MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
State Higher Education Institution
"National Mining University"

FACULTY OF GEOLOGICAL PROSPECTING
Department of General and Structural Geology

FACULTY OF MANAGEMENT
Department of Foreign Languages

GEOLOGY. LABORATORY OPERATIONS MANUAL. STUDY OF THE MATERIAL COMPOSITION OF THE EARTH'S CRUST

for students of the specialities: 184 Mining, 185 Oil and gas engineering and technologies

Dnipro
NMU
2018

General Geology. Laboratory Operations Manual. Study of the Material Composition of the Earth's Crust for the students of specialty 6.040103 Geology/ N.V. Bilan, I.S. Nikitenko, O.A. Tereshkova, O.V. Khazova; Ministry of Education and Science of Ukraine; National Mining University. – D.: NMU, 2018. – 34 p.

Автори:
Н.В. Білан, кандидат геологічних наук, доцент;
І.С. Нікітенко, кандидат геологічних наук, доцент;
О.А. Терешкова, кандидат геологічних наук;
О.В. Хазова, викладач англійської мови

Затверджено до видання методичною комісією з напряму підготовки 6.040103 Геологія (протокол № 4 від 06.05.2014) за поданням кафедри загальної та структурної геології (протокол № 8 від 23.04.2014).

Laboratory operations manual is a self-study material for students of the specialities 184 Mining, 185 Oil and gas engineering and technologies. It provides both theoretical concepts of the material composition of the Earth's crust and practical recommendations for the laboratory classes focused on mineral study, physical properties, mineral composition and conditions of rock origin. It facilitates students' preparation for the Modular assessment of the labs in the course of "Geology" and "Geology with the bases of geomorphology" and develops their practical skills.

Test assessment criteria of the laboratory module are given.

Відповідальний за випуск завідувач кафедри загальної та структурної геології, канд. геол.-мін. наук, доц. С.В. Шевченко.

CONTENTS

INTRODUCTION

General Geology course introduces basic information about the Earth, the processes taking place in the interior of the planet and on its surface, and the effect of the anthropogenic activity on these processes.

The importance of the Earth's crust material composition study is related to the main objectives of geology.

The objects of study in geology are

- composition and structure of natural bodies and the whole Earth;
- processes on the surface and in the interior of the Earth;
- history of the planet evolution;
- distribution of mineral deposits.

This is precisely why learning of abundant rocks and their properties lays the basis for further study of geological sciences. In turn, the study of rocks cannot be conducted without learning the main types of minerals which are the building blocks of rocks. It determines the conditions to perform the laboratory studies on the material composition of the Earth's crust.

This Laboratory Operations Manual provides

- the procedure of laboratory works;
- information and methodological support for self-study;
- diagnostic tools of the conceptual laboratory module learning outcomes.

1. GENERAL GUIDELINES ON LABORATORY PRACTICALS

Laboratory work is a form of training session where a student carries out experiments or simulations for practical verification of some theoretical concepts of a subject under the supervision of a lecturer.

The topics of the laboratory works are specified in the course syllabus of General Geology. These labs are a part of the first quarter laboratory module which consists of:

- laboratory work No. 1 – the study of major rock-forming and ore minerals of different classes (native elements, sulfides, sulfates, oxides and hydroxides, carbonates, halides, phosphates, silicates) – a total of 27 minerals;
- laboratory work No. 2 – the study of major rocks belonging to three main genetic types – igneous, sedimentary and metamorphic – a total of 50 rock types.

The overall objective of the laboratory works is to study the material composition of the Earth's crust for fundamental understanding of all branches of general geology as well as other geological and mining subjects.

The first laboratory work is performed during first 4 classes, and the second one is completed during the next three classes. The topics are as follows:

Laboratory work No. 1

The first lesson – the study of the physical properties of minerals. Introduction to the collection of minerals in the Geological Museum of the National Mining University.

The second lesson – the study of major mineral groups: native elements and sulfides.

The third lesson – the study of major mineral groups: oxides and hydroxides, halides, carbonates, sulfates and phosphates.

The fourth lesson – the study of silicate minerals.

Laboratory work No. 2

The fifth lesson – introduction to the rock types, their origin, structure and texture. The study of igneous rocks.

The sixth lesson – the study of sedimentary (clastic, chemical and organic) rocks.

The seventh lesson – the study of metamorphic rocks.

At the end of the 1st quarter laboratory module students will be able to answer the questions related to:

- mineral classification;
- methods of determining the physical properties of minerals;
- structural and textural features of rocks to determine the conditions of their origin;
- origin conditions of natural compounds and mineral assemblages.

Laboratory works are performed in the classrooms. A classified collection of minerals and rocks from the laboratory of the Department of General and Structural Geology (Building 1, Room 55) and pertinent objects of the Geological Museum of the University are used during the classes.

The particular attention should be paid to safety arrangements and precautions during the work. Students must be careful handling hydrochloric acid solution, cutting and piercing items. They must avoid striking the specimens because their fragments can get into eyes.

It is required to learn the general characteristics of minerals and rocks, their origin, composition, abundance, classification from the textbooks [1-3] before dealing with specimens of minerals and rocks in the collections. This theoretical information is briefly described in the manual.

Self-study includes additional investigation of minerals and rocks specimens from the Department of General and Structural Geology laboratory collection (Building 1, Room 55) as well as self-preparation for the Module control.

2. GUIDELINES ON PREPARATION AND PERFORMANCE OF THE LABORATORY WORK No. 1

Topic: *"A study of the physical properties of the common rock-forming and ore minerals"*

The objective of the laboratory work is to introduce the main minerals of the Earth's crust, their origin and structure, physical properties, as well as the methods of mineral identification by their physical parameters.

Preparation for the laboratory work requires a careful study of the theoretical information presented below and the literature recommended.

General information about minerals and their internal structure

The Earth's crust, rocks and mineral deposits are composed of minerals. A *mineral* is a naturally occurring substance that is solid, representable by a chemical formula, has an ordered atomic structure and has been formed as a result of geological processes.

By now we know over 4,900 known mineral species (over 4,660 of them have been approved by the International Mineralogical Association) ranging from one chemical elements (native gold, graphite, native sulfur) to the very complex ones in their chemical composition. However, only about 70 the most abundant minerals compose the rocks of the Earth's crust and are called *rock-forming minerals*.

Some solids of natural occurrence are found in the amorphous state (opal, limonite), i.e. they do not demonstrate crystallinity. Such compounds are often called *mineraloids*.

Minerals have an ordered atomic structure. This internal structure of minerals (crystal lattice) is formed in the process of continual nucleation and crystal growth. Naturally, a variety of crystal structures is determined by the characteristics of chemical bonds between atoms and their sizes.

If a mineral grows in a place with enough room, in cavities or on a rock surface, the external shape of the crystals reflects the features of a crystal lattice. Thus, the cubic form of halite lattice (rock salt) determines its cubic form of crystals, while a layered, planar lattice of graphite, mica, and talc defines scaly and foliated form of crystals of these minerals.

If a mineral fills the space between the previously formed mineral grains, it takes the irregular shape of the space while keeping the internal crystal structure. Most of rocks consist of these minerals.

The lattice features in various minerals define a great variety of forms of natural crystals. The surface of the crystal is bounded by planes – faces, the lines of planes intersection are called edges. The points of edges intersection form the lattice points. In general, the shape of crystals (habit) can be characterized by the following characteristics (see Fig. 1):

- elongated in one direction or bladed crystals (prismatic, columnar, acicular or needlelike, fibrous);
- elongated in two directions (tabular, platelet, foliated, scaly);
- equally developed in three main directions (isometric ones in the form of cube, octahedron, etc.);
- twins, interpenetration twins, etc. – the intergrowth of two or more crystal of single mineral species.

