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PETROGRAPHIC COMPOSITION AND ORE POTENTIAL OF LOW-TEMPERATURE METASOMATITES OF THE MIDDLE-DNIPREAN MEGA-BLOCK OF THE UKRAINIAN SHIELD

Purpose. To substantiate the formation conditions, distribution patterns and metallogenic specialization of low-temperature metasomatites of the Middle Dnipro megablock of the Ukrainian Shield based on the research results obtained.

Methodology. The authors used a set of field and laboratory methods. Petrographic, mineragraphic, petrochemical studies were carried out. Interpretation of the results of chemical, laser microspectral, X-ray diffraction, scintillation spectral, thermal analyses is carried out.

Findings. A generalized petrological description of low-temperature metasomatites of the Middle Dnipro megablock of the Ukrainian Shield is carried out, taking into account the composition of the original rocks, characteristics of newly formed mineral parageneses, metallogenic specialization and patterns of distribution of metasomatic formations. The study on occurrences of vertical and horizontal metasomatic zoning within the greenstone structures of the Middle-Dniprean region was carried out. The composition of telescoped metasomatites spatially related to the intersection of deep faults is characterized. The metallogenic specialization of low-temperature metasomatic formations is determined and the process of formation of ore concentrations of complex composition in the nodes of intersection of deep faults has been characterized. Based on the results of studies on the composition and ore content of metasomatites, an insignificant level of erosional truncation of vertical ore-metasomatic columns within greenstone structures is substantiated.

Originality. The aspects of petrology and ore content of the group of low-temperature metasomatic formations of the Middle Dnipro megablock of the Ukrainian Shield have been revealed. The spatial relationship of the metasomatic areas with the systems of deep faults has been substantiated, which justifies using the identified metasomatic formations as geological indicators of deep fault zones. The features of ore content of low-temperature metasomatic formations of the Middle Dnipro megablock are characterized. It is shown that formations of telescoped metasomatites with a complex composition of mineralization are spatially associated with the intersection of deep faults.

Practical value. The metallogenic specialization of low-temperature metasomatic formations has been determined, which can be used as a search criterion for various types of deposits of metallic and non-metallic minerals within the Ukrainian shield.

Keywords: *metasomatites, deep faults, formations, petrology, ore content, erosional truncation*

Introduction and literature review. The Middle Dnipro megablock is located in the southeastern part of the Ukrainian Crystalline Shield (UkH). According to the chronostratigraphic scheme (2003), there are six structural-tectonic units within the Ukrainian shield, defined as megablocks: Azovian, Middle-Dniprean, Inhul-Inhuletskyi, Ros'-Tykych, Dniester-Buh and Volynian. Moreover, according that scheme, three suture zones are also marked out, which are natural geological boundaries between adjacent megablocks: Orekhiv–Pavlohrad, Kryvyi Rih-Kremenchuk and Holovanivsk. In the west, the Middle Dnipro megablock is bounded by the Kryvyi Rih-Kremenchuk and West-Inhulets deep faults, between which the Kryvyi Rih suture zone is located, separating the Middle Dnipro megablock from the Inhul-Inhuletskyi megablock. The eastern border of the Middle Dnipro megablock is represented by the Orekhiv-Pavlohrad suture zone. Within the Middle Dnipro megablock, the thickness of the earth's crust varies from 36 to 50 km. The southern and northern boundaries of the megablock are determined by hypsometry of the same name slopes of the Ukrainian Shield (Fig. 1).

Tectonically, the Middle Dnipro granite-greenstone area most closely corresponds to the dome-depression type, which is expressed in the synformal, rarely monoclinal nature of disconnected greenstone structures (GSS), which are separated by granite domes and swells and are limited by higher-order faults. A. A. Sivoronov & A. B. Bobrov (1996) distinguishes three morphostructural types of GSS in the Middle Dnipro megablock: linear (Konkska), brachial (Sofiyivska, Surska, Chortomlykska), and amoeboid one (Verkhivtsevska). Bilozerska GSS occupies an intermediate position in this series, since it combines the features of each of the three types of structures.

Seventeen types of polychronous metasomatic formations of pneumatolytic-hydrothermal, metamorphogenic-hydrothermal, plutonogenic and volcanogenic-hydrothermal genesis have been marked out within the Middle Dnipro megablock [1].

Purpose is to substantiate the formation conditions, distribution patterns and metallogenic specialization of low-temperature metasomatites of the Middle Dnipro megablock of the Ukrainian Shield.

The group of low-temperature metasomatites of the Middle Dnipro megablock unites three main formations: epidote-chlorite-quartz-albite (propylites), sericite-carbonate (listvenites and beresites), and albite-carbonate (eisites).

Epidote-chlorite-quartz-albite formation (propylites) is one of the most widespread in the Middle Dnipro megablock.

These formations are described in the Surska, Verkhivtsevska, Chortomlykska, Bilozerska, Konkska and Sofiivska greenstone structures of the Middle Dnipro megablock of the Ukrainian shield.

In accordance with the Petrographic Code of Ukraine (1999), propylites belong to low-temperature formations (t° below 350 °C) of the subclass of acid metasomatites (pH = 3–7) [2]. The most stable mineral paragenesis of propylitization

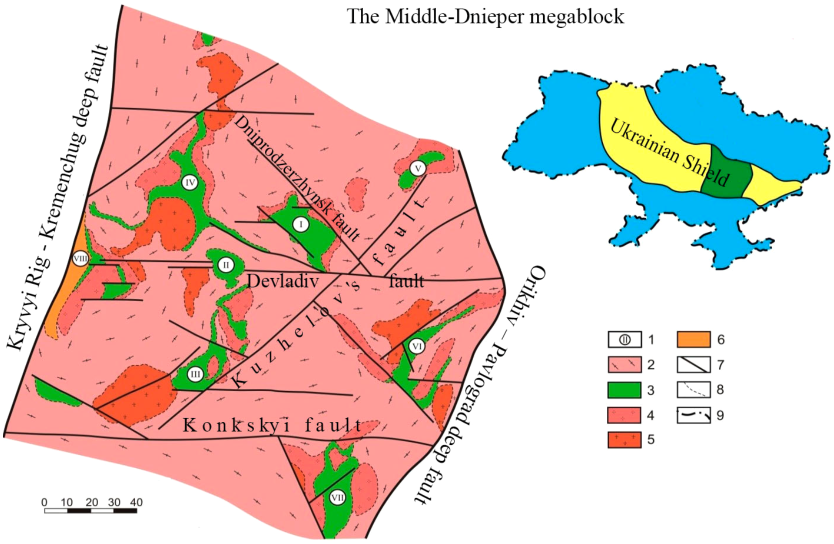

Fig. 1. Geological scheme of the Middle Dnipro mega-block ([1] *as amended and supplemented by V. V. Sukach & L. V. Isakov*):

