine is glass. Cleavage is perfect. Hardness – 8. Density – 3,5 (Fig. 2,5).

Garnets . Have cationic complex composition (Ca, Mg, Mn, Fe, Al, Cr), which affects their properties. The group brings together seven garnet minerals. Those of most widespread are brownish-red *almandine* , red – *pyrope* , pale green – *grossular* . Origin – igneous, metamorphic, hydrothermal. Shine is glass. Hardness – 6,5–7,5. Density – 3,5–4,2. Used as abrasive and in jewelry.

Pyroxene . Known as rock-forming minerals of magmatic, sometimes metamorphic origin. The most characteristic representatives are– *augite* minerals (black) and *diorite* (gray). Shine is glass. Hardness – 5,5–6,0. Density – 3,1–3,6. They are part of the igneous rocks.

Amphibole . Lime-magnesia and water containing magmatic silicates of metamorphic origin. A typical representative is *hornblende* . The color is black. Shine is glass. The hardness of 5,5–6. Density 3,2–3,3. Hornblende is a rock-forming mineral.

Kaolinite $Al_4[Si_4O_{10}](OH)_8$. Origin is sedimentary through chemical decomposition of feldspars. Forms from earthy masses. The color is white, yellow, brown, green, black. Glitter is mat. Hardness – 1. Density 2,6. In wet condition is plastic. Rock-forming minerals. It is used in ceramics, in porcelain production, refractory products and, therefore, in steel industry.

Mica . Mica is a mineral that can split into thin flexible leaves. Origin is igneous, metamorphic, hydrothermal. Shine is glass. Hardness 2–3. Density 2,8–3,1. Most characteristic are *biotite* (black), *muscovite* (transparent), *phlogopite* (brown). Rock-forming mineral. It is used in radio technology and other industries.

Talc $Mg_3[Si_4O_{10}](OH)_2$. Hardness – 1. Oily. Color is green. Shine is metal. Density – 2,8. Origin – hydrothermal and metamorphic. Used in the manufacture of refractories, paper, perfumes.

Feldspars . The most common group of rock-forming minerals of magmatic, sometimes metamorphic origin. Their chemical composition is divided into potassium, natrocalcium and plagioclase. Potash feldspar is *orthoclase* $K[AlSi_3O_8]$. Can be gray, pink, red. Shine is glass. Hardness – 6. Density – 2,5. It is used in manufacturing of pottery and glass.

Plagioclase combines six minerals: *albite*, *oligoclase*, *andesite*, *labrador*, *bitovnit*, *anorthite*. Except for the blue-green Labrador, they all are white to dark gray. Shine is glass. Hardness 6–6,5. Density 2,7. Plagioclase are the main rock-building minerals. Labrador is used in carpentry and as facing material.

Ukrainian depth is rich in various minerals (Fig. 2.7–2.9). Every region has its characteristic mineralogical associations.



Fig. 2.7 – Minerals:

1 – labrador; 2 – plagioclase; 3 – sphalerite; 4 – native gold; 5 – pyrite;
6 – amethyst; 7 – amber; 8 – beryl; 9 – cuprite

The rocks consist of one (marble – with calcite) or more minerals (granite – with feldspar, quartz, mica and hornblende). In the first case they are referred to as *monomineral* (one mineral), in the second – *polymineral* (many minerals).

The science that deals with the study of rocks is called *petrography*. Sedimentary rocks are studied by *lithology*. There are about 1.000 different types of rocks.

The rocks vary in color, structure, texture, mineral composition and form of occurrence.

The structure of rock we understand as the features of its composition due to the size, shape and relationship of mineral grains. *The structure* of rocks characterizes the relative position of their parts. *The form of rock occurrence* is a form of volume which they occupy in the geological space.

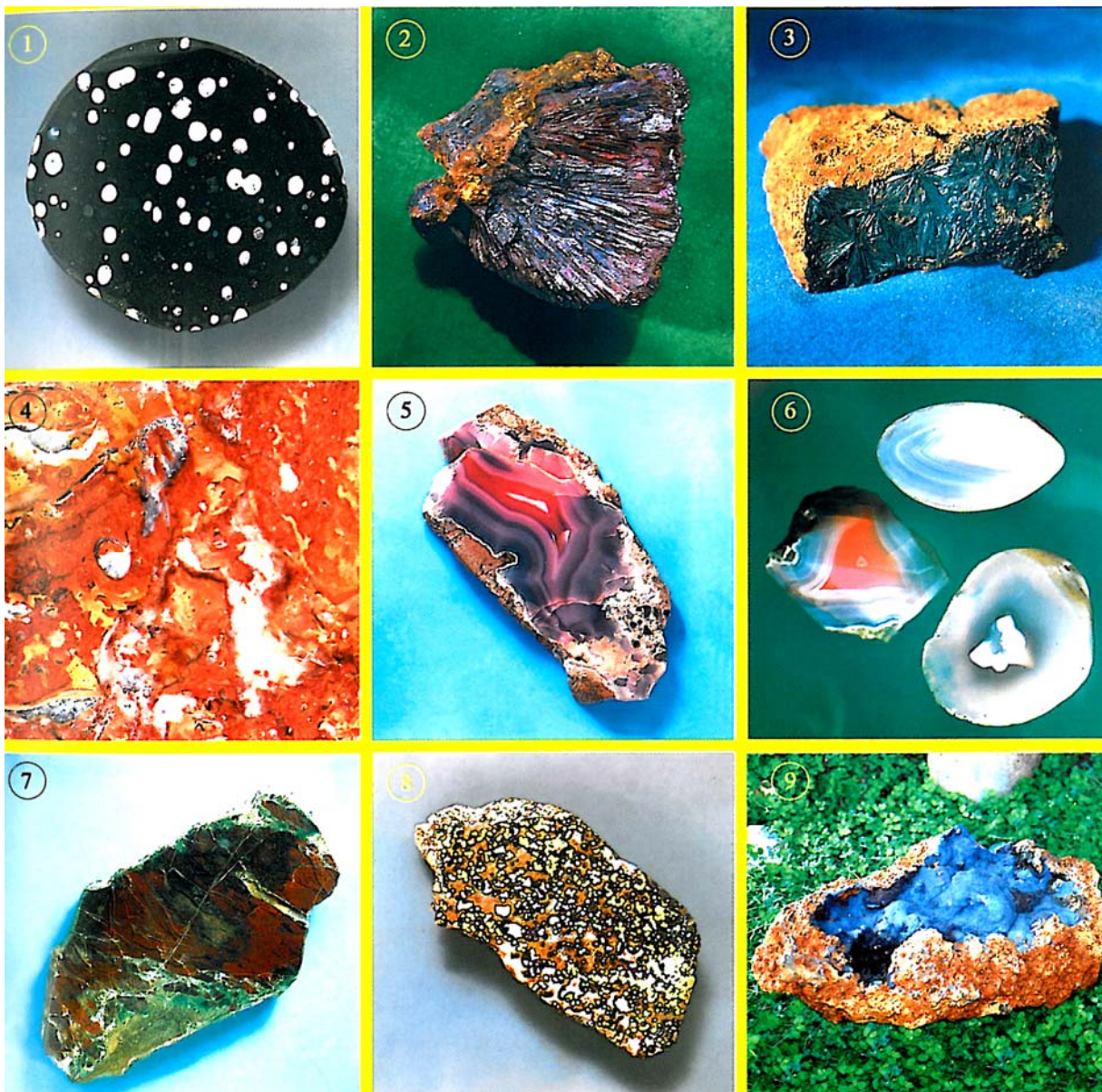


Fig. 2.8 – Minerals:

1 – andesite porphyries; 2 – oxikerchinit; 3 – ironstone; 4 – yellow-brown marble; 5 – carnelian; 6 – agate; 7 – landscape jasper; 8 – brocade jasper; 9 – vivianite on iron ore

Minerals, forming rocks are called *rock-forming*. About 100 rocks are rockforming minerals of 2000 known minerals. Among the most wide spread are feldspar, quartz, pyroxene.

The main properties and external features of a rock are determined primarily by the conditions of its formation. Therefore, in petrology rocks are classified by their origin. According to this classification all rocks are divided into igneous, sedimentary and metamorphic. Igneous rocks occupy the largest share of the crust (about 95 % of its mass). The surface of the Earth consists of 75 % of sedimentary and 25 % of igneous and metamorphic rocks.



Fig. 2.9 – Minerals:

- 1 – crystals, aggregates on druse like plaster; 2 – anhydrite with gypsum; 3 – selenite in marl veins;
 4 – halite interbedded with clay; 5 – cave pearls and sinter crust of karst cavities;
 6 – coarse gypsum and selenite in marl; 7 – small peel plaster on limestone;
 8 – sinter forms calcite in limestone; 9 – marble onyx on limestone

2.3. Magmatism and magmatic rocks

The rocks formed from molten magma of different composition and genesis are called igneous rocks.

Magmatism is a set of endogenous geological processes generated by the internal energy of the Earth and connected with the formation and movement of magmas in the crust.

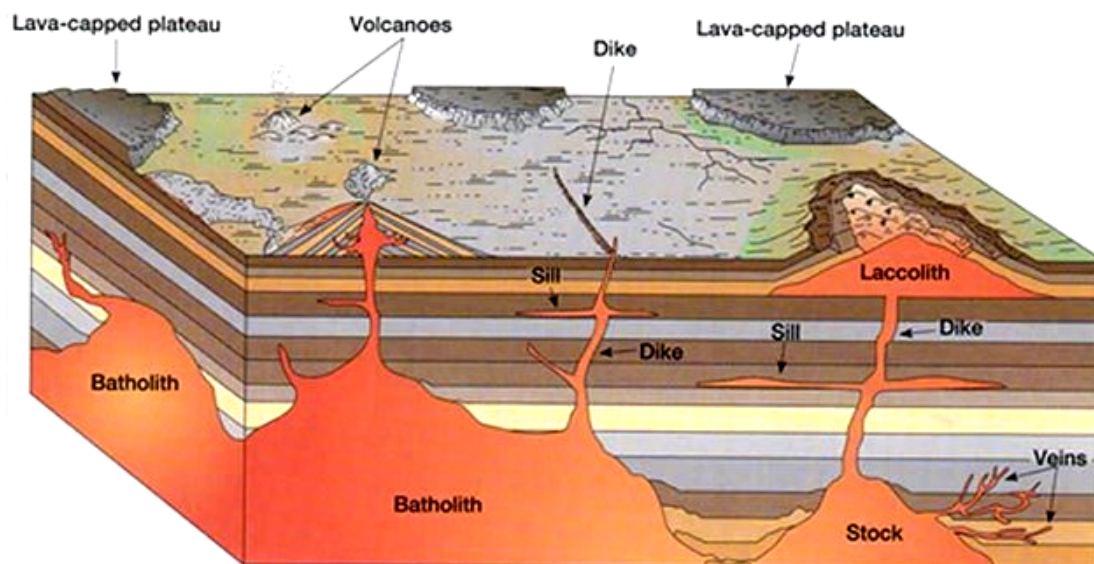
Magma is a natural flame of liquid silicate melt saturated with gases generated in the upper mantle (asthenosphere) or in the Earth's crust. The composition of magma depends on the melted parent rocks.

Magmatism can be *intrusive* and *effusive*.

In *intrusive magmatism* magma reaches the Earth's surface, freezes in cracks and voids, forming a deep magmatic body or *intrusion* (Fig. 2.10). In *effusive* magmatism magma reaches the Earth's surface, pours out and hardens in surface conditions.

Magmatism develops in the areas of the lithosphere, where thermodynamic equilibrium is disturbed. About 90 % of the entire crustal rocks are of magmatic origin.

Intrusive magmatism appears in the upper mantle and crust, including birth of magma, its migration and formation of intrusive (deep) igneous bodies. By place of origin magma is divided into *mantle* and *crust*.



<https://libguides.mcckc.edu/c.php?g=465903&p=3265179>

Fig. 2.10 – Intrusive and effusive covers

Emergence of mantle magma is associated with melting of peridotitic rocks in asthenosphere and smelting the melt of them that by composition corresponds to basalt (basalt magma). Crust magma occurs in the crust at

depths of 10–30 km due to melting of igneous, sedimentary and metamorphic rocks by heat, stored during radioactive decay. The composition of magma crust mainly corresponds to granite (granite magma). Huge underground reservoirs filled with liquid flame melt – magma, are called *magmatic foci*. They are primary, secondary and intermediate. The primary foci are the places of magma birth while the secondary are the places where magma moved. As a result of geophysical studies, the primary foci are formed at depths 200–60 km, the secondary at – 7–5 km. In the process of its movement magma splits into two phases: melt and gases. The share of the latter is 1,5–12 % of the total volume of magma.

The melt – a multicomponent system consisting of oxides: SiO_2 , Al_2O_3 , FeO , Fe_2O_3 , MgO , CaO , Na_2O , K_2O . Water vapor and volatile compounds: CO_2 , SO_3 , SO_2 , H_2S , Cl , F , B dominate in gas. Oxides of silicon dominate in granite magma, so they are called *acidic*. Basalt magmas rich in bases Ca, Mg and Fe, are called – *major* magmas.

Magma with temperature of 1500°C or more cools, contacting with containing rocks during the process of migration. Breakdown of liquid magma into fractions according to chemical composition is *magmatic differentiation*. It results in heavy, enriched with oxides of Ca, Mg, Fe melt and light, full of oxides of Si and Al, one. After that the second stage of splitting the primary melt begins – *crystallization differentiation* – sequential crystallization of refractory, then fusible elements and compounds.

Silicates of magnesium and iron are the first to crystallize, compounds of potassium and sodium are the last. The process of assimilation (melting of rocks) and primary magma differentiation is explained by the diversity of igneous rocks. Due to this *ultra-basic* igneous rocks are initially formed from hard refractory melt and only later – the *basic, medium, acidic* and *alkaline* rocks.

Depending on the depth, the intrusion can be *abyssal* (deep) or *hypabyssal* (moderate depths). The first – the large size (batholiths, stocks), the second – a smaller but more diverse in form (laccoliths, dikes, etc.).

Postmagmatic processes are processes developing around intrusion during and after cooling and crystallization of magma. Hydrothermal hot gases and solutions from which minerals crystallize, play a major role in postmagmatic processes.

Among them are:

1. *Pneumatolytic process* – the formation of minerals from gases at temperature 800–4500°C (quartz, mica, wolframite, molybdenite, etc.).

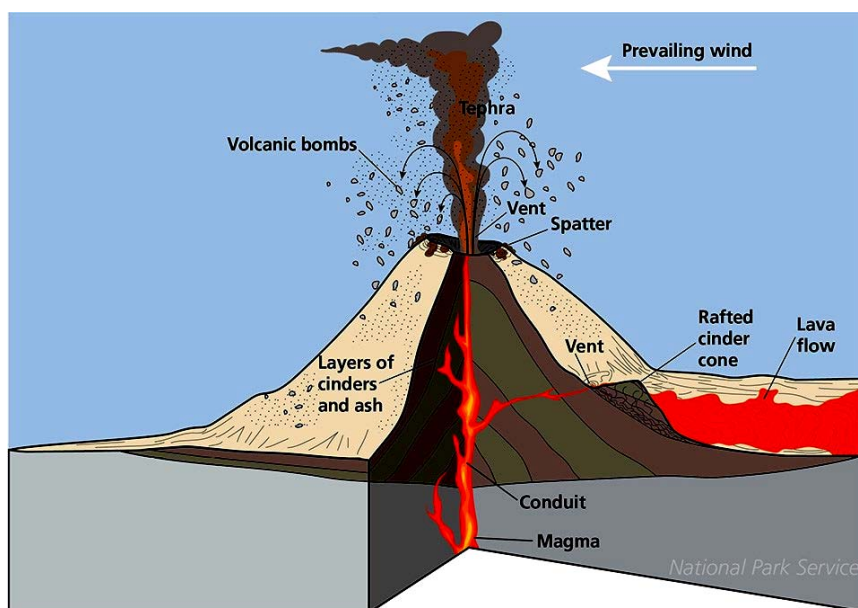
2. *Hydrothermal process* – formation of minerals from high temperature aqueous solutions at temperatures from 450°C to 90°C (quartz, sulphides of mercury, lead, zinc, native gold, silver, copper, etc.).

3. *Metasomatism* – the process of changing chemically active rocks which contain carbonates (limestone, dolomite, chalk, etc.) by gases and thermal solutions, replacing carbonate compounds with calcium silicate, magnesium, iron, aluminum with simultaneous deposition of ore minerals in these rocks.

As a result of these processes, qualitatively new species – *skarns* are formed.

Postmagmatic phenomena play an important role in the formation of many ore deposits and deposits of precious stones and simple stones. In Ukraine these are mercury deposits (Donbass), gold (Transcarpathia, Donbass, Ukrainian Shield), poly (Donbass), precious stones (Ukrainian Shield) and so on. In the literature there is evidence about postmagmatic synthesis of carbohydrate compounds.

Effusive magmatism is associated with the spout of magma and water-gas fluid on the Earth's surface. This phenomenon is called *volcanism*. Volcanism occurs on areas of land or sea bottom, formed by the magma chamber. An important condition of volcanism is crustal movements leading to the appearance of faults – deep cracks that connect the magma chamber to the surface. The main cause of volcanic eruptions is gas pressure in the magma. *Volcanoes of central type* are formed in the most relaxed bounded areas of faults (Fig. 2.11). *Volcanoes of fracture type* are formed in places where the fault zone is weakened in length. The term "volcano" means an outlet hole through which solid, liquid and gas erupt from the depth of the Earth to the surface. These notions often include uprise formed by the products of eruption called a *cone*.



<https://www.nps.gov/subjects/volcanoes/anatomy-of-a-volcano.htm>

Fig. 2.11 – Cut of central type volcano

In the process of volcanism together with cones *dome*, *caldera*, *lava flows*, *pumice curtains*, *geysers*, *hot spring*, etc. occur on the Earth's surface. Active volcano throws a large amount of volcanic gases into the atmosphere that are basis for the formation of Earth's atmosphere and hydrosphere.

We distinguish platform, geosynclinal and orogenic volcanism. The most intense volcanism in our era is manifested in middle ocean ranges in island arcs, reef valleys and young mountains on the continents. Volcanism is a powerful planetary process that occurs on the Moon, Mars, Mercury, Venus and other planets and satellites.

Volcanoes on the Earth are divided into active, dormant and extinct (buried). There are more than 1.340 volcanoes on our planet, among them about 950 are active now. Volcanoes are divided into surface (80 %), located on the continents, island arcs, ocean coasts, and underwater (20 %), located on the ocean ridges.

In a year they take not less than 5–6 km³ of volcanic material from the depth of the earth. By nature, volcanic eruptions are divided into lava, mixed and gas explosive. Products of eruptions are: gases, solid products and solutions of different composition and temperature.

Lava is magma that poured onto the surface of the Earth. Unlike magma it contains few volatile substances because of their degassing. Lava as magma by the chemical composition can be acidic, secondary and basic. During these volcanic eruptions the superstructures such as *caldera* – volcanic cones that sank into the depths; *somme* – young cones in old craters of volcanoes and others, are formed. *Craters* – huge recesses (gaps) in the center of the volcanic cones – are in most volcanoes.

The diameter of the largest of them is 30 km and its depth is thousands of meters. The crater is directly connected to the underwater channel or *vent* through which products of eruption come from the depths. In periods of volcanic eruption the crater is filled with lava. Volcanoes have mantle, crust and mixed supply. Among the most famous volcanoes are Etna and Vesuvius in the Alps, Mount Elbrus in the Caucasus, Kileuea in Hawaii, Kilimanjaro in Africa, Krakatoa in Indonesia, near Saint-peak in South America and others. In Ukraine, volcanoes are known in the Carpathians (volcanoes Vygorlat – the Hutyn ridge in the Transcarpathian region) and in Crimea. The largest Ukrainian volcano – Mt. Buzhora (1081 m) is in the Carpathians. They all belong to the extinct volcanoes. The Earth's largest volcano is Yellowstone (Wyoming, USA), which also belongs to the extinct volcano. But over the last 100 years a raising center of the volcano caldera to 8 m was recorded, indicating the increase in internal pressure and possible eruption. About 50 volcanic eruptions are annually observed on Earth. As it has already been noted, the eruption products are gases, volcanic ash, volcano-clastic

(pyroclastic) rocks and lava. *Gases*, which are part of magma, nearing the Earth's surface, separate from the melt and outstripping it, escape into the atmosphere. Part of the drop-liquid magma invaded by them turns into ashes, sand and sometimes into volcanic bombs in the air. The height of emission depends on the power of the explosion. Thus, during the catastrophic eruption of Krakatoa, clouds of gas, ash and dust rose to a height of 80 km. A sound of explosion was heard at a distance of 4800 km.

Gas clouds do not always rise up. Sometimes they spread on the Earth and cause great destruction because of their temperature – up to 600–800°C and volume – tens and hundreds of million m³.

Volcanic ash – small fragments (1 mm) of minerals feldspar, hornblende, pyroxene, leucite, volcanic glass. Color of ashes – from light pink to gray and brown and black. The ash can fall on a distance of thousands of kilometers from the volcano.

Volcanic sand is presented by fragments of 1–2 mm, so it is spread by eruption on shorter distances than ash.

Lapili – pieces of lava 3–30 mm. They are formed mainly from volcanic glass.

Volcanic bombs – lava pieces of pear or spindle form (which they acquire in-flight). Their sizes are up to 3 meters, sometimes up to 15 m and more. During the eruption, large bombs fall within a radius of 5–7 km and smaller – up to hundreds of kilometers.

Solid products of eruptions (pyroclastic material) form the bulk of the eruptions.

Post-volcanous phenomena occur in the process of reducing the activity of the magma chamber and are manifested in periodic emissions of gases, hot steam and other volcanic activity on a damping stage. These phenomena are different.

Fumarole – small holes and cracks through which a jet of hot steam and gases (H₂O, HCl, HF, SO₂, CO₂, H₂S, H₂, etc.) rises, coming out of magma (primary fumaroles), hot lava flows and pyroclastic deposits (secondary fumaroles). Fumaroles originate in the crater, on the slopes and at the foot of volcanoes. They are divided according to the composition of volcanic gases into jets of sulfur fumarole – *solfatary* and carbon – *mofety*. Solfatary has temperature 180–100°C, and mofet – lower than 100°C.

Geysers are steam emissions in the volcano area occurring at regular intervals. This phenomenon is explained by the fact that water that fills the cracks in the rocks, is heated to a temperature higher than 100°C at a depth. Pressure of water column bedding prevents its boiling. With further heating, superheated water reaches the areas of lower pressure, boils and immediately is thrown up in the form of steam. Then the cooled remaining water again fills the upper channels of cracks. After some time everything repeats. Eruption of

water and steam occurs from the bowl-shaped depressions called *gryphons*. Geysers are known in Kamchatka (Russia), Iceland, the US, New Zealand. In Ukraine, the only geyser is near the village Vuchkove (Transcarpathia).

Besides these, there are also *mud volcanoes* (salse) – geological formations. Continuous or periodic eruption of mud masses, combustible gases and so on are connected with them. By the form, they are small conus like volcanoes. The height of the largest mud volcanoes are 300–500 m in diameter with bases of 5–6 km. Mud volcanoes are associated with volcanic activity known in Kamchatka, Sicily, the island of Java. They are also found in oil areas where they occur as a result of breakouts of hot gases and petroleum waters on the surface. Eruption of mud volcanoes is accompanied by powerful gas emissions (Methane and its homolog), solid debris, with a sludge to a height of several kilometers. These volcanoes are in Azerbaijan, Turkmenistan, on Taman (Kuban), Romania, Italy, Iran, Burma, Venezuela and others. In Ukraine, they are on the Kerch Peninsula and the Sea of Azov. In recent years, mud volcanoes have been discovered to the west and south near Sevastopol in the Black Sea. The largest of these volcanoes is Central Lake (on the Kerch Peninsula) which emits up to 100 m³ of methane and more than 5,000 liters of dirt per day.

Distribution of volcanoes is characterized by natural belonging to deep faults, separating individual lithospheric plates. There are three volcanic zones on the earth: Pacific, Indonesian-Mediterranean and Atlantic (Fig. 2.12).

The Pacific belt stretches from Kamchatka to Antarctica and includes the Kuril, Japanese, Filipino islands and New Hybrids. On the eastern coast of the ocean the volcanic belt extends from Tierra del Fuego, across the Andes, Cordillera to Alaska and the Aleutian Islands. The most famous volcanoes in this belt are: Kamai (Alaska), Isalko, Lassen Peak (Central America), Mauna Loa and Kilauea (Hawaii), Mont Pele (Lesser Antilles) Bayday-san, Fuji, Asama (Japanese islands).

In Kamchatka, there are 180 known volcanoes, 23 of which are acting. There are periodical eruptions of Kluchevsky, Avachinsky, Tolbachek, Bezimenny, Sheveluch, Kuril volcanoes. Lava is mainly of middle and basic composition. Volcanoes of Kuril islands are continuation of deep faults of Kamchatka. From 398 volcanoes 38 are active ones. Among them are Alayid, Sarychev Peak, Ebeko and others.

Indonesian-Mediterranean zone extends towards the Alps through the Apennines, the Caucasus Mountains of Minor Asia, the islands of the Small Archipelago. On the island of Sumatra there are 11, on Java – 19, small Sunda Islands – 15 active volcanoes. Among them are Krakatau, Tambora, Papandayan. The second area is the dissemination of mediterranean volcanic coast, where there are 10 land and 7 underwater volcanoes. The largest of these are the Vesuvius, Etna, Stromboli, which are periodically active (Etna – in 2011–2012).



https://www.e-education.psu.edu/earth520/content/l6_p2.html

Fig. 2.12 Volcanism manifestations
Map of volcanism manifestations



https://en.wikipedia.org/wiki/Mount_Kilimanjaro

Fig. 2.13 – Mount Kilimanjaro in Africa

Atlantic volcanic belt brings together 67 volcanoes, of which 40 are situated on the islands, while 27 are under water. This belt stretches in meridian direction parallel to the coast of Africa and Western Europe and belongs to the middle Atlantic ridge at the junction of two oceanic plates. Starting near the islands of Tristan da Cunha, it stretches to St. Helen Islands, Ascension, Cape Verde, the Canary Islands, Madeira, the Azores and ends by volcanoes of Iceland where there are 26 active volcanoes. The most popular of them are Lucky and Hecla.

A small number of volcanoes are located outside the volcanic zones: the volcanoes of Africa, Indian Ocean Islands and others. There are 12 known active volcanoes in Africa, including one of the highest volcanoes in the world – Kilimanjaro with the cone height 5895 m above the sea level (Fig. 2.13).

Volcanic eruptions cause significant damage, consuming lives. Signs of modern and ancient volcanic activity are studied by geologists by volcanic rocks – basalts, andesites, liparites, etc., and tuff rocks – tuffs and breccia, etc.

Classification of igneous rocks is based on conditions of their formation. Rocks formed from magma at great depths are called *intrusive* and those formed in surface conditions – *effusive*. Effusions can be distinguished from intrusive by structure, formed under various conditions of crystallization. Fully crystallized rocks, depending on the size of the grains form the following structures: coarse grains with a diameter more than 5 mm, medium – 2,5 mm, small grains-less than 2 mm.

Effusive rocks are characterized by typical glassy (resembling glass), crystallized (grains of minerals are not visible to the naked eye) and porphyritic structures (hidden crystallized mass with distinguished mineral grains). The structure of igneous rocks is mostly massive. The main rock-forming minerals of magmatic rocks are potassium feldspar, plagioclase, nepheline, quartz, pyroxene, amphiboles, mica, olivine. Depending on the share in rocks, rock-forming minerals are divided into major (more than 10 %), secondary (3–4 %) and accessory or rare (less than 3 %).

The most common forms of intrusive rocks occurrence are batholiths, stocks, laccoliths, dikes, veins.

Batholiths – gigantic domed size bodies (more than 100 km²).

Stocks – have the same shape, but their area is less than 100 km².

Laccoliths are igneous bodies of mushroom shape, formed by the penetration of magma into cracks between layers by squizzing up layers of rocks which lie above.

Dikes – linearly elongated vertical or steeply falling magmatic bodies formed as a result of magma filling subvertical cracks in the Earth's crust. Sizes of dikes range from millimeters to several kilometers.

Veins – geological bodies, formed by rocks that filled cracks. They are not sustained by thickness, nor by stretching.

Typical forms of bedding for effusive rocks are flows, domes, covers. *Flows* are frozen lava rivers with length to 80 km. *Domes* are buried or modern volcanic cones. *Covers* are coat like bodies, formed by lava, filling large territories.

Igneous rocks are divided by chemical composition (based on the content of silicon oxide SiO₂) into: *acidic* – (SiO₂ > 65–52 %), *basic* – (SiO₂ 52–45 %) and *ultrabasic* (SiO₂ < 45 %). The rocks enriched with oxides of potassium and sodium are called *alkaline*.

Acid rocks . They are widely distributed in the Earth's crust and consist of feldspar (70 %), quartz (25 %), mica and hornblende (5%), typical acidic rocks are granite. Their color is light gray, pink and red. They are small-, medium- and big-grains structure. Veined granites with grains larger than 25 mm are called pegmatites. Granites occur as batholiths, stocks, dikes.

Middle rocks by mineral composition fall into two groups: diorites, syenites. Syenites have much in common with granite, but differ by high content of quartz and hornblende (20 %). They include about 0.6% of all igneous rocks. Syenites consist mainly of plagioclase, potassium feldspar, hornblende and have the same color as granites.

Basalts are the most common among *the main rocks*. Their color is from dark gray to black. Structure is crystal hidden.

Ultrabasic rocks are rarely found on the surface, forming masses – small batholiths and stocks. Like olivine, pyroxene can make up to 100 % of the rock. Most often intrusive ultra basic rocks – dunite (olivine) and peridotite (olivine, pyroxene) are found in the Earth's crust.

Alkaline rocks make up about 1 % of igneous rocks. Their main representatives are nepheline syenite of gray, pink, green color, with massive texture and deposited in the form of batholiths and stocks.

The rocks of diorite group are composed of plagioclase (~ 65 %) and hornblende ~ 35 %). Color is green-gray.

Andesites – effusive analogues of diorites with dark gray to black color. They are hard to distinguish from basic igneous rocks – basalts.

The main rocks form deepest parts of the ocean floor and some oceanic islands. As small intrusions outcrop on the surface. The main mineral composition: plagioclase – 55 %, pyroxene – 45 %. Deep rock of basic composition is called gabbro, and effusive – basalt, diabase.

Gabbro – dark gray or greenish-gray intrusive rocks with middle- or big-grain structure. Gabbro, consisting mainly of plagioclase and labrador, is a valuable precious-facing material that is produced in Ukraine (Zhytomyr and Vinnytsia regions) and called labradorite.

2.4. Sediment genesis and sedimentary rocks

Sedimentary rocks form the upper part of the lithosphere. They are widespread on the continent and the bottom of the oceans. Their formation and accumulation is of a wide time range – from early proterozoic (3,5 billion years ago) to modern period – going through the process of *sediment genesis* (lat. – *sediment* – deposit, *genesis* – creation). The thickness of the sediment reaches tens of kilometers.

Exogenous processes play a leading role in sediment genesis as a source of energy is solar radiation.

Sediment genesis is a process of interaction between the geosphere with the surface of the Earth (atmosphere, hydrosphere and lithosphere) with living organisms (biosphere), leading to the formation of mineral and organic formations on land and in water environment (oceans, seas, rivers, lakes, marshes). Energy basis of them is solar radiation.

A schematic diagram of sedimentary rocks' formation comprises a sequence of major rock-forming processes: *sedimentation* or *sediment genesis* (accumulation of sediments) – *katagenesis* (change of sedimentary rocks, accompanied by a sealing and recrystallization of sedimentary material) – *metagenesis* (deeper change of rocks at depth) – *supergenesis* (changes under the influence of rock weathering in surface crust).

Depending on the nature of sedimentation, rocks are divided into clastic (terrigenous), chemicals (chemogenic) and biological (biogenic). The source material of sedimentary rocks are:

- products of weathering (destruction) of magma, metamorphic and more ancient sedimentary rocks;
- components of aqueous solutions;
- products of organisms life (organic matter, gases, etc.);
- products of volcanic eruptions (solid particles, hot solutions, gases);
- cosmic material (balls of iron, nickel and silicates, fragments of different sizes, cosmic dust);
- products of human activity (for deposits of the quaternary period).

Various exogenous processes, involving sedimentation, are interrelated having common features and significant differences. The common is that each of the processes, contributing to the destruction of rocks, leads to the formation of sediments. However, the focus, the duration and scope of them is different. The biggest differences are found in exogenous processes of land and sea. While erosion and denudation processes are widespread on land, causing the reduction of the Earth's surface, sedimentary processes dominate at the bottom of the ocean, leading to filling cavities by sediments.

The extent of the continental sedimentation is limited by area and mainly confined to depressions in the terrain – foothills, lakes, river valleys, wetlands and so on. Distribution of continental sediments different by composition and conditions of formation depends on climatic conditions. Areas with hot arid climate are characterized by aeolian deposits and salt; for plains with wet humid climate – alluvial, deluvial, eluvial, lake-marsh sediments; for mainland ice areas – moraine, fluvioglacial, lacustrine-glacial deposits. In oceans, whose area is twice as large as the land, sedimentation happens almost everywhere. Shallow zones are dominated by terrigenous deposits, characterized by large

thickness of sediments, difference in their composition and abundance of fauna. Fine silts and clay sediments of plankton shells are developed in deep water areas. Marine sediments like continental ones, also depend on climatic conditions. Warm seas with normal salinity are characterized by silts and coral reefs, while cold sea water – by deposits of diatom silts, etc.

Duration of exogenous processes can be estimated by thickness of sedimentary layers, lifetime of watersheds, erosion depth of cut and others. The longest is marine sedimentation. Over millions of years sediments with thickness of hundreds or thousands of meters have accumulated on the seabed.

Over the long geological history of exogenous processes on the Earth the position of continents and oceans, climate was changing, flora and fauna renewed. Thus, each geological stage brings its own characteristics in the formation of sedimentary thickness and their distribution.

Formation of sedimentary rocks occurs in several stages. Sediments, transforming into the fossil state, change compacting and turning into sedimentary rocks. This facilitates the process of diagenesis.

Diagenesis (greek. – *degeneration*) – a set of geological transformation processes that transform loose sediments into sedimentary rocks. Changes happen under cover of younger sediments under conditions of pressure and temperature in upper zone of the crust. The nature of diagenetic transformation depends on the Eh environment (oxidation or renovation) in which the sediment is located.

Sediment diagenesis stages:

- consolidation;
- dehydration (water displacement);
- dissolution and leaching;
- recrystallization.

Compaction occurs under the weight of deposits that lie above. Consequently, the sands are transformed into sandstones, silts – into clay, shells and cluster – into limestone. As a result of sludge sealing its *dehydration* takes place. Water comes out of it. Water loss is often accompanied by passing of soluble compounds. Carbonate and sulfate salts of calcium (gypsum, aragonite, calcite), sometimes compound silica (opal) and others undergo *dissolution*. Removal of individual compounds from mineral sediment is called *leaching*. Leaching causes the formation of small voids in the rock or cavities.

Cavernousness is found in carbonate rocks, dolomites, limestone. Subsequently cavity is filled with other minerals. Pyrite, chalcopyrite and other minerals appear in the rock. In the parts of sediment, producing high concentrations of various chemical elements, the processes of *recrystallization* of mineral substances occur, forming siliceous, iron or phosphorus nodules.

The nature of chemical reactions in sediment medium is determined by the terms of its location. The environment can be *oxidizing* or *renovating*. When there is free oxygen, ferrous iron and manganese compounds become oxides. Siderite [Fe CO_3] oxidized, transforms into limonite $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. Restorative environment forms in the presence of organic matter in the sediment. Bacteria, decomposing organic matter and hydrocarbons, contribute to the release of carbon dioxide and hydrogen sulfide. Chemical reactions of CO_2 and H_2S with minerals lead to the formation of carbonate compounds and sulfides (dolomite, siderite, pyrite).

Facies. Sedimentary rocks formed in different physical and chemical conditions differ in their chemical and mineral composition, appearance and other features. A group of sedimentary rocks formed in the same conditions of sedimentation and characterized by certain features is called *facies* (lat. – *face, type*). Depending on physical and geographical conditions there are the sea, the lagoon and continental facies.

Marine facies, depending on the depth of sediment accumulation are divided into coastal, shallow, and middle deep-water, deep-water.

Coastal facies are composed of big and middle fragment sediments (rocks), including the existing shells of mollusks characteristic of the littoral zone of existence. *Shallow (100 m)* and *moderately deep (deeper than 100 m)* facies are very diverse in composition and fauna. They are sand, gravel, clay and foraminiferous, coral, brahiopodovous limestone and chalk. Homogenous deposits are bauxite, iron ores, manganese, phosphates. Deep-water facies are very deep, they are blue, red, green clay, glauconite sands, volcanoes–sediments, deep-red clay, limestone, diatomite and others.

Lagoon facies formed in shallow marine basins are separated, presented by homogenous rocks (limestone, dolomite, salt, gypsum) and terrigenous sediments that are similar in composition to sea sediments but with the presence of glauconite, phosphorite, coal-bearing rocks. Among them there occurs fauna of crustaceans, fish.

Continental facies are divided into surface and deposits of continental reservoirs. The surface facies include:

a) facies of crust weathering consisting of kaolin clay, laterite and other weathering products;

b) aeolian (sand) or facies – facies of desert sands characterized by spreading of large and small thickness;

c) glacial (moraine, glacial alluvium,) unsorted facies composed of sediments, gravel, sand, ribbon clay without the presence of organic material;

d) foothill facies that are talus deposits and temporary mountain streams (boulders, gravel, boulders, gravel, sand, clay) characterized by absence of organic remains.

Facies of continental reservoirs include:

a) *river facies*, connected with hidden ancient and modern river valleys, consisting of alluvial and diluvial deposits;

b) facies of *lakes and wetlands* characterized by lens- like form of bedding and low thickness. Fresh water facies are composed of sand, gravel, aleurites, clays that contain organic remains.

Deposits of salt lakes make layers of salt, sylvite, gypsum and other salts in the absence of organic material. Wetlands are characterized by deposits of peat and iron ore.

Formation is a set of sedimentary rocks of different petrographic structure formed in varying physiographic conditions, but by the same tectonic regime of crustal movements. Most spread are solid, red-colored and coal-bearing formations. *Solid (halogen)* formations differ in composition of homogenous rocks (dolomite, gypsum, anhydrite, rock and potassium salts, etc.) which may include sand and clay. The thickness of salt layer is measured in tens or hundreds of meters. *Red colored rocks* are formed by sediments of rivers, their deltas, lake and coastal marine sediments. *Coal-bearing* formations are characterized by the presence of sandstone, clay, limestone lenses and layers of coal. The thickness of the coal-bearing formations is hundreds and thousands of meters.

There are many **classifications of sedimentary rocks**. The simplest of them is based on their composition and genesis (origin). According to this, sedimentary rocks are divided into fragments (terrigenous) organogenic, chemogenic, pyroclastic.

1. Wreckage or terrigenous rocks depending on the size of wrecks are divided into coarse clastic – diameter larger than 1 mm, sand – 0,05–1 mm, silty – 0,00–0,05 mm and clay – no more than 0.005 mm. Fragments of rock can be either separated from each other or cemented by different cement (carbonate, phosphate, etc.).

Coarse clastic rocks (psephite) are boulders, pebbles, gravel, conglomerates and breccias.

Boulders – run-fragments of solid rock with a diameter of 100 to 1,000 mm and more. They are in the areas of glaciers, on the shores of the seas, in the valleys of mountain rivers.

Aggregates – unrun fragments of solid rocks 10–100 mm size.

Pebbles – run-solid fragments of rocks and minerals from 10 to 100 mm in diameter. The deposits of gravel are the most common among coastal sediments.

Gravel – run-fragments of minerals and rocks with a diameter of 1 to 10 mm. Boulders, gravel, pebbles, gravel are used in building as crushed stones and for manufacturing of concrete. Cemented gravel and pebble (rolled) rocks are called *conglomerates* . They are well represented among the ancient marine sediments. Cemented unrun rock is called *breccia* .

Sand rocks include sandstones and sand. Sands – soft rocks, consisting of fragments of solid minerals, mainly quartz. Depending on the impurities, they are clay, carbonate, mica, glauconite, iron and so on. If sands are composed exclusively of quartz, they are called quartz. Sands can be white, yellow, brown, red and others. Their texture can be small, medium and big grains. Structure is mainly layered. Sands are widely used in production of glass, brick and other building materials. Cemented sands are called *sandstones*. According to mineral composition of cement sandstones are quartz, clay, carbonate, gypsum, iron, silicon and so on. Color, structure and form of their occurrence are the same as in the sand. Sandstones are used in construction as crushed and rubble stone, etc.