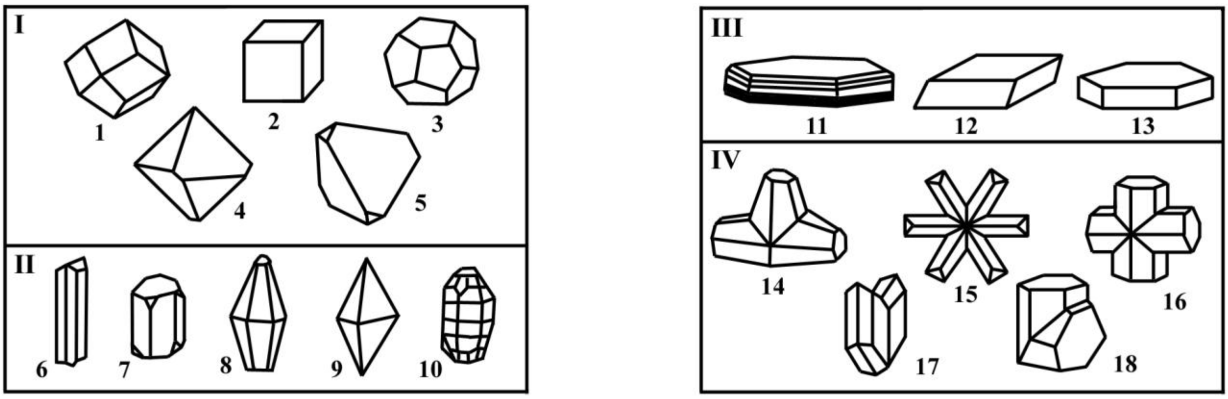

Fig. 1. Some crystalline forms of minerals and their structure types:

I – isometric crystals: 1 – rhombic dodecahedron (garnet), 2 – cubic (galena), 3 – pentagon-dodecahedron (pyrite), 4 – octahedron (diamond), 5 – tetrahedron (sphalerite);

II – bladed or elongated in one direction crystals: 6 – columnar (barite), 7 – short columnar (corundum), 8 – truncated bipyramidal (corundum), 9 – pyramidal (sulfur), 10 – barrel-shaped (corundum);

III – elongated in two directions crystals: 11 – tabular (graphite), 12 – rhombohedron (calcite), 13 – tabular (pyrrhotine);

IV – types of crystal growth: 14 – pyrrhotine twin, 15 – cyclic twin of arsenopyrite, 16 – penetration twins of staurolite, 17 – gypsum twin, 18 – calcite twin.

The same lattice structure of different specimens of the same mineral determines the same values of angles between corresponding faces and edges. This regularity is called the law of the constancy of interfacial angles.

The main feature is that the structure of mineral lattice, the bond type and the bonding force determine the physical parameters and properties of minerals – their color, hardness, diaphaneity (transparency), conductivity, etc. For example, both diamond and graphite are composed of carbon, but their physical properties are very different.

Another important feature is that the value of the physical parameter in a crystal depends on the direction of measurement. It is natural because interatomic distance and the strength of the bonding in different directions in a lattice are different. This property is called *anisotropy* of crystalline substances. Thus, all crystalline minerals are anisotropic bodies.

The structure of the lattice depends both on the chemical composition of the mineral and the conditions under which it was formed, primarily on temperature and pressure. Therefore, the lattice of graphite, diamond and many other minerals with the same chemical composition is different. This phenomenon is called *polymorphism*. For example, quartz (SiO_2) can crystallize under different temperatures. Thus, low-temperature (< 575 °C) and high-temperature (575-870 °C) quartz, tridymite (870-1470 °C) and cristobalite (1470-1710 °C) are distinguished. Stishovite, which was found in meteorite craters, has the same chemical composition (SiO_2), but greater density (4.35 g/cm^3).

Mineraloids have amorphous (irregular) internal structure. Their molecules are just jumbled together in a disorganized way. The physical parameters of such formations are identical in all directions – they are *isotropic* (Greek "iso" – the same, "tropos" – property). Examples of amorphous substances are natural and artificial glass, opal.

<u>Formation of minerals. Natural forms of minerals</u>

Minerals are formed within the Earth's crust and the Earth itself as a result of endogenous and exogenous geological processes.

Endogenous minerals are formed as a result of:

- cooling and solidification of magma (magmatic processes);
- deposition in fractures and interstices due to the circulation of hot mineralized water solutions (hydrothermal processes) and gases (pneumatolytic processes);
- recrystallization of previously formed minerals into other mineral types under high temperature and pressure (metamorphism);
- chemical alterations between magma and its wallrock (metasomatism).

Exogenous minerals are formed as a result of:

- chemical and biochemical decomposition of minerals and rocks under the influence of atmospheric oxygen, water and aqueous solutions (weathering);
- salts and other compounds precipitation (evaporation) out of solutions and accumulation on the bottom (chemical sedimentation);
- interstitial water mineral mixture residing in the sediment pore spaces (diagenesis processes).

The prevailing mineral forms are granular, earthy and oolitic aggregates (concentrations).

<u>Granular aggregates</u> are the rocks consisting of crystal grains of minerals of one or more species. For example, granite, sandstone.

<u>Earthy aggregates</u> are unconsolidated concentrations of minerals which could be mashed by fingers.

Oolitic aggregates (concentrations of oolites) are rounded, up to 5 mm particles with concentric conchoidal internal structure. Oolites are formed in mineralized water environment and can be represented by carbonate, ferruginous, manganese compounds.

Minor mineral forms include individual crystals, druse, vug and geode, nodule, dripstone, crystal dendrite (Fig. 2).

Druse is an aggregate of crystals oriented in different directions.

Vug and geode are varieties of hollow voids formed by filling them with mineral substance deposited on the walls. Vugs are irregular voids or cavities within a cross-cutting formation. Geode is a spheroidal void with a diameter more than 10 mm. Small filled voids (up to 10 mm in diameter) are called amygdale.

Nodule is a mineral aggregate of a rounded, flattened or irregular shape with a concentric or radially fibrous structure. These forms are gradually formed within sedimentary rocks as a result of contraction and concentration of mineral substances such as ferruginous, carbonate, siliceous and other compounds.

Dripstone occurs on the walls of voids by the evaporation or cooling of solutions. These formations can be of reniform (kidney-shaped), globular, and film form. For example, stalactites and stalagmites in caves.

Crystal dendrite is formed by mineral growing along microfractures in the rocks. These forms have a multi-branching tree-like structure. The genesis of dendrites can be explained by a higher speed of growth on the edges than on the facets of crystals. Dendrites are formed when a big amount of material for crystallization is available.

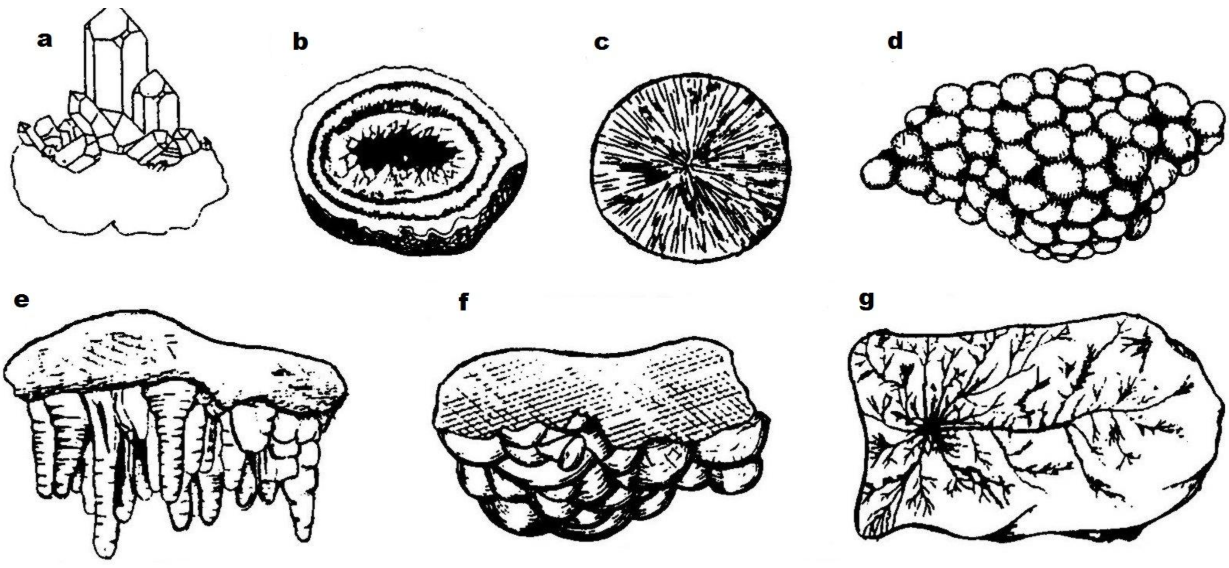

Fig. 2. Some natural forms of minerals:

a – druse; b – geode; c – nodule; d – oolites, e – stalactites, f – kidney-shaped dripstone; g – crystal dendrite

Physical properties of minerals

Every mineral is characterized by its unique physical properties. These properties can be identified in the laboratory using special methods (chemical, microscopic, thermal, X-ray, etc.) and directly in-field. The mineral can be identified in-field according to specific characteristic features or their combinations (macroscopic method). Density of minerals and their morphological, optical, mechanical and so-called specific features are estimated.