1 – numbers in circles – greenstone structures: I – Surska, II – Sofiyivska, III – Chortomlytska, IV – Verkhivtsevska, V – Deryzuvatska, VI – Konkska, VII – Bilozerska, VIII – Kryvyi Rih; 2 – the formation of Aulska structural-facial complex (SFC); 3 – greenstone rocks of the Middle Dnipro SFC; 4 – plagiogranites of the surska complex; 5 – post-greenstone two-feldspar granites; 6 – metasedimentary formations; 7 – faults; 8 – geological boundaries; 9 – state border

zones is represented by a combination of epidote + quartz + + chlorite + albite. Relatively permanent mineral components of propylites are potassium hydromica, pyrite, calcite, actinolite. Propylitization is usually followed by sericitization, kaolinization, and silicification, and then ore deposition is followed. In contrast to the processes of greenstone regional metamorphism, propylitization is genetically associated with acid leaching of rocks and ore deposition, the development of potassium metasomatism, and the absence of a transition from propylitization products to ones of a higher degree of metamorphism (amphibolite facies). Hydrothermal solutions participating in the propylitization process contain carbon dioxide and sulfur in significant amounts and are formed by mixing postmagmatic solutions in the stage of ascending acidity with flows of vadose waters. The propylitization process is characterized by the transformation of mafic minerals into chlorite, epidote, and calcite with simultaneous albitization (or adularization) of plagioclase. The source rocks undergoing propylitization are mainly represented by acidic or intermediate effusive rocks and their tuffs. Propylites are found within the Middle Dnipro megablock in the Sofiivska and Bilozerska GSSs.

The propylites actually include metasomatites consisting of quartz (25–35 %), epidote and zoisite (30–40 %), carbonate and albite (up to 10 %), admixtures of actinolite, chlorite, leucoxene (up to 10 %), as well as residual minerals – blue-green hornblende, biotite and ilmenite (up to 10 %) (Fig. 2). The propylitized formations also include metabasites with the following composition: actinolytic hornblende – 25–30 %, zoisite and epidote – 30–40 %, albite – 10 %, carbonate – 10 %, chlorite – 5–10 %, chlorite – 5–10 %, biotite, sulfides, ilmenite, leucoxene (together – 5–10 %).

Monakhov V. S. (1986) studied propylites in the Surska GSS in detail. A thorough description of such formations is given on the example of propylitization sites in the Surska GSS (eastern flank of the structure). Within these areas, in the zone of development of dark green, weakly epidotized plagioclase-hornblende amphibolites, thin zones of carbonate-quartz epidosites are observed, with which quartz, carbonate-quartz with dissemination of sulfides, bunches and veinlets are spatially associated. Zones of quartz epidosites are bordered by carbonate-quartz zones, and then transition zones of epidote-hornblende, albite-epidote-hornblende composition are observed.

When comparing the chemical composition of the initial amphibolites with the propylitization products (quartz epidosites), it was found that in the metasomatites of the inner zones there is an increase in the content of calcium, ferric iron, alumina and a decrease in the concentrations of alkalis, ferrous iron, magnesium and, less often, silicon. These data probably indicate a weakly alkaline reaction of metasomatizing solutions, gradually deoxidizing as the degree of metasomatic processing of rocks increases, and their relatively high oxidizing ability.

In the Verkhivtsevska GSS, propylites are mainly products of transformation of volcanic rocks of mafic composition. The most stable newly formed mineral paragenesis is quartz + albite + epidote + carbonate + chlorite. Propylitization is confined to weak tectonic areas in volcanic strata of mafic composition. The propylitization process in the Verkhivtsevska GSS is characterized by the concentrations of copper, cobalt, nickel, and gold.

Within the Konkska GSS, propylitization processes are exposed in the southern section of the Konkskyi region. The propylitization process took place under the influence of calcium-magnesian-silicate metasomatism, which led to the formation of concentrations of cobalt and gold.

Within the Sofiivska GSS, the mineral composition of propylites is represented by the paragenesis hornblende + albite + epidote + actinolite + chlorite. The thickness of the propylitization zones is 1–3 m. The ratio of minerals is as follows (in %): brown hornblende (relics) – 10–12, dark green hornblende – 5–10, amphibole of the tremolite-actinolite series – 15–40, main plagioclase – 20–30, albite – 2–3, epidote – up to 15,

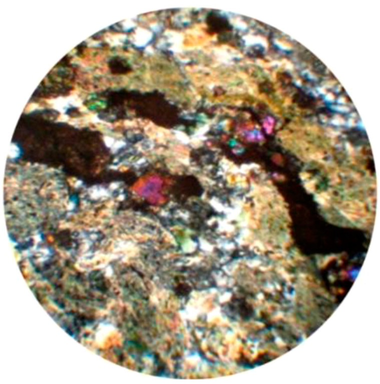

Fig. 2. Epydot-chlorite-albite propyllite. 90x zoom. Cross-polarized light

quartz – 40, chlorite – 2–40, biotite, garnet – single grains. Accessory minerals are represented by apatite, sphene, leucoxenized ilmenite, and zircon. Ore minerals are represented by pyrite, chalcopyrite, pyrrhotite, and magnetite. The source rocks are represented by apogabbro amphibolites and gabbronorites. The formation of low-temperature propylites of this type was facilitated by metamorphic and metasomatic processes, as a result of which, at the initial stage of transformation, pyroxene and hornblende of unaltered gabbro and gabbronorites underwent uralization with the formation of amphibole of the tremolite-actinolite series. Then, the formation of blue-green hornblende occurred, bordering the relics of primary brown and uralized hornblende. The basic plagioclase was deoxidized to form albite along the grain periphery and along cleavage cracks. The removal of calcium contributed to the formation of epidote and carbonate. Thus, the original gabbros and gabbronorites were transformed into propylitized amphibolites.