Silty rocks (silts) are composed of tiny grains of quartz, feldspar, mica, glauconite. Firmly cemented rocks with 50 % of the particle size of 0.01–0.1 mm are called *siltstones*. Very often there are sandy siltstones in siltstone, consisting of an equal number of siltstone debris with particle size 0,05–0,1 mm, sand particle size 0,1–0,15 mm. Color of siltstones is green, usually gray, red, brown. A clay substance, carbonates, iron oxides and silicon are the cement for them. They are used in construction.

Clay rocks consist of up to 50–60 % of the sedimentary rocks. Their typical representative is clay composed of kaolinite and other clay materials. Mineral (oxides of iron, aluminum, copper, etc.) and vegetable impurities color clay in yellow, brown, green, dark gray, red and white. In the wet state they are plastic. After baking they become sintered rocky mass. They are used for the production of porcelain, pottery, building and refractory (melting temperature up to 1700°C) brick.

2. Organic rocks are formed in water and coasts. They are represented mainly by various limestone, chalk and chert, which consist of shells or debris of skeletons of simple organisms. Organic rocks usually include combustible rocks – caustobioliths (peat, fossil coal, oil shale, sometimes – oil), even though chemical processes play a huge role in their formation.

Studying organic rocks, one should bear in mind that formation of many of them one way or another is connected with chemical processes and, therefore, rocks with clear signs of chemical and organic origin are to be associated with biochemical rocks.

Limestone – dense or porous rock, light gray, sometimes colored with impurities in light yellow, gray, dark gray and other colors. Depending on the organisms, which form the shell of limestone, the latter is divided into coral, foraminifera, etc. They deposit in layers and lenses. They are used in metallurgy for the production of lime and cement as a building material.

Chalk – white earthy porous rock. It consists of calcareous remains of marine algae – coccolithoforide and small shells of foraminifera. Sometimes

there are big mollusc shells, sea urchins and other organisms in it. Chalk is used to make lime, cement, toothpaste and others.

Marl – rock composed of fine-grained calcite and clay material. In appearance – soft, sometimes hard flint-like rock, colored in white, gray or yellowish-gray, green. It is used in the manufacture of cement.

Diatomite – rock consisting of microscopic small diatoms. Color – white. Due to the very high porosity rock is so light that floats in water. It is used as a filling in polishing material.

3. Chemogenic rocks are formed in water with a chemical deposition of minerals from the real suspension and solutions. Among them are salt, phosphates, bauxite, dolomite, marl, jasper.

Salt – salt sediments of lakes or lagoons that are in conditions of dry and hot climate. Sometimes their formation is associated with discharge of hot chloride sodium solutions in the sea. Salts include rock salt or halite – NaCl, sylvite – KCl, sylvinite (a mixture of 25 to 85 % of halite and sylvite 10–60 %), gypsum – $\text{Ca}[\text{SO}_4]\cdot 2\text{H}_2\text{O}$, anhydrite – CaSO_4 and others. They are deposited by layers, lenses, stocks. Their structure is crystal-grained, used in food, chemical and other types of industry.

Phosphorites – sand-clay or clay-carbonate rocks cemented with phosphate cement. The composition is granular, concretion, homogeneous. Shark teeth are sometimes found in the phosphates, containing up to 65 % of calcium phosphate. The color is gray, brown or black. They are deposited in layered form. Used for the production of fertilizers in farming.

Bauxite is aluminum ore. It is formed in weathering crusts of crystalline feldspar rocks. They are of white, gray, red and brown color. Redeposited bauxites are of lake and sea origin. They are both loose and dense (with oolite structure), used to produce aluminum.

Dolomite – $\text{CaMg}(\text{CO}_3)_2$ is formed in marine evaporite basins, most often – by metasomatic replacement of limestone, and sometimes as a result of hydrothermal processes. It has a white, gray, green or reddish color depending on impurities. Soluble in HCl. Participation of organisms in the formation of dolomite is not installed. It is used in building, metallurgy (in manufacture of refractory bricks and metallic magnesium), chemical and other industries, and in agriculture.

Jasper – silicic sedimentary rock, mottled and spotted that consists of crystalline quartz with chalcedony impurities. Stained by iron and manganese oxides in various shades of red and yellow color. Jasper has chemical, sedimentary and volcanic, biochemical origin. Due to its high hardness (7), strength and good coloring it is used for small valuable items in jewelry.

4. Pyroclastic (volcanic-sedimentary) rocks. Genetically connecting with magmatic processes, but in terms of formation and surface appearance belong

to sedimentary. Volcanic eruption products emitted into the air, fall to the ground, become simple rubble. Their conversion to rocks in water pools is a little different from other sedimentary rocks formation.

Pyroclastic rocks are classified by the size of fragments: volcanic ashes – with particle sizes up to 1 mm, volcanic sand – from 1 to 2 mm lapili – from 2 to 10 mm, volcanic bombs – more than 30 mm. This material turns into rocks – *tuff*, during diagenesis if fragments are larger – in *tuff breccias* and *tuff conglomerates*. Often volcanic material is mixed with sedimentary in the flow of water, and if there is significant quantity of it, various *tuffs* are formed. *Tuffs* – the common name of cemented and porous sedimentary volcanic-sedimentary rocks. There are calcareous tuffs, volcanic tuffs and geysirites. In Ukraine, they are in the Crimea, the Carpathians and Podillya. They are used in construction.

Tuff breccia – compacted rock, consisting of various size of angular, rarely – weak-run volcanic rock fragments cemented in volcanic ash. Tuff breccia form hard layers which make up the volcanic strata. It is used as a building material.

Tufit – volcanic-sedimentary rock consisting of volcanogeneous material ejected during the eruption (slag, ash, pumice, rock fragments) and sedimentary material mixed with it. It may contain rolled fragments of intrusive rocks. The content of pyroclastic material is more than 50 %. Cement can be carbonate or clay. It is used as a building material.

2.5. Metamorphism and metamorphic rocks

Metamorphic rocks are formed in the deep zones of the earth's crust due to endogenous processes of metamorphism – significantly different temperature, structure and mineral composition of rocks as a result of high *temperature, pressure, deep fluids* and other factors.

The term *metamorphism* (greek. – *conversion*) was introduced in geological science by French geologist Charles Lyell in 1885.

Metamorphic processes usually take place in the temperature range of 1100–300°C and pressures 6000–1 atm. Metamorphism includes recrystallisation, mineralogical and chemical changes in sedimentary, igneous and metamorphic rocks formed earlier, so that they turn into *metamorphic rocks*.

Genetic sense of metamorphism is in change of the initial chemical composition of minerals and emergence of new ones, resistant to certain physical and chemical conditions of the created geological environment. Under the influence of external factors (high pressure and temperature, thermal fluids) partial or complete recrystallization of rocks takes place, accompanied by a fundamental changes in their structure and texture. Metamorphic processes are different manifestations both in form and in character of transformations.

Metamorphism of rocks can be *cosmogenic*, occurring in astrobleme (big meteor craters) and *endogenous* developed under the influence of heat, pressure and fluid of subsurface on the rock.

Cosmogenic metamorphism of rocks is generated by the energy of shock waves transforming the surface rocks into metamorphic. It is associated with sharp short-term growth of temperature and pressure at the time of large meteorites' fall on the Earth. As the result, *impactites* form in places where there are high-pressure minerals (diamonds, pyrope, koxit, stishovite, etc.), together with the products of melting, deformation and fragmentation of primary mineral rocks. This type of metamorphism is much inferior than endogenous metamorphism in the development of the Earth's crust and above all on its surface.

Endogenous metamorphism has many forms integrated into three main types: regional, contact and ultrametamorphism.

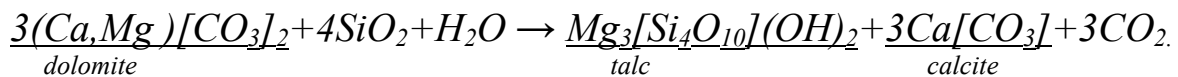
Regional metamorphism occurs at great depths at high temperatures and pressures caused by powerful layers of rocks and thermal fluids. Migration of thermal solutions is the cause of *metasomatosis* (replacement of mineral complexes), temperature is the cause of recrystallization of minerals and rocks, and directed pressure causes their delamination.

All these processes appear in large spaces in connection with the formation of geosynclinal (mobile) zones of the crust and are outside magma influence. Regional metamorphism of geosynclinal volcanic-sedimentary formations is in the parallel-serial passage of rocks to areas where termobaric indexes constantly increase. All this leads to a change in structure, texture, mineral and chemical composition of rocks. In regional metamorphism sand and clay rocks change into shales (siltstone), dense limestone through recrystallisation – into crystal – grained marble, clastic sandstones – crystalline quartzite, magmatic rocks – into granite, clayey – sand – into gneiss. Slate, gneiss, amphibolic structures are caused by the development of regional metamorphism under stress (directional pressure, which causes deformation in rocks).

Contact metamorphism occurs close to intrusions or extrusions (spills) of magmas under the influence of heat flux and fluids on host rocks. Complex physical and chemical processes emerge at the contact between magma and rocks, leading, on the one hand, to contact metasomatism, and on the other hand – to temperature changes in minerals. The intensity of these processes depends on the composition of the magma and the surrounding strata. The greatest changes occur at the contact of acid magmas with carbonate rocks. Changes relate to both sides of the contact. Halo toward intrusion is called *endocontact zone* (zone of internal contact) and toward containing rocks – *exocontact zone* (zone of external contact). Exocontact halo is much larger than the endocontact and sometimes reaches up to 5 km or more.

Both sedimentary and igneous rocks undergo changes. Clays and sand rocks, therefore, are converted into dense hornfels. Granites are converted to grayson. As a result of hydrothermal solutions penetration in sedimentary rocks they enrich with oxides of silicon (silicification), calcium carbonate and magnesium (carbonization). Other transformations also take place.

Each process covers only a certain set of rocks. Magmatic minerals of basic and ultrabasic composition and sedimentary dolomites undergo transformations into talc. In the latter case, enriched in silica (SiO_2) hot water steam, changes dolomites into talc. The reaction is as follows:



Greisens and skarns are most productive in searching for minerals from the rocks of contact metamorphism. Deposits of tin, tungsten, molybdenum, lithium, uranium are connected with greisens. Deposits of copper, iron ore, gold, uranium, polymetallic ores can be found in skarns.

Ultrametamorphism. The highest degree of metamorphism is ultrametamorphism (*ultra* latin. – more) that relates to the deepest zones of the crust. Ultrametamorphic phenomena include *migmatization*, *granitization*, *anatexis*, *palingenesis*. Ultrametamorphism of rocks is available both at the stage of geosynclinal areas immersion, and at the stage of inversely-folded development.

Immersion ultrametamorphism – is the process of rocks melting due to the growth of regional progressive metamorphism without introducing significant mineral matter in temperatures higher than geothermal level of melting of granite composition rocks. This type of metamorphism is the most characteristic for archaic and early proterozoic stages in the development of the Earth's crust when the value of the regional heat flow was significantly higher than at present, and the processes of anatexis and palingenesis occurred at a depth of 5–9 km.

Palingenesis – the process leading to the formation of secondary magmas by full or partial melting of *igneous rocks* in the lower crust under intensive warming.

Complete melting, leading to the formation of magma is called *anatexis* (greek. *ana* – higher measure, *taxis* – fusion).

Uplifting ultrametamorphism is a set of complex processes developing at inversion-folding stages of evolution in conditions of considerable substance input and thermal energy in a zone of intensive tectonic activity, targeted in the formation of magmatic melt of granit composition (granitization).

Granitization – is transformation of chemical and mineral composition of rocks of different genesis, leading to the formation of granite. Areas of metamorphic granite are found among pre-cambrian gneisses and schists that make up the core of most present-day mountains. The fact that these granites

are metamorphological, not the magmatic, shows no trace of rooting characteristic of magmatic formations and surrounding of granitoid rocks with metamorphic rocks.

The experiments made it possible to obtain a granite melt from different metamorphic rocks and to explain the melting of granites in the strata of deeply metamorphosed rocks. Deeply metamorphosed Precambrian rocks, represented mainly by gneiss, amphibolites, crystalline shales, etc., are characteristic of continental lithospheric plates. Oceanic plates are formed by rocks with lower degrees of metamorphism.

The structures of metamorphic rocks, that lost relics of primary minerals are called *crystallblast*. Among them are *profirblast*, *profirsseingblast*, *lepidblast (slate)*, *grainlepidblast (gneiss)* *grainnemablast*, *micrograinblast* and others.

Metamorphic rocks are of *slate* and *gneiss* texture, homogeneous or striped. Striped texture is divided into relict (inherited from layered strata that have undergone metamorphic changes) and metamorphic (caused by metamorphic differentiation). *Slate* and *gneiss* structures are inherent to regionally metamorphic rocks and *hornfels* – to the product of contact metamorphism.

Migmatites are complex rocks of contact-metamorphic origin formed from a mixture of magma and rocks contacting with it of injecting texture (texture of penetration). Metamorphic rocks are also characterized by a large number of deformation textures.

Classification of metamorphic rocks is based on their formation features. Often, there are two groups of them – *contact or deep* that differ on the nature of metamorphism. Rocks of first group have local distribution, while the second – regional.

The type of the first group of metamorphic rocks is determined by the composition of primary rocks and the role of mineralizers extracted from the deep interior. On this basis we allocate, first, the rocks, formed from igneous rocks by recrystallization with a great amount of mineralizers of postvolcanic origin (gases and solutions), and *secondly*, the contact-metamorphic rocks created by insignificant introduction of fluids.

The former type includes *serpentinites* associated with ultramafic igneous rocks: *graysens*, formed by granites, and *propilites* associated mainly with porphyries and porphyies. The second type includes *contact hornfels*, partly *marbles*, etc. Metamorphic rocks of the second group *schists* are better developed, they originate from regional metamorphism.

Gneisses are full crystal, schistose, light colored or colorful rocks composed of feldspar, quartz and mica. Mica is composed of either individual leaves or forms the thinnest layers (banded gneiss). Their texture is lenticular-shale. Gneisses are named by the most characteristic minerals – main and

secondary. Rocks both of magmatic and sedimentary origin transform into gneisses under metamorphism. They often have thin-layer injection (piercing) of granites in primary sedimentary rocks (migmatites).

Mica schists (biotite, muscovite and doublemica) differ from gneiss by absence or small amount of feldspars. Their color is dark. Schist is parallel or wavy. Granularity is clear and usually lower than in gneiss.

Mica microschists (philetus) – the least metamorphosed from other crystal schists. They form transitions to various clay shales, differed by fully crystallized structure and silky shine of parallel planes, covered by the smallest plates of mica. Mica is almost always light. Among them chlorite is often found, which produces a greenish shade.

Amphibolites are composed of almost equal amounts of amphibole and plagioclase and correspond to the composition of gabbro rocks and dark colored diorite. These are massive schistose rocks – from fine-grained to big-grain size. They differ from amphibole gneiss by dark gray-green or dark green color.

Amphibole schists are fine-grained rocks, microscopically almost indistinguishable from amphibolite. They consist of hornblende with or without quartz.

Chlorite schist is green (preferably dark green) soft (easily cut by knife). They consist mainly of mineral chlorite.

Talc schist is greenish (due to the presence of chlorite and serpentine), oily to the touch and very soft rock.

Test questions to the theme

- 1. What is a mineral? Give its definition.*
- 2. What are endogenous processes of mineral formation connected with and at the expense of what energy do they occur?*
- 3. How do igneous, sedimentary and metamorphic minerals form?*
- 4. What is crystalline and amorphous state of minerals? How do they differ from each other?*
- 5. What is singonia?*
- 6. What is the crystalline lattice?*
- 7. What is the axis of symmetry?*
- 8. What are the main physical properties of minerals?*
- 9. How to classify minerals?*
- 10. What factors affect the hydrothermal minerals?*
- 11. What hydrothermal minerals do you know?*
- 12. What igneous minerals do you know?*
- 13. What metamorphic minerals do you know?*
- 14. What sedimentary minerals do you know?*

15. *What is a rock?*
16. *What is meant by structure and texture of rocks?*
17. *What are igneous rocks and environments from which they are formed?*
18. *What is the difference between intrusive and effusive rocks?*
19. *Describe the main forms of magmatic rocks' occurrence.*
20. *What are skarns and what processes are they formed by?*
21. *What is volcanism, where and how does it happen?*
22. *When do the postvolcanous processes happen?*
23. *Give the classification of igneous rocks and their examples.*
24. *What are sedimentary rocks and the conditions in which they are formed?*
25. *Describe the main types of sedimentary rocks.*
26. *What is the sediment diagenesis and how is it determined?*
27. *What is the catagenesis and what are its consequences?*
28. *Define metamorphism and give its variants.*
29. *Give examples of metamorphic rocks.*
30. *What are energy sources of rock formation?*

CHAPTER 3

WEATHERING OF ROCKS

Weathering – the process of destruction and changes of rocks in conditions of the Earth's surface or near-surface zone under the influence of *exogenous factors* (solar heat, water, atmospheric gases and organisms). According to it, there are *physical, chemical and biological* weathering. All types of weathering of rocks are interrelated and work at the same time. The advantage of one way or the other depends on climatic conditions.

For the first time the term was applied to remnants of rocks in the desert "turned" by wind.

Products of weathering, consisting of elluvium, are called the *crust of weathering*. There are crusts, which include mainly the products of physical destruction and those formed by products of chemical and biological weathering: kaolin, laterite, montmorillonitic, oxidized ores, soils and others.

Kaolin weathering crust develops mainly on granites. In its structure there is a noticeable zoning. Over fresh, not altered granites there are usually light kaolinic, fractured granites, which are transformed above into the mass of clay, composed of kaolinite and hydromica (mica-like minerals formed during decomposition of mica). The upper section of the weathering crust is represented by white kaolin, grains of quartz and feldspar, which are not decomposed, and scaly-like mica minerals. This weathering crust is developed on the granite massifs of the Ukrainian shield.

Lateritic weathering crust occurs in areas of wet tropical climates. It develops mainly on alkaline and basic igneous rocks, and is provided by iron hydroxide and aluminum and has a brick-red color. Lateritic rocks enriched by aluminum oxides are called *bauxite*. Lateritic weathering crust type is known in Africa, South America, Australia and other areas. In Ukraine, the crust of this type is known in Transcarpathia, the Azov Sea and the Ukrainian shield. In the unearthed form – in the Dnieper-Donets basin, the Carpathians and other regions.

Soils – is a surface layer of the lithosphere, characterized by fertility. Studies have shown that in addition to the primary minerals (quartz, feldspar, mica, etc.), soils contain products of chemical weathering (kaolinite, etc.), organic acids and humus (lat. *humus* – earth). *Humus* – amorphous organic matter of brown or black color. It consists of protein, fat, carbohydrates, resins, waxes and other products of organic matter decomposition. Organic acids play a significant role in the process of soil formation.

Soils are formed on rocks of any composition. Bacteria, lichens, mosses are the first to settle on the rock. Decomposing minerals and protozoa saturating them with organic matter, prepare the ground for more highly-organized types of plants like shrubs and trees. The structure identifies a number of genetic soil horizons. The upper, *eluvial* horizon is characterized by prevalence of leaching substances that accumulate in the next – *iluvial* horizon. The soil layer is transferred to the parent rock. Soils of different climatic zones vary in composition, color and thickness. There are around 30 genetic types of soils. In Ukraine there are:

- forest (podzolic) soils characteristic of the northern regions of the country;
- meadow steppe soils (black earth) formed in the central regions, representing a third of all European black soil;
- dry steppe soils (chestnut) developed in southern regions;
- soils of subtropical zones (black), formed in warm subtropical climate of the Crimea.

In addition to modern, more ancient fossil soils formed in past geological epochs at shallow depths in the quaternary sediments sometimes can also be found.

3.1. Physical weathering

This type of weathering is manifested in mechanical destruction of rocks minerals without changing their structure due to daily and seasonal fluctuations in temperature, freezing and thawing of water in cracks, mechanical removal of mineral substance particles by water or by wind. Physical weathering is mostly characteristic for territories with Arctic climate, highlands and deserts.

Uneven flow of solar heat not only in different seasons but on different days causes periodic heating and cooling of rocks. Fluctuations in temperature is accompanied by multiple changes in volume of minerals grains, resulting in *volume deformations*. The result is at first small and then large cracks. Three-dimensional deformation depends on the *coefficient of thermal expansion* (which is numerically equal to the increase in volume when heated by 1°C, provided that at 0° volume equals to 1) of minerals, depending on their composition and physical properties. In quartz, for example, it is equal to 0,00031, feldspar (orthoclase) – 0,00017. Gradually cracks penetrate deeper into the rock. Water contributes to this. When freezing, it increases in volume by 9 % and with strength to 87 MPa presses on the crack walls, widening them. In polar areas where ice plays a major role in the destruction of rocks, soils are called *frosty*.

One reason for the formation of cracks in the rocks is their periodic moistening with rain water. With repeated moistening and drying, the adhesion

forces between the rock particles decrease and it breaks into pieces (debris). Brittle and coarse-grained rocks composed of minerals of different colors crack faster. The viscous, fine-grained rocks, which consist of light-colored minerals (Fig. 3.1), decay more slowly.

Climatic conditions play an important role in physical weathering.

In extreme continental, arctic and arid climate destruction is more intense than in the moderate climates due to sharp fluctuations in temperature during the day and night. For example, in deserts the surface is heated to 70–80°C during the day in summer, and at night the thermometer goes to 0°C. Bare slopes devoid of vegetation are destroyed faster than the grassy areas with bushes and trees.



<https://www.travel-tour-guide.com/sahara-desert-trip/05-sandstone-pinnacles.htm>

Fig. 3.1 – Weathered sandstone

In the process of weathering, monolithic rocks are fractured and covered with rubble. Resistance of debris on the slopes is determined by the *angle of natural slope* (where loose material can stay on the slope). For different rocks it ranges from 27 to 37°. The angle of inclination is affected not only by the composition of rocks, but by size, shape of fragments, the degree of

saturation with water. Collapse of debris from big slopes may be caused by thunder, shouting, shot, and especially – by earthquake. Falling, fragments crush and are stored at the foot of the slopes, causing *scattering of scones*. Such products of weathering are called *colluvium* (lat. *colluvio* – cluster).

Accumulation of debris that remain at the site of destruction are called *stone placers*. Debris from the slopes are often swept away by rainwater and then they are called *delluvial*. Moving the debris from the slopes can be slow, sometimes fast, sometimes disastrous. Massive debris falling from the hill is called the *landslide*. The reasons for the collapse can be earthquakes, avalanches, rain, hurricanes and others. In order to prevent collapses people cement dangerous cracks or unstable rocks. The most common types of physical weathering are *insolutic weathering* – the process of rocks destruction as a result of cracking due to sharp fluctuations in temperature, especially when heated by the sun.

3.2. Chemical weathering

This is a process of chemical transformation or destruction of minerals and rocks under the influence of natural waters (atmospheric, surface, ground, underground), accompanied by their *solution* and *leaching*. Water, which contains various chemical compounds leads to solution, oxidation, hydrolysis, hydration and dehydration of minerals.

The intensity of chemical weathering depends on many reasons, foremost of which is the terrain, climate, chemical properties of rocks and the duration of water affecting them. Flat, weakly dissected landscape is most favorable for chemical weathering. In a warm and humid climate chemical weathering leads to complete decomposition of primary products, and in cold climates only partial changes occur in minerals. Because of chemical weathering natural water is saturated with various chemical elements and compounds and often change their chemical composition.

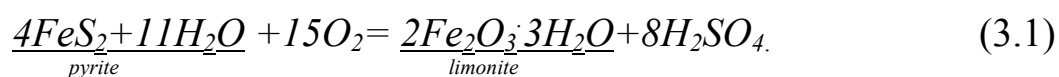
Let's look at the most common chemical weathering processes.

Solution. It depends on mineral composition of rocks, water chemical activity, natural and climatic conditions. Halides, sulphates, some carbonates are readily soluble. Chemical activity of water plays an important role, depending mainly on the content of H⁺ and OH⁻ ions. *Acidic solutions* enriched with H⁺ ions, are capable of dissolving compounds of calcium, magnesium, sodium and iron. Alkaline solutions enriched with OH⁻ ions dissolve even poorly soluble compounds, including quartz. The solubility of natural waters is enhanced in warm and humid climates.

The process of solution, accompanied by the removal of soluble chemical compounds from rocks is called leaching. *Leaching* is accompanied by the formation of cracks in the rock and cavities. An example is leaching of readily soluble calcite grains from carbonate rocks, leading to carst cavities and caverns.

Oxidation of rocks and minerals occurs under the influence of free oxygen in water, air and moisture. Here, sulphides transform in sulphates, carbonates and other oxygen compounds; iron and copper oxide compounds – in oxides and the latter – in hydroxides, which are more stable under Earth conditions.

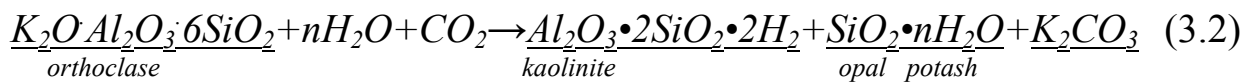
Characteristic is the oxidation of pyrite (FeS₂):



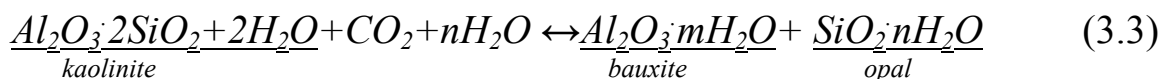
Mineral limonite and sulfuric acid are formed during this oxidation reaction. Limonite takes place of pyrite, and sulfuric acid transforms into aqueous solution. Oxidation zones appear at the background of primary ores by color. So, in black magnetite rocks an oxidation zone has reddish or brown color.

Hydrolysis – a reaction of decomposition exchange between matter and water. Aqueous solutions not only saturate minerals with water but also cause their chemical decomposition, accompanied by solution and metabolism. This process leads to destruction of the crystal lattice of minerals and formation of new chemical compounds. In nature hydrolysis is mostly expressed in silicates. Minerals of this class created at high temperatures and pressures on the Earth's surface in presence of water and carbon dioxide break down into components and in the process of exchange form new chemical compounds. Some of these compounds are easily transformed into solution and are carried out of the weathering zone, while others remain in place, forming weathering crusts. Easily soluble compounds include acidic and carbonic salts of sodium, potassium, calcium, magnesium. Soluble are aqueous oxides of silicon, aluminum, iron.

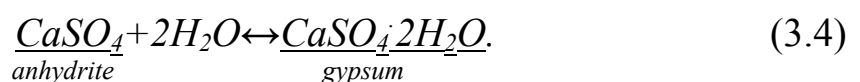
One of the typical examples of hydrolysis are kaolinisation of feldspar, which constitute nearly half of all mineral crust. Solid grains of feldspar in presence of water and carbon dioxide decompose with the formation of earthy kaolinite, amorphous opal and soluble salts of potassium, sodium, calcium. The process of hydrolysis goes on the scheme:



In a moderate climate zone feldspar hydrolysis is called by the final product – *kaolin weathering*. In regions with tropical climates aluminosilicate goes deeper, forming water oxides of aluminum – bauxites.



Hydration (water saturation) is a phenomenon of water joining anhydrous minerals. These water molecules are in the mineral structure and can be removed only in the process of its heating at more than 400°C. A classic example of minerals hydration is transformation of anhydrite into gypsum. Absorbing water, anhydrous anhydrite is transformed into calcium sulfate (gypsum), which holds water:



Water saturation is accompanied by restructuring of the mineral crystal lattice and increasing its volume. Gypsum compared with anhydrite increases in volume by 33 %. The hydration process is also accompanied by the development of fracturing rocks.

Dehydration – the process of water allocation from minerals and rocks. It occurs by separating water molecules from compounds containing hydroxyl groups, crystallisation and zeolite water. Dehydration in nature is associated with solar radiation, internal heat of the Earth, with the effect of water-intaking salts, and leads to cracking of minerals and rocks.

Chemical weathering products, remaining on the site of rocks destruction, are called *eluvium* (lat. *eluvio* – leaching). The residual weathering products retain all the characteristics of the parent rock, its occurrence shape and texture. Vertical zonation is noticeable in the structure of eluvium. Upper layers usually contain physical weathering products and are much more changed than the lower ones.

Chemical underwater weathering is called *hemolysis*. Underwater weathering occurs in water surrounding because of the lack of free oxygen and carbon dioxide. As a result, deep red clays, bentonite clays, iron and manganese nodules are formed.

3.3. Biological weathering

Biological weathering is the result of animals', plants' and microorganisms' waste. The organic world is changing and destroying rocks, acting on them mechanically and chemically. Earthworms drill and loosen the soil. It is estimated that on average every 0.5 ha of soil contains to 150.000 of worms that lift from 10 to 15 tons of finely crushed material to the surface a year. Great work is done by separate groups of bacteria (there are from 3 to 7 tons of microorganisms per 1 ha of soil).

Mechanical work of plants is in the destruction of rocks with roots which penetrate into the cracks.

The chemical action of living organisms and plants is manifested by their life when they produce organic acids, and after their extinction when there is the chemical decomposition of living matter. Carbon dioxide and ammonia, organic acids and other nitrogenous solutions vigorously destroy the rocks. Products of animals and plants' remains decomposition are transformed into humus, which not only works as soil fertility, but at the same time is a powerful chemical factor of rocks destruction. Nitrifying bacteria that absorb nitrogen from the soil, and carbon from carbonates directly decompose rocks.

In modern time a man whose livelihood causes physical, chemical and biological weathering of rocks has the biggest and most intense impact on the near-surface rocks of the lithosphere.

Test questions to the theme

- 1. What is the weathering of rocks and what are its types?*
- 2. In what ways is a geological wind activity manifested?*
- 3. What conditions are necessary for the occurrence of physical weathering?*
- 4. What are different kinds of weathering?*
- 5. Under what conditions does chemical weathering occur?*
- 6. What determines the intensity of chemical weathering?*
- 7. Describe chemical weathering: oxidation, hydration, solution, hydrolysis.*
- 8. What processes lead to the formation of alluvial deposits?*
- 9. What processes lead to the formation of diluvial deposits?*
- 10. What processes lead to the formation of eluvial deposits?*
- 11. What processes lead to the formation of illuvial deposits?*
- 12. What processes lead to the formation of proluvial deposits?*
- 13. What processes lead to the formation of aeolian deposits?*
- 14. What processes lead to the formation of colluvial deposits?*
- 15. What is the difference between dissolution and leaching of minerals and rocks?*
- 16. What are the main factors and processes of biological weathering?*
- 17. What is the weathering crust and what types are formed in different conditions?*
- 18. What useful rocks are formed in the residual soils?*

CHAPTER 4

UNDERGROUND WATER

Underground water is water located in rocks in different physical states – liquid, solid and vapor. Studies about groundwater is *hydrogeology*.

Water is one of the easiest natural compounds of hydrogen with oxygen. Under normal conditions – colorless liquid with no odor or taste. Molecular weight is 18,0153, density – 1,0.

Water is part of the minerals, fills pores and cracks in rocks. The top five-kilometer layer of the crust holds about 60 million km³ of water, or 42 % of total hydrosphere. In deep zones of the earth's crust water has a high temperature (sometimes more than 100–200°C), preferably sodium chloride composition and high mineralization – up to 200–300 g/dm³ (which transforms it into a state of brine). The top of the lithosphere (1000 m) is dominated by cold, fresh, hydrocarbon and hydrocarbon-sulfate water.

Groundwater is able to move both in horizontal, and vertical directions. The vertical movement of water can be *ascending* and *descending*. In the first case they rise by canals of different filtration under high pressure of subsoil (geostatic, geodynamic, hydrostatic, heat, etc.), and in the second – they sink as a result of gravitational forces.

Outputs of groundwater to the surface are called *sources*. Groundwater dissolves, transfers and deposits mineral substances.

Water is found in rocks in liquid and solid vaporous states. In the form of ice it is available in rocks in the areas of the world where the average temperature is below zero degrees. Water vapor saturates rocks in areas with arid climates. Water is mainly in the crust in liquid condition. There are several types of water in the rocks.

Crystallization (chemically bound) water – part of crystal lattices of minerals. Examples include gypsum – Ca[SO₄]2H₂O and limonite – Fe₂O₃·nH₂O.

Hygroscopic water – is present in weak damp rocks surrounding mineral grains with thin (molecular) layer. It is formed by condensation of water vapor from the air and is removed only when heated.

Pellicle water forms a thin pellicle on mineral grains that can move under the influence of molecular forces.

Capillary water – fills small pores up to 1 mm. It is held in them by surface tension. As the pellicle water under high evaporation, it moves from

down lying horizons to high lying. Capillary water is in thin-porous rocks (clay, loam, sandy loam, etc.).

Crystallization, hygroscopic, capillary and pellicle water does not play an important role in geological processes.

Gravitational water is found in large pores (larger than 1 mm) and cracks. It moves under the forces of gravity (gravitational) from high lying horizons to down lying. Unlike previous types of water, it is called *free*. Gravitational water plays a very important role in the underground water draining.

By origin underground water is divided into infiltration, sedimentary, magmatic and condensation (juvenile).

Infiltration water is formed by infiltration (sucking) of rainfall into the soil and surface water. It plays the most significant role in the cycling of underground water in near-surface zone of the lithosphere (the zone of free water exchange).

Sedimentary water is water in sediments, buried with them at different stages of their re-formation into the rock – *diagenesis* and *katagenesis*. It may be the same age as the rocks containing relict water. However, due to the compaction of water-bearing rocks, sedimentation waters often move into contacting strata of a different age, and sometimes (brines) into the lower parts of the hydrogeological section (sedimentary moved waters).

Condensation water –is formed by the condensation of water vapor in soils as well as boiling due to the sudden change in temperature and pressure in deep aquifers. It has a great value in replenishment of groundwater in desert regions.

Magmatic water –is deep water of magmatic origin. E. Suess (1902) called it *juvenile* (lat. *juvenilis* – young). It is created by cooling of magma, the water content of which is 10–12%. It almost never occurs in its pure form, except magmatic melts, because it is mixed with other genetic types of waters in hydrosphere.

4.1. Hydrogeological properties of rocks

The ability of rocks to absorb and retain water is called *moisture capacity*, defined by volume or porosity of cavities in the rock. Porosity percentage is determined by the formula:

$$n = Vn/V 100 \% \quad (4.1)$$

where n – porosity, %;

Vn – pore volume of the sample;

V – volume of the sample.

The porosity of the rocks varies widely (Tab. 4.1).

Table 4.1

Porosity of some rocks

Rocks	Porosity, %	
	Minimum	Maximum
Granites and gneisses	0.02	0.60
Marble	0.20	0.40
Shale	0.50	7.5
Siliceous schist	0.85	0.90
Limestone	0.50	13.50
Dolomites	1.05	22.0
Limestone tuff	20.2	32.2
Sandstones	3.5	28.5
Sands	35.0	42.0
Clay	25.0	55.0
Lesia	40.0	55.0

Permeability of rocks is their ability to pass water through them. Water in the rocks can move under the influence of gravity (gravitational movement), external pressure, capillary (capillary movement), adsorption and capillary-osmotic forces if there is a difference in concentrations of dissolved substances in water in different parts of rocks (osmotic movement), electric current in a potential difference (electroosmosis), temperature gradient (convection, thermoosmosis), evaporation, freezing, pressure of fluids (gases, vapors, liquids), etc.

Rocks that can accumulate and filter water and other fluids (oil, gas) under natural pressure through existing cavities (pores) interbed with rocks. Their pores are mostly sub capillary channels with a diameter less than 2 microns and under natural pressure differences are virtually impervious to fluids. These rocks are called *waterproof* (water-resisting, fluid-resisting). They are mostly clays, argillites and silicate dense carbonate and silicate rocks and salts.

The movement of groundwater in the lithosphere can be laminar or turbulent. The *turbulent motion* is characteristic of karst waters or opened macrocracks systems. The main type of free movement of underground water is *laminar filtering*. Considering large internal surface of pores, their small cross-sections and heterogeneity, large resistance to the movement of water appears in filtering which explains their low speed and subordination to the law of Darcy's.

Filtered liquid forms a *filtration flow* – fluid flow through porous or fractured-porous medium (aquifers). It is conventionally believed that filtering

encompasses the entire thickness of the rock. Though, in fact, the flow is only through interconnected pores and cracks.

The elements of a filtration flow are: piezometric pressure, pressure gradient, hydroisopiea (conventional lines of equal pressures), conditional filtration lines, filtration rate, flow rate.

Linear flow filtration (Darcy law) can be written as:

$$Q = k_{\phi} \cdot F \cdot \frac{\Delta H}{\Delta l}, \quad (4.2)$$

where Q – flow rate;

k_{ϕ} – filtration coefficient, whose value depends on the environment abilities of filtration and filtered fluid;

F – cross-sectional area of filtration medium;

ΔH – pressure gradient towards filtration flow pressure Δl .

A very important question in hydrogeology is about the lower limit of Darcy law correctness, describing groundwater movement in the minimum permeability of the medium, minimum hydraulic gradient and filtration rate, and maximum values of filtered fluid viscosity (both water, and brine) when their movement obeys Darcy law in its "classic" form.

Filtration coefficient – a value that represents the degree of rocks waterproofing. Its value equals to the speed of laminar traffic through the rocks, in a way when piezometric traffic equals to one. Its dimensions – cm/s, m/day, etc. Rocks with high permeability (pebble, gravel, coarse sand) has a filtration coefficient that exceeds 10 m/day, while in low-penetrating rocks (sands, loam) it is 0,01–0,001 m/day. Rocks with low filtration rate (lower than 0.001 m/day) are *waterproof*.

Waterproof rocks are characterized by the ability to give water – *water loss*. Water loss ratio is determined by a coefficient counted as the ratio of water volume involved in the processes of filtration to the volume of water-bearing rock. The larger sizes of filtering channels (pores, cracks) are, the higher is *the coefficient of water loss*.

Hydrogeological properties of rocks have a significant influence on the formation of underground waters, their dynamics, mode and operating properties.

4.2. The structure of the aquifer and circulation conditions (dynamics) of groundwater

Sedimentary strata, associated with the main reserves of groundwater, are made up of permeable and impermeable layers of rocks. Under the influence of gravity precipitation and surface water gradually penetrate in layers that lie below,

accumulating on the first waterbath. Groundwater aquifers are formed in this way – water layers of rocks containing water, deposited on waterproof layers.

The structure of any aquifer includes the following elements: *bed (water part)*, *aquifer (horizon)* and water table (*rate*) of groundwater .

The shortest distance between the waterbath or groundwater table is called thickness of the aquifer. Location of aquifer bed in space can be horizontal, sloping and curved (synclinal). The area of the Earth's surface, from which water aquifer replenishes its stocks, is called a *feeding area* . If the aquifer is open by ravine, river valleys or other natural decrease, groundwater comes to the surface. The area of leaking water is called *discharge area* or *drainage* , and the place of water outlet – *springs* or *wells* . In the discharge area, water table of the aquifer curves and gets a bent or whirlpool form. Unloading of deep groundwater occurs in the zones of discontinuous tectonic disturbances. If there is a discharge area, water moves toward structures that revealed the aquifer. The velocity of the water is measured in meters per day and the proportion varies from centimeters to 100 m/day. In fine-grained sands water velocity is 1–5 m/day, in coarse grains and pebbles – from several dozens to 100 m/day.

There may be not one, but several aquifers separated by water-impermeable layers in one area. Systems of adjacent aquifers with similar hydrodynamic and hydrogeochemical conditions form aquifers.

With increasing depth of bedding pressure, temperature and salinity of groundwater increases, and they become older.

Since groundwater circulates in rocks, underground hydrosphere is spatially aligned with the upper part of the lithosphere, forming almost a single system – *lithohydrosphere* .

Gravitational (free) groundwater moves in collectors of different types: *porous, fractured, karst* and their modifications. This movement is defined by *geohydrodynamic zonation*. Natural geohydrodynamic systems of three genetic types are formed in most underground water pools: *infiltration, ellisial and thermal hydrodynamic*. (Fig. 4.1).

Infiltration systems are developed in aquifers and complexes, lying at a depth of a few hundred meters (Dnipro-Donetsk basin, Donetsk folded structure). Underground water in reservoirs of various types – porous, karst and cracks move under the influence of hydrostatic pressure, whose value is determined by difference between the sections of hypsometric marks between the aquifers' supply and discharge. The speed of groundwater movement varies from $n \cdot 10^{-3}$ to $n \cdot 10^2$ m/day, and aquifers are "well-washed" in intensive water exchange.