Mineral density is estimated approximately. Minerals are divided into three groups: *light* (less than 3.0 g/cm^3), *intermediate* (from 3.0 to 4.0 g/cm^3) and *heavy* (more than 4.0 g/cm^3).

Morphological properties or a habit is a form of a mineral crystal, conditions of its occurrence in rocks, and the appearance of mineral aggregates.

Optical properties of minerals describe their color, the color of streak, diaphaneity and luster.

The color is determined by several factors namely the chemical composition of the mineral, its internal structure and impurities.

The color of the mineral may be complicated by the interference of light while reflecting internal defects (fractures), inclusions and films on the surface of the mineral. This phenomenon is called iridescence. Examples are the play of blue color in the depth of subtransparent crystals of labradorite as well as particolored iridescent chatoyment of opaque (nontransparent) chalcopyrite. In the second example iridescence is called "*tarnish*". Therefore, the yellow and orange particolored tarnish is the characteristics of chalcopyrite.

Diaphaneity is the mineral ability to transmit light. It depends on the crystal structure of the mineral, its composition and impurities. Minerals are classified into transparent, opaque, subtransparent (translucent) and transparent on feather edge. Microgranular aggregates composed of transparent minerals lose their ability to transmit light and become opaque or translucent.

Luster depends on the characteristics of the mineral surface that reflects light. There are three types of luster: *metallic*, *submetallic* and *nonmetallic*. Varieties of nonmetallic luster are *adamantine* or *brilliant*, *vitreous*, *greasy*, *pearly*, *silky*, *resinous*, *dull* or *earthy* (do not shine).

Mechanical properties of minerals are determined under mechanical impact on them and include such terms as cleavage, fracture and hardness.

Cleavage is the ability of crystals to break along specific directions producing equal flat surfaces. Cleavage can occur along one, two, three, four and six crystallographic directions. As expected, these surfaces correspond to the directions in the lattice, where the bonds between atoms are the weakest.

Fracture is a form of the mineral surface if it is not split by cleavage. In crystals with cleavage fracture is characterized as plane by cleavage. In crystals with no cleavage fracture can be irregular or uneven, conchoidal (like a broken glass). Mineral aggregates may have granular, fibrous (hackly),

Table 1

The Mohs scale of mineral relative hardness

Minerals of the Mohs scale	Mohs hardness
Talc	1
Gypsum	2
Calcite	3
Fluorite	4
Apatite	5
Orthoclase	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10

needle and earthy fracture.

Hardness has been defined as the level of difficulty with which the smooth surface of a mineral specimen may be scratched. Ten-point relative scale of mineral hardness, which was created by the German mineralogist Friedrich Mohs in 1812, is used (Tab. 1). Mohs based his system of measuring and describing the hardness of a sample on the definition of hardness as resistance to scratching. Each reference mineral will scratch the test specimen with hardness less or equal to its own.

Indicators of absolute hardness measured by instruments of different designs are applied in engineering and scientific studies.

Classification and characteristics of the minerals being investigated

Chemical classification of minerals takes into account their chemical composition and lattice structure. There are about twenty different classes and subclasses of minerals. Minerals, being studied in the laboratory work, include eight main classes:

1. *Native elements* – graphite (C), sulfur (S).
2. *Sulfides* (metal compounds with sulfur) – pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), sphalerite (Zn,Fe)S), cinnabar or cinnabarite (HgS).
3. *Halides* (metal compounds with Cl, F, Br, I) – halite (NaCl), fluorite (CaF_2).
4. *Oxides and hydroxides* – quartz (SiO_2), chalcedony (SiO_2), magnetite (Fe_3O_4), hematite (Fe_2O_3), limonite ($FeO(OH){\cdot}nH_2O$), pyrolusite (MnO_2).
5. *Carbonates* (salt of carbonic acid) – calcite ($CaCO_3$).
6. *Sulfates* (salts of sulfuric acid) – gypsum ($CaSO_4{\cdot}2H_2O$).
7. *Phosphates* (salts of phosphoric acid) – apatite ($Ca_5(PO_4)_3(F,Cl,OH)$).
8. *Silicates* – garnet, pyroxene, hornblende, biotite, muscovite, serpentine, kaolinite, talc, labradorite, orthoclase.

Silicates make up 75 % of the Earth's crust mass and have the most complex chemical composition and structure of minerals. O, Si, Al, Fe, Mg, Mn, Ca, Na, K dominate in their composition. Li, Be, B, Ti, Zn, rare-earth elements, F, OH, H_2O, and others are present in many minerals. Silicates count for 34 % of a total number of the Earth's minerals.

All silicates are based on complex anions such as silicon-oxygen tetrahedron $[SiO_4]^{4-}$. The complicated chemical structure of silicates is conditioned by the presence of free oxygen valences in the tetrahedral. In result, metals and other elements may participate in their structure. The external form (habit) of silicate crystals and their physical properties are directly related to the internal structure.

The characteristics of the minerals under investigation are given in Tab. 2.

Table 2

Characteristics of the common rock-forming and ore minerals

№	Name and composition	Luster	Color	Streak	Cleavage; fracture	Hard-ness	Occurrence form	Diagnostic properties	Field of application
1	Graphite C	Submetallic; cryptocrystalline aggregates are earthy	Iron-black to steel gray	Glance black	Perfect (unknown); flaky or irregular	1	Flaky aggregates and impregnations	with a greasy feel, hardness, streak	Electrical engineering
2	Sulfur S	Adamantine on the faces, greasy on the fracture	Gradations of yellow, bright green	Light yellow	Indistinct; from irregular to conchoidal	1.5	Earthy aggregates and impregnations	Yellow, streak, brittle	Chemical industry, agriculture
3	Galena PbS	Metallic	Lead gray and silvery	Lead gray	Cubic perfect	2-3	Granule aggregates or impregnations; irregular shape mass	Color, cubic cleavage in step fracture, heavy	The primary ore of lead
4	Pyrite FeS_2	Metallic	Pale brass-yellow; tarnishes darker and iridescent	Greenish-black to brownish-black	Indistinct; very uneven, sometimes conchoidal	6-6.5	Granular, globular, and stalactitic aggregates and impregnations	Color, luster, streak, high hardness	Paper industry, electrical engineering
5	Sphalerite (Zn,Fe)S	Adamantine, resinous, greasy	Brown sometimes with gradations of yellow, red, green, black	Brownish white, pale yellow	Perfect; uneven to conchoidal	3.5-4	Granular aggregates and impregnations	Adamantine luster, streak, cleavage	The primary ore of zinc
6	Chalcopyrite $CuFeS_2$	Metallic	Brass yellow, may have iridescent purplish tarnish	Greenish black	Indistinct; irregular	3.5	Globular aggregates and impregnations	brittle, do not scratch the glass, tarnish	The most important copper ore

