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Horizontal and vertical zonation of the weathering rind of the northern part of the Krivy Rig Basin

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Abstract. The ferriferous-siliceous formation of the Kryvyi Rih Basin has been formed as a result of the effect of different geological processes: sedimentation, diagenesis, dynamothermal metamorphism, metasomatosis, orogenesis, hypergenesis. Hypergenic changes are manifested to a different extent within iron ore deposits of the Kryvyi Rih Basin. In the south part of the basin, thickness of the weathering rind in some places reaches 1,000-1,500 m, it is up to 2,500 in the central, and in the northern part this parameter is much lower. Hypergenic processes are observed in the sections of all stratigraphic horizons of the Saksahanska suite of the iron ore deposits of the Kryvyi Rih Basin. The thickness of their manifestations changes depending on the horizon (schist, ferriferous). Therefore, over the study, we determined the impact of stratigraphic horizon on variance of thickness of the weathering rind within the northern area of the Kryvyi Rih basin, on example of the Hannivsk deposit. The surveys were performed in all hypsometric levels of the deposit. Schematic sections of the deposit`s weathering rind were made. The products of hypergenesis are hematite quartzites with qualitative parameters (total content of iron) no lower than in magnetic quartzites. In some deposits, the reserves of the hematite quartzites are quite large, but they are not being extracted. For more detailed study of the structure of the weathering rind, manifestation of its vertical zonation was investigated, a schematic section of the weathering ring within the ferriferous-siliceous formation of the deposit was made designating all mineralogical zones. We studied the variance of mineral composition of the ferriferous rocks depending on the manifestation of horizontal zonation of the weathering rind and impact of hypergenic processes on authigenic-metamorphogenic zonation of the productivity of the deposit`s layer. We developed a scheme of mineralogical zonation of the weathering rind, therefore facilitating the enlargement of the mineral-ore base of the Hannivsk deposit and the Kryvyi Rih Basin in general for further extraction and beneficiation of hematite quartzites.

Key words: ferriferous-siliceous formation, Kryvyi Rih Basin, zonation of the weathering rind, hematite quartzites

Горизонтальна і вертикальна зональність кори вивітрювання північної частини Криворізького басейну

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Анотація. Залізисто-кремниста формація Криворізького басейну сформувалась в результатів дії різних геологічних процесів: седиментації, діагенезу, динамотермального метаморфізму, метасоматозу, тектогенезу, гіпергенезу. Гіпергенні зміни різною мірою проявлені в межах залізорудних родовищ Криворізького басейну. В південній частині басейну потужність кори вивітрювання іноді досягає 1000-1500 м, в центральній – до 2500 м, в північній частині цей показник значно менший. Гіпергенні процеси спостерігаються в розрізах усіх стратиграфічних горизонтів саксаганської світи залізорудних родовищ Криворізького басейну. Потужність їх прояву змінюється в залежності від горизонту (сланцевий, залізистий). Тому в процесі досліджень був визначений вплив стратиграфічного горизонту на варіативність потужності кори вивітрювання в межах Північного району Криворізького басейну, на прикладі Ганнівського родовища. Дослідження проводились по всіх гіпсометричних рівнях родовища. Були побудовані схематичні розрізи кори вивітрювання родовища. Продуктами гіпергенезу є гематитові кварцити, які за якісними показниками (загальний вміст заліза, якість концентрату, втрати заліза у відходах збагачення) не уступають магнетитовим кварцитам. На деяких родовищах запаси гематитових кварцитів достатньо значні, але видобуток їх не ведеться. Для більш детального вивчення будови кори вивітрювання було досліджено прояв її вертикальної зональності, побудовано схематичний розріз кори вивітрювання в межах залізито-кремнистої формації родовища з виділенням всіх мінералогічних зон. Вивчено варіативність мінерального складу залізистих порід в залежності від прояву горизонтальної зональності кори вивітрювання та впливу гіпергенних процесів на аутигенно-метаморфогенну зональність продуктивної товщі родовища.

Побудована схема мінералогічної зональності кори вивітрювання залізисто-кремнистої формації родовища. Отримані результати можуть бути основою для детального вивчення можливості розвитку мінерально-сировинної бази Ганнівського родовища і Криворізького басейну в цілому для подальшого видобутку і збагачення гематитових кварцитів.

Ключові слова: залізисто-кремниста формація, Криворізький басейн, зональність кори вивітрювання, гематитові кварцити

Introduction. The processes of weathering are manifested in the layer of ferriferous-siliceous formation of the northern part of the Kryvyi Rih Basin and within the Hannivsk deposit due to interruptions of accumulation of sediments (Bespoyasko, 2005.; Ginzburg, 1987; Dmitriev, Kravchenko, 1965). The most ancient parts of the weathering rind are Middle-Archean granites of the Prydniprovsky complex and Upper-Archean metabasites of metaclastic Konkska series.

For the ferriferous rocks of the northern part of the area, hypergenesis was the longest geological process that affected their formation. The beginning of the hypergenic process coincided with the beginning of the continental stage of existence of the Ukrainian Shield. Weathering of the ferriferous rocks is still going on, thus affecting the mineralogical transformations of metamorphogenic and metasomatically altered ferriferous quartzites and schists of the Saksahanska suite. Thus, in the faces of the quarries, weathering rind is observed, which has been forming since the Paleoproterozoic Era up to this day with an insignificant interval between the Meso-Paleogene and Meso-Neogene (Bespoyasko, 2004.; Dmitriev, Kravchenko, 1965).

The weathering rind of the deposits is represented by hematite quartzites, the total content of iron in which equals 34-35 mass percents, which, according to this parameter, is close to the magnetic quartzites. Currently, hematite quartzites are not used by the Northern Ore Mining and Processing Enterprise, though their deposits are quite large. The objective of this study has been conditioned by the necessity of increasing the coefficient of complex use of mineral mass extracted from the deposit, by developing technologies of beneficiation of the hematite quartzites. The latter cannot be done without detailed mineralogical analysis of the weathering rind, which has not been so far conducted within the productive and containing layers of the Hannivsk deposit.

