Peculiarities of the raw material base of the 
Lykhmanivka iron ore region in Kryvyi Rih basin

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Abstract. Lykhmanivka (Inhulets) iron ore district takes the southernmost position in the Kryvyi Rih iron ore basin. In the north, it is bordered by a series of sublatitudinal faults with the Southern Iron Ore District of Krivbas. The productive strata of the area are Lykhmanivka iron ore pay streak, in the southern part of which the Inhulets deposit of magnetite quartzites is located in the zone of closing of Lykhmanivka syncline. However, in addition to them in the area, there are more than 20 types of other minerals, which are mined by-products and can be successfully used in the national economy.

Syngenetic (sedimentation, diagenesis, dynamothermal metamorphism) and epigenetic processes (tectogenesis, metasomatism, hydrothermal processes, hypergenesis), which occurred during the formation of iron ore and host strata, have contributed to the formation of several minerals and rocks, which can be considered as associated complex useful minerals. The relevance of the work is due to the need for detailed research of the localization, formation conditions, directions of use of metallic and nonmetallic minerals of the area, the geological justification for their priority varieties. As a result of these studies, systematization of minerals of the area has been developed, their priority varieties have been identified. Their involvement in mining and processing significantly expands the spectrum of alternative ways of use of minerals and rocks of iron-banded formation, which will contribute to a significant addition to the mineral resource base as in Kryvyi Rih iron ore basin, and in Ukraine as a whole.

1. Introduction

The Kryvyi Rih basin (Dnepropetrovsk region, Ukraine) is a world-famous iron ore basin of high-quality iron ores, located in the central part of the Ukrainian shield, where the Kryvyi Rih structure in the form of a narrow strip more than 100 km long and 0.5 to 18 km wide stretches in a submeridional direction along the border of two heterochronous megablocks of the Ukrainian shield. They are the Inhul megablock (Kirovohrad), composed of the Paleoproterozoic granitoids with inclusions of the Archean, Paleoproterozoic metabasites, metaclastoliths, and the Middle Dnipro megablock, in the structure of which the Mesozoarchean plagiogranitoids predominate, metabasites and metaclastoliths of the Archean and Paleoproterozoic occur in a subordinate quantity \cite{1,2}.

Iron ores have been the main mineral wealth of the Kryvyi Rih basin for more than 140 years of exploitation of its deposits. However, in addition to iron ores, more than 50 types of metal and non-metal minerals occur within the deposits of the Kryvyi Rih basin and the Right-Bank...
magnetic anomalies located nearby, which are simultaneously mined at iron ore deposits and can be successfully used in the national economy. The integrated use of the mineral mass extracted from the depths has become one of the main tasks on the way to increasing the supply of the national economy of Ukraine with mineral raw materials.

The Kryvyi Rih basin is divided into four iron ore regions: Northern (Hannivka), Central (Saksahan), Southern and Lykhmanivka (Inhulets) (figure 1).

Figure 1. Schematic geological map of the Kryvyi Rih structure. **Metamorphic formations.** The Upper Archean: 1 – Konka series. The Lower Proterozoic: 2-5 - Kryvyi Rih series: 2 - Novokrivorizka suite; 3 - Skeliuvatka suite; 4 - Saksahan suite; 5 - Hdantsevka suite. The Middle Proterozoic: (6) Hleiuvatka suite. Igneous formations: (7) granitoids of the Dnipropetrovsk Complex of the Middle Archean; (8) the Upper Proterozoic diabase dikes. Other symbols: 9 - mantle faults; 10 - mantle-crustal and crustal faults; 11 – lines of stratigraphic contacts. Iron ore regions: I - Northern (Hannivka) region; II - Central (Saksahan) region; III - South region; IV - Inhulets (Lykhmanivka) region. Iron ore packs: 1 - Eastern- Hannivka pack; 2 - Western- Hannivka pack; 3 - Distant Western packs; 4 - Saksahan pack; 5 - section of the Kryvyi Rih synclinorium closing; 6 – Lykhmanivka pack. Faults: K-K – Kryvyi Rih-Kremenchuk fault; D-D - Devladovo fault; Dn-Dn - Diagonal fault; S-S - Skeliuvatka fault zone.