Table 2 continued

№	Name and composition	Luster	Color	Streak	Cleavage; fracture	Hard-ness	Occurrence form	Diagnostic properties	Field of application
7	Cinnabar HgS	Adamantine to dull	Bright red to brownish red, sometimes gray	Scarlet	Perfect (unknown); uneven to subconchoidal	2-2.5	Tabular, granular aggregates and incrustations	Red color, low hardness, brittle	The common ore of mercury
8	Halite $NaCl$	Vitreous	Colorless or white; also blue, purple, red, pink, yellow, orange, or gray	White	Perfect, three directions cubic; conchoidal	2-2.5	Granular, fibrous aggregates	Salty flavor, low hardness, three directions cubic cleavage	Food, chemical industries
9	Fluorite CaF_2	Vitreous	Colorless, white, purple, blue, green, yellow, orange, red, pink, brown, bluish black; commonly zoned; can be of any color of the spectrum	White	Perfect (octahedral cleavage), subconchoidal to uneven	4	Nodular, botryoidal, rarely columnar or fibrous, granular aggregates and impregnations	Multicolored crystals, octahedral cleavage, brittle	Metallurgy, chemical industry
10	Gypsum $CaSO_4 \cdot 2H_2O$	Vitreous to silky, pearly, or waxy	Colorless to white; can be yellow, tan, blue, pink, brown, reddish brown or gray due to impurities	White	Perfect; conchoidal	2	Elongated and generally prismatic crystals	Scratched by fingernail, one direction cleavage	Building construction

Table 2 continued

№	Name and composition	Luster	Color	Streak	Cleavage; fracture	Hard-ness	Occurrence form	Diagnostic properties	Field of application
11	Calcite $CaCO_3$	Vitreous to pearly on cleavage surfaces	Colorless or white, also gray, yellow, green	White	Perfect along three directions with angle of 74°55'; conchoidal	3	Crystalline, granular, stalactitic, concretionary aggregates, crystals	Rhombohedral cleavage, effervesces weakly in dilute HCl, curved crystal faces, twinning	Chemical industry, building construction, metallurgy, jewelry
12	Magnetite $Fe^{2+}Fe^{3+}{}_2O_4$	Metallic	Black, gray with brownish tint in reflected sun	Black	Indistinct; uneven	5.5-6.5	Microgranular aggregates, crystals	Magnetic, black streak, heavy	Common ore of iron, chemical industry, magnetic recording
13	Hematite Fe_2O_3	Metallic to splendent	Black to steel-gray to silver; red to reddish brown to black	Cherry-red to reddish-brown	None; uneven to sub-conchoidal	5.5-6.5	Tabular crystals; platy, columnar; earthy, granular, oolitic	Dark red streak, heavy, unmagnetic	The ore of iron, jewelry
14	Limonite $FeO(OH)\cdot nH_2O$	Earthy	Various shades of brown and yellow	Yellowish brown	None; uneven	4-5.5	Fine grained aggregates, powdery coating	Color, yellowish brown streak, heavy	The ore of iron
15	Pyrolusite MnO_2	Metallic, dull to earthy	Darkish, black to lighter grey, sometimes bluish	Black to bluish-black	Indistinct,perfect; brittle or earthy	2; 6-6.5	Granular aggregates and dendritic	Color, streak, readily soils the fingers	The ore of manganese

14

Table 2 continued

№	Name and composition	Luster	Color	Streak	Cleavage; fracture	Hard-ness	Occurrence form	Diagnostic properties	Field of application
16	Quartz SiO_2	Vitreous – waxy to dull when massive	Occurs in virtually every color: colorless to black	Absent	None; conchoidal	7	6-sided prism ending in 6-sided pyramid (typical), druse, fine-grained to microcrystalline, massive aggregates	High hardness, indistinct cleavage, color	Electrical engineering, glass production, jewelry
17	Chalcedony SiO_2	Waxy, vitreous, dull, greasy, silky	White to gray, grayish-blue or a shade of brown	Absent	None; uneven, splintery, conchoidal	6.5-7	Geode, veinlet, dripstone	Cryptocrystalline aggregates, high hardness	Jewelry
18	Apatite $Ca_5(PO_4)_3(F,Cl,OH)$	Vitreous on the faces, greasy on the fracture	Green, less often colorless, yellow, blue to violet, pink, brown	White	Indistinct; conchoidal to uneven	5	Tabular, prismatic crystals, massive, compact or granular aggregates	Massive, granular sugar-like aggregates	Agriculture
19	Garnet	Vitreous to resinous	Virtually all colors, dark red	Absent	Indistinct; conchoidal to uneven	6.5-7.5	Rhombic dodecahedron or cubic aggregates, crystals	Color,high hardness	Jewelry, abrasive materials
20	Hornblende	Vitreous to dull	Black/dark green	Pale gray, gray-white	Distinct; uneven, needle	5-6	Granular aggregates, crystals	Color, streak, prismatic crystals	out of use

15

End of Table 2

№	Name and composition	Luster	Color	Streak	Cleavage; fracture	Hard-ness	Occurrence form	Diagnostic properties	Field of application
21	Biotite (dark mica)	Vitreous to pearly	Dark brown, greenish-brown, blackish-brown	White	Eminent; micaceous	2.5-3	Massive to platy aggregates	Color, cleavage, platy crystals	Thermal insulating material
22	Muscovite (potassium mica)	Vitreous, silky, pearly	White, grey, silvery	White	Eminent; micaceous	2-2.5	Massive to platy aggregates	Color, cleavage, platy crystals	Insulating material
23	Serpentine	Greasy, waxy	Greenish, brownish	White	Unknown; uneven	3-4	Cryptocrystalline aggregates, sometimes fibrous aggregates of asbestos	Banded color, greasy luster, presence of asbestos	Fire-resistant material, jewelry, hardstone carving
24	Kaolinite (white clay)	Pearly to dull, earthy	White, sometimes red, blue or brown tints from impurities	White	Perfect (unknown); uneven, earthy	2-2.5	Clayey masses	Soft, earthy, swells on wetting	Ceramics
25	Talc	Waxlike or pearly	Light to dark green, brown, white, grey	White to pearl black	Perfect (unknown); uneven	1	Cryptocrystalline aggregates	Color, hardness, with a greasy feel	Fire-resistance and lubricating material, cosmetics, paper manufacture
26	Labradorite	Vitreous to pearly on cleavages	Blue, gray, brown, greenish, colorless with iridescence	White	Perfect; uneven to conchoidal	6-6.5	Tabular crystals	Color, iridescence, hardness, cleavage	Facing stone
27	Orthoclase	Vitreous, pearly on cleavage surfaces	Colorless, greyish, white, pink	White	Perfect; uneven	6	Elongate with a tabular appearance grains	Color, hardness, cleavage	Ceramics, porcelains

Performance guidelines

Given:
- general information about minerals and their conditions of formation;
- description of the physical properties of the minerals and their classification;
- a collection of the mineral specimens without name indication;
- specimens of minerals in the Geological Museum of the University.

Define:
- main physical parameters of mineral specimens (color, streak, luster, cleavage, peculiar properties);
- names and classes of minerals from the collection;

Equipment: laboratory equipment for determining the relative hardness and some peculiar properties of minerals (a piece of glass, a porcelain plate, reference mineral specimens, magnets, 10%-hydrochloric acid solution).

Methodology for determining the physical properties of minerals is the macroscopic examination. It is applied both in the laboratory and in field survey. Sequence of research to determine the physical properties of minerals should include the following steps.

The luster and the color are defined visually. The term luster refers to the quantity and quality of light which is reflected from a mineral's exterior surface. Luster identifies how much the mineral surface “sparkles”. This quality is determined by the type of atomic bonds within the substance. It is related to the indices of absorption and refraction of the material and the amount of dispersion from the crystal lattice, as well as the texture of the exposed mineral surface.

Minerals are primarily divided into two categories of **metallic** and **nonmetallic** luster. Minerals possessing metallic luster are opaque and very reflective (gold, silver, galena, pyrite, chalcopyrite; all ore minerals). The luster of a mineral which is similar to metal, but duller and less reflective, is termed **submetallic** (graphite, hematite). Adjectives such as "vitreous”, “dull”, “pearly”, “greasy”, “silky”, and “adamantine” are frequently used to describe various types of nonmetallic luster. Minerals of *dull* or *earthy* luster reflect light very poorly and do not shine. This type of luster is often seen in minerals which are composed of fine-grained aggregates (kaolinite, limonite). *Pearly* luster can be iridescent, opalescent, or pearly. This type of luster is typical for mineral surfaces which are parallel to the planes of perfect cleavage (talc). A surface which possesses *greasy* luster is covered with a thin layer of oil (serpentine). *Silky* luster is found in minerals with a parallel arrangement of extremely fine fibers causing them to display similar optical properties to silk cloth (muscovite). *Vitreous* luster occurs in minerals resembling the reflective quality of broken glass (many silicates, quartz). A *brilliant* luster such as the sparkling reflection of diamond is known as *adamantine* (cinnabar, sphalerite).