Ellisial water-pressure system is formed in aquifers and complexes deposited under the powerful regional water-impermeable strata (salt, clay, etc.) at depths of thousands meters. Groundwater located in fracture and fracture-pore reservoirs move with very low speed, sometimes not exceeding $n \cdot 10^{-3}$

m/year. They are compared with speeds of oscillatory tectonic crustal movements and changes in structural plans of aquifer systems. Speed of groundwater movement in vertical unloading in zones of tectonic disturbances (in fractured reservoirs) reaches $n \cdot 10^0 - n \cdot 10^1$ m/year.

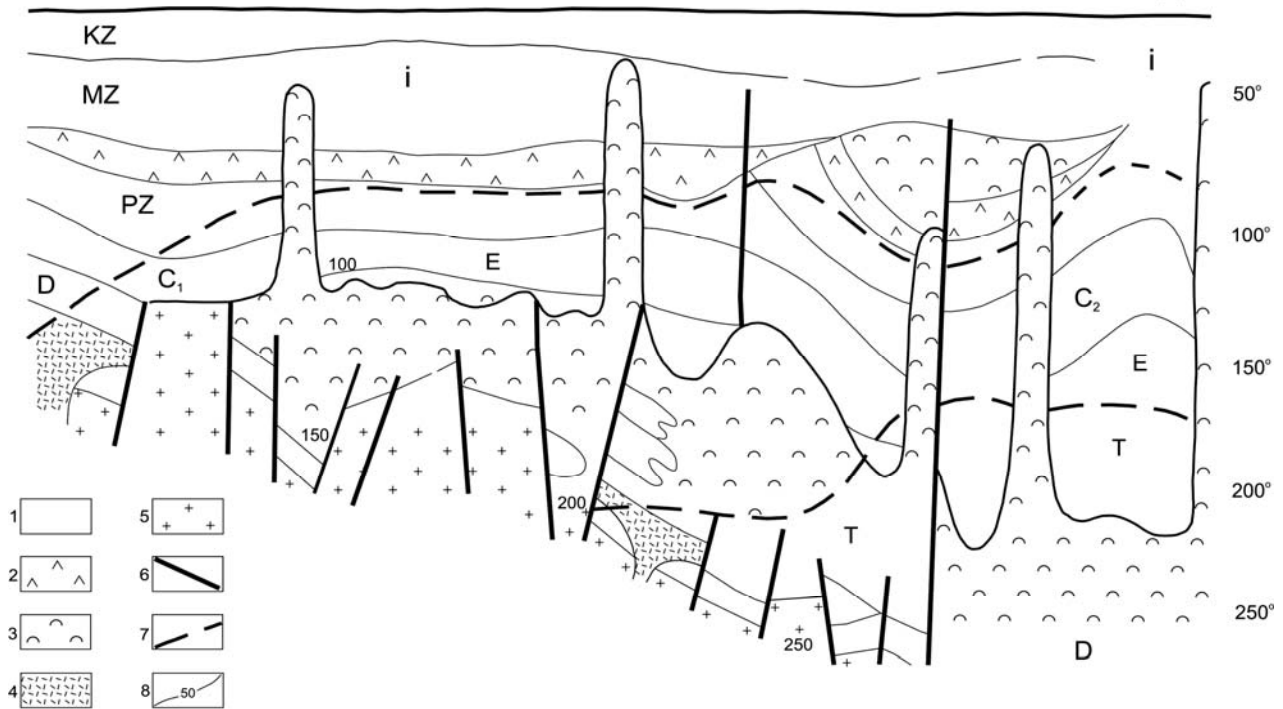


Fig. 4.1 – Geohydrodynamic system of Dnieper-Donets water pressure pool (C. Kolodiy, 1983)

Geohydrodynamic system: I – infiltration; E – ellizial T – thermohydrodynamic;

1 – sedimentary rocks; 2 – permian salt formation; 3 – devonian salt formation; 4 – volcanic rocks; 5 – bedrock; 6 – faults; 7 – border water pumping systems; 8 – heoisotherms, °C

Thermohydrodynamic water-pressure systems develop in most submerged high temperature paleozoic strata. Due to thermal hydration processes water and fluids separate from rocks. Their migration occurs in porous-fractured reservoirs with lower speed than in ellizial systems and is fully determined by tectonic stresses in the Earth's crust. In conditions where unloading of these waters in the zones of faults is complicated, local branches of upper hydrostatic reservoir pressure are formed in some places.

Geohydrodynamic zoning corresponds to *hydrogeochemical zoning*, defined by regular changes in chemical composition of groundwater within certain hydrogeological structures both in areas, and breakdowns. Hydrogeochemical areas are determined by mineralization, ion -salt and gas composition of groundwater.

In nature, as a rule, there is no clear boundary between different zones of *hydrogeochemical zones* (relatively homogeneous physical and chemical

characteristics of groundwater, aquifers and complexes). In hydrogeological structures salinity and alkalinity of groundwater increases with depth, and their chemical composition changes regularly. Thus, hydrogeological section of Dnieper-Donets water-pressure basin has formed groundwater of different chemical composition – from calcium hydrocarbon to sodium chloride, their pH ranging from 4,5 to 9,2, and mineralization varying from 0,1 to 320,2 g/dm³. Among them, from top to bottom, there are main geochemical types of water:

- hydrocarbonate (calcium, magnesium, calcium-magnesium-sodium) with mineralization 1,0–3,0 g/dm³ and pH 6,8–7,2;
- bicarbonate-sulfate (different cationic composition) with mineralization 1,0–3,5 g/dm³ and pH 6,7–7,4;
- sulfate (calcium, sodium, magnesium) with mineralization 3,0–7,0 g/dm³ and pH 5,04–7,6;
- sulfate-chloride, chloride-sulfate (sodium, calcium, magnesium) with mineralization of 3,0–8,0 g/dm³ and pH 6,5–7,8;
- bicarbonate (bicarbonate-chloride) sodium with mineralization of 0,1–2,0 g/dm³ and pH 7,8–9,0;
- sodium chloride (calcium) with mineralization up to 320–340 g/dm³ and pH up to 9,5.

A combination of hydrogeochemical zones can be varied, reflecting the direct, inverse, variable and complex hydrogeochemical cut zoning.

Consistent increase of mineralization and geochemical types of water with depth is understood as direct zoning. *Inverse zoning* or *hydrogeochemical inversion* characterizes decrease of water salinity in terms of depth. In case of variable (complex) zoning, there is no clearly defined parameters of hydrogeochemical changes with depth.

One or other type of geohydrochemical cut depends on hydrogeological history of the region, composition of aquifer rocks, tectonic activity, structure, depth of erosion cut, etc.

There are different classifications of groundwater based on their origins, dynamic features, chemical composition, salinity, temperature, presence of gases, radioactivity, etc. The most common is classification in terms of occurrence in which groundwater is divided into *capillary*, *perched*, *reservoir*, *fracture* and *karst*.

Capillary water fills pores and cracks in the top layer of soil, is not waterproof and takes "hanging" position in the layer of permeable rock. It is in direct proportion to climate conditions and a season, providing moisture to plants.

Perched water – is the highest aquifer in which water is stored in small waterproof lens or light waterproof rocks. It has a small thickness (1–2 m) and is limited in space.

Groundwater is the first from the surface aquifer, which differs from perched water by significant proliferation. Its depth is from several centimeters to tens of meters. It is supplied by rainfall infiltration and surface water in sedimentary rocks. Layers of rock through which water is sucking from the surface are called *aeration zone (infiltration)*. A *zone of saturation* is at its core (waterproof rocks filled with water). Level of groundwater is not permanent. It depends on climatic and weather conditions, increases during the rainy season and flood-time and decreases during the heat. Moving groundwater is called *groundwater flows*. These waters are used for local water supply and often as wells.

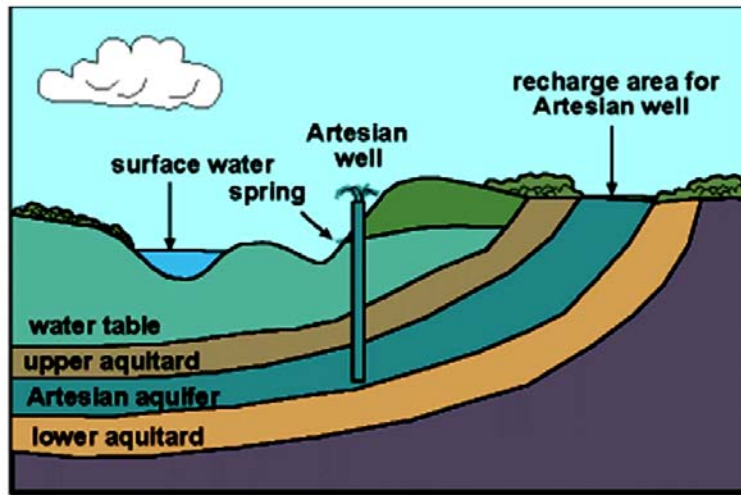
Stratum (between stratum) water, which is typical for the feeding zone, occurs in the aquifer between two water layers, one of which underlies the aquifer, and the other covers it. It is supplied by groundwater overflow of the upper and lower aquifers and complexes. By nature of pressure these waters are divided into *free-flow* and *pressure*.

Pressure underground water, contained in the aquifer between two layers of waterproof rocks, is called *artesian* (Fig. 4.2). Disclosed by wells, under the influence of hydrostatic pressure it rises above the waterproof roof and often gushes. There are three large pools of artesian water in Ukraine: Dniper-Donetsk, Volyn-Podilsk and the Black Sea.

Fissure water is groundwater contained in the cracks of rocks, circulating in fracture zones in crystal, volcanic and sedimentary rocks. There is fissure-vein, fracture-pore, fracture-reservoir and fracture-karst water. The regime, chemical composition and mineralization of the fractured waters are variable. Aquifers of fissure water are often characterized by relatively high filtration properties, low mineralization, free-flow or light pressure regime. It is used for water supply. In Ukraine, there is a large water-pool of fissure waters in the Ukrainian crystal shield and small amounts of fissure waters in the Carpathians, the Crimea and the southern slope of Voronezh crystalline massif.

Karst water is groundwater confined to the caverns in carbonate, halogen, halogen-carbonate and other rocks. It sometimes occurs in artesian basins in a layer form. It is characterized by high filtration rate and turbulent motion. Its chemical composition depends on the composition of rocks. It can be fresh hydrocarbon (calcium, magnesium, sodium) water and sodium chloride brines with mineralization above 100 g/dm^3 . Karst water is developed in carbonate rocks in Donbass, the Carpathians, the Crimea, halogen sequences of Dnieper-Donets basin.

Natural exits of underground water to the surface are called *sources*. Sources are formed on the landscape forms that revealed the aquifers, on the banks of rivers and seas; on the slopes, ravines or in zones of discontinuous tectonic disturbances. According to the direction of underground water flow sources are divided into *ascending* and *descending* (fig. 4.3).



<https://slideplayer.com/slide/10004232/>

Fig. 4.2 – Scheme of artesian basin structure

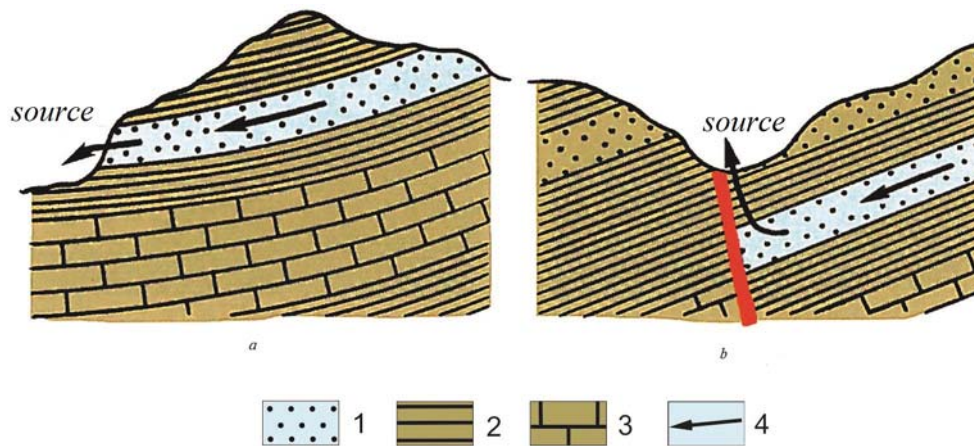


Fig. 4.3 – Sources of groundwater:

a – downlink; *b* – rising; 1 – bearing sands; 2 – waterproof clay; 3 – limestone;
4 – direction of groundwater movement near the source

Ascending sources are typical for perched water discharge and groundwater, and descending – for artesian water reservoir. According to temperature they are divided into cold and hot (thermal), and according to the mineralization degree – into *fresh* and *mineralized*.

The amount of water that pours from the source (and a well, revealing aquifer) per unit of time is called *discharge*.

4.3. Physical properties and chemical composition of groundwater

Groundwater is characterized by physical and chemical properties according to particular filtration and depth of aquifers' location.

Physical properties are color, clarity, smell, taste and water temperature. Groundwater usually has no color. Only in the presence of impurities it acquires different shades. So, oxidation compounds of iron give yellow and red hues; ferrous compounds of iron and hydrogen sulfide – greenish-blue; – suspension and colloidal particles – gray, organic products, etc. – brown.

Dissolved salts in groundwater give it taste: NaCl – salty, KCl – bitter and so on. In most cases, groundwater has no smell. However, water containing H₂S, smells of rancid eggs, water containing organic substances smells of swamp. The temperature of ground water varies from 8-10 to 350–400°C. The lowest temperature is characteristic of regions with permafrost and the highest – for volcanic waters. Depending on the temperature, underground water is divided into *cold* (below 20°C), *warm* (20...37°C), *hot* (37...42°C) and *thermal* (over 42°C). In Ukraine, cold water is dominant. In the mountainous regions of the Carpathians and the Crimea there is warm and hot water. Groundwater with no color, clear, cold, odorless and with pleasant taste is used for drinking. Treating water may have certain other properties that distinguish them from drinking water.

Chemical composition of drinking water is determined by the geological history of geological structures' development, mineral composition of water containing rocks, water circulation conditions, climate and, finally, anthropogenic influence. Moreover, anthropogenic and climatic factors have the most important influence in the upper groundwater aquifers (especially in vadose and groundwater). Circulating in different types of reservoirs, underground water, dissolving minerals and rocks, is enriched with various chemical elements and compounds.

Groundwater is a complex aqueous solution. In its composition there are: macro and microcomponents, gases, organic substances, microorganisms. Isotopes of chemical elements in water and dissolved substances in it are of great importance. Today, 85 (from 105) elements of the Mendeleev periodic table are determined by different methods of analysis in groundwater that characterize general chemical type of water, its properties and have a particular scientific or practical value.

According to the State standards, natural water is divided by the value of mineralization into the following groups: *fresh* (up to 1 g/kg), *slightly salty* (from 1 to 20 g/kg), *salty* (20–35 g/kg) and *brines* (more than 35 g/kg). In turn, brines are divided into *very weak* (less than 70 g/kg), *weak* (70–140 g/kg), *strong* (140–270 g/kg), *very strong* (270–350 g/kg) and *super strong* (from 350 to 760 g/kg).

Macro components determine a chemical type of water, its overall mineralization (dry residue) and the name of the general chemical composition. The main macro components are cationic – the most widespread in the Earth's crust (Ca, Mg, Na, K, Fe) and anionic (Cl, S, C, Si) elements. Possible

accumulation of a certain macrocomponent in the water is defined by solubility of compounds formed by the main cationic elements with key anionogeneous elements. Increase in groundwater salinity is due to appearance of soluble compounds in a solution. Super strong chloride sodium brines are the most mineralized (M to 760 g/dm³), and the least mineralized (M less than 10 mg/dm³) are ultra fresh sodium bicarbonate water.

Micro components are in underground water in small amounts, determined by milligrams, micrograms and parts of micrograms in 1 dm³. Sometimes their concentration reaches an amount equal to the contents of macrocomponents. In this case, they are included in the formula of water chemical composition, determining its overall chemical type. Many micro components (Fe, Mn, Cu, Zn, Pb, Al, Be, Mo, As, Se, Sr, F, etc.) must be determined in fresh water because they define its toxicological and other indicators.

Different types of mineral water have *therapeutic effect* on the human *organism* due to biologically active trace elements (Fe, Br, I, B, As, Si, F) in it. Such microelements as I, Br, B, Li, Pb, Sr, W, S, Y, etc. are removed from *industrial water* (which is hydro-raw materials). The total number of chemical elements removed from the groundwater at industrial scale and perspective for exemption is 30. As indicator elements Ag, As, Au, B, Cu, F, Fe, Hg, Li, Mo, Ni, Pb, Zn, Sn, V, U, Ra, etc. (all 50 items) are widely used in *hydrogeochemical exploration* (according to chemical composition of groundwater) as indicator elements.

A wide range of *organic compounds* represented by all groups (carbohydrates, proteins, lipids) and classes (carboxylic acids, hydrocarbons, alcohols, aldehydes, amines, esters), studied by organic chemistry, is in groundwater. The most important characteristic of water-soluble organic matter is their amount and the total content of chemical elements that make up the individual organic compounds (Corg., Norg., Porg.).

The most important *microorganisms* in groundwater are bacteria, microscopic algae, protozoa and viruses. The bacteria group includes most of the unicellular microbes.

Gases in groundwater are in adsorbed, dissolved and free states. Between free and soluble gases there exists a dynamic balance, which is broken under the temperature and pressure. The main gases in groundwater are: O₂, N₂, CO₂, H₂S, H₂, NH₃, He, Rn, Ne, Ar, Xe, Kr. By origin they are divided into groups:

- air (N₂, O₂, CO₂, Ne, Ar), entering the groundwater from atmospheric air;
- biochemical (CH₄, CO₂, N₂, H₂S, H₂, O₂, heavy hydrocarbons), formed by decomposition of organic microorganisms and minerals;
- chemical (CO₂, H₂S, H₂, CH₄, CO, N₂, SO₂, NH₃), formed by the interaction of water and rocks;
- radioactive and nuclear reactions (He, Rn).

Isotopes – variations of the same chemical element that differ in mass of atoms. There are stable and radioactive isotopes of chemical elements both of water (H and O), and macro and micro components in it.

The study of natural isotopic composition of groundwater and artificial radionuclides as indicators of hydrogeological, hydrogeochemical, ecological processes is essential. First of all, it is determination of groundwater age, identification of groundwater supply areas, determination of oil and gas deposits age, issues of environmental protection and others.

To analyze the chemical composition of groundwater physical-chemical (colorimetric, kinetic, fluorescent, electrochemical) and physical (spectral, radio activated, roentgen spectrum) methods are often used.

The results of chemical analysis of groundwater can be represented in various forms – ionic, equivalent and percentage-equivalent. The most common form of groundwater composition is *Kurlov formula* (pseudo fraction, the numerator of which is specified in content-percentage equivalent form of the major anions and the denominator shows the content of basic cations). Moreover, the value of content elements and compounds is written in the form of chemical symbols.

Ions are placed in descending order of concentration in the solution. The ions in an amount of less than 1 percent equivalent are usually not shown in the formula. In determining a chemical type of water we consider only ions with concentrations equal to 25 or more percentage-equivalents. The most important gas-like components of water value and its overall mineralization (M) in g/dm³ are written before the fraction. After the fraction pH (and temperature Eh, etc.) is written, for example:

$$M_{2,5} \frac{\text{HCO}_3 \quad 60 \quad \text{Cl} \quad 25 \quad \text{SO}_4 \quad 13}{\text{Na} \quad 41 \quad \text{Ca} \quad 38 \quad \text{Mg} \quad 20} \text{pH } 7,2; \text{Eh}+0,5. \quad (4.3)$$

In oil and gas hydrogeology water analyses are given in ionic, equivalent, percentage-equivalent forms, using the so-called Palmer's characteristics.

We can show chemical composition of water in graphs – circles (graph – Tolstihin's circle) and other geometric shapes. Very often oil and gas hydrogeologists use V. Sulin's classification.

A special form of graphic description of groundwater's chemical composition is hydrogeochemical maps and sections.

Test questions to the theme

1. *What water is called underground?*
2. *What causes groundwater to move?*
3. *What types of water are found in rocks?*

4. *What is a source?*
5. *What types of groundwater sources do you know?*
6. *How is juvenile water formed?*
7. *What is porosity of the rock and how is it determined?*
8. *What is permeability of rocks and its definition?*
9. *What is water bath, fluid part?*
10. *State the law of Darcy and explain where it is used.*
11. *What is filtering coefficient?*
12. *What is the water loss of rocks and how is it determined?*
13. *How are near-surface aquifers formed and what is their structure?*
14. *What is aquifers and aquifer complex?*
15. *What classification of groundwater do you know? What are they based on?*
16. *What are pressure and non-pressure underground water?*
17. *How is groundwater divided on the degree of salinity?*
18. *Describe physical properties of groundwater.*
19. *How is groundwater divided according to temperature?*
20. *What groups is natural water divided into according to mineralization degree?*

CHAPTER 5

TECTONIC PROCESSES

By *Tectonic processes* (greek. *tektonos* – creating) we mean redistribution of rocks weight in the Earth's lithosphere and upper mantle (tectonosphere), whose energy source is endogenous energy. Its generation is connected with its physical and chemical transformations at different levels of deep subsurface (radioactive decay, chemical reactions) and formation of the Earth's gravitational field (due to the influence of Sun, Moon, planets and galaxies in general).

5.1. Manifestations of tectonic processes

Manifestations of tectonic processes are *tectonic movements* that lead to changes in both forms of occurrence and internal structure of rocks. Under the direction of shear efforts they are divided into *radial* or *vertical* and *tangential* or *horizontal*. By the speed they are *slow* and *fast*, by the interval of action – *constant* and *periodic*, according to time – *modern*, encompassing the historic period (last 6–8 thousand years), *neotectonic*, which occurred in Quaternary and Neogene periods, and *old*, which occurred on the Earth before neogenious time. As a result of actions on lithosphere tectonic movements are divided into *oscillation*, *folded* and *discontinuous*.

Radial movements are directed along the Earth radius vertically. Movements have ascending or descending nature and lead to lifting or sinking of the Earth's surface. By the speed of distribution in the area and the changes that occur in the Earth's crust vertical movements are divided into *vibration*, *wave* and *boulder*.

Vibration motion is a slow secular uplift or sinking of the Earth's surface. They cover large areas. They take place smoothly and continuously so slowly that they are practically not felt by man. Their effects can be seen only after long periods of time according to changes in the height of landscape elements. Thus, sinking of the crust in the Netherlands and neighboring countries that has been going on for more than 700 years, has resulted in the fact that much of the western coast of Europe stretching for over 1600 km sunk below the level of sea currents flow. Dams are built to prevent flooding of lands in these areas.

Wave movements are a kind of oscillatory movement, causing uplifts in some crustal areas, and in the related areas– sinking. Wave movements can be traced on the example of surface oscillation marks in Ukraine. In the direction

from north to south there is changing of sinking by elevation and vice versa. In some regions elevation of areas reaches 10–12 mm/year or more (district of the town of Konstantynivka, Donetsk region), while others sink at speeds up to 5.7 mm/year (southern coast of Crimea).

Blocky movements, creating enormous pressure on the rock layers in the depths, break open the Earth's crust into pieces or chunks. Blocky movements occur quickly and dramatically. They are of unstable character. On the ground and ocean bottom blocky structures look like mountain uplifts (the Carpathians, Crimea) or deep chasms (the Dnieper-Donetsk paleoryft).

Tangential movements unlike radial ones have horizontal orientation. There are rotational, folded, sliding tangential movements.

Rotational movements occur at the border of physically heterogeneous geosphere of the Earth: a core and a mantle, a mantle and a crust. They are connected with the forces of the Earth's rotation (hence their name). With a variety of momentum and moment of inertia, earth shells are shifted relative to each other during rotation. Quite other reasons are at the heart of the folding movements that cause the layers of rocks to collapse into folds. Folding is the result of gravitational and tectonic forces on sub plastic weights of rocks. Most geologists explain the action of folding by side compression that appear on active crust. Folding movements are usually accompanied by orogeny (the Carpathians, the Caucasus, Crimean mountains, etc.).

Shift-type movements are defined as tangential and vertically directed forces. They occur along oceanic faults and continental crust that restrict individual lithospheric plates.

By direction tectonic movements are divided into *essentially vertical* and *essentially horizontal*. Both can be *upper* (blanket) that affect only the uppermost layers of the Earth's crust, *crusted*, distributed to the entire crust and *deep*, covering also the upper mantle of the Earth. Depending on the nature of the deformations, the types of tectonic movements are distinguished by motions of folded, block and boulder nature.

Tectonic movements deformed the crust layers throughout its existence, creating a variety of tectonic structures. *Geotectonics* studies tectonic movements of the crust in the geological past. *Neotectonics* studies the latest and current tectonic movements. The movements of the crust are caused by magmatism, playing a significant role in the formation of hydrocarbons and other minerals and rocks. They change the topography of the Earth, creating high mountains and deep depressions.

5.2. Vibration movements

Displacement of the shoreline of the seas and oceans is associated with the vibrational movements of the earth's crust. The indentation of the sea, caused by

the rise of the Earth's crust, is called *maritime regression*. In case of sinking of the Earth's crust, a reverse phenomenon occurs – *transgression* (offensive of the sea to land with the flood of its large areas). Since the velocity of oscillatory movements is measured in fractions of a millimeter or several millimeters per year, their apparent effects are revealed only after a certain time. But this does not mean that the vibrational motion can be ignored. On the Black Sea coast of Crimea, the coastal strip in the area of Koktebel Bay is systematically submerged below the sea level. As a result, sanatorium beaches began to disappear underwater. Such phenomena are observed in different regions of the world. Thus, on the California coast of the United States, transgression of the ocean flooded half of the naval shipyard. The Temple of Seranis, built in the second century BC on the shores of the Bay of Naples (Italy), plunged into the water repeatedly and rose again above the sea level.

Modern vibration movements are recorded by aerospace, geodesic and geophysical instruments. Multiple measurements of continents indicate that some areas of land go higher and some are set up, while others sink. Higher marks are on the islands of the Arctic Ocean (Svalbard, New Land). Hills of Greenland, Iceland, Scandinavia, southern Alaska, the coast of the Great Lakes in North America and other areas rise. Speed of lifting surface is from a fraction of a millimeter to a few centimeters a year. Uplifting covers Donetsk ridge also.

Land immersion is recorded in Northern Europe on the southern coast of England, California, Peru, Australia, Ukraine – on the Black and Azov seas and in many other regions of the world.

The study of oscillatory motions is carried out by historical, geodetic, geomorphological and geological methods.

Historical method is the survey of historical monuments, the study of archaeological finds and documents (including maps).

Geodesic method is based on releveling every 7–8 years. The obtained data are compared with the previous results and determine the position of the land surface. This method allows you to accurately determine the amplitudes of tectonic movements, including even very weak ones.

Geomorphological method underlies the study of the latest tectonic movements. The patterns of terrestrial surface topography and their altitude change determine the nature of the earth's crust fluctuations. Mountains with marine sediments on the peaks indicate the long rise of large sections of the earth's crust, and depressions – the immersion of territories.

Geological methods are used to study both recent and ancient tectonic movements. These include: the stratigraphic method; method of comparison of thickness of layers; facial-paleogeographic analysis; sequence analysis of layers, breaks and inconsistencies, geophysical methods.

Stratigraphic method is based on the comparison of facies. Changes in the geological section of the marine facies to the continental uplift indicates the elevation of the site, and the continental on the maritime facies – the immersion.

Lifting may result in the deposition of sediment accumulated on the seabed to the bottom surface. In case of new submergence of this area new marine sediments will accumulate on the eroded surface.

In this case, separate layers will fall out of the section, breaking the continuity of sedimentation and the age sequence of sediments. Such violations can be established by analyzing *breaks* and *disagreements* in sediments. The presence of erosion in the rocks and the geological section of individual stratigraphic units indicates a *continental break* and *stratigraphic mismatch* in sedimentation.

Speed and time of tectonic movements are established by facial-paleogeographic analysis and layer thickness analysis.

On the basis of the first orientation and speed of tectonic movements are determined by the forms of terrestrial topography, conditions of sedimentation, lithological composition of the rocks. In the second case, the length of sedimentation processes is judged by the thickness of the sediment layers.

Paleogeographic curves are constructed according to the analysis of sedimentary strata, showing the sequence of sediment layering on a certain scale.

Aerospace methods of studying tectonic movements are becoming increasingly popular.

Tectonic movements are one of the determining factors controlling the course of geological processes. They affect the conditions of sedimentation, including the location of oil, gas and other minerals accumulations, determine the geological structure of the earth's crust, create positive and negative forms of topography, change the contours of land and sea.

5.3. Tectonic deformation and elements of rocks occurrence

Tectonic deformations (deformatio – distortion) – change of forms and volumes of geological rocks in individual parts of the crust under the influence of tectonic forces. Deformations are divided into *elastic* (plastic), *plastic* and *tensile*. In elastic deformations the body shape is restored after removal of load. Plastic and bursting deformations of rocks are irreversible. Most of them undergo all three types of deformation under increased load. Rock deformation is due to static (rock pressure) or dynamic (tectonic movements) loads.

Plastic deformations are particularly important in deep areas of the Earth's crust. They occur by tectonic movements in certain directions without breaking the layers of rocks. Discontinuous deformations are accompanied by fracturing due to excessive efforts that cause plastic deformations.

The rocks that form the crust, occupy a certain spatial position in it, having a shape and size. In igneous rocks the occurrence form is most often irregular (batholiths, stocks, veins), and in sedimentary rocks it is predominantly sustained in distribution and thickness. The form of rocks occurrence, acquired by them during the formation, is called the *primary* or *intact form*.

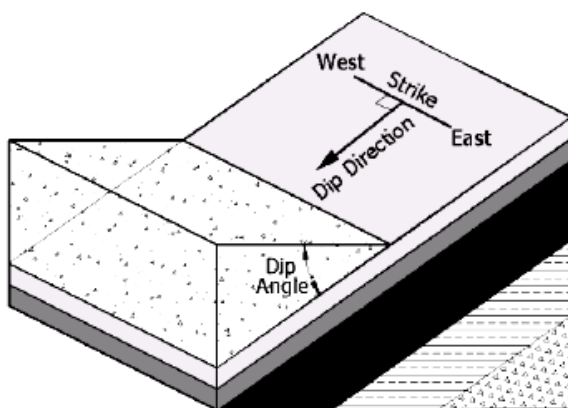
The most common form of occurrence of sedimentary rocks is a *layer* or *stratum* – a geological body, made up of homogeneous sedimentary rock. It has an isolated *roof*– an upper limiting surface and a *sole*. The shortest distance between them is *thickness of a layer* . Sometimes sedimentary rocks occur in the form of *lenses* – a geological body that wedge in all directions.

The provisions of the layer in the space is defined by elements of dip: strike, fall, angle of incidence (Fig. 5.1).

The position of the layer in space is determined by the elements of occurrence: extension, falling, angle of incidence (Fig. 5.1).

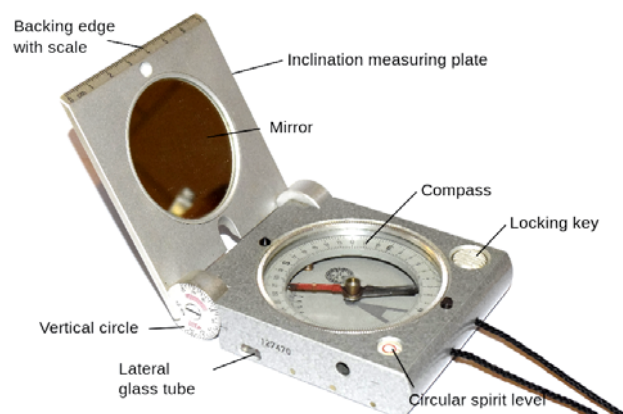
The extension of the layer or its length in space is expressed by the line of extension formed by the intersection of the horizontal plane with the surface of the layer, the fall – the line of incidence that lies in the plane of the layer and is perpendicular to the line of extension. The spatial position of these lines is measured by azimuths.

The azimuth of extension is the right vertical angle formed by the magnetic meridian and the line of extension; the azimuth of the fall (as opposed to the azimuth of the stretch) has a fall line as the measurement direction; angle of incidence – the angle formed between the line of incidence and its projection on a horizontal plane. The elements of the occurrence are determined by using a mining compass (Fig. 5.2).



https://www.researchgate.net/figure/Dip-and-Dip-direction-angle-definition_fig3_237033299

Fig. 5.1 – Elements of rocks formation



<https://courses.lumenlearning.com/geo/chapter/reading-geologic-tools/>

Fig. 5.2 – Mining (geological) compass

A *mining compass* is a magnetic device used in geological practice to orientate the terrain, visual recordings and identify rock elements.

Tectonic movements, which are diverse in shape and direction, are the disturbance cause of the primary occurrence of rocks.

Under the action of oscillating, folding, viscous or displacement motions, magmatic bodies, metamorphic and sedimentary strata change positions in space. Layers of plastic sedimentary rocks under the influence of horizontal and vertical deforming forces bent, taking the form of folds.

Harder rocks (sandstone type), bending, are broken by cracks.

The change in the primary occurrence of rocks is called *tectonic disturbance*. Tectonic disorders are divided into folds or plicate (lat. *plikatus* – folded) and discontinuous or disjunctive (lat. *disjuncto* – divide). The type of disturbance allows you to reproduce history of crustal movements in this area at a long geological time and to establish whether these were rock-forming movements or movements caused by other processes.

Tectonic structures formed as a result of tectonic movements usually contribute to the creation of conditions for the accumulation of oil and gas, as well as formation of other mineral deposits. For example, in fracturing structures, ore-bearing solutions deposit hydrothermal minerals of lead, copper, mercury, gold, silver, etc. Folding structures are a kind of trap for the accumulation of hydrothermal mineralization and hydrocarbons. Fracturing breaks sometimes destroy previously formed fields. Therefore, the study of tectonic forms and the dynamics of their formation allows geologists to navigate the search and exploration of mineral deposits.

The science of geotectonics deals with the study of *geotectonics*, while *structural geology* deals with the geological forms resulted from tectonic movements.

Under the influence of vibration, folded, clod or fault igneous body, metamorphic movements and sedimentary strata change their position in space. Layers of plastic sedimentary rocks under the influence of horizontal and vertical deforming effort bended, acquiring the form of folds.

Folding tectonic disturbances

The main type of folding disorders is the fold. The fold is called a wavy bend in a layer of rocks formed during their plastic deformation.

The folds are convex – anticlinal and concave – syncline (Fig. 5.3). In their structure we distinguish wings, a lock and a core.

Tighter rock (sandstone-type), bending, break into crack.

Change of primary occurrence of rocks is called *tectonic violation*. Faults are divided into *folded* or *plicative* (lat. *plikatus* – folded) and *discontinuous* or *disjunctive* (lat. *disjuncto* – divide). The type of violations allows us to reproduce the history of crust movements in this region in the distant geological time.

Formed as a result of tectonic movements, tectonic structures usually contribute to the creation of conditions for oil and gas accumulations, as well as the formation of other mineral deposits. So, *explosive structures* of ore-bearing hydrothermal solutions lay minerals of lead, copper, mercury, gold, silver, etc. Folded structures are sort of traps for hydrothermal mineralization and accumulation of hydrocarbons. Faults sometimes destroy the deposits that were formed earlier. Therefore, the study about tectonic forms and dynamics of their formation allows geologists to understand prospecting and exploration of mineral deposits.

Researching of tectonic disturbances engaged the science called *geotectonic* and geological forms, which are formed by tectonic movements – *structural geology*.

Folded tectonic disturbances

The main type of *folded violations* are fold. *Folds*, called wavy, bend in a layer of rock formed in the process of plastic deformation.

Folds are convex – *concave* anticline and – *synclinal* (Fig. 5.3). There are wing, lock and core in their structure.

The wings are the lateral parts of the fold. The place of their closure (the largest bend) is called a lock. The part of the fold that lies between the wings and the lock forms its core. The cores of anticlinal folds contain older rocks than the wings, and younger rocks are found in synclinal folds.

There are concepts about the geometric elements of the fold – axial surfaces, hinges, axes and corners of the fold, studying the folds and determining their position in space.

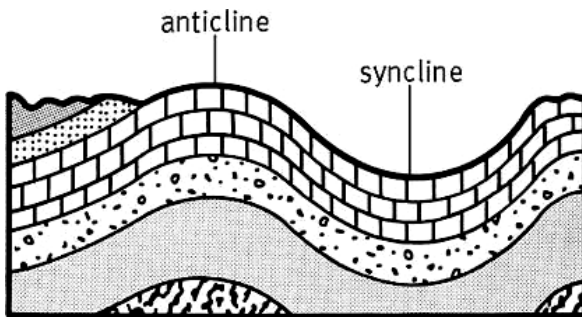
The axial plane (surface) is an imaginary plane that passes through the fold lock and divides it approximately into two symmetrical parts. Cutting the fold along the axial plane forms a line of intersection with the surface of each layer of rocks – the hinge fold.

There are as many hinges as the layers in the folds. The hinge behaves in the space as the fold. If the fold is submerged or deflected sideways, the hinge draws a wavy line in space.

Extending the axial surface to the intersection with the earth's surface, we get a new intersection line – the axis of the fold, which coincides with its extension. If we continue in the space of the wings until they intersect, we get the *angle of fold* α (Fig. 5.4).

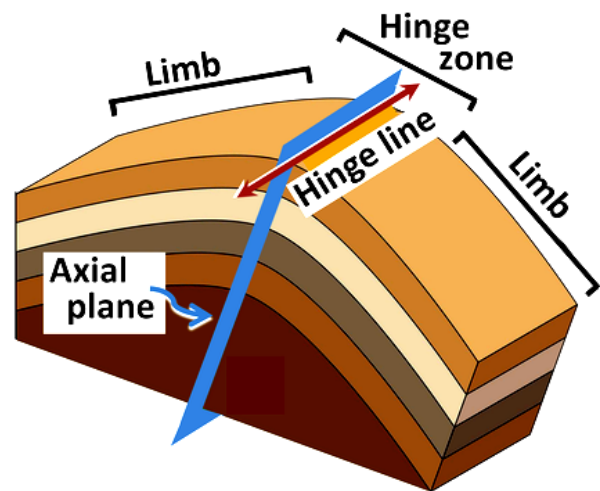
Most folds have a linear-elongated shape. Their length ranges from tens of meters to hundreds of kilometers. The size of the folds is determined by the height, width and length. The length has linear measurements from one closure (in plan) to another. Because folded structures are usually an alternation of anticlines and synclines, the height of the fold is taken as the distance between the highest point of the anticlinal and the lowest – adjacent syncline, which is

measured by the roof or sole of the same layer of rocks. The width of the fold is determined by the distance between two adjacent anticlinal or syncline folds.



<https://www.pinterest.com/pin/726486983610466655/>

Fig. 5.3 – Types of folds



<https://www.wikiwand.com/en/Anticline>

Fig. 5.4 – Element of an anticlinal fold

Individual folds occur rarely in nature. More often, they are observed as whole complexes of structures different in morphology and origin.

According to the position in the space of the axial plane and wings we distinguish folds: *straight, oblique, inverted, lying, tilted*. Peculiar east-frequent folds (in which one wing is vertical and the other is sub-horizontal) are called flexures. (Fig. 5.5). The morphological features of the lock distinguish *ridge-shaped, chest, fan-shaped and isoclinal* folds.