Materials and methods. Structural peculiarities of the weathering rind of different geological objects are continually studied by scientists (Marszałek, 2014; Sidorova, 2015). One of the main characteristics is the depth of distribution of weathering rind . For ferriferous rocks within the Kryvyi Rih Basin, it reaches 3,000-3,500 m in some places. Its thickness changes, the main reason for this is the different tempi of epeirogenic upheavals of the blocks of the Earth's crust. Earlier, (Dodatko, Dorfman, 1973; Dmitriev,Kravchenko, 1965; Evtekhov, 2002) determined that depth of distribution of the weathering rind depends on the mineralogical composition of the ferriferous rocks, their structure, texture, intensity of the manifestation of tectonic processes. Rocks of the schist horizons differ from the rocks of the ferriferous horizons by lower fragility, higher flexibility and lower total water-penetrability (Gershoyg, 1960;Ginzburg, 1955;Dodatko, Dorfman, 1973). Therefore large thickness of the weathering rind is characteristic for ferriferous horizons.

Thickness of the weathering rind of the Hannivsk deposit in the northern area of the Kryvyi Rih Basin was measured uniformly for all hypsometric levels using geological sections. Schematic sections of the weathering rind were developed using CorelDraw 2017 software.

For mineralogical analyses, we selected 102 samples of hematite quartzites with different geological positions within the weathering rind of the Hannivsk deposit. The studies were undertaken using standard methods with serial microscopes. All analyses were performed at the laboratories of the Geology and Practical Mineralogy Department of Kryvyi Rih National University.

Results and their analysis. For detailed characteristic of hematite quartzites of Hannivsk deposit, authors of the article studied the change in the thickness of weathering rind. The measurements were performed for all hypsometric levels in the deposit. For more objective assessment of the variance of the layer thicknesses, the deposit was divided into three parts: northern, central, and southern (Fig. 1).

According to Fig. 1, thickness of the weathering rind changes from the northern to southern parts of the deposit with the following pattern: in the central part, in the zone of intense fractioning of the ferriferous rocks, due to manifestation of significant sublatitudinal rupture, its highest value is up to 138.3 m along the line of the exploration profile 27-27. Towards the northern and southern parts, thickness of the weathering rind significantly decreases, its minimal parameters were observed in the southern part of the deposit.

Also, one can also see that the thickness of weathering rind of ferriferous horizons exceeds the corresponding parameter of schist horizons, which proves a well-known pattern in the structure of the

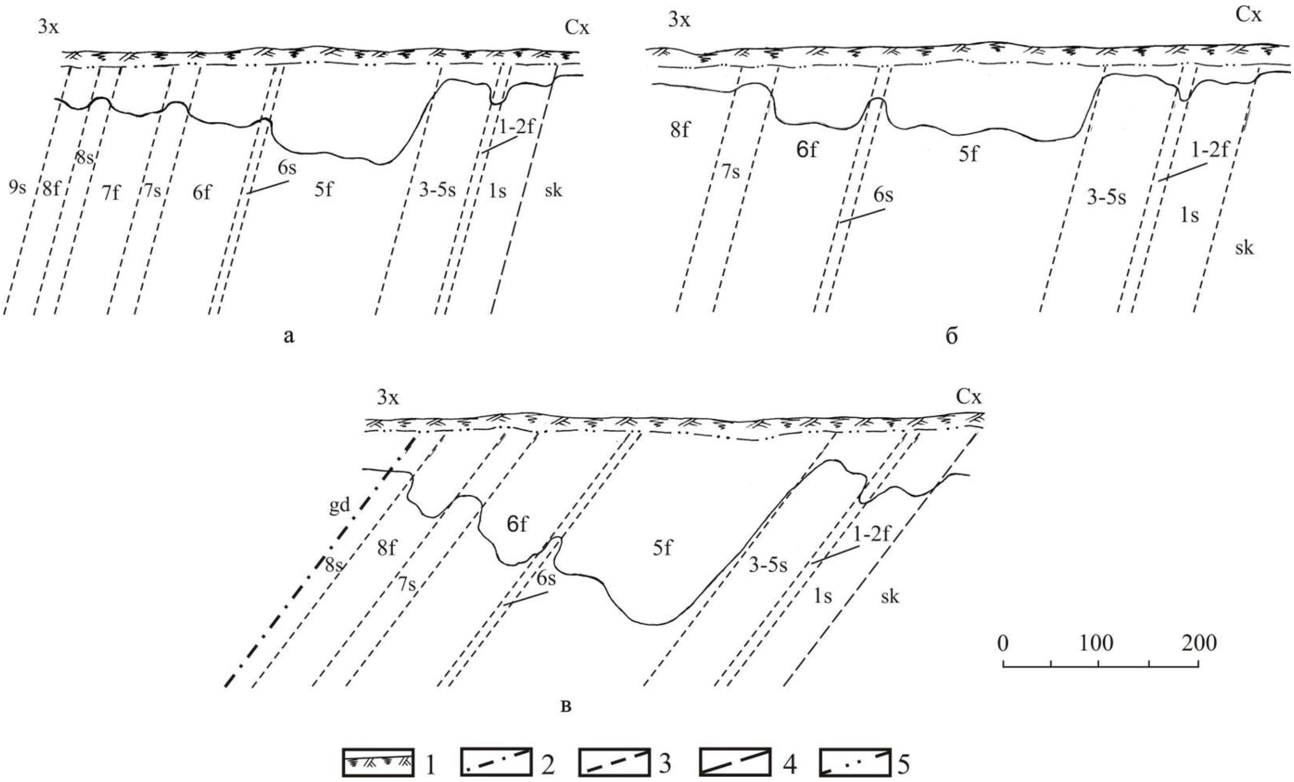


Fig. 1. Schematic sections of the weathering rind of productive and containing layers of the Hannivsk deposit.