When comparing the chemical analyses of propylites, amphibolites and gabbro-amphibolites of the Sofiivska GSS, a decrease in the content of SiO_2 and CaO was found at a rather high content of Fe_2O_3 + FeO, MgO, CO_2, as well as impurity elements – Cu, Au. Thus, it is likely that when amphibolite and gabbro-amphibolite were exposed to carbonic solutions containing sulfur and chlorine, a redistribution of elements occurred, in which calcium was removed from hornblende, pyroxenes, and plagioclases with its redeposition in the form of carbonate and epidote. Hornblende became more magnesian and less ferrous and was transformed into actinolite and chlorite. The released iron was concentrated in the form of magnetite. Sulfur input led to the formation of pyrite and chalcopyrite. In addition, plagioclase was deanortized with the formation of oligoclase-albite varieties. In the zone of contact of greenstone strata with granitoids, occurrences of propylitization were also traced. They are characterized by the development of zones of silicification, chloritization, epidotization, feldsparization of amphibolites and gabbro-amphibolites. In such zones, sulfide mineralization is not found, but recrystallization and enlargement of amphibole crystals, the appearance of new mineral phases are observed. At the same time, the preservation of relict gabbro structures is noted. In such zones of activation, depending on the predominant type of process, the following types of rocks are observed:

1) epidote-hornblende-albite (%): albite – 30, hornblende – 25, epidote – 15, chlorite – 6, biotite, apatite, titanomagnetite – single grains;

2) epidote-hornblende-biotite-quartz-chlorite (%): epidote – 8, hornblende – 7–15, biotite – 10–25, quartz – 20–30, plagioclase – 30–40, chlorite – 3, apatite – single grains, magnetite – single grains;

3) chlorite-epidote-quartz (%): quartz – 20–75, epidote – 7–20, chlorite – 10–60, sphene – up to 10, – drill hole 824, depth 148.0 m and 160.4 m;

4) epidote-quartz (%): quartz – 45–85, epidote – 15–55.

Occurrences of epidosites are spatially associated with these zones. The mineral composition of epidosites is represented by epidote (up to 50 %), hornblende (up to 45 %), quartz (7–10 %), chlorite and leucoxene – single grains. Sometimes there is an increase in the content of epidote to 95 %. In addition to epidote, such zones contain albite, quartz, and hematite (up to 15 %).

In the gabbro-amphibolites of the Sofiivska GSS, the propylitization zones are spatially associated with zones of shear, sheeted zones, crushing and fracturing zones with hydrothermal-secretory occurrences of silicification and feldsparization. The increased sulfide content in propylitization zones, spatial coincidence with quartz and quartz-feldspar veins (including those containing gold ore mineralization), and connection with fault zones within the Sofiiivska GSS suggests that propylitization is a pre-ore hydrothermal process and, at the same time, there is a genetic connection between propylization process and acid leaching.

Metasomatites of the sericite-carbonate formation (listvenites and beresites). Metasomatites of this formation type are the most studied formations both in the history of studies of metasomatic processes and in the Middle Dnipro megablock. They were first observed and described as aposerpentinite quartz-carbonate rocks (listvenite) and apogranite quartz-carbonate-sericite (beresite).

Currently, by ***listvenitization*** is meant the process of transformation of serpentinite, mafic and intermediate rocks, as well as tuffs, calcareous shales, sandstones, conglomerates and carbonate rocks into listvenites under the influence of acidic, carbonic, hydrogen sulfide-containing solutions as a result of hydrothermal auto- and allometamorphic processes [3].

Listvenite is the carbonate rock (breinerite, magnesite) with the quartz composition and an admixture of talc, chlorite, epidote, actinolite, fuchsite, magnetite, rutile, actinolite.

The main difference between listvenite and beresite is the presence of carbonate. According to the Petrographic Code of Ukraine (1999), listvenites belong to the subclass of acidic metasomatites (pH = 3–7) of the group of low-temperature metasomatites (the formation temperature is below 350 °C).

Beresites are hydrothermally altered vein rocks consisting of quartz and sericite with an admixture of pyrite and rutile. Formed due to the transformation of acidic aluminosilicate rocks, as well as secondary quartzites, greisens and propylites, refer to the products of low-temperature metasomatism and arise during the transition of an alkaline medium of propylite formation to an acidic medium – secondary quartzites. The leading mobile components of the listvenitization and beresitization processes are K^+, CO_2, H_2S.

Within the Middle Dnipro megablock, in addition to the listvenite and beresites, there are metasomatites of a mixed type: listvenite-beresite and listvenite-propylite.

Listvenite-beresites are rocks consisting of carbonate, chlorite, sericite, albite, talc and quartz with an admixture of pyrite, rutile, and magnetite. They rarely contain biotite, chalcopyrite and ilmenite. Thus, mineral assemblages of listvenites and beresites represent the composition of such metasomatites. The formation of this type of metasomatites can be explained by the multistage influx of hydrothermal solutions of various compositions into joint weak tectonic zones.

Listvenite-propylites are rocks of carbonate-quartz composition with zoisite-clinozoisite and admixture of chlorite, biotite and ore minerals. Regarding the combined listvenite-propylite metasomatites, it should be noted that a number of researchers refer the listvenite to the advanced propylite facies. This allows us to consider the origin of such metasomatites as a completely natural phenomenon.

In the Middle Dnipro megablock, metasomatites of the sericite-carbonate formation are found in almost all greenstone structures and often accompany gold ore occurrences.

Within the Bilozerska GSS of the Middle Dnipro megablock, listvenites are one of the most common metasomatic formations, which is confirmed by their development over serpentinites, metabasites, and even some varieties of ferruginous quartzites and rich magnetite ores. It has now been reliably established that the listvenitization process was most intensely revealed in serpentinites and metabasites in the Western section of the Bilozerska GSS, as well as within the sill of serpentinites with gabbro-dolerite dikes of the Pivdenno-Bilozerske and Pereverzivske iron ore deposits. The main form of structural control of listvenites is faults and schistosity zones, and interboudinaged reduced thickness of ferruginous quartzites in the Pereverzivska flexure area is for rich talc-magnesite ores.

The composition of listvenites and associated alterations depends on the composition of the source rocks. Within the Bilozerska GSS, listvenized metabasites are represented by zoisite-quartz-carbonate, chlorite-quartz-carbonate formations with admixtures of amphibole, biotite (relics), leucoxene, sulfides, ilmenite (with leucoxene margins). In this case, rocks close to the listvenite have the following composition: quartz – 20–25 %, carbonate – 30–40 %, chlorite – 5–15 %, zoisite-clinozoisite – 5–10 %, hornblende – 5–10 %, biotite – 3–5 %, albite – up to 5 %, sulfides – up to 5 %, rutile – 2 %.