The Lykhmanivka iron ore region is part of the Kryvyi Rih iron ore basin, it occupies the southernmost part of the Kryvyi Rih basin. The productive stratum of the region is the Lykhmanivka iron ore pay streak, in the southern part of which, in the closing zone of the Lykhmanivka syncline, the Inhulets deposit of magnetite quartzites is located. To the north
of it, there is a chain of relatively small deposits of high-grade and low-grade hematite and magnetite ores along the entire strike of the Lykhmanivka pay streak. Most of its high-grade ores deposits have been worked out by open pits and underground mines of the former Inhulets and Rakhmanivka mining operations. At present, low-grade magnetite ores (magnetite quartzites), the feedstock for producing iron ore concentrate at the Inhulets Mining and Beneficiation Works, are the main mineral resources of the Lykhmanivka region.

Syngenetic (sedimentation, diagenesis, dynamothermal metamorphism) and epigenetic processes (tectogenesis, metasomatism, hydrothermal processes, hypergenesis) that occurred during the formation of the iron ore and enclosing strata of the region contributed to the formation of a number of minerals and rocks that can be considered as accompanying complex minerals.

2. Methodology
The authors have carried out detailed geological and mineralogical studies of the Kryvyi Rih series and underlying amphibolites and granitoids within the Lykhmanivka iron ore region. As a result of the research, minerals and rocks that can be mined as minerals have been identified. Their resources and technological possibilities of their extraction have been defined.

3. Results
Based on the results of geological, mineralogical and technological studies, the authors have concluded that there are occurrences of gold, platinoids, manganese, bauxites, garnet, muscovite, chlorite, talc, mineral pigments, facing stone, rock for the producing breakstone in the iron ore and host strata of the region. Their formation is associated with manifestations of syngenetic (sedimentation, diagenesis, dynamothermal metamorphism) and epigenetic (tectogenesis, metasomatism, hydrothermal processes, hypergenesis) processes that occurred during the formation of the Lykhmanivka region. A classification of associated minerals has been developed, and their priority types have been identified. According to their mineral and chemical composition, they can be divided into iron ores and metal and non-metal minerals (table 1).

| Table 1. Main and associated minerals of Lykhmanivka iron ore region. |
|------------------|--|--|
| **Metal**        | **Non-metal**                  |
| High-grade iron ores | Talc                      |
| Low-grade iron ores | Garnet                    |
| Gold             | Muscovite-biotite schist      |
| Platinum and platinoids | Granite             |
| Manganese        | Muscovite quartzite and quartz-muscovite schist |
| Bauxites         | Ocher                      |
|                  | Reddle                      |
|                  | Limestone                   |
|                  | Clay                        |
|                  | Loam soil                   |
|                  | Bentonite clay              |
|                  | Gemological and collectable raw materials |
|                  | Waste of beneficiation plants |
3.1. Iron ores

Low-grade hematite ores (hematite quartzites) are a product of post-Paleoproterozoic weathering of magnetite quartzites. Hematite quartzites compose the weathering crust of the ferruginous horizons of the Saksahan suite [3]. Its thickness is variable, within the boundaries of the Inhulets deposit it makes up from 50 to 100 m in the southern part and increases up to more than 450-500 m in the north. The horizontal thickness of the deposit (from east to west) varies within 400-600 m, the strike is 900-1000 m in the north-south direction. The main indicators of hematite quartzites (total iron content, structure, texture of ores) are close to the corresponding indicators of magnetite quartzites. These circumstances, as well as the growing volumes of hematite quartzites extraction from the Earth’s interior, necessitate the search for ways of using them as additional iron ore raw materials. The composition of hematite quartzites is heterogeneous (figure 2).