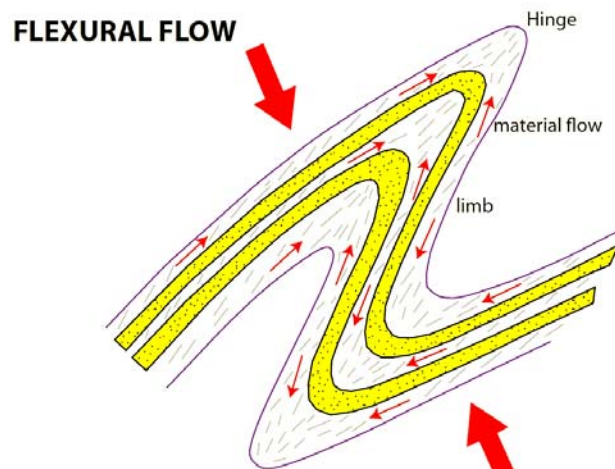
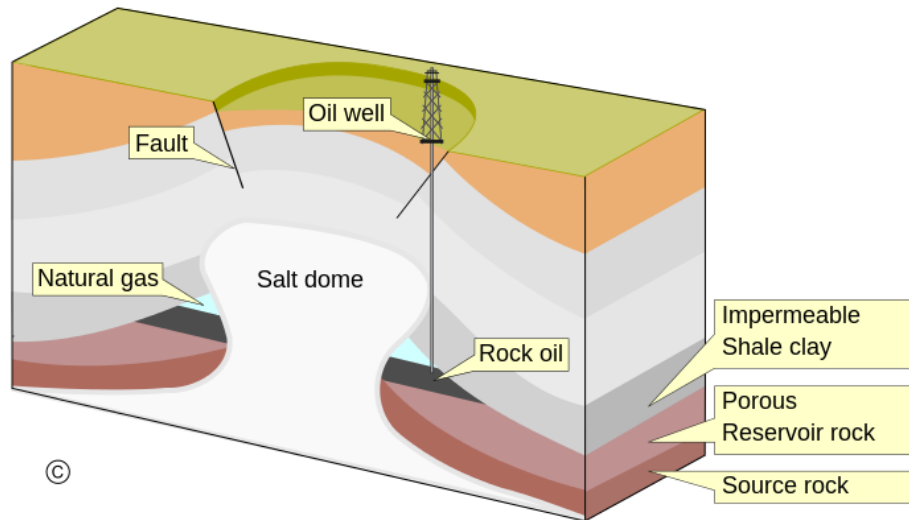


Fig. 5.5 – Flexural flow

<https://www.geoexpro.com/articles/2015/01/folds-and-folding-part-ii>

The most common are closed structures – brachy folds (Greek. *brahis* - short) – relatively short lengths (hundreds of meters, first kilometers) of folded

structures in which the length corresponds to a width of no more than 5: 1, and arcuately curved hinge. Among them there are *brachyanthyclinal* and *brachysynclinal*. Brachyanthycline structures often serve as traps of oil and gas in different regions of the world, including Ukraine. If the ratio of length to width of the folds is close to 1: 1, then the anticlinal folds are called *domes*, and the synclinal folds are called *moulders*. The domes formed as a result of spinning from the depths of plastic rocks (salts, clay) are named *diapiric structures* (Fig. 5.6).



<https://www.geologypage.com/2015/02/petroleum-traps.html>

Fig. 5.6 – Diapiric oil and gas structures

The nature of the folds is determined by the properties of the rocks and the degree of tectonic activity of the crust. In regions with relatively calm tectonic regime of the crust, there are some folds with inclined fall of wings. In places where active tectonic movements occurred, groups of linearly elongated folds are formed with steeply falling wings. Plastic rocks form folds of more complex shapes.

The fold group is called a *folding*. In the vast majority of cases, the folds in the earth's crust are formed by magmatic, metamorphic, and tectonic processes. Tectonic movements, which create the largest folded structures, occupy a special place.

Oscillatory movements cause the formation of *steep, sloping, closed* in terms of groups of folds, called *anticline* (anticlinal structures) and *syncline* (syncline structures).

The structures of the mountainous areas – anticliniums and synclines have a more complex shape and a considerable length. Anticlinories are complex anticlinal structures of hundreds of kilometers in length, formed as a

result of the earth's crust rise. They are complicated by smaller folding (advanced ridges of mountains) on the wings.

Synclinorias are large dome sites filled with folds and smaller sediments than in neighboring regions.

A study of the geological structure of the crust shows that not only individual layers but entire thicknesses of rocks become crumpled into folds. The folding of the lower strata is often different from the folding of the overlying rocks. The boundary dividing the strata of different ages with different angles of rocks occurrence is called *angular mismatch*.

Discontinuous tectonic disturbances

Tectonic disturbances with rupture of rocks are called *ruptures*. The gap looks like a crack that divides a monolithic rock into parts or blocks. Depending on the direction of forces, the blocks of rocks either remain in the previous state after the break, or shift relative to each other. Therefore, all breaks are divided into two groups: *non-displacement breaks and displacement breaks*.

Breaks without displacement (cracks). Cracks are present in any rock. They differ in size, position in space and origin. Cracks, that are invisible to the naked eye, are called microcracks. The cracks that are visible usually have a width of several millimeters to tens of meters. Most of them are filled with mineral matter. Mineral bodies that fill the cracks are called veins. Cracks are open, closed and blind. Blind cracks have no surface access.

According to the position in the geological space, the cracks are *horizontal* (incidence angle $0-10^\circ$), *obliquely falling* ($10-50^\circ$) and *steeply falling* ($50-90^\circ$). Most often, cracks form systems called *fractures*.

The depth of cracks is determined by the nature of their formation. *Exogenous cracks* associated with the processes of physical weathering have a depth of up to the first tens of meters. *Endogenous cracks* are traced by geophysical devices to depths of hundreds of meters to tens of kilometers.

The formation of such tectonic forms is mainly related to the action of endogenous forces aimed at compressing or stretching rocks. Position in the geological space distinguishes cracks as horizontal (angle of $0-10^\circ$), falling obliquely ($10-50^\circ$) and falling steeply ($50-90^\circ$). Most cracks - forming systems are called *fractures*.

The depth of the cracks is determined by the nature of their formation. *Exogenous cracks* related to physical weathering processes have depth to a few tens of meters. *Endogenous cracks* are observed with geophysical instruments at depths of hundreds of meters to tens of kilometers.

The formation of such tectonic forms is due mainly to the action of endogenous forces aimed at compressing or stretching of the rocks. In a displacement burst, we distinguish the mixer, wings or blocks and the

displacement amplitude. Displacement (C) is a crack along which displacement of torn sections of the earth's crust occurs. The surface of the displacer walls is usually smoothed, and in solid rocks – polished. Sometimes scratches are left on the walls by fragments of solid minerals.

They are observed on the walls. Direction of the blocks movement is determined by the direction of scratches. Blocks or wings (A, B) are sections of the earth's crust (layer, thicker), located on either side of the mixer (Fig. 5.7).

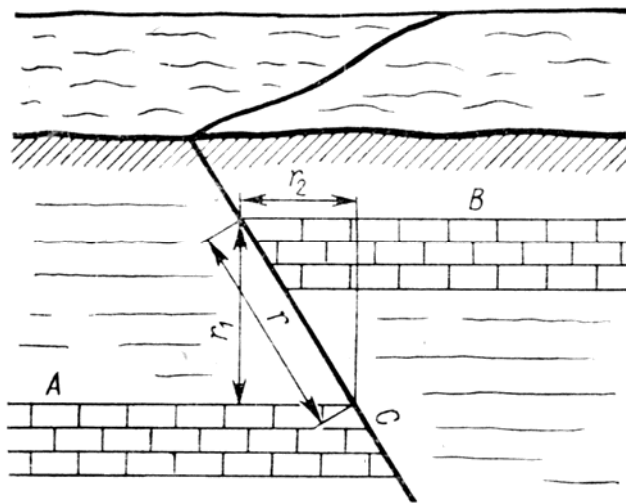


Fig. 5.7 – Elements of faults:

A – lying wing (embedded);

B – hanging wing (raised);

C – mixer;

r – true amplitude;

r_1 – vertical amplitude;

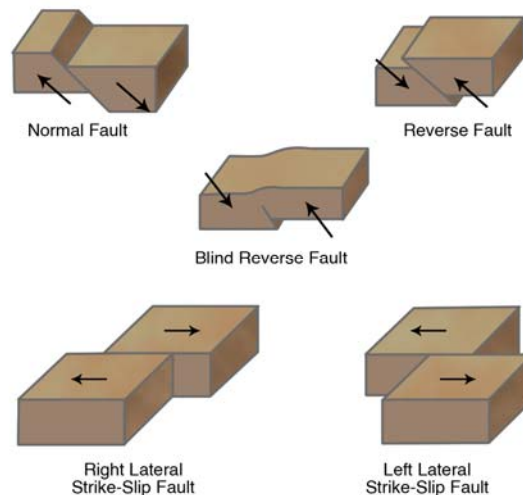
r_2 – horizontal amplitude

In relation to one another, the wings can be lifted, lowered, moved. An *immersion* is called a block or wing that is displaced relative to the other down. The wing that is moved up is called *raised*. In the inclined position of the mixer, the wings above the mixer are called hanging, and below them – lying. The distance at which the wings are displaced relative to each other is the displacement amplitude. It is vertical, horizontal and true. Vertical amplitude is the distance between the roof (sole) of the wing lifted and the roof (sole) of the sunken wing. The true amplitude is also determined by the mixer in the same way.

Horizontal amplitude indicates how far the fractured layer wings are slid horizontally. In the direction of blocks movement, the spatial position of the mixer and some other special features distinguish such types of discontinuous disturbances as discharges, tilts, landslides, etc. (Fig. 5.8).

A *reset* is a discontinuous violation in which the mixer is tilted towards the submerged wing and the hanging wing is offset relative to the recumbent. Discharges are thought to be formed by stretching the crust.

When compressing the crust, the hanging wing moves up the mixer, forming a discontinuous violation – throw. In tilts, the mixer tilts to the side of the raised wing, and the hanging wing is positioned higher than the recumbent one.



<https://open.oregonstate.edu/earthquakes/chapter/earthquake-basics/>

Fig. 5.8 – Breaking tectonic disturbances

Pulling morphologically resembles throw. It differs from it by more inclined position of the mixer: in throws it is tilted at an angle of more than 45° , in the pulling – up to 45° . Another distinguishing feature of pulling is a significant amplitude measured in hundreds of meters, sometimes in tens of kilometers.

The *shift* is formed by horizontal movement of crustal blocks along old or steeply falling mixer. Sometimes landslides coexist with faults or throws, forming structures of combined type – throw faults or shift faults. They are characterized by offset of blocks both in vertical and horizontal directions.

Stepping discharges and throws, horsts and grabens are complex breaking disturbances.

Stepping reset is a system of parallel mixers, in relation to which there is a stepped sinking of blocks.

Stepping tilting is formed when there are tilting steps between the parallel mixers.

Horst (German. horst – height, hill) – an elevated block section of the earth's crust, limited by discontinuous disturbances (discharges or throws).

Graben (German graben – moat) – a chasm or depression formed by the sinking of a block of the earth's crust section by discharge or throws.

Faults are gigantic breaks in the lithosphere that often have their roots in the mantle (deep faults). On the Earth's surface, faults are determined by the zones of blind and open cracks. They are well visible from space. The width of the fault zones is 1–2 km, sometimes tens of kilometers. Fracture lengths are hundreds and thousands of kilometers. Along the faults, blocks of the Earth's crust move.

The geological role of the faults is very important. They are channels through which the deep zones of the Earth are connected with the upper layers

of the Earth's crust and its surface. Magma takes root in them, hot fluids and hydrothermal solutions arrive, modern heat and mass transfer takes place.

Oil, gas and other mineral deposits are often associated with faults.

Deep faults separate individual lithospheric plates. They are associated with both modern and ancient tectonic movements of the crust. On the ocean floor, mid-ocean ridges extend along the deep faults, which are often the boundary of oceanic lithospheric plates of different orders.

Test questions to the theme

1. *What is the energy source of tectonic processes?*
2. *What are the consequences of tectonic processes?*
3. *How are tectonic movements divided?*
4. *How do tectonic movements affect topography?*
5. *Explain the phenomenon of marine regression and transgression.*
6. *What is the basis of the oscillatory movements study?*
7. *How is the speed and time of tectonic movements established?*
8. *What methods register oscillatory motion?*
9. *What are tectonic deformations?*
10. *What is the purpose of mining geological compass?*
11. *How are tectonic disturbances divided?*
12. *What is the anticlinal fold, and what elements does it characterize?*
13. *What is the synclinal fold and elements which characterize it?*
14. *What is the flexure?*
15. *What characterizes brachiantiklinal or dome structure?*
16. *What is the diapirs (salt) structure?*
17. *What characterizes discontinuous tectonic form?*
18. *What is the difference between pulling and discharge?*
19. *What does vertical and horizontal displacement amplitude characterize?*
20. *What unit of discontinuous tectonic structure is called "lying" and "hanging" wings?*
21. *What is the difference between horst and graben?*
22. *What is the fault?*
23. *What processes are related to exogenous and endogenous fissures?*

CHAPTER 6

AGE OF THE EARTH'S CRUST CONCEPT OF GEOCHRONOLOGY

Geochronology (Greek: *geo* - Earth, *chronos* - time, *logos* - science) is the study of age, duration and sequence of formation of rocks that make up the earth's crust. Based on it, we divide geological time into separate parts, geological stages in the history of the Earth and define its organic world, developing geochronological scale. There is relative and absolute (nuclear, isotope) geochronology.

6.1. Relative geochronology. Geochronological scale

Relative geochronology determines a relative age of sedimentary, volcanic and metamorphic rocks based on the sequence of layers (the so-called *law of layering sequence* by Danish researcher N. Steno, 1669). According to it, with undisturbed occurrence, each layer above is younger than the one below it. The simultaneity of rock formation is established in relation to the thicknesses of layered rocks. The basis for the scale of relative geological time – the geochronological scale – became a general stratigraphic scale, developed as a result of European geologists' practice for many years in the second half of the XIX century. In the first version, it was proposed and adopted at the International Geological Congress in 1881. This scale has been repeatedly supplemented and has changed to this day. Its modern version is given below (Table 6.1). Each geochronological subdivision corresponds to a sub-section of stratigraphic one – real expression of the fraction of geological time. Stratigraphic units are combined into a stratigraphic scale, reflecting the accumulation sequence of sedimentary, volcanic and metamorphic formations.

According to the accepted geochronological distribution, geologic time is divided into two nonequilibrium eons (lat. Aeon – long period of time) – Cryptozoic and Phanerozoic. Cryptozoa (Greek. Cryptos – hidden, secret, zoe – life) covers a geological time span of 3 billion years. During this time basalt and granite shells of the Earth's crust were formed. Organic lattices are absent in cryptozoic rocks (except for its upper thicknesses). Phanerozoic (Greek phaneros – explicit) includes upper strata of the earth 's crust characterized by reliable organic remains. They are divided into eras. The first two, Archean and Proterozoic, are cryptozoic, while the other three are Paleozoic, Mesozoic, and Cenozoic are Phanerozoic.

Table 6.1

Geochronological scale

Eons	Era (group)	Period (system)	Epoch (section)	Start, mln. years ago	Duration, mln. years
1	2	3	4	5	6
Phanerozoic	Cenozoic (CZ)	Quaternary (Q)	Modern	0,7	
			Late(upper)	(1,8)	
			Middle (middle)		
			Early (lower)		
		Neogene (N)	Plinocene	25±2	25
			Miocene		
		Paleogene (P)	Oligocene (top)	66±3	41
			Eocene (middle)		
			Paleocene (lower)		
		Mesozoic (MZ)	Cretaceous (C)	Late (upper)	132±5
	Early (lower)				
	Jurassic (J)		Late (upper)	185±5	53
			Middle (middle)		
			Early (lower)		
	Triassic (T)		Late (upper)	235±10	50
			Middle (middle)		
			Early (lower)		
	Paleozoic (PZ)		Permian (P)	Late (upper)	280±10
		Early (lower)			
		Coal (C)	Late (upper)	345±10	65
			Middle (middle)		
Early (lower)					
Devonian (D)		Late (upper)	410±10	55	
	Middle (middle)				
	Early (lower)				

		Silurian (S)	Late (upper)	435±10	30
			Early (lower)		
		Ordovician (O)	Late (upper)	490±15	65
			Middle (middle)		
			Early (lower)		
		Cambrian (C)	Late (upper)	570±20	80
			Middle (middle)		
			Early (lower)		
		Cryptozoic (before Cambrian lasted more than 3 mlrd. years)	Proterozoic(PR), More than 2 mlrd. Years Archaean, (AR) more than 1 mlrd. years	Vendian	
Rephean				1650-2600	1100-950
	Have only local units			more 3500	more 1000

Units of stratigraphic scale – *erathemes* or *groups* with names of eras (Archean, Proterozoic, Paleozoic, Mesozoic, Cenozoic erathemes) correspond to eras. Archean and Proterozoic erathemes have no generally accepted stratigraphic units (except local) due to lack of knowledge on deposits because they are often isolated as *Precambrian*. Phanerozoic eras, due to sufficient deposits scrutiny, are divided into 12 periods including 33 eras.

Indexes are used for abbreviation of geochronological units. Eras and erathemes are designated by two capital letters (archaea – Ar), periods and systems – by one (Perm – P), epoch or department is designated by digit in base letters (C₂ – Upper Cretaceous). Marks of age, used in geochronological scale, are widely used in geological practice in the preparation of geological maps, geological cross-sections and other documents. To make reading easier, colors are used to designate the rocks outcrops of a particular stratigraphic unit. For example, Jurassic deposits are colored in blue, Paleogenic deposits are orange, Carbon – gray, Permian – brown, Archaea – red, etc.

For stratigraphic breakdown of rock thicknesses by age, geology uses paleontological methods based on the study of fossil remains of organisms and plants (relative geochronology). Until recently, this has been the only way to determine the age of the rocks.

6.2. Absolute geochronology

With the advancement of science and, above all, nuclear physics, new possibilities have emerged to date the formation of minerals and rocks more

accurately. It is a question of nuclear or isotope methods for determining their age, called absolute geochronology.

Absolute or nuclear (isotope), geochronology establishes the age of rocks (mainly metamorphic and magmatic) and every ore and minerals in units of astronomical time (in millions of years). It is based on the phenomenon of radioactive decay of chemical elements, provided that its speed throughout the existence of the Earth remained constant, specific to each element. Age measurement is performed on the content in the rocks and minerals of native and daughter radioactive decay products.

Age of rock t is calculated using the formula:

$$t = \frac{1}{\lambda} \ln \left(\frac{D}{M} + 1 \right), \quad (6.1)$$

where λ – the constant decay;

D – number of atoms of radioactive substances which occurred during the collapse of t ;

M – the number of atoms of a radioactive element at the moment.

In determining the age, we use the following methods of nuclear geochronology: lead (uranium – thorium – lead), potassium – argon, rubidium – strontium, mainly for determination of old Precambrian and Phanerozoic rocks. The age of the latest geological formations (Upper Pleocene and Quaternary) is determined by radio-carbon, uranium-ionium, thermal-luminiscent, fluorine and other methods.

The real age of rocks can be established by simultaneously using independent radiometric methods of research.

6.3. Geological history of the Earth's crust

Precambrian. Precambrian history characterizes the initial stage of geological development of the Earth. It is the longest and little understood phase, which lasted more than three billion years. Precambrian covers *Archean* and *Proterozoic* eras.

Precambrian rocks are closed mostly by younger sediments. They are represented mainly by *magmatic* rocks of *metamorphic origin* – granites, gneisses, schists, quartzites and amphibole. Metamorphic rocks are composed of $\frac{3}{4}$ primary sediment rocks and spread wider at the top of the lithosphere relative to magmatic rocks. Conglomerates, sandstones, crystalline limestones, dolomites are found in sedimentary rocks in the upper strata of Precambrian. Remains of foraminifera, coelenterates, blue-green algae and other organisms

sometimes can be seen in weak metamorphological Proterozoic rocks of the Lower Riphean.

Highly developed organic world of Proterozoic indicates that life on the Earth appeared in archaea or even earlier. Presence of igneous rocks and lava in Precambrian formations show the signs of intense magmatism.

Precambrian rocks are usually creased and fractured. Repeated movements of the Earth's crust made the structure of the Earth's crust complicated. By the end of the Cambrian, within the individual lithospheric plates, East European, North Asian (Siberian), South Asian (China), North American (Canadian), Hindustan, Australian, African, South American, and South African plates were formed, united into one Gondwana supercontinent. Precambrian rocks contained 70 % of chromium reserves, 70 % iron, 70 % nickel, 90 % gold and cobalt, and 50 % uranium.

Paleozoic. Its duration is about 340 million years. The difference in fauna, petrographic composition of the rocks and other features allow the group to share Paleozoic rocks on six stratigraphic systems: the *Cambrian*, *Ordovician*, *Silurian*, *Devonian*, *Carboniferous* and *Permian*. During the Paleozoic Era (greek. *paleos* – old) great changes occurred on the Earth. Topography, climate and organic world changed. In parallel with the development of marine organisms (Fig. 6.1) land animals appeared – first amphibians and reptiles. In the plant world in the early Paleozoic were moss, stem, fern reached their peak and became the source material for the formation of numerous deposits of coal at the end of the era (Donetsk and Lviv–Volyn coal basin in Ukraine, etc.)

Changes in topography were caused by tectonic movements of the crust. Orogenic processes of the early Paleozoic contributed to the formation of the mountains of Iceland, Great Britain, Scandinavia, Kazakhstan and others, and the middle – the end of the Paleozoic – the formation of mountain structures of the Urals, southern Tien Shan, Altai, Western Siberia, Donbas, Apalachee, Australian Cordillera and others. Over time, some of them were destroyed by geological processes (the mountains of Donbass, Western Siberia, the Southern Urals, and Kazakhstan). Vibration movements of the earth's crust caused multiple lifting and sinking of Precambrian platforms and displacement of the coastline.

Changes in land and sea ratio had a major impact on the Paleozoic climate. In Carbon the climate was warm and humid on most of the platforms of the Northern Hemisphere, and dry and hot in Perm. This is evidenced by numerous coal deposits discovered in Upper Paleozoic deposits. The climate was very cold in the southern hemisphere at this time. There were several centers of icing here. Morain sediments confirming the spread of glaciers have been found in northern Africa, South America, and Australia.

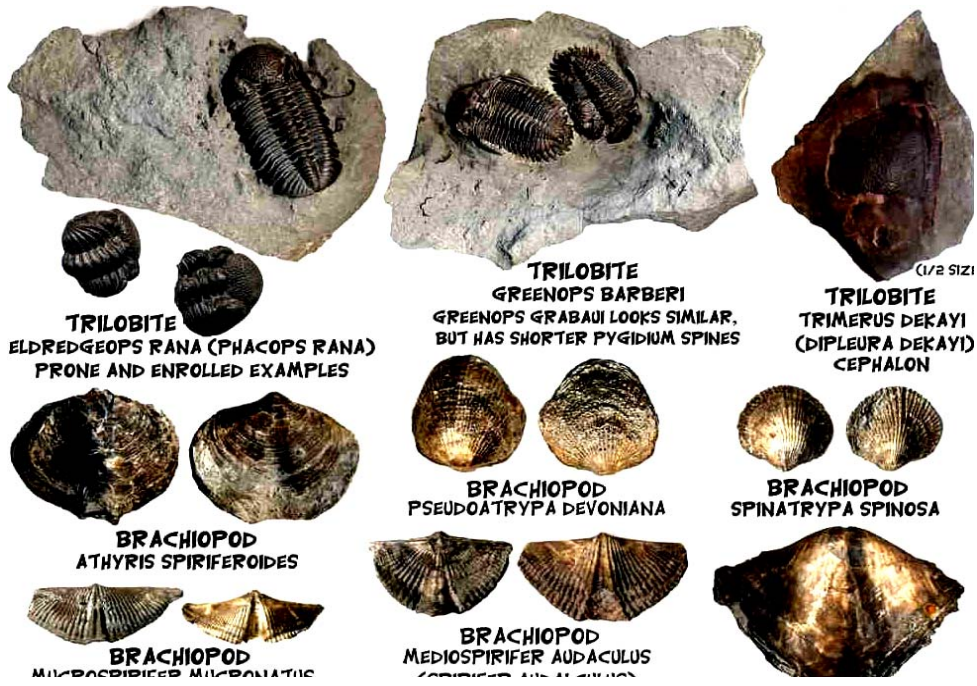
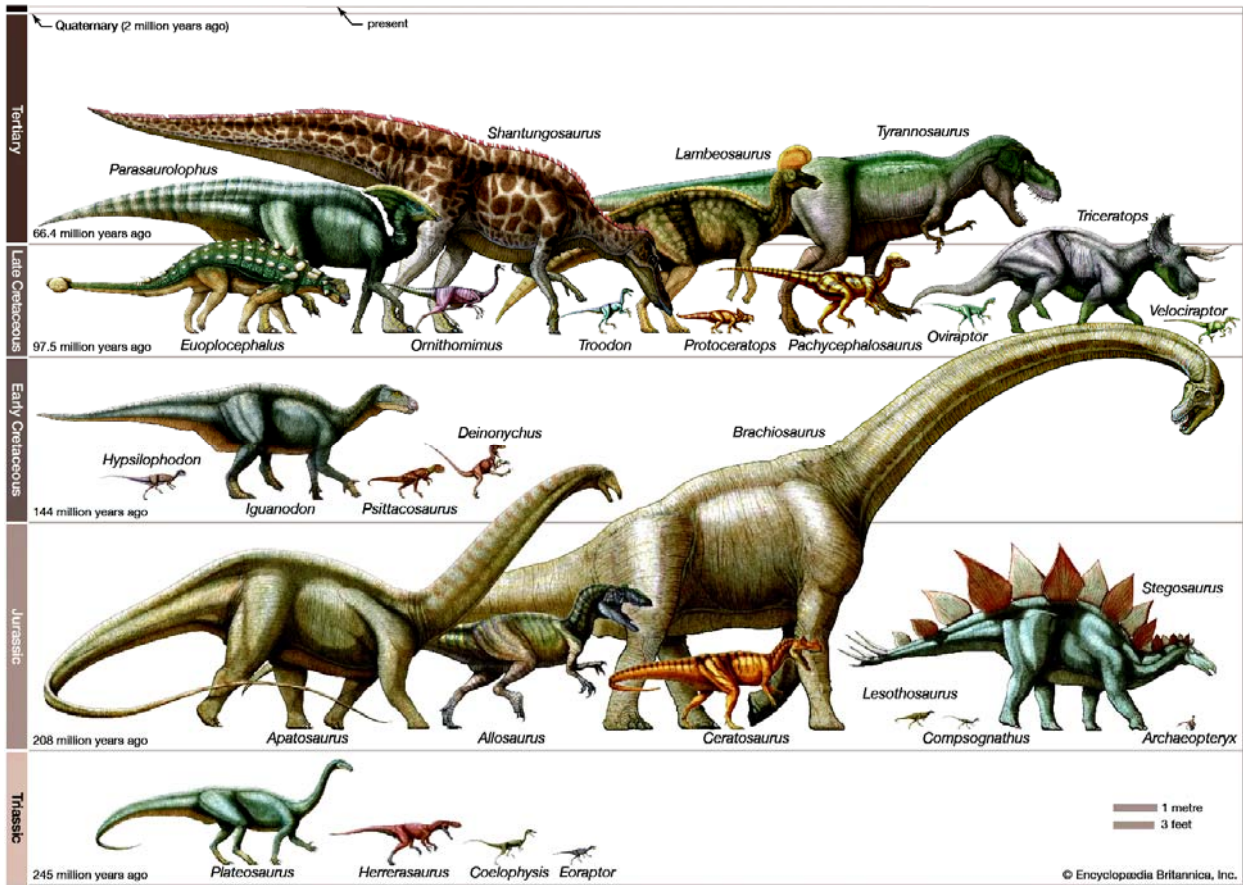


Fig. 6.1 – Basic fossil shells of carbon mollusks:
a – Chaetetes; b – Productus giganteus; c – Fusulina; d – Schwagerin



<https://www.britannica.com/science/Mesozoic-Era>

Fig. 6.2 – Representatives of the fauna of the Mesozoic era

Most oil and gas deposits in Ukraine, Siberia, the Volga region, Belarus, Donbass coal, Kuzbass, Silesia and deposits of ferrous, nonferrous, rare and precious metals, salts, phosphates, bauxite and other minerals are associated with Paleozoic rocks.

Mesozoic. Mesozoic era (greek. *mézos* – average) lasted over 170 million years. According to organic remains its rocks are divided into three systems – the *Triassic*, *Jurassic* and *Cretaceous*.

At the beginning of the Paleozoic era, many animals and plants (trilobites, spine-skin, corals and others) died and they were replaced by cephalopods and bivalves, Mesozoic dinosaurs, birds, and plants – gymnosperms. There appeared new, previously unknown, representatives of spine-skin, foraminifera, fish, gastropods. Land and water were inhabited by reptiles, birds were flying in the air (Fig. 6.2). Forests of Mesozoic continents consisted primarily of gymnosperms, and in the Cretaceous they were joined by angiosperms.

Orogenic processes in the Mesozoic developed in the Pacific Ring region, completing the formation of ridges and entire mountain systems of Chukotka, Kamchatka, Eastern Siberia, the Far East of Russia, as well as the Rocky Mountains of North America, the mountains of Eastern China and Indochina.

At the beginning of the Mesozoic, Gondwana was divided into five parts: the Australian, the Hindustan, the African, the Brazilian and the Antarctic. In northern hemisphere, North America and Eurasia were separated at this time. At the same time, huge basins of the Indian, Atlantic and Arctic Oceans were laid.

At the beginning of the Mesozoic, the climate in the Northern Hemisphere remained warm and moist, as evidenced by coal deposits in many regions (Siberian Platform, Indochina), oil and gas fields (Western Siberia, Mangyshlak Peninsula), and others.

In Ukraine, Mesozoic sediments are associated with some oil and gas fields, phosphorite deposits, chalk, dolomite, clay, sand and other minerals.

Cenozoic. The Cenozoic era (Greek - Kainos - new) has lasted for the last 67 million years. The Cenozoic group of rocks is divided into three systems: Paleogene, Neogene and Quaternary. The sediments of these systems, covering both the bed of modern seas and oceans and continents, contain many organic residues. Organic world of Cenozoic is characterized by the emergence of new forms of animals and plants with a simultaneous increase in the number of species. In the Cenozoic seas, bivalves and gastropods, fish, and simple organisms became widespread. On land, almost completely extinct reptiles are replaced by mammals. In the Paleogene and Neogene trunks (mammoths), equines, rodents, humanoid monkeys appear at the end of the Neogene. The youngest, Quaternary period, lasting about a million years, was marked by the appearance of man.

The Cenozoic flora is characterized by the occurrence of coated seed plants. But gymnosperms, ferns, and mosses develop alongside them.

In the Cenozoic, such mountain structures as the Alps, the Balkans, the Carpathians, the Caucasus, the Pamirs, the Altai, the Himalayas, the Andes were formed. Continuation of endogenous tectonic processes is evidenced by modern volcanism, earthquakes and boulder elevations.

Tectonic movements, for example, led to the formation of rift systems (chasms on faults). In their places lakes and inland seas were formed (African lakes Kivu, Tanganyika, Siberian Lake Baikal, Red Sea, etc.).

At the end of the Cenozoic, climatic changes took place in the Northern Hemisphere. In the Neogene, cooling began, covering the northern regions of Europe, Asia, and North America in the Quaternary period. The glaciation of these areas began. The centers were the Canadian Shield, Greenland, Novaya Zemlya, the Scandinavian Mountains, and the Polar Urals. Warming at the end of the late Quaternary and at the beginning of the modern era caused melting of glaciers and the gradual formation of modern climatic conditions. Glaciers left not only a huge amount of debris (moraine) in the form of boulders, gravel, sand, variegated clays and loams, but also glacial lakes (Shatsky lakes in Volyn, Ukraine, etc.).

Test questions to the theme

- 1. What is the geological age of the Earth?*
- 2. By what methods can we determine the relative age of the geological rocks?*
- 3. What is a stratigraphic method for determining the age of rocks based on?*
- 4. Name the eons, age, geological periods and age of the Earth.*
- 5. In what period do we live?*
- 6. What methods determine the absolute age of rocks?*
- 7. Describe the purpose and structure of geochronological scales.*
- 8. Which of the eras lasted the longest period in the history of the Earth?*
- 9. Was there any living matter on the Earth in archaean?*
- 10. What marked the beginning of biological evolution on Earth?*
- 11. When did the first animals appear?*
- 12. When were mountain structures in Ukraine formed?*
- 13. What mountain structures were formed in the Cenozoic?*
- 14. Which era does the formation of modern man belong to?*
- 15. What era does Hercynian folding belong to?*
- 16. What do we call the folding that originated in the late Triassic?*
- 17. What factors and processes are the periods of our planet's development based on?*

CHAPTER 7

GEOLOGICAL STRUCTURE OF THE TERRITORY OF UKRAINE

Geographically, Ukraine is located in the southwestern part of the east European platform. It is surrounded by mountain structures that are part of the Mediterranean Alpine folded region. The structure includes rock platforms of Precambrian, Paleozoic, Mesozoic and Cenozoic age, forming three structural floors: Precambrian, Paleozoic and Meso Cenozoic.

On the Ukrainian platform, there are the following important geological structures: Ukrainian crystalline shield and Voronezh antecline; the Dnieper-Donets basin; Donetsk folded structure; the Black Sea, Lviv and Transcarpathian basins; Volyn-Podilsky and Scythian plates; Carpathian trough; the Carpathian mountains, Crimea and Dobrudja; the Black Sea and Azov Sea shelf (Fig. 7.1).



Fig. 7.1 –Scheme of the geological structure of Ukraine

7.1. Ukrainian crystalline shield and Voronezh antecline

Ukrainian crystalline shield occupies the central part of Ukraine. It is compiled with severely dislocated magmatic, metamorphic and metasomatic

complexes of Archean and lower Proterozoic. The oldest rocks date back to 3,6 billion years ago.

Ukrainian crystalline shield is a blocky uplift of the crystalline basement of the East European platform. In Ukraine, it extends for over 1000 km in wide band along the middle reaches of the Dnieper, about 250 km wide. It is the oldest Precambrian structure, formed over 3,7 billion years ago. The shield, boarded on Dnieper-Donetsk and Prypiat paleorifts in the west and north, is obliquely immersed in the south where it is overlapped by a platform cover of Paleozoic, Mesozoic and Cenozoic sediments.

From west to east the structure of the shield is divided into five large meridian blocks (zones): Volyn-Podilsk, Bilotserkivka-Uman, Kirovograd, Dnieper and Azov. They are split by *deep fault zones* – Orihiv-Pavlograd, Talniv, Kryvyi Rih and others, laid in the late archaean and actively developed in the Proterozoic. Ukrainian crystalline shield has been formed by 85–90 % of *metamorphic* rocks (migmatite, gneiss, granite, schists, etc.) and 10–15 % of *magmatic* rocks (granitoids, gabbro, diabase, etc.) of Proterozoic and Archean age. In the central part they come to the surface or are covered with a small layer of *sedimentary* rocks, and on the sides of the shield are immersed in sediments of the Dnieper-Donets and Black Sea basins.

Ukrainian crystalline shield is characterized by high ore productivity. Minerals such as iron and uranium ores, rare metals, construction materials, precious stones, mineral water, etc., are connected with the rocks of different ages. Powerful deposits of manganese, limonite, zircon, kaolin are associated with crust and sediments' weathering. Resources of these minerals within the shield take a leading place in Europe and the world. Certain types of ore formations are exclusive and have been found for the first time (for example, rare metals and uranium-bearing alkaline metasomatites, gold objects in tectonometasomatic areas, chamber pegmatites and other minerals).

The Voronezh anteklise (Greek - protrusion), or the Voronezh crystal-face massif, with its southern part, enters the North-Eastern part of Ukraine. Thus, as the Ukrainian shield structure it is the performance of the Precambrian basement of the East European platform recovered with Mesozoic and Paleozoic rocks. On the territory of Ukraine, the anteklise, on the southern submerged block of which the Starobil-Mileriv monocline was formed in the sedimentary complex, borders the Dnieper-Donetsk depression.

Formation of the structure began in the Devonian, and its southern wing was a result of expansion in the Carboniferous Donets depression (syncline). *Precambrian foundation* of the anticline blocked by sedimentary cover with the thickness does not exceed 100-150 m in the vaults. Voronezh crystalline massif is well-studied in the Kursk Magnetic Anomaly, where it has been bored on a large number of wells and opened by numerous mine workings.

The foundation is formed by the same rocks and structural complexes as the foundation of the Ukrainian Crystalline Shield. It is broken by systems of deep faults, some of which extend (through the DDZ) on the Ukrainian Shield.

Sedimentary rocks cover of the anticline has been compiled by medium and upper Devonian, Carboniferous, upper Jurassic, upper Cretaceous, Paleocene and Quaternary deposits. Devonian rocks developed on the vault and the north wing of Voronezh shields. They have continental and lagoon sediments, which sometimes contain many plant remains – colorful sandstone, dolomite, clay, gypsum lenses, rock salt and powerful red sand layers. Carboniferous sediments are distributed both on the north and the south-east wings of "Ukrainian" anticline slope. These are limestones interbedded with clay, dolomite, sandstone and sand, which sometimes contain char. Upper Jurassic sandstones and clays are represented by fauna of ammonites, covering more ancient creations. Rocks of the upper Cretaceous (white chalk, marl, sand from diverse fauna of ammonites, belemnites, peletsypod, foraminifera, etc.) are widely spread. Paleogene is represented by all tiers and is similar to the Paleogene of the Ukrainian shield. Quaternary deposits are made up of deluvium, silt-like loams, and alluvium. Deposits of hydrocarbons are found in sedimentary complexes of Starobilsk-Milerovo monocline.

7.2. Dnieper-Donetsk cavity

The Dnieper-Donetsk Basin (DDB), which is part of the Dnieper–Donets'k Avlakogen together with the Donetsk Folding Structure (DSS), is part of the Sarmat-Turan Line and is located within the Eastern European Platform. The Baranovychi–Astrakhan Deep Fault in the north and the Pripyat-Mańych Fault in the south separate it from the Voronezh Antecline and the Ukrainian Crystal Shield. Its northwestern boundary runs along the Bragin-Lviv anticline and south-eastern boundary in the development of Herzin folded structures (open Donbass). This geological structure is at the same time a part of the Dnieper–Pripyat oil and gas province and the Dnieper-Donetsk artesian basin.

The discovery of oil and gas fields has contributed to various geological-geophysical studies of the region, its tectonics, lithology, stratigraphy, hydrogeology, etc.

The sedimentary layer of the DDB rests on the Precambrian foundation, which consists of three structural-formation complexes: Early Archean, Late Archean and Lower Proterozoic. They are represented by ultrametamorphic, intrusive, volcanic, and metamorphosed sedimentary rocks. Among them are: crystalline shales, gneisses, granites, plagioclases, amphibolites, quartzites and others.

Sedimentary cover in the central and northwestern parts of the DDB begins with the Devonian sediments that lie directly on the foundation. They consist of a thick layer of mudstone, siltstone, sandstone, marls, limestones, dolomites, rock salt, gypsum, anhydrite, pyroclastic and effusive rocks with a total thickness of 2000 to 7500 m. In the section of the Devonian, there are two divisions – the middle (Eiffel and Livian tiers) and the upper (French and Famennian tiers). Oil and gas is confined to the super-salt strata.

In the section of the coal system, the DDBs are divided into lower, middle and upper sections. The Lower Coal Division consists of the Tournian, Vizian and Serpukhov tiers. The rocks of the Tournian tier are represented by clay, biomorphic-detritic and bituminous limestones, sandstones, mudstones. Visayan sediments have the largest distribution area, occurring at different stratigraphic levels of the Tournian tier. They are represented by limestones, terrigenous and carbonaceous rocks.

Serpukhov rocks are represented by mudstones with layers of coal, sandstones, limestones. Deposits of the Middle Carboniferous (Bashkir and Moscow tiers) unconformably lie on rocks of the Lower Carboniferous. The Bashkir tier is represented by clay-carbonate, clay-siltstone, carbonate and carbonaceous rocks. The sedimentary layer of the Moscow tier consists of terrigenous rocks, which are rhythmically interbedded with low-lying layers of coal and limestone. Upper carbon is represented by a cyclic thickness of mainly sandy-clay deposits with low content of limestone, dolomite, coal and coal shale. In the southeastern part of the depression, the Upper Carboniferous is divided into oil horizons according to the "Donbass Scheme" (Isaev, Avilov, Araucaritic) and is characterized by alternation of mudstones and sandstones with layers of siltstones, limestones and dolomites. Oil and gas industry is associated with areas of dispersal in rocks of different types.

In the section of the *Permian system*, only the lower part is established in the DDZ, in which the Asel and Samara layers are distinguished. The rocks of the Asselian tier are divided into three horizons: the Kartamysh, the Mykytiv, and the Sloviansk. The Kartamysh oil horizon is represented by red-colored terrigenous deposits, and the upper two are carbonate-saline, carbonate-sulfate-saline and terrigenous rocks. Industrial oil and gas is linked to carbonate horizons.

Triassic sediments are distributed throughout the DDZ. They are divided into three sections: lower, middle and upper. In the lower section, there are the drone and the lower part of the serebriansk horizon formed by brown-red and light brown sandy-clay rocks. The Middle-Triassic Division (upper part of the serebriansk horizon) is sandstone with layers of pebbles and gravel. Upper Triassic sediments are the Protopov and Novoray horizons, represented by coarse-sands and clay-siltstones.