Listvenized rocks of mafic composition show the following mineral associations: hornblende of two generations – 40–45 %, chlorite – 10 %, carbonate – 10–20 %, quartz – 10–20 %, zoisite – 5–10 %, leucoxene, ilmenite, rutile, apatite (up to 5 %).

The listvenitization of ultramafic rocks, revealed in the serpentinite of the Bilozerska GSS, is represented by intensely talcose and carbonatized serpentinites with an admixture of chlorite and ore minerals. The mineral composition of these rocks is as follows: talc – 15–35 %, carbonate – 20–40 %, tremolite-actinolite – 5–10 %, serpentine (antigorite, lizardite) – 30–40 %, chlorite – 10–15 %, magnetite, chrome spinel – up to 2 %.

Listvenites include talc-carbonate rocks with serpentinite relics. The main carbonate is magnesite; calcite is found in the veinlets. Ore minerals are mainly inherited from the source rocks. At the same time, almost complete replacement of chromespinelide with newly formed magnetite with the formation of limbate, sheath-like, "remnants of replacement" structures is characteristic. The quartz zone of listvenites is usually absent in ultramafic rocks, but in isolated anomalies it is presented in the form of quartz veinlets in listvenite. Tremolite schists are spatially conjugated with serpentinites; tourmaline occurs in isolated cases.

Along with the characterized metasomatites, there are frequent formations of the combined type, which can be called listvenite-propylites in composition. For example, carbonate-quartz rocks with veins of biotite-zoisite composition. Their texture is banded, the mineral composition is combined: quartz – 40–45 %, carbonate – 20–25 %, zoisite – 10–15 %, ilmenite, rutile, leucoxene, pyrite (3–5 %).

Changes in the chemical composition are determined by the intense input of magnesium and carbon dioxide, and silicic acid in the silicification zone. This led to a close to neutral reaction of the medium with pH = 6–8 and the formation temperature at the level of 200 °C.

Beresites within the Bilozerska GSS are relatively rare metasomatites that were formed in zones of crushing and schistosity of acidic metavolcanics, partly also of metaterrigenous rocks. In the zones of beresitization, massive metavolcanics with a porphyry structure, composed of tabular phenocrysts of albite-oligoclase and rounded quartz (10–30 % of the volume of rocks), which are surrounded by the micro-grained mass of quartz-albite-chlorite-carbonate composition with an admixture of ore minerals, acquire the foliaceous structure and preform into fine-flaked quartz-sericite schists with a relict-porphyry structure. Sericite in them is often composed in lenticular aggregates subconcordant with schistosity. At the current its massive texture, sericite develops in the form of a fine net of veinlets, sometimes forming a lattice pattern of beresitization, due to the mutually orthogonal arrangement of sericite aggregates (Fig. 3). Scattered dissemination of pyrite grains (1–3 %) is present almost everywhere in beresites. Listvenite-beresites are often spatially combined with beresites, in which, in addition to quartz, sericite, and pyrite, carbonate appears in large quantities.

In terrigenous rocks, especially in phyllitic schists, beresitization is poorly noticeable due to the generality of their mineral composition with beresites. However, its presence can be assumed by the lightening of the gray color of the schists and the appearance of an admixture of a fine-flaked talc-like mineral (presumably pyrophyllite).

This phenomenon is most clearly presented in the zones of rock alteration of black schists, which in the zones of transformations acquire an ash-gray, almost white color due to the complete oxidation of an admixture of organic matter.

In addition to the alterations described above, the sericitization of cement in schistous quartz metasandstones of the Eastern section of the structure should also be attributed to beresitization in the Bilozerska GSS. The detrital part in them is up to 75 % of the rock volume and is represented by semi-rounded and rounded quartz grains, 0.5–0.8 mm in diameter. Pore cement occupies 25 % of the volume of the rock, respectively, and consists of sericite, quartz and chlorite with an admixture of ore minerals and zircon. It is characteristic that newly formed cement minerals have an "oriented" appearance due to the arrangement of sericite aggregates according to schistosity. The main changes in rocks are caused by active behavior and the addition of silicic acid and hydrogen sulfide with an insignificant participation of carbon dioxide, which determined a close to neutral, but definitely acidic reaction of the medium with pH = 6–7, with a slight decrease in temperature compared to listvenitization (about 200 °C).

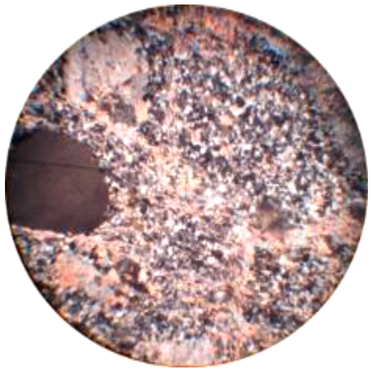

Fig. 3. Listvenite-berezite through rhyolite. 90x zoom. Cross-polarized light

Within the Verkhivtsevska GSS, the listvenitization process is shown up mainly in ultramafic rocks, less often in phyllites overlying ultramafic rocks and in rocks of mafic composition.

Listvenitization occurrences are confined to the upper horizons of ultramafic strata, where listvenites proper are formed, consisting of quartz, carbonate (breinerite) and micas (talc, fuchsite).

Ankerite, quartz, talc, chlorite, biotite, sericite, albite, and sulfide minerals also represent the mineral composition of the listvenites through ultrabasites.

The most typical areas of listvenitization occurrences within the Verkhivtsevska GSS are folded areas of the upper horizons of ultramafic strata. At the same time, the bodies of listvenites are confined to the crest parts of the secondary folds, to deep faults and have a thickness of 1–30 m with a length of 100–200 m. The richest zones of sulfide mineralization have a thickness of up to 1 m with a nickel content of 0.6–0.9 %, cobalt – 0.1–0.2 %, copper – 0.3 %, zinc – 0.1 %, gold – 0.3–1 g/t.

As a result of listvenitization of phyllites, albite-quartz-fuchsite-ankerite and chlorite-biotite-ankerite-albite-quartz varieties of rocks with pyrrhotite and pyrite-chalcopyrite mineralization are formed. Listvenites, formed by replacing mafic rocks, consist of quartz, dolomite, chlorite, sericite, and pyrite.

Beresites in the Verkhivtsevska GSS are developed mainly through quartz keratophyres and, less often, through granites. According to mineral composition, these are quartz-sericite-carbonate rocks with an admixture of pyrite, albite, chlorite, and biotite. Sericite was formed when silicates of the source rock were replaced.