![Figure 2. Hematite quartzites of the Lykhmanivka iron ore region. a - micaceous hematite-martite quartzite; b - thinly-mediumly-coarsely laminated martite quartzite; c - goethitized dispersed hematite-martite quartzite; d - breccia, cavernous texture of martite-dispersed hematite-dispersed goethite quartzite.](image)

The main reason for it is the manifestation of vertical and horizontal mineralogical zonality. In the vertical section, from top to bottom, the following mineralogical and geochemical zones are distinguished: goethite-martite → martite → magnetite-martite → martite-magnetite → unaltered magnetite quartzites. The horizontal mineralogical zonality of hematite quartzites deposits is due to the fact that the weathering crust succeeds their authigenic mineralogical zonality.
According to the results of preliminary laboratory mineralogical and technological studies, it is possible to obtain iron ore concentrate from hematite quartzites with an iron content of 66.5 to 68.5 mass percent. During the experiments, gravity, magnetic and combined schemes such as magnetic-gravity, magnetic-flotation flowsheets were used.

The high-grade iron ore deposits of the region are considered to be the so-called “lost” ones [1, 2]. During the mining activity of the mines of the former Inhulets mining operations, they were left in situ due to their small size, remoteness from the main deposit. At present, due to the advancement of the faces of the Inhulets open pit to the north, their approach to the leasehold of closed mines, the “lost” deposits have been opened up in the central part of the deposits of hematite quartzites of the fifth and sixth ferruginous horizons. Every year, together with hematite quartzites, high-grade hematite ores of the “lost” deposits of the Inhulets mining operations and the Inhulets open pit are extracted. Due to subsidence and mine workings sloughing, these ores are mixed with host hematite quartzites. Deposits of the Cenozoic martite-brown hematite ores have a total iron content of 50 mass pct. Lenticular and sheet-like ore bodies occur in the basal part of the Cenozoic sedimentary cover.

3.2. Metal minerals

Gold. There are 4 generations of gold within the Lykhmanivka iron ore region [4]. The clastogenic gold of the Paleoproterozoic clastic rocks – metaconglomerates, quartzites, metasandstones, schists of different compositions of the Saksahan, Skeliuvatka and Hlantsevka suites is the most ancient. The size of the segregations is from less than 0.001 to 0.1 mm. The metal content does not exceed 0.2 g/t.

The sedimentation phase is associated with the accumulation of gold in the rocks of the ferruginous horizons of the Saksahan suite. It is the most dispersed, the size of the segregations does not exceed 0.01 mm.

The second generation of gold is associated with metamorphogenic gold of Alpine veins of hematite-quartz, carbonate-biotite-cummingtonite-quartz, pyrite-quartz composition. The size of gold segregations of this generation is more than 0.5 mm, the content is from 0.01 to 0.5 g/t.

The third generation is associated with the processes of post-metamorphic sodium metasomatism. The gold content in metasomatites is 0.01 - 0.3 g/t, at some points it is up to 1 g/t, the size of the segregations is up to 0.5 mm.

The gold of the fourth generation is associated with zones of hydrothermal-metasomatic transformations of rocks of the Kryvyi Rih series and host granitoids. The gold content at some points reaches 6-7 g/t.

Platinum and platinoids are present in the metaultrabasites of the upper subsuite (carbonate-talc horizon) of the Skeliuvatka suite [5]. Platinum, palladium, osmium with a total content of 1 g/t have been identified by atomic absorption analysis in titanium-chromium-vanadium concentrate from talc-bearing schists of the Inhulets deposit.

Manganese. The deposit of manganese ores with a thickness of 0 to 50 cm occurs in the basal part of the sedimentary cover. It is a continuation of the deposits of manganese ores of the Nikopol basin to the west [6] (figure 3).

The content of manganese ranges from 10 to 35 mass pct., the average content is 20 mass pct. According to preliminary data, the resources make up about 20 million tons.