The Jurassic system is represented by the middle and upper divisions. The middle -Jurassic sediments are divided into the Bayesian and the Batian tiers. Bayesian sediments are marine clays with sandstone, limestone shells, distributed throughout the DDZ. The Bat tier is composed of clays with siderites, tuffogenic marine sandstone with layers of clay, limestone and brown iron. Among the middle-Jurassic sediments are the Kelowy, Cambridge and Volga tiers. These are black and gray clays, light gray and glauconitic (green) sands with layers of clay and limestone shells. They are gradually replaced by a colorful lagoon-continental thickness to the south and east.

Rocks of *Cretaceous system* which belong to continental Lower Cretaceous facies are composed mainly of sand and clay rocks, while marine – of sand. Upper Cretaceous deposits are divided into two zones. The lower zone is terrigenous (sands, sandstone, pebbles, gravel) and the top – carbonate (chalk, marl) rocks.

Paleogene sediments represented by cherts, siltstones, marls, clays, sands, loose sandstones, are spread over the entire territory of the DDZ.

Neogene rocks make up the upper parts of watershed sections and Pliocene-new river terraces. Basically, these are sands and clays with layers of limestone.

Anthropogenic (Quaternary) deposits cover almost the entire territory of DDZ. They are presented by various alluvial and eluvial formations.

7.3. Donetsk folded structure

The Donetsk folded structure (DFS) is the south-eastern part of the Dnieper–Donetsk deflection (auglagen), formed as well as the DDZ in the crystalline foundation of the Eastern European Platform between the Voronezh Antecline in the north and the Ukrainian Crystal Shield in the south. Its occurrence is related to Herzinic tectonic movements. In the course of geological development, the deflection was filled with terrigenous-effusive carbonaceous and halogenic sedimentary rocks of the Devonian, Coal-Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary periods. The sedimentary complex of rocks forms three structural floors: Paleozoic, Mesozoic and Cenozoic. The sedimentary column is intensely cut by breaking faults and crushed into folds. Large and small linear folds, as well as numerous dome structures, extend mainly in the sub-latitudinal (northwest) direction along the zones of deep faults. A mountain system was formed at the place of deflection in the Paleozoic due to orogenesis, which then collapsed because of the processes of peneplenization (topography alignment).

At the end of the Late Permian period, the Saal phase of Herzine tectogenesis took place, leading to the formation of the structural forms in the region.

At the same time, the eastern part of the Dnieper-Donetsk avlagogene was inverted (raised) due to mountain-forming processes and transformed into a Donetsk folded structure. Instead, the Dnieper-Donets Basin was formed in its submerged western part.

The main tectonic elements in the Donetsk folded structure are deep regional faults that reach the mantle by breaking the earth's crust. The main structural development of the DFS (as well as the DDB) took place against the backdrop of Late Herzine tectonic activation. However, movements of individual blocks of the Earth's crust took place at its platform stage. This became a determining factor in the accumulation and formation of a structural plan for the sedimentary strata of the region in which deep faults appear as zones of discontinuous disturbances with amplitudes from tens of meters to the kilometers, as well as linear anticlinal folds and dome structures. Depth-related faults are associated with the flow of ore-generating solutions to the upper layers of the lithosphere, migration of hydrocarbons, formation of the chemical composition of deep-horizon waters, the phenomenon of neotectonics and modern thermal mass transfer.

There are deep faults of two main directions in DFS: submeridial and sub-latitudinal. The submeridial faults are more ancient as they were laid in the early Proterozoic time. The faults of the sub-latitudinal "Donetsk" direction are of the Paleozoic (Hercynian) age clearly manifested in the sedimentary strata.

At the platform stage, the Paleozoic rocks, formed on the development of the DSS, are characterized by the accumulation of huge (up to 20 km) thick sedimentary (terrigenous-volcanic, carbonate, carbonaceous, red-colored and halogen-carbonate) formations. Thicker rocks of the Devonian age are at the bottom.

Devonian deposits lie on the eroded surface of the Precambrian magmatic-metamorphogenic thickness. Their outcrops are found in the south of the DFS, in the zone of its joining the Azov massif of the Ukrainian Crystal Shield. Stratigraphically, the Devonian rocks are divided into three horizons (tiers): Mykolaiv (White Devon), Dolginsky (Brown Devon), and Rizdolnensk (Gray Devon). They are represented by brown conglomerates, coarse-grained sandstones, paleobasalts, limestones, gravelites, siltstones, tuffs and lavas of basic composition.

Carboniferous sediments are deposited on both the Devonian, and the crystalline basement. Their total thickness ranges from 4–5 km to the northwest and 12 km to the southeast. They are split into three divisions which, in turn, are divided into tiers. Layers of limestone, sandstone and coal are well-traced

by spreading and act as marking horizons. Sediments of the *lower carbon* (C_1) represented by terrigenous-carbonate rocks (limestones, dolomites, sandstones, mudstones), are up to 3200 m thick.

Deposits of the *Middle Carbon* (C_2), which are the main coal-bearing strata, contain more than 100 layers and seams of coal. Clay and sand rocks dominate in the lower part of the section, containing hydrothermal mineralization in Nagolny ridge (Lugansk) and Mykytivka (Donetsk region). The total thickness of the Middle Carboniferous rocks is 4500 m.

Formation of *Upper Carbon* (C_3) covers almost a third of total coal deposits of DFS section of about 3000 m thick. The top of the cut increases the importance of colorful sand and argillaceous rocks while the amount of limestone and general carboniferous rocks decrease.

The Permian system is represented mainly by the Lower Permian sediments, divided into four horizons (tiers): Kartamisk (Copper sandstone), Mykytivka (limestone-dolomitic), Sloviansk and Kramatorsk (saline), which are associated with large deposits of rock salt (Bakhmut, Sloviansk and others).

Mesozoic rocks with a total thickness of up to 1000 m lie on the eroded surface of Paleozoic strata. They are most widespread in the western, northwest and eastern parts of the DFS.

The Triassic system is represented by sandstones, conglomerates, motley clays, limestones, brown iron, siderites, lenses of coal with a thickness up to 500 m. Fractures of the sub-latitudinal "Donetsk" direction are of Paleozoic (Herzinian) age and are clearly manifested in the sedimentary strata.

The Jurassic system with rocks up to 350 m thick is subdivided into three sections: the Lower Jurassic, (montmorillonite clays with seams of siderites and clay limestones, in places – basal conglomerates, brown iron and coarse sandstones); the Middle Jurassic (sandy clays, limestones, mica and glauconite sandstones, siltstones, ferruginous sandstones) and the Upper Jurassic (alluvial sands, lenses of coal, shallow limestones and sandstones, oolitic and siliceous limestones).

Cretaceous system. The rocks of this system reach thickness of 650 m. They are represented by continental sands, clays and fluffy carbonaceous sandstones, quartz-glauconitic sands, sand-marls and strata of white chalk.

Cenozoic deposits are mostly sand and clay that lie on the eroded surface of Palaeozoic and Mesozoic.

Paleogene sediments that are missing in the central part of Donbass, reach their maximum thickness (up to 950 m) in the northwest part of DFS, filling in the salt superciliary depression funnels and interdome deflections. Here they are confined to industrial deposits of lignite.

Neogene sediments are fully represented in the southern part of the Donetsk basin, except in places where there is limestone, sand and clay. The total thickness of Neogene rocks is 50–70 m.

Quaternary sediments are found everywhere, they are alluvial and eluvial formations with thickness from 1 to 40 m.

7.4. The Black Sea depression

The Black Sea depression is a sub-latitudinal syncline of a block structure filled with sedimentary rocks of the Mesozoic-Cenozoic age with growing thickness in the southeastern direction (up to 6–7 km in the Sivash region). The Paleozoic sedimentary platform and the Precambrian rocks of the Eastern European Platform lie beneath sedimentary rocks of the depression. The depression is divided by local synclines and anticlines into several blocks, one of which, the Sivash shaft, forms the Perekop Isthmus and divides the Black Sea basin into its own Black Sea and Azov-Kuban hollows (depressions).

Geographically, the southern slope of the Precambrian platform (Ukrainian Shield) and elements of the Dobrudzha folding structures stand out in the Black Sea depression. The formation of the depression began at the end of the Early Cretaceous (about 110 million years ago) period. Three geological structural floors (lower, middle and upper) are traced in the crust within the Black Sea depression. The lower floor is the crystalline foundation of the southern slopes of the Ukrainian Shield. The upper two floors are a 300-400 m thick sedimentary cover.

The boundaries of the Black Sea basin are conditionally determined. In the north it is the slope of the Ukrainian Shield, which is reflected in the topography by the Dnieper hill; in the east – Paleozoic Scythian plate; in the west – folding structures of Dobrudzha (Frunzensk-Artsyzsk fault along the Prut valley); in the south – the Black Sea shelf zone.

The Black Sea basin arose as a result of a long-term subsidence of the southern slopes of the Ukrainian Shield, which occurred most intensively in the Late Mesozoic – Cenozoic period. The latitudes of the latitudinal and meridional directions formed the block structure of the crystalline foundation. The morphostructural blocks are clearly reflected in modern relief in the form of heights and hollows.

The Black Sea syncline is filled by Paleozoic, Mesozoic and Cenozoic sediments. The Paleozoic, known only in the northwestern part of the depression, reaches a thickness of about 1000 m and is represented by sandstones, shales and gravelites of the Silurian age. *Mesozoic sediments* within the Black Sea syncline are known only in some places. *Jurassic* deposits are conditionally attributed to a thickness containing the remains of wood in the valley of the Molochna River. Cretaceous deposits are known in the natural outcrops to the day surface in the northwest of the depression (Gulyai-Pole) and in the Tarkhankut Peninsula

(Crimea). In addition, they have been identified by wells near Odessa, Velyky Tokmak and some other places. *Cretaceous deposits* are represented by chalk, marls and glauconite sands more than 400 m thick.

Cenozoic rocks are very widely developed in the depression. These are sand and clay complexes of the Eocene and sandy-clay deposits of oligocene up to 100 m thick each. The Neogene sediments are represented by sand-limestone strata (Chokrak, Karagan and Konsk horizons) with a total thickness of 50–60 m. The sediments of the Sarmatian tier (black clays and sand-clay-limestone rocks) can be 140 m thick. Myotic sediments are composed of limestones, sands and clays. Quaternary sediments – from brown clays, forests, loams up to 20 m thick.

The Black Sea basin is an important oil and gas province of Ukraine, linked to the country's strategic power supply plants.

7.5. Volyn-Podilsk and Scythian plates

Volyn-Podilsk plate is a geological structure created within the Volyn-Podilsk block – Western submerged part of the Ukrainian shield. It extends from the Pripyat to the Dniester and emerges from the UkSh by a deep fault. It consists of individual units of lower rank. It differs from the adjacent geostructures by age, composition, degree of crystalline rock metamorphism, and structural forms.

Its base is formed of magmatic and metamorphic rocks of the Archean and Early Proterozoic ages divided into separate fragments. Structurally, the plate is divided into a monocline slope of the Ukrainian Shield and a Paleozoic depression – Galicia-Volyn syncline, within which the foundation lies at a depth of 7000 m.

According to geomorphological features, Volyn and Podilsky hills, the Podilsk lowland and a hilly slope – Roztochy are distinguished within the Volyn-Podilsk plate.

The oldest rocks are metamorphic gneisses and crystalline shales associated with rocks of the Archean intrusive complex. There are also Lower Proterozoic rocks: gneisses, crystalline shales and metavulcanites, granitized by intrusions of various composition, as well as granites, gabbro and anorthosites. Extends from the Pripyat and Dniester are divided from UCS by faults. It consists of individual blocks of lower rank. Neighboring geostructures differ by age, composition, degree of crystalline rocks and metamorphic structural forms.

Its foundation was formed from igneous and metamorphic rocks of early Proterozoic and Archean age cut into separate fragments. The structural plate is divided into monocline slope of Ukrainian shield and Paleozoic trough – Galicia-Volyn syncline within which foundation lies at a depth of 7000 m.

According to geomorphological features, Volyn and Podilsk uplands, Podilsk plain and hilly ridges of Roztochchia are distinguished within the Volyn-Podilsk plate.

The oldest rocks are metamorphic gneisses and schists associated with intrusive rocks of the Archean complex. There are lower Proterozoic rocks: gneisses, schists and metavolcanites, granited by intrusions of various compositions, granites, gabbro and anorthosites.

The Scythian Plate is a young platform within the Mediterranean geosynclinal belt in southwestern Europe. It is located in the south of Ukraine, covering the central part of the Crimean peninsula and the shelf of the Black and Azov Seas. The plate foundation was formed during the Baikal-Cimmerian tectonic stage and is composed of fractured volcanic-sedimentary deposits of geosynclinal formation. The sedimentary cover was formed unevenly, beginning with late Proterozoic. It is represented by poorly positioned platform rocks. From mid-to-late Cretaceous, geosyncline conditions resumed on most of the Scythian Plate, triggering the appearance of the latest Azov-Black Sea geosynclinal system.

7.6. Lviv depression

In addition to the Dnieper-Donets Basin located on the left-bank of Ukraine, cutting it from north to southeast, there are other geosynclinal deflections, the largest of which is the Lviv Basin.

Lviv depression (Lviv Paleozoic depression) is a geological structure within Volyn, Lviv, Ivano-Frankivsk, Chernivtsi and Ternopil regions. It is made up of rocks of the crystalline foundation, which sinks westwards for 160–7000 m, reef-venda deposits (sandstones, mudstones, basalts, tuffs with a total thickness of 1000–1200 m), lower Paleozoic (sandstones, mudstones, limestones – up to 2000 m), Devonian (limestones, sandstones, marls) - up to 1700 m), carbon (sandstone, mudstone, coal – up to 1200 m). There is a dislocation zone in the Paleozoic thickness of the bend, which overlaps the earlier (Baikal) structures of the Western European Platform and the monocline part located on the western edge of the Volyn-Podilsk Monocline. Loess prevails among Quaternary sediments. Volyn and Podilsk hills are distinguished in the topography of the depression. The Lviv-Volyn coal basin and the hydrocarbon fields of the Carpathian oil and gas province are linked to the carbon deposits of the depression.

7.7. Mountain building of the Carpathians, Crimea and Dobrudja

Mountain structures of the *Carpathians, Crimea and Dobrudja* are in the territory of Ukraine. They are part of a tectonically active Alpine (Mediterranean) geosynclinal folded belt formed from the Baikal, Caledonian, Herzinian, Cimmerian and alpine orogenic formations.

The Carpathians. A mountain system in the east of Central Europe is located in the territory of Ukraine, Hungary, Poland, Czech Republic, Slovakia and Romania. In Ukraine, the Carpathians occupy the territory of Lviv, Ivano-Frankivsk, Chernivtsi (Precarpathian) and Transcarpathian regions.

The Carpathian mountain system up to 430 km wide, extends for 1500 km. In Ukraine, at a width of 100–110 km, it is 250 km long. It is one of Europe's most important watersheds between the Baltic and the Black Seas. We distinguish Western, Eastern (some of which are Ukrainian) and the Southern Carpathians, the Beskids, the Western Romanian Mountains, and the Transylvanian Plateau. The height of the mountains does not exceed 800–1.200 metres on average. The highest mountain Gerlachowski-Shield reaches 2655 m (Tatra Mountains, Western Carpathians). The highest peak in Ukraine is Mount Hoverla – 2.061 m.

The Carpathians form the northeastern branch of the Alpine folded geosynclinal region of Europe. There are large structural elements of the northwestern – southeastern reaches: the Pre-Carpathian depression, the Outer (Fleisch or Folding Carpathians) and the Inner Carpathians and Transcarpathian depression.

Pre-Carpathian advanced depression is a geological structure extending along the strip joints of the Carpathian Mountains with Eastern European and Scythian platforms for more than 1.700 km long (within Ukraine – 300 km) and up to 75 km wide. In the bend filled with Neogene and Quaternary molasses, there are three zones: the Outer (Bilche-Volyn), Central (Sambir) and Inner (Boryslav-Pokut). The latter two are often combined into one – the Inner Zone. The geosynclinal flysch-based inner zone flexed at the initial orogenic stage of development (Miocene) with the accumulation of lower and then upper molasses. The area is dislocated into "scaly" folds, separated by inclined pulling. The central zone, formed in the early Miocene, also has a complex internal structure. In the present form, the Inner and Central zones are mobile allochthonous (alluvial-outwardly) geosynclinal overlays supported by an autochthonous (on-site in situ) stable, outer zone, formed in the early Miocene on a platform basis. The Domiocene base of the Outer Zone is sinking towards the Carpathians. The thickness of volcanic-sedimentary deposits also increases in the same direction.

The outer Carpathians are composed of a powerful thickness (more than 4–5 km) of Cretaceous and Paleogene sediments, forming a system of linear, torn-out, scaly folds (slides), which are overturned and shunted to the Precarpathian Depression with an amplitude of more than 20 km. The outer Carpathians are a typical myogeosyncline, subdivided into separate structural-facial (tectonic) zones. The base of the outer Carpathians is represented by the crust of transitional and oceanic types, the relicts of which (the outcrops of porphyrites, splits, and their tuffs lavas) form massifs in adjacent seam zones.

The major folding phase is pre-Miocene (Early Neogene). The outer and inner Carpathians are separated by a deep slope, which forms the Marmorosa and Beijing Beskids.

In the Inner Carpathians in the territory of Ukraine, we distinguish the Marmorosa crystal massif and the Podgaly zone. The first is made up of metamorphic Precambrian rocks cover, Middle and Upper Paleozoic and Mesozoic formed in the Middle Cretaceous. The minimum displacement amplitudes are 12–15 km. General direction of the lithospheric masses movement is from the Inner to the Outer Carpathians.

Transcarpathian internal depression is composed of volcanic-sedimentary rocks of the Neogene. It distinguishes the Solotvynsk (Higher Tysa) and Chop-Mukachivsk depressions and the Vygortat-Huta volcanic ridge. Salt dome (diapir) structures are developed in the Solotvyno depression, from the depths of which rock salt is extracted. The Transcarpathian depression is separated from the Pannonian basin from the west by the near Pannon deep fault (the area of the Berezhivsky volcanic hill). The Inner Carpathian Volcanic Belt, the steepest in Europe, covering the Chop-Mukachevo and the inner edge of the Solotvyno concave, runs along the inner edge of the Carpathian Arc. The volcanic zone developed in multiple phases (from the early Miocene to the Pliocene, inclusive), gradually migrates from the edge of the massif towards the Flysch Carpathians. The processes of younger volcanism took place from north-west to south-east along the entire volcanic belt. The main centers of Cenozoic eruptions are located in zones of longitudinal deep faults.

The Crimean mountains is the mountain system in the south of the Crimean peninsula. It extends 180 km from southwest to southeast. The width of the mountain strip is up to 60 km. The topography clearly distinguishes three almost parallel ridges with steep northern slopes: Main, Inner and Outer. The height of the mountains is 700–1200 m. The maximum height is 1545 m (Roman-Kosh).

The Crimean Mountains is a folded-block tectonic structure that is part of the Mediterranean (Alpine) mobile belt. The boundaries of this structure are determined by deep faults. There are core and the northwest and south wings of the structure. The structure of the core includes the dislocated Upper Triassic and Lower Jurassic clay shales and sandstones (flysch), which are uncoordinated, covered by inclined-frequent, tectonically deformed younger Cretaceous and Cenozoic rocks. The Main ridge is formed from reef limestones, the main structural elements of which are the South Coast, Balaklava, Tuatsk, Kachyn anticline elevations, and the West Crimea, East Crimea, and Sudak synclinal zones. These structures are complicated by numerous discontinuous disturbance of the dumping, shear and thrust character. Upper Cretaceous Paleogene, Neogene, and sometimes Cretaceous rocks are involved in the structure of the northern wing: limestones, chalk, marls that occur monoglycally. Formation of the Crimean

fold-and-block structure began in the Mesozoic in the process of Cimmerian folding. The process was accompanied by intense volcanic activity. At the end of the Early Cretaceous, a single large uplift arose at the site of the modern Crimean Mountains, which was eroded and leveled (peniplenized) by the end of the Paleogene. At the beginning of the Neogene, the Cimmerian folded structure under the influence of alpine mountain-forming processes rose to an altitude of 1500 m or more and turned into a modern mountain structure.

Dobrudja is a component of the Carpathian folded system in the lower Danube. Part of it is located within the territory of Ukraine – in the south-west of Odessa region. It was formed as a result of two tectonic cycles, which respectively took place during the Baikal-Herzine and Cimmerian tectonic stages of the Scythian plate. In the middle of the alpine epoch, weak mountain-forming processes occurred here, forming low (tens and hundreds of meters) mountains. Like the Carpathians and the Crimean Mountains, the Dobrudja massif, the main part of which is in the territory of Romania, is part of the Mediterranean mobile belt.

Test questions to the theme

1. *What are the major geological structures in Ukraine?*
2. *What part of the country does the Ukrainian crystalline shield occupy? What is it?*
3. *Where is Voronezh anticline in Ukraine?*
4. *What are the main features of the Dnieper-Donets basin?*
5. *What are the sections that distinguish the coal system?*
6. *What tectonic elements are in the Donetsk folded structure?*
7. *What rocks make up the Donetsk folded structure?*
8. *How did the Black Sea depression arise?*
9. *What are the features of the geological structure of the Scythian plate?*
10. *What rocks formed the Volyn-Podilsk plate? How old were they?*
11. *What is the structure of Lviv depression?*
12. *What deposits are the coalfield and hydrocarbon deposits of Carpathian oil and gas province associated with?*
13. *What mountain structures are in Ukraine?*
14. *What mountain range is the main watershed of Europe between the Baltic and Black Seas?*
15. *What transregional folded system includes the Carpathian, Dobrudja and the Crimea mountains?*
16. *What elements characterize a tectonic geological structure of the Carpathian Mountains?*
17. *What are the main structural elements of the Crimean Mountains?*

CHAPTER 8

GEOLOGY OF OIL AND GAS FIELDS

Petroleum and natural hydrocarbon gas is one of the main energy sources of modern society. It is through their use in industry and everyday life it has become possible to implement science and technological revolution in the twentieth century. Today, the richest countries in the world are oil and gas countries.

Oil and gas are formed in different geological circumstances – both on land and in the sea basin (mainly in offshore zones). The geology of oil and gas fields considers the processes of their formation, patterns of distribution and features of the occurrence of deposits in geological structures, the genesis (origin) of hydrocarbons and methods of forecasting, prospecting, exploration and development of oil and gas fields. Resources and hydrocarbon reserves in the depths are calculated geologically.

8.1. Chemical composition of oil and gas

Oil and natural gas are complex combustible mixture of hydrocarbons of various classes that contain non-hydrocarbon impurity substances. The latter are absorbed by them from oil and gas environment or assimilate with hydrocarbon filtration channels and often show features of oil and gas origin. In the depths hydrocarbons constantly interact with groundwater.

Oil is a multicomponent hydrocarbon oily liquid that has a color from beige to black. Its main elemental composition is: carbon 80...88 % hydrogen 11...14,5 %; sulfur 0.01...5,0 %; oxygen 0,05...0,7 %; nitrogen – 0,01...0,6 %. Different traces (up to 50 chemical elements) are present in oil. These are the so-called trace elements (over 30 metal and 20 non-metals). Among them are: V, Ni, Fe, Zn, Al, Hg, Cd, Cu, Mn, Se, As, Pb, Sb, Ba, Mo, Cr, Ag, Au, Na, Ca, Br, Si, Sr, Co, Ti, Ga, Ge, Sn and others. Some metals in oil are in the form of salts of organic acids and hilate complexes in which the metal atom is located in the heart of paraffin cycle or cavities of condensed aromatic fragments, and the majority – in the form of complex polydental compounds. A number of these complexes may participate in ion exchange with metals in solution or on the surface of rocks that contact with oil. The greatest number of metals are in asphalt-tar substances (vanadium, nickel, cobalt, etc.).

Oil density ranges from 650–1.050 kg/m³. Its combustion temperature is from 43,7 to 46,2 MD/kg.

Hydrocarbons removed from various oils belong to three main series: *methane* – C_nH_{2n+2} (alkanes, paraffin), *naphthene* – C_nH_{2n} (cycloparaffin, cyclines) and *aromatic* – C_nH_n (arena).

Technological classifications of oils are based on the content of

- a) *sulfur* – low sulfur (0,5 %), sulfur (0,51–2,0 %), high sulfur (> 2,0 %);
- b) *resins* – low resin (< 18 %), resin (18–35 %), high resin (> 35 %);
- c) *paraffin* – low paraffin (< 1,5 %), paraffin (1,50–6,0 %), high paraffin (> 6 %).

The composition of the oil is also characterized by liquid-gas fractions arising in certain temperature ranges.

Natural hydrocarbon gases are a multicomponent mixture of methane hydrocarbons and non-hydrocarbon components capable of burning. They occur in the lithosphere (mainly in the sedimentary complex of rocks) in the form of free clusters, as well as in dissolved (in oil and formation waters), scattered (sorbed rocks) and solid (in the form of gas hydrate deposits) states. They are represented by methane (up to 85–90 %), ethane, propane, butane and pentane (total content up to 20 %), as well as a couple of liquid hydrocarbons. The non-hydrocarbon components are predominantly nitrogen, carbon dioxide, water vapor, sulfur compounds (hydrogen sulfide, mercaptans, sulfur dioxide, etc.), helium, argon, hydrogen, mercury vapor and the like.

CO₂ content in combustible natural gas can be from parts of a percent to 10–15 %, and sometimes more. N concentration does not exceed 2–3 %, but in some oil and gas basins its content can reach 30–50 %. In the known fields with a predominant nitrogen content it can be up to 80 %.

The amount of hydrogen sulfide usually does not exceed 2–3 % here, but sometimes it reaches 15–20 % or more. Concentrations of helium are usually hundreds and thousandths of a percent, sometimes reaching 5–8 %. Sulfur, helium, mercury and other valuable components are extracted from natural gas in various countries.

Gas condensate. Natural gas contains liquid hydrocarbon particles very often. The degree of saturation is determined by the condensation (cm³/cm³, g/m³), which also determines the formation of condensate.

Condensate is a hydrocarbon mixture (C₅ + C₆ + higher) present in a gas-condensate deposit in a gaseous state and falls out as a fluid with a decrease in reservoir pressure (to condensation start pressure) in the development process of the deposit.

Crude condensate refers to liquid hydrocarbons (C₅ + higher) with dissolved gaseous components (methane, ethane, butane, propane, hydrogen sulfide, etc.).

The onset of condensation pressure is the pressure in the reservoir at which the condensate of the deposit begins transition from a vapor state to a liquid, leading to transformation of a single-phase system into two-phase. Condensate is present in most gas fields.

Gas hydrates (crystalline) are formed under conditions of certain pressures and temperatures. Hydrogen bonded molecules form crystalline lattices, which are penetrated by structural molecules of methane and other hydrocarbon gases. The solid compounds (clathrates) thus formed are called gas hydrates. Temperature increase or reduction of pressure is accompanied by the destruction of the lattice and decomposition of hydrates into gas and water.

Accumulations of gas hydrates in water basins (the Black Sea, Arctic Ocean, etc.) and in the zones of perennial frozen rocks (the Polar Urals, Scandinavia, Alaska, Northern Canada, etc.) create gas hydrates deposits, which do not require lithological coverings for the formation and storage. Under certain thermodynamic conditions they themselves play the role of impermeable screens for ordinary oil and gas deposits.

The formation conditions of hydrates in each case depend on the composition, pressure and temperature of gas. Each hydrocarbon compound is characterized by a specific critical hydration formation temperature. The critical hydration formation temperature ($^{\circ}\text{C}$) is: for methane – 1,5; ethane – 14,5; propane – 5,5; isobutane – 2,5; of n-butane is 1,0. From pentanes, hydrocarbons do not form hydrates.

Chemical formula of methane gas hydrate is $\text{CH}_4 \cdot 7\text{H}_2\text{O}$; ethane – $\text{C}_2\text{H}_6 \cdot 8\text{H}_2\text{O}$; propane – $\text{C}_3\text{H}_8 \cdot 18\text{H}_2\text{O}$, etc.

Density of natural gas hydrates ranges from 900 to 1100 kg / m^3 .

8.2. The origin of oil and gas

The origin (genesis) of oil and gas has been a debating issue for over 100 years. It is not only of scientific but also of a great practical importance. Knowledge of formation conditions and sources of oil and gas deposits allows us not only to forecast, prospect and explore them productively, but also to develop fields rationally.

Since there is no consensus on the origin of oil and hydrocarbon gases, two essentially scientific concepts are considered – organic and inorganic genesis of hydrocarbons. As the theory of organic origin of hydrocarbons seems more reasonable, it has more supporters. Geologists, relying on it, have discovered many deposits around the world. These deposits are mainly associated with folding (anticlinal) structures in sedimentary strata of different age and composition. G. Potonyer (1905), I. M. Gubkin (1932), and later A. Levorsen (1954), V. V. Weber (1955) and M. M. Strakhov (1956) developed the theory of

the original petroleum horizons and showed possible schemes of hydrocarbons formation from scattered organic raw materials in their works.

A schematic diagram of organic matter conversion to oil and gas is the following. Organic matter of plant and animal origin is deposited in sedimentary rocks in a scattered or concentrated form. The most favorable conditions for this were created in coastal (shelf) zones of the seas, in lagoons and gulfs, in lakes and marshes. The conversion of organic matter to oil or gas is facilitated by reducing environment. Historical-geological patterns of hydrocarbon deposits distribution indicate that they are predominantly organogenic in the upper, explored part of the sedimentary strata, 90 % of which are known oil and gas fields. This is evidenced by isotopic composition of carbon in hydrocarbons, which is similar to its composition in organic matter.

However, we should not reject the possibility to produce oil and gas abiogenically. There are three hypotheses regarding inorganic hydrocarbon synthesis (carbide, space, and volcanic). In the 1960 s, Ukrainian geologist, Academician V. B. Porfiryev substantiated the magmatic hypothesis of hydrocarbon formation. The carbide (mineral) hypothesis of hydrocarbons formation in the interaction of water vapor with heavy metal carbides was put forward in 1877 by D. I. Mendeleev. The hypothesis of cosmic genesis was proposed in 1889 by M. O. Sokolov.

Experiments and physical-chemical calculations prove possible hydrocarbons formation by inorganic synthesis. However, the question is whether it is possible to form huge volumes of hydrocarbons – oil and gas – this way? On the other hand, how to explain the formation of oil and gas deposits in crystalline massifs and zones of deep faults with the help of organic theory of oil and gas accumulation? The magmatic hypothesis of oil and gas is the answer to these questions. V. B. Porfiryev and his followers (I. I. Chebanenko and G. M. Doglenko, E. B. Chekalyuk and V. A. Krayushkin and others) proved that the formation of oil and gas fields is connected with processes in the upper mantle of the Earth. From there, hydrocarbons migrate through the zones of deep fractures to the earth's surface, where oil and gas deposits can form in the pore-fractured rocks-collectors of the base and sedimentary cover.

There are also "mixed" hypotheses of oil and gas origin (M. I. Pavlyuk, I. I. Chebanenko). They try to reconcile supporters of organic and inorganic hydrocarbons. An analysis of these theories gives good reason to conclude about the polygenic (both organic and inorganic) origin of oil and gas. According to the authors, hydrocarbons of organic origin predominate in the upper sedimentary layers of the lithosphere. In mantle regions, in deep fracture zones, and in some cases within crystalline shields and massifs, there are hydrocarbons, formed inorganically. The validity of this assumption is often confirmed by isotopic studies.

8.3. The concept of collector - rocks

Oil and gas, along with water, circulate in the lithosphere in reservoir rocks characterized by relatively high permeability. Mineral composition of the oil and gas reservoirs is divided into quartz, quartz-feldspar, carbonate and evaporite (homogeneous). Productive reservoirs are characterized by a wide variety, due to different mineral composition of the skeleton, the type of intergranular cement, clay, the size of the pores and grains of the rock, etc. By the type of pore space the rocks are distinguished as: intergranular, intergranular-fracturing, fractured, fractured-cavernous and cavernous.

The porosity of the rocks characterizes the presence of pores in them. Due to the porosity rocks can contain liquids and gases. We distinguish between general, open and closed porosity. Total porosity is the total volume of open or closed pores of a mineral or rock. *Open porosity* is the volume of pores that contact with the atmosphere (or other medium in which the rock is (mineral)).

Closed porosity is the volume of pores that do not contact with the external environment (calculated by the difference between total and open porosities).

In petroleum geology, there is also an *effective* porosity – the volume of pores occupied by a moving fluid (oil, gas) when the pore space is completely saturated with that fluid. It is less than the open porosity by the volume of bound (residual) fluids.

The porosity value is closely related to the material composition of the rocks. In silts, loesses it reaches 80 %; in sedimentary rocks (limestones, dolomites, sandstones) it varies from one to 35 %; in volcanic-sedimentary rocks (tuff sandstones, tuffs) – within 5–20 %; in magmatic rocks – not more than 5 %. Porosity determines such physical properties of rocks as hardness, velocity of elastic waves propagation, compressibility, electrical, thermophysical, etc. parameters. In oil and gas geology, industrial geophysics methods are based on the use of dependencies between these parameters.

Porosity causes *permeability* – the ability of a rock to pass through a system of interconnected pores of liquid (water, oil, etc.) and gases or other mixtures if there is a pressure drop. Permeability quantitatively characterizes the filtration properties of the collector.

Due to the lack of bond between the pores, the rock can be impenetrable even with high overall porosity (chalk, marl, and some clay). The permeability of the same rocks to different fluids is different: rocks that are impermeable to oil and water can be permeable to gas (due to its greater permeability) and rocks that are not permeable to high viscosity oils are permeable to low viscosity oils.

In oil and gas reservoirs, both porosity and permeability depend on geostatic pressure (inverse dependence) and temperature (direct dependence).

The filling of the pore space by oil and gas is characterized by the coefficients of oil and gas saturation. They are determined both experimentally (in laboratory conditions) and in the process of industrial-geophysical exploration in wells (methods of electrical resistance, neutron methods).

8.4. Occurrence conditions of oil and gas deposits

Oil or gas deposit is a natural, local accumulation of oil and gas in one or more interconnected reservoirs controlled by a single (joint) water-oil or gas-oil contract. If the accumulation of hydrocarbons is large enough and profitable to develop, it is called the industrial oil and gas deposit.

The shape and size of the hydrocarbon deposit are related to the shape and size of the trap. The main parameter of the deposit is its reserves.

Hydrocarbon fluids in the Earth's crust occur in a confined space. Their existence is conditioned by the ratio of collectors with impermeable rocks – covers.

A cover is a complex of low-permeable rocks that overlap the productive reservoir and prevent the destruction of hydrocarbons. Rocks that form covers include salts, clays, mudstones, gypsum, chalk, dense limestone, etc. Availability of covers in the geological section is a basic condition for conservation of oil and gas deposits in the lithosphere, where they retain their insulating properties under certain conditions of temperature and pressure for a long geological time. With a certain pressure drop, the shielding ability of the cover decreases and hydrocarbon filtration can occur through it. The same happens with increasing temperature. Cover thickness ranges from several meters to tens and hundreds of meters (in regional covers). The best (the tightest and the largest in area) covers are salt-bearing thicknesses, and the most common are clay covers.

Based on the sizes, there are regional, zonal and local covers. Regional covers, developed within the oil and gas regions and provinces, are characterized by great thickness and lithological homogeneity. Zonal covers spread over the entire area of oil and gas accumulation or several fields, while local ones are of the same field.

Oil and gas in the Earth's interior are in *natural reservoirs*, formed by overlapping *reservoir rocks*. According to the collector properties and conditions of occurrence there are: bedded, massive, bed-massive and lithologically limited reservoirs (Fig. 8.1).

Hydrocarbons in natural reservoirs are in constant motion outside the areas of accumulation. However, water and other fluids are filtered through the zone of rocks permeability. Their movement speed reduces with depth but in zones of tectonic faults it has high values at great depths.

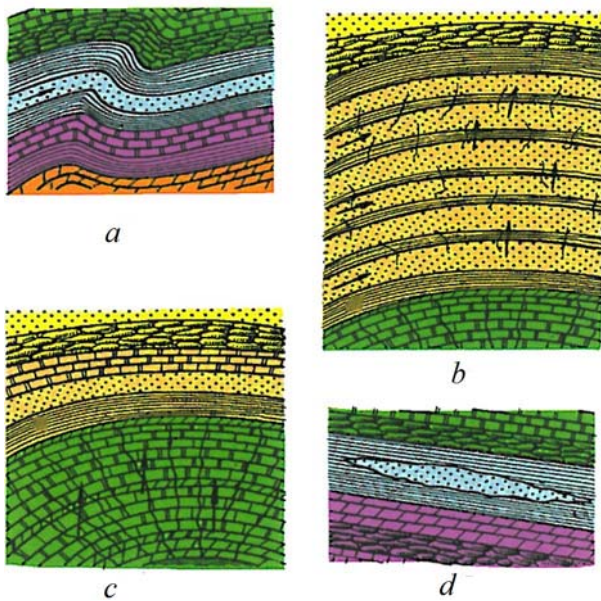


Fig. 8.1 – Natural reservoirs of hydrocarbons:
 a – the reservoir;
 b – massif;
 c – strata-massive;
 d – lithological limited

A *bedded reservoir* is usually characterized by a small thickness and extends over vast areas (hundreds and thousands of km²). At the bottom and the top it is limited by fluid-tight rocks. The fluids in such a reservoir move from the areas of greatest pressure (greatest depth) to the areas of lowest pressure (lowest depth).

A *massive reservoir* is a large thickness (up to 1.0 km or more) of permeable rock, covered from above and from the sides by impervious rocks. Tanks of this type often formed in ancient (fossil) reefs. Hydrocarbon filtration here occurs toward the cover.

A *bedded-massive reservoir* is a combination of bedded and massive reservoirs. These are usually collector thicknesses overlapping with fluid resistant layers. As there are numerous tectonically weakened areas (zones of discontinuous disturbances) in this massif of rocks, all of it is a single fluid-dynamic system. Hydrocarbons in such a reservoir are filtered both horizontally (by rocks-reservoirs) and vertically (by zones of discontinuous tectonic disturbances).

A lithologically restricted reservoir is a thickness of collector rocks surrounded by fluid-tight rocks. It usually looks like a lens. Fluids move in a confined space because of the small size of the tank.

The *capacity of oil reservoirs* is determined by their size and the porosity value of the reservoir. The first three types of reservoirs have the largest capacity.

There are areas of hydrocarbons accumulation called *traps* within the natural reservoirs.

Oil and gas trap is part of the bed-collector. Its occurrence conditions and the relationship with the shielding rocks provide accumulation and long-term storage of hydrocarbons (oil and gas) in it. It is a stagnant part of the natural

reservoir, where oil, gas and water are equilibrated, preventing fluid from flowing in a geological space.

By genesis (origin) traps are divided into structural, lithological, stratigraphic, riphogenic and mixed (lithologic-stratigraphic, structural-lithological, etc.) (Fig. 8.2).

Structural traps are associated with anticlinal folds (structures) – anticlines and domes. They are formed as a result of tectonic movements, accompanied by contractions and breaks of layers of rocks. The shielding of hydrocarbons in such layers is mostly tectonic. Salt is often found in the nuclei of the anticlinal structures, deposited on weakened zones (diapiric structures). In such cases, the salt layers is a reliable fluid cover for the accumulations of oil and gas.

Lithological traps are formed by changing the material composition of rocks associated with upwelling of bed-collectors or replacement of collectors with impermeable layers.