The geochemical difference between the beresites of the Verkhivtsevska structure and listvenites is that the listvenites, in contrast to the beresites, contain nickel and cobalt, and such ore mineralization has not been found in the beresites. In addition, listvenites contain talc and fuchsite, while beresites contain sericite [3].

Beresites, replacing keratophyres, are mainly confined to deep faults. The process of beresitization of keratophyres of the Verkhivtsevska GSS is characterized by a high mobility of components – the subtraction of silicon, the addition of iron and sulfur that make up sulfides, the addition of carbon, magnesium, calcium and carbon dioxide, as well as an increase in the content of potassium, which is traced in sericite and potassium feldspar.

Beresites contain ore mineralization (up to 10 %), represented by pyrite, chalcopyrite, magnetite, as well as galena found in the composition of feldspar-carbonate-quartz veinlets intersecting the beresites.

Structurally, the occurrences of beresites are confined to contacts of lithological varieties of rocks, contacts of sedimentary-volcanogenic strata with granitoids, as well as to faults, cataclase sites, fractured, shear, and sheeted zones.

In the Surska GSS, listvenite-beresites have been revealed through mafic, intermediate and felsic rocks, ferruginous quartzites and paraschists. The source rocks of mafic and intermediate composition belong to the spilite-keratophyric formation and are represented by apodiabases, apoporphyrites, their tuffs, and tuff schists. The zones of listvenite-beresitization of these rocks are spatially associated with occurrences of epidotization and propylitization. At the same time, a clear zoning was established according to the degree of metasomatic transformation of the source rocks and the composition of newly formed minerals in the listvenite-beresitization process (V.S. Monakhov, 1986):

1) the outer zone of metasomatism characterized by a change in the association of relict epidote + chlorite (pennine-clinochlore) + calcite + magnetite + biotite to mineral paragenesis – ankerite + ferruginous chlorite at the current magnetite and the complete disappearance of biotite and epidote;

2) the middle zone characterized by the development of a newly formed mineral paragenesis ferrous chlorite + ankerite + pyrite + sericite;

3) the inner zone – the main newly formed minerals are represented by the paragenesis of ankerite + sericite + pyrite + + quartz. It should be noted that metacrystals of pyrite, with the general development of cubic forms in the inner zone, are modified by the faces of the octahedron, rhombic dodecahedron, and pentagondodecahedron.

Similar changes in the morphology of pyrite crystals in different zones of listvenite-beresitization are described in a number of works [4, 5]. When studying typomorphic features of pyrites from gold deposits, A.F. Korobeynikov found that the most informative features of pyrites are crystal morphology, chemical composition and thermoelectric properties of pyrites. At the same time, the zonal distribution of morphological types of pyrite crystals in the space of endogenous deposits is distinguished. Towards the ore bodies in metasomatites and ore columns, the variety of crystals increases due to the appearance on them of weakly developed facets (111), (210), (321), (211), i.e. the crystallomorphology of pyrite in ore bodies is sharply complicated.

In the Surska GSS, according to V.S. Monakhov, and in the Bilozerska and Konkska GSS, according to the authors' observations, listvenite-beresites with a peculiar, lattice pattern of sericitization, developed through rocks of felsic composition, were established. Initial felsic volcanites are represented by keratophyres, feldspar gelleflints through quartz apoporphyres, felsite porphyries, apodacites and their tuffs. The composition of phenocrysts is represented by polysynthetically twinned tabular grains of plagioclase (oligoclase-albite) and quartz (round and idiomorphic grains, often with melted edges). The size of the phenocrysts is from 0.3 mm to 1–2 mm (Fig. 4). The main substance of the rock is represented by a hornfels-like mass of quartz-albite composition. The grain size of the main fine-grained mass is 0.01 mm or less.

In zones of metasomatic transformations, mashing of albite phenocrysts is observed with their transformation into a fine-grained aggregate of quartz-albite composition. Quartz phenocrysts are more resistant to destruction and are preserved in relict porphyry segregations. In massive varieties of listvenite-beresite, sericite develops in mutually perpendicular directions in the form of a peculiar lattice along the main rock-forming substance of quartz-albite composition. Along with newly formed sericite, the presence of calcite and pyrite is noted. The described type of alteration is very widespread, often covering the entire volume of substituted felsic rocks and refers to alterations characteristic of external beresitization halos.

In the transitional middle zone, albite relics are preserved, while in the inner zone, albite and chlorite are completely replaced by sericite, ankerite, and pyrite. The development of quartz of two generations is observed: initial, rock-forming and leached, redeposited in pressure shadows around carbonate and pyrite. Thus, the paragenesis of sericite + ankerite + + pyrite + quartz (of two generations) can be considered typomorphic for the inner zones of listvenite-beresite after felsic rocks in a number of GSS of the Middle Dnipro megablock (Surska, Konkska, and Bilozerska ones).

Metasomatites of the listvenite and beresite formations are widespread in low-temperature deposits of Au, Ag, As, Hg, Pb, Zn, formed at the final stages of the formation of fold belts and (or) stages of tectonomagmatic activation. This type of alteration is associated with tonalite-granodiorite or gabbro-granite formations, granite-porphyry dikes, and felsic subvolcanic formations. The temperature of the hydrothermal solutions averaged 250–300 °C, the pressure 0.6–1.8 kbar, the solutions had a chloride composition and were enriched with CO_2, K, S [3]. In general, the process of beresitization-listvenitization is characterized by the addition of CO_2, K, S, the subtraction of Na (for the muscovite subformation), and sometimes silicon, the general differentiation of Al, Ca, Mg, Cr and a number of other elements in the volume of the ore-metasomatic system.

The depth of formation of ore deposits associated with zones of beresitization-listvenitization is 2.5–4 km.

The formation of metasomatic halos occurred in two stages: 1) acid leaching; 2) deposition of leached elements in sulfide form.

Dawson K.R. first described metasomatites of the albite-carbonate formation (eisites) in 1956 at the uranium deposits Ace and Rae (Saskatchewan province, Canada) [6, 7]. Later, metasomatites of this formation type were discovered and studied in Northern Kazakhstan associated with the occurrence of uranium ores, in Western Uzbekistan associated with the occurrence of non-ferrous metals [8]. In the Middle Dnipro megablock, metasomatites of the eisite formation were found within the Bilozerska GSS (Ruzina, M.V., 2008).