According to the results of mineralogical studies, three typical varieties of the ores of the Nikopol basin are distinguished in the composition of ores. They are oxide ores (manganite-pyrolusite with psilomelane); carbonate-oxide ones (pyrolusite-oligonite with psilomelane) and carbonate ones (oligonite with an admixture of pyrolusite and psilomelane). The content of manganese depends on the mineral composition and ranges from 10 to 35 mass pct., the average one is close to 20 mass pct. According to the results of preliminary laboratory mineralogical and technological studies, it is possible to obtain a concentrate of about 30-32 mass pct. by
crushing, washing and screening. A concentrate of this quality does not meet the requirements of the world market. The presence of the oligonite component in the ores interferes with upgrading of the concentrate and improvement of the quality of manganese in its composition.

The resources of manganese ores, according to preliminary data, are about 20 million tons.

Bauxites. Bauxite deposits occur on weathered crystalline rocks of the ferruginous-siliceous and host formations. The thickness of the layers and lenses is up to 5 m, the strata of the sedimentary Cenozoic cover overlies them. Preliminary and detailed exploration of several bauxite ore deposits of the Shesternya deposit in the Shyroke district has been carried out. The resources are about 50 million tons. The aluminum content is from 20 to 45 mass pct., the average one is 30 mass pct. (figure 4).

Figure 3. Massive pory (a) and impregnated oolitic (b) oxide manganese ore.

Figure 4. The impregnated oolitic (a) and massive porous (b) bauxite.
3.3. **Non-metal minerals**

The upper subsuite of the Skeliuvatka suite is composed of talc-bearing schists. Most researchers consider it to be a product of dynamothermal metamorphism of effusives and tuffs of ultrabasic and basic composition [1]. Talc is the main rock-forming mineral of breunnerite-actinolite-chlorite-talc schists, the content of talc in schists is from 20 to 85 mass pct., on average, it is about 60 mass pct. (figure 5).

![Figure 5. Actinolite-chlorite-talc schist.](image)

The thickness of the stratum varies from 5 to 80 m. The main reason for significant fluctuations in the thickness is the high degree of rock plasticity. The mineral composition depends on the degree of their dynamothermal metamorphism. The content of schist, chlorite, and carbonate decreases in schists, and the content of amphibole increases with the transition from the thermodynamic conditions of the greenschist to the conditions of the epidote-amphibolite facies. This is accompanied by a deterioration in the chemical composition, physical and technical properties of schists.

Approved reserves of talc-containing schists are about 75 million tons, the resources make up 200 million tons.

The main properties of talc, determining the way of its use, are low hardness, eminent cleavage, high heat resistance (melting takes place at a temperature of 1800ºC).

Based on the results of preliminary technological studies, it was established that these schists can be used as raw materials for the manufacture of dry and oil paints, the production of sitall, ceramic bricks, fillers for pesticides and fertilizers, coating of welding electrodes, facing tiles, magnesia cements.

**Garnet** is a rock-forming mineral of the first and second schistose horizons of the Saksahan suite; it is also present in the rocks of the thin third, fourth, and sixth schistose horizons. The garnet formation was caused by dynamothermal metamorphism of primary alumina-iron-siliceous sediments under conditions of epidote-amphibolite facies [7, 8]. Garnet-quartz-biotite, cummingtonite-garnet-quartz-biotite, biotite-garnet-quartz-cummingtonite schists are most common within the region. The average content of garnet in schists ranges from less than 5 to more than 20 mass pct. According to preliminary data, the resources of garnet-bearing schists with an average content of 15-20 pct. are estimated at 300 million tons within the boundaries of the Inhulets deposit.

The chemical composition of the mineral corresponds to almandine, which is a variety of garnet with the highest hardness. In this regard, it serves the raw material for the manufacturing abrasives. Associated minerals are biotite, quartz, to a lesser extent, they are chlorite,
Garnet forms round-shaped crystals of a tetragon-triocahedral, rhombohedral habitus. Their size is from 0.5 to 5.0 mm, the predominant size is about 2 mm.

It is possible to produce a high-quality concentrate with a garnet content of about 98 mass pct. from the garnet-bearing rocks of the first and second schistose horizons (figure 6), which meets the requirements of the world market.