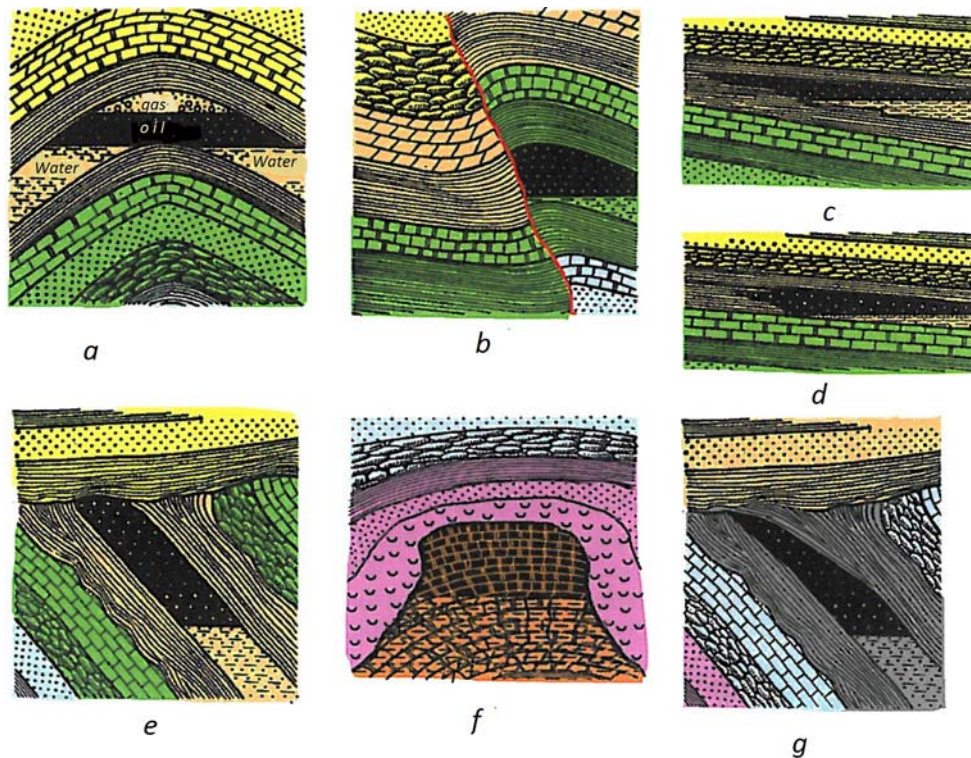


Fig. 8.2 – Oil and gas traps:

a – structural vault; *b* – structural tectonically shielded; *c* – stratigraphic; *d* – reefgeneous; *e* – lithological pinch of collector; *f* – lithological replacement of the collector impermeable layers; *g* – a combined type trap (lithologic and stratigraphic)

Stratigraphic traps are associated with non-agreement of stratigraphic layers in rocks that are collectors and fluid resistance falls. These traps are often formed on the anticlines, if inconsistencies are fluid resistance falls. On a monocline, a stratigraphic trap can be formed in the event of a reservoir formation wedge, the sole and roof of which border on impermeable rocks.

Reefgeneous traps are formed in buried reef bodies created in different geological eras by different corals. This happens when they are covered with impermeable layers (salts, clays, etc.).

Mixed-type traps are formed by the combination of two or more of the above factors.

According to the search and genetic traits we distinguish the following traps: vaulted, deadlocked (shielded) and lenticular.

Vault traps are formed in the vaulted parts of anti-wedges, under salt domes, clay diapirs, intrusive arrays, buried reef massifs and erosion protrusions under the covers.

Shielded traps occur on the wings of the anticline, flexure and monoclines with lithological or hydrodynamic shields.

Lenticular (lithologically restricted) traps are formed in lens-shaped reservoirs (buried sand bars, channel and delta sands, porous zones of carbonate rocks).

Traps of shielded type have anticline wings, the flexure and monoclinities under the presence of lithological or hydrodynamic shields.

Lenticular (limited lithologic) trap is formed in lines like collector (buried sand bars, fluvial and deltaic sands, porous zones of carbonate rocks).

8.5. Oil and gas resources and reserves

To determine the presence of oil and gas in the depths of a certain territory we use such concepts as "*resources*" and "*reserves*".

Resources – the expected amount of oil, gas and condensate in the depths of a geological object (oil and gas prospecting complex, a province, etc.) Resources are of likely nature.

Reserves – the amount of oil, gas and condensate contained in oil and gas reservoirs of the identified deposits.

When performing exploration work to refine the structure and oil and gas content of rocks, resources can be redeployed to reserves. Reserves are distinguished from resources by the fact that there is a performance installation layer, that is, the fact of the deposit opening.

According to the degree of geological study, the resources of oil and gas are divided into two groups: *projection and perspective*.

According to the degree of validity among the projection resources of carbon-hydrogen we distinguish:

- *Category D₂* – projection resources of significant regional geological structures, whose oil and gas content has not been proven;

- *Category D₁* – projection resources of lithologic-stratigraphic complexes within significant regional structures with proven oil and gas content.

Prospective resources (category C_3) – volumes of oil and gas in geological sites prepared for deep drilling and quantified according to the results of geological and geophysical studies. Prospective resources are the basis for geological and economic evaluation of advisability for exploration.

Oil and gas reserves are divided into two groups by the degree of study: *preexplored* and *explored*.

Preexplored reserves (category C_2) – a group of oil and gas reserves whose quantity, quality, technological properties, mining, geological and other conditions of occurrence have been sufficiently studied for technical feasibility report of commercial value of the deposit. Category C_2 includes reserves of a deposit (or part of it), the oil and gas content of which is determined by the results of well testing and exploration, as well as surface geological and geophysical studies. These reserves also include those undeveloped parts of deposits adjacent to the sites with explored reserves. Pre-prospected reserves are used to determine prospects for the field, to plan exploration or geological and industrial research, and to design deposits.

The explored reserves are the volumes of oil and gas, quantity, quality, technological properties, mining, and other conditions of occurrence. They have been studied with completeness, sufficient for drafting the design and arrangement of deposits.

Geological study of the explored reserves varies in size and detail. Accordingly, the exploration reserves are divided into the following categories:

– *category C_1* – reserves of oil (its parts), industrial oil and gas content of which is established by the results of exploratory development and testing of wells with industrial inflows of oil or gas, as well as geological and geophysical explorations in untested wells with detail, sufficient for substantiation of economic feasibility of industrial development;

– *category B* – reserves (its part), oil and gas of which are set on the basis of the industrial flow of oil or gas at different hypsometric marks, and basic peculiarity of the deposit, determining the conditions of its development, studied with completeness sufficient for the development of the deposit project.

– *category A* – reserves (or part thereof) studied in detail that provides a complete type definition, shapes and sizes of the deposit, effective oil- and gas-saturated thickness, type of collector, the nature of the changes in collector properties, oil and gas saturation of productive layers of oil, gas and condensate composition, as well as the main features of the deposit that affect the conditions of field development.

Oil fields have been discovered on all continents except Antarctica, as well as offshore zones in the oceans. There are more than 30,000 oil fields known in the world, 15 to 20 % of which are oil and gas. About 85 % of the world's oil production is accounted for by 5 % of the fields. Its largest stocks are in Saudi

Arabia, Kuwait, Russia, Iran, Iraq, Norway, the United States, Azerbaijan, Mexico, Venezuela, UAE, Brazil.

The majority of explored reserves of natural gas (90 %) is in the gas or gas-condensate fields. There are more than 80 trillion m³ of the explored gas reserves in the world. About 60 trillion m³ of gas have been extracted from the depths with annual production of more than 2 trillion m³ of gas. Explored gas reserves are (in billion tonnes of conventional fuel): world – 180; European – 70; Ukrainian – 1,5. According to forecasts, the depletion of planetary natural gas reserves should be expected in 2050–2070.

There are more than 10,000 gas fields known in the world but major gas reserves are concentrated in a small number of unique (more than 1 trillion m³) and largest (0,1–1,0 trillion m³) gas and gas condensate fields.

By geological age, the gas content of sedimentary rocks is distributed as follows: in Paleozoic sediments – 23,5 %; in the Mesozoic – 65,5 % and in the Cenozoic – 11,0 %. Sand collectors account for 76,3 % of reserves and carbonates for 23,7 %. Clay covers control 65,7 % of gas reserves, saline – 34,3 %. The vast majority of gas reserves are concentrated in structural traps.

The largest reserves of natural gas are concentrated in the depths of the USA, Norway, Canada, Mexico, Algeria, Russia, Turkmenistan, Indonesia. It should be noted that the first industrial oil fields in Europe were opened in Ukraine in 1810, Boryslav (Ivano-Frankivsk).

Test questions to the theme

1. *What is oil?*
2. *What technology is based on oil classification?*
3. *What gases are called combustible natural gases?*
4. *How is gas-condensate formed?*
5. *What are the scientific theories of the origin of oil and hydrocarbon gases?*
6. *How is organic matter converted to oil and gas?*
7. *What is inorganic theory of oil and gas based on?*
8. *What is the natural geological reservoir of oil and gas?*
9. *What types are oil and gas reservoirs divided into?*
10. *What characterizes the porosity of rocks?*
11. *What is the difference between total and open porosity?*
12. *What is effective porosity?*
13. *What parameters determine permeability of rocks?*
14. *What do we call oil and gas deposit?*
15. *What rocks can be a cover?*
16. *What is a hydrocarbon trap?*

- 17. What is oil and gas reservoir?*
- 18. What is the area of thinning rocks?*
- 19. What types of oil traps do you know?*
- 20. Describe the lithological and tectonic shielded trap.*
- 21. What are the resources and reserves of oil and gas?*
- 22. What are the categories of resources and hydrocarbon reserves?*
- 23. Where is the majority of world resources of oil and gas located?*
- 24. What are the major oil- and gas-bearing regions of Ukraine?*
- 25. In what geological conditions are gas hydrates formed?*

CHAPTER 9

HYDRO-GEOLOGICAL PECULIARITIES OF OIL AND GAS DEPOSITS

Groundwater is a constant satellite of oil and gas in the Earth's crust. Migration of hydrocarbon fluids in rocks is often accompanied by groundwater circulation in thermodynamic, elution and infiltration water systems. These waters are characterized by significant pressure, high mineralization (up to 320 g/dm^3), alkalinity (pH 7,5–8,5) and predominance of chlorine and sodium ions in their composition in almost complete absence of sulfate ions. Sometimes alkaline water of oil and gas fields have very low mineralization (up to $1\text{--}5 \text{ mg/dm}^3$) and sodium bicarbonate composition (condensation water). They are all called "oil waters".

Oil water was described for the first time by a Canadian geologist T. Gantt. Its uniqueness has always attracted the attention of many researchers. Now there is a whole scientific field, called petroleum (or industrial) hydrogeology, the foundations of which are laid in the works of Russian (A. Abramovich, V. Sulin, N. Ignatovich, A. Kartsev, M. Altovsky, V. Shvets, A. Nikanorov and others), American (I. Talmer, J. Rogers, D. Crow-Ford, A. Laversen, J. White, etc.), Ukrainian (A. Romanyuk, E. Gavriglenko, V. Kolodiy, O. Shtogryn, L. Gutsalo, A. Babinets, O. Lukin, L. Shvai, Yu. Zastezhko, A. Terdovidov, V. Tereshchenko, etc.) researchers and scientists from other countries.

The works of the famous Ukrainian geologist O. Lukin take a special place, as the scientist has perfectly proved the unity and interconnection of hydrogeological, geodynamic, lithological, structural, geochemical and other factors of oil and gas accumulation in the earth's depths.

9.1. Conditions for finding water, oil and gas in natural reservoirs

Conditions for finding water, oil and gas in a natural reservoir depend on the interaction of several factors: ratio of fluid density (liquid-gas mixtures), relative saturation of the pore space of each of the components, the hydrodynamic conditions in the reservoir layer, as well as its lithological features.

In traps, which also contain oil, gas, and water, the fluids are uniformly distributed vertically, each occupying a horizontal layer. The lightest component of the fluid–gas is located in the pore space at the top of the trap. Oil is the main substance that fills the pores of the productive layer. Below pore space is filled with water (Fig. 9.1).

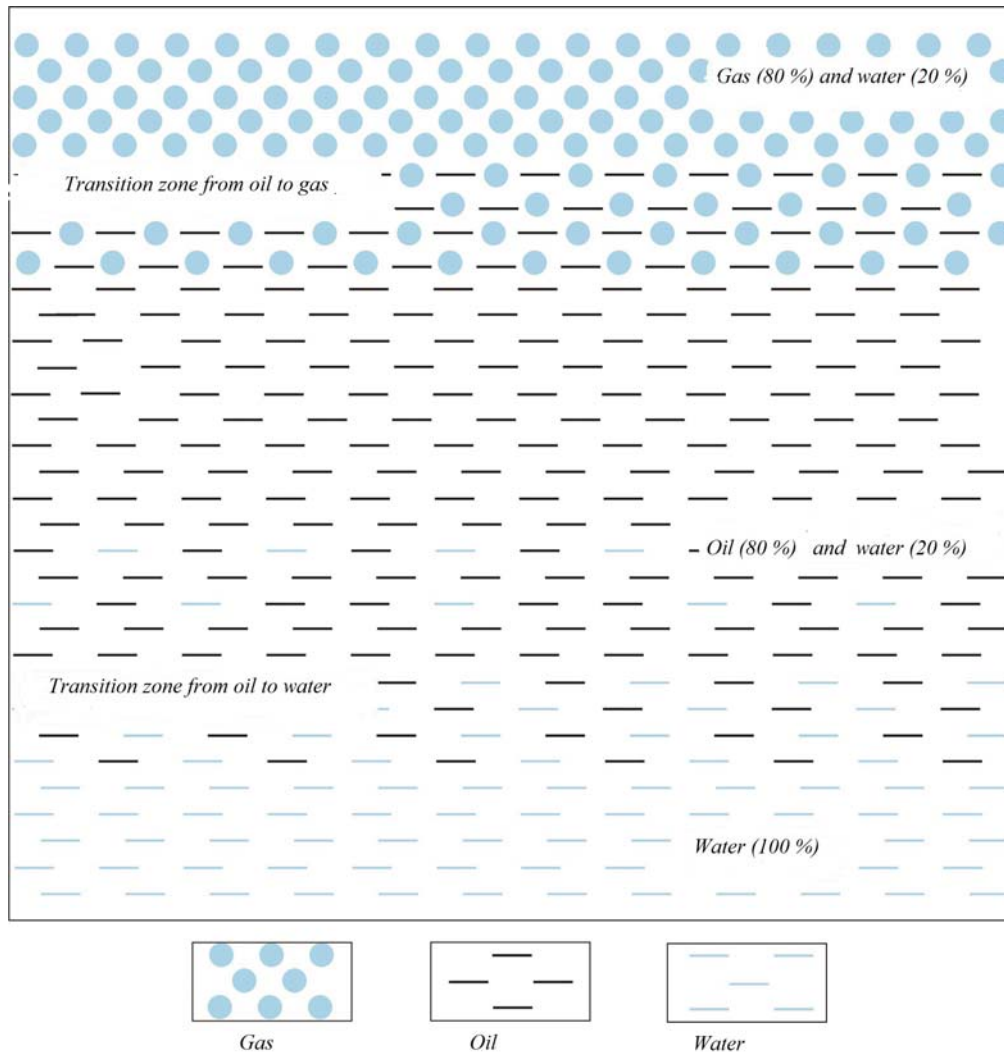


Fig. 9.1 – Relative distribution of gas, oil and water in a typical natural reservoir

The boundary between oil and water is called water-oil contact (WOC). In traps where oil is absent and trap fluids are represented only by gas and water, the boundary between them is called gas-water contact (GWC) (Fig. 9.2).

The magnitude of the GWC slopes is a direct indicator of the conditions for the conservation of oil and gas deposits from mechanical destruction by groundwater.

It should be noted that water in pores is in the natural reservoir everywhere. It can take up to 50 % of this volume.

Water does not enter the well until the amount of oil and gas in the reservoir rocks decreases to a level at which the rock becomes more permeable to water than to other fluid components (oil and gas).

The nature of the WOC (water-oil contact) of the deposit indicates the conditions of oil and gas accumulation in the trap and the features of its geological and structural formation.

Because oil, gas, and water form a single fluid system, oil and gas fields can be considered as separate elements of large hydrogeological structures. Among them, special attention is paid to water basins consisting of pressure aquifers and complexes controlled by depressed regional tectonic structures filled with sedimentary rocks. Therefore, oil and gas zoning of large territories often coincides with the hydrogeological one.

Wells, that in the process of prospecting and exploration for oil and gas fields revealed porous rocks only with water or water with non-industrial quantities of oil and gas (i.e, those that did not find oil and gas deposits), are called "dry", "water" or non-productive .

As we noted earlier, the lower boundary of most oil and gas deposits is water or gas contact. Free waters surrounding the deposit, filling the pore space below and around it, are called plantar or marginal waters, depending on their position relative to the deposits (Fig. 9.3).

With decreasing oil and gas flow, petroleum water (brine) begins to flow from most wells and volumes are steadily increasing. These are pores, plantar or marginal waters. In some deposits, water comes with oil from wells in the early stages of operation, and in other cases, the extraction of oil or gas is never accompanied by significant amounts of water. Formation waters in the strata above the deposit are called upper waters. Waters from aquifers lying between productive horizons are called *intermediate*.

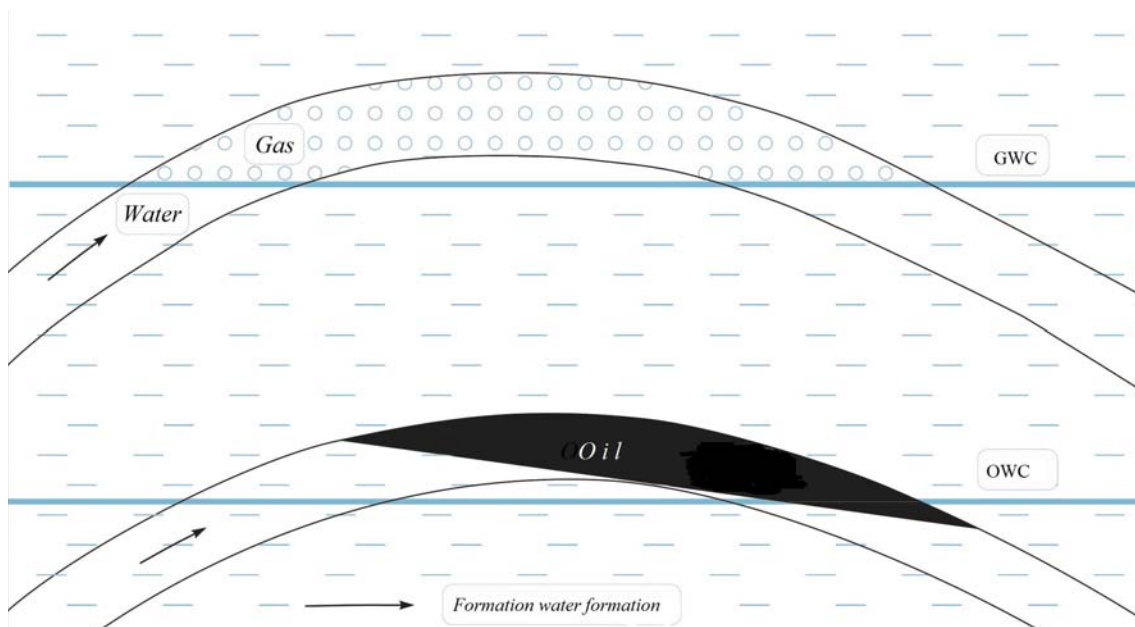


Fig. 9.2 – Gas – water (GW) and oil – water (OW) contacts in the deposit of oil and gas deposits

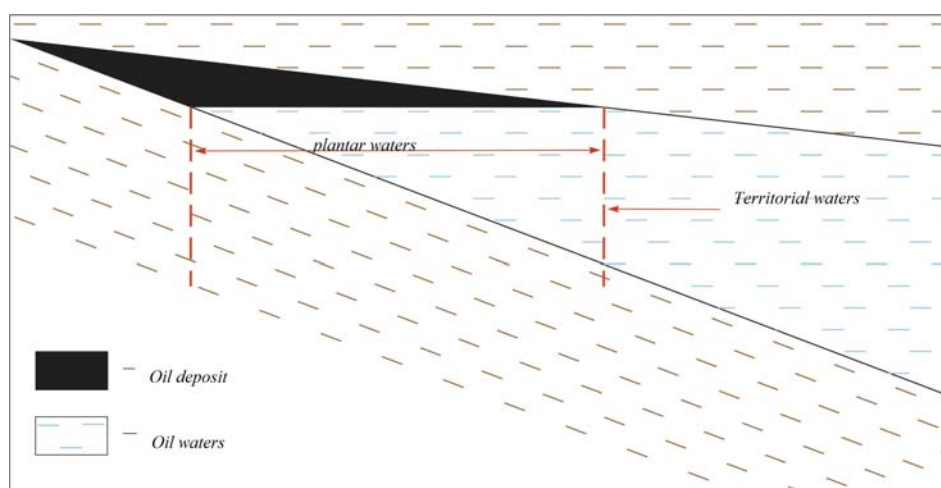


Fig. 9.3 – The position in the context of floor and boundary waters relatively to oil deposits

9.2. Genetic and geochemical characteristics of groundwater in gas deposits

By origin, oil and gas fields can be divided into meteoric, buried and mixed.

Meteoric waters are waters that are infiltrated into porous and permeable rocks of the upper horizons of a geological section. The presence of carbonates and bicarbonates, and sometimes sulfates in the waters of some oil and gas fields indicates that these waters, at least partially, come here from the surface.

In oil and gas hydrogeology, waters in the reservoirs before drilling are called *buried waters*. Most buried water or brine is characterized by a high content of chloride and sodium. Concentrations of NaCl in it are much higher than in ocean water. General hydrogeological meaning of the term "buried" water is that it is a syngenetic or autochthonous water that has been deposited at the same time as its formation and preserved after its transformation into rock.

Mixed water contains chloride, hydrocarbonate and sulfate ions. This indicates their complex nature due to the mixing of buried and infiltrated waters.

The waters of the oil and gas fields may be *free and bonded*.

Free formation water, having a different composition and origin, migrates on the same filtration channel as hydrocarbon fluids. Instead, *bound water* exists in the pore space of oil and gas reservoir. Here the bulk of bound water is absorbed by mineral particles or is held by capillary forces. Such waters with increasing water saturation to the sole of the deposit, pass into free water. The free water is displaced by oil and gas during the formation of hydrocarbon deposits.

Waters of oil and gas fields are often characterized by alkalinity. The concentration of hydrogen ions (hydrogen ions) in them is 7,5–9,0, and the redox potential (Eh) of petroleum water, measured in millivolts, is usually negative. This indicates their restorative character due to their deep occurrence and isolation from the earth's surface.

Groundwater of oil and gas fields has mainly sodium chloride composition and a large set of trace elements and gases, including hydrocarbons, halogens, nitrogenous compounds, metals, inert gases and others.

A measure of minerals dissolved in water is its total mineralization, determined by the mass of dry residue after evaporation.

According to general mineralization among the oil waters there are (g/dm^3):

- ultra fresh – up to 0,1;
- fresh – 0,1–1,0;
- poorly mineralized – 1,0–3,0;
- average mineralized – 3,0–10,0;
- highly mineralized – 10,0–35,0;
- brines – over 35,0.

In their turn, the brines of oil and gas fields are divided into weak (up to $140 \text{ g}/\text{dm}^3$), strong ($140\text{--}270 \text{ g}/\text{dm}^3$) and very strong ($270\text{--}340 \text{ g}/\text{dm}^3$). The presence of calcium and magnesium ions in water determines its hardness, which is directly proportional to the content of these elements.

Gases of oil and gas deposits are natural carbohydrate mixtures, mostly methane series of the general chemical formula $\text{C}_n \text{H}_{2n+2}$ (from methane to butane). As impurities, and sometimes in significant quantities are H_2S , CO_2 , N_2 , and in small – H, Ar, He, Hg and a couple of others. Natural gases are dissolved in water and oil. Their solubility depends on pressure, temperature and gas composition. Methane, its homologues, carbon dioxide, nitrogen, hydrogen sulfide, inert gases – helium, argon, neon, radon, and others are present in groundwater in a soluble state.

According to Kolodiy V. (2009), the content of dissolved oxygen in waters is up to $20 \text{ cm}^3/\text{dm}^3$, H_2S – $2000 \text{ cm}^3/\text{dm}^3$ and H_2 – up to $1000 \text{ cm}^3/\text{dm}^3$.

Gases form molecular solutions with water. Underground waters of oil and gas structures are dominated by CH_4 and its homologues. Among other gases there are CO_2 , N_2 , NO , H_2 , inert gases.

The volume of gas dissolved in a unit of water volume under normal conditions (pressure of 760 mm Hg. and temperature is about 20°C) is called *gas saturation of water*. It is the sum of all amounts of dissolved gases, expressed in terms of volume of gas per volume of water (hm^3/m^3 or hcm^3/cm^3).

The content of hydrocarbon gases in the waters of oil and gas fields sometimes exceeds $13000 \text{ cm}^3/\text{dm}^3$. The actual gas saturation of groundwater can be determined only on the basis of deep analysis of samples taken by special probe (KII – 65, etc.).

Groundwater from natural gas deposits contains a variety of organic matter (OM), among which (mg/dm^3) fat ($n \cdot 10^{-3}\text{--}n \cdot 10^3$) and naphthenic ($n \cdot 10^{-2}\text{--}n \cdot 10^2$)

acids; aromatic hydrocarbons – benzene ($n \cdot 10^{-2} \cdot n \cdot 10^2$), toluene ($n \cdot 10^{-3} \cdot n \cdot 10$), phenol ($n \cdot 10^{-2} \cdot n \cdot 10$), compounds of nitrogen ($n \cdot 10^{-1} \cdot n \cdot 10$), phosphorus ($n \cdot 10^{-2} \cdot n \cdot 10$), and others. But these waters are the most common hydrocarbons present in oil and gas deposits.

Formation of chemical composition of reservoir water in oil and gas fields is due to paleohydrological conditions, rocks composition of bearing strata, depth and other factors. The main components of ion-salt composition is Cl^- and Na^+ . The subordinate importance have HCO_3^- and SO_4^{2-} , and also Ca^{2+} and Mg^{2+} . In very strong brines ($>300\text{г} / \text{дм}^3$) Ca^{2+} ion can dominate on ion Na^+ . Therefore, in addition to mostly sodium chloride, there are also calcium chloride brines, sodium bicarbonate and water. So, with a salinity of 5–10 times lower than the figures of hydrogeochemical background it is called *condensing* or *sallucial water*.

Condensation water borders on deposits of hydrocarbons. They are high in iodine, bromine, ammonium, sillicium, potassium, strontium, lithium, rubidium, cesium and others.

While the content of microelements in the formation waters (brines) increase with increasing salinity, in fresh condensing water such dependence is absent. This is evidence that these types of geochemical water formed under different schemes.

9.3. Hydro-geochemical indicators of oil and gas presence

Underground formation water of oil and gas deposits has specific features, used as indicators in forecasting oil and gas. There are *local* (on separate structures and sites) and *regional* (large areas) types of forecast.

As groundwater is the main carrier of not only minerals but also the thermal energy, they are the main factor in *heat and mass transfer* processes in the crust. Warm water is often found in areas of oil and gas fields controlled by fault structures. This phenomenon is connected with a rising hydrocarbon fluid discharge, groundwater and thermal flow on the same filtering channels. That is why hydrogeothermal anomalies are an important indicator of oil and gas clusters in the depths.

A geochemical type of water and the nature of its overall mineralization, sulphatation, content of trace elements (ammonia, iodine, bromine, boron, mercury, helium, strontium, vanadium) and other features are also used in forecasting of oil and gas.

The most common indicators of oil and gas content in stable platform conditions are chemical composition (sodium chloride) of groundwater and its

high mineralization. In areas of alpine activity, which is also manifested in modern tectonic movements, a reliable indicator is sodium bicarbonate water with low mineralization.

An important criterion for the assessment of oil and gas content is groundwater sulphate, which sharply decreases when approaching the contour of the oil and gas reservoir.

Organic substances dissolved in groundwater are a direct indication of the carbohydrates presence in the subsoil, since they are not only a source of oil and gas, but can also enter groundwater from an oil deposit due to convective and molecular diffusion processes. It should be noted that the presence of organic matter in groundwater is mainly related to oil and gas condensate deposits.

A fairly reliable indicator of oil deposits is radioactivity of groundwater due to the enrichment of their salts with radium. Instead, the oils themselves are low in radium.

The content of *aromatic hydrocarbons* (benzene and toluene) in the groundwater can also serve as a direct indicator of oil and gas content. Approaching oil and gas condensate deposits, their concentration significantly increases.

Phenols, reaching 20–30 mg/dm³ in oil and gas condensate fields may be a sign of light oil and gas condensate in the depths.

Gases, present in groundwater, are an important indicator of oil and gas content. Most important are hydrocarbon gases, as well as helium, mercury vapor, nitrogen compounds (N, NO, NO₂, NH₃) and others.

Total groundwater gas saturation is defined as the amount of gas dissolved per unit of water volume. The highest gas content is found in methane gas zones.

Hydrogeochemical anomalies, which are the areas of a dramatic change in the chemical composition of groundwater compared to background values, are an important criterion for predicting and finding oil and gas fields. This is determined by the huge role that water plays in the formation and destruction of hydrocarbon deposits in the Earth's interior.

Anomalous areas are characterized by contrast, understood as the ratio of the components content in water within the anomaly to their background (average) values. The greater the contrast, the more reliable the predicted anomaly value is.

Hydrogeochemical anomalies are mostly confined to tectonically weakened areas where upstream discharge of deep horizons, oil and gas fluids, heat flow and chemical elements and compounds of deep genesis occur. Very often chloride brines or fresh hydrocarbonate condensation (salution) water are unloaded on or near the bottom of the surface, which is an important sign of the possible presence

of oil or gas deposits. This is the so-called "hydrogeochemical inversion" which often accompanies hydrocarbon deposits.

Test questions to the theme

- 1. Why is groundwater a constant companion of oil and gas?*
- 2. What features characterize oil water?*
- 3. How are gas-water (GW) and oil-water (OW) contacts formed?*
- 4. What are plantar and boundary waters?*
- 5. What are the upper and intermediate waters?*
- 6. What genetic types of water are present in oil and gas fields?*
- 7. What dissolved gases are present in groundwater?*
- 8. What factors condition the formation of chemical composition of water and gas deposits?*
- 9. What is condensation water?*
- 10. What hydrogeological parameters are used for oil and gas forecasting?*
- 11. What is the formation nature of hydrodynamic anomalies?*
- 12. What is the hydrogeochemical inversion?*
- 13. What hydrogeochemical anomalies indicate possible presence of hydrocarbons accumulation?*
- 14. Describe hydrogeothermal hydrocarbon indicators.*

CHAPTER 10

UKRAINIAN MINERALS

In terms of mineral resources base, Ukraine is one of the leading countries in the world. Occupying only 0,4 % of the earth's surface with 0,8% of the planet's population, it has 5 % of the world's mineral resources in its depths. More than 20,000 fields have been explored in the country and more than 200 minerals have been identified, 120 of which are used by humanity today. Of these, more than 8 thousand of 94 mineral deposits are of industrial importance. Coal, oil and gas, iron and manganese ores, native sulfur, rock and potassium salts, non-metallic construction materials, and mineral waters are of the greatest economic importance. Their deposits are in different geological regions. According to the explored reserves of some useful deposits, Ukraine is ahead of the Russian Federation, the United States, Great Britain, France, Germany, Canada and other major powers of the world. In particular, in terms of reserves and production of iron, manganese, titanium-zirconium ores, many types of non-metallic raw materials, Ukraine holds a leading position among European countries and the world.

10.1. Combustible minerals

In early 2011, the state balance in Ukraine took into account 385 hydrocarbon fields in three oil and gas regions. Of them in the Eastern region there are 228, in the Western – 112, and in the South – 45 deposits. The country's initial potential hydrocarbon resources are about 9,4 billion tonnes of conventional fuel.

The main oil and gas structure is the Dnieper-Donetsk oil and gas region, discovered in the 1950s with a prospective area of 78 thousand square kilometers.

Oil and gas deposits are confined to the dense zones of the crystalline basement rocks and deposits of the Devonian, Coal, Permian, Triassic, and Jurassic ages contained in the terrigenous and carbonate rocks. Oil fields occur mainly at depths of up to 4.500 m, gas and gas condensate – up to 5,000–6,000 m. The largest gas fields are Shebelinka, Zakhid-Khrestyshche, Yefremivsk (total reserves exceed 970 billion m³). The largest oil fields are Lelyakivsk, Gnidnitsevska, Glynsk-Rozbyshiv, which produced over 80 % of oil

in the Dnieper-Donetsk oil and gas province. (Fig. 10.1). Carpathian oil and gas region covers the Carpathians, Ukrainian Carpathians and Transcarpathia.

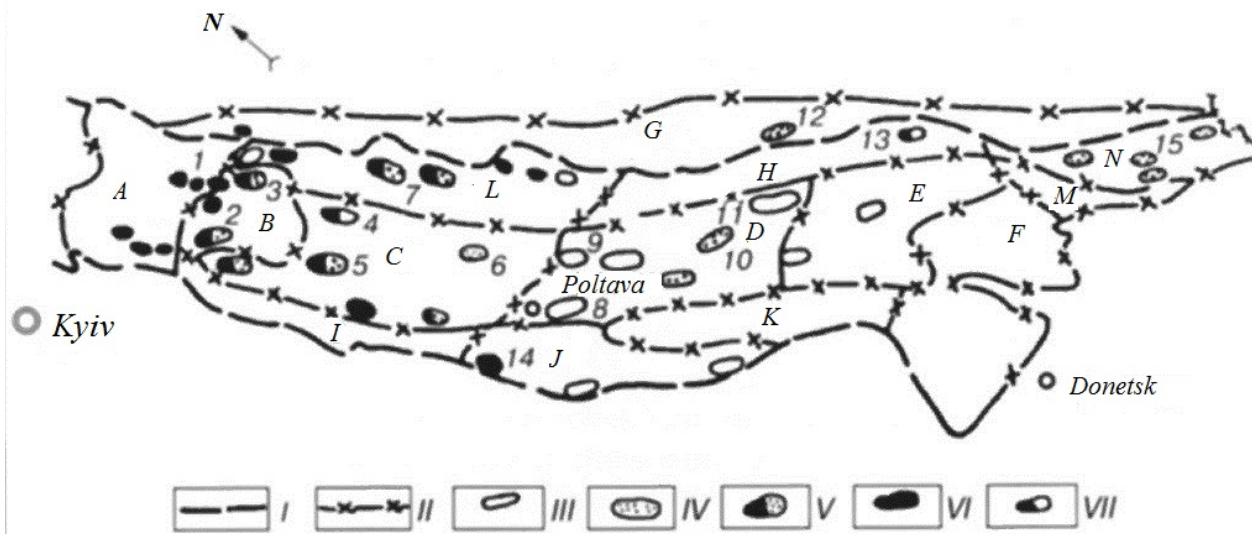


Fig. 10. 1 – Oil and gas geological zoning scheme of Dnieper-Donetsk cavity: I – boundary faults; II – the border of oil and gas areas; A – Monastyrishensk-Sophia; B – Sribnensk, C – Glinsko Solohivsk; D – Mashevsk-Shebelynsk; E – Spivakivsk, F – Kalmius-Bahmutskiy; G – Northern board; H – Ryabuhinsko-Pivnichnoholubivskyy, I – Antonov-Bila; J – Rudenkovsk-Proletarian; K – Zhovtneva-Lozova; L – Anastasievsk-Rubachij; M – Lisichansk; N – Krasnoritsk; III prospective area; IV – gas fields; V – oil and gas fields; VI – oil fields; VII – gas condensate, oil and gas deposits (figures on the map): 1 – Yaroshivsk, 2 – Lelyakivsk, 3 – Talalaevsk, 4 – Glinsko-Rozbyshivsk, 5 – Yabluniv, 6 – Solohivsk, 7–8 – Mashevsk, 9 – Zahidnohrestyschensk, 10 – Yefremivsk, 11 – Shebelinsk, 12 – Korobochkynsk, 13 – Druzhelyubivsk, 14 – Zachepilovsk, 15 – Olhivske

Most deposits are in the Carpathian basin. Oil deposits are concentrated in the Paleogene, while gas – in the Upper Jurassic, Upper Cretaceous and Miocene sediments. The depth of the oil deposits is 500–4800 meters, gas – from 100 to 500 m. The deposits of hydrocarbons are confined mainly to the sand, at least – carbonate strata. The largest oil fields are Volyn and Boryslav (Fig. 10.2).

Black sea-Crimean oil and gas province includes the Black Sea basin on the Crimean peninsula and waters of Black and Azov Seas. There are more than 60 oil and gas fields explored. Industrial gas, gas condensate and oil deposits are in Paleocene and Cretaceous rocks at the depth of 100–4500 m. In the Black Sea shelf gas deposits are already at depths of 300–750 m.

The largest gas fields are Storm, Fontaniv, Holitsynsk. The vast majority of hydrocarbon deposits are associated with zones of deep faults (Fig. 10.3).

Coal is the only combustible fossil raw materials. Its supplies in two coal basins – Donetsk and Lviv-Volyn can meet the needs of Ukraine in the next 200–300 years. In the energy balance of the state coal has a leading place. In the

structure of world reserves coal takes 67 %, oil – 18 % and gas – 15 %, in Ukraine, respectively, it is 94,5 %, 2 % and 3,6 %. At the beginning of the XXI century coal resources in the country at the depth of 1500 m are more than 115 billion tons. Its explored reserves are more than 60 billion tons, and perspective – more than 20 billion tons.

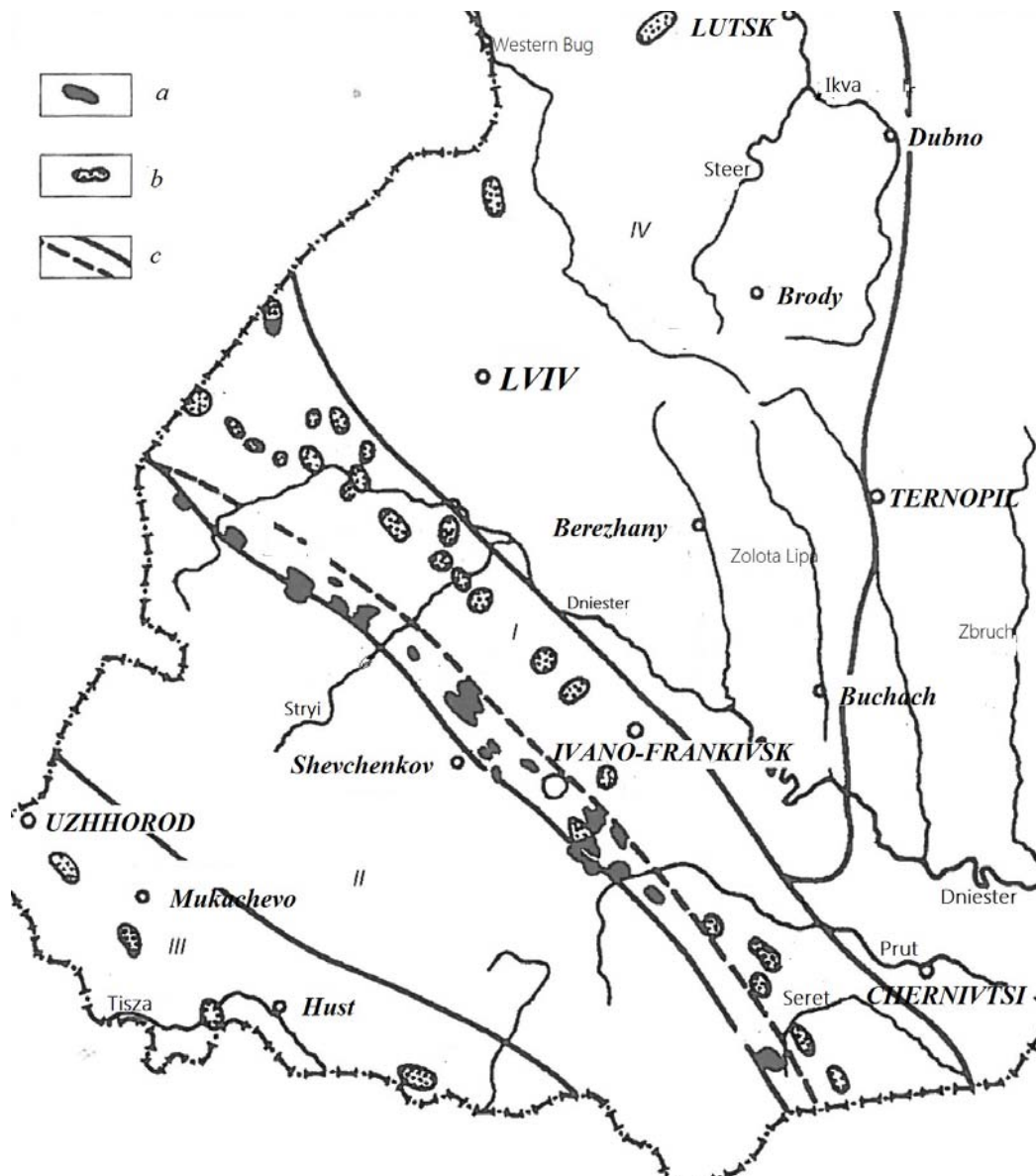


Fig. 10.2 – Scheme of Volyn-Carpathian oil and gas province

Hydrocarbon deposits: a – oil, b – gas, c – the border areas of oil and gas; d – oil and gas field:
I – Pre-Carpathian, II – Folded Carpathians III – Transcarpathian, IV – Volyn-Podolsky

The conditions of coal occurrence in Donbass are difficult, its depth is more than 1000 m, the thickness of layers with different slopes is 0.5-2.0 m. Coal production in Lviv–Volyn basin is simpler. The thickness of the layers is to 2.0 m, and 1 billion tons of reserves.