Areas of the deposit: a – northern, b – southern; c – central.

Suites of the Kryvorizka series and stratigraphic horizons of the Saksahanska suite: Skeliuvatska suite; stratigraphic horizons of the Saksahanska suite: 1s – first schist horizon; 1-2f – fused first-second ferriferous horizons; 3-5s – fused third-fifth ferriferous horizons; 5f – fifth ferriferous; 6s – sixth schist horizon; 6f – sixth ferriferous; 7s – seventh schist; 7f – seventh ferriferous; 8s – eighth schist; gd – the Hdanivska suite;

1 – soil-vegetation layer and rocks of the Cenozoic sedimentary cover; 2 – rupture changes; 3 – lines of contacts of stratigraphic horizons; 4 – lines of contacts of the suites; 5 – line of the surface of erosive section of the rocks of the Kryvorizka series.

weathering rind of the Saksahanska suite of other iron-ore areas of the Kryvyi Rih basin. The results of determining thickness of weathering of schist and ferriferous horizons of the Saksahanska suite within the entire deposit are presented in Fig. 2.

The weathering rind of the Hannivsk deposit is characterized by horizontal and vertical mineralogical zonation . During the process of its formation, newly-formed hypergenic zones overlayed the mineralogical zones of iron-ore formation formed as a result of sedimentation, dynamothermal metamorphism (Karpenko, e. a., 2009), sodium metasomatosis (Tikhlivets, Filenko, 2017) and other geological processes.

Mineral composition of the original ferriferous quartzites (cummingtonite-, riebeckite-, biotite-containing and others) affected the pattern of hypergenic zonation, but in general for the deposit, general patterns of mineralogical orientation of the processes of hypergenesis and formation of the zonation of the weathering rind are observed.

For magnetite, is gradual replacement with martite is characteristic. The process occurs according to the pattern standard for magnetite quartzites: flexible crystals of martite at original stages of the replacement are formed along the cracks of the fractured parts of the magnetite crystals, gradually covering their entire volume (Evtekhov. e. a., 2002).

Micaceous iron oxide and quartz are resistant to hypergenic changes, as a result of which, they are present in the original rocks and products of weathering in almost the same amounts.

Hypergenic changes of silicates occur first of all due to removal of active cations (K^+, Na^+, Ca^{++}, Mg^{++}) from their crystal lattice, which causes its destruction. Out of relic chemical components of non-aluminous silicates (cummingtonite, riebeckite, aegirine, tetraferribiotite, and others) (Fe_2O_3, SiO_2, H_2O), crystal lattices of hypergenic minerals form in quartz or chalcedony, and also dispersive hematite, and at more intense weathering – goethite and dispersive goethite. If silicates of alumina are present (biotite, almandine, celadonite, stilpnomelane, etc), formation of iron hydroxides is accompanied by formation of clayey minerals, mainly kaolinite. Aluminium silicates (muscovite, cyanite, andalusite), which in notable amounts are present in schists of the first and third-fifth schist

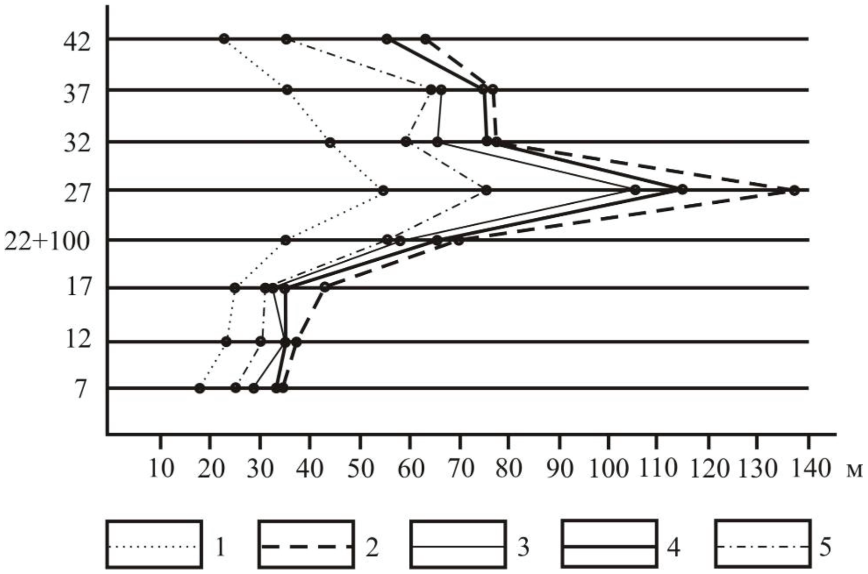


Fig. 2. Variance of thickness of the weathering rind of productive and containing layers of the Hannivsk deposit.
Stratigraphic horizons of the Saksahanska suite: 1 – third-fifth schist horizon; 2 – fifth ferriferous; 3 – sixth schist; 4 – sixth ferriferous; 5 – seventh schist.
7-42 – exploration profiles from north (profile 42) to south (profile 7).

horizons, in conditions of weathering become gradually replaced by aggregates of kaolinite, quartz, chalcedony, opal.

In insignificant amount (up to 3-3.5 vol% in total) within ferriferous rocks, carbonates are present. Their non-ferriferous types – calcite, dolomite – in the zone of intense hypergenic changes undergo complete dissolution. Iron-containing carbonates represented by sideroplesite and pistomesite, are sometimes replaced during weathering by disperse hematite, disperse goethite, and more rarely with goethite.

Gradual pattern of hypergenic replacement of metamorphogenic and metasomatic minerals causes different quantitative proportion between them and the newly formed hypergenic minerals at different hypsometric levels of productive and containing layers of the Hannivsk deposit. As a result, vertical mineralogic zonation of the weathering rind is observed.