![Figure 6](image)

**Figure 6.** Garnet-bearing schist (a) and garnet concentrate obtained from it (b).

Preliminary studies of the garnet concentrate received from schists showed that it can be used in the manufacture of soft abrasives, water filters, abrasives for hydraulic cutting, etc.

**Muscovite.** Muscovite quartzites and quartz-muscovite schists make up the lower and middle subsuites of the Skeliuvatka suite and are the product of dynamothermal metamorphism of high-alumina clasticogenic sedimentary formations [1]. As a result of metamorphism, clay minerals were replaced by muscovite forming thin (0.1 - 2 mm) parallel layers (figure 7).

![Figure 7](image)

**Figure 7.** Quartz-muscovite schist.

The total thickness of their layers in the eastern wing of the Lykhmanivka syncline varies from 30 to 120 m. The inferred resources of muscovite quartzites and quartz-muscovite schists are more than 0.5 billion tons.
It is possible to produce fine-grain muscovite (muscovite scrap) by crushing quartz-muscovite schist to a particle size of 1-0 mm, followed by air separation of crushed products. According to preliminary data, it can be used in the manufacture of electrical insulating, building materials, mineral paints, rubber, plastics, etc.

Muscovite quartzites can also be used to obtain high-quality facing tiles and paving flagstones (figure 8).

Figure 8. Unframed (a) and framed (b) facing tiles made of muscovite quartzite (white), two-mica schist (gray), aspide schist (black) and riebeckite-magnetite quartzite (blue).

There has been a practice of the extraction and production of facing tiles and paving flagstones from muscovite quartzite from the Hannivka deposit of the Northern GOK in the Kryvyi Rih basin. The range of facing tiles can be expanded by the use of certain types of barren, low-ore ferruginous quartzites and schists of various composition as the starting material.

Limestone within the boundaries of the Lykhmanivka iron ore region forms a layered deposit with a thickness of 5 to 30 m as part of the Cenozoic sedimentary cover. Its formation is chemogenic-organogenic, the main mineral component is calcite, dolomite is present in an insignificant amount. (figure 9).

Figure 9. High-quality shell limestone (a) and shell limestone with opal-clay cement (b).
Limestone resources make up about 500 million tons. According to preliminary data, its quality indicators meet the requirements for a metallurgical one (as one of the charge components).

Mineral pigments. There are about 10 minerals and rocks that can be used as mineral pigments of industrial and artistic quality within the boundaries of the Lykhmanivka iron ore region [9].

Industrial pigments include the following ones:
Reddle is a product of weathering of schists and silicate, magnetite-silicate quartzites of various compositions. The main mineral for reddle is dispersed hematite, which is a weathering product of iron-bearing silicates. Kaolinite is the main impurity. The color saturation of reddle depends on their quantitative ratio.
Ocher is a genetic analogue of reddle, the difference is that the main mineral of ocher is dispersed goethite. Its color varies from light yellow to dark brown, depending on the quantitative ratio of dispersed goethite and kaolinite.
Martite is a weathering product of magnetite, the main rock-forming mineral of the weathering crust of ferruginous quartzites, finely ground martite powder has a rich dark red (cherry) color.
Magnetite is the main rock-forming mineral of unweathered ferruginous quartzites; when crushed, it has a rich black color. (figure 10).

Figure 10. Engineering grade mineral pigments: a - ocher; b - magnetite; c - martite, d - reddle.

Riebeckite, celadonite, and goethite from the Lykhmanivka iron ore region (figure 11) can
be considered as mineral pigments of artistic quality.

Figure 11. Mineral pigments of artistic quality: a - riebeckite metasomatite; b - quartz-celadonite diaphthorite; c - sintered aggregate of goethite (dark brown) and dispersed goethite (yellowish brown).

Ceramic clays and loam soils form interbeds from 3 to 40 m thick in the Cenozoic cover [1]. The mineral and chemical composition of clays and loam soils has not been studied enough; according to preliminary data, they can be used for the production of ceramic bricks, tiles, etc. The inferred resources within the boundaries of the mining license area of the Inhulets deposit are 0.5 billion tons.