Brown coal deposits which are mainly concentrated in the Dniper coal basin, as well as in the Donbas, in Zakarpattia, Kharkiv, Poltava regions are hardly developed. They are associated with Paleogene-Neogene sediments. The main deposits are Korostyshiv (Zhytomyr region), Zvenigorod (Cherkasy region), Oleksandrivsk (Kropyvnytsky region.). The reserves of brown coal in Ukraine are about 3.0 billion tons.

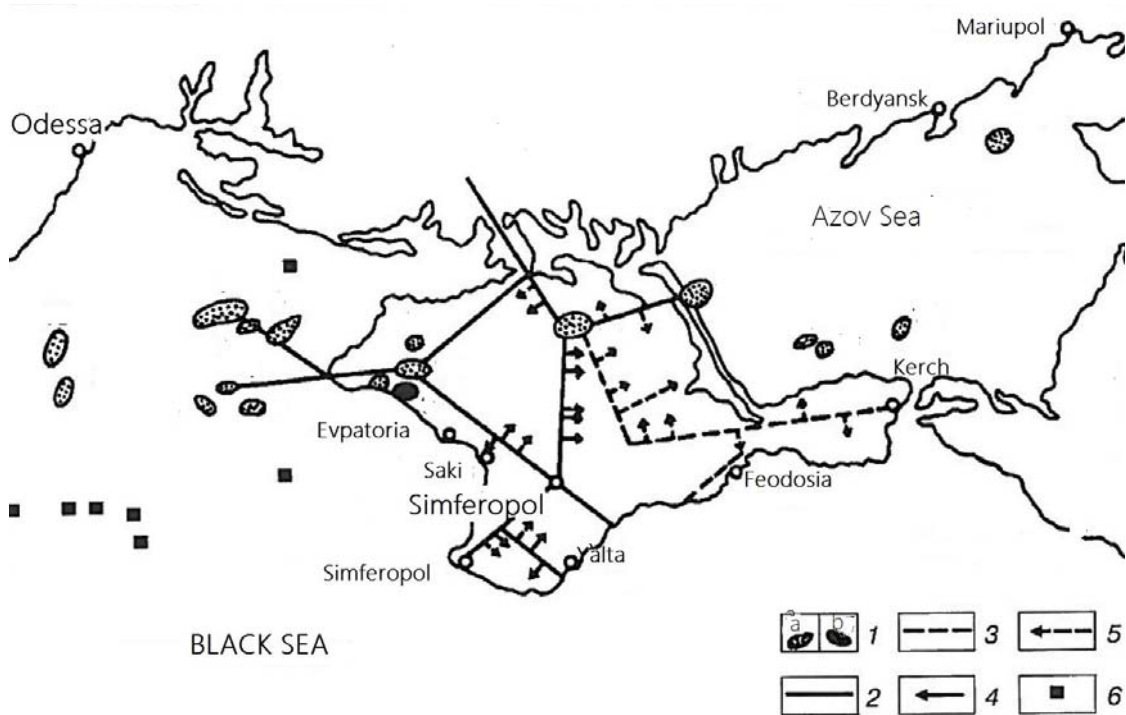


Fig. 10.3 – Scheme of hydrocarbons in the Crimea and Ukrainian Waters of Black and Azov Seas:
 1 – gas fields (a) and oil (b); 2 – existing pipelines; 3 – project pipeline;
 4 – existing pipelines; 5 – project gas pipelines; 6 – output of natural gas from the seabed

Oil shale . Substantial deposits of oil shale (3,7 billion tons) are discovered in Boltsh basin on the border of Kropyvnytsky and Cherkasy regions, where they are confined to the Paleogene sediments. The content of criogene is 30–40 %, 10–20 % resin output. Deposits of this type of minerals are also found in the Dnieper-Donets basin, in Volyn-Podilsk plate, in the Carpathian and Crimean mountains. The importance of oil shale in Ukraine is growing due to the technological capabilities of industrial extraction of natural gas.

Peat . There are over 2,500 peat deposits, in Ukraine with reserves of 2.2 billion tons. It is concentrated in Polissia – Volyn, Rivne, Kyiv, Chernihiv and Lviv regions. Industrial development of peat in our country is constantly decreasing.

10.2. Other minerals

Iron. With the proven reserves of iron ore Ukraine takes first place in the world (16 %), followed by Russia and Australia (15 %), China (11 %), the US (9 %), Brazil and Kazakhstan (6 %), other countries – 22 %.

Total reserves of iron ore in Ukraine are estimated at 27,4 billion tons. 60 of 88 fields are located in Kryvyi Rih basin, which supplies 18,7 billion tons. In Kremenchug field there are 4,5 billion tons, in Bilohirsk region (Zaporizhia region) – 2,5 billion tons. The estimated resources of iron ores in Ukraine are about 20 billion tons.

Iron ore deposits are metamorphogenic, associated with the iron-siliceous formations of the Precambrian (Kryvbas, Kremenchuk, Bilo-Zersk, Pryazov and other areas) and sediments of the Neogene (Kerch basin).

Manganese. The main reserves (about 2,3 billion tonnes) are concentrated in Nikopol Manganese Ore Basin (33 % of the country's explored reserves) and the Great Tokmak deposit (67 %). Ores are sedimentary, attached to oligocene deposits. There are three types of ores: *carbonate, oxide and mixed ores*.

Copper, cobalt, nickel. Native copper was discovered within the Volyn–Podilsk plate in the ladder coverings of the Precambrian basalts. Estimated resources are at 25 billion tonnes. Copper ores are also known in the red-colored Lower Permian sandstones of the Kartamsky formation (P1kg) in Bahmut basin of northwestern Donbass. Cobalt reserves in Ukraine are insignificant – 8 thousand tons (0.1 % of the world). There are also large manifestations and deposits of nickel with total reserves – 190 thousand tons (0,4 % of the world). Small deposits of cobalt-nickel ores have been found in Pobuzhzhya (6 deposits – Kapytoniv, Derenukh and others) and in the Dnieper region (4 deposits – Devladiv, Ternavsk and others). They are related to the surface weathering of Proterozoic metamorphic rocks.

Polymetals. The deposits and manifestations of lead-zinc ores are known in the Paleozoic rocks of Transcarpathia (Muzhiyi, Bregiv, Beggan), in the Donbass (Nagolny ridge, Slavyansk), in DDZ (Bilyaev) and in Precarpathians (Volyn Strait). The Transcarpathian volcanogenic-hydrothermal deposits and epithermal Bilyaiv (Kharkiv region) are of industrial interest.

Transcarpathian polymetallic subsidence is associated with Miocene volcanic zones and is confined to the inner volcanic arcs. Vein ore bodies controlled by discontinuous disturbances up to 5 m in size contain up to 2% Pb and 4,5 % Zn, as well as Ag. There are more than 500 ore zones on Nagolny ridge, individual ore bodies reaching 4–5 m. The polymetallic mineralization of Slavyansk brachianticline is in the Upper Permian deposits. Pb content is 1 %, Zn content is 3–10 %. It is bitumen-polymetallic ore. On the Bilyaiv salt-dome structure, lead-zinc depletion is confined to a supersaturated breccia. Contents

of Pb is 0,1–10,3 %, Zn – 0,4–15,72 %. Prospective resources here are 1,11 million tons with an average content of polymetals in the ore of 6,14 %.

Aluminum. Deposits of bauxites, nepheline ores and alunites are the mineral base of aluminum within Ukraine. Ukraine is poor in bauxite. There are only 3 deposits in the the Ukrainian shield's crust of weathering: Vysokopilsk, Nikopol and Smilyansk with total reserves of up to 20 million tons. The reserves of nepheline ores of Mazury and Kalino-Shevchenkiv fields are about 3.0 billion tons, but the processing of ores of this type requires considerable energy resources, so the development of deposits is so far unprofitable.

Titanium. Ukraine has Europe's largest titanium reserves and resources. 15 deposits of this metal have been discovered, 4 of which are being developed (within Kyiv, Kharkiv, Dnipropetrovsk and Donetsk regions). Titanium deposits are represented by indigenous, residual and alluvial deposits. The main mineral base is ilmenite (FeTiO_2) and rutile – zircon – lmenite deposits of Cenozoic with an ilmenite content of up to 25 % and apatite up to 12 %. The thickness of the ore layers in the weathered crust deposits is 25–30 m with the ilmenite content up to 150–200 kg / m³.

Rare metals. Rare-earth deposits of various ages, composition and origin have been found in Precambrian rocks of the Ukrainian Shield in Volyn, Podilsk, Central, Kryvyi Rih-Kremenchug and Pryazov geological regions. All known ore objects are connected with granite pegmatites, beryllium alkali meta-somatites, carbonates, nepheline and alkaline syenites.

By the so-called coefficient of uniqueness (the ratio of forecast resources to their clark in the earth's crust), the largest rare metal deposits of Ukraine are classified into certain categories. In the reserves of the USh, various deposits belong to:

a) niobium: giant – Chernihiv (Novopoltavsk), large – Oktyabrsk and Yastrubets;

b) zirconium: giant – Yastrubets, medium – Chernihiv, Oktyabrsk, Azov;

c) rare earth: large ones – Chernihiv and Yastrubetsk, middle – Oktyabrsk and Azov;

d) tantalum: large – Chernihiv and Oktyabrsk;

e) strontium: large – Chernihiv;

f) molybdenum: large ones – Verbinsk and East Sergiyevsk, medium – Balka Mazurova;

g) lithium: medium – Polokhiv. A powerful source of rare metals can be infrequent metal deposits containing industrial concentrations of rare metals, as well as highly mineralized waters of Donbas, DDZ and other regions with high content of lithium, rubidium, cesium, strontium, germanium and other elements, used as hydromineral raw materials in many countries.

Mercury and antimony. In terms of total mercury reserves, Ukraine ranks 5th in the world (after Spain, Algeria, China and Kyrgyzstan). Mercury ores are represented by hydrothermal volcanic deposits in the Trans-Carpathians (Borkut, Kamiany Quarry and others) and epithermal in Donetsk mercury province (deposits of Mykytiv ore field). The total balance of mercury in our country is 29,000 tonnes. Ores are represented by cinnabar (HgS) with antimonite (Sb_2S_3) impurities. Antimony is an important accompanying component of the mercury ores of Mykytiv ore field. Its explored reserves amount to about 4,200,000 tonnes. As a result of the sharp decline in the use of mercury in industry due to its toxicity, Mykytiv mercury plant was closed in the 1980 s.

Germanium. The reserves of germanium (in coal and lignite) in Ukraine amount to 36 thousand tons. In addition, germanium is in the iron ores of the Kryvyi Rih and Kremenchug deposits.

4 molybdenum ore manifestations were found in the Ukrainian Shield. The forecast resources of the most studied Verbino ore manifestation are 9,5 million tons with an average Mo content of 0,054 % to a depth of 150 m.

Chromite ores. Deposits of these ores are known in Pobuzhzhia and are accustomed to Precambrian hyperbasites. At Kapitoniv deposit, where the thickness of the ore bodies is from 0,2 to 12,0 m, the content of chromium oxide in the ore is 9–40 % (average – 29 %), reserves are 600 thousand tons. On the basis of the development, it is possible to produce 52–53 thousand tons of concentrate with Cr_2O_3 content of about 50 %.

Tin and tungsten ores are located mainly in the northwestern part of the Ukrainian Shield (Sushan-Perzhan Zone). The total reserves here are about 100 thousand tons with a tin content of 0.1 to 1–2 %. Ores are complex, containing cassiterite, columbite, tungsten, fluorite. Total tungsten forecast resources are estimated at 105,000 tonnes of metal.

Platinum-containing magnesium ores are found in the Middle Pobuzhzhia, where they are dated to ultrabasites with a magnesium oxide content of 43%, nickel – 35 %, and platinum – 0,4 %. The prospective resources of these ores here are 546 tons, and the forecast resources within Ukraine are up to 300 tons (~ 0.6% of the world).

Gold. Ukraine identifies three major gold-bearing provinces: the Carpathian, the Ukrainian Shield, and Donetsk. It has identified 6 gold-mining regions with a resource potential of several thousand tons of gold with an average content of 6–8 g/t. About 75–80 % of total gold resources are concentrated in the UCH, up to 16 % in the Carpathian region and up to 10 % – in the depths of Donbass. In the Ukrainian Carpathians, 3 gold deposits (Muzhyivsk, Brehivsk, Saulyak) and numerous ore manifestations of indigenous and placer gold have been discovered.

The most promising is the province of the Ukrainian Shield. Several deposits have been discovered here (Klyntsiiv, Balka Shyroka, Balka Zolota, Berdyansk, Sergiyev, Maiske and others), more than 10 ore manifestations and more than 20 prospective sites. Gold mining is associated with gneiss-magmatite complexes of the upper Proterozoic. There are 7 gold-bearing formations at UChS: gold-uranium, gold-sulfide-uranium, gold-skarn, gold-mudstone, gold-sulfide-quartz, gold-quartz, gold-silver – sulphide. Deposits of indigenous and placer gold have been discovered in Donetsk province, dated to the black-slate carbonate formation. The most important is the Nagolchansk ore site, which contains gold-sulfide and polymetallic – old-silver ores of Bobrykiv, Hostrobugorsky, Yesaulivsk and Nagolno-Tarasivsk ore fields. Ore bodies lie at depths from 300–400 m to 3300 m. Gold is promising in the Crimea, the Dobrudja Mountains, on the Black and Azov seas. The total gold reserves in Ukraine are estimated at 30 tons, and confirmed – at 20 tons. The total projected gold resources in the UCH rocks are 2400 tons.

Uranium. Ukraine ranks 1st in terms of uranium resources and reserves in Europe. Russia exceeds Ukraine by these indicators but its deposits are on the Asian continent. All deposits are matamorphogenic.

Graphite. The state balance includes 5 deposits of graphite. Crystalline graphite deposits (Zavaliiv, Troitsk and others) are associated with graphite gneisses and their weathering crust. Ore bodies contain an average of 6 % graphite. The balance reserves of graphite ore are about 126 million tons, graphite – 7843 thousand tons.

Rock salt is associated with Permian (Donbass, DZZ), Jurassic (Predobrudzha) and Neogene (Precarpathian and Transcarpathian) halogen formations. The reservoirs are operated by mines in Donbas (Artemivsk, Novo-Carthage) and Precarpathian (Hubytsk, Verkhnostutin), salt dome - in Dnieper-Donetsk depth (Yefremivsk, Romensk), in Donetsk region (Sloviansk) and Transcarpathia (Solotvyno). NaCl content in salts reaches 98–99 %. Significant reserves of sodium chloride are contained in brine salts and estuaries (Sivash et al.) and natural underground brines (Precarpathian). The state balance has taken into account 14 deposits with more than 16,6 billion tonnes (mostly rock salt).

Potassium salts are associated with Neogene foredeep formation of Precarpathian deflection with more than 20 fields (Stebnykivsk, Kalush-Holynsk and others). Average content of K_2O is 10–11 %. Balance reserves are 250 million tons.

Apatite. The deposits found on UCS. They are related with Precambrian gabbro-anorthosites, carbonates and crusts of their weathering. There are three deposits of apatite-titanium-rare metal ores containing P_2O_5 from 2,5 to 10 %. Apatite reserves are about 67 million tons (P_2O_5), and resources – 130 million tons.

Fluorspar (fluorite) forms deposits on the north-west part of UCS, Volyn-Podilsk region and in the Azov Sea (where there is the only taken into account Pokrovo-Kireevsk deposit with reserves of 20, million tons of ore (CaF_2). In general, in Ukraine there are 221,8 million tonnes.

Sulfur . With the proven reserves of native sulfur Ukraine has one of the highest places in the world and is the first among the CIS countries. The deposits are concentrated in the Carpathian sulphur pool. There are 12 fields, 5 of which are being developed. Reservoir-lens sulfur deposits are confined to Neogene gypsum-anhydrite thickness and represented by lime – sulfur ores containing S to 20–27 %. The biggest deposits are Nemyriv, Yazivsk, Podorozhnensk, Rozdolsk and Yavoriv. Balance reserves of ore are 665 million tons, and sulfur – 166 million tons.

Phosphorites. Phosphorite deposits in Ukraine are related to Predniper (Nezvansk), Sumy (Krolevetsk) and Kharkiv (Izyumsk) regions. They are also in Crimea (Pokrovo–Kerch, etc.). The reserves are 300 million tons of ore and 6.7 million tonnes of P_2O_5 .

Precious and ornamental stones are insufficiently studied in Ukraine. Exceptions are Volyn gems, Transcarpathian almandine, opal of Katerynivsk display and quartzite of Zhovtorichnyansk field. 8 fields have been discovered and more than 300 manifestations of 40 types of jewelry and gemstones have been found. All of them, as well as ornamental stone deposits are mainly concentrated in four geological structures: Ukrainian crystalline shield, the Carpathian and Crimean Mountains and Dnieper-Donets Basin. In Ukrainian geological formations the following precious stones have been found: diamond, ruby, topaz, emerald, rock crystal, morion, smoky quartz, amethyst, citrine, chrysoprase, opal, phenacite, zircon, beryl, pirop, almandine, helior, aquamarine, tourmaline, amber chalcedony, serdolik, agate, tiger, cat and falcon eye, rhodonite, nephrite, labrador, amazonite, sodalite, jasper, quartzite, jaspilites, obsidian, petrified wood, pyrophyllite, rhodochrosite, marble onyx, marble, and others. The best known deposits of precious stones in Ukraine are: Volyn (topaz, beryl, quartz, graphic pegmatite), Klesiv (amber), Golovinsk and Fedorivsk (labrador) Kalyusytsk (marble onyx), Pryluky (rhodonite, rhodochrosite), Kuryany and Nahornyansk (ahalmatolit). Most unique deposits are located in the Ukrainian shield. In general, stocks of gems are in Rivne and Volyn regions, Azov and in Krivyi Rih. Here there are beryl, topaz, amber, amethyst, agate, jasper, rock crystal.

Diamonds of all known genetic types were found in the late twentieth century on the Ukrainian crystalline shield, Donetsk folded structure and Scythian plate. The first findings were the discovery of diamonds from kimberlite structures (tubes) Azov.

Facing stone . Ukraine has explored more than 300 deposits of natural facing stone. The main source is UCS, within which there are about 140 deposits of

granite, charnockites, gabbro, labradorite with high technical and decorative properties.

Building and industrial minerals. In Ukraine, there are numerous deposits of gypsum (Piskivsk, Myhailivsk, Artemivsk, etc.), Kaolin (Glukhovtsy, Volodymyrsk, Velykohadominetsk, etc.), bentonite and clays (Cherkasy, Gorske and others), zeolites (Sokyrnytsk), fluxing limestone and dolomite (Olenivsk, Novotroitsk, Karakubsk, etc.), refractory clays (20 deposits, including Chasiv–Yarske, Novoraysk, Novoselytsya, Pology, etc.) quartzite (Ovruch, Banych), forming sands (Orikhiv, Pology, etc.), quartz sand (Velykohlibov, etc.), wax (Boryslav), natural pigments (Tselyk), magnesite (Pravdinsk), nepheline in the Azov and others. State balance considers the deposits: 35 of gypsum, 34 – kaolin, 6 – bentonite clay, 22 – molding sand, 8 – dolomite, 5 – quartzite and quartz sand.

In terms of hydro-mineral resources, Ukraine is among the first in Europe. 200 mineral water deposits have been explored: carbon dioxide, sulfate, rhodonite (Polyana Kvasova, Shayan, Truskavets, Svalyava Group, Myrhorod, Berezovsky, Kuyalnik and others). Thermal water deposits are known in Transcarpathia (Uzhgorod and others) and in the Crimea (Saky, Krasne, Kolodyazne, and others). Their depth is from 300 to 3000 m, water temperature – from 40–80 to 110°C. Well flow rates reach 2500 m³/day.

Test questions to the theme

- 1. What is mineral potential of Ukraine in the world?*
- 2. How many deposits and manifestations of minerals are explored in Ukraine?*
- 3. What kinds of minerals have the most industrial and economic importance for our country?*
- 4. How many oil provinces are known in Ukraine?*
- 5. How many explored hydrocarbon deposits are there in Ukraine?*
- 6. In the borders of what geological structures do the Carpathian region belong to?*
- 7. To what geological structure does Dnieper-Donetsk oil-gas bearing region belong to?*
- 8. What territory does Black Sea-Crimean oil and gas province cover?*
- 9. What is the depth of Ukrainian oil, gas and gas condensate deposits?*
- 10. What oil and gas condensate fields are the largest in Ukraine?*
- 11. What place does the coal industry occupy in the energy balance of the country? Why?*
- 12. What place in the world does Ukraine occupy as to the proven reserves of iron ore?*
- 13. What metal deposits are there in Ukraine?*

- 14. What deposits of rare elements are explored in Ukraine?*
- 15. Where and in what rocks are gold deposits in Ukraine?*
- 16. What geological structures are deposits of rock salt and potash associated with?*
- 17. What deposits of precious stones are being developed in Ukraine?*
- 18. What building materials are in the depths of Ukraine?*
- 19. How many mineral water deposits are explored in Ukraine?*
- 20. By what types of mineral raw materials does Ukraine occupy a leading position in the world and Europe?*

CHAPTER 11

TYPES AND METHODS OF GEOLOGICAL STUDIES

Our knowledge of the Earth is constantly expanding with increasing depths of mining. The scientists are conducting new deep-sea studies, including the Earth's mantle and the processes of heat-mass transfer. Further study of seismicity allows us to predict earthquakes. Among the current problems of geology are the studies of chemical composition of various spheres of the planet, explanation of the geochemical processes in its depths (phenomena of metamorphism, hydrothermal ore, oil and gas deposits formation, etc.). Hydrogeology, aimed at the study of resources, processes of formation and movement of groundwater, provides society with its basic vital resource – water. Instead, oil and gas geology explores the possibility of providing society with the most important energy resources – oil and gas. Thus, the purpose of geological research is to expand the resource base of human existence.

11.1. Research methods in geology

The primary method of studying the Earth's subsoil is geological survey – a set of works that result in mapping. Maps are built on a topographic or geographical basis, on which both rocky outcrops on the bottom surface and rocks lying on depth are applied. Symbols record their composition, age, occurrence, tectonic disturbances, etc. Geological survey is carried out by terrestrial method, using technical means. Land surveys use natural rock outcrops, mining, and wells. Geological survey is accompanied by geophysical and geochemical studies.

Geophysical methods study physical fields of the Earth: electromagnetic, gravitational, thermal, and others. They help to reach depths of deep mines and wells. So, with the help of seismic methods, the deepest spheres of the planet are probed down to the mantle and the core.

Methods of underground geophysics – radio-wave luminescence, induced polarization, well-hole electro-exploration are increasingly used at present (Fig. 11.1).

These methods are of great importance not only in the process of geological survey work, but also in prospecting and exploration of mineral deposits.

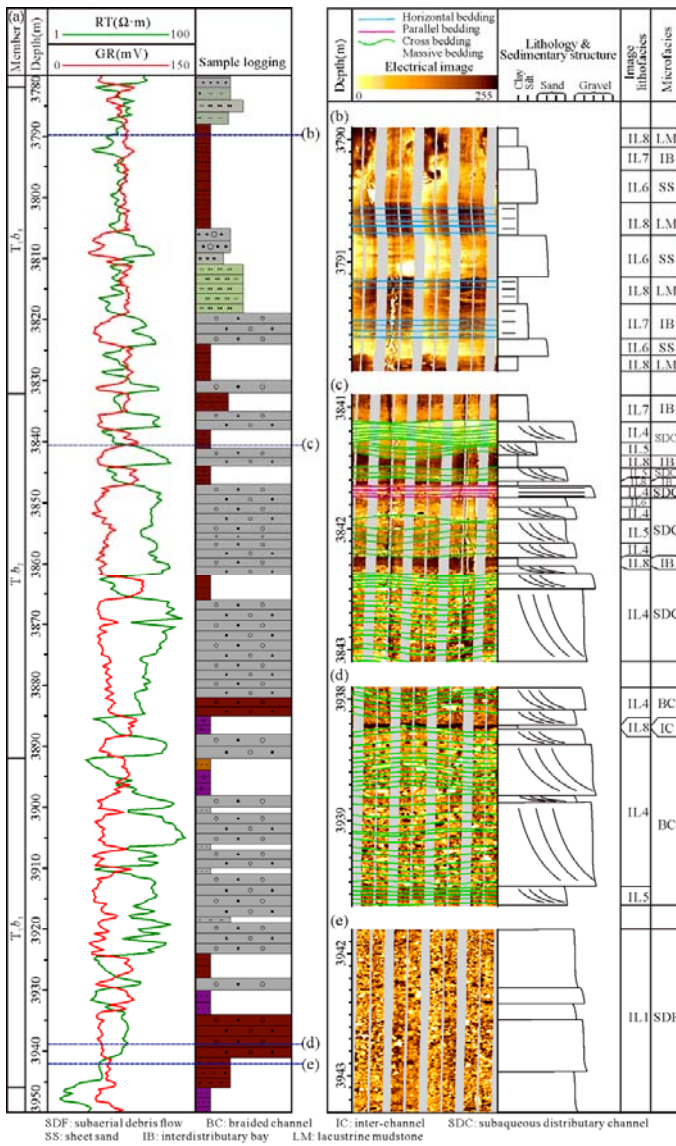
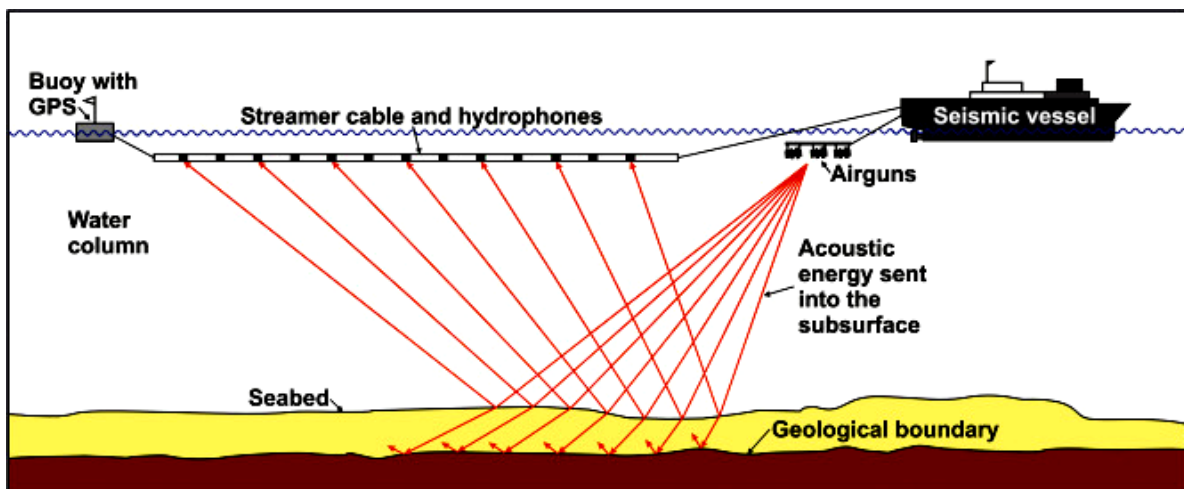


Fig. 11.1 – Diagram of electric logging results in the well

<https://www.degruyter.com/document/doi/10.1515/geo-2017-0041/html>



<https://www.sciencedirect.com/science/article/pii/B9780444641342000201>

Fig. 11.2 – Scheme of propagation and reflection of elastic seismic waves in the process of seismic exploration and seismogram view

1. *Method of deep seismic sounding (DSS)*. This is the main method of studying the depth zones of the Earth (Fig. 11.2) based on the behavior of seismic waves at different levels of the earth. With the help of seismic waves it is possible to determine density and phase state of the matter, to determine the depths of the boundaries of the Earth's shells (crust and upper mantle), the structure of deep faults, magmatic cells, etc. There are three types of seismic waves: longitudinal, transverse, and surface. They are born by underground shocks caused by natural or artificial sources. This method is important in identification of the areas of decomposition in the rocks associated with hydrocarbon deposits.

2. *Comparison method of seismic wave velocities*. It is based on the comparison of seismic waves in the earth's crust and in rock samples.

Laboratory studies conducted with rock samples in conditions close to great depths (high temperature and pressure) prove that seismic waves propagation velocities in some magmatic rocks correspond to the velocities of seismic waves in the lower layers of the earth's crust and upper mantle. On the basis of such comparisons, it was concluded that rocks similar to granites and basalts, lie beneath the sedimentary layer of the earth's crust, and the crystalline rocks of the upper mantle are close in density to peridotites. It is used in detection of oil and gas tanks and traps.

3. *Gravimetric methods* are used to study the gravity of the Earth. Studies have shown that acceleration of free-fall is gradually increasing with depth, reaching maximum at the boundary of the mantle with the core. In the core, it decreases to zero in the center of the Earth. Different density of rocks causes local deviations of gravity from normal or calculated values in the upper layers of the earth's crust. These deviations, called gravitational anomalies, are widely used in prospecting for both oil and gas fields and other minerals.

4. *Magnetometric methods* are based on the study of the magnetic properties of rocks and ores. Magnetic anomalies are established in their massifs. Each of them characterizes a particular mineral complex, which often lies at depths of thousands and tens of thousands of meters.

5. *Geothermal methods* are used to determine the areas of upward unloading of heat flows coming from deep zones of the Earth. Geothermal anomalies, in which the temperature of rocks and groundwater are higher than the background, indicate the existence of modern centers of heat and mass transfer in the Earth's crust. These methods are very important for detecting upstream discharge of oil and gas fluids.

6. *Geochemical methods* (litho-geochemical, hydro-geochemical, gas-geochemical, bio-geochemical) allow to study not only general chemical composition of rocks and minerals, groundwater and natural gases, but (most

importantly) to identify geochemical anomalies in different natural environments. These anomalies help to search for hydrocarbons and other minerals, study the ecological state of the geological environment and address other theoretical and practical problems.

7. *Drilling* makes it possible to directly study the subsurface minerals. With rock samples (cores) from different depths, raising the surface of drill pipes, we can answer different questions that interest us. But along with the core, there is also a coreless drilling. In this case, the rocks are studied by various geophysical methods by lowering certain devices into the well (industrial geology). Those or other physical characteristics compared with standard parameters allow us to determine not only the type and composition of the rock, but its properties as well. Wells are drilled at different depths depending on designation (geological, geotechnical, hydro-geological, oil and gas, structural, parametric, prospecting, exploitation, etc.). So, geological wells reveal rocks from several to a few tens of meters. Those, drilled for oil and gas are 3.7 km, and the depths of parametric wells studying the geological section of the lithosphere reach 10 km (Kolsk ultradeep). Wells are the most important type of research in prospecting and exploration for oil and gas, underground water, coal, metallic and non-metallic minerals.

Aerospace research methods have been widely used in recent decades. They are based on the photographing of the Earth's surface from the air and space, as well as on the registration of radiation devices of various types: thermal, infrared, ultra-high frequency and others. Photos consist of complex photo plans, which later build regional geological maps. However, they are not very detailed. The scale of the maps depends on the height of the shooting. Decryption of the images takes place both by the color tone of the captured fields and by comparing the images with the geological and tectonic maps of the well-studied regions. The faults, salt domes, and other geological structures are most clearly deciphered. The faults in the photos usually look like lines of black or dark gray.

There are other types of geological studies combined in *complex exploration*.

Promising areas and separate mineral deposits are studied consistently. In this process, we increasingly determine the features of their geological structure, mining and geological characteristics, quality of minerals, etc.

Preliminary exploration work is a kind of *prediction* of individual mineral deposits and prospective geological areas. Prospecting is based not only on geological study of the areas, but the method of *analogies* ((comparison of territories with a similar geological structure, one of which has been explored for deposits of certain minerals)).

11.2. Exploration work

Exploration work of **solid fuels** is divided into six stages:

1. *Regional geological-shooting and geophysical work.*

According to their results, we distinguish prospective for the identification of minerals structure, thickness and area for the formulation of prospecting work.

2. *Search of fields* is aimed at identifying mineral deposits. It is performed in three substages: a) a general prospecting; b) detailed prospecting for the areas where promising signs of mineral resources were found; c) prospecting and estimation works using mining and drilling wells. According to the results of this sub-stage, we assess the industrial value of the discovered deposit.

3. *Previous exploration*, during which general parameters of deposits, the amount of ore bodies, quality and technological properties of ore are determined. According to the results of this work mineral reserves are counted by category C_1 and C_2 and a feasibility study (FS) of detailed exploration is made.

4. *Detailed exploration* is carried out only in the fields or their separate areas, when their industrial value is proven by prior survey. As a result of detailed exploration of deposits we calculate mineral resources by category C_2 , C, B and A.

5. *Further exploration* of the deposits is carried out within the boundaries of the mountain drainage in parts of the field that are not well explored (flanks, deep horizons, and individual sections). The categories C_2 , C, B, and A are calculated as inventories resulting from these works.

6. *Operational exploration* occurs at the same time as mining and preparation work. It ensures the rational ongoing extraction of minerals while refining the data obtained from previous exploration stages within the field.

Exploration for oil and gas consists of two stages: prospecting and exploration.

1. *The search phase* is divided into 3 stages:

a) *regional geological* and geophysical works (small-scale geological and structural-geo-morphological surveys in combination with geochemical, hydrogeological and other studies; aeromagnetic and gravimetric surveys; exploration and seismic exploration, as well as drilling of basic, parametric and structural wells);

b) *preparation of areas* (structures) for deep exploratory drilling. It includes structural geological survey of average and large scale, detailed seismic survey, gravity exploration, electrical exploration, structural and parametric drilling, estimation of forecast resources and reserves;

c) *search for deposits*. It includes drilling and comprehensive geological and geophysical exploration in wells. As a result, stocks of categories C_2 and C_1 are calculated and a preliminary geological and economic assessment

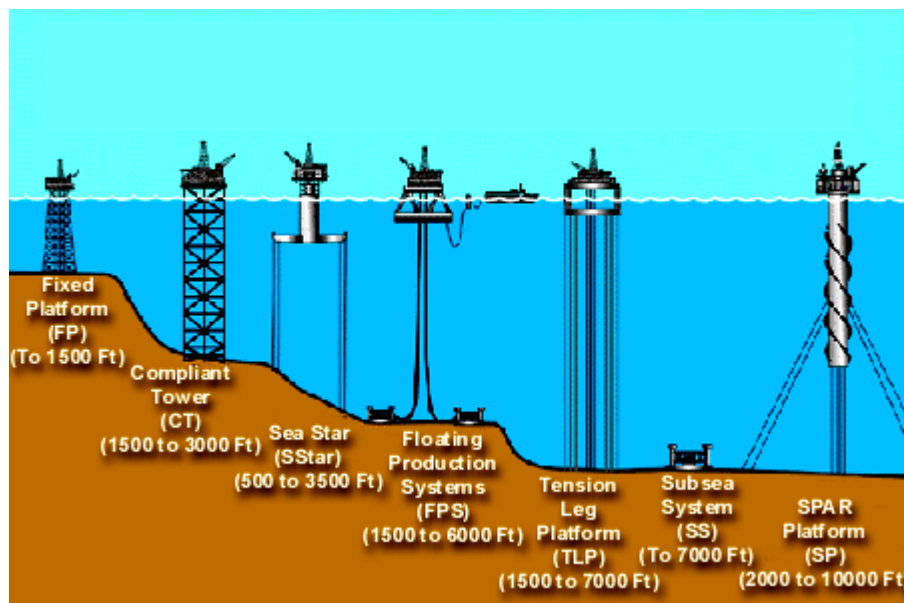
(GEO) of individual deposits is conducted to justify the conduct or termination of further exploration activities.

2. *Prospecting stage* prepares the deposit for development. For oil and gas deposits this stage includes:

- a) a complex of geophysical and other studies conducted in prospecting wells;
- b) studying the structure of the deposit;
- c) isolation of productive layers;
- d) determination of possible oil, gas, condensate and water flow rates;
- e) reservoir pressure forecasting;

f) substantiation of the indicators required for the design of operational works, including capital investments in industrial construction. The study of hydrogeological characteristics of the deposit and individual productive strata is important at this stage.

Prospecting for oil and gas in the Black and Azov shelves, where dozens of hydrocarbon fields and clusters of "unconventional" gas have been explored, (Fig. 11.3) is promising in Ukraine.



<https://www.indelac.com/blog/introduction-to-oil-gas-offshore-drilling>

Fig. 11.3 – Sea drilling platform

11.3. Geological documentation. Geological mapping, assembling sections and stratigraphic columns

Geological exploration of any area begins with geological shooting. It is carried out to establish the geological structure of the area and identify promising areas for prospecting and exploration of mineral deposits. Geological documentation is maintained from all types of work: geological maps, geological sections, stratigraphic columns are compiled.

A *geological map* is a graphical representation of a geological structure of a certain territory on topographic basis. The map shows the boundaries of distribution, composition, age and conditions of rocks occurrence, as well as tectonic structures (both folded and discontinuous), location of minerals and other data. Some special features of the study area are displayed on special maps – tectonic, hydrogeological, geochemical, minerals and others.

The purpose of geological maps is determined by their scale. Small-scale maps include survey maps in scale 1:1000000 and smaller. Their purpose is to show the geological structure of individual countries and continents. Surveying geological maps in scale of 1:1000000 and 1:500000 have been issued for the territory of Ukraine. The most common in geological practice are medium scale maps (1:200000–1:50000). They are used to prospectively evaluate the area or search for particular minerals.

Large-scale and detailed maps (scale 1:25000–1:5000) are the most complete and present detail images.

They are used to describe the geological structure of minerals deposits, their individual plots or fields. On the medium and large scale maps topography is depicted by horizontals.

Topographic base of geological maps in medium and large scales is a schematic topographical map on which there are horizontals, hydrographic network and individual settlements for orientation and binding to the terrain.

Geological mapping usually involves some *convention* – they do not show the youngest (Quaternary) sediments, except in those areas where these deposits reach a great thickness (tens or hundreds of meters). This is due to the fact that the Quaternary deposits cover older rocks almost everywhere. Therefore, special maps are used to display Quaternary sediments.

The composition and age of rocks on geological maps are indicated by *symbols*. The age of the rocks is indicated by indexes and corresponding colors. Geological maps have adopted a single color scale for the indication of the age of rocks on geological maps. Thus, the pre-Cambrian undivided is pink, archeus is dark pink, the Proterozoic is pale pink, the Paleozoic is indistinct – brown, the Cambrian system is blue-green, the Ordovician and Silurian are light gray-green, the Devonian is brown, carboniferous – gray, Permian – dark orange, Mesozoic undissociated – green, Triassic system – purple, Jurassic – blue, Cretaceous – green, Cenozoic indistinguishable – yellow, Paleogene system – Ohrid, Neogene – light-yellow, Quaternary – grayish-greenish. To indicate the age of rocks, in addition to coloring, we must always indicate the age indexes that are given in Latin letters.

Indices of parts are composed of system indices by adding them digital sign in the departments order (such as the lower – carboniferous division – C₁; medium-carboniferous – C₂; upper-carboniferous – C₃) right at the bottom.

Indices of layers are formed from parts of additional letters of a sign (first or first and subsequent letters of the consonants tier), which is placed near the sign department (for example C_{2m} – Moscow tier).

Igneous rocks outcrop very often to the surface of the Earth. Their age is not always possible to establish. So, geological maps indicate not their age, but their composition. For acidic and medium intrusions medium- red color, for main – dark-green, for ultramain – deep-purple.

Petrographic (lithological) maps show only the composition of rocks that outcrop.

Paleogeographic maps show the contours of the land and the sea, the location of mountains, volcanic area, features of a period, era or age.

Tectonic (structural) maps show certain conventional signs, indicating placement of the main types of structures (folded zones, fault zones, foothill deflections, etc.), as well as some antyclinal and synclinal folds and faults with regard to their hypsometric (tall) provisions in the geological space (Fig. 11.4).

Geophysical maps show reflection of the gravity, magnetic, radioactive anomalies on isolines.