For the **vertical section** of the weathering rind of the Hannivsk deposit, according to the content of the main ore mineral – magnetite – one can distinguish four mineralogical zones (downward by the section): goethite-martite → martite → magnetite-martite → martite-magnetite zones (Fig. 3). The latter zone has a gradual transition of pre-hypergenically unchanged magnetite quartzites. The zone of goethite-martite is the zone of maximum hypergenic changes of ferriferous rocks. It was composed of goethitised rocks of the martite zone. Contact of goethite-martite martite zone is gradual, designated by total content of iron hyperoxides (goethite, lepidocrocite and dispersive goethite), which in the content of ferriferous goethite-martite zone is higher than 5 vol%. Content of magnetite in this rock in this zone is insignificant – no higher than 2 vol%, and equals 0.47% on average. Original silicates and carbonates are absent; martite, micaceous iron oxide and quartz are partly replaced by goethite. Apart from typomorphic goethite, lepidocrocite and dispersive goethite in the rocks of the goethite-martite zone quartz, martite, micaceous iron dioxide, dispersive hematite are present as rock-forming minerals.

Ferriferous quartzites of this zone are intensely fractured, cavernous, with high number of goethite veinlets, but, despite deep hypergenic changes, original lamination is maintained.

In the sections of schist horizons, and also ferriferous quartzites adjoining to them, kaolinite is present. Broadly distributed are hematite-chalcedony, goethite-chalcedony, goethite-quartzitic jaspers, which fill the cavities in the weathered rocks.

Thickness of the zone equals around 15 m on average.

The martite zone is a zone of intense hypergenic changes. It is composed of micaceous iron dioxide-martite, martite, disperse-hematite-martite and more rarely , martite-disperse-martite quartzites. Contact of this zone and magnetite-martite is gradual. It is designated by total content of hyperoxides of iron (goethite, lepidocrocite and dispersive goethite), which in the content of ferriferous rocks of the martite zone did not exceed 5 vol%, and equals 2.37% on average. Content of magnetite is not higher than 5 vol%, equaling 1.78% on average.

The main rock-forming minerals of this zone are martite and quartz. Flooded aggregates of goethite,

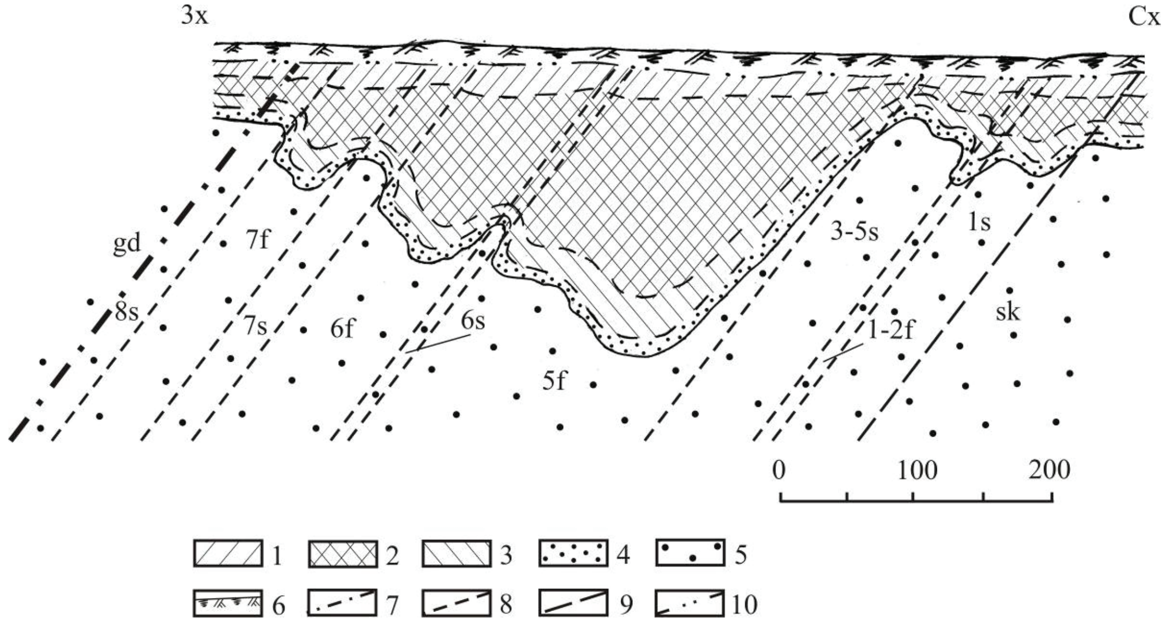


Fig. 3. Schematic geological section of the weathering rind of productive and containing layers of the Hannivsk deposits.

The suites of the Kryvorizka series and stratigraphic horizons of the Saksahanska suite: sk – Skeliuvatska suite; stratigraphic horizons of the Saksahanska suite: 1s – first schist horizon; 1-2f – fused first-second ferriferous; 3-5s – fused third-fifth ferriferous; 5f – fifth ferriferous; 6s – sixth schist; 6f – sixth ferriferous; 7s – seventh schist; 7f – seventh ferriferous; 8s – eight schist; gd – Hdanivska suite;

1-4 – zones of hypergenic changes of magnetite quartzites: 1 – goethite-martite; 2 – martite; 3 – magnetite-martite; 4 – martite-magnetite 5 – hypergenically altered ferriferous quartzites and schists; 6 – soil-vegetative layer and rocks of Cenozic sedimentary cover; 7 – ruptures; 8 – lines of contacts of stratigraphic horizons; 9 – line of contacts of the suites; 10 – line of the surface of erosive section of the rocks of the Saksahanska suite.

chalcedony, druses of quartz, calcite, dolomite and other hypergenic minerals fill the caverns and fractures, the number of which is higher within the martite zone. Texture of the rocks maintains relic lamination.

Vertical thickness of the martite zone is the largest among all the zones of the weathering rind – 40-45 m.