To characterize the color of minerals the rainbow colors and the terms like colorless (clear), white, black, gray, brown are used. The names of well-known color objects (cherry, bright green, etc.) are used too. The color of the mineral can be spotted, changeable.

The streak of a mineral refers to the color of a mineral in a powdered form, which may or may not be identical to its body color. Typically, an edge of the sample is rubbed across the porcelain plate leaving behind a “streak” of a finely ground material. The streak of a mineral is independent of trace elements or any weathering surface. For example, hematite sample is colored black, silver, or red but it has a cherry-red streak; pyrite is brass-yellow, but its streak is black. Thus, streak is more reliable identification property than a color. Streak testing is constrained by the hardness of a mineral, as those harder than 7 powder the streak plate instead. Minerals which possess a metallic luster tend to have a thick, dense, dark streak whereas those which possess a nonmetallic luster tend to produce a thinner, less dense streak, which is also lighter in color.

The diaphaneity of a mineral describes the ability of light to pass through it. Transparent minerals do not diminish the intensity of light passing through it (muscovite). Translucent minerals allow some light to pass, but less than those that are transparent. Minerals that do not allow light to pass are called opaque. Minerals may have varying degrees of transparency, e.g. quartz can be transparent (berg crystal), translucent and opaque. Relative differences in opacity and transparency are described as luster. The diaphaneity of a mineral depends on the thickness of a sample. When a mineral is sufficiently thin (a thin section for petrography), it may become transparent even if that property is not visible in hand samples. In contrast, some minerals, such as hematite or pyrite, are opaque even in thin-section. Some minerals permit light through the edges or on cleavage surfaces.

Cleavage means breaking of a crystal along a flat plane. A cleavage plane is a plane of structural weakness along which a mineral is likely to split. The quality of a mineral's cleavage refers both to the ease with which the mineral cleaves and to the character of the exposed surface. Not every mineral exhibits cleavage.

Cleavage of minerals can be one-, two-, three-, four- and even six-directional. Thus, mica and gypsum have one-directional cleavage, orthoclase – three-diractional, sphalerite – six-directional. The quality of a sample's cleavage is typically described by the following terms

- *eminent* – cleavage always occurs readily (mica cleaves readily into thin, flat sheets);
- *perfect* – mineral breaks easily exposing continuous flat surfaces which reflect light (fluorite, calcite, halite, galena, feldspars);
- *distinct or imperfect* – cleavage surfaces are present although they may be marred by fractures or imperfections (hornblende);
- *indistinct* or *difficult*– cleavage produces surfaces which are neither smooth nor regular; samples possessing such cleavage tend to fracture rather than split (beryl, apatite);
- *unknown* – minerals have rough surfaces, cleavage could be observed only with the use of a microscope (talc, kaolinite, graphite);
- *none* – crystals have uneven surfaces while splitting (quartz, cassiterite).

When a mineral is broken in the direction that does not correspond to the plane of cleavage, it is termed to be fractured.

In addition to cleavage, the fracture must be identified. Fracture takes place when a mineral sample is split in a direction which is not a plane of perfect or distinct cleavage. In other words, fracture takes place along a plane possessing distinct, indistinct, or none cleavage. The difference between fracture and indistinct cleavage is not clearly delineated. So, glass, flint, porcelain, quartz possess a *conchoidal*, i.e. with fine edges, fracture; asbestos – a *hackly* fracture; hornblende – a *needle* one; fine-grained mineral aggregates, composed from kaolinite, pyrolusite, limonite, have an *earthy* fracture. *Irregular* or *uneven* fracture results in a rough, rugged surface.

Relative hardness has historically been measured according to the ten-point Mohs scale (Tab. 1). To determine the relative hardness of a mineral means to compare it with the reference mineral from the Mohs scale. While performing this laboratory work, the analogs of reference minerals with different hardness (metal, window glass, porcelain, etc.) are used. Determination should start with a piece of glass. A mineral leaving a scratch on the glass has hardness more than 5 and, if it slides on, then hardness is less than 5. Many minerals have intermediate hardness between two standards on the Mohs scale. In this case, the hardness must designate fractional number, for example, between 3 and 4 – 3.5. Tab. 3 gives the values of absolute hardness of minerals which can be used for comparison.

Table 3

Scale of mineral hardness and their analogs

Mohs hardness	Minerals of the Mohs scale	Mohs hardness of analog	Analog of the Mohs scale	Absolute hardness indicated by Khrushchev-Berkovich device
1	Talc	1	Pencil lead	2.4
2	Gypsum	1.5-2	Finger skin, an aluminum needle	36
3	Calcite	2.5-3	Fingernail, a copper penny	109
4	Fluorite	4	Mild iron (a nail)	189
5	Apatite	5	Window glass	536
6	Orthoclase	6-6.5	A knife blade, a porcelain plate	795
7	Quartz	7	Engineers file	1,120
8	Topaz	8	Special-property alloys	1,427
9	Corundum	9	Emery stone	2,060
10	Diamond	10	–	10,060

Specific characteristics of minerals include reaction to acid, magnetism, taste or smell, adustion, conductivity, radioactivity, etc. These characteristics expose properties specific for certain minerals or their groups.

Magnetism is the ability of a mineral to affect the compass needle. Magnetite strongly exhibits this property.

Taste is a characteristic of soluble minerals. For example, halite (NaCl) is salty; its potassium-bearing counterpart, sylvite (KCl), has a well-defined bitter taste.

Smell. Sulfur specimens, in standard room conditions, exude a mild odor resembling the smell of a burning match. Many sulfides, such as pyrite, emit a rotten-egg odor if heated or struck. Minerals containing arsenic in their chemical formula (arsenopyrite) exude a garlic odor if struck or heated. One should never heat a mineral that possibly contains arsenic since its fumes are toxic. If wet or under moist conditions, minerals of the clay group (kaolinite) emit an odor resembling fresh clay.

Reaction to acid. Dilute acid (often 10% HCl) helps distinguish carbonates from other mineral classes. The acid reacts with the carbonate ($[CO_3]^{2-}$) group, which causes the affected area to effervesce emitting carbon dioxide gas.

It is important to pay careful attention to safety arrangements and precautions when conducting experiments using glass, porcelain plates and hydrochloric acid solution:

- glass or porcelain plate should be pressed by one hand to the desk, while the other hand drags a mineral across the glass or plate;
- hydrochloric acid solution can be used only under the supervision of a lecturer!

Research report on physical properties of major rock-forming and ore minerals should be presented in the form of a table following the example given below (Tab. 4).

Table 4

Characteristics of mineral specimens in the collection

No.	**Luster**	**Color**	**Streak**	**Hardness**	**Cleavage, fracture**	**Diagnostic properties**	**Name, Formula, class**
1	Vitreous	Colorless, white	White	3	Perfect, conchoidal	Effervescence under the impact of HCl	Calcite $CaCO_3$, carbonate

Processing laboratory results means

- formulating unique diagnostic properties of each mineral distinguishing it from any other minerals;
- identifying the name, the chemical composition (formula) and the class of a mineral.

For this purpose, the defined parameters are compared with the data presented in Tab. 3.

Conclusion should focus on

- describing the key parameters that can more or less specify the mineral before its final identification by consequent mineralogical studies;
- the analysis of the occurrence of minerals by their chemical composition, including their percentage of abundance in the Earth's crust.

Being in the classroom, students can consult a lecturer about the correctness of a mineral identification.