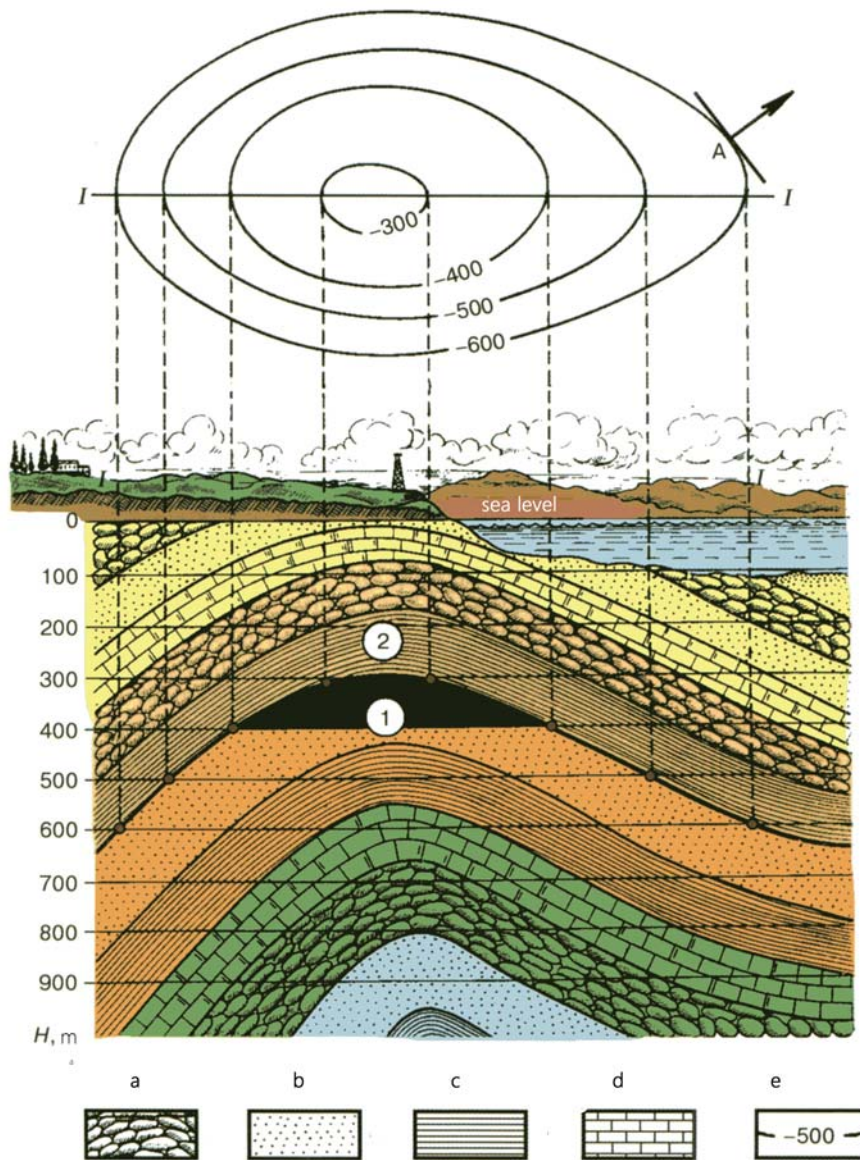
Geochemical maps reflect the chemical composition of rocks, underground water, gas and geochemical anomalies, which often involve a variety of processes and phenomena in the Earth's crust.

Geological maps help understand the features of the tectonic structure of the area. They describe the age and composition of the rocks and groundwater, location of areas forming various geophysical and geochemical anomalies. Analyzing these maps, you can predict the possible finding of mineral deposits, including oil and gas accumulations. An explanatory note is always attached to the map.

While geological maps mostly characterize the geological features of certain sections of the lithosphere in horizontal projection, geological sections reveal the geological structure of a separate area at depth (Fig. 11.5).

Geological section – a graphical representation in the vertical plane of the geological structure of the site. It is usually made along a line that is perpendicular to the extension of the rocks according to geological prospecting and mining (drilling, mines, wells, etc.), geophysical studies and geological constructions, taking into account the angles of rock occurrence. Analyzing these maps, you can predict the possible finding of mineral deposits and including accumulations of oil and gas. An explanatory note is always attached to the map.

To construct a section on the geological map, choose the direction (line) of the section, denoting it with letters or Roman numerals.



*Fig. 11.4 – Display of the geological structure using structural maps:
 1 – seam, roof which reflects a structural map; 2 – layer, whose floor reflects structural map;
 I-I' – Line profile; a – gritstone; b – sandstone; c – clay; d – limestone; e – contour line*

(A-A' or I-I'). An auxiliary or zero line is drawn on a piece of paper to which the intersection points of the cut line with horizontal are applied (a₁, a₂, a₃) and the boundaries of the rock outcrop (1, 2, 3). On the left, below the auxiliary line, draw a vertical line, indicating a vertical scale. Often, the vertical and horizontal scales are one-to-one. However, if the thickness of the layers indicated on the section is very small and on one (horizontal) scale cannot be shown, then the vertical scale is increased to the required size. Lowering the perpendiculars from points a₁, a₂, etc., located on the auxiliary line, to the intersection of them with the lines of the corresponding marks of the vertical scale, get a number of points. By connecting the dots with a smooth line, they get a curve – a topographic profile of the terrain along the section.

Perpendiculars are lowered from the points 1, 2, 3. The intersection points are built by places where the boundaries of the rock layers reach the surface. Knowing the elements of the bed formation (the angle of incidence, the line of incidence and the extension) at an appropriate angle to the horizon, they extend its boundary below the topographic profile. If the layer of rock lies horizontally, the horizontal lines are drawn from the point of intersection, and if inclined, at the point of intersection, the angle of its fall is constructed. Between the boundaries of the layers, the dotted lines indicate their lithologic composition. According to geographical sides, the letters indicate the orientation of the section, and the indices – the age of the rocks. In absence of a horizontal map, the principle of section construction remains the same, except for the construction of a topographic profile. Instead, the surface is denoted by any wavy line in accordance with the composition of the rocks facing the bottom surface.

Construction of the geological section according to only *geology research workings* also begins with building a topographical profile, which is applied to the working (well, etc.) That is the line cut. From their location points to a depth of suitable scale wells are built: border even-aged (or the same composition) layers are connected by lines, indicating the roadway, their depths and orient the cut.

A *stratigraphic column* is made for a detailed specification of geological features of some areas, except for geological maps, boreholes on individual wells, geological cuts and schemes.

It reflects the characteristic for the entire sequence of studies forming layers of rocks, their material composition, interruption of sediment storing, thickness and age, although in some places some layers (strata) species may be absent.

In order to reduce the size of the combined stratigraphic column, if individual layers of rocks reach a large thickness, it is allowed to reduce the graphic image by its conventional discontinuity. They are based on the material, describing the core of several or many wells or other mine workings. The boundaries of rocks, despite their possible inclined occurrence, are held in columns horizontally. Where age sequence of sediments layers is undisturbed, the borders are held in the form of straight lines. However, where individual stratigraphic units fall – it is wavy. The composition of rocks is represented with dotted signs. Columns are additions to geological maps and sections (Fig. 11.6).

A complex of field investigations is conducted to study and map groundwater – *hydrogeological surveys*. Their aim is to draw hydrogeological maps. Hydrogeological surveys include hydrogeological, geological, geophysical, geotechnical and hydrogeochemical research.

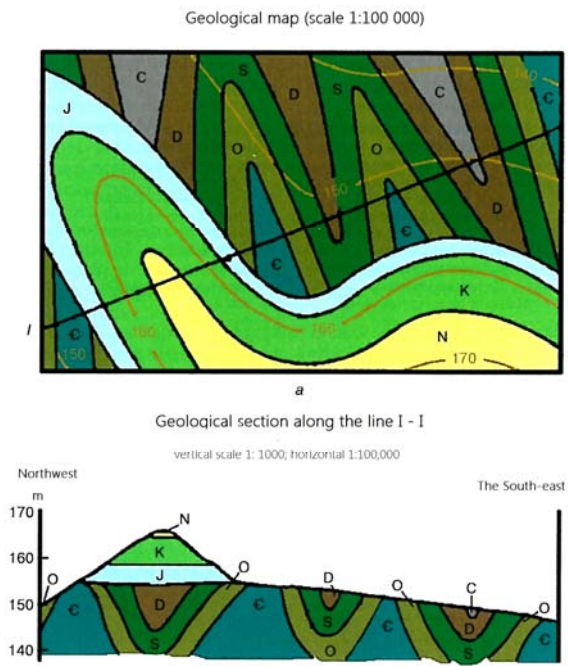
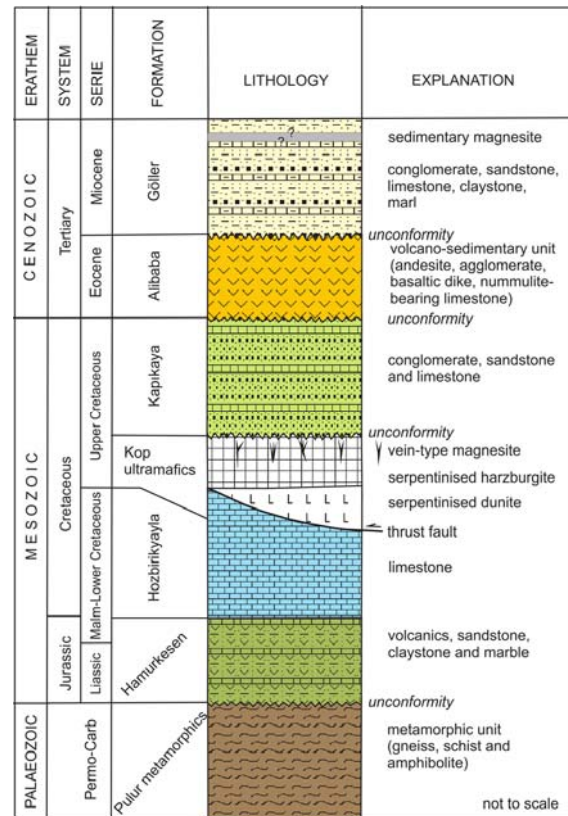


Fig. 11.5 – Schematic geological map (a) and geological cut along the line I-I (b)



https://www.researchgate.net/figure/Simplified-general-stratigraphic-column-section-of-the-study-area-modified-from-Kolayli_fig2_260190514

Fig. 11.6 – Stratigraphic column

The scale of hydrogeological surveys depends on the tasks of hydrogeological studies: for survey maps – 1:500000; for depiction of general hydrogeological conditions – 1:200000–1:100000; to substantiate the selection of areas of water intakes and study the irrigation of mineral deposits – 1:50000–1:10000. Each survey scale assumes a certain number of observation points established by existing geological survey standards. A hydrogeological map is drawn up as a result of the hydrogeological survey.

A hydrogeological map is a cartographic representation of general information about the hydrogeological conditions of a particular area. It shows the conditions of occurrence and composition of water-bearing rocks, their stratigraphic position, nature of feeding and unloading, directions of movement, chemical composition of groundwater, etc.

Mandatory elements of a hydrogeological map are conventional designations (legend), hydrogeological sections and columns. The conventions are drawn with the help of systematic signs that reflect the contents of the map and sections. Conventions consist of the following main sections:

- a) hydrogeological units (aquifers, complexes, waterproof strata);
- b) water points and water intakes (springs, wells, wells, etc.);
- c) hydro-dynamic parameters;
- d) chemical composition of groundwater;
- e) hydrogeological zoning;
- f) other signs (gas composition of water, anthropogenic pollution etc.).

There are several types of hydrogeological maps. The most common type is a consolidated hydrogeological map based on the materials of four maps: maps of actual material, maps of major aquifers, maps of aquifers of rocks of Quaternary age and maps of aquifers of Quaternary sediments.

The map of the actual material indicates the sampling points of water – wells, springs, wells. Each water point records its number on the left, the depth to the water level and the static level mark – on the right.

The contours of their distribution are indicated on the map of the main aquifers, the lithological composition, indicating the reference hydrogeological wells.

The aquifer maps of the pre-Quaternary and Quaternary rocks indicate the hydrogeological areas, age, lithological composition and the aquifer of the rocks, indicated by the boreholes, wells, springs.

Rock age is represented by colors that match the colors of the geological map, and the lithological composition of the rocks by black symbols. Hydrogeological areas that characterize the distribution of certain aquifers in the study area, the depth and conditions of their occurrence, the aquifer of rocks, the chemical composition of groundwater and other hydrogeological factors, are outlined by thickened lines with digital designations of the area.

Hydrogeological map indicates the explored deposits of drinking groundwater, areas of reduction of groundwater levels (depressions), as well as areas of their technogenic pollution.

Special hydrogeological maps are drawn for a specific purpose. Their content depends on the purpose of the research. These can be maps of hydro-dynamics, hydrogeochemistry, reserves and water resources. An explanatory note is attached to the maps.

Each hydrogeological map is usually accompanied by (one or more) geological and hydrological sections. The cut-line is marked on the map denoted, as in the case of a geological section, by capital letters (A`–A`) or Roman numerals (I`–I`). The cut is made according to groundwater testing in wells performed by different methods and devices (samplers). The latter are lowered into the well by drill pipes or cables (depending on the depth of the well and hydrogeological conditions).

The *hydrogeological section*, built on the principles of geology, indicates the hydrogeological horizons and water branches, chemical composition and

temperature of groundwater, as well as the directions of their movement, feeding and unloading, and other parameters of the underground hydrosphere. The hydrogeological column reflects the generalized order of the spatial position in the earth's crust of aquifers and complexes as well as water-bearing strata. The color and the markings indicate the lithologic composition of the sediments, the coefficient of filtration, chemical types of water and some other characteristics.

Test questions to the theme

1. *What is the practical purpose of geological research?*
2. *What is the main result of geological surveys?*
3. *What is the physical basis of deep seismic sounding method?*
4. *What are magnetometric research methods based on?*
5. *What is investigated by geochemical methods?*
6. *What is the purpose of aerospace research methods?*
7. *Where are geothermal research methods used?*
8. *What is defined by gravity methods research?*
9. *What is the purpose of drilling exploration wells?*
10. *What is forecasting of mineral deposits based on?*
11. *What types of research include oil and gas exploration?*
12. *On what stages is exploration of solid fuels divided?*
13. *At what stage is the search phase divided into oil and gas exploration work?*
14. *What is the geological map?*
15. *What types of geological maps do you know?*
16. *What is the basis for building a geological map?*
17. *What kinds of geological maps scales do you know?*
18. *What do geochemical maps reflect?*
19. *What is the geological section?*
20. *In what order are a stratigraphic column, conditional marking and geological sections placed?*
21. *What characteristics are given in the stratigraphic column?*
22. *What is the purpose of conducting hydrogeological surveys?*
23. *What do the hydrogeological map and section show?*
24. *What is the difference between structural and topographic maps?*

CHAPTER 12

THE CONCEPT OF THE NOOSPHERE. PROTECTION OF NATURAL RESOURCES AND GEOLOGICAL ENVIRONMENT. GEOLOGICAL SURVEY, EDUCATION AND SCIENCE IN UKRAINE

The consequences of human intervention in the Earth's subsoil are not smaller in magnitude and sometimes exceed the effects of some geological processes. The total number of mines extracted per year during mine development and rock quarries exceeds the volume of eruption products released by volcanoes each year. The subsidence of soils in the places of exploitation of liquid and gaseous minerals is at a rate not less than the immersion of the earth's surface by tectonic oscillatory movements. In the geological activity of a person it is possible to distinguish destructive work, processing of mineral raw materials, placement of exposed rocks and industrial waste, etc.

12.1. Human activity as a geological factor

Destruction of the upper layers of the Earth's crust in Ukraine occurs during the passage of mines, quarries, tunnels, laying canals, digging ditches, agricultural activities and more. The appearance of millions of cubic meters of large cavities at depths and the collapse of the roof above them leads to the formation of a dip in the diameter of more than 60–100 m on the earth's surface.

Another form of the lithosphere's destruction is the development of oil, gas, groundwater. Consequently, there is a decrease in the density of the productive layers and the subsidence of rocks over them, which is gradual and often accompanied by small earthquakes, whose magnitudes sometimes reach 4–6. On the surface, they can cause the destruction of buildings and structures. Thus, the pumping of artesian waters in Mexico City (Mexico) led to a lowering of the earth's surface by 8.5 m. This caused the destruction of a large number of buildings. The subsidence of the karst cavities formed in the salt mines of the Artemsil plant has led to the destruction of buildings and structures in Soledar, Donetsk region. Subsidence also occurs with long-term additional loads on the land surface.

Such loads can be caused by the construction of large quantities of structures, dams and reservoirs. Under the structures, compression and shear zones are formed. Depths of subsidence zones are measured from 2 to 50 m. As

a result of subsidence under the cities, cup-shaped relief depressions are formed, which are bordered on the outer side by annular zones of uplift. Significant disturbances are observed within the reservoirs, where huge masses of water press on the bed of the reservoir with great force, causing compaction of rocks beneath it.

Processing of mineral raw materials, placement of exposed rocks and industrial wastes. In the processing and using of mineral raw materials, much of it is scattered, enriching the surface layers of the earth with certain chemical elements and compounds. According to experts' estimates, in the next 30–40 years the content of iron deposits in the surface deposits of industrial regions will increase by 2–4 times, lead – by 10–12, mercury – by 100, arsenic – by 200 times.

Practical human activity in most cases leads to scattering of chemical elements. Instead, natural processes often concentrate them in one place in the form of mineral deposits. Metals on the Earth's surface scatter much faster than new deposits are formed. Most metals are scattered and only some of them are accumulated (gold, silver, iron, polymetals, copper, etc.). Much of the production of man and his household and biological waste eventually goes into anthropogenic deposits (Greek. *Anthropos* – man).

Depending on the purpose, nature of mineral processing and extraction of rocks, *anthropogenic sediments* are subdivided into mining dumps, construction soils, industrial and household waste, artificial reservoir deposits.

Bulk anthropogenic sediments are distinguished by their accumulation character.

Mining piles are accumulated near mines and quarries for the development of ores, coal, non-metallic raw materials. Usually, the landforms of the mines are hilly landforms consisting of empty rocks that contain a number of industrially valuable minerals. At coal deposits such dumps are called heaps (Latin terra – earth, rock, conicus – conical), whose height reaches tens of meters. The largest bulk forms of relief occur near the quarries. Sometimes they resemble small ridges consisting of many hills of empty rock that have merged with each other. Part of the mass of such rock is used as *construction soil*.

Construction soils are specially or collectively extracted loose rocks (sand, gravel, pebbles) that are used without any further processing for the construction of buildings and structures, dams, railway embankments, highways, beach floods, etc.

Building materials include products obtained in the previous processing of debris (concrete, mortar), carbonate (cement, lime) and other rocks. Various household and industrial buildings are erected from them.

Industrial and household waste consists of ash, slag, metal and wood sawdust and shavings, waste from processing factories, landfills, cemeteries,

destroyed structures and more. The thickness of the "cultural" (anthropogenic) layer often reaches 2–3 meters or more.

Deposits of artificial reservoirs . Man-made reservoirs, ponds and other water bodies may not differ from natural lakes according to their geological activity. It also destroys the shoreline, and at the bottom fragile, homogeneous and organogenic sediments accumulate.

Urbanization processes cover all countries of the world. Scientists estimate that in 150 years, almost 1/3 of the planet will be inhabited by urban populations. The construction of cities and industrial sites requires a large number of building materials, the deposits of which are most often searched for near construction sites. The exploitation of these fields often greatly changes the suburban relief. With the development of new territories, networks of railways and highways are expanding, for which embankments, bridges are being built, tunnels are being traversed.

There is an increasing number of arable farmland where chemical and organic fertilizers are intensively used, as well as means of combating harmful plants, insects, and crop diseases. At the same time, the layer of upper anthropogenic (Quaternary) sediments on a huge area is being destroyed, small rivers are silted and artificial, sometimes very harmful compounds, contaminate soil and groundwater.

The influence of man on the geological work of the sea is increasing. As the river runoff decreases, sea levels decrease, which in turn leads to an increase in the salinity of these waters and a change in their organic world. Recently, oil leakage from tankers, pipelines and wells has increased.

Thus, by changing natural landscapes into technogenic, revealing the subsoil and removing various minerals, polluting the environment, man influences the course of exogenous geological processes, slowing down or accelerating both their destructive and creative work. All these problems are studied by technogenic geology.

Technogenic geology is a modern geological area that develops measures to control the impact of human civilization on the geological environment. It examines the patterns of change in the earth's crust as a result of human activities aimed at extracting, redistributing, and creating new raw materials, as well as for the protection of subsoil.

The main directions of technogenic geology are:

- creation of methods;
- and technical means for preparing technogenic deposits for development;
- prospecting and exploration of artificial fields (based on working or closed enterprises);
- development of methods and tools for managing modern geological processes;

– prospecting and exploration of underground, mine and industrially polluted water fields used as hydromineral raw materials (for extraction of industrially valuable chemical elements).

Technogenic deposits are the accumulation of minerals on the Earth's surface, in the depths or in mining, formed as a result of their separation from the geological massif in the form of mining, concentrating, metallurgical and other production wastes, suitable for industrial use because of their quantity and quality. Technogenic deposits include dumps that are formed during the extraction of coal mines, tailings storage of processing plants, gold, and the slag removal of thermal power plants, stored metallurgical waste, etc. manufacturing, mine water, chemical plant sewage, etc.

Technogenic deposits are a unique source of numerous rare and scattered elements. For example, the main source for germanium production is the ash of EPS; rhenium – dust of burning molybdenum concentrates; selenium and tellurium–waste of sulfide copper ores processing; cadmium, thallium and indium–polymetallic ores; gallium is a bauxite waste and nephelines. The urgency of developing technogenic deposits is constantly increasing.

In Ukraine, the largest technogenic deposits have been formed as a result of activity of ferrous and non-ferrous metallurgy, chemical, coal, power and other industries. Search and forecasting work of Ukrainian enterprises "Geoprohnoz" shows that even through the development of a small part (approx. 10 %) of domestic technogenic deposits Ukraine can meet their needs in Sc, Ga, Y, Ta, Nb, Hg, Cs – for tens and hundreds of years, and Pb, Zn, Cu, V, Zr, Au, Ag, Li – by 10–25 % annually. Groundwater, polluted with industrial effluents, accompanying brines by gas industry, coal-mining waters in the coal mining regions (Donbass, Lviv-Volyn basin), existence of natural hydrogeochemical anomalies with high concentrations of chemical elements and high content of the latter in industrial water reservoirs leads to the use of natural and man-caused waste water as *hydromineral* raw (industrial water).

Industrial water is groundwater and surface water solutions from which it is technologically possible and economically advantageous to extract valuable chemical elements and compounds. As technological capabilities and indicators of economic profitability are constantly changing, the conditions characterizing industrial waters by the qualitative and quantitative composition of valuable components are constantly diminishing. Hydro-mineral raw materials are extracted from various countries in different countries: in the USA – Rb, Li, Br, I, B, W, K, Mg, U; in Italy – B, NH₄; in Germany – Rb and Cs; in France – Li; in Israel - Li, Br, Rb, K. In Ukraine, Br and I are extracted from seawater (Crimea, Saky). But there are many areas where water (and especially groundwater) can serve as a conditioned hydro-mineral resource. This also applies to "oil" waters, which may be the industrial source of Li, Rb, Cs, Br, B,

Na, Sr and other elements. – it's underground and surface water solutions, including technologically possible and economically profitable to extract valuable chemical elements and compounds. As technological capabilities and profitability indicators economic constantly changing, the condition that characterized industrial water qualitative and quantitative composition of components continues to reduce. From hydromineral raw useful components are removed in different countries: in the US – Rb, Li, Br, I, B, W, K, Mg, U; in Italy – B, NH₄; in Germany – Rb and Cs; in France – Li; Israel – Li, Br, Rb, K. in Ukraine – Br and I extracted from seawater (Crimea, Saki). But there are many areas where the water (especially underground) can serve as hydromineral certified raw materials. This applies to "oil" water that can be the source of industrial Li, Rb, Cs, Br, B, Na, Sr and other elements.

12.2. The noosphere as a sphere of human activity

The main natural environments of the Earth are the lithosphere, hydrosphere, biosphere and atmosphere. However, at the beginning of civilization human activity created preconditions for the formation (within existing) of a new shell with its characteristic features and regularity of development. In this shell of the Earth where nature and human society interacts, the influence of man on the structure and chemical composition of the surface of the planet is felt more and more. Analyzing the processes of this interaction, Academician V. I. Vernadsky concluded that a new artificial geosphere, the sphere of human activity, was forming on our planet. The theoretical basis of this concept was his lectures on the Sorbonne biosphere (Paris, 1922–23 years). Subsequently, in 1927, French philosopher E. Leroy introduced the term *noosphere* into science. However, it was V. I. Vernadsky who developed the doctrine of the noosphere on a materialistic basis and is rightly considered the founder in the world science.

The noosphere components are the *anthrosphere* (the totality of humans as organisms), *the technosphere* (the set of artificial objects created by man and natural objects, modified as a result of human activity, and the *sociosphere* (a set of social factors characteristic of this development stage of society and its interaction with nature).

Human activities in mining, including prospecting, exploration and production of oil and gas, occur within the *techno-sphere*. In the *noosphere* there is a giant displacement of atomic elements, their scattering and concentration. With the products of agriculture and industry, atoms and their compounds migrate to different regions and continents. For many years, entire mineral deposits have been scattered, formed as a result of geological processes over millions of years.

The noosphere is inherent in both *mechanical*, *physical-chemical* and *biological* processes. But they do not determine its originality. Technogenic transformations play a major role in the noosphere.

While the influence of primitive society on the geological environment was almost indistinguishable from that of the animal, in ancient states that radically changed the valleys of the Nile (Egypt), Amu-Daria (Khorezm), Tigris and Euphrates (Babylonia), Tiber (Rome), etc., this impact is already becoming an important geological factor. Therefore, some scientists call geological history that began about 8,000 years ago a technozoic stage.

In the XXI century technogenesis has become a major geological factor on the Earth's surface. More than 200 billion tonnes of mineral resources are extracted annually from the depths of the earth. As a result of mining and construction work, more than 20–30 billion tonnes of rocks are relocated a year. Production capacity doubles every 15–20 years. Hence the significant difference between the noosphere and the biosphere – the noosphere has changed substantially over the decades.

It is estimated that only 19 chemical elements were used in the ancient era, in the 18th century – 28, in the XIX century, – 50, and in the early XX century. – 60. At present, about 100 chemical elements are used in science and technology. Moreover, the production and use of elements that are absent in the earth's crust – Pu, Np, Cf, etc., began. The need for humanity in water – both drinking and technical, is constantly increasing. This necessitates the exploration and exploitation of new groundwater intakes and the construction of reservoirs.

The need for mineral raw materials outstrips Earth's population growth. Only from 1940 to 2000 the use of raw materials increased by 3 to 100 times, and the population of the globe has increased by less than 2 times during this period. At the same time, with the use of raw materials, the depth of mineral deposits development is increasing. In South Africa, the world's deepest mine (the Witwatersrand) is developing a gold mine at a depth of 3,5–3,7 km. Oil and gas fields reached considerable depths of up to 5,0–7,0 km. High-grade Donbass coal is mined from a depth of 1,0–1,5 km.

Currently, the main direction of energy development is thermal power and nuclear power, while hydropower is less important. Humanity uses the Earth's deep heat, solar and other types of energy.

In this case, some energy used in the noosphere does the work and the other part is released in the form of heat, which is the reason for the atmosphere warming. Increasing energy production from 4 to 10 % per year can lead to the fact that the amount of heat produced by humans will equal the magnitude of the radiation balance of the entire earth's surface in 100–200 years. In this case, there will be a huge climate change across the globe.

There are many examples of current or future changes in the noosphere. From this comes one important conclusion – the noosphere, which was formed through human activity as a separate geosphere within the litho-, hydro-, atmo- and biosphere and biosphere, is a vulnerable natural-social system that should be protected from destruction and destitution.

12.3. Protection of natural resources and geological environment

For centuries, geochemical and biochemical equilibrium have been established in nature. This created preconditions for the development of organic world. With the development of human society and intensification of man-made activity, these equilibria began to gradually break. Initially, human activity could be compared with natural processes, but then it was far superior to them. This has led to undesirable consequences: depletion of the depths, contamination of soil, water and air, disappearance of many species of plants and animals, etc. To restore the natural balance, we must address important environmental issues. The latter is a set of measures aimed at the conservation and restoration of the environment, and includes the protection of atmospheric air, groundwater and surface water, land, flora and fauna, geological environment.

The purpose of environmental protection is to counteract the negative changes that took place in the past, are happening now or will happen in the future. The urgency of this problem, which has turned into a global one, has to do with the growing anthropogenic impact. This is due to the demographic explosion, urbanization, development of mining and communications, waste pollution, excessive load on arable land, forests, reservoirs, subsoil, including the lithosphere and underground hydrosphere.

Subsoil protection is a set of measures undertaken for the purpose of their comprehensive use, complete extraction of useful minerals from them and maximum possible reduction of losses during their development. As a result of mining activities, no less than 15–20 million hectares of land have been discovered in the world, of which 50 % is used for various mining operations, 38 % – for waste heaps or enrichment waste, 3 % – occupy areas of subsidence, dips and other surface disturbances associated with underground mining. The volume of waste heaps and production waste is over 2000 km³. To obtain mineral raw materials and fuel, humankind has to use deeper and deeper layers of the earth's crust. Mining operations are accompanied by artificial water lowering.

About 15 km³ of water is pumped per year only in the extraction of coal from mines and cuts. Wastewater discharges lead to contamination of surface water by various salts, petroleum products and heavy metals. Rock displacements in areas under development, subsidence, scattering of rock from dumps have a negative

impact on the state of land resources. Significant pollutant inputs into the geological environment occur in the communication and transport hubs (90 tonnes of dust per 1 km of railway track per year). When operating oil pipelines and product pipelines, major damage to the geological environment is caused by emergency oil leaks. The problem of water depletion is caused by rising water consumption by industry, agriculture and utilities on the one hand, and pollution of water sources, aquifers and complexes – on the other. Every year, humanity uses an average of 6000 km³ of water, of which about 3400 – in agriculture, 2200 – in industry, 400 km³ – for municipal needs. Contamination of many groundwater bodies (especially in Europe and North America) and the oceans has reached a dangerous level. Annually (million tons): 0,2–0,5 toxic chemicals; 0,1 – organochlorine pesticides; 5–11 – petroleum and other hydrocarbons; 10 – chemical fertilizers; 6 – phosphorus compounds; 0,004 – mercury; 0,2 – lead; 0,0005 – cadmium; 0,36 – copper; 0,44 – manganese; 0,37 – zinc ,etc., enter the aquatic system of the planet. In the North Atlantic, oil film occupies 2–3 % of the area. The most polluted by oil is the North and Caribbean seas, Persian Gulf, as well as the parts of Africa and North America where it is transported by tanker fleet. One of the most important consequences of intervention in the geological environment is deterioration of land resources. Over the long term, as a result of accelerated erosion, deflation and other negative processes, humanity has lost almost 2 billion hectares of productive land.

Desertification processes take place on an area of 4,5 billion hectares, home to about 1 billion people. Deserts are rapidly growing in many parts of America, Africa, Asia, and Australia due to disappearance of forests at the rate of 6–20 million hectares per year. Therefore, the problem of geological environment protection – the upper part of the lithosphere, which is regarded as a multicomponent dynamic system that is influenced by the engineering and economic activities of people and, in turn, fully defines this activity, is important for mankind. The most important component of the geological environment is rocks containing gases and groundwater at the level of solid mineral and organic components. Technogenic disasters, the largest of which in the 20th century happened in Ukraine – at the Chernobyl nuclear power plant, has a particularly significant impact on the geological environment.

In the development of deposits, some minerals remain in the depths, some of them enter the environment, contaminating it. Thus, in the development of oil fields more than half of the oil remains in the depths, while the accompanying gas is burned in torches. Therefore, an important task of oil and gas production is the complex development of fields with the extraction of oil, gas and condensate from the productive layers. For more complete extraction of hydrocarbons various technologies of production intensification (hydraulic fracturing of layers; acid treatment of productive thicknesses; pumping into oil

layer of natural gases, etc.) are widely used. The main tasks of the oil and gas industry are: complex extraction and use of oil and natural gas, concomitant extraction of condensate, sulfur, helium and other components.

One of the most important tasks for the exploitation of solid minerals deposits is complete mining of deposits and the complexity of extraction of minerals ores. It is within the competence of the subsoil protection to prevent the development of areas of explored deposits. There are many examples of industrial and residential construction within the contours of explored deposits, which exclude a big portion of the field from industrial stocks.

As subsoil protection in general context of nature conservation is a set of measures undertaken with the purpose of the most complete extraction of mineral resources from the depths with minimal damage to the geological environment, the main requirements of the Ukrainian legislation are:

- to ensure a complete and comprehensive geological study of the subsoil;
- to observe the procedure for granting subsoil use and prohibit the unauthorized use of the over-frame;
- rational extraction and use of the reserves of useful minerals and their components;
- to protect mineral deposits from flooding, fires and other factors that affect the industrial value of the deposits and complicate their development;
- to prevent subsoil contamination during underground storage of oil, gas and various substances and materials, underground disposal of industrial wastewater and other production wastes;
- to observe other requirements stipulated by the legislation on environmental protection.

Rare geological, mineralogical and paleontological sites, as well as other areas of subsoil of particular scientific or cultural value may be declared the objects of the nature reserve fund in accordance with the law. If such objects are found, subsoil users are obliged, under the Ukrainian law, to stop work in the relevant area and notify the state authorities (State Technical Supervision, Environmental Inspection, local authorities, etc.).

12.4. Geological survey, education and science in Ukraine

Geological activity in Ukraine is managed by the State geological service and protection of natural resources in Ukraine. It is the central specially authorized executive body of geological subsoil study and use, which organizes and ensures the implementation of state policy in the sphere of subsoil use, provides systematic realization of regional geological studies and the required exploration and strategically important mineral resources, accumulation and

storage of geological information on mineral resources, establishment of conditions on mineral raw materials for calculation of mineral reserves in depths, research in the field of geological study and use of mineral resources, coordinates and carries out geological control over the activities of other geological bodies.

The structure of the geological service in Ukraine consists of central executive body; eight regional companies that study and collect geological information; Ukrainian State Geological Institute (USGI), which provides scientific support to work related to depth, using and conducting basic and applied research investigation, including the development and introduction of scientific and methodological foundations of forecasting, prospecting and exploration of mineral resources, forecasting changes in the geological environment and other needs of geological study; Ukrainian State Commission of minerals reserve; two state enterprises "Ukrgeoexamination" and "Amber of Ukraine" and six state inspections of geological control. To implement the program and to increase state reserves and mineral resources, exploration companies and other scientific institutions from geological areas are involved additionally.

The purpose of the State Service of Geology and Mineral Resources of Ukraine is to provide public interest in the geological issue and rational, ecologically safe use of mineral resources on the territory of Ukraine, its continental shelf and in the maritime economic zone.

The objectives of the service are:

- to improve and increase the mineral resource base of the state as the basis for the development of mining and processing industries of the national economy;

- geological, hydrogeological, geotechnical and environmental geological study and mapping of geological environment, including dangerous geological phenomena;

- to monitor geological environment and mineral resources;

- fundamental and applied scientific research associated with the development and introduction of scientific and methodological foundations of forecasting; prospecting and exploration of mineral deposits; predicting changes in the geological environment and other needs of geological study;

- to create a unified information system of subsoil;

- to ensure protection and rational use of mineral resources in the mining and use of subsoil for purposes not related to mining;

- to promote entrepreneurship in the depth use.

The main areas of work and practical tasks the State Service of Geology and protection of natural resources of Ukraine in the near future are:

- to prepare a new edition of the Code of Ukraine on mineral resources;

- to further improve the mechanisms of state regulation and legal relations in the sphere of subsoil use;
- the tasks and activities of the National Program of mineral resources development of Ukraine till 2030 and State order of geological study and to ensure reserves growth and mineral resources for the current year;
- to participate in the development and implementation of other government programs;
- organizational and staffing political implementation of the state in the subsoil;
- state control over geological study of subsoil and use, control over compliance with nature protection legislation;
- to grant special permits for subsoil use, including the auctions;
- international cooperation in the framework of the Intergovernmental Council of the exploration, use and protection of natural resources.

In the structure of the State Geological Survey of Ukraine, depending on the region and the tasks, there are smaller production units: state geological prospecting enterprises (DIGP), which in turn are divided into exploration expeditions (AWU), and those – into separate parties in the areas of work (geological survey, hydrogeological, non-metallic raw materials, geochemical, geophysical, thematic, exploration, etc.). The smallest unit in production geology is the geological unit. DHRPs usually have chemical laboratories, repair shops, geological foundations, garages, and other units.

In Ukraine, there is an extensive network for training of geological personnel of higher qualification. These are mostly old universities with a long tradition of IV–V accreditation levels. Among them are Taras Shevchenko National University of Kyiv (1834), Ivan Franko National University of Lviv (1661), V.N. Karazin Kharkiv National University (1805), I. Mechnikov Odessa National University (1865), Dnipropetrovsk National University (1918), Dnipropetrovsk National Mining University (1899), Kryvyi Rih Technical University (1922), Donetsk National Technical University (1921), Ivano-Frankivsk National University University of Oil and Gas (1967) and others. They train geologists and hydrogeologists, lithologists and geomorphologists, geochemists and geophysicists, industrial and mining geologists. Bachelors and masters are trained in all educational establishments and in postgraduate and doctoral studies – candidates and doctors of geological sciences in various specialties.

Scientific geological institutions.

Research in the field of geology is conducted by the institutes of the National Academy of Sciences (NAS) of Ukraine, industry-specific research institutes (research institutes), higher educational establishments.

The system of NAS of Ukraine includes: Institute of Geological Sciences (Kiev, 1926) – general geology and geotectonics, stratigraphy and paleontology, lithology and marine geology, hydrogeology and engineering geology, geology of mineral deposits, etc.; S. I. Subotin Institute of Geophysics (Kyiv, 1960) – study of the lithosphere structure by geophysical methods, geodynamics, theory and methods of earthquake prediction; the Symonenko Institute of Geochemistry, Mineralogy and Ore Formation (Kiev, 1969) – study of crust composition, development of geochemical models, physical-chemical properties of minerals, petrology of volcanism and metamorphism, geochemistry and patterns of ore deposits localization, geochemistry of ore deposits, methods of geochemical prospecting of mineral deposits; Institute of Geology and Geochemistry of Combustible Minerals (Lviv, 1951) – geochemical features, prospecting and exploration of combustible minerals (oil, gas, coal, shale, ozokerite, sulfur); Institute of Environmental Geochemistry of NAS and Ministry of Emergencies of Ukraine (Kyiv, 2001) – geochemistry, radio geochemistry, space chemistry, technogenic and ecological safety, nuclear geochemistry, ore formation and mineralogy, search of mineral deposits; Ukrainian State Research and Design Institute of Mining Geology, Geomechanics and Mine Surveying of the NAS of Ukraine (Donetsk, 1992) – surveying, mining geology and geophysics, prospecting for oil, gas and coal deposits, coal geology, coal geology development, study of geodynamic phenomena, geoecological studies, etc.

The largest among the sectoral research institutes are: Ukrainian Research Institute of Geology of Ukraine with branches in Kyiv, Chernihiv, Poltava, Simferopol (Lviv, 1957) – regularities of mineral deposits formation, prognostic assessment of mineral resources, hydrogeological and engineering geological researches, search for drinking and mineral waters, methodology of geochemical mineral exploration, geoecology, location of oil and gas fields, forecasting of resources and exploration for oil and gas, methods of industrial geophysical research; Ukrainian Scientific Research Institute of Natural Gases of Naftogaz of Ukraine (Kharkiv, 1959) – geology, development and operation of gas and gas condensate fields, calculation of reserves of gas and gas condensate fields, remote methods of hydrocarbon prospecting, oil and gas hydrology, lithology; State Research and Design Institute of Petroleum Industry (Kyiv, 1966) – geology and hydrogeology of oil fields, calculation of oil reserves, lithology.

In addition to these, there are other research institutes involved in the development of geological problems. Many of them are created at higher education institutions (Mining Institute at the National Technical University, Donetsk, etc.).

Test questions to the theme

- 1. What causes technogenic destruction of the lithosphere?*
- 2. What does processing of mineral raw materials, disposal of exposed rocks and industrial waste lead to?*
- 3. How are anthropogenic sediments formed and what types are they divided into?*
- 4. What does technogenic geology study?*
- 5. What mineral deposits are called technogenic?*
- 6. What does the term "noosphere" mean?*
- 7. What is called hydrothermal raw material?*
- 8. What is the purpose of environmental protection?*
- 9. What set of measures does subsoil protection include?*
- 10. What causes water depletion?*
- 11. Why is water a major life-sustaining component on Earth?*
- 12. What is the problem of geological environment protection?*
- 13. What are the main requirements of the current legislation of Ukraine for protection of subsoil?*
- 14. What areas of subsoil are considered to be objects of the nature reserve fund?*
- 15. What is the problem of protecting geological environment?*

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