The magnetite-martite zone is the zone of moderate hypergenic changes of the original ferriferous quartzites. Contact with the martite-magnetite zone is gradual. Average content of the magnetite there equals 12.49%, ranges from 5 to 15 vol%. In the solution of productive tasks, this zone is called the zone of “demi-oxidized” magnetite quartzites, which become orientated towards the ore flow, because the content of magnetite in their content corresponds to the requirements to the iron ore material.

Out of newly-formed minerals, there are martite, disperse hematite, in lower amount – goethite, disperse goethite, and in rocks of pre-contact zones of ferriferous and schist horizons – kaolinite. A significant amount of half-replaced products of weathering crystals of original silicates, and also newly formed products of incomplete weathering silicates – hydromicas, beidellite, and others have been observed.

Ferriferous quartzites of this zone are characterized by heightened number of fractures, the original lamination is maintained.

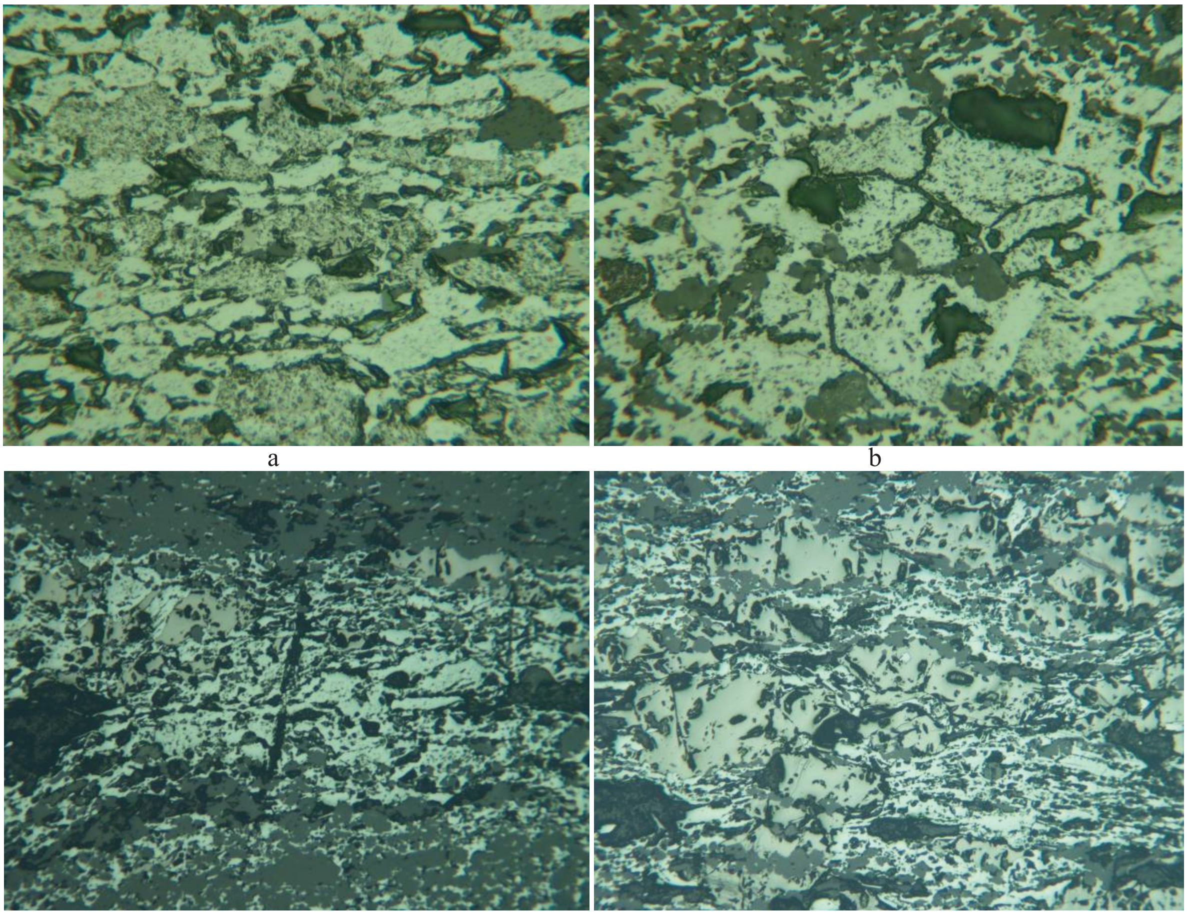
The thickness of the zone ranges from 1 to 20 m, and equals 15 m on average.

The martite-magnetite zone is the zone of original hypergenic changes of original micaceous iron oxide-magnetite, magnetite, cummingtonite-magnetite, magnetite-cummingtonite quartzites.

Contact of martite-magnetide zone and zone of unchanged ferriferous quartzites is gradual, designated according to the total content of martite, the average content of which is 12.85 vol%. The average amount of magnetite is 23.06 vol%, which is by 12.77 vol% lower compared to unchanged ferriferous quartzites. According to the requirements of production, ferriferous quartzites of this zone are identified as conditional iron ore – so called “poorly-oxidized” magnetite quartzites. The dominating minerals are those of the original ferriferous rocks, intermediate products of weathering (hydromicas, beidellite) and newly-formed hypergenic silicates (mainly kaolinite) are characterized by insignificant content.

Ferriferous quartzites of this zone are insignificantly fractured, the number of veinlets of hypergenic minerals is low original lamination is entirely maintained. Thickness of the zone ranges 1 to 15 m, and equals 7 m on average.

Results of the analysis of mineral composition of rocks of the weathering rind of fifth ferriferous



a b c d

Fig. 4. Mineralogical zonation of the weathering rind of the Hannivsk deposit.
Zones: a –goethite-martite; b – martite; c – magnetite-martite; d – martite-magnetite.
Microscopic examination in reflected light. 50^X zoom.
a, b – light-grey – martite; dark-grey – goethite;
b, c – white – martite; light-grey – martite; dark-grey – quartz.

horizon Fig. 4 represents the mineral types of these zones of vertical zonation of the weathering rind of the productive layer. indicates that the content of the main rock-forming minerals in its section changes in the zones in relation to the intensity of manifestation of hypergenesis (Fig. 5).