Gemological and collectable minerals. There are more than 20 minerals and rocks that can be used as gemological and collectable minerals in the productive and enclosing strata of the Lykhmanivka iron ore region [7, 10, 11]. The main types include: chalcedony, red-layered ferruginous quartzite, dispersed hematite-quartz-chalcedonic and dispersed goethite-quartz-chalcedonic jasperoids, crystals and druses, druses of quartz of different shades (rock crystal, milky, blue, yellow quartz, etc.), crystals and aggregates of calcite crystals, aragonite, gypsum, aegirine, riebeckite, goethite, hematite, celadonite, palygorskite, martite and other minerals.

Red-layered and yellow-layered ferruginous quartzites (figure 12) are the most common types of ornamental stone. They are used for manufacturing both large forms (balls, writing instruments, other gift items) and small artistic items (inserts in rings, brooches, gems, intaglio, etc.).

Hydrothermal and hypergene veins contain sinter aggregates, druses of quartz, pyrite, chalcedony, celadonite, calcite, aragonite, and other minerals (figure 13).
Figure 12. Red- (a, b) and yellow-layered (c) ferruginous quartzites of the Lykhmanivka iron ore region.

Many of them are brightly colored and have shapes characteristic of individuals and aggregates of these minerals. Crystals, druses, and other aggregates are the material for the creation of mineralogical, regional, and art collections.

Granites and migmatites are the most ancient formations, their age is 3.2-2.8 billion years, they are framing the rocks of the Kryvyi Rih series of the Lykhmanivka iron ore region from the east and from the west. Two massifs of granites differ in mineral composition, structure, texture. The granitoid massif of the western part is dominated by migmatites, granitoids with relict schistosity. (figure 14).

It is possible to manufacture block stone, road and sidewalk paving stones, high-quality crushed stone with a low flakiness index from granites of the eastern massif.

Due to its relict schistosity and gneissic nature, granite of the western massif can be used for the production of lower quality, flaky rubble.

Man-made deposits of natural minerals include mining and processing waste from the Inhulets Mining and Beneficiation Works, the former Inhulets operations, stored in dumps, tailings, emergency and other containers.

Tailings [12] in the amount of about 500 million tons are stored in the tailings storage facilities of the Works. The particle size ranges from 0.01 to 3 mm. Due to gravitational differentiation, there is a concentration of open ore particles and the most coarse-grained tailings material in the dam parts of the tailings storage facilities maps. The content of magnetite increases from 1-2 to 7-9 mass pct., the hematite one is up to 6-8pct. Based on the results of preliminary
mineralogical and technological studies, it is possible to produce a complex hematite-magnetite concentrate with an iron content of 65-67 mass pct. and a yield of 6-8 pct. from dam deposits of mature tailings.

The technogenic types of iron ore raw materials also include the tailings of the flotation upgrading of the rough concentrate of the beneficiation plant No. 2 of the Inhulets Mining and Beneficiation Works. However, today their quality indicators, the possibilities of extraction and processing have not been studied enough.
Overburden rocks of different mineral, chemical composition and origin are stored in the
dumps of the Works, they are sedimentary rocks of the Cenozoic cover, schists of different
composition, monomineral silicate, substandard magnetite-silicate quartzites, products of
supergene transformations of schists and ferruginous quartzites. The stripping rocks are stored in
a non-selective way. Mineralogical, petrographic, and technological studies of the accumulated
material have not been systematically carried out so far. In this regard, it is impossible to
determine the potential of the dump material as a mineral raw material.

4. Conclusions
The deposits of the Lykhmanivka iron ore region are complex ones. According to the results
of the studies, among about 20 types of associated minerals, several priority ones can be
distinguished in terms of prevalence, degree of geologic certainty, existing methods of use,
positive technical, economic, social, and environmental consequences of their utilization: high-
grade and low-grade hematite ores (hematite quartzites), talc-containing schists, muscovite
quartzites.