Questions to prepare for the laboratory work defense

1. Give the definition of the term *minerals*.
2. What is the difference between *absolute and relative hardness*?
3. Specify the minerals of the following classes: native elements, sulfides, halides, carbonates, sulfates, phosphates, oxides and hydroxides, silicates.
4. Give the definitions of *isotropy, anisotropy, isomorphism*.
5. What minerals are *isotropic and anisotropic*?
6. What do the terms *cleavage, hardness*, *streak* and *luster* mean?
7. Describe the conditions of mineral formation.
8. What is the method of macroscopic examination of minerals based on?
9. The building-up principle of the Mohs scale of minerals hardness. What is the hardness of apatite?
10. Principles of mineral classification. Which minerals from the laboratory work can be classified as native elements?
11. What are the main classes of minerals? Give the examples of the abundant minerals from each class.
12. What geological processes is mineral formation related to?
13. Specify the physical properties of minerals. What types of luster do you know?
14. Does Mohs scale describe absolute or relative hardness of minerals?
15. What are the main classes of minerals? Which minerals from the laboratory work are classified as sulfides?
16. What processes influence the formation of endogenous minerals?
17. What is *cleavage*. What is cleavage conditioned by?
18. What scale is used to determine the hardness in mineralogy?
19. What are the main classes of minerals? What minerals from the laboratory work are classified as silicates?
20. What processes influence the formation of exogenous minerals?
21. Physical properties of minerals: color and hardness.
22. What methods can be used to determine the relative hardness of a mineral in the laboratory?

3. GUIDELINES ON PREPARATION AND PERFORMANCE OF THE LABORATORY WORK No. 2

Theme: ***“Studying of the main types of rocks”***

The purpose of the laboratory work is to explain structural and textural features of rocks of different genesis, as well as to provide information on their classification and the most common types.

Preparation for the laboratory work requires a careful study of the theory given below and in the recommended literature.

General information on rocks, their structure and texture.

The Earth’s crust consists of mineral aggregates (rocks) of different shapes and sizes. Each rock is formed under appropriate geological conditions which determine the shape of its body, its deposition inside the Earth’s crust, mineral composition and inner structure. Therefore, different rocks have specific physical properties: color, density, mechanical density, etc.

Thus, **rocks** are mineral aggregates with more or less homogeneous mineral composition and physical properties formed as a result of different geological processes.

All the rocks are divided into three main groups by origin:

- *igneous* – formed by magmatic processes;
- *sedimentary* – related to exogenous processes taking place on the surface of the Earth and inside the hydrosphere.
- *metamorphic* – formed as a result of igneous and sedimentary rocks recrystallization (metamorphic processes).

Igneous and metamorphic rocks form 95 % of the Earth’s crust mass.

The main diagnostic characteristics of rocks are their structural and textural features as well as their material composition.

Rock texture *(structure in ukr., fr., germ.)* is a shape and size of mineral grains, debris or organic residues that form the rock, as well as its crystallinity range. For example, there are coarse-grained, cryptocrystalline and oolitic textures.

Rock structure *(texture in ukr., fr., germ.)* is features of spatial and positional relationship of minerals, debris and other components of rocks. For example, there are homogeneous (massive), flaky, spotted structures.

Material composition of rocks. Components of rocks include grains of minerals, non-crystallized substance of magma (volcanic glass), fragments of pre-existed rocks and a mineral substance which cements them, organic residues of animal and plant origin, space dust and meteorites. But the main components of rocks are minerals.

Igneous rocks

Igneous rocks are formed as a result of cooling of liquid silicate melt – magma which comes from the abyssal magma chambers. Magma can get cool both inside the Earth’s crust and on its surface, where it can flow out during volcanic eruptions. Igneous rocks are divided into three classes according to the conditions of crystallization:

- *plutonic (intrusive)* – formed as a result of prolonged cooling and crystallization of magma at great depths;
- *volcanic (effusive)* – formed on the crust's surface in the daylight or underwater due to fast cooling of lava (magma which has lost solute gases);
- *hypabyssal* – formed as a result of cooling and solidification of magma in the zones just beneath the Earth surface.

Plutonic and volcanic rocks are easily identified due to their texture and structure. **Intrusive rocks** have a *phaneritic* – giant-, coarse-, middle- or a fine-grained texture with the mineral grain size more then 10, 5÷10, 2÷5 and 0.5÷2 mm correspondingly. The structure of the rocks is homogeneous which is caused by the equal distribution of different mineral grains inside them.

Volcanic rocks have a cryptocrystalline or an amorphous (glassy) texture of the groundmass where only single crystals of refractory minerals can be embedded. The structure of igneous rocks is homogeneous, often porous.

According to the "Petrographic Codex of Ukraine" (1999), all the igneous rocks are divided into four main groups with different silica SiO_2 content: felsic (64÷78%), intermediate (53÷64%), mafic (44÷53%) and ultramafic (30÷44%). This systematization, combined with the information on an abyssal or surface origin of igneous rocks, afforded ground for their classification. Its simplified version is presented in the Tab. 5 where only the main igneous rock types are shown.

Table 5

Classification of igneous rocks

Chemical composition groups (content of SiO_2, %)	**Genesis conditions classes**		**Mineral composition**
	Plutonic (intrusive)	**Volcanic (effusive)**	
Felsic (64÷78 %)	***Granite***	***Rhyolite, obsidian***	Potassium feldspar, quartz (25–45%), sodium-rich plagioclase, biotite, muscovite, sometimes hornblende
Intermediate (53÷64 %)	***Diorite*** (normal series)	***Andesite***	Sodium- and calcium-rich plagioclase – approximately 70%, hornblende, sometimes pyroxene, biotite
	Syenite (alcaline series)	***Trachyte***	Potassium feldspar – 60–90 %, sodium-rich plagioclase, hornblende, sometimes biotite, pyroxene
Mafic (44÷53 %)	***Gabbro, labradorite, pyroxenite***	***Basalt***	Pyroxene, calcium-rich plagioclase, hornblende
Ultramafic (30÷44%)	***Dunite, peridotite***	***Picrite, Kimberlite***	Olivine, pyroxene, sometimes biotite, hornblende

Sedimentary rocks

Sedimentary rocks are formed in different ways:
- accumulation of rock debris, residues of animals and vegetal origin;

- precipitation of salts and chemical compounds;
- combination of the mentioned above processes, particularly including the processes of volcanic product formation.

Depending on formation and composition, sedimentary rocks can be divided into *clastic, chemical, organic, compound, volcanogenic-sedimentary* groups. This course studies clastic, chemical and organic rocks only.

Mineral sediments, which are formed out of sedimentary rocks, deposit as layers and beddings of different thickness. Therefore, the common feature of sedimentary formations is their flaky macro- and microstructure.

Clastic rocks consist of debris and clay formations which are the products of the destruction of rocks forming the surface of the Earth's crust.

Clastic sediments can be both friable and consolidated (monolithic). Cementing substance can be represented by clayey, siliceous, carbonaceous, ferriferous and other compounds.

Debris of rocks can be *angular* or *rounded* to a variable degree. Fragments become rounded as a result of the processes of transportation by water flows, wind and sea surf.

The size of fragments can be widely different – from clayey and pulverescent elements to meter-sized lumps. Therefore, the textures of clastic rocks can be *psephitic (coarse debris), psammitic (sandy), silt and pelitic (clayey).*

Structures of clastic rocks can be friable, concrete bound (monolithic), flaky, earthy.

The classification of clastic sediments and rocks takes into consideration their three main features – size of fragments, rounding and solidity (consolidation of the rock) (Tab. 6).

Table 6

Classification of clastic sediments and rocks

Groups of rocks	**Fragment size, mm**	**Names of the rocks**			
		Friable sediments		**Consolidated rocks**	
		Angular particles	***Rounded particles***	***Angular particles***	***Rounded particles***
Psephites (coarse particles)	> 200	Lump	Boulder	Lump breccia	Boulder conglomerate
	10÷200	Crushed rock	Pebble	Breccia	Conglomerate
	2÷10	Gruss	Gravel	Gruss breccia	Gravelite
Psammites (sandy)	1÷2	Very coarse sand		Very coarse sandstone	
	0.5÷1	Coarse sand		Coarse sandstone	
	0.25÷0.5	Medium sand		Medium sandstone	
	0.1÷0.25	Fine sand		Fine sandstone	
Silt	0.01÷0.1	Silt (aleurite), loess		Siltstone (aleurolite)	

Pelites (clayey)	< 0.01	Clay	Mudstone (argillite)

Chemical rocks were formed from the products of chemical decomposition of other rocks on the Earth's crust surface or as a result of salts and other solutions precipitation on the bottom of reservoirs.