Maximum content of hematite (43.30 vol% on average) is characteristic for the martite zone. Towards the original non-weathered ferriferous rocks, its content naturally decreases: to 32.70 vol% within rocks of the magnetite-martite zone, to 21.15 vol% – martite-magnetite and to 7.39 vol% within the original non-weathered ferriferous rocks. In the latter, hematite is represented by micaceous iron oxide of original micaceous iron oxide-magnetite and magnetite quartzites. In upward direction, in the section of the weathering rind – in the rocks of the goethite-martite zone – average content of hematite is lower (38.98 vol%) compared to the rocks of the martite zone due to partial replacement of hematite by iron hydoxides.

An opposite tendency was observed for distribution of magnetite in the section of horizon. In the goethite-martite zone, it is practically absent (0.47 vol%), within the martite zone its amount equals on average 1.78 vol%; within the magnetite-martite zone – 12.49 vol%; within the martite-magnetite zone it functions as a rock-forming mineral (23.06 vol%); maximum content of magnetite was observed in the original non-weathered ferriferous rocks (35.83 vol%). This is explained by the decrease in activity of hypergenic processes with depth.

The latter has conditioned the amount of quartz, which naturally increases from goethite-martite (49.72 vol%) to original non-weathered ferriferous rocks (50.79 vol%).

Maximum value of content of iron hydroxides represented by goethite, disperse goethite and lepidocrocite (8.55 vol% on average) is characteristic for the goethite-martite zone. Towards the zone of original hypergenic changes, its content reduces

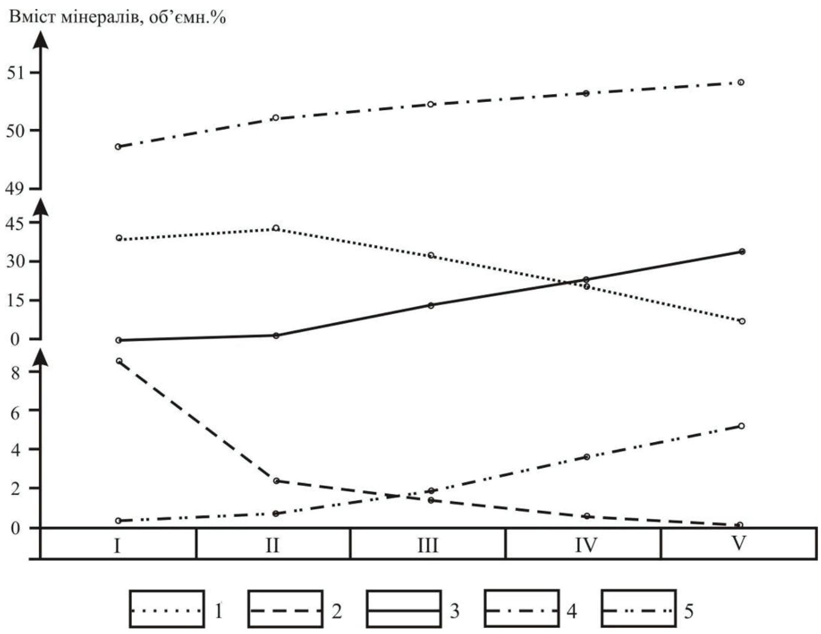


Fig. 5. Variance of content of main rock-forming minerals within hypergenically changed rocks of the fifth ferriferous horizon (according to the vertical zonation of the weathering rind).

Minerals: 1 – hematite (martite + micaceous iron oxide + disperse hematite); 2 – iron hydroxides (goethite + lepidocrocite + disperse goethite); 3 – magnetite; 4 – quartz; 5 – relic silicates (hypergenically changed cummingtonite, biotite, chlorite, ferriferous talc (minnesotaite), garnet, celadonite, stilpnomelane, albite, magnesium-riebeckite, aegerine, and others).

Zone of the weathering rind: I – goethite-martite; II – martite; III – magnetite-martite; IV – martite-magnetite; V – original non-weathered ferriferous rocks.

to 2.37 vol% in the martite zone, 1.5 vol% in the magnetite-martite zone, 0.67 vol% in the martite-magnetite zone. In the zone of original non-weathered ferriferous rocks, micaceous iron oxides are almost absent (0.1 vol%).

The opposite tendency was observed for distribution of silicates in the section of weathering rind. In the goethite-martite zone, they are practically absent (0.31 vol%), within the martite zone its amount equals 0.74 vol% on average; within the magnetite-martite zone – 1.94 vol%; within the martite-magnetite zone its amount slightly increases up to 3.86 vol%; maximum value of content of silicates was observed in the original non-weathered ferriferous rocks (5.12 vol%).