The eisite formation combines metasomatic rocks of the low-temperature stage of the postmagmatic process associated with granitoids of moderate depths with the composition: albite, quartz, carbonate, and apatite. In contrast to the high-temperature metasomatites of the albitite formation, there are no alkaline amphiboles and pyroxenes in the eisites, and a stable albite + carbonate association is noted.

There is a subdivision of eisites into two facies: albite-carbonate and albite-chlorite. These metasomatites develop over metariolites, granites, diabases, sandstones and limestones. The most important, very characteristic sign of eysitization is the appearance of a red, brownish-red color due to the presence of finely dispersed hematite, and in some zones – an apple-green color due to the presence of hydromica and chlorite.

Within the Middle Dnipro megablock, metasomatites of the eisite formation were established in the Bilozerska GSS

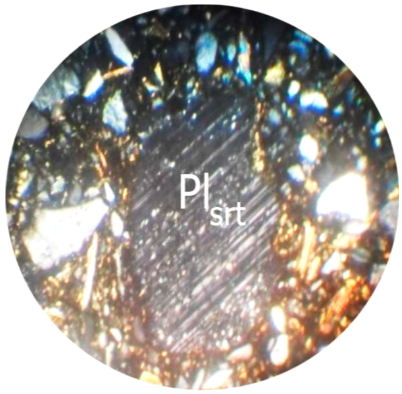

Fig. 4. Listvenite-berezite through rhyolite with relict porphyry structure of quartz-plagioclase phenocrysts. Bilozerska GSS. 90x zoom. Cross-polarized light

from metaryodacites. The following combinations represent newly formed mineral parageneses: quartz + carbonate + albite, quartz + carbonate + albite + hematite; quartz + carbonate + albite + hydromica, sometimes pyrite and sericite are present. The main difference between the metasomatites of this formation from similar listvenite-beresites is the presence of albite, hematite, and hydromica in their composition. These metasomatites are well detected in the field due to the cherry color characteristic of the most transformed rocks, due to the presence of finely dispersed hematite.

Eisites complete the metasomatic process and are formed later than greisens and beresites, and, thus, can serve as a kind of indicator during investigation the sequence of formation of metasomatites.

In relation to the acidization process summarizing the above, it should be noted that the chemistry of this process as a whole is characterized by the subtraction of potassium and the addition of sodium, calcium, carbon dioxide. The stability of the association of calcite and albite makes it possible to classify them as low-temperature formations.

Low-temperature metasomatites are distributed mainly within the greenstone structures of the Middle Dnipro megablock. The ore content of the metasomatic formations of the low-temperature group is unequal.

In the Sofiivska GSS, sulfide mineralization is confined to the areas of propylitization of gabbro-amphibolites and apodolerite amphibolites. Propylites are characterized by pyrrhotite-pyrite (sometimes with sphalerite) mineralization. Pyrrhotite is the predominant ore mineral (Fig. 5), forming inclusions of irregular-shaped grains, ranging in size from 0.03 × 0.01 to 0.3 × 0.6 mm. Sometimes vein precipitates are noted.

Pyrrhotite contains an admixture of Ni and Co in an amount of up to 0.2 %, and, sometimes, insignificant amounts of Cu and Se.

Pyrite is less common in the propylitized rocks of the Sofiivska GSS and occurs in the form of independent segregations of xenomorphic grains with a size of 0.09 × 0.1–0.45 × 0.9 mm. It contains impurities of Co (up to 0.7 %) and, rarely, Se. Chalcopyrite, melonite, magnetite, titanomagnetite are observed as accompanying minerals in the propylitization zones of greenstone rocks of the Sofiivska GSS.

Within the Verkhivtsevska GSS, the propylitization process is represented by two types of end products: propylites and prazinites [9]. The propylites of the Verkhivtsevo region are mainly confined to weak tectonic zones in volcanic strata of the mafic composition. This process, like listvenitization, leads to the release of ore components from silicates with subsequent concentration in the sulfide form under favorable structural and lithological conditions. Cobalt-nickel-copper mineralization is spatially and genetically associated with the propylitization zones in the Verkhivtsevska GSS. Such mineralization with a high cobalt content is confined to the stratum of greenschists, occurring among talc-carbonate rocks. The cobalt and nickel contained in these zones are likely to have come from ultramafic rocks. The process of propylitization in general is characterized by more significant concentrations of copper, since in the mafic rocks its content significantly exceeds the content of cobalt. Along with the concentration of cobalt, nickel and copper, in the process of propylitization, the formation of increased concentrations of gold occurs.

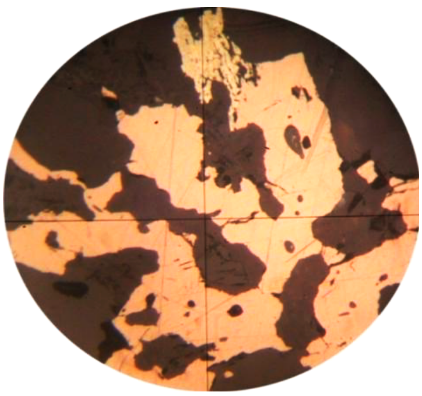

Fig. 5. Metasomatic dissemination of pyrrhotite and pyrite in propylite through gabbro-dolerite. Reflected light, nicols ||, 90x zoom. Sofiivska GSS

Ore mineralization is represented by cobaltine, cobalt pyrite, chalcopyrite, sphalerite, pyrrhotite and pyrite, which form scattered dissemination, veinlets and sulphide interlayers.

In the Bilozerska GSS, the propylitization process occurred in the stratum of metabasites of the Western site. In the propylitized metabasites, low complex anomalies of precious metals were recorded. In the Surska GSS, areas of the propylitization process are associated with increased concentrations of molybdenum. Molybdenum mineralization is confined to quartz veins and veinlets, which occupy a central place in propylitization halos.

Molybdenum mineralization of the Vasylivska site of the Surska GSS was found in the zone of the eastern contact of amphibolites with framing granitoids. The thickness of the quartz zones containing molybdenum mineralization is not more than 1 cm. According to the results of V. S. Monakhov's research, it has been established that the formation of molybdenum-bearing epidosites of the Vasylivskyi area, like ordinary propylites, is caused by moderately alkaline solutions with a relatively high oxidizing potential, but proceeding in the stage decreasing alkalinity. The molybdenum-bearing solutions are probably derivatives of moderately acidic granitoid magmas.

In Konkska GSS, increased concentrations of cobalt and gold are spatially associated with propylitization zones. There is also a spatial combination of areas of propylitization, silicification and carbonatization.