Low-grade hematite ores make up the weathering crust of the ferruginous horizons. The
deposits of high-grade ores represent the "lost" ore bodies of the mines of the former Inhulets
mining operations. Ores of both varieties can be used as feedstock for the production of iron
ore concentrate.

Other metal minerals include gold, platinum and platinoids, manganese, and bauxite. Their
manifestations are insignificant in size, the quality of ores has not been studied enough.

Non-metal minerals in the Lykhmanivka iron ore region are represented by talc-, garnet-,
muscovite-bearing schists, granites and migmatites, reddle, ocher, ceramic clay, gemological and
collectable raw materials, mature tailings and overburden rocks from dumps. The talc-bearing
schists have been studied most deeply. Other minerals require detailed study.

The studied metal and non-metal minerals form industrial deposits that can be developed
simultaneously with the extraction of iron ores. Involving them in mining and processing
significantly expands the range of alternative directions for using the mined mineral mass.

The integrated use of metallic and non-metallic minerals of the Lykhmanivka iron ore region
significantly expands the range of alternative directions for the use of minerals and rocks of
the banded iron formation, their involvement in mining and processing will contribute to a
significant addition to the mineral resource base of both the Kryvyi Rih basin and Ukraine as a
whole.

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References
[1] Akimenko N M, Belevtsev Y N, Goroshnikov B I, Dubinkina R P, Ishchenko D I, Karshenbaum A P,
Kulishov M P, Lyashchenko K P, Maksimovich V L, Siroshstan R I, Skuridin S A, Tokhtuev G V, Fomenko
V Y and Shcherbakova K F 1957 Geological structure and iron ores of the Kryvyi Rih basin (Moscow:
Gosgeoltekhdzhat)
[2] Belevtsev Y N, Bura G G, Dubinkina R P, Yepatko Y M, Ishchenko D I, Melnik Y P and Strygin A I 1959
The genesis of iron ores of the Kryvyi Rih basin (Kyiv: Publishing House of the Academy of Sciences of
the Ukrainian Soviet Socialist Republic)
[3] Tikhlivets S V and Truin O M 2019 Journal of Geology, Geography and Geocology 28 581–590
[4] Machado O T and Yurtaeva A D 1997 Bulletin of the Academy of Mining Sciences of Ukraine 4 110–111
[5] Spiak S M 1999 *Geological and Mineralogical Bulletin of Kryvyi Rih Technical University* **1** 89–93

[6] Pirogov B I and Pirogova V V 1973 *Mineralogical study of iron and manganese ores* (Moscow: Nedra)

[7] Blokha V 1997 *Bulletin of the Academy of Mining Sciences of Ukraine* **4** 45–46

[8] Kharitonov V M, Filenko V V, Yurin A O and Grytsay O Y 2020 *Geological and Mineralogical Bulletin of Kriviy Rig National University* **1-2** 30–42 URL https://doi.org/10.31721/2306-5443-2020-43-44-1-2-30-42

[9] Hrytsai O, Mumriyk M and Filenko V 2018 Manifestations of mineral pigments of the Krivoy Rog basin: Modern technologies for the development of ore deposits. *Ecological and economic consequences of the activities of the enterprises of the MMC: A collection of scientific work on the results of the work of the V International Scientific and Technical Conference* (Kriviy Rig: R. A. Kozlov) p 46

[10] Evtokhova A V, Evtokhov V D and Georgieva O P 2020 *Geological and Mineralogical Bulletin of Kriviy Rig National University* **1-2** 18–29 URL https://doi.org/10.31721/2306-5443-2020-43-44-1-2-18-29

[11] Petrun V F 1961 *Bulletin of scientific and technical information. Gems*. **2** 60–66

[12] Carmignano O R, Vieira S S, Teixeira A P C, Lameiras F S, Brandão P R G and Lago R M 2021 *Journal of the Brazilian Chemical Society* **32** 1895–1911 URL https://doi.org/10.21577/0103-5053.20210100