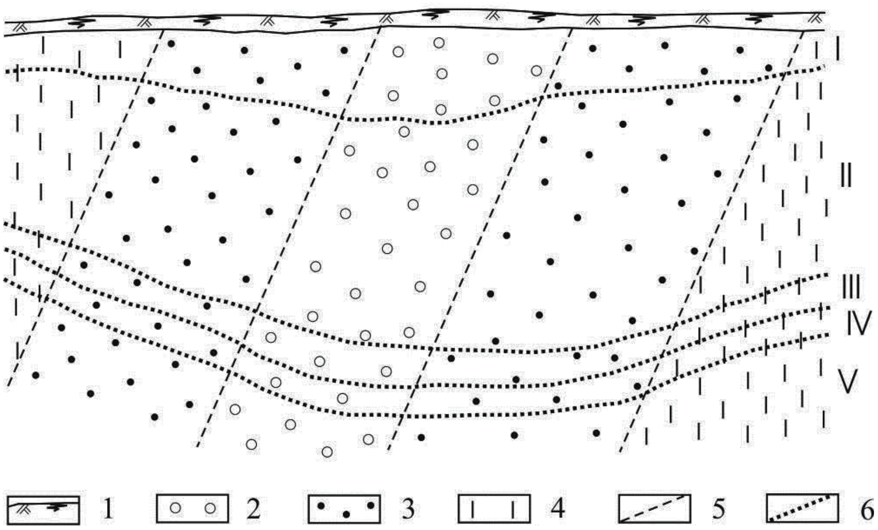


Fig. 6. Sketch of the upper part of the western face of the productive layer of the Hannivsk deposit.
1 – surface of the Earth; mineralogical types of ferriferous quartzites; 2 – micaceous iron oxide-magnetite; 3 – magnetite; cummingtonite-magnetite; 4 – borders of mineralogical types; 6 – borders of hypergenic zones: I – goethite-martite; II – martite; III – magnetite-martite; IV – martite-magnetite; V – hypergenically unchanged quartzites.

Mineralogical zonation of the weathering rind has overlain authigenic-metamorphogenic zonation of the ferriferous horizons. As a result, a complex (interferent) zonation of the productive layer of the deposit has formed (Fig. 6).

Horizontal hypergenic mineralogic zonation of the fifth, sixth ferriferous and sixth schist horizons of the Hannivsk deposit, as well as the vertical hypergenic zonation, formed under the impact of factors of weathering over a long Proterozoan-Cenozoic stage of the formation of ferriferous layer of the deposit. In the structure of the weathering rind, there are observed manifestations of horizontal zonation of the three orders. Their presence in the weathering rind of the ferriferous layer is a consequence of inheriting the zonal structure of the original geological bodies by the hypergenic formations.

Horizontal hypergenic zonation of the first order inherited the original macrozonation of the ferriferous Saksahanska suite of the deposit (Fig. 7). The central position is occupied by the macrozone of hypergenically changed rocks of the productive layer (fused layer of the fifth, sixth ferriferous and sixth schist horizons). It comprises most ferriferous types of weathered iron ores – micaceous iron oxide-martite, martite, disperse goethite-martite. In an insignificant amount, there are also martite-disperse hematite quartzites, a product of weathering of non-conditional magnetite-silicate quartzites of the sixth schist horizons and peripheral zones of the fifth and sixth ferriferous horizons.

The weathering rind of the productive layer is fringed by hypergenically changed rocks of underlying and overlying layers. The first are represented by the products of weathering of original rocks of the first, third-fifth schist and first-second ferriferous horizons – kaolinite-quartz-disperse hematite, kaolinite-quartz-disperse hematite, martite-quartz-disperse hematite schists and disperse hematite-martite, martite-disperse hematite quartzites. Weathering rind of the overlying layer is represented by hypergenically altered rocks of seventh, eighth, ninth ferriferous and seventh, eighth, ninth, tenth schist horizons – kaolinite-martite-disperse hematite, martite-kaolinite-disperse hematite quartzites.

In the sections of the weathering rinds of all stratigraphic horizons of the Saksahanska suite, horizontal hypergenic mineralogic zonation of higher (second) order is manifested, which was inherited during the weathering from their original authigenic-metamorphogenic geochemical zonation (Karpenko,EvtekhovV., EvtekhovaA., 2009). It was observed most completely in the section of productive layers.

According to generalization of the results of the mapping of the faces of the quarry, made by the author, and data of boring of the exploration wells, a topomineralogical scheme of weathering rind of the Hannivsk deposit`s productive layer has been developed (Fig. 8).

Conclusions. The obtained data demonstrate that the thickness of the weathering rind of the Hannivsk deposit of the Kryvyi Rih basin changes from the northern to southern part of the deposit with the following pattern: in the central part it has highest value; towards the northern and southern part, thickness of the weathering rind significantly decreases, reaching minimum parameters in the southern part of the deposit.

Weathering rind is characterized by manifestation of vertical and horizontal mineralogical zonation. For the former, from the surface downward, the sections were observed to contain the following mineralogical zones: goethite → martite-goethite →

	III							I			II			
	10s	9f	9s	8f	8s	7f	7s	6f	6s	5f	3-5s	1-2f	1s	
gd	sx													sk

Fig. 7. Scheme of mineralogical zonation of the iron ore layer of the Hannivsk deposit.

Suites of the Kryvorizka series: gd – Hdanivska; sx – Saksahanska; sk – Skeliuvatska.

Schist horizons of the Saksahanska suite: 1s – first; 3-5s – fused third-fifth; 6s – sixth; 7s – seventh; 8s – eighth; 9s – ninth; 10s – tenth

Ferriferous horizons of the Saksahanska suite: 1-2f – fused first-second; 5f – fifth; 6f – sixth; 7f – seventh; 8f - eight; 9f – ninth.

Macrozones of the Saksahanska suite I – central (productive); II – underlying; III – overlaying.

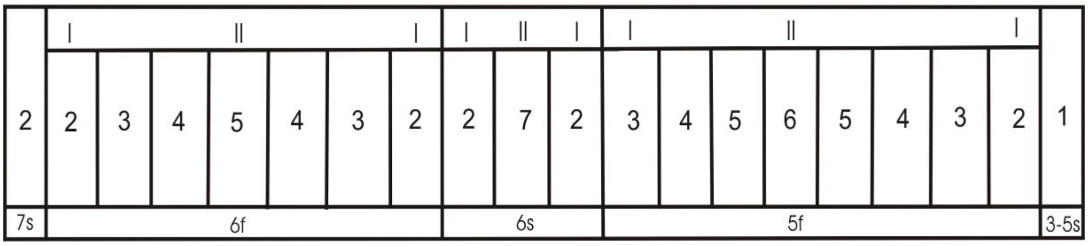


Fig. 8. Scheme of mineralogical zonation of the weathering rind of the productive layer of the Hannivsk deposit (at hypsometric level of the martite zone).