When studying ore deposits of different composition, the formation of which is associated with different stages of tectono-magmatic and metallogenic development of mobile regions, it was found that the endogenous concentration of metals mainly occurs after regional propylitization. Ore bodies are found in already propylitized rocks or in metasomatites associated with them, and mineralization is accompanied by wallrock alteration of pre-ore hydrothermally altered rocks. In general, this fact makes it possible to classify propylites as pre-ore metasomatites.

However, it has been established that a number of metals (iron, copper) are capable of forming increased concentrations precisely in the process of propylitization. In this regard, endogenous ore concentrations are subdivided into two types: epimetasomatic (epipropylitic) and synmetasomatic (synchronous with the propylitization process).

Metasomatites of the listvenite formation are mainly characterized by gold ore specialization. As, Co, Ni, Hg are present as accompanying ore elements. At a number of deposits in Morocco, Saudi Arabia, and France, the gold content in the zones of listvenization of hyperbasites is 5–20 times higher than in the associated ultramafic rocks. Mineable grades range from 1 to 10 g/t. The highest concentrations are observed in pyritization zones, with which Co-As mineralization is spatially associated. Listvenite zones are confined to large faults, with which quartz veins are also combined. Listvenitization of ultramafic rocks, like serpentinization, was the result of medium-low-temperature hydrothermal alteration with Na and Cl brines. Gold was leached from amorphous minerals of serpentinized ultramafic rocks. During the development of the hydrothermal system, gold was transported by fluids enriched in CO_2-S-As-Cl-Na-K-B along the rock contacts and was deposited by quartz, sulfides, arsenides when the fluids were reduced under alkalinity conditions of carbonated rocks. Listvenization zones in these regions are considered as objects of prospecting for gold mineralization.

Listvenites are widespread in almost all greenstone structures of the Middle Dnipro megablock. The most studied in terms of composition and ore content are currently listvenites based on ultramafic rocks. In the Surska GSS, ultramafic listvenites are mainly represented by two varieties: quartz-actinolite and quartz-carbonate. The typical ore minerals of quartz-carbonate listvenites are pyrite and chalcopyrite. More common are listvenites with gersdorfite-cobaltine mineralization, confined to ultramafic strata.

Copper concentrations of 0.30–1.2 % were found in listvenites of all types. The zones of listvenite of ultramafic massifs are spatially associated with areas of occurrences of sulfuric acid metasomatism, leading to dolomitization of strata. The highest concentrations of nickel and cobalt were found within such zones.

Along with the formation of their own mineral forms, nickel and cobalt in the form of impurities were found in the composition of magnetite, pyrite, pyrrhotite and chalcopyrite. Their amount in listvenite pyrite reaches 0.4 % (according to microspectral laser analysis).

In the listvenites of the ultrabasites of the Verkhivtsevska GSS, gold mineralization was found in combination with nickel, cobalt, copper and zinc sulfides. The main types of ore mineralization associated with listvenite zones are represented by three main varieties:

1) nickel-cobalt mineralization with gold, copper and zinc in listvenite along ultramafic rocks;

2) arsenic-antimony-zinc mineralization in listvenite-like rocks;

3) mineralization of copper and gold in listvenites and potassium metasomatites (listvenites of the external contact zone).

The first type of ore mineralization is concentrated within the upper horizons of ultramafic rocks of the Varvarovsky rock mass, altered during the listvenitization (the so-called listvenites of internal contact). Ore minerals are mainly observed in the form of scattered dissemination, sometimes there are veinlets and sulphide interlayers.

The most typical ore minerals are cobalt- and nickel-containing pyrites, pyrrhotite, gersdorfite, pentlandite, chalcopyrite, sphalerite, millerite, cobaltite, berthierite, and ulmanite (Stulchikov V.A., 1991). The accompanying mineralization is represented by gold and platinum. The association of nickel-cobalt parageneses with gold is explained by the superposition of a later gold ore mineralization on an early nickel-cobalt one.

The arsenic-antimony-zinc association represents the second type of ore mineralization associated with the listvenites of the Verkhivtsevska GSS. This occurrence was found in a deep fault zone (western contact of the Varvarovsky ultramafic deposit) and is confined to metasomatically altered rocks. Ore minerals include arsenopyrite, berthierite, sphalerite, chalcopyrite, pyrrhotite, pyrite, galena, and boulangerite.

The third type of ore mineralization associated with listvenites and potassium metasomatites (listvenites of the outer contact zone) is represented by occurrences of copper with gold. This type, in contrast to the mineralization of listvenites of the internal contact, is represented by pyrite-pyrrhotite mineralization with an admixture of chalcopyrite, sphalerite and gold, sometimes changing to pyrite-chalcopyrite mineralization.

Results. It was established that the process of listvenitization in ultrabasites of the Verkhivtsevska GSS leads to a concentration of platinum, which is probably associated with the destruction of chromespinelides. As a result of the process, nickel-cobalt with gold, antimony-sulfur-arsenic mineralization of a very complex composition is formed. The main minerals are gersdorfite, corinite, villiamite, and violarite. Zinc-antimony-arsenic mineralization is also associated with the listvenites of the Verkhivtsevska GSS, represented by berthierite, sphalerite, arsenopyrite, corynite, boulangerite, antimonite.

In the Bilozerska GSS, the listvenitization process was occurred within the Western area, where listvenites were found through serpentinites and metabasites of the Konska series, as well as in the sill of serpentinites of the Pivdenno-Bilozerske and Pereverzivske deposits and adjacent sections of the upper shist and iron ore horizons of the Bilozerska series. A large number of precious metal anomalies are associated with the listvenite zones of the Bilozerska GSS. Some varieties of listvenite in serpentinite are of inherent value as talc-magnesite mineral raw materials.

In the Konkska GSS, chromium anomalies have been revealed in talc-carbonate metasomatites and talc-serpentine-magnesite rocks of the Veselyanskyi area. Zones of nickel-cobalt mineralization are found in talc-carbonate rocks within the Central Konkska syncline. Ore mineralization is represented by pyrite, pyrrhotite, chalcopyrite, cobaltine.

Beresites are found in almost all greenstone structures of the Middle Dnipro megablock, showing a stable metallogenic specialization.