Depending on the chemical composition, rocks are divided into *carbonaceous* (limestone, travertine), *siliceous* (siliceous tufa, flint), *ferriferous* (brown iron ore), *halogen* (rock-salt), *sulfate* (gypsum), *aluminous* (bauxite), *phosphate* (mudrock with phosphates), *compound* (marl).

Special attention should be paid to the "Mineral composition" column in the classification of chemical rocks (Tab. 7).

<u>Textures of chemical rocks</u> can be *crystalline*, *cryptocrystalline*, *oolitic.*

<u>Structures of chemical rocks</u> are *flaky*, *earthy*, *chaotic.*

Organic rocks are formed as a result of plant and animal activity, their subsequent extinction and organic residues accumulation. According to their composition and origin, rocks are divided into three main types:

- *zoogenic* (lat. zoo – animal) formed from animal organic residues;
- *phytogenous* (gr. phytos – plant) consisting of humified plant organic residues;
- *sapropelic* (lat. sapros – rotten; pelos – mud).

Zoogenic rocks consist of fossils, such as intact shells of mollusks, fragmented shells (detritus) or skeletal residues of organisms (shell rock, coral limestone, chalk, etc.).

Table 7

Classification of chemical and biochemical rocks

Groups of rocks	Chemical rocks	Biochemical rocks	Mineral composition
Carbonaceous	***Chemogenic limestones***: - pelitomorphic - oolitic - travertine	***Biochemical limestones***: - shell rock - detrital limestone - coral limestone - fusulina limestone, etc.	Calcite– $CaCO_3$
Siliceous	***Siliceous tufa*** ***Geyserite*** ***Flint (chest)***	***Diatomite*** ***Rotten stone*** ***Opoka***	Opal – $SiO_2 \cdot H_2O$ Chalcedony – SiO_2
Ferriferous - oxide - silicate - carbonaceous	***Brown iron ore***	–	Limonite – $FeO(OH) \cdot nH_2O$ Goethite – FeOOH
Manganous	***Manganous ore***	–	Pyrolusite – MnO_2
Halogen	***Rock-salt***	–	Halite – NaCl

	Potash		Sylvite – KCl Carnallite – $KCl \cdot MgCl_2 \cdot 6H_2O$
Sulfate	***Gypsum Anhydrite***	–	Gypsum – $CaSO_4 \cdot H_2O$ Anhydrite – $CaSO_4$
Aluminous	***Laterite Bauxite***	–	Diaspore – AlO(OH) Gibbsite – $Al(OH)_3$
Phosphate (phosphorite)	***Mudrocks with calcium phosphate***	–	Apatite – $Ca_5[PO_4]_3(F, Cl, OH)$

Phytogeneous rocks form the genetic series of rocks starting from *peat* that is accumulated in wetlands. Peat is a vegetative mass, regenerated into *humus*, the product of the decomposition in the wetlands where oxygen from the atmosphere is obstructed. As a result of the tectonic setting of peat seams, the rock is subjected to the complicated processes of coalification and it is gradually transformed into brown coal and then into higher rank coals. Burial at the depth of more than 7÷8 km transforms coal into anthracite.

Sapropelic rocks are formed from sapropel that is accumulated in stagnant basins – lakes, bogs, several seas, lagoons, former river-beds. Sapropel is a mixture of thin mineral mud and decomposed organic mass formed from organic residues of primitive algae and animals as well as soft tissues of higher organized animals. In contrast to phytogeneous sediments, which mainly consist of cellulose $[n(C_6H_{10}O_5)]$, organic mass of sapropel is formed of fats, albumen and carbohydrates of organism soft tissues.

Further transformation of sapropel depends on the depth of burial in the Earth's crust. Various sapropel sediments can form *sapropel coal, shale oil, bitumen* (lat. bitumen – resin), *oil, gas,* etc. depending on the depth of burial, sapropel seam thickness, content of organic matter and other conditions.

All the combustible organic minerals are called *caustobiolithes* (gr. kaustos – combustible, bios – life, lithos – stone).

<u>Texture of organic rocks</u> can be *phytogeneous and zoogenic.*

<u>Structure of organic rocks</u> can be *flaky, disorderly, homogeneous, earthy.*

Description of the main zoogenic, phytogeneous and sapropelic rocks is presented in the Tab. 8.

Table 8

Description of several organic rocks

Names of rocks	Color	Composition and origin conditions	Specific features
Shell rock	White,	Cemented shells	Mollusk species

	yellow		composition is used to determine the age of a rock
Chalk	White	Skeletal residues of primitive sea organisms	Leaves a white line on hard surfaces
Peat	Brown	Humified fragments of plants	Easily mashed
Brown coal	Brown	Solid, completely carbided peat under the temperature of 60–70°C	Light, highly porous mass with fragments of plants
Coal of different ranks	Black	Series of rocks of different coalification stages under the temperature up to 370°C	Dull luster, very chinked, soils hands
Anthracite	Black	The highest coalification stage under the temperature of more then 370°C	Chinked, shining, doesn’t soil hands
Shale oil	Deep-brown	Solid clayey substance with the smell of bitumen	Fresh thin chips burn with a smoking flame
Oil and ***combustible gas*** (methane CH_4)	From white to black	Liquid and gaseous carbohydrates of phytogeneous and zoogenic origin	Oily liquid of different tenacity, colorless and inodorous gas

Metamorphic rocks

Metamorphic rocks were formed as a result of transformation of sedimentary, igneous or pre-existing metamorphic rocks under the influence of temperature, pressure and active chemical agents – liquid and gaseous fluids. Transformations take place in the solid phase and result in mineral alteration, alteration of chemical composition, texture and structure of initial rocks.

The level of changes depends on intensity, depth and duration of metamorphic factors effect. Therefore, we can talk about series of metamorphic rocks from the primary to highly metamorphosed rocks with all the intermediate types. For example, such primary rocks as clay or mudstone transform into slate first. Then, as the depth is increasing, the slate is turning into phyllite, phyllite transforms into mica-schist, mica-schist becomes gneiss. Such transformations occur during tens and hundreds of millions of years.

The factors of metamorphism – temperature, pressure and fluids – are the result of geological conditions under which the primary rocks are formed. They are caused by mineral burial on big depths, intrusion of magma or mechanical effect on rocks. All these features are reflected in the mineral composition, texture and structure of metamorphic rocks. Some of these features are derived from primary rocks.

Mineral composition of metamorphic rocks depends on both conditions of metamorphism and composition of primary rocks. The main rock-forming minerals of metamorphic rocks are quartz, feldspar, mica, pyroxene, hornblende, and calcite. Besides, such minerals as garnet, chlorite, talc, serpentine, which are formed as a result of metamorphic processes, are also present.

Metamorphic rocks formed during the process of recrystallization in solid state have crystalline textures. The typical texture of a dislocation metamorphism is a *cataclastic texture* that is a result of rocks and minerals comminution (breaking).

Structure is the main feature of metamorphic rocks. There are foliated, banded, gneissose and homogeneous (massive) structures.

Foliated structure is caused by a parallel arrangement of neogenic scaly and tabular minerals within a rock. The rock is cleaving into thin blocks along these directions. The formation of foliated structures occurs when primary rocks are subjected to one direction pressure.

Banded structure is characterized by its band, flaky-kind alternation of layers of different composition, color and other features. Such structures are derived from flaky sedimentary rocks.

Gneissose structure is characterized by parallel orientation of oblong crystals, alternation of separate parts such as lenses and stripes with different mineral composition inside the rock in the same direction.

Homogeneous (massive) structure is a uniform allocation of minerals inside a rock similar to igneous rocks.

The description of the most common types of metamorphic rocks is presented in Table 9. In the last column the names of primary rocks are stated – the appropriate metamorphic rocks were formed from them. For example, mudstone is the primary rock for the formation of slate.