Indexes of mineralogical types of ferriferous rocks in the section: 1 – garnet-kaolinnite-quartz-disperse hematite schists; 2 – martite-disperse hematite quartzites with kaolinite; 3 – disperse hematite-martite quartzites; 4 – martite quartzites with disperse hematite; 5 – martite quartzites with micaceous iron oxide; 6 – micaceous iron oxide-martite quartzites; 7 – kaolinite-disperse hematite quartzites with martite.

Stratigraphic horizons of the Saksahanska suite: 7s – seventh schist horizon; 6f – sixth ferriferous; 6s – sixth schist; 5f – fifth ferriferous; 3-5s – third-fifth schist.

I – peripheral zones of the horizons; II – central zones of three horizons.

goethite-martite → martite → magnetite-martite → martite-magnetite → hypergenically changed magnetite quartzites.

Horizontal zonation of the weathering rinds of ferriferous horizons is inherited by their authigenic-metamorphogenic zonation. The difference is the replacement of magnetite by martite, and ferriferous silicates and carbonates – by dispersive hematite; micaceous iron oxide and quartz during weathering are relatively stable. At complete manifestation of authigenic-metamorphogenic mineralogic zonation, horizontal zonation of the weathering rind of ferriferous horizons looks as follows (from central part of the horizon towards its periphery): micaceous iron oxide quartzites → martite-micaceous iron oxide quartzites → micaceous iron oxide-martite quartzites → martite quartzites with micaceous iron oxide → martite quartzites with disperse hematite → disperse hematite-martite quartzites → martite-disperse hematite quartzites with kaolinite.

Using the results of the study, we developed schematic mineralogical sections of the weathering rind of the deposit, which were used during operative and promising planning of the mining works, development of schemes of distribution of the mineral-raw material base of the deposit, and in constant monitoring of areas of mining of ores by their mineralogical parameters.

References

Bespoyasko E.O., 2005. Tekhnolohichna mineralohiya hiperhenno zminenykh zaliznykh rud Inhulets′koho rodovyshcha Kryvoriz′koho baseynu [Technological mineralogy of hypergenetically altered iron ores in the Ingulets deposit of the Kryvy Rih basin] Extended abstract of Candidate's thesis (Mineralogy, Crystallography). Kryvyi Rih, 20 p. (in Ukranian).

Bespoyasko E.O., 2004. Vplyv mineral′noho skladu na fizychni ta tekhnichni vlastyvosti vyvitrenykh zalizystykh porid Inhulets′koho rodovyshcha (Kryvoriz′kyy baseyn) [Effect of mineral composition on the physical and technical properties of weathered ferruginous rocks of the Ingulets deposit (Kryvy Rih basin)]. Geological and Mineralogical Bulletin of Kryvyi Rih Technical University, №1, 40-47(in Ukrainian).

Gershoyg Yu. G. 1960. Zona okisleniya bogatykh zheleznykh rud inguletskogo tipa v Krivorozhskom basseyne. [The oxidation zone of rich iron ores of the Ingulets type in the Krivoy Rog basin]. Weathering crust, №3, 190-202. (in Ukranian).

Ginzburg A.I., 1955. O gipergennykh protsessakh v Krivorozhskom basseyne. Geologiya i genezis rud Krivorozhskogo zhelezorudnogo basseyna. [On hypergene processes in the Krivoy Rog basin. Geology and genesis of ores of the Krivoy Rog iron ore basin]. Kiev: Ed. AN USSR, 232-240. (in Ukranian).

Dmitriyev E.V., Kravchenko V.M., 1965. Protsessy glubinnogo vyvetrivaniya i zonal'nost' ikh proyavleniya v Saksaganskom rayone Krivogo Roga. [The processes of deep weathering and the zonality of their manifestation in the Saksagansk region of Krivoy Rog]. Geology of ore deposits. № 5, 76-90. (in Ukranian).

Dodatko O.D., Dorfman YA.Z., 1973. Pro kory vyvitryuvannya porid zalizysto-kremnystoyi formatsiyi Kryvorizhzhya. [About the weathering crust of the iron-siliceous formation of Kryvorizhya]. Reports of the Academy of Sciences of the USSR. Series B. №5, 395-398 (in Ukranian).

Evtekhov V.D., Machado O.T., Bespoyasko E.O., 2002. Topomineralohiya kory vyvitryuvannya saksahans′koyi svity Inhulets′koho rodovyshcha. [Topomineralogy of weathering of the Saksaganskaya world of Ingulets deposit]. Geological and Mineralogical Bulletin of Kryvyi Rih Technical University. №2, 5-17 (in Ukranian).

Karpenko S.V. Evtekhov V.D., Evtekhova A.V., 2009. Autigenno-metamorfogennaya mineralogo-geokhimicheskaya zonal'nost' produktivnoy tolshchi Annovskogo mestorozhdeniya (Krivorozhskiy basseyn). [Authigenic-metamorphogenic mineralogical and geochemical zoning of the productive stratum of the Annovskoye field (Krivoy Rog basin)]. Scientific bulletin of NMU. №3, 54-57 (in Ukranian).

Marszałek Mariola, Zofia Alexandrowicz, and Grzegorz Rzepa. 2015. Composition of weathering crusts on sandstones from natural outcrops and architectonic elements in an urban environment. Environmental Science and Pollution Research International, 22(6). doi:10.1007/s11356-014-3312-y

Sidorova Elena, Sitdikova Lyalya, Izotov Victor , 2014. The Major Types of the Weathering Crust of the Eastern Russian Plate and its Mineralogical and Geochemical Features. Procedia Earth and Planetary Science Volume 15, 2015, Pages 573-578

Tikhlivets S., Filenko V., 2017. Mineralogy of sodium metasomatites of the Pervomayske deposit and their influence on quality of iron ore concentrate. Visnyk of Taras Shevchenko National University of Kyiv: Geology`, 4(79), 53-58.