As a result of studies on the relationship between systems of deep faults with occurrences and precious metals, it was found that the high ore content of the greenstone structures of the Middle Dnipro region is explained by their combination with the intersection nodes of the faults (Surska, Chortomlytska, Bilozerska, Konkska GSSs), or by overlapping the area of greenstone structures by the most productive subsystems in terms of gold content faults (Verkhivtsevska GSS) [10–12]. Such regulations are explained by the spatial overlapping and repeated activation of faults of different systems, accompanied by the renewal of magmatogenic and metamorphogenic hydrothermal activity, as a result of which polychronous, complex in composition occurrences of rare and precious metals are formed, spatially associated with zones of telescoped metasomatic formations.

At the same time, the composition of metasomatic formations, in particular, the presence of low-temperature metasomatites (listvenites and beresites) practically in all greenstone structures of the Middle Dnipro megablock [12], makes it possible to substantiate a small level of erosional truncation of greenstone structures in accordance with the scheme of ore-metasomatic zoning of gold fields by A. F. Korobeynikov [13–15] (Fig. 6).

Conclusions. Analysis of the ore content of the metasomatic formations of the Middle Dnipro megablock reveals a number of regularities in relation to the connection between metasomatic processes and mineralization:

1. Each metasomatic formation of the group of low-temperature metasomatites of the Middle Dnipro megablock is characterized by a certain metallogenic specialization, which makes it possible to use metasomatites as search criteria for a number of minerals in the Middle Dnipro megablock: propylites – Ni, Co, Cu; listvenites and beresites – Au, Ag, Pb, Zn, Cu; eisites – U, Pb, Zn, amphibole metasomatites – Cu, Au.

2. Telescopic metasomatite formations with a complex composition of mineralization are spatially associated with the intersection nodes of deep faults in the Middle Dnipro megablock. The prospect of deposits of a complex composition rises with an increase in the number of deep faults intersecting at a node, which can acquire the role of an ore cluster, concentrating deposits of precious metals and other minerals of different age and composition, including non-metallic mineral raw materials.

3. Spatial alignment (telescoping) of different types of metasomatic processes in the nodes of deep faults in the Middle Dnipro megablock has a dual meaning for ore formation:

- for some ore formations, it causes the appearance of useful mineralization of a complex composition and contributes to the formation of secondary concentrations of useful components (mineralization of precious metals);

- for other ore formations, it leads to dilution of concentrations and a decrease in the quality of minerals associated with earlier stages of metasomatic processes (replacement of chromite with magnetite and removal of platinoids during serpentinization of ultrabasites, destruction of chrysotile asbestos in the process of epigenetic talcation).

4. Ore bodies are mainly confined to the central (inner) zones of metasomatic halos; the largest ore bodies are accompanied by the most significant alteration halos.

5. The most promising are metasomatites with a full set of zones, including internal ones, since this determines the in-

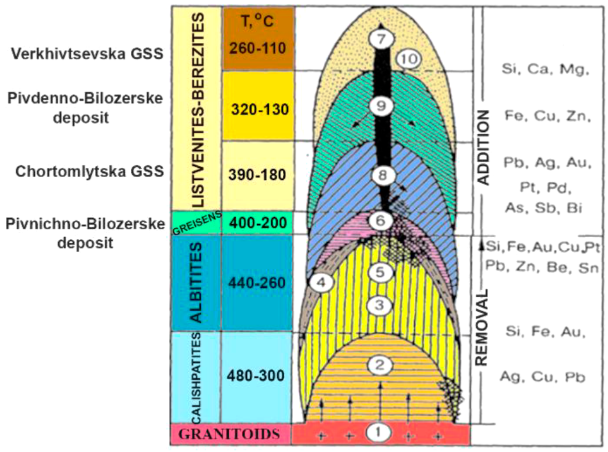

Fig. 6. Distribution of gold mineralization zones of hydrothermal genesis of the Middle Dnipro GSSs in the scheme of ore-metasomatic zonation by A. F. Korobeynikov [14]

tensity and duration of the manifestation of the hydrothermal-metasomatic process.

6. The ore content of metasomatic rocks is associated with the facies composition of the replaced rocks, which determines the nature of mineralization, metallogenic specialization, the scale of occurrence, the mode of occurrence and the prospects for distribution.

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Петрографічний склад і рудоносність низькотемпературних метасоматитів Середньопридніпровського мегаблоку Українського щита

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Мета. На підставі отриманих результатів досліджень обґрунтувати умови формування, закономірності розміщення й металогенічну спеціалізацію низькотемпературних метасоматитів Середньопридніпровського мегаблоку Українського щита.

Методика. Авторами використано комплекс польових і лабораторних методів. Проведені петрографічні, мінераграфічні, петрохімічні дослідження. Проведена інтерпретація результатів хімічного, лазерного мікроспектрального, рентгеноструктурного, сцинтиляційного спектрального, термічного аналізів.

Результати. Виконано узагальнений петрологічний опис низькотемпературних метасоматитів Середньопридніпровського мегаблоку Українського щита з урахуванням складу вихідних порід, характеристики новоутворених мінеральних парагенезисів, металогенічної спеціалізації й закономірностей поширення метасоматичних формацій. Проведено вивчення проявів вертикальної та горизонтальної метасоматичної зональності в межах зеленокам'яних структур Середнього Придніпров'я. Охарактеризовано склад телескопованих метасоматитів, просторово пов'язаних із вузлами перетину глибинних розломів. Визначена металогенічна спеціалізація низькотемпературних метасоматичних формацій та охарактеризовано процес формування рудних концентрацій комплексного складу у вузлах перетину глибинних розломів. За результатами досліджень складу й рудоносності метасоматитов обґрунтовано незначний рівень ерозійного зрізу вертикальних рудно-метасоматичних колон у межах зеленокам'яних структур.

Наукова новизна. Виявлені особливості петрології та рудоносності групи низькотемпературних метасоматичних формацій Середньопридніпровського мегаблоку Українського щита. Обґрунтовано просторовий зв'язок ділянок метасоматозу з системами глибинних розломів, що підтверджує правомірність використання виявлених метасоматичних формацій як геологічних індикаторів зон глибинних розломів. Охарактеризовані особливості рудоносності низькотемпературних метасоматичних формацій Середньопридніпровського мегаблоку. Показано, що з вузлами перетину глибинних розломів просторово пов'язані формації телескопованих метасоматитів із комплексним складом зруденіння.

Практична значимість. Визначена металогенічна спеціалізація низькотемпературних метасоматичних формацій, що може бути використана в якості пошукового критерію різних видів металевих і неметалевих корисних копалин у межах Українського щита.

Ключові слова: *метасоматити, глибинні розломи, формації, петрологія, рудоносність, ерозійний зріз*

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