Table 9

The main metamorphic rocks

Metamorphic rocks	Mineral composition	Main features	Primary rocks
Slate	Clay minerals, sericite	From dark-grey to black color, foliated structure	Mudstone
Phyllite	Sericite, quartz	The same as slate, but with a silky luster	Slate
Schist and Mica-schist	Quartz, mica, garnet	Foliated structure, scaly-granular texture	Phyllite, sand-clay rock
Gneiss	Quartz, feldspars, mica	Appearance and mineral composition similar to granite, gneissose structure	Schist
Talc schist	Talc, chlorite, calcite	Scaly and cryptocrystalline mass of talc	Igneous ultramafic rocks
Serpentinite	Serpentine	Greenish spotted rock, often contains veins of	Igneous ultramafic rocks

		asbestos	
Amphibolite	Hornblende, plagioclase	From greenish-gray to black color. Homogeneous structure	Igneous mafic and intermediate rocks
Marble	Calcite ($CaCO_3$)	Crystalline texture. Homogeneous structure, often banded. Effervescence under the action of HCl	Limestone
Quartzite	Quartz (SiO_2)	Consists of minor grains of quartz bounded by quartz cement. Very dense and hard rock. Homogeneous structure.	Quartz sandstone
Ferruginous quartzite	Quartz, hematite	Banded structure formed by the alternation of quartz and ore bands	Sandstone with brown iron ore

Guideline for performance

Given:
- general information about rocks;
- classification and description of igneous, sedimentary and metamorphic rocks;
- collections of rock specimens without origin and name indications;
- pertinent objects of rocks in the Geological museum of the NMU.

***Define*:**
- mineral composition of the specimens of igneous, chemical sedimentary and metamorphic rocks;
- texture and structure of the rock specimens;
- genetic type of a rock (by origin) according to the material composition, textural and structural features.

Equipment:
- equipment to determine the relative hardness of rock-forming minerals (glass);
- 10 % solution of hydrochloric acid for determining the carbonate-containing rocks;
- a ruler or a diagram of M.M. Vasilievsky to determine the texture of rocks by measuring their grains;
- the scale for determining the roundness of sedimentary rock fragments.

Methodology. The investigation of rocks is carried out in the field or in the laboratories where chemical, petrographic, radiological and engineering, and geological methods can be implemented. In a classroom the identification of rocks is carried out by macroscopic methods.

The determining of mineral composition (i.e. rock-forming minerals) is illustrated in Lab. 1 in this manual.

The formation conditions of rocks are reflected both in their mineral composition and their texture and structure.

The determining of the rock structure and texture is carried out visually or with the help of the appropriate equipment. The distinguishing of texture or structure is performed by comparing the specimens with the etalons provided by teachers, or using schemes, pictures and photos given in the books [1-3].

The rock type is determined by the structure and texture of each rock specimen.

Special attention should be paid to safety arrangements and precautions during the experiments where glass or HCl are used:

- glass or porcelain plate should be pressed by one hand to the desk, while the other hand drags a mineral across the glass or plate;
- hydrochloric acid solution can be used ONLY under the supervision of a lecturer!

Research report on mineral composition, structures, textures and types of rocks by their origin should be presented in the form of a table following the example given below (Tab. 10).

Processing of laboratory results includes the description of the diagnostic characteristics, structure and texture of each rock specimen distinguishing it from other rocks, and the identification of the rock genetic type. For this purpose, the determined properties should be compared with the data presented in the Tab. 5-9.

Table 10

Description of several rock specimens from the collection

No.	**Texture**	**Structure**	**Mineral composition**	**Diagnostic features**	**Name**	**Genetic type**
1	2	3	4	5	6	7
1	Phaneritic, middle-grained	Homogeneous	Quartz, orthoclase, muscovite, biotite, hornblende	Rosy-grey color	Granite	Felsic igneous rock

Conclusion should focus on

- describing the key properties that can more or less specify the mineral before its final identification by consequent petrographic research;
- the analysis of the investigated rock abundance by genesis (origin).

Being in the classroom, students can consult a lecturer about the correctness of a mineral identification.

Questions to prepare for the laboratory work defense

1. Define the term *"rocks"*.
2. What are the main types of igneous rock textures?
3. What type of rock origin does marble belong to?
4. What are the main texture types of metamorphic rocks?
5. What features lay the ground for clastic sedimentary rock classification?
6. Describe the conditions of igneous volcanic rock formation.
7. What factors of metamorphism take part in the formation of metamorphic rocks?
8. What diagnostic features have been used for rock identification in the laboratory work?
9. What are the geological bodies of igneous rocks?
10. What are the geological bodies of sedimentary and metamorphic rocks?
11. Describe the conditions of plutonic igneous rock formation.
12. What groups are sedimentary rocks divided into, according to their composition and origin?
13. Define the concepts of "texture" and "structure".
14. Describe the conditions of sedimentary rock formation.
15. What are the types of igneous rocks according to the content of SiO_2?
16. Describe the conditions of metamorphic rock formation.
17. What types are igneous rocks divided into by the conditions of their origin?
18. What does the composition of rock mean?
19. What is the difference between rocks and minerals?
20. What is the principle of clastic sedimentary rock classification?
21. What types are chemical and biochemical sedimentary rocks divided into?
22. How are phytogenous, zoogenic and sapropelic sedimentary rocks formed?

4. PERFORMANCE REQUIREMENTS AND ASSESSMENT CRITERIA FOR THE LABORATORY WORKS

Performance requirements for the laboratory works

A laboratory work report has to be submitted in a 12 page copy-book. It must include:

- key theoretical concepts about minerals and rocks according to the laboratory work requirements;
- results of the individual identification of the physical properties and names of the minerals from the sample collection(Tab. 4);
- results of the individual identification of the physical properties and names of the rocks from the sample collection (Tab. 10);
- conclusion.

The report should be written with a contrast ink and indicate the date of classes. A front page should contain a group index, a student name, and the name of a copy-book for laboratory works in "General Geology".

Laboratory work assessment

Assessment criteria include:

- relevance of the material in the report to the laboratory work submission requirements;
- achievement in theoretical aspects;
- achievement in determining rock-forming minerals according to their features (hardness, cleavage, color, streak, etc.) and classification;
- achievement in determining mineral composition, texture, structure and origin conditions of rocks (rock types).

The laboratory work can be defended immediately after its completion and (or) during the module week (the 8^{th} week). The defense includes an open test with five theoretical questions for each laboratory work (look at the sample below) and the mineral / rock identification practical task (5 specimens out of 27 / 50 items correspondently) to define the names of the minerals and rocks, their physical properties, texture and structure.

Questions for the defense are given at the end of each laboratory work.
Correct answers to the questions can be found in [1-3].

<u>An open test sample for laboratory work No. 1:</u>

1. Define the term “minerals”.
2. What is the difference between absolute and relative hardness?
3. What sulfide minerals can you name?
4. What minerals are isotropic?
5. What is the meaning of cleavage?

<u>An open test sample for laboratory work No. 2:</u>

1. Define the term “rocks”.
2. What are the main textures of igneous rocks?
3. What type of rock genesis does marble belong to?
4. What are the main structures of metamorphic rocks?
5. What features lay the basis for clastic sedimentary rock classification?

The achievement rate of the laboratory work is calculated according to the formula:

$$C = N/P,$$

where N is a number of correct identifications of minerals or rocks and correct answers to the questions given; P is a total number of proposed significant operations.

Grading scale:

“Excellent” – $C > 0.9$;

“Good” – C = 0.8÷0.9;
“Satisfactory” – C = 0.7÷0.8;
“Unsatisfactory” – C < 0.7.

Laboratory work achievement cannot be graded positively if a student has not met all the assessment criteria.

The total grade of the laboratory module is an average grade of the laboratory works 1 and 2.

REFERENCES

1. Marshak S. Essentials of Geology. 4th Edition. – W.W. Norton & Company, New York – London:, 2007. – ISBN 978-0-393-91939-4. – 648 p.

Students can use additional books and electronic resources for more thorough preparation and broadening their outlook.

2. Outline of geology – Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Outline_of_geology.

3. Geoscience news and information. http://geology.com/general